Federal Aviation Administration

Research & Development Annual Review

FY 2011 Accomplishments

2011 R&D Annual Review
March 2012

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 *R&D Annual Review* highlights the 2011 research and development (R&D) accomplishments of the Federal Aviation Administration (FAA) and serves as a compendium to the FAA 2012 *National Aviation Research Plan* (NARP). The FAA's R&D portfolio contributes to achieving the 10 R&D goals described in Chapter 2 of the NARP. The *R&D Annual Review* features accomplishments for each of the R&D goals: Fast, Flexible and Efficient; Clean and Quiet; High Quality Teams and Individuals; Human-Centered Design; Human Protection; Safe Aerospace Vehicles; Separation Assurance; Situational Awareness; System Knowledge; and World Leadership.

Additionally, the R&D portfolio supports the FAA's overarching goals to enhance safety, improve efficiency, and increase capacity of the national airspace system or NAS. In that effort, it continues to lay the groundwork for the Next Generation Air Transportation System known as NextGen.

NextGen is a wide-ranging transformation of the entire NAS to meet future demand and support the economic viability of the system while reducing delays, improving safety, and protecting the environment. NextGen is not a single piece of equipment or a program or a system that will instantaneously transform the NAS. It is an evolutionary process, and existing systems must be sustained in the transition. NextGen builds on legacy systems to increase capability in today's airspace system, adds new performance-based procedures and routes, and ultimately delivers programs that will transform the NAS.

For the nation, NextGen will enable a better way of doing business; reduce aviation's environmental impact; enable a more proactive approach to preventing accidents with advance safety management; get the right information to the right individuals at the right time; lay the foundation to continually improve air travel and strengthen the economy; meet increasing national safety and security needs; and maintain one seamless, global sky.

How the FAA will achieve that NextGen transformation is detailed in the R&D accomplishments found in this issue. The following are two examples of accomplishments made in FY 2011:

- *Fast, Flexible and Efficient*: Integrated Departure Route Planning (IDRP) combines predictions of weather impact along departure routes and predictions of congestion at departure routes and fixes and in nearby en route airspace into a single decision support tool that will help traffic managers manage departure traffic proactively.

- *Clean and Quiet*: Increased efficiency with NextGen operations will lead to reduced fuel consumption resulting in lower carbon emissions. The agency's R&D effort is researching engine and airframe design and alternative fuels that will produce the changes needed to reduce aviation's environmental impact.

These accomplishments, along with those in the rest of the report, illustrate the FAA's core R&D research efforts as well as the NextGen story, providing a glimpse into the future of our nation's world-class aviation system.

Fast, Flexible, And Efficient

A system that safely and quickly moves anyone and anything, anywhere, anytime on schedules that meet customer needs

Impact Of Jet Fuel Price Uncertainty On Airport Planning And Development:

The Airport Cooperative Research Program (ACRP) designed a computer model that airport operators and planners can use to examine the effects of jet fuel price on supply and demand for air service at commercial service airports as well as the resulting impact on airport development and finance. The model uses sustained jet fuel prices that range from $1 to $5 per gallon; however, the model can also do analyses at higher rates, if necessary. This program draws information from the following airport parameters: Origin and Destination (O&D) market size; airport role as an O&D airport or as a connecting hub; nature of economic activity in the surrounding community; link between airport activity and regional economic growth and development; changing passenger demographics; leisure versus business travel demand; geographic characteristics and proximity to competing airports; freight and cargo activity; and differential levels of service to domestic and international markets. (ACRP)

Airport Terminal Facility Activation Techniques:

Airport Terminal Activation refers to the process of transitioning a new or reconditioned airport terminal from a state of contractual completion to full operations. ACRP – Capacity developed a report synthesizing the many techniques and best practices currently used in the industry to activate new and reconditioned airport terminal facilities. The report presents a review of the available literature on airport terminal activation techniques. Additionally, the report provides the results of a survey of representatives from organizations involved in recent airport openings. The survey identified and collected information about the techniques used and how well they worked. Airport operators and planners can use this report to study existing proposals and to prepare new terminal facility activation plans. (ACRP)

Passenger Level Of Service And Spatial Planning For Airport Terminals:

As aviation demand continues to grow, increased traffic and passenger volumes will stress our nation's airports. The past few years have seen rapid changes in airport terminals as more competing uses vie for a finite amount of terminal space. The result of this growth is that the passenger experience has worsened with increased terminal congestion. Therefore, ACRP – Capacity conducted research to obtain a better understanding of level of service (LOS) and passenger behavior concepts. The FAA published these results as a set of passenger space-allocation guidelines for terminal functional areas. LOS scales, developed from data collected at a sample of 10 airports, provide the basis for these guidelines. Airport operators, planners, and consultants can use these guidelines for many years to come as new facilities are built and existing facilities are expanded or renovated to accommodate passenger movements. (ACRP)

Performance Measures For Automated People Mover Systems At Airports:

ACRP – Capacity created a user-friendly guidebook for measuring the performance of Automated People Mover (APM) systems at airports. This guidebook identifies a set of performance measures and associated data requirements for airport APM operators to assess and improve performance, compare APM systems, and plan and design future APM systems. The performance measures address the efficiency, effectiveness, and quality of APM systems at airports, particularly focusing on their effects on APM passengers and on airport performance. (ACRP)

Guidelines For Preparing Peak Period And Operational Profiles To Improve Airport Facility Planning And Environmental Analyses:

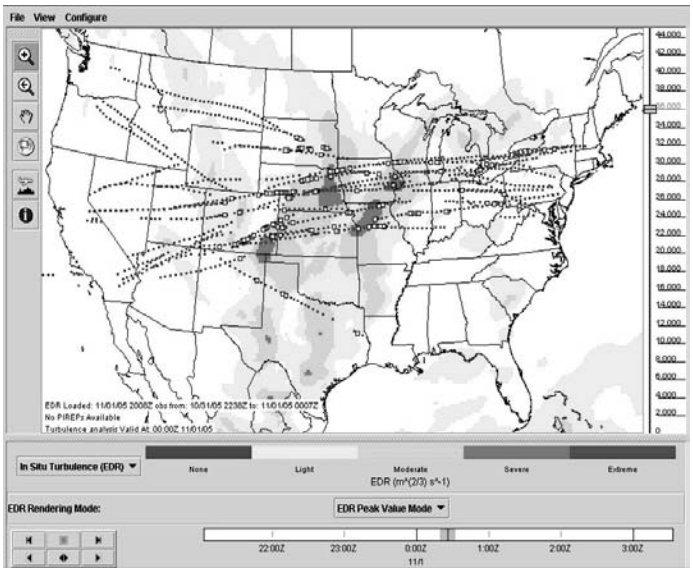
ACRP – Capacity developed a guidebook to enable airport operators to more effectively define the airport peak period and operational profiles that are necessary for facility and environmental planning. This guidebook includes an analytical toolbox as well as associated application and implementation procedures. It will help airport facility managers and operators evaluate (a) capacity requirements and operational improvements (e.g., examine how common-use or preferential gate use can accommodate increased passenger demand); (b) implications of designing facilities to accommodate alternative peak periods (e.g., those occurring more or less frequently); and (c) specific facility requirements as a function of larger-scale control totals (e.g., annual passengers or aircraft operations). (ACRP)

Airport Passenger Conveyance System Usage And Throughput:

ACRP – Capacity prepared a comprehensive guidebook that serves as a decision-support tool for planning, designing, and evaluating passenger conveyance systems at airports. This research examined how passenger conveyance systems operate and provide service to different areas within the airport environment. For the purpose of this research project, passenger conveyance components included, but were not limited to, escalators, elevators, moving walkways, wheelchairs, and passenger assist vehicles and carts. (ACRP)

Avoiding Severe Icing Conditions:

National Transportation Safety Board (NTSB) data indicate that inflight icing causes more than 25 accidents each year, with more than half of those accidents resulting in fatalities and destroyed aircraft. This equates to more than $100 million in injuries, fatalities, and aircraft damage annually. To address this problem, the FAA developed Current and Forecast Icing Products (CIP and FIP), which provide more accurate and timely diagnoses and forecasts of atmospheric conditions that could lead to ice accretion on aircraft during flight. In FY 2011, the FAA implemented FIP-Severity operationally on the Web-based Aviation Digital Data Service at the National Oceanic and Atmospheric Administration (NOAA) Aviation Weather Center in Kansas City. FIP-Severity is an update to the original FIP (which provided only uncalibrated icing potential) and provides computer-based forecasts of the probability of icing based on an analysis of temperature and humidity data associated with clouds. This automated algorithm gathers real-time information from satellites, radars, weather models, surface stations, and pilot reports; and determines the probability of encountering icing, its expected severity, and the likelihood of large droplet icing conditions. This capability is especially beneficial to commuter planes and small aircraft without ice protection as well as those



The Flight Path Tool provides hazardous weather information, including in-flight icing severity forecasts, for a selectable route of flight.

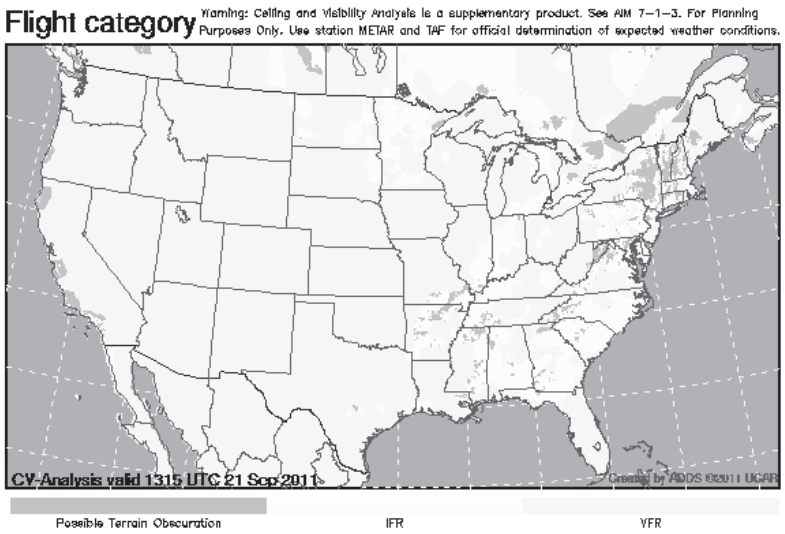
flying at relatively low altitudes—lower than 24,000 feet—where they are more likely to encounter atmospheric conditions conducive to icing. (Weather Program)

Avoiding Turbulence:

Turbulence accounts for 65 percent of all weather-related injuries, costing more than $41 million annually in injuries, fatalities, and aircraft damage. In FY 2010, more than 4,000 severe encounters occurred. Because observations and forecasts have not been accurate enough to pinpoint the location, time, and intensity of turbulence, FAA researchers developed an algorithm that computes eddy dissipation rate (EDR), a measure of turbulence intensity independent of aircraft type. These EDR data, which also provide the location and time of the density, have been useful in making improvements to the FAA-developed Graphical Turbulence Guidance forecast, already in use in the National Airspace System (NAS) via the National Oceanic and Atmospheric Administration (NOAA) Aviation Weather Center in Kansas City. In FY 2011, the FAA in collaboration with Delta Airlines completed a demonstration to show how flight dispatchers could use the real-time turbulence observations provided by EDR data to help pilots plan and alter flight routes. This demonstration provided visual displays of EDR data to dispatchers to help them spot hazardous turbulence areas and warn pilots to avoid them and, therefore, enhance safety. Due to the more accurate turbulence information, flight efficiency improved because pilots were able to stay at their optimum fuel-burn altitudes for longer periods. Initial findings from this demonstration suggests that better turbulence information leads to better decisions on flight altitude selections and deviations, which could potentially save a large airline tens of millions of dollars in fuel annually. (Weather Program)

Enhancing General Aviation Safety:

Each year, low ceilings and visibility are the cause of 72 percent of general aviation (GA) accidents in the contiguous United States. In Alaska, these cause 55 percent of GA weather-related accidents. The most deadly of GA encounters result from inadvertent flights into Instrument Meteorological Conditions (IMC) by Visual Flight Rules (VFR) pilots or a poorly prepared Instrument Flight Rules (IFR) pilot. The FAA developed a National Ceiling and Visibility Analysis (CVA) capability that provides real-time analysis of current ceiling and visibility (C&V) conditions, updated every five minutes with a 5 km grid, across the continental United States. In FY 2011, this capability underwent a successful scientific review and a safety assessment and is anticipated to be implemented operationally on the Web-based Aviation Digital Data Service (at the NOAA Aviation Weather Center in Kansas City) in FY 2012. As a safety tool to improve situational awareness, CVA targets the safety-of-operations needs of less-equipped GA pilots. (Weather Program)



NCVA provides five-minute nowcast updates of ceiling, visibility, and flight category conditions to enhance safety, especially for GA.

Suggestion By FAA Air Carriers Results In RTCA Operational Services And Environmental Definition:

In 2007 a concept was presented at a wake turbulence research and stakeholder community meeting to use ground-based wake turbulence transport predictions to allow better use of an airport's closely spaced parallel runways (CSPR) during IFR operations. The chief obstacle to the concept was of accurate wind information on the ground along the approach paths to the CSPR. Ground-based wind sensors were unreliable above 500 feet in many of the weather conditions that would cause the airport to be in IFR operations and wind sensors would need to be positioned at multiple locations along the approach path. Many times, CSPR approach paths exceed 10 miles in length and include segments over water or densely populated areas. Air carrier representatives at the meeting suggested that wind information was always available from onboard aircraft systems; perhaps the aircraft wind data could be transmitted to the ground at certain locations along the aircraft's approach to the CSPR.

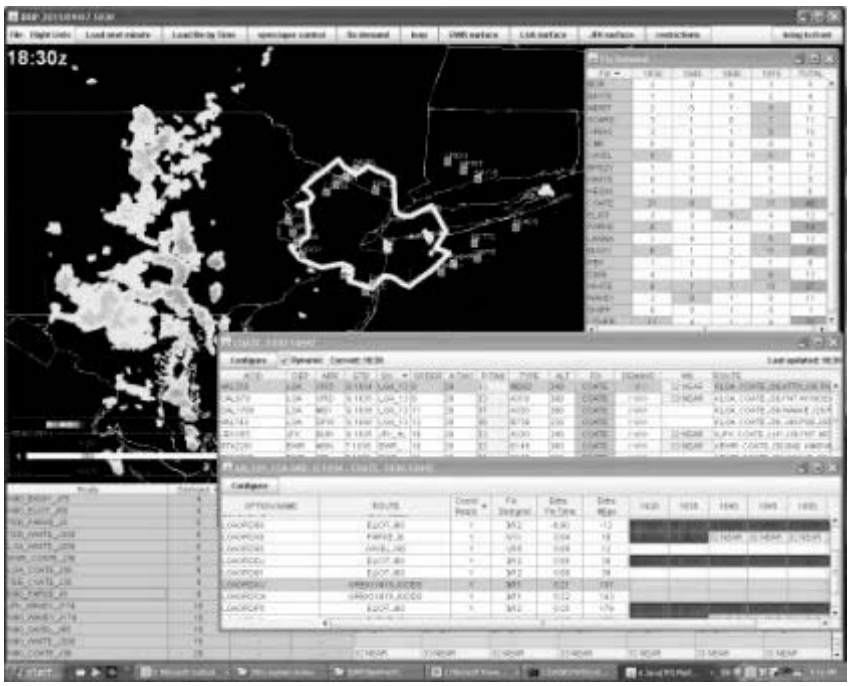
That suggestion started the development a detailed concept of how aircraft wind data could be used in ground-based near-real time wake turbulence transport predictions, completed in 2008. Members of the wake research, air traffic management, and weather communities discussed the concept with RTCA and in 2009, informative appendices were published in DO-260B and DO-282B detailing a concept for transmission of aircraft derived meteorological data over Automatic Dependent Surveillance-Broadcast (ADS-B) data links. Subsequently, the RTCA formed a working group to refine further the concept of aircraft derived meteorological data NextGen-era ground-based and air-to-air applications. One of the primary applications considered was near real-time prediction of wake turbulence transport for use in setting aircraft wake separations on CSPR approaches. An engineering analysis, a benefit assessment, and other trade-off analyses supported the workgroup in their selection of aircraft meteorological data to be transmitted as well as in determining the timeliness requirements for the aircraft data. In September 2011, RTCA approved the workgroup product, *Aircraft Derived Meteorological Data via ADS-B Data Link for Wake Vortex, Air Traffic Management, and Weather Applications Operational Services and Environmental Definition (OSED)* for final review and comment. The ADS-B (In) Aviation Rule Making Committee (ARC) adopted materials from this OSED document and included them in their final recommendations. This has the potential to affect both the ASD-B (Out) and the ADS-B (In) requirements and engineering—ensuring detailed consideration of downlinked aircraft derived meteorological data for use in NextGen-era capacity enhancing applications. (Weather Program)

Integrated Departure Route Planning:

In current day operations, Traffic Management Coordinators (TMCs) must face the challenge of managing departure operations without the support of integrated actionable information or decision support systems. During traffic congestion and convective weather, TMCs must gather important information from a variety of data sources and multiple systems. TMCs must then mentally integrate this information to project the future situation. This process is difficult, time-consuming, and prone to error. Because TMCs across facilities lack a common information source, it is challenging for decision makers and/or stakeholders to plan collaboratively to reduce the impact of off-nominal events on departure efficiency. As a result, TMCs have difficulty in fully exploiting the capacity of the airspace in a timely manner, resulting in increased departure delays and unused capacity.

Integrated Departure Route Planning (IDRP) is a prototype decision-support capability the Center for Advanced Aviation System Development (CAASD) is developing in partnership with the Massachusetts Institute of Technology's Lincoln Laboratory (MIT/LL). IDRP combines state-of-the-art weather forecasts with operational flight data and is intended to assist FAA air traffic managers and commercial airline users in making proactive Traffic Flow Management (TFM) decisions, both during severe weather and during clear weather conditions when traffic demands are reaching or exceeding the nominal or reduced capacity of NAS resources.

IDRP combines predictions of weather impact along departure routes, predictions of congestion at departure routes and fixes and in nearby en route airspace, and an automated reroute identification algorithm into a single decision support tool that will help traffic managers manage departure traffic proactively. IDRP identifies departure flights whose flight plans cannot be executed due to weather or volume constraints, along with their order in the queue. It then searches a set of alternatives acceptable to TFM/Air Traffic Control (ATC) and airline operations to find a feasible reroute for the right flight at the right time. IDRP also provides information to help decision makers evaluate and implement different solutions, taking into account all significant data such as filed flight plans and acceptable alternatives, surface departure queues with integrated surface information, predicted convective weather and traffic congestion impacts to routes in the terminal area and nearby en route airspace, and forecast uncertainty.



Screen capture of the Integrated Departure Route Planning (IDRP) prototype, deployed for field evaluation in New York in 2011. IDRP combines state-of-the-art weather forecasts with operational flight data.

To define and quantify the potential benefits of this prototype capability further, the FAA Air Traffic Organization's System Operations Service (AJR) TFM Weather Program Office sponsored a series of field evaluations to assess the benefits of IDRP during the 2010 and 2011 summer convective weather season.

During the 2011 summer field evaluations, FAA researchers collected 90 hours of observation data at eight Air Traffic Control (ATC) facilities and two airline facilities. Researchers collected nearly 70 percent of the observations when clear weather was present in New York airspace, while they collected the remaining 30 percent under Severe Weather Avoidance Plan operations. Preliminary results indicate that TMCs and Supervisory TMCs (STMCs) at the targeted facilities used the IDRP system to support airport load balancing, to offload saturated departure fixes, to reduce constraints posed by traffic management initiatives both within and between centers, and to balance proactively the demand across a set of fixes to prevent congestion. In addition to these documented use cases, STMCs and TMCs noted 115 instances where IDRP supported situation awareness of demand, surface status, aircraft status, and the impact of weather or traffic management initiatives on traffic flow. Researchers are currently using these observations to quantify observed benefits of the prototype IDRP system as well as to identify requirements for additional capabilities. The FAA will use the findings from this research to refine the understanding of needs for future TFM and terminal capabilities. (CAASD)

Boeing 787 And Boeing 747-8 Series Aircraft Successfully Integrated Into The NAS:

- **Boeing 787 Series Aircraft:** In 2003, Boeing introduced a new aircraft design, the Boeing 7E7 (later designated Boeing 787), which was to be more fuel-efficient than the similar sized Boeing 767. While not a certification requirement, the National Transportation Safety Board (NTSB) recommended that, during certification of a new aircraft series, wake mitigation separations must be determined for aircraft that would be behind the Boeing 787 and the safe wake mitigation separations for the Boeing 787 when it is behind another aircraft. As the FAA and the European Aviation Safety Agency (EASA) worked on the certification of the 787 Series, they also assumed responsibility for determining the wake separations that the global air navigation services providers would apply to the aircraft. A joint FAA-Boeing task group was formed and provided EASA its recommendations, and upon EASA acceptance, the FAA transmitted these recommendations to the International Civil Aviation Organization (ICAO). ICAO issued guidance based on the FAA recommendations to its member states in 2011, before the Boeing 787 entering operational service for All Nippon Airways (ANA). The work by the FAA to determine the Boeing 787 wake separations used the extensive aircraft wake turbulence transport databases collected by the NextGen – Wake Turbulence research program, modeling tools developed by the program, and analysts who support the program.

- **Boeing 747-8 Series Aircraft:** In 2004, Boeing announced that it would build a 747 advanced aircraft, which would be the largest production aircraft it had ever built. In 2005, Boeing changed the aircraft's name to Boeing 747-8 and clarified that it would be a series of aircraft, with the 747-8F as the freighter version and the 747-8I as the passenger version. To determine wake separations of the new aircraft, the FAA formed a joint steering group with EASA, EUROCONTROL, and Boeing. In the absence of any data to the contrary, the steering group provided interim guidance that the B-747-8 should have a wake separation from other aircraft, which would be greater than the ICAO prescribed standard for Heavy wake category aircraft. In 2007, Boeing decided to conduct a flight test to acquire wake turbulence data to use as the primary basis for establishing wake separation standards for the 747-8 series. Boeing designed a flight test program, which the FAA/EASA work group approved, and they successfully completed testing in 2010. Based on the test program data and other wake turbulence data collected by the NextGen – Wake Turbulence research program and associated analytical and statistical models, the FAA/EASA task group determined in 2011 that the Boeing 747-8 series aircraft should be classified as a Heavy wake category aircraft, which would not require any additional wake separation distance than that provided for other like-category aircraft. Thereafter, the working group provided its recommendation to ICAO. In August 2011, ICAO transmitted guidance on Boeing 747-8 wake separations to its member states based on the working group's recommendations. (NextGen – Wake Turbulence)

  This work also supports R&D Goal 10 – World Leadership.

Clean And Quiet

A reduction of significant aerospace environmental impacts in absolute terms

Guidebook On Preparing Airport Greenhouse Gas (GHG) Emission Inventories:

A growing need exists to provide airport operators with clear and cohesive information on the national inventory of airport-level GHG emissions. Given the rising level of interest regarding aviation's contribution to GHG emissions and ultimately to climate change, it is imperative that airports have the most up-to-date information necessary to address potential concerns. In response to this need, ACRP – Environment has developed a guidebook that can be used to prepare airport source-specific inventories of GHG emissions. This guidebook provides methods for calculating airport GHG emissions inventories in a consistent manner and provides information on considerations that should be taken into account when scoping and preparing such inventories. This guidebook focuses on the following six GHG emissions since they are widely recognized as relevant and quantifiable: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6), hydrofluoro compounds (HFC), and perfluorocarbons (PFC) (ACRP 2-06, Report 11). (ACRP)

Quantifying Contribution To Local Air Quality Impacts From Airport-Related Emissions:

ACRP – Environment developed effective tools and techniques for airport operators to measure airport contributions to ambient air quality. This research evaluated existing and potential monitoring strategies and forecasting techniques that airport operators can use to measure airport-related air quality impacts on local jurisdictions that may exceed what is traditionally measured and modeled for National Environmental Policy Act (NEPA) purposes. This research project also identified (a) gaps in existing models and the inputs to those models; (b) future research needed to fill those gaps to improve the predictive capabilities of available models; (c) a set of detailed recommendations for implementing an optimal emissions monitoring and forecasting strategy; and (d) guidance to airport operators on how to select and carry out that strategy. (ACRP)

Evaluation Of Stormwater System Design Conditions For Deicing Management:

Winter storms are highly variable and present significant operational challenges for airlines and airport operators who must ensure compliance with both aircraft safety standards and environmental standards. As a result, the design of airport infrastructure to manage stormwater from aircraft deicing operations cannot be standardized across all airports. Development of stormwater management systems for worst-case deicing events could result in high costs for managing rare events. Alternatively, a stormwater management system that allows for frequent overflows could raise concerns about the ability to meet permit limits and/or water quality standards. To provide guidance to airport designers and operators, ACRP – Environment created a guidebook defining the relevant winter storm design factors and how to use those factors in determining a winter storm design (i.e., for sizing and selecting a collection, conveyance, storage, and treatment system in the management of runoff from aircraft deicing operations). (ACRP)

Environmental Optimization Of Aircraft Departures—An Investigation Of Fuel Burn, Emissions, And Noise Interdependencies:

ACRP – Environment developed a departure optimization methodology to: (1) quantify potential reductions in fuel burn and source emissions; (2) estimate possible increases in air traffic capacity that can be achieved by optimizing departure procedures while continuing to address noise exposure for communities around airports; and (3) account for existing and future fleet mixes and improvements envisioned under NextGen. In the context of current noise-abatement departure procedures, this methodology estimates the environmental and capacity-related benefits associated with the two localized contributors: source noise reduction in future engine and airframe technologies and realistic alterations to present noise-abatement departure procedures. The output of this research provides directly quantifiable metrics that will help regulators and airport management make environmentally optimal decisions, such as improving noise-abatement departure procedures, making aircraft and engine design improvements, and improving air traffic optimization by designing more efficient departure procedures. (ACRP)

Dependence Of Hazardous Air Pollutant Emissions From Idling Aircraft On Ambient Conditions:

ACRP – Environment designed and implemented a test system to measure gaseous Hazardous Air Pollutant (HAP) emissions from in-production jet engines operating at a range of idle settings and ambient temperatures. The primary research objective of this program is to measure total hydrocarbons and speciated hydrocarbons, including HAPs, within the exhaust plume at a reasonable proximity of the engine nozzle to capture emissions before condensation of volatile gasses. The secondary objective of this program is to measure at a downstream location where the plume has cooled to near-ambient temperatures. With a better understanding of aviation HAP emissions, airport operators will be able to develop accurate inventories and provide state and local constituencies with the information they need. (ACRP)

Guidebook Of Practices For Improving Environmental Performance At Small Airports:

Small airports have limited resources and staffing and, as a result, these airports usually do not have an environmental practitioner on staff that is intimately knowledgeable in the environmental arena. No single resource is available to airport managers—or their governing boards—outlining all Federal environmental regulations. In addition, practices that exceed requirements and promote environmental stewardship, sometimes referred to as sustainable practices, are also not familiar to small airports. In response to this need, ACRP – Environment assembled a guidebook for managers of small airports that: (1) promotes environmental awareness; (2) identifies Federal environmental compliance requirements; (3) outlines those best management practices that proactively enhance environmental stewardship; and (4) identifies resources/tools that airports can use to be proactive. (ACRP)

Evaluating Requirements Associated With Locating Alternative Fuel Production Facilities On Or Adjacent To Airports:

Drop-in, alternative jet fuel provides great promise for the aviation industry from environmental, energy security, and economic perspectives. Several demonstration flights during the past year have shown that technology is available to produce alternative jet fuel that aircraft operators can use to fly existing aircraft safely. A key challenge to moving forward with commercial use of alternative jet fuel includes forming an effective business plan addressing production at marketable prices and quantities, and delivery at the appropriate point in the supply chain. One concept receiving significant industry interest is locating an alternative fuel production facility on, adjacent to, or within easy access of an airport to take advantage of established demand. Access to a known demand at an airport could encourage investment by an alternative fuel producer. To provide a path forward for situating an alternative fuel production facility and associated infrastructure, research was done to evaluate the legal, financial, environmental, and logistical considerations and opportunities associated with launching such a project. Based on the results, ACRP – Environment prepared a handbook for airport operators and others associated with drop-in jet fuel production and delivery summarizing issues and opportunities associated with locating (either on or off airport) an alternative jet fuel production facility and its storage and distribution requirements. This handbook identifies potential benefits; addresses legal, financial, environmental, and logistical considerations and opportunities; and aids in evaluating the feasibility of providing this capability. (ACRP)

Evaluation Of Aviation Growth Capacity Within State Implementation Plans:

The growth of air traffic operations in the United States has resulted in an increase in traffic at the nation's major airports, accompanied by a corresponding increase in emissions. Approximately 158 commercial service airports are currently located in Environmental Protection Agency (EPA) designated nonattainment or maintenance areas. As EPA's emission control strategies for non-aviation sectors take effect, the aviation emissions sources could become more prominent within the current emission inventories conducted for our nation's poor air quality regions as well as the future forecasted State Implementation Plan (SIP) emission budgets. Therefore, ACRP – Environment developed a guidebook for airport operators and state and local air quality planners describing the development of the airport emissions component of a SIP, including emission inventories and projections and key data elements for airside non-road emissions sources. The focus is on civilian airports, both commercial service and general aviation (GA). This guidebook includes a description of the state of the practice, guidance on how to develop a civilian airport emissions component of the SIP, and direction on how to harmonize future civilian airport emissions estimates with aviation forecast information. (ACRP)

Evaluating Green Engineering And Construction Practices At Airports:

Attention to and awareness of green and sustainable initiatives is increasing in the design and construction of not only commercial and residential properties, but also in the construction and renovation of airports. Most people are aware that incorporating these initiatives may incur higher initial costs, but they frequently do not realize the benefits these initiatives can provide. In some cases this perception has inhibited the use of these concepts and technologies in traditional airport projects (i.e., airport projects not planned and designed with sustainability in mind). Airport decision makers could benefit from a better understanding of the social, economic, and environmental benefits of incorporating sustainable design concepts and technologies into their projects. They

also need a process to evaluate and determine achievable, sustainable design concepts and technology alternatives that they could incorporate into traditional projects. In response to this need, ACRP – Environment created a guidebook that airports can use to assist them in evaluating sustainable design and technology alternatives during the planning and design phases of airport project development. (ACRP)

Sustainable Airport Construction Practices:

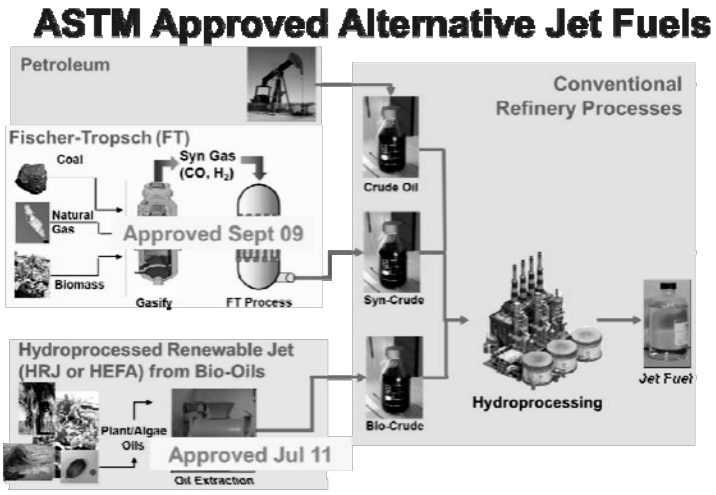
Airports strive to be fiscally, socially, and environmentally responsible as well as to be good neighbors. They consider their activities in terms of achieving excellence in economic growth, environmental stewardship, and social responsibility. While information is readily available to support a movement toward integrating sustainable concepts into facility design, little information on sustainable practices, methods, procedures, and technologies that developers can incorporate during construction is available. ACRP – Environment has therefore developed a report containing a collection of sustainable practices that developers can implement during airport construction. This report includes best practices, methods, procedures, and technologies for all stakeholders involved in the planning, design, and construction of airport development or redevelopment projects. (ACRP)

Airport Energy Efficiency And Cost Reduction:

Airport terminals use large amounts of energy for lighting, heating, ventilation, air conditioning, and more. Some airport operators have reduced their operating expenses by focusing on energy efficiency, considering both energy supply as well as energy consumption. Some airports have used terminal roofs or land areas to host alternative energy systems, and many airports have eliminated unnecessary energy use in airport facilities as a way to reduce operating expenses. For example, airports have updated mechanical systems and lighting technology to current standards, and some airports have used available rebates to install up-to-date technology. ACRP – Environment produced a compendium of information that focuses on selected airport energy efficiency and cost reduction opportunities. This compendium contains a description of successful practices that airports have implemented to increase airport energy efficiency and reduce airport operating costs and puts additional focus on no-cost, low-cost, and moderate-cost improvements. The compendium will help identify real, implementable actions that will result in reducing energy consuming system costs in terminals. The audience for this synthesis of practice is airport managers and their staff that are responsible for these systems and their effect on airport operating budgets (energy, equipment, and staff). (ACRP)

Sustainable Alternative Jet Fuels:

On July 1, 2011, standard-setting organization ASTM International approved a bio-derived sustainable alternative jet fuel known as Hydroprocessed Esters and Fatty Acids, or HEFA, for commercial use at a 50 percent blend level. HEFA is a drop-in jet fuel that industry can use without making changes to aircraft systems or fueling infrastructure and will reduce aircraft emissions and enhance US energy security. This approval required extensive collaboration over a period of three years with all stakeholders, including FAA, Department of Defense (DOD), engine and aircraft



ASTM International approves fuel that meets specifications for use in commercial jet aircraft. In addition to conventional Jet A fuel derived from petroleum, two alternative jet fuels have been approved at a 50% blend with Jet A. These include fuels using the Fischer-Tropsch process as well as fuels derived from plant oils and animal fats (e.g., Hydroprocessed Esters and Fatty Acids or HEFA).

manufacturers, airlines, and fuel suppliers. This jet biofuel approval will spur fuel deployments to meet the growing demand of commercial carriers.

In partnership with the US Department of Agriculture, the FAA developed a Feedstock Readiness Level (FSRL) tool to show developmental progress and to assess the availability of different kinds of feedstocks that biorefineries will need to produce renewable jet fuels. This nine-step scale also helps to clarify efforts needed to bring new feedstocks to market. Boeing completed a study on how alternative jet fuel affects material in aircraft fuel systems, demonstrating rubber seals are not adversely affected by a blend of alternative jet fuel and Jet A fuel. Honeywell demonstrated a jet biofuel blend that will not clog fuel systems at cold temperatures. Rolls-Royce completed laboratory testing of future jet biofuels under development by nine fuel companies.

The FAA and the National Aeronautics and Space Administration (NASA) completed measurements of aircraft exhaust emissions from the combustion of renewable alternative fuels for existing aircraft engines. Emission measurements on the combustion of 50/50 blends and 100 percent renewable fuels showed significant reductions in particulate matter emissions. (Environment and Energy)

Continuous Lower Energy, Emissions, And Noise (CLEEN) Program:

In partnership with industry, CLEEN is accelerating development of aircraft technologies that reduce noise, emissions, and fuel burn. In FY 2011, FAA researchers tested several technologies to demonstrate capabilities and advance toward future commercial products beginning in 2015. These technology demonstrations include the following:

- Boeing completed wind tunnel tests of advanced wings to improve aerodynamic efficiency, leading to an estimated two percent reduction in aircraft fuel burn and emissions. Flight tests of the advanced wings will take place in August 2012.
- Component tests of Ceramic Matrix Composite (CMC) engine nozzles demonstrated weight savings and noise absorption, which will ultimately reduce aircraft fuel burn. Flight tests of the CMC nozzles will occur in August 2013.
- General Electric (GE) continues to make progress on low nitrogen oxide (NOx) engine combustors. Full combustor rig tests demonstrated that landing and takeoff NOx emissions could be reduced 60 percent from existing emission standards, meeting a CLEEN goal. Full-scale engine core-demonstration tests began at the end of FY 2011, with NOx emissions measurements planned for early FY 2012. This advanced low NOx combustor will be used in CFM International's LEAP-X turbofan engine, which will enter service in 2015.
- The LEAP-X engine will power Boeing's 737MAX aircraft. GE also completed high- speed wind tunnel tests of advanced Open Rotor fan blades, demonstrating improved aerodynamic and noise performance.
- Rolls-Royce completed component tests of CMC turbine engine shrouds. These advanced, lightweight materials can withstand higher temperatures and will increase engine fuel efficiency. Full-scale engine endurance tests will take place in July 2012. (Environment and Energy)

Characterization Of Aircraft Combustion Emissions Of Alternative Fuels:

In March 2011, the FAA conducted an emissions measurement campaign at a NASA-sponsored project, Alternative Aviation Fuel Experiment II (AAFEX II), at the NASA Dryden Flight Research Center facility in Palmdale, California. AAFEX II used the Center's DC-8 aircraft to test the emission effects of several fuel types, including a natural gas-derived Fischer-Tropsch fuel, a Hydrotreated Renewable Jet (HRJ) biofuel, as compared to conventional JP-8 fuel. The DC-8 right inboard engine used in testing is a CFM 56 model, which was previously used to test other fuels and thus has a well-documented performance and emission profile that researchers can use for comparing emissions performances. Although the CFM 56 used in testing is of a somewhat older vintage, they are the most widely used engine within the current commercial fleet—almost all B-737 use some versions of this engine—and are representative of the technology that is likely to be in place for the next several years. Thus, the acquired dataset will have broad relevance to current studies of air quality and engine technology.

A key objective to AAFEX II is to determine the effects of these alternative drop-in fuels on particulate matter (PM) and gas-phase exhaust emissions. The test plan was to characterize engine emissions as a function of power for five different fuel blends under various daytime and nighttime ambient conditions. Test results showed clear differences between these fuels, with HRJ and FT fuels reducing PM emissions by one to two orders of magnitude at low engine powers.

Another key objective is to investigate exhaust plume chemistry, including the role of fuel sulfur in regulating volatile aerosol formation in engine exhaust plumes. FAA researchers made downwind observations at several locations, at 30 meters, 143 meters, and adjacent areas using the mobile lab, during all tests. Results showed volatile PM number and mass emissions are highly dependent on fuel sulfur and change significantly with ambient temperature and plume age. Data obtained are particularly valuable in validating microphysical computer models of sulfate aerosol formation and growth.

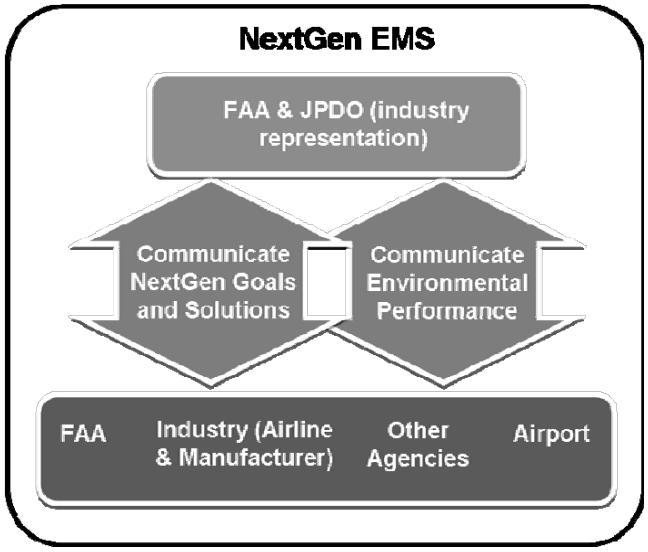
The FAA is currently working with AAFEX II participants to review test results and complete an in-depth analysis of the collected data as well as to help NASA prepare the final report for release to the public in mid-2012. (Environment and Energy)

NextGen Environmental Management System:

It is important to manage aviation environment and energy impacts to implement NextGen effectively. Stakeholders must address aviation-related noise, air quality, climate, and energy issues in areas where they have influence (such as in technology, operations, research and development, etc.). The FAA is coordinating a NextGen EMS framework to work across aviation stakeholders to collaborate on approaches to address environmental issues critical for efficient NextGen implementation.

In Phase I, FAA researchers completed a number of baselining and scoping activities. These included pilot studies at Denver International Airport (DEN) and Dallas–Fort Worth (DFW) to investigate environmental issues with the potential to constrain future airport growth. Researchers were then able to investigate how NextGen procedures and technologies might mitigate these constraints. Additionally, the FAA worked with manufactures to investigate some of the important issues they should address for new technologies to produce a maximal environmental and operational benefit. In addition to pilot studies, the FAA conducted a range of communications and outreach activities focused on industry, airports, and the FAA. These activities aimed to improve stakeholder understanding of the potential environmental benefits of NextGen as well as their role in ensuring these benefits come to fruition.

Through these baselining and scoping activities, researchers were able to identify areas of focus for NextGen EMS. These areas of focus include the following: (1) establish aviation environmental goals and targets against which the FAA can measure progress; (2) define each stakeholder's role in addressing critical aviation environmental issues, (3) establish a framework within which stakeholders can collaborate (e.g., identify barriers to success, share best practices and drive future direction); (4) understand the environmental benefits of FAA NextGen Operational Improvements and implementation requirements; and (5) develop collaborative approaches to address NEPA requirements more effectively and efficiently during implementation.



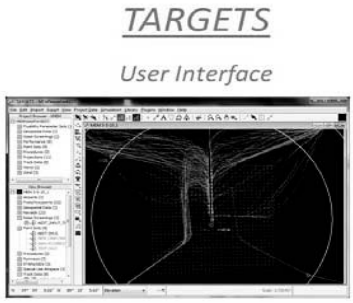
EMS: The NextGen Environmental Management Approach

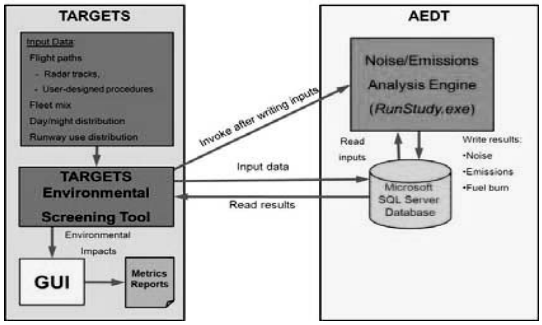
Based on these findings, the FAA has organized an industry-wide NextGen EMS Forum. This will provide an opportunity for aviation stakeholders to exchange ideas on and approaches to address the critical environmental and energy issues facing NextGen implementation. The FAA has also initiated a collaborative pilot study aimed at improving the efficiency of NextGen implementation by addressing environmental requirements associated with implementation more effectively. In addition, FAA researchers are conducting a comprehensive assessment of NextGen Operational Improvements to identify those with substantial potential environmental benefits or to which environmental requirements may apply during implementation. (Environment and Energy)

TARGETS-AEDT DATA COMMUNICATION INTERFACE:

The FAA's Terminal Area Route Generation, Evaluation, and Traffic Simulation tool (TARGETS) is being coupled with the FAA's new Aviation Environmental Design Tool (AEDT) software tool to allow assessment of new, more efficient aircraft procedures being developed under NextGen.

Currently, the TARGETS tool contains an Integrated Noise Model (INM) plug-in. This plug-in allows for noise consequences of the designed procedures to be developed. This plug-in has limited capability to model three dimensional trajectories as it currently uses standard altitude profiles within INM. In addition, those standard profiles are limited to 6,000 feet above ground level (AGL) for arrivals and 10,000 feet AGL for departures. By upgrading the plug-in in TARGETS away from the legacy INM tool to the Agency's new environmental compliance tool, AEDT, enhanced capabilities, such as altitude controls and longer aircraft profiles are available.





TARGETS/AEDT Integration schematic

The coupling of TARGETS with AEDT results in a highly efficient process to determine environmental trade-offs and consequences of aircraft noise exposure, emissions, and fuel consumption at the early design phase. It allows the designer to consider the environment when designing the procedure after all safety and efficiency considerations are taken into considerations. This allows for early identification of environmental consequences, allowing the Agency to understand the

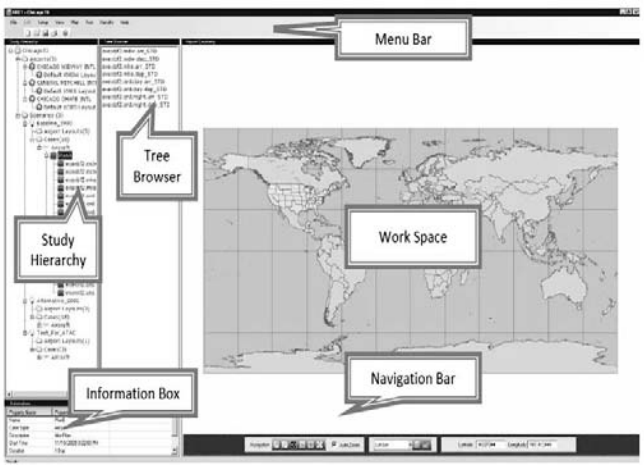
extent of the environmental review necessary, providing more information prior to beginning the NEPA process.

In FY 2011, much work was done in developing the prototype. As AEDT is still under development, TARGETS developers began working with a beta version of AEDT to create the interface needed. The developers have accomplished taking TARGETS output and populating the appropriate AEDT database tables, allowing the environmental consequences to be computed in AEDT to produce results. In addition, they have been able to display the noise results in TARGETS (fuel burn and emissions to come in FY 2012). Finally, the ability to stipulate altitude controls along the procedures has been implemented.

In FY 2012, the FAA will develop an interface between TARGETS and AEDT. This interface will enable users to analyze the environmental impacts within TARGETS using AEDT as the environmental analysis engine. The capability will allow TARGTS to provide input data to AEDT for performance, noise and emissions, and to read output produced by AEDT and display this output to the TARGETS users. (Environment and Energy)

Aviation Environmental Design Tool (AEDT):

The Environment and Energy Program continued to enhance Aviation Environmental Design Tool (AEDT). AEDT uses a single set of inputs to calculate aircraft performance, which is used to compute noise levels, fuel consumption, greenhouse gas emissions, and criteria pollutant emissions. The AEDT software tool will be used to evaluate the environmental trade-offs associated with informing billion-dollar investment decisions for implementing NextGen technologies and procedural changes.



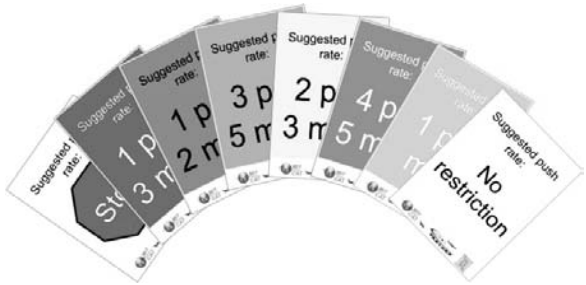
The FAA's Aviation Environmental Design Tool (AEDT), version 2a, is a Windows application that quantifies aircraft noise, emissions, and fuel burn, and employs GIS technology to explore tradeoffs among environmental consequences.

Multiple developmental milestones have been achieved in FY 2011 in preparation for the release of AEDT 2a in FY 2012. A beta version was completed in October 2010, and subsequently released to the Design Review Group (DRG) for further testing and evaluation. DRG members include other FAA offices, NASA, EPA, other service providers, industry, airport authorities, and contractors. In addition, a public demonstration of AEDT2a was held at the AEE Tool Colloquium in December 2010. In February 2011, the first public training was held at the UC Davis Aviation Noise and Emission Symposium, giving the wider public their first chance to exercise AEDT 2a. In March 2011, full functionality for AEDT 2a was reached. In June 2011, a test-driven code-coverage version of AEDT 2a was completed. Since the June milestone, AEDT 2a has been going through optimization and fault testing. In this phase of development, AEDT is being optimized to reduce runtime; meanwhile fault testing continues to explore potential vulnerabilities prior to public release. Additionally, AEDT 2a has undergone extensive validation and verification of methodologies against gold standard data and the legacy tools. In addition, capability demonstrations to ensure AEDT 2a can perform the analyses it will be required to perform once released has been undertaken in FY 2011 in anticipation of the FY 2012 release.

AEDT will be released in two phases. AEDT 2a will be used to model the environmental consequences of air traffic airspace actions where the study area: is larger than the immediate vicinity of an airport, incorporates more than one airport, or includes actions above 3,000 feet above ground level (AGL). AEDT release will sunset the legacy tool used for these analyses, the Noise Integrated Routing System (NIRS). AEDT 2b, to be released in FY

2014, will sunset the legacy Integrated Noise Model (INM) and the Emissions Dispersion Modeling System (EDMS). (Environment and Energy)

SURFACE MOVEMENT OPTIMIZATION:



Researchers used these color-coded cards to communicate suggested pushback rates to air traffic controllers during the Phase 1A demonstration. This approach eliminates the need for verbal communication.

Airport surface congestion at major airports in the United States is responsible for increased taxi-out times, fuel burn and emissions. Domestic flights in the United States annually emit about 7.5 million tons of CO_2, 58,000 tons of CO, 10,000 tons of NOx, and 5,000 tons of HC taxiing out for takeoff. A key contributor to taxi delay and emissions is the prevalence of excessive surface congestion. Decision support tools and modified operating procedures hold the promise of helping manage surface congestion (and hence reduce excessive surface fuel burn and emissions) without adversely affecting departure throughput at the airport. This is typically achieved by holding aircraft at the gate or in the ramp area instead of releasing them onto the active movement area during periods of high departure demand.

An initial demonstration of a pushback rate control approach termed "N-Control" at Boston Logan International Airport (BOS) showed significant reductions in aircraft taxi time, fuel burn, and emissions. As a result of this analysis, a number of items were identified that warrant further investigation. The objective of Phase 1B is to evaluate different operating scenarios and weather conditions that can be leveraged into more refined surface congestion management processes. These scenarios were included into a refined model that was tested at BOS.

The FAA conducted a second field demonstration at BOS airport to evaluate the operational benefits of surface movement optimization strategies that reduce congestion while improving environmental performance. The MIT research team targeted taxiing-out delays and improved surface operational efficiency by controlling the aircraft pushback rate at the gate. This field study showed a reduction in gate-hold time by an average of 5.5 minutes per aircraft pushback, resulting in a savings of 22–26 gallons of fuel burn per operation. This estimated fuel savings is roughly equal to the fuel savings from Continuous Decent Approach (CDA, which is now commonly known as Optimized Profile Descent or OPD)—an operational procedure which is widely used worldwide and was pioneered by the FAA.

The development and findings of the Phase 2 studies will be coordinated with complementary studies as the Tower Flight Data Manager (TFDM), STBO's Collaborative Departure Queue Management (CDQM), and Collaborative Departure Scheduling (CDS). (Environment and Energy)

	Phase 1A Results	Phase 1B Preliminary Results
Total Flights Held	247	136
Average Gate Hold per Flight	4.3 Minutes	5.5 Minutes
Fuel Saved*	3,900–4,900 Gallons	3,000–3,500 Gallons
Taxi Out Time Savings	17.8 Hours	12.5 Hours
Emission Reduction	84,000 Pounds of CO2	65,000 Pounds of CO2
Cost Savings**	$15,600–$19,600	$12,000–$14,000

*Dependent on APU use

**Estimated using $4.00 per gallon

NAS-WIDE ENVIRONMENTAL IMPACT ASSESSMENT FOR NEXTGEN:

This CAASD research project is focused on bridging the gap between fast-time simulation tools and environmental models, to enable a more comprehensive NAS-wide benefits assessment capability, including both operational and environmental metrics. There were three main objectives for this research effort in FY 2011: (1) identifying key research priorities for bridging the gap between fast-time NAS-wide simulation tools and environmental models; (2) proposing and testing solutions for these research questions given that both tools are continuing to undergo development; and (3) conducting a sample analysis to illustrate key findings. This research involved close collaboration with the FAA's Office of Environment and Energy and the AEDT development team at the Volpe National Transportation Systems Center. Since this research was exercising the beta versions of AEDT, the work also provided the added benefit of serving as an external test bed for the AEDT development team.

This research links CAASD's fast-time simulation tool, *systemwide*Modeler, with AEDT. Research priorities addressed in FY 2011 include improving the terminal area representation of flight paths from *systemwide*Modeler and proposing delay absorption mechanisms for translating en-route delay information from the *systemwide*Modeler to the appropriate flight path information inputs for AEDT. The *systemwide*Modeler trajectories were augmented by introducing radar paths in the terminal area and delay vectors in the en route area. A library of historical radar track data was developed to support terminal area trajectory enhancements. This work investigated several delay absorption mechanisms such as speed changes, vectors, and holds, and an initial algorithm for introducing delay vectors into *systemwide*Modeler trajectories was developed. A sample analysis was conducted on a city-pair basis to illustrate the key assembly blocks required to conduct an environmental assessment of operational changes.

Initial results have demonstrated the promise and potential of integrating these two environments. Results from this work will also be applied to developing guidelines for connecting another FAA system-wide analysis tool, the System Wide Analysis Capability (SWAC), with AEDT as part of a parallel work effort. (CAASD)

High Quality Teams And Individuals

A reduction of significant aerospace environmental impacts in absolute terms

Front Line Managers:

In 2011, FAA human factors researchers administered a comprehensive survey to all En Route and Terminal Front Line Managers (FLM). The survey assessed the utility, usability, and perception of the consolidated *Front Line Manager Quick Reference Guide* (FLM QRG), which was deployed to all En Route and Terminal facilities in 2010. Survey results will be used to update and improve the QRG, assist in developing FLM training and reference materials, and serve as a baseline to assess out-year organizational impacts. Since its deployment, the QRG has received positive internal and external feedback. It has also been referenced in Congressional testimony and news reports. (Air Traffic Control/Technical Operations Human Factors)

Controller Job Analysis:

In 2011, FAA human factors researchers updated the job analysis for front line controllers to a new baseline, including the nature and use of current technology and support tools. They evaluated emerging technology drivers that were added to the air traffic control environment including both improved information sources and decision support tools, and described the impact of these changes on how controllers will manage traffic. While the major functions and tasks being performed by controllers remain the same, there are changes to the knowledge required, the skills used, and the relative importance of some abilities. (NextGen – Air Traffic Control/Technical Operations Human Factors (Controller Efficiency and Air Ground Integration))

HUMAN-CENTERED DESIGN

Aerospace systems that adapt to, compensate for,
and augment the performance of the human

Pilot Training For Visual Approaches:

Even though pilots are frequently asked to perform visual approaches, the overwhelming feedback from airline training personnel indicates that current training for visual approaches is ineffective and, therefore, a potential safety concern. This project developed two types of training that should improve visual approach performance; one is conceptual training and the other is exemplar-based training. The conceptual training provides an overview of planning a visual approach, with emphasis on energy management, and an overview of visual illusions that can make it difficult to plan an approach by looking out the window. The exemplar-based training provides pairs of images of the runway and asks pilots to judge if the two views show aircraft coming in at the same approach angle to the runway. The conceptual training touches on the illusions. The exemplar training consists solely of judging many pairs of images with feedback will help pilots learn to recognize visual illusions. FAA researchers collected data with pilot participants by giving the pilots one, both, or neither of the two forms of training. After training, participants received a multiple-choice questionnaire on visual approach energy management and visual illusion concepts. Where possible, researchers collected instructor ratings of pilot performance during the next visual approach pilots performed after this training. Data collection occurred at both regional and major training centers and the data are currently undergoing analysis. The FAA will submit a final report, along with training guidelines, for air carrier-training departments and FAA oversight offices. (Flightdeck/Maintenance/System Integration Human Factors)

A Multi-Disciplinary Approach To Fatigue Risk Management In Aircraft Maintenance—Near Term And Nextgen Time Frame (Maintenance Fatigue):

This research focuses on finding viable, practical, and implementable means to prevent or reduce fatigue for maintenance personnel. FAA researchers reviewed and published current best practices and potential future countermeasures for fatigue risk management for maintenance in a FAA technical report entitled, *Fatigue Risk Management in Aviation Maintenance: Current Best Practices and Potential Future Countermeasures*. The best practices report provides the foundational framework for the development and evaluation of fatigue countermeasures. To date, a number of fatigue countermeasure tools have been developed and are being beta-tested in the lab and/or in industry. Example tools include the following: supplemental accident form, automated fatigue risk assessment, fatigue countermeasure training, and a return-on-investment model. The data collected during beta testing indicate the fatigue countermeasure training program is a valuable tool that influences knowledge transfer and improves attitude and behavior. Based on the beta testing, the FAA Safety Team adopted the fatigue countermeasure training program as the core course for the Aviation Maintenance Technician Awards program (AC 65.25E), and 9,000 GA pilots and technicians have completed the course during 2011. The fatigue risk-assessment tool is ready for industry beta testing and the return-on-investment interface is expected in late 2011. The operational handbook for fatigue risk management is under development and review, with the handbook expected in late 2011. (Flightdeck/Maintenance/System Integration Human Factors)

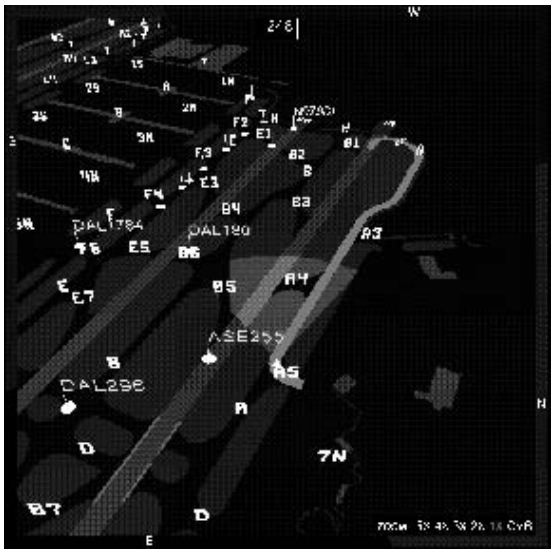
Electronic Flight Bag (EFB) Technologies And Interfaces:

The Electronic Flight Bag (EFB) helps pilots perform flight-management tasks.

Researchers helped the FAA address human factors issues related to EFBs and supported development of EFB-related policies and guidance. The EFB market continues to evolve, and the lines between the classes of EFBs are merging. Research to understand the impact of these changes was conducted via interviews and/or observations of commercial airline pilots to gather their perceptions on integration and use of EFBs in operations. Additionally, usability evaluations were conducted to systematically identify potential human factors issues. The results of this research are summarized in a draft report and synthesized in comment form to provide input to the FAA for consideration in their revision of AC 20-176A. (Flightdeck/Maintenance/ System Integration Human Factors)

Airport Map Displays:

Research was conducted to understand what additional guidance and approval criteria were needed to establish minimum standards and best practices to support flight deck integration of surface moving maps depicting aircraft position and traffic information. Several advanced functions have been identified for consideration including display of surface traffic and alerts of potential runway incursions. A technical report was published which documents human factors considerations for integration of traffic information and alerts on airport moving maps. This document was shared with the RTCA Special Committee (SC)-186 Working Group, which is developing minimum operational performance standards (MOPS) for surface conflict detection and alerting. Researchers also provided technical support to evaluate the impact of a surface moving map with aircraft position on several classes of electronic flight bags. A draft report that compiles FAA regulatory and guidance material, industry recommendations, and human factors research was developed to identify and address common human factors issues that may arise in the evaluation of airport surface moving maps. This document is intended to provide input and data to the FAA on human factors pilot interface issues such as colors, symbols, fonts, labels, workload, situation awareness, and errors related to the airport moving map function. (Flightdeck/Maintenance/System Integration Human Factors)



Screen capture illustrating a surface moving map, which displays aircrafts' positions on the airport surface.

Proactive Audit Approach To Support Safety Management System In Airline Maintenance And Ramp Operations:

Researchers studied airline maintenance and ramp operations during normal situations to develop maintenance and ramp Line Operations Safety Audit (LOSA) processes. LOSA is a formal process where trained observers collect safety-related data on maintenance performance in a non-jeopardy environment. Information obtained via a LOSA provides the maintenance organization a diagnostic snapshot of safety strengths and weaknesses. Proactive approaches, as opposed to post accident and event investigation, align with the principles of risk management and Safety Management System. The research team updated, expanded, and refined LOSA training materials based on feedback from field tests. The team completed a literature review that provided an overview of previous LOSA efforts and the accomplishments of the FAA-Air Transport Association (ATA) LOSA team. A multi-tier prototype database for storing and analyzing safety related LOSA data was tested and fielded. The team, with the assistance of the ATA Human Factors Committee and other industry partners, will provide all materials to the public for implementation. The research outputs will also be used to develop an advisory circular. (Flightdeck/Maintenance/System Integration Human Factors)

Automatic Dependent Surveillance–Broadcast (ADS-B):

Researchers provided human factors support for applications that use ADS-B, including Cockpit Displays of Traffic Information (CDTI). One area of research addressed traffic symbology. Research examined whether symbols for CDTI should match symbols for the Traffic Alert and Collision Avoidance System (TCAS), with focus on whether symbol-fill should indicate target proximity. Researchers examined this issue by presenting pilots with dynamic traffic simulations with and without the proximate status indication. Results indicated that pilots seem to perceive the most proximate aircraft as also the most threatening, which is not necessarily the case. A technical report on these results will be published in FY 2012. A follow-on study examining the intuitiveness and consistency in the design of traffic symbols and the information that can be encoded graphically is planned. The findings from these studies will be used to provide input to the RTCA SC-186 Working Group to support development of MOPS for traffic surveillance technologies. A second area of research focused on developing an industry survey of CDTI products. Through coordination with vendors, researchers gathered information on both symbol and display format with particular focus on the human factors aspects of displays. A third research area provided human factors support to ongoing operational evaluations. In coordination with US Airways, researchers provided human factors support for operational evaluation of the CDTI. Researchers worked with industry representatives to gather human factors feedback during the evaluation on communication, ease of CDTI use, and workload. Researchers also provided on-going human factors guidance to develop a Traffic Situation Awareness with Alerts application that uses ADS-B to provide traffic alerts. (Flightdeck/Maintenance/System Integration Human Factors)

Develop Initial Mid-Term Analysis Describing The Relationship Between Human Pilots And Controllers With Associated Automated Systems:

Two multi-year research efforts provided human factors technical information to address the relationship between human pilots, controllers, and associated automated systems:

1. A university team developing a Human Automation Relationship Taxonomy (HART) for NextGen delivered an interim product that provided a comprehensive review of human factors scientific literature related to human-automation interaction and a detailed description of current flight deck automated systems. The HART, which will be completed in early FY 2012, is expected to provide both a theoretical basis and a practical tool to aid FAA field office analyses of human-automation interactions in support of aircraft equipment certification and operational approval for flight procedures in the NextGen context.

2. A major aircraft avionics manufacturer leveraged prior internal R&D efforts to provide an analysis of likely human factors implications and recommended mitigation strategies to: (1) improve flight crew-automation performance benefits, and (2) reduce potential adverse effects of adaptive automation flight deck technologies (i.e., non-deterministic automated systems). Guidelines and recommendations for design of adaptive flight deck systems are expected in early FY 2012.

Both projects support regulatory guidance for the pending new rule in 14CFR 25.1302. (NextGen – Air Ground Integration Human Factors)

Collaborative Airport Capital Planning Handbook:

ACRP – Capacity developed a handbook identifying best management practices in all phases of development, management, financing, and oversight of airport capital plans. The handbook includes those elements, steps, and key milestones necessary to create a collaborative business process that ensures the consistent flow of information and maintains the capital plan. This includes reporting, updating, and tracking financial and individual project information and identifying the processes that facilitate communication between internal and external stakeholders (e.g., airlines, FAA, and state and local officials). The handbook also identifies and translates the elements of collaborative business process so airport operators can incorporate it into an information technology solution. The program developed this handbook for those individuals at an airport who have a responsibility in the development, financing, management, or oversight of the airport capital plan or who has the information required to maintain and ensure the capital plan is current and up to date (e.g., project managers, chief financial officers, chief operating officers, and engineers). (ACRP)

Airport Concession Planning—Concepts And Business Terms:

ACRP – Capacity created a resource manual to help airports and managers understand market potential and implementation requirements for an effective in-terminal concession program while recognizing evolving challenges. This resource manual is a tool for airport staff involved in and responsible for the business decisions affecting the development of concession programs and plans. It can also serve as an informational tool for other stakeholders, including, but not limited to, airport board members, airlines involved in creating concession programs, and concessionaires. For the purpose of this research, in-terminal concessions refer to the following: food and beverage, retail, amenities, and services (e.g., vending, banking, luggage carts, postal services, telephones and wireless communications, advertising, and personal services). (ACRP)

A Primer For Enterprise Information Systems At Airports:

ACRP – Capacity developed an easy-to-read primer that speaks to two distinct audiences, the airport executive manager and the information technology (IT) professional, to facilitate mutual understanding of the other's perspective of the fundamental considerations for IT at the airport. Fundamental considerations include functional architectural concepts, functional and strategic objectives, mutual and disparate expectations, total costs (i.e., lifecycle, acquisition, implementation, activation, operation, and maintenance), benefits, consequences, priorities, and risks. The primer also (a) describes the steps and approaches to acquire, implement, and maintain IT at the airport; (b) includes a description of guiding technical principles; (c) presents applicable standards and recommended practices; (d) provides a list of considerations for making informed go/no-go acquisition, implementation, and commissioning decisions; (e) describes different approaches for placing the IT function within the airport organization; (f) presents and defines relevant terminology; and (g) is scalable to large, medium, and small airports. The primer is concise, creative, visual, and straightforward in its discussion of the following: (a) considerations that are important to the executive manager, (b) considerations that are important to the IT professional, (c) what the executive manager would like the IT professional to understand, (d) what the IT professional would like the executive manager to understand, and (e) issues that are common to both perspectives. (ACRP)

Strategies And Funding Opportunities For Airport Environmental Programs:

ACRP – Capacity created a comprehensive summary of funding opportunities as well as strategies available to airports for their environmental programs and objectives. For this summary, FAA researchers reviewed the Grants.gov site (http://www.grants.gov) as well as individual state and territorial government Websites. Researchers also reviewed specific examples of successful pursuit of airport environmental funding. The project objective was to identify funding programs potentially available to airport operators to assist them in meeting their environmental responsibilities or in undertaking environmental initiatives. The report identifies funding opportunities from private sources, including for-profit and nonprofit entities. (ACRP)

Aviation Workforce Development Practices:

Aviation industry leaders are constantly seeking intelligent, trainable, and enthusiastic professionals to meet airport technical, operating, and managerial demands. Airports are also looking to provide job opportunities in their communities, in part, as a method of increasing support for the airport itself. Trained and skilled aviation professionals are essential to the health and growth of airports and adjoining communities. ACRP – Capacity developed a report that collects information and reports on airport operating entity jobs and related skill sets needed to perform those jobs. The report also identifies educational opportunities (high school, community and technical colleges, and universities) that provide training on the skill sets needed to fulfill airport-related jobs. The report also documents gaps between skill sets and educational and advancement opportunities. (ACRP)

Common Airport Pavement Maintenance Practices:

ACRP – Capacity produced a compendium of airport practices that document how airports implement a pavement maintenance management program, including inspection and tracking pavement condition, scheduling maintenance, identifying necessary funds, and treating distresses in asphalt and concrete pavements. The goals of the study were to document effective practices and differences in maintenance practices by pavement type, airport category, and geographical considerations (e.g., weather and availability of materials). The report also includes a

literature review and survey of airport pavement maintenance program managers from medium and large air carrier airports as well as state aviation officials. The target audiences for this report include airport pavement engineers and pavement maintenance managers and personnel. (ACRP)

Developing And Leasing Airport Property:

ACRP – Capacity developed a guidebook for airport management and other relevant stakeholders to implement leasing, property management, and development agreements in the context of airport improvement and expansion plans. This research identified and defined best management practices used in formulating airport leasing and development policies to support public and private investments for aeronautical and non-aeronautical uses at airports. This research assists airport proprietors in making planning, policy, and financial decisions that will protect both Federal and local investment in the national airport system. (ACRP)

Advanced Training Technology For Terminal ATC Training:

The FAA has an ongoing need to hire and train new air traffic controllers for both en route and terminal ATC. Current facility training practices rely largely on classroom and on-the-job training and are, therefore, labor intensive. Moreover, training practices are not universal across facilities. This training model likely cannot meet NextGen training needs, which will require continuous training of new controllers as well as training the existing workforce as the FAA implements new ATC capabilities and operational procedures. The FAA needs to develop new, efficient, and innovative approaches to controller training to enhance the training process and to provide the flexibility needed to deal with changing automation and procedures.

CAASD and the FAA have been conducting research over the past several years to identify innovative capabilities and processes that will meet both near-term and future training demands. Since 2005, CAASD has collaborated with the Indianapolis Air Route Traffic Control Center (ARTCC) to define, test, and validate advanced training capabilities in the en route environment. This work led to the development of a training prototype, currently undergoing evaluation at the facility. The prototype was later extended to include the terminal domain.

As part of the research on terminal training, CAASD conducted a review of the latest practices in use for industry, military, and international ATC training. CAASD examined the training programs used at eight different terminal facilities in the FAA's Eastern Service Area in an effort to determine how advanced training technologies could be integrated into the overall process. A significant finding of CAASD's assessment is that the current methods of training site-specific airspace and procedures could result in poor retention of the information. Because students tend to forget the information after a short period, they must relearn it during simulation and on-the-job training, which is a time-consuming process. Field training experts expressed the opinion that terminal training could be more efficient and effective if knowledge such as airspace and procedures could be acquired as a prerequisite to simulation and on-the-job training through methods that result in improved long-term retention and understanding of the information.

In response to this recommendation, CAASD began to explore ways to augment current terminal training with a variety of advanced technologies and techniques. The intent was to identify methods that would make this phase of training more interactive, engaging, and context-based, so trainees could effectively learn and apply the knowledge and skills in an integrated, realistic way. In addition, augmenting airspace and procedures training to include advanced capabilities was anticipated to lead to better retention and preparedness, support improved standardization of the training process, reduce the need for instructor resources and complex scheduling, increase the availability of the training, improve the training quality, and potentially reduce the overall time to certification.

This work also identified that terminal training programs should be designed in a way that allows curriculum development and maintenance to be more efficient. In traditional computer-based training, a significant amount of time is spent creating the content, and it can be equally time consuming to make changes to that content. In an attempt to address development and upkeep issues, CAASD investigated ways to build training lessons for large-scale implementation and maintainability efficiently. Incorporating features such as synthesized voice and speech recognition technology as well as using a data-driven design allowed for the rapid development of training content and facilitated the maintenance of that content.

To evaluate the use of these advanced training technologies in the terminal environment, CAASD developed a prototype that incorporates a variety of new and innovative capabilities. The prototype presents ATC training curriculum in a Web-based framework that includes voice synthesis, speech recognition, multimedia lessons, game-based training techniques, simulation, and interactive training tools. The purpose of the prototype is to provide a research platform that can assess the benefits of these automated capabilities and support capability evaluation and validation in order to reduce the FAA's risk in the eventual acquisition of specific technologies.

The assessment of the benefits of advanced training technologies in the terminal domain is a multi-year effort that began with iterative development and evaluation activities at the Miami (MIA) Terminal Radar Approach Control (TRACON). The first version of the prototype was delivered in November 2008. This iteration provided airspace training for the 14 radar positions at the facility and did not include any content related to procedures. The evaluations showed that students were able to complete their airspace training successfully using the Terminal Trainer instead of the traditional classroom methods. Instructor and student feedback, in addition to the students' success with the prototype, confirmed that the prototype's capabilities can have beneficial impacts on training efficiency, quality of training content, effectiveness of training delivery, and degree of student preparedness for further stages of training. The prototype also demonstrated the ability to reduce the burden on facility resources.

To validate the results from the MIA TRACON evaluation and demonstrate the adaptability of the prototype to another facility's airspace training curriculum, a subsequent version of the Terminal Trainer was developed for the Potomac Consolidated TRACON (PCT), a larger and more operationally diverse facility, and thus provided a good test site to explore the Terminal Trainer's capabilities in the context of more complex airspace. Whereas MIA TRACON has one area of airspace that all students learn, PCT has four areas of airspace, with each area representing a former TRACON. Students at PCT receive specialized training on one of the four areas. PCT also has a more complex route structure than MIA and a wider variation of traffic and operations covering several busy terminal areas. Following the enhancement and development of the prototype for the PCT airspace-training curriculum, CAASD began to conduct evaluations with students assigned to the Mount Vernon Area. The field evaluation at PCT began in September 2010 and is ongoing. The evaluation results from PCT have validated the results from the MIA TRACON evaluations and have shown that the prototype is effective in training airspace at a different facility. Students have been able to complete all of their airspace training requirements using the prototype and have demonstrated a significantly greater operational understanding of airspace design than students using traditional methods during subsequent training such as simulation. Feedback collected from the PCT field evaluation has resulted in additional modifications and refinements to the Terminal Trainer. The technology and design requirements for the prototype's current set of airspace training capabilities have been transferred to the FAA. (CAASD)

Human Protection

No fatalities, injuries, or adverse health impacts due to aerospace operations

Best Practices Of Airport Operators In Managing The Use Of Towbarless Tractors On Airport Movement And Non-Movement Areas:

ACRP – Safety created guidance for airport management in developing and implementing airport rules and regulations for the use of towbarless (TBL) tractors in towing aircraft in airport movement and non-movement areas. This report includes a collection of the best practices and airport rules and regulations enacted by airports in managing TBL tractor operations. Safety Program researchers gathered information for this report from airlines, aircraft operators, aircraft manufacturers, TBL tractor manufacturers, and the FAA. From the compilation of this information, researchers developed the publication entitled, *Best Practices of Airport Operators in Managing the Use of Towbarless (TBL) Tractors on the Movement and Non-Movement Areas*. (ACRP)

Risk Assessment Method To Support Modification Of Airfield Separation Standards:

ACRP – Safety developed a method for assessing the risks associated with non- standard separations at existing constrained airports where standards cannot be practicably met and applied nationally. The risk assessment method supports, explains, and justifies requests to modify standards for non-standard separations. Specific situations covered by this project include the following: separations standards between taxiways and runways, taxiways/taxilanes and taxiways/taxilanes, and taxiways/taxilanes and fixed or movable objects. (ACRP)

Bird Harassment, Repellent, And Deterrent Techniques For Use On And Near Airports:

ACRP – Safety produced a compendium of procedures used to repel birds and minimize the potential of bird strikes near airports. The report synthesizes literature and practices relating to wildlife management plans and procedures for repelling birds and minimizing bird-strike potential. Information on equipment requirements, costs, and training needs to implement a bird repellant portion of airport wildlife management programs are included as well as a representative set of case studies of airports using various repellants to manage diverse bird species across North America. The target audience for this report includes airport operations staff responsible for airfield safety and wildlife management. (ACRP)

Current Airport Inspection Practices Regarding Foreign Object Debris (FOD):

Self- inspection to promote airfield safety is a primary responsibility of the airport operator. Recent events have focused increased attention on airports' responsibilities to mitigate FOD and wildlife hazards. Airports conduct mandatory airfield and runway inspections, in part to monitor and mitigate hazards. However, there is wide variation in how airport operators incorporate FOFD and wildlife-hazard inspections into airport management. Additionally, there is no readily available compendium of current airfield and runway monitoring and inspection practices at US airports from which airport operators can review and improve their own inspection practices. In response to this need, ACRP – Safety produced a report that compiles FOD and wildlife management-inspection practices across a wide variety of North American airports. This research effort includes a synthesis of current literature as well as FOD and wildlife hazard- inspection practices at various US airports. The report describes the range of inspection practices, from low-tech to fully automated and high-tech, and contains reasons why airport

operators choose those practices, including all benefits in addition to cost. The target audience for this report is airport operators responsible for FOD, wildlife hazard, and other airfield and runway safety inspections. (ACRP)

Options To The Use Of Halons For Aircraft Fire Suppression Systems:

In 2011, researchers completed the draft copy of the report *Options to the Use of Halons for Aircraft Fire Suppression Systems—2011 Update*. This updated report reflects the many changes that have occurred in the aircraft-fire suppression arena since the publication of the last update in 2002. Changes have occurred in regulatory restrictions, commercialized halocarbon replacements, halocarbon replacements under development, alternative technologies, and the evaluation of firefighting effectiveness for aircraft onboard applications.

In the report, FAA researchers discuss and assess fire suppression technologies and the applicability of each to the four primary aircraft applications for halon fire extinguishing/suppressing agents: (1) engine nacelles, (2) hand-held extinguishers, (3) cargo compartments, and (4) lavatory protection. Fire suppression halon equivalency guidance is also provided for these applications.

This report contains a summary of available fire suppression agents as well as their properties and is a source of information on physical properties, design concentrations, and exposure limits for Halon replacements. This report also discusses and tabulates the environmental and toxicological properties of halon replacement agents. Moreover, the report provides the name of agent manufacturers, product names, and company contact information for commercially available agents and systems.

Assigned experts within the International Aircraft Systems Fire Protection Working Group (IASFPWG), which the FAA Fire Safety Team chairs and administers, wrote the chapters and sections. Writing assistance included fire safety engineers and chemists, environmental regulators, airframe and agent manufacturers, and a nonprofit trade corporation HARC, which promotes the development and approval of environmentally acceptable Halon alternatives. The members at large of the Halon Option Task Group, a subgroup of the IASFPWG, provided additional review and contributions. (Fire Research and Safety)

The 6th Triennial International Aircraft Fire And Cabin Safety Research Conference:

The 6th Triennial International Aircraft Fire and Cabin Safety Research Conference convened in Atlantic City, New Jersey, on October 25–28, 2010. The series of conferences are held to inform the aviation community about recent, ongoing, and planned research activities in aircraft fire and cabin safety. It is the only technical conference devoted exclusively to fire and cabin safety R&D in civil transport aircraft and is sponsored by the following regulatory authorities: the FAA, the United Kingdom Civil Aviation Authority (CAA), Transport Canada, Brazil's Agência Nacional de Aviação Civil (ANAC), Australia's Civil Aviation Safety Authority (CASA), the Civil Aviation Authority of Singapore (CAAS), and the European Aviation Safety Agency (EASA).

Papers on material flammability test-method development, lithium-battery fire hazards, cargo- compartment fire safety, fuel tank flammability, halon replacement, and magnesium applications in aircraft dominated the fire safety sessions. Attendees described new flammability tests for ducting, wiring, and composite fuselage (interior surface); aimed at reducing the risk of inflight fires originating in hidden areas. Presentations on lithium batteries delved into aircraft fire accidents and incidents with lithium batteries as well as tests demonstrating their unusual fire hazards. Recent cargo compartment fire-safety work has focused on the detection and difficult challenge of suppressing a fire in a large freighter main deck cargo compartment. Fuel tank flammability work included

experiments and modeling related to gaining a better understanding of the vulnerability of aircraft to fuel tank explosions, including comparative experiments with composite and traditional aluminum wing fuel tanks. Halon replacement presentations included the main drivers—contaminated halon and potential environmental mandates, and promising progress for determining replacements for hand-held extinguishers and engines. The magnesium session included presentations on new fire resistance alloys, potential aircraft applications, and their demonstrated post-crash fire safety when used as lightweight seat structure.

The three sessions on advanced fire resistant materials focused on the development of ultra-fire resistant materials and understanding the behavior of polymers during thermal degradation and burning. Attendees described research on novel materials, including nanocomposites, benzoxazine resins, preceramic polymers, graphite oxide flame-retardants, and deoxybenzoin-containing polymers. Attendees repeatedly emphasized the need for environmentally safe flame-retardants due to cabin health concerns with certain brominated types of fire retardants.

The cabin safety sessions addressed emergency evacuation, cabin air quality, passenger briefings, and cabin crew training. Presentations on emergency evacuation included studies of group behavior, selection of exits, effect of preflight briefings, problems related to baggage retrieval, injured passengers, and computer modeling the effects of fire and ventilation and advanced blended body designs. A number of presentations addressed cabin air-quality health concerns associated with engine-oil fume exposure, including pyrolyzed oil, and instrumentation developed to monitor cabin air quality. The effectiveness of passenger briefings and benefits of improvements was a recurrent theme as was the need to assess current crew firefighting training in terms of current and future needs.

Child restraint systems is an area of considerable crash dynamics research because of the challenges of protecting small infants and the difficulty of extrapolating automotive applications to an aircraft. The industry is conducting research to reduce and simplify dynamic seat test requirements, which can be costly, by using computer models to address variations in seat cushion designs, for example. Additionally, researchers are developing numerical models to examine and compare the crashworthiness of new composite fuselages to contemporary aluminum structures. Finally, operators are deploying air bags in general aviation aircraft and as a potential means for vertical energy absorption.

The proceedings of the 6th Triennial, including abstracts and PowerPoint presentations, attendees list and executive summary, as well as for the previous five triennials, are available at http://www.fire.tc.faa.gov. (Fire Research and Safety)

Toxicity Model For New Halocarbon Fire Extinguishers:

A simple kinetic model for calculating the blood concentration history of humans exposed to time-varying concentrations of gaseous, halocarbon fire-extinguishing agents was published in the *Inhalation Toxicology Journal* in December 2010.[1] The publication in a peer- reviewed inhalation toxicology journal provides credibility to the kinetic calculations developed and employed by the same authors in the basis document[2] for the FAA Advisory Circular (AC) 20-42D *Hand Fire Extinguishers for Use in Aircraft.*[3]

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[1] Lyon, R.E. and Speitel, L.C. (December 2010.) A kinetic model for human blood concentrations of gaseous halocarbon fire-extinguishing agents, *Inhalation Toxicology, 22*(12–14), pp. 1151–1161.

[2] Speitel, L.C., Lyon R.E. (August 2009.) *Guidelines for Safe Use of Gaseous Halocarbon Extinguishing Agents in Aircraft*, FAA Report DOT/FAA/AR-08/3.

[3] FAA AC 20-42D *Hand Fire Extinguishers for use in Aircraft*, January 2011.

Researchers developed the kinetic model to extend experimental physiologically based pharmacokinetic (PBPK) models for arterial blood concentration of halocarbons, obtained from constant concentration exposures of dogs, to time-varying exposure conditions for humans. The kinetic model for the transport of halocarbon appears in Figure 1. In this kinetic model, the rate constants k_1 and k_2 represents the rate of transport between the cabin air (in the lungs) and the bloodstream, k_3 and k_4 represents the rate of transport between the bloodstream and the organs and tissues, and k_5 represents the rate of transport from the organs and tissues to waste. In the present work, researchers calibrated the simplified kinetic model using published PBPK-derived arterial concentration histories for constant concentration exposure to several common halocarbon fire-extinguishing agents.

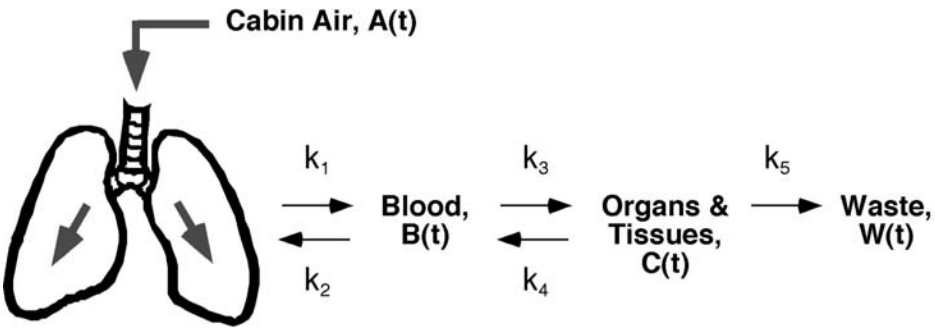


Figure 1 - This graphic illustrates a kinetic model of halocarbon transport in humans.

The calibrated kinetic model was able to predict the blood concentration histories of passengers in perfectly mixed, constantly ventilated aircraft cabins in which these agents are instantaneously discharged as well as the PBPK model for HCFC-123. Figure 2 illustrates that the kinetic model also captured the magnitude and dynamics of the human arterial blood concentration history as well as the PBPK model for a time-varying Halon 1211 concentration in a small compartment.[4] Researchers therefore concluded that the kinetic model, properly calibrated with PBPK-derived human arterial blood concentration data for a constant exposure concentration, represents an economical methodology for calculating safe exposure limits in compartments with time-varying concentrations of halocarbon fire extinguishing agents. (Fire Research and Safety)

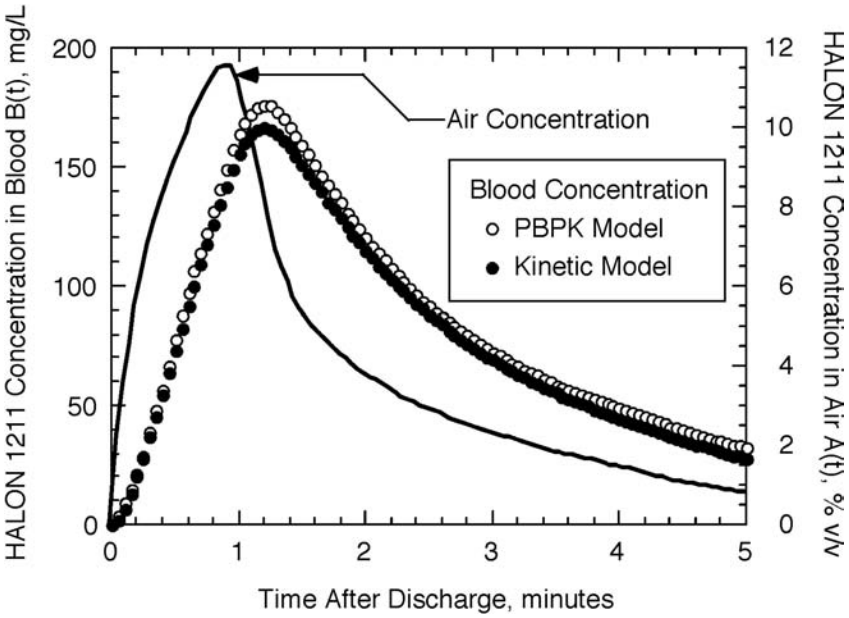


Figure 2 - This graph illustrates a comparison of the arterial blood concentration history in a small compartment for a time-varying concentration of halon 1211 calculated by the Kinetic Model (black circles) and the Physiologically Based Pharmacokinetic (PBPK) Model (white circles) [4]. The average relative deviation of the Kinetic and PBPK Models is 5.7%.

[4] Vinegar, A., Jepson, G.W., Overton, J.H. (1998.) PBPK Modeling of Short-Term (0–5min) Human Inhalation Exposures to Halogenated Halocarbons, *Inhalation Toxicology, 10*, pp. 411–429.

Development Of Side-Facing Seat Aircraft Neck Injury Criteria:

Currently, the FAA bases its side-facing seat certification requirements primarily on auto safety standards; however, the FAA also considers aviation-unique injury risks (e.g., arm and leg flailing). In recent years, an increased demand has emerged for side-facing aircraft seats (oriented more than 18 degrees off the aircraft centerline). FAA researchers have conducted several research initiatives to provide information for an equivalent level of safety comparable to forward- and aft-facing seats. Researchers conducted tests to establish side-facing neck injury criteria and new certification requirements. The latest effort was to characterize neck response and injury when subjected to a high-lateral bending moment/low tension load at the neck. To simulate the required loading condition, a custom component-level test apparatus was fabricated to apply a lateral bending moment on the occipital condyles of the side-facing test subject. The tests consisted of a series of incremental dynamic lateral loads to simulate real impact conditions. Displacement, force, acceleration, and velocity data were measured. Post-mortem human subjects and a side-facing impact dummy were tested in matched pairs to establish injury assessment-reference values. Researchers will use the data obtained in this research, in addition to data from previous research, to establish FAA side-facing aircraft seat policy and guidance. (Advanced Materials and Structural Safety)

Analytical Methods For Aircraft Seat Design And Evaluation—Update:

This image illustrates testing to establish neck injury criteria for side-facing aircraft seats.

The Society of Automotive Engineers (SAE) Aerospace Recommended Practice ARP-5765, Analytical Methods for Aircraft Seat Design and Evaluation, is an industry document that describes the recommended practices for using simulation in the design and certification of aircraft seats. The FAA Civil Aerospace Medical Institute (CAMI) Biodynamics Research Team, through the SAE Aircraft SEAT Committee, has contributed extensively to the development of this document. The ARP has three main sections: (1) calibration of a virtual anthropomorphic test device (v-ATD), (2) validation of a full seat system, and (3) best practices. The best-practices section includes suggestions for both modeling and testing. The system validation section expands on the concepts previously introduced in the FAA AC 20-146, Methodology for Dynamic Seat Certification by Analysis for Use in Part 23, 25, 27, and 29 Airplanes and Rotorcraft. ARP-5765 also contains a recommended procedure for comparing the results of sled tests to the output from a computer model. Results of this effort were presented at the 6th Triennial International Aircraft Fire and Cabin Safety Research Conference, October 25–28, 2010, Atlantic City, New Jersey: Moorcroft D. SAE ARP 5765: Analytical Methods for Aircraft Seat Design and Evaluation—Update http://www.fire.tc.faa.gov/2010Conference/proceedings.asp. (Aeromedical Research)

International Blood And Breath Alcohol Conversion Tool:

Researchers at the CAMI Bioaeronautical Sciences Laboratory developed a software tool for converting blood and breath alcohol units into the units of measure for 30 countries, including the US. The software also compares the measurement to the legal limit for driving in each of the countries. This tool is available on the Internet for the benefit of regional flight surgeons, aviation medical certification personnel, air traffic controllers, pilots, cabin personnel, and the public (both in the United States and internationally). This provides a readily accessible method to mitigate the risk of an inadvertently violating another country's alcohol laws. The tool also offers a reliable single point source for converting the units of one country's alcohol concentration into the units of another country, which is something that was not previously available. The National Safety Council has agreed to host the Website, currently available at http://discoversoft.serveftp.com:3030/IBBAC/default.aspx. (Aeromedical Research)

Aircraft Accident Medical Review Workflow System:

CAMI Aeromedical Research Division personnel developed a software program that (1) integrates information obtained in an aircraft accident investigation; (2) facilitates the aeromedical review of such accidents; (3) provides a database for future research applications; and (4) provides a basis for the assessment and tracking of medical certification decision making processes. The software tool, known as the Aircraft Accident Medical Review Workflow System (AAMRWS), includes, among other information: (a) autopsy data provided by medical examiners and coroners, (b) airman medical certification records obtained from the FAA Document Imaging and Workflow System (DIWS), (c) FAA forensic toxicology findings, (d) summaries of aeromedical hazard analysis assessments for each of the DIWS, autopsy, and toxicology reviews, and (e) NTSB accident investigation summaries. The database resulting from the collection of this information in the AAMRWS is of benefit to all personnel involved in aircraft accident investigation processes. During 2011, 264 cases underwent review and FAA accident investigators and regional flight surgeons have received over 1,000 aeromedical review reports. (Aeromedical Research)

Aeromedical Considerations Of Stowaway Attempts:

A stowaway is a person who secretly boards a vehicle, such as an aircraft, to travel without paying and without detection. The first recorded case in history of an aircraft stowaway occurred June 13, 1929. The Bernard monoplane Oiseau Canari, piloted by Frenchmen Assollant, Lefevre, and Lotti, had trouble taking off in spite of its powerful Hispano Suiza engine. The crew later discovered the cause of the problem: a stowaway on board, a young American, Arthur Shreiber. Despite the overload, the plane landed in Spain after 22 hours of flight over 2,410 miles, setting many records: a first for France over the North Atlantic, the longest flight over the ocean, and the first stowaway in air history.

Stowaways face dangerous situations and risk death. Usually, a stowaway jumps into an aircraft by hanging on to the airliner's landing gear as the plane takes off, and the force of the wind can easily make a stowaway fall to his death. Because people flying on aircraft as stowaways must stay within the landing gear area, they face other risks too, such as being crushed in a confined space when the gears retract, falling when the plane is landing, or dying from the heat produced by the engines of the aircraft. Death from hypothermia, caused by the extreme cold at high altitudes, or hypoxia (inadequate oxygen supply to the tissues), has also been documented. The 1993 case that started the review of wheel-well stowaways concerned a young Colombian whom, authorities believed, paid someone to hide him in the cargo area as a stowaway (though, in reality, he hid in the wheel well himself). In 1969, the famous case of Armando Socarras demonstrated that, however unlikely, based on what we know about human physiology, survival as a wheel-well stowaway is possible. The CAMI Bioinformatics Research Team has been monitoring wheel-well stowaway events, focusing on those cases that result in survival from the event.

Initially using the newspaper media archives, CAMI researchers were able to identify prior cases and document some survivors. In sum, 89 people (on 79 flights) have attempted to fly in the wheel well or other compartments exterior to the aircraft cabin, excluding the cargo area. Of those 89, only 18 survived. The 80 percent fatal/20 percent survive rate is a quite stable statistic. These experiments of human nature, while not considered scientifically sound (conventional research in this area would be ethically impossible), do contribute to our understanding of human physiology in extreme environments. These aviation cases, in addition to those of young people surviving prolonged emersion in ice-cold water, highlight some surprising aspects of our physiology. For example, a stowaway case from Tahiti in 2000 had, in the Emergency Room, a rectal temperature that was lower than any temperature associated with survival by 6° F; yet, we also know that the use of body lowering temperature techniques is of vital importance to open-heart surgery.

Monitoring and assessing stowaway cases offers valuable information, such as (a) showing how lethal such exposures are, (b) documenting that humans have been able to survive supposedly non-survivable environmental conditions, and most importantly, (c) point out a weakness in airport security that permit these desperate people to attempt the impossible to escape their circumstances. The FAA, working with the Transportation Security Administration (TSA) of the Department of Homeland Security (DHS), has continued to monitor these breaches of security and augment security at airports. Prior to 2010, the last stowaway originating from a US airport occurred in 1972, thus, TSA efforts were successful until the sad case of the young boy from Charlotte, North Carolina, who was killed in his attempt to stowaway in the wheel well of a flight to Boston, Massachusetts, in 2010. This incident highlighted the ongoing need to review perimeter security at airports to deter such desperate attempts. Researchers at CAMI will continue to track stowaway attempts and the aeromedical considerations associated with these events, as described in the *Focus FAA* article of May 3, 2011, https://employees.faa.gov/news/focusfaa/story/?newsId=63174. An updated report of their findings is available as a DOT Technical Report, Véronneau, S.J.H. Aircraft Wheel Well Passengers (Stowaways). (Aeromedical Research)

Atmospheric Ozone In Aircraft Cabins:

Ozone pollution in the aircraft cabin environment is a serious concern. Research has linked ground-level ozone to asthma, bronchitis, and serious related cardiopulmonary health issues. The FAA has established both airworthiness (Federal Aviation Regulation (FAR) 25.832) and operational (FAR 121.578) regulations to limit ozone in passenger cabins.

Originating in the stratosphere and produced by natural chemical processes, ozone can enter airliner cabins through the aircraft ventilation system during flight. Research has also shown that winter storm fronts produce aircraft ozone levels potentially above the regulations due to turbulent atmospheric mixing. FAA-sponsored researchers in the Airliner Cabin Environment Research (ACER) Program at the University of California–Berkeley and the University of Medicine and Dentistry have made extensive measurements of ozone levels in passenger cabins. They found that on 8 of 46 domestic flights without converters, at some point during the flight ozone levels exceeded the 0.1 parts per million by volume (100 ppb) level specified in the FARs.

Surprisingly, in a separate series of experiments in a reconstructed section of a B-767 aircraft cabin, half of the ozone removal within the cabin was attributable to ozone oxidation reactions with exposed skin lipids on the skin, hair, and clothing of passengers and crew. The ozone decomposition products included carbonyls, dicarbonyls, and hydroxycarbonyls—some of which are hazardous to human health at elevated levels. Several journal papers describe the results of this research effort and are available in the following ACER publication: Nazaroff, W.W., Weschler, C.J. *Ozone in Passenger Cabins: Concentrations and Chemistry*, Report No. RITE-ACER-CoE-2010-2, August 2010 available at ftp://ftp.eng.auburn.edu/pub/overfra/ACER/Ozone ACER Aug2010.pdf. (Aeromedical Research)

Impairing Medications—An Equation For Assessing A Safe Return To Duty Time For Pilots:

The law requires pilots who use an impairing medication to treat a medical condition to wait an appropriate amount of time after completing their treatment before returning to active duty. CAMI's Forensic Toxicology Research Team conducted a study to assess compliance with this requirement. Toxicology analyses on pilots who have died in an aviation accident have shown that not all pilots wait a sufficient amount of time for an impairing medication's strength to decrease to sub-therapeutic concentrations. FAA researchers have found pilots to have impairing concentrations of their medications in their blood at the time of the accident.

In the past, pilots used arbitrary wait times based on half-lives, dosage intervals, and other subjective methods to estimate a return to duty time. These methods do not take into consideration the time required for the drug to decrease from therapeutic to safe sub-therapeutic concentrations.

FAA researchers developed an equation based on the therapeutic range and the maximum expected half-life of the medication to calculate an objective, safe return to duty time for pilots. The equation developed assumed the treating physician would not dose the patient beyond the upper therapeutic range of the medication and that the individual presented the maximum half- life reported in the literature. Researchers evaluated the resulting equation for possible use in determining a safe return to duty time for pilots.

Researchers recruited anonymous subjects according to a research protocol approved by the FAA Institutional Review Board for the protection of human subjects. All research subjects had a pre-existing medical condition that they taking some type of medication as treatment. Researchers collected blood and plasma samples two hours after the subjects took their last dose of the medication. Researchers collected a second set of specimens after waiting the minimum time predicted by one of the methods referenced. Researchers then asked the subjects to provide the drug name, dose, dosing interval and their age, weight, height, and gender. Researchers then performed chemical analyses on the specimens collected to determine the concentration of the medication at the first and the second collection times. Researchers then evaluated the equation to determine whether the calculated wait times were sufficient to eliminate the medication to a concentration below its therapeutic level. The study found that the equation was successful in determining a safe return to duty. The results of this research effort are available in a FAA report under review, Canfield D.V., Berry, M., Whinnery, J.E., Lewis, R., Dubowski, K.M. *The Evaluation of an Equation Used to Determine a Safe Return to Duty Time for Pilots Who have Used an Impairing Medication*. (Aeromedical Research)

A Physiological Modeling Analysis Of Rapid Decompressions To 40,000 And 45,000 Feet:

In 2006, the FAA issued an interim policy that changed the procedure for certifying new airliners relative to the capability of the aircraft to conduct an emergency descent following a loss of cabin pressure. The new policy allows aircraft a total of three minutes to descend below 25,000 feet and allows a one-minute cabin-pressure excursion above 40,000 feet. CAMI's Environmental Physiology Team developed a computational model that provides a second-by-second prediction of physiological responses to altitudes between 40,000 and 45,000 feet during and following a rapid decompression (i.e., a rapid loss of cabin pressure).

This physiological model can estimate hypoxic injury resulting from airliner decompression at high altitude as well as the effect of this event on passengers who are not able to don their oxygen masks in time to avoid this physiologic consequence. A review of the literature demonstrates the human body contains finite and measurable oxygen reserves; when these reserves are depleted, the result is hypoxia and potential brain damage. Researchers

developed the model by using a well-established respiratory equation to address high-altitude exposure and determine when the oxygen reserve expired. Researchers then integrated the results with information from the clinical medicine literature, specifically those concerning a blood enzyme used to determine the extent of hypoxic brain injury resulting from various medical conditions. The resulting calculations were able to determine the extent of the hypoxic episode.

The FAA projects this model will become a valuable tool for regulators in calculating the risk of hypoxia at altitude as well as its consequences. The results of this innovative research study will address an important regulatory requirement, ensuring that the regulation is realistic, yet conservative, and safe. An arbitrary altitude limit that is unrealistically conservative could cost the airline industry millions. Conversely, allowing an unsafe altitude limit could cost lives. The FAA will validate the model by simulating a decompression profile in an altitude chamber. The results of the study will provide guidance for the FAA in future decisions regarding the safety of changes to operational ceilings. Self, D.A., Shaffstall, R.M., Moorcroft D.A. *Physiological Modeling Analysis of Rapid Decompressions to 40,000 and 45,000 Feet*. Proceedings of the 6th Triennial International Aircraft Fire and Cabin Safety Research Conference October 25–28, 2010, Atlantic City, New Jersey, USA, http://www.fire.tc.faa.gov/2010Conference/proceedings.asp. (Aeromedical Research)

Measurement And Purification Of Bleed Air Supplies:

Except for the new B-787, nearly all modern airliners use compressed air from the jet engine compressor for inflight cabin pressurization and aircraft ventilation. Typically, high- and low-pressure bleed air ports allow the source pressure to be matched to systems' needs with different engine and compressor speeds. The compression process heats bleed air and leaves the engine at high temperatures, pressures, and flow rates.

Under certain circumstances, the engine compressor seals can leak, allowing lubricating oil into the compressor and, ultimately, into the bleed air stream. In addition, modern aircraft contain myriad hydraulic control lines, including controls in and around the engines. Leakage from hydraulic lines can also enter the engine compressor and leak into the bleed air supply. Both engine lubricating oil and hydraulic fluid are serious contaminants in the cabin supply air. Shortly after the bleed air is extracted from the engine, it passes through the pre-cooler and the bleed air remains at a high temperature for only a short time. Nevertheless, the temperatures and residence times are sufficiently high and long enough to create the potential for pyrolysis of contaminants in the bleed air, adding further concern about the seriousness of the contamination in the air supplied to the cabin.

FAA-sponsored ACER scientists and engineers at Auburn University and Kansas State University have been collaborating with engineers from Boeing and Honeywell to understand and model the flow dynamics and thermal conditions representative of bleed air supplies for typical aircraft. Researchers are integrating these data with models of droplet pyrolysis to quantify the expected generation of carbon monoxide, carbon dioxide, and unburned hydrocarbons to predict more accurately expected passenger and crew exposures for specific amounts of working fluids potentially contaminating the bleed air supply.

ACER R&D continues to establish important performance specifications for sensors in aircraft cabin air-quality applications (measurement ranges, sensitivity and detection limits, sensor selectivity, precision and accuracy, calibration procedures and intervals, sensor life, sensor size, weight, cost, etc.). The research teams at Auburn University and Boise State University are evaluating commercial carbon monoxide and carbon dioxide sensors to determine whether commercial sensors are able to detect and measure evolved carbon monoxide and carbon dioxide from bleed air contaminants. In addition, ACER scientists and engineers at both Boise State University and Kansas State University have already made extensive measurements of the aircraft cabin environment on over 200 flights using portable sensors attached to seatback pockets to collect data throughout the flights.

The ACER R&D is developing the means to characterize the cleaning of aircraft air and to monitor the cleaned air automatically to provide criteria to determine when aircraft air has been adequately cleaned. Researchers will provide recommendations to the FAA for appropriate policy regulations and guidelines to ensure that hazards and risks from such contaminants in aircraft air are monitored and maintained at levels consistent with public health standards. (Aeromedical Research)

SAFE AEROSPACE VEHICLES

No accidents and incidents due to aerospace vehicle design, structure, and subsystems

FAA/NASA-Sponsored LS-Dyna Aerospace Users Group:

In 2003, the FAA and NASA helped to establish the LS-DYNA finite element code Aerospace Quality Control Users Group. The FAA and NASA initially established this Users Group after FAA research programs identified significant differences in results from different computer platforms and versions of LS-DYNA. This group's goal was to assure that aerospace industry users of LS-DYNA would have their modeling problems continually run through several computer platforms and versions of LS-DYNA to maintain accuracy and performance. Participants in this group consist of several major manufacturers, including Boeing, Pratt Whitney, GE, Honeywell, Williams, Rolls-Royce, and FTT. This quality control system is modeled after an established system by Livermore Software Technology Corporation (LSTC) (developer of LS-DYNA) for the automotive industry. In July 2011, an annual review meeting took place at LSTC; George Washington University, Arizona State University, Central Connecticut State University, and FAA Chief Scientific and Technical Advisors (CSTA) presented FAA-sponsored research in material model development. The MAT224 material model, developed under this research program, has been approved for production in LS-DYNA and is available to all LS-DYNA users. The users group also compiled several aerospace guidelines, which the group is currently refining, that will be issued as aerospace guidelines available to the industry in the future. The users group Website was completely overhauled. It consists of several generic aircraft models and provides tips for using LS-DYNA for aerospace impact applications. (Aircraft Catastrophic Failure Prevention Research)

Turbine Engine Containment Titanium Material Testing:

FAA engineers need publicly available tools to standardize the analysis of engines and aircraft for rotor burst and fan blade containment. An increasing number of engine and aircraft projects rely on proprietary analysis tools to show compliance, complicating the FAA task of making compliance findings and allowing potential variation in the standard of safety. One aspect that requires improvement is the material models used for this analysis. The goal of this research is to have a public tool with validated public material models for aircraft materials. This will allow engineers to validate the proprietary tools, streamline the certification process, and help mitigate fatalities and injuries when these events occur.

The FY 2011 research concentrated on the development of a titanium material model. Under an FAA grant, the Ohio State University completed a series of material characterization tests on titanium 6Al-4V material. Researchers planned and completed over 200 tests, using tension and compression tests to compare specimens made from ¼-inch and ½-inch thick plates. Results from these material tests shown significant differences in strength between ¼-inch and ½-inch- thick titanium plates with the same material specification. The anisotropic aspects of the sheet are much more pronounced in the thinner sheet, which is a result of the additional rolling during manufacture. Researchers had planned to test some of each sheet to develop the material characterization. However, it now appears that researchers need to characterize each thickness independently, which is a significant addition to the test effort. Researchers plan to complete these additional tests in FY 2012. (Aircraft Catastrophic Failure Prevention Research)

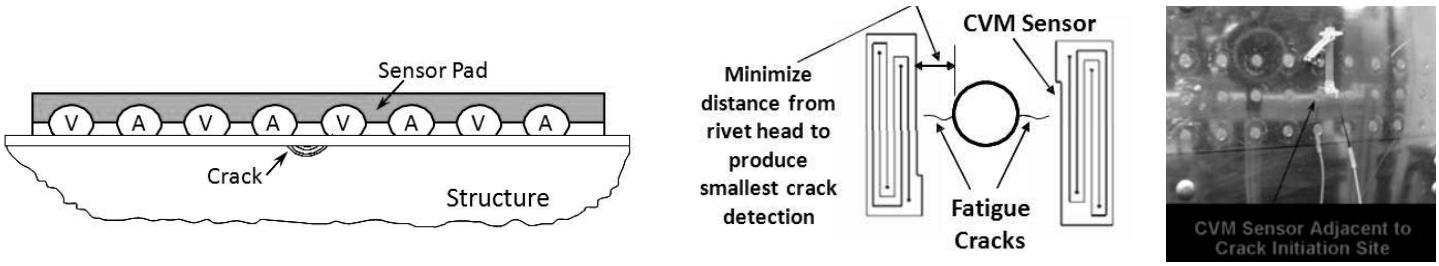
Damage Detection Technologies:

Current aircraft maintenance operations often require personnel entry into areas that are difficult or time consuming to access to perform mandated nondestructive inspections (NDI). Typically, to gain access for these inspections, structure must be removed, sealant must be removed, fuel cells must be vented to a safe condition, or other disassembly processes must be completed. These processes are not only time consuming but they provide the opportunity to introduce damage to the structure. The FAA has studied the use of in-situ sensors, coupled with

remote interrogation, to overcome myriad inspection impediments stemming from accessibility limitations, complex geometries, and the location and depth of hidden damage.

The FAA's Airworthiness Assurance Nondestructive Inspection Validation Center (FAA-AANC) at Sandia National Labs, in conjunction with industry and airline partners, applied an in-situ crack detection system known as Comparative Vacuum Monitoring (CVM) to several large transport and regional jets asses and validate CVM technology as a standard NDI practice for conducting remote inspections.

CVM sensors were developed on the principle that a small volume maintained at a low vacuum is extremely sensitive to any ingress of air and is thus sensitive to any leakage. Figure 1 shows top- and side-view schematics of the self-adhesive, elastomeric sensors with fine channels etched on the adhesive face along with a sensor being tested on an aircraft lap joint panel. When the sensors are adhered to the structure under test, the fine channels and the structure itself form a manifold of galleries alternately at low vacuum and atmospheric pressure. Vacuum monitoring is applied to small galleries that are placed adjacent to the set of galleries maintained at atmospheric pressure. If a flaw is not present, the low vacuum remains stable at the base value. If a flaw develops, air will flow from the atmospheric galleries through the flaw to the vacuum galleries. When a crack develops, it forms a leakage path between the atmospheric and vacuum galleries, producing a measurable change in the vacuum level. In Figure 2, the CVM monitoring system detects this change. Figure 2 also shows sample CVM sensors mounted on an aircraft structure as part of a performance validation effort.



These schematics show the operation of the CVM sensor (left) as well as a CVM sensor mounted on the outer surface of a riveted lap joint (right).

During this project, researchers mounted a series of 26 sensors on structures on 4 different in-service DC-9, B-757, and B-767 airplanes to validate the CVM sensors in actual operating environments. Researchers also conducted laboratory tests, which confirmed that the CVM sensors could readily detect surface-breaking cracks with a high level of reliability. Researchers conducted another series of flight tests on regional jets that resulted in the detection of two in-service cracks that routine NDI also verified. When using these in-situ CVM sensors, it is possible to monitor the integrity of an aircraft structure remotely by detecting the onset of incipient cracks before structural failures occur. The FAA will conduct a follow-on project to identify and streamline issues related to the certification of structural health monitoring (SHM) technologies for large transport airplanes during FY 2012–FY 2013. (Continued Airworthiness)

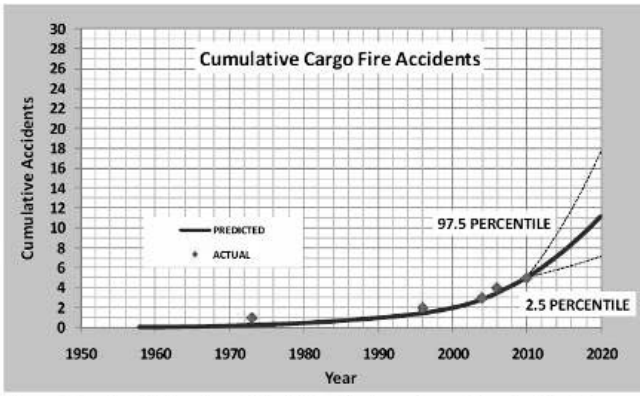
Freighter Airplane Cabin Fire Risk Analysis Model:

The number of accidents caused by in-flight fire in freighter aircraft appears to be increasing. In 2006, a UPS DC-8 freighter experienced an in-flight fire in the main cargo compartment during approach to Philadelphia International Airport. Although the airplane landed safely and both pilots escaped, fire gutted the aircraft. In 2010, a UPS B-747 crashed while attempting to land at Dubai International Airport, United Arab Emirates. Before the fatal crash, the pilots reported a heavy build-up of smoke in the cockpit. Both aircraft reportedly carried large

quantities of lithium batteries. Therefore, the FAA initiated a study to assess the magnitude of the potential threat to freighter airplanes from onboard cargo fires.

As part of this study, researchers developed a risk model to assess the likely number of US-registered freighter fire accidents through the year 2020 as well as the average annual cost of such incidents. The study focused on the potential fire threat from the bulk shipment of lithium batteries because they were likely contributors to the freighter fire accidents that occurred in Philadelphia and Dubai. For this reason, the risk model considered the potential threat from lithium batteries separately from other cargo.

The risk model is based on the assumption that the risk of a cargo fire accident occurring is a function of the revenue ton-miles (RTM) of the cargo, which is the product of the quantity of cargo shipped and the distance the cargo is carried. RTM is a usage value that is routinely recorded by the air transport industry. Similarly, to predict the probability of a cargo fire in which lithium batteries were a contributing factor, calculations were made of the shipment of lithium batteries by air in terms of RTM. The rate of freighter fire accidents is the ratio of the number of such accidents and the cumulative revenue ton-miles. However, because of the small number of data sets, it is more realistic to develop distributions that indicate a confidence level in a range of accident rates rather than determining an average value. Although the risk model predictions are considered reasonable, the limited number of accidents contained in the data set results in a large range in the prediction of future accidents. For example, on average, the model predicts about 6 cargo fire accidents from 2011 through 2020; however, the 95 percent confidence level has a wide range of about 2 to 13 accidents over that period. Additionally, lithium batteries may be a contributing factor in as many as four to five of these accidents if it is assumed this was the cause in the 2006 accident in Philadelphia (the model user has the option of selecting this accident as battery or non-battery related). The risk model predictions are also highly sensitive to the future predictions of RTM, which are, by necessity, based on extrapolations from past data.



Predicted number of freighter airplane cargo fire accidents through to 2020.

The model also calculates the cost of future cargo fire accidents on US-registered freighter airplanes, considering crew injuries, airplane damage, cargo damage, and collateral damage. It was calculated that the largest accident cost was the cost of the airplane (84 percent), followed by crew fatalities (12 percent), cargo (3 percent), collateral damage (2 percent), and serious crew injuries (1 percent).

FAA Report DOT/FAA/AR-11/18, entitled, *Freighter Airplane Cargo Fire Risk Model*, summarizes the risk model, explains the data and algorithms used, and explains how the model may be used. The report and model are available on the Fire Safety Team Website at http://www.fire.tc.faa.gov. (Fire Research and Safety)

Development Of Guidance For The Safe Shipment Of Lithium Batteries:

The Pipeline and Hazardous Material Safety Administration (PHMSA) and the FAA are proposing new regulations for the shipment of lithium-ion and lithium primary batteries and cells. Much of the regulation involves recordkeeping, package markings, cell size, and lithium content. Part of the regulation may restrict packaging, shipping mode, and cell type for those shippers who elect to ship their devices on transport category aircraft.

In support of this regulatory initiative, the FAA conducted additional fire tests in FY 2011 to add to the flammability knowledge of lithium-ion and primary cells generated in earlier test efforts. Based on the previous work of the FAA William J. Hughes Technical Center (WJHTC) Fire Safety Team, the FAA conducted tests with larger number of cells in a bulk shipment package with a single cell experiencing a simulated thermal runaway condition. Researchers evaluated the effectiveness of Halon 1301 from both the perspective of suppression of open flames as well as the ability to halt the propagation of thermal runaway within a shipment. Researchers also conducted preliminary tests to characterize the flammability hazard of lithium polymer batteries of the type used in some laptop computers.

The oxygen generator over pack failed to contain a lithium metal battery fire.

Researchers evaluated the capability of existing shipping containers to contain a lithium-ion and lithium primary fire and developed a proposed draft specification for a fire-safe shipping container or over pack for lithium-ion cells.

The results from these tests confirmed that Halon 1301 is effective at suppressing open flames from lithium-ion cells in thermal runaway. However, the halon, as expected, was completely ineffective at stopping the progression of thermal runaway. Even in the presence of Halon 1301, fire consumed all cells in the shipment. The research team collected data showing the propagation rate between adjacent cells as well as cell temperature while in thermal runaway.

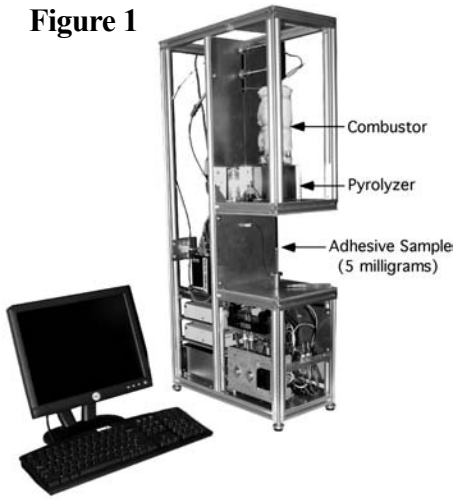
Currently available, robust shipping containers, such as metal pails and drums, were not effective in controlling lithium primary fires, but were effective in containing lithium-ion fires. Researchers tested a fiberboard container designed to ship oxygen generator canisters against a 100-cell lithium-ion fire; the fiberboard container successfully contained the fire. The proposed draft specification for a fire-safe over pack for lithium-ion cells is based partly on the oxygen generator over pack specification.

The findings of this test effort served as the basis for a Safety Alert for Operators (SAFO) issued by the FAA Flight Standards Service: SAFO 10017, *Risks in Transporting Lithium Batteries in Cargo by Aircraft*. The SAFO presents important safety information to airline and air cargo operators regarding safe handling and shipment of lithium batteries. The information contained in the SAFO is largely based on FAA report DOT/FAA/AR-10/31, *Fire Protection for the Shipment of Lithium Batteries in Aircraft Cargo Compartments*, authored by Harry Webster. The report and SAFO are available on the Fire Safety Team http://www.fire.tc.faa.gov. (Fire Research and Safety)

Combustion Characteristics Of Adhesives Used In Aircraft Cabins:

Adhesives are widely used in the construction of aircraft cabin materials because they provide a lightweight and fatigue-resistant method of assembly. Currently, no separate requirement exists for the flammability of adhesives, potting compounds, and fillers used in construction of cabin materials. This makes substitution or replacement of these adhesive compounds for reasons of performance, supply, or changing environmental regulations costly to the industry because the entire cabin material or part must be fabricated and tested with the new adhesive according to approved FAA procedures (certificate). The Flammability Standardization Task Group (FSTG) is an aircraft industry workgroup that is interested in establishing the similarity of different adhesives, with regard to flammability, by comparative testing of the adhesive separately from the cabin material, part, and construction in which it is used and for which it was originally certified. To this end, the FSTG has proposed[5] testing adhesives in a standard size by the 12-second and 60-second and vertical Bunsen burner (VBB) requirement for cabin materials in FAR 25.853, a test that adhesives currently do not have to pass as separate components. Cabin materials pass or fail the VBB test based on criteria for burn length, after flame time, and the time required for flaming drips to extinguish. The present study was conducted to determine whether the microscale combustion calorimeter (MCC) test, which is a quantitative laboratory test for flammability, supported the use of the VBB to establish similarity of adhesives, potting compounds, and fillers used in the construction of aircraft cabin materials.

Figure 1



Combustion Characteristics of Adhesives Used in Aircraft Cabins II – This is a photograph of the FAA's microscale combustion calorimeter (MCC) showing the sample platform, the sample chamber (pyrolyzer) with controlled heating, and the high temperature combustion chamber. The MCC separately reproduces the conditions of flaming combustion in a simple laboratory test.

Several aircraft material suppliers in the FSTG provided adhesive samples to the FAA Fire Safety Team at the WJHTC along with the pass/fail VBB test results determined in their laboratories using (in most cases) FAR 25 standard 6-mm x 100-mm x 300-mm (¼ x 4 x 12 inch) specimens as shown in Figure 1. Researchers tested adhesive samples weighing 5±2 mg in the MCC, also shown in Figure 1, according to a standard procedure[6] to obtain thermal combustion properties that they correlated with the VBB ratings. A qualitative analysis showed a critical threshold value for each of the several thermal combustion properties measured during the MCC test, below which all of the samples passed the VBB test.

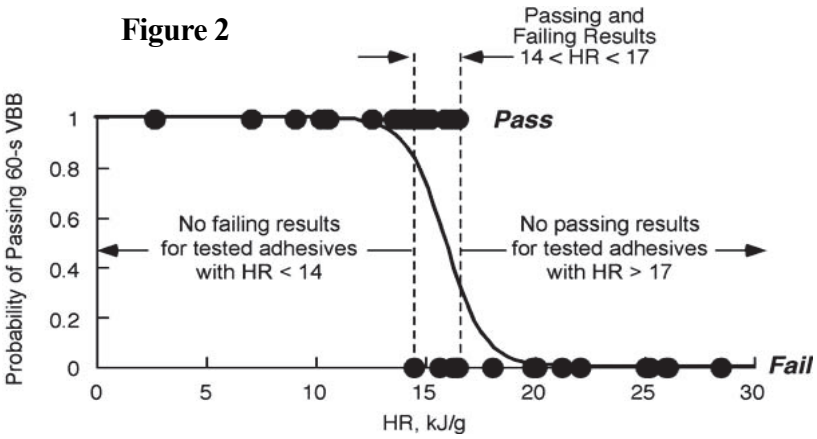
The use of a threshold value of the thermal combustion property to classify adhesives is warranted only if all possible adhesives are tested and analyzed to determine the value of the property, i.e., the threshold value is specific to the data set. In practice, new adhesives are introduced and old ones are replaced as circumstances (e.g., supplier issues, environmental regulations, etc.) require, so a statistical analysis of the data was performed to determine the *probability* of passing the VBB test given a particular value of a MCC thermal combustion property. To this end, pass/fail VBB data were converted to binary outcomes (Y = 1 for pass and Y = 0 for fail) and the

[5] Flammability Standardization Task Group Kickoff Meeting, International Aircraft Materials Fire Test Working Group, Clearwater, FL, January 12, 2010.

[6] Standard Test Method for Determining Flammability Characteristics of Plastics and Other Solid Materials Using Microscale Combustion Calorimetry, ASTM D 7309-07.

binary data were fit to a continuous probability distribution $p(X)$ developed for fire tests[7] using values X of each of the MCC thermal combustion properties as explanatory or predictor variables. These binary (pass/fail) and continuous probabilities are shown in Figure 2 for the 60-second vertical Bunsen burner test classification versus the heat of combustion of the adhesive *HR* as the predictor variable *X*. Figure 2 shows that the solid line representing the continuous probability distribution captures the binary data in the region where both passing and failing results are obtained, and can therefore be used to calculate the likelihood of passing the 60s VBB test for candidate replacement adhesives. (Fire Research and Safety)

Figure 2



Combustion Characteristics of Adhesives Used in Aircraft Cabins I – This graph shows the likelihood (probability) of passing the FAA requirement for ignition resistance of cabin materials in the 60-second vertical Bunsen burner ignition test versus the heat of combustion of the cabin material measured in the FAA's microscale combustion calorimeter. Passing results are virtually guaranteed for cabin materials with a heat of combustion less than 14,000 Joules per gram.

Predicting The Burning Rate Of Charring Materials:

Aircraft cabin materials are required to meet the stringent flammability requirements of FAR 25.853. Thermoformed parts, ducting, and decorative panels account for nearly 50 percent of the weight of cabin materials[8] and all of the plastics used in these applications leave a carbonaceous residue (char) after burning that enables them to meet the fire performance requirements.[9] Charring is a process that takes place in the solid plastic that reduces the amount of combustible fuel gases in a fire and provides a molecular mechanism of fire resistance that minimizes the need for potentially toxic flame retardant chemicals. Despite the demonstrated importance of char formation of aircraft materials in passing fire tests,[9] very little is known about the mechanisms by which charring affects ignition and flame spread; however, this knowledge is fundamental to the development of cabin material sub-models for our long-range goal of predicting fire growth in aircraft cabins.

During the past decade, there has been a significant effort to develop mathematical models of polymer pyrolysis, which is the process by which a burning plastic thermally decomposes to char and fuel gases in a fire. Typically, the pyrolysis model parameters are the thermal and chemical properties of the material, and these are used as adjustable parameters to fit experimental burning rate data from bench scale fire calorimeters. The parameterized pyrolysis model is then used with a model of gas phase combustion to predict the development of a large-scale fire. The main drawback of this approach is that deriving material properties from the results of fire calorimetry is under defined, that is, more than one set of material property values can exist that provided a good fit to a particular set of test data. Consequently, this approach provides only a limited understanding of the physics and chemistry of pyrolysis because the properties are specific to the test used to obtain them and may be inappropriate for other scenarios, such as an aircraft cabin fire.

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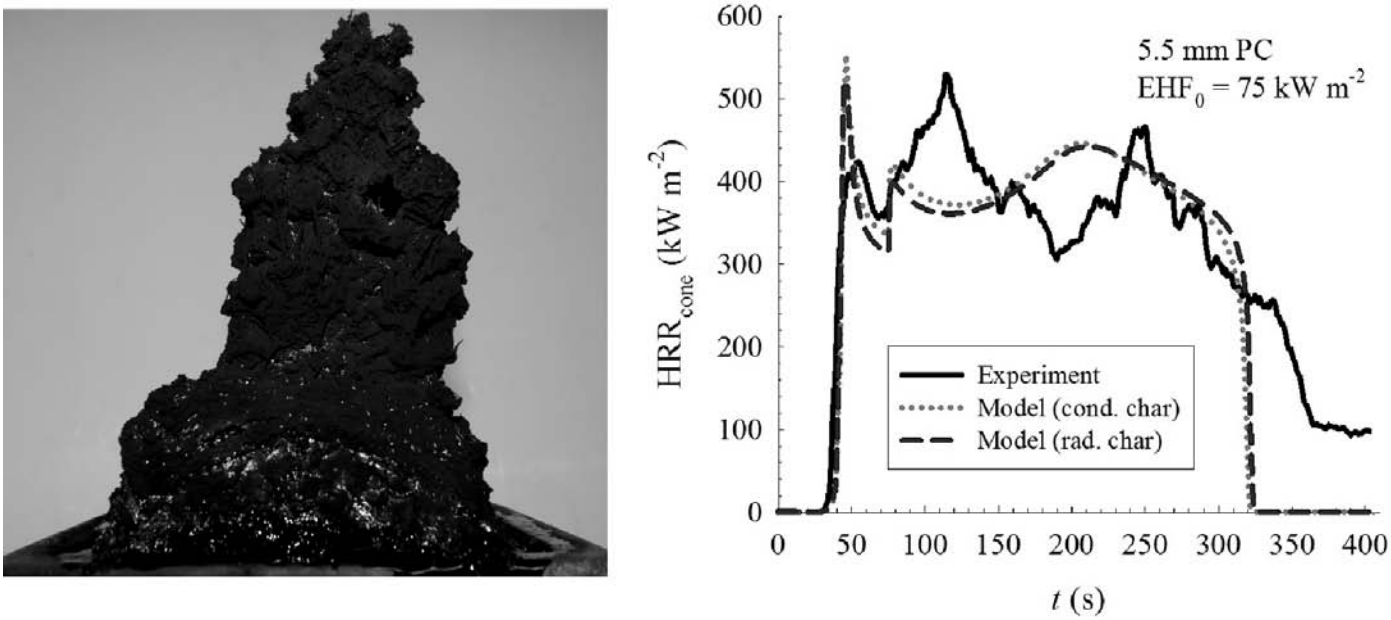
[7] American Society for Testing and Materials (International), West Conshohocken, PA, 2007.

[8] Lyon, R.E. (2008.) *Materials with Reduced Flammability in Aerospace and Aviation, Advances in Fire Retardant Materials*, A.R. Horrocks and D. Price, Eds., Chapter 20, CRC Press: Boca Raton, FL.

[9] Lyon, R.E. and Emrick, T. (2008.) Non-halogen Fire Resistant Plastics for Aircraft Interiors, *Polymers for Advanced Technologies, 19*, pp. 609–619.



Predicting the Burning Rate of Charring Materials – The is a photograph of the voluminous char that forms during the burning of polycarbonate plastic (left). The graph (right) is the measured burning rate (solid black line) and the burning rates (dashed lines) predicted by the FAA's ThermaKin computer code using two different models for how heat is transferred from the fire to the plastic in the test.

The principal objective of the present effort was to measure precisely the thermal and chemical properties of common plastics that exhibit charring and swelling and try to predict bench-scale burning rate data *a priori* using our detailed one-dimensional pyrolysis and combustion model ThermaKin.[10,11,12] ThermaKin is a flexible computational framework that solves energy and mass conservation equations describing a one-dimensional material object subjected to external heat. In ThermaKin, a mixture of components that can interact both chemically and physically represents the material. The components are assigned individual properties and categorized as solids, liquids, or gases. Of particular interest in this study was determining the best way to represent heat transfer from the radiant heater, flame, and burning surface through the expanded, low density, carbonaceous char layer to the underlying polymer. To this end, researchers investigated a pure conduction mechanism and a radiation diffusion mechanism of heat transfer through the low density, graphitic char layer.

The polymers used in this study were bisphenol-A polycarbonate (PC) and polyvinylchloride (PVC). Researchers tested each in a fire calorimeter at various radiant heat fluxes using a bench-scale fire calorimeter according to a standard method.[13] Figure 1 shows a 6-mm thick sample of PC after burning in a fire calorimeter at 75 kW/m^2 external flux on the left and the ThermaKin simulation of the PC fire test on the right. Researchers observed that heat transfer from the burning surface to the underlying polymer by pure conduction through the char and radiation diffusion produce equivalent burning rate histories for PC (shown) and PVC.

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[10] Stoliarov, S.I. and Lyon, R.E. (2008.) Thermo-Kinetic Model of Burning, Federal Aviation Administration Technical Note, DOT/FAA/AR-TN08/17.

[11] Stoliarov, S.I., Crowley, S., Lyon, R.E., and Linteris, G.T. (2009.) Prediction of the Burning Rates of Non-Charring Polymers, *Combustion and Flame, 156*, pp. 1068–1083.

[12] Stoliarov, S.I., Crowley, S., Walters, R.N., and Lyon, R.E. (2010.) Prediction of the Burning Rate of Charring Polymers, *Combustion & Flame, 157*, pp. 2024–2034.

[13] Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using and Oxygen Consumption Calorimeter, ASTM E 1354-04a, American Society for Testing and Materials International, West Conshohocken, PA.

The results of this study demonstrate that researchers can use the ThermaKin one-dimensional numerical pyrolysis model to predict the outcome of fire calorimeter experiments performed on a charring and intumescing polymer. These predictions require the knowledge of the thermal and optical properties of the polymer and a quantitative description of the kinetics and thermodynamics of its decomposition. All this information can be obtained from direct milligram and gram scale measurements or obtained from existing structure-property correlations. A simple heat transfer model of the char, based on the thermal properties of graphite and a single adjustable heat transfer parameter determined from a cone calorimetry experiment, provides a reasonable approximation of the heat transfer through the charred surface. (Fire Research and Safety)

Intermixing Cells In Aircraft Nickel-Cadmium Batteries:

The FAA issues Parts Manufacturer Approvals (PMA) for aircraft replacement parts that the original equipment manufacturer (OEM) do not manufacture. To obtain a PMA, the replacement part manufacturer must meet the FAA requirements for safety regulations and standards, and it must meet the OEM's specifications and standards for the part it will replace.

Replacement battery cells within aircraft batteries are issued PMAs from the FAA; however, there have been claims from OEMs that intermixing PMA with OEM cells in an aircraft battery can have drastic effects on battery performance and may cause a safety of flight issue.

Researchers used this SAFT 4078-7 NiCd Battery in testing.

Confusion also exists within FAA regulations as to what practices are acceptable relative to PMA cells. Technical Standard Order (TSO) C173, which specifies the minimum performance standards required for nickel-cadmium (NiCd) and lead-acid batteries, says these batteries must adhere to RTCA/DO-293. This document however, states that "mixing cells or batteries with different part numbers, made by different manufacturers for from different sources, is a non-acceptable practice." This statement contradicts the FAA PMA process and clearly advises against the intermixing of cells, yet the applicable TSO references it.

To address these concerns, the Fire Safety Team performed tests to determine whether intermixing cells within an aircraft NiCd battery has an effect on battery performance, and if any such effect results in a safety of flight issue.

FAA researchers evaluated two aircraft SAFT 4078-7 batteries through a series of tests specified in RTCA/DO-293, including several rated capacity tests at various temperatures, a charge stability test, a duty cycle test, and an induced destructive overcharge test. One of the batteries remained in its original form with all OEM cells, while researchers replaced half of the cells in the other battery with PMA replacement cells. Before testing, researchers fully serviced both batteries as though they were being commissioned for service onboard aircraft.

Throughout the tests, researchers observed only slight differences between the OEM and intermixed batteries. The PMA cells consistently charged at a higher voltage; however, none of the cells exceeded the maximum voltage of

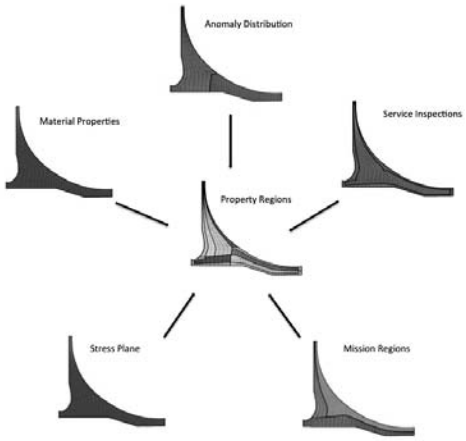
1.7 V. During some tests, individual cells showed particular differences in behavior and recorded battery temperatures. The most notable difference occurred during the induced destructive overcharge tests, in which a larger number of cells from the intermixed battery recorded increased voltage readings, indicating signs of possible thermal runaway. However, these measurements were all within the requirements of the test standard and no resulting flame or explosion of either of the batteries occurred. The main conclusion from the study, based on these various tests, was that the intermixing of OEM and PMA battery cells within a nickel-cadmium aircraft battery provided no indication of any safety of flight issues. (Fire Research and Safety)

Recent Developments In Turbine Engine Component Risk Assessment Software:

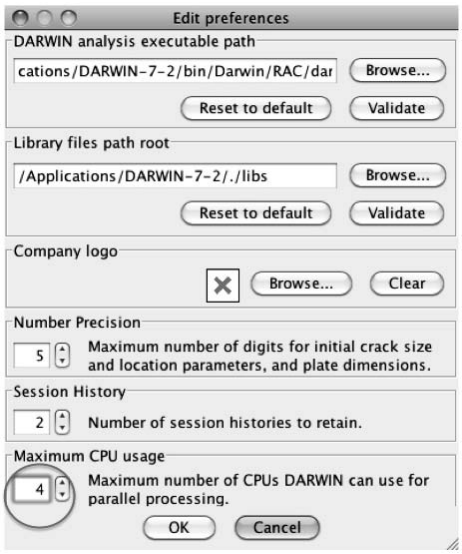
Rotating components of aircraft gas turbine engines are susceptible to uncontained aircraft engine failures due to material anomalies that occur only rarely. The FAA has issued several ACs in recent years to address specific types of inherent and induced anomalies (AC 33.14-1 and AC 33.70-2, respectively) and to establish a general framework for all life-limited engine parts (AC 33.70-1). The associated risk of fracture can be predicted using DARWIN®, a probabilistic fracture mechanics software code developed by Southwest Research Institute under FAA R&D funding.

DARWIN® uses a zone-based risk assessment approach in which a component geometry is subdivided into small regions of approximately equal risk that are later combined to predict the total disk fracture risk with and without the influences of non- destructive inspection. In previous versions, human judgment was required to define zones and the orientation and boundaries of the associated fracture mechanics models, and risk results could vary considerably from analyst to analyst.

The most recent release, DARWIN® 7.2, includes an initial capability for automatic generation of zones for risk assessment of engine components containing inherent material anomalies. The user interface was enhanced to enable an analyst to assign component properties directly to finite elements (FEs). Once the properties have been assigned, DARWIN® automatically generates a zone at each finite element in the user-supplied finite FE model. The orientation and boundaries of the fracture model are then computed using the automatic geometry model process introduced in DARWIN® 7.0. This new capability significantly reduces the amount of human time and judgment required for risk assessment of gas turbine engine components. Enhancements to increase the computational efficiency of the zoning process by combining small adjacent zones with similar properties are planned for future DARWIN® versions.



DARWIN version 7.2 includes an initial capability for automatic generation of zones for the risk assessment of engine components that contain inherent material anomalies.



This image shows the graphical user interface of a new parallel processing capability that was introduced in DARWIN 7.2, which substantially reduces the computation time required for risk assessment of gas turbine engine components.

DARWIN version 7.2 includes an initial capability for time-dependent fatigue crack growth assessment, as displayed on the graphical user interface.

DARWIN® 7.2 includes an initial capability for a time-dependent fatigue-crack growth assessment. This capability is especially important for components exposed to higher temperatures and longer mission times. The user provides material properties for time-dependent crack growth as well as the elapsed time associated with each load step of the flight history (as shown in the adjacent figure). The crack growth life is then computed using a superposition of the cycle-dependent and time-dependent crack growth rates.

Computational efficiency is a critical aspect when performing risk assessment of engine disks where millions of numerical simulations are often required to satisfy computational accuracy requirements. To address this issue, a new parallel processing capability was introduced in DARWIN® 7.2 that automatically subdivides the risk computation for simultaneous application to multiple CPUs on a single computer. The GUI includes a feature to allow the analyst to specify the number of CPUs to be allocated for DARWIN® computations. The new capability substantially reduces the computation time required for risk assessment of gas turbine engine components. (Propulsion and Fuel Systems)

Impact Damage Formation On Composite Aircraft Structures:

The FAA has been involved in research efforts directed at the expanding composite applications to transport wing and fuselage structure (i.e., the Airbus A350 and B-787 aircraft). Part of this effort investigates impact damage formations on composite aircraft structures including low velocity, wide-area blunt impact caused by service vehicle and ground maintenance collision and high velocity impact such as hail or bird strikes. The goal is to provide a better understanding of the damage tolerance characteristics of composite airframe structures and to

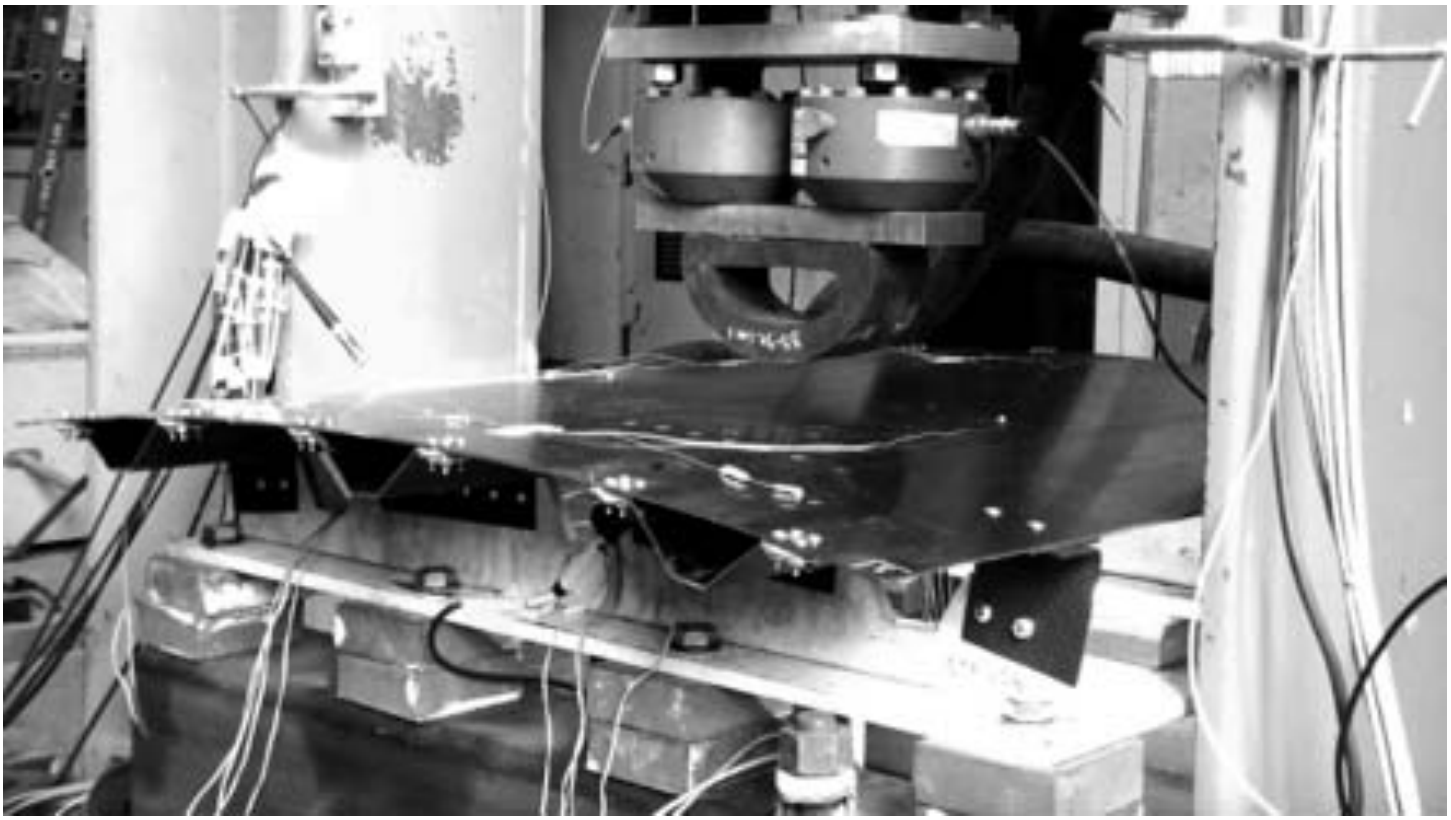


Figure 1 - This image demonstrates dynamic impact testing on a composite panel to study impact damage caused by a ground-service vehicle.

provide FAA guidance and policy on impact damage tolerance guidelines, maintenance practices, and control damage aspects beyond design considerations.

The research focuses on ground-service equipment impact onto composite fuselage structures. Five different specimens were tested. Various configurations showed different modes of damage, depending on the indentation and impact location relative to the stringers. The dynamic tests on two specimens showed visual skin-cracking damage in addition to skin-stringer separation. Figure 1 shows a typical dynamic test setup. While the load vs. indentation displacement was almost identical for dynamic and static tests, the damage developed was more localized for the dynamic case. Computer simulation of the impact, Figure 2, shows good correlation between the FE model results and the dynamic and static test data. FE modeling development is an ongoing effort to predict the sequence of failures experimentally observed in the test specimens; identify what parameters can be used for establishing failure threshold criteria associated with the onset of damage; and define general modeling methodologies for predicting damage to composite structure due to blunt impact. (Advanced Material/Structural Safety)

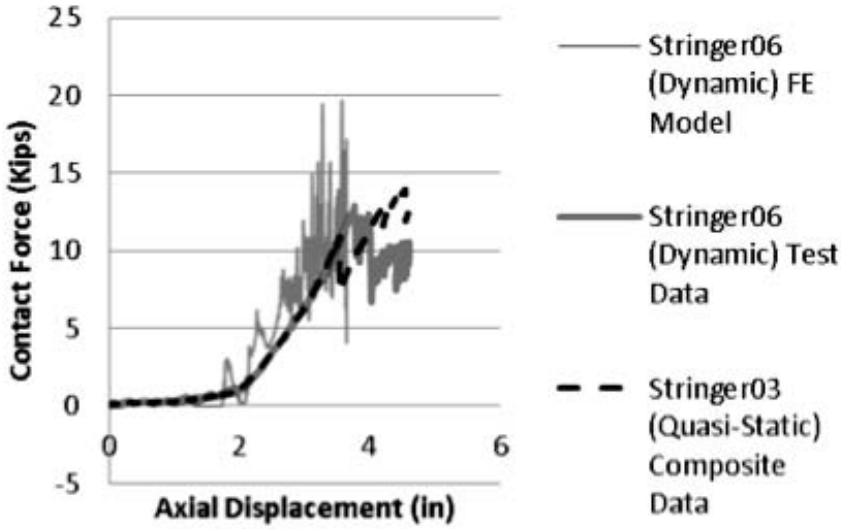


Figure 2 - Comparison of FE Results and Dynamic and Static Test Data.

Rudder Control Systems In Transport Aircraft:

In an effort to increase aviation safety by reducing the number of accidents, the FAA initiated a study on the use of rudder in transport category airplanes. The study consisted of five separate but related research efforts that, when analyzed together, allowed researches to better understand transport category rudder control systems and the way these systems are used by pilots during various stages of flight. The five parts of this study included: (1) studies of existing directional control standards, (2) literature and accident and incident reviews, (3) desktop flight simulation and analysis, (4) global transport-airplane pilot survey of in-flight rudder usage, and (5) real-time, full-scale piloted simulations.

The results of this study are documented in FAA reports and show that different rudder control system designs have different responses to pilot inputs with regard to rudder movement and vertical stabilizer loads. Furthermore, different designs cause dissimilar pedal feedback, which may cause pilots to react differently from one design to another. Depending on the individual pilot training and past experience, these variations could lead to the tendency of rudder over- control and overstress on the airframe structure. (Continued Airworthiness)

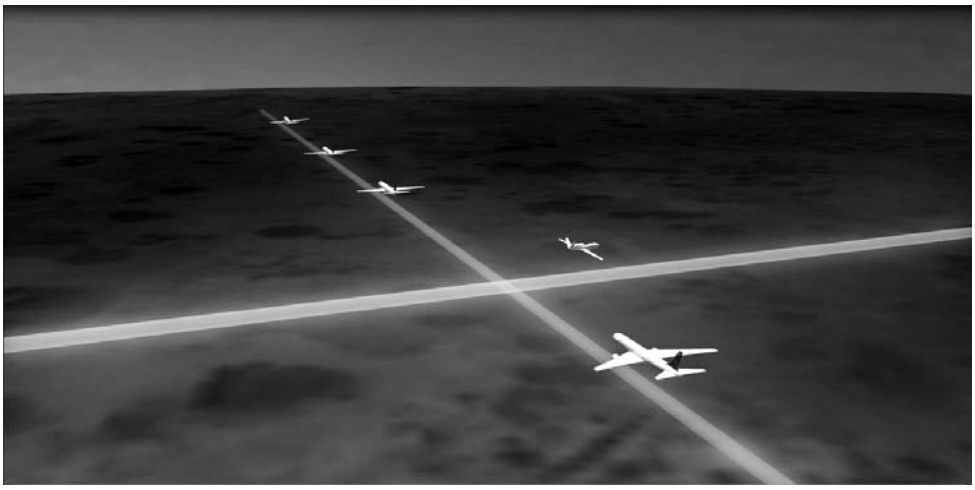
Implications Of UAS Operations In Controlled Airspace:

The need for unmanned aircraft systems (UAS) access to the NAS is increasing. The DOD uses unmanned aircraft to test aircraft and procedures and to train for overseas missions. The DHS uses unmanned aircraft to patrol the nation's borders. Other agencies and organizations use them for activities such as disaster relief or scientific research. These missions often require UAS access to non-segregated airspace, where they fly together with manned aircraft, and are managed by FAA air traffic controllers. The purpose of this research is to understand the impact UAS have on these controllers from a human factors perspective, including how they affect the safety and capacity of the airspace.

In FY 2011, CAASD researchers used a combination of analyses of current UAS operations along with human-in-the-loop (HITL) experimentation to explore the issues and problems that arise when UAS are integrated into the airspace. The research focused on Class A (high-altitude, en route) airspace where UAS are operating on IFR flight plans, using discrete transponder codes, and communicating with air traffic controllers. Today these operations require special waivers and tight restrictions. NextGen plans envision a less restricted comingling of manned and unmanned aircraft in shared airspace.

The current operation analyses consisted of historical radar tracks of Global Hawk (RQ-4) and Predator-B (MQ-9) flights from January 2009 through December 2010 and voice and radar synchronized data for Global Hawk flights in Oakland ARTCC and Predator-B flights in Albuquerque ARTCC.

The radar analysis showed the areas with heaviest UAS flights are the border patrol operations areas. However, these operations are away from busy airspace, with few manned aircraft passing through, and therefore mostly remain segregated except for a few north-south international routes. The border patrol UAS flights, however, fly very complex routes that make it difficult for ATC to predict their paths and therefore complicate the task of separating UAS from other traffic. Another area of high UAS activity, northern California (in the area of Beale Air Force Base), has fewer total flights, yet has higher rates of interaction between the UAS and manned aircraft due to its location. UAS arriving at and departing from Beale Air Force Base must transition through the same airspace as San Francisco Bay area arrivals from the north.



The unique performance characteristics and routings of Unmanned Aerial Systems (UAS) present new challenges to ATC.

CAASD researchers used a sampling of voice data from these two areas to understand how UAS flights affect controllers. Researchers accessed voice data synchronized with radar through an FAA post-operations analysis tool called Falcon. UAS communications whenever UAS are beyond the line-of-sight of the ground control station are relayed through a satellite and then through the aircraft before being sent to ATC. Researchers conducted an analysis to determine if ATC could detect any differences between UAS and manned aircraft communications.

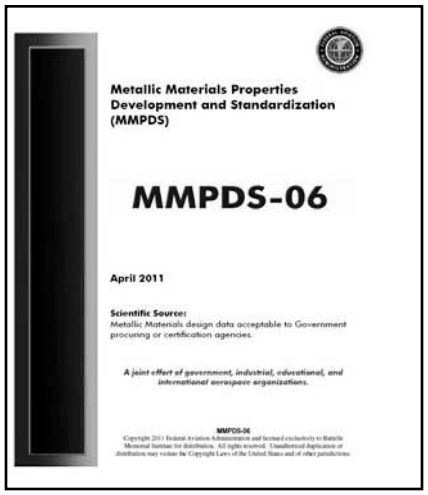
Based on the Falcon analysis, CAASD researchers found that, on average, pilots of manned aircraft respond to ATC clearances in one second, while pilots of unmanned aircraft take three seconds. This delay is likely due to the satellite relay, as it does not appear to be related to the type of clearance or whether the UAS and ATC have already established communications. Another finding was that as much as 14 percent of the time the UAS pilot would completely miss clearances from ATC, compared to 3 percent of the time for manned aircraft. Further analyses are looking at additional metrics such as types and lengths of clearances as well as clearances for the purposes of separation.

In addition to the current operations analyses, researchers conducted a HITL experiment to explore the methods of indicating a loss of the command and control (C2) link to the controller. A previous HITL experiment conducted in FY 2010 showed that, in some cases, controllers took over three minutes to notice the lost C2 link situation in the sector. The FY 2011 HITL experiment explored better ways of catching the controller's attention. The experiment used a combination of auditory and/or display indications for the lost C2 link and determined that the addition of an audible alert or color on the display did improve the detection time. The experiment also indicated that further exploration is necessary to determine whether controllers need a separate identification code indicating a lost C2 link as opposed to a loss of two-way radio communications, as today they appear the same.

This research has begun to quantify some of the differences and similarities between UAS and manned aircraft from the perspective of the air traffic controller. Some key outcomes include the identification of several research questions that require investigation before full UAS integration as well as contributing input into the development of a mid-term concept of operations for UAS in the NAS. (CAASD)

Metallic Materials Properties Development And Standardization (MMPDS):

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). MMPDS 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.



Cover of MMPDS-06

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. Toward this goal, the commercial version of the MMPDS-06 was released in April 2011. There has been a substantial upgrade to the Handbook with the addition of six new metallic alloys and updates to six existing alloys.

Damage Containment Using Advanced Integral-Stitched Structure:

An area that shows promise in enhancing the structural integrity of aircraft and aerospace structures is integral stitched composite technology. Compared to conventional stiffened composite panels with co-cured or bonded interfaces, stitched composite technology offers superior out-of-plane load and damage-containment capabilities. A key feature is through-the-thickness stitching, which suppresses out-of-plane damage and creates a damage-arresting behavior. The most recent generation of this technology is the Pultruded Rod Stitched Efficient Unitized Structure (PRSEUS) concept shown in Figure 1.

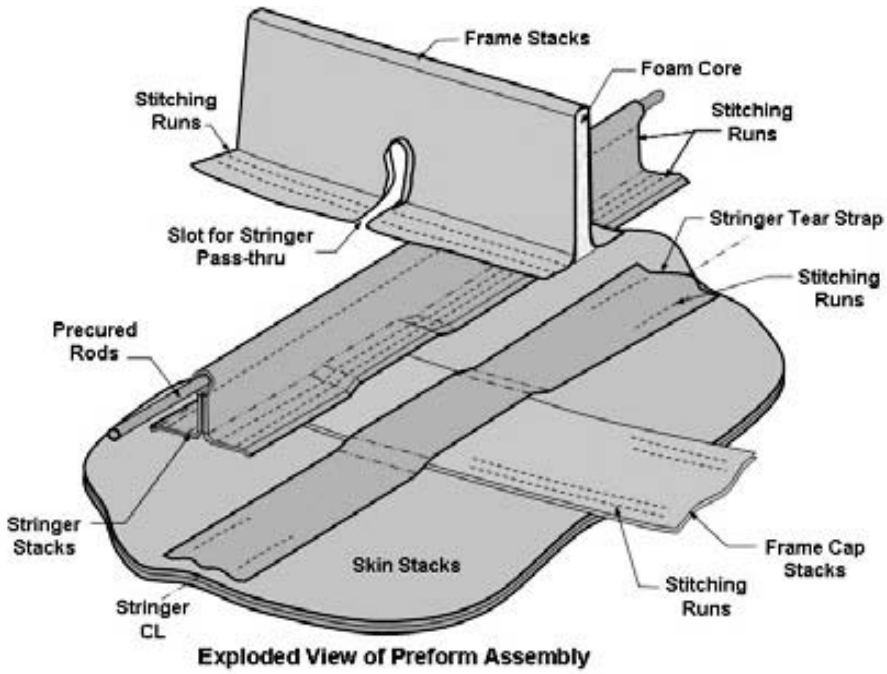


Figure 1 - PRSEUS Concept – Integral-Stitched Preform

NASA, the Boeing Company, and the FAA have partnered in an effort to assess the damage-containment features of a full-scale, curved PRSEUS panel using the FAA Full-Scale Aircraft Structural Test Evaluation and Research (FASTER) laboratory. The objectives of this test are to: (1) characterize the damage arrestment features, and (2) demonstrate compliance with the strength, deformation, and damage tolerance requirements of Title 14 Code of Federal Regulations (CFR) Part 25 using guidance provided by FAA AC 20-107B. For this purpose, the FASTER load fixture has been modified (as shown in Figure 2) to accommodate the larger radius PRSEUS panel and to have the increased axial

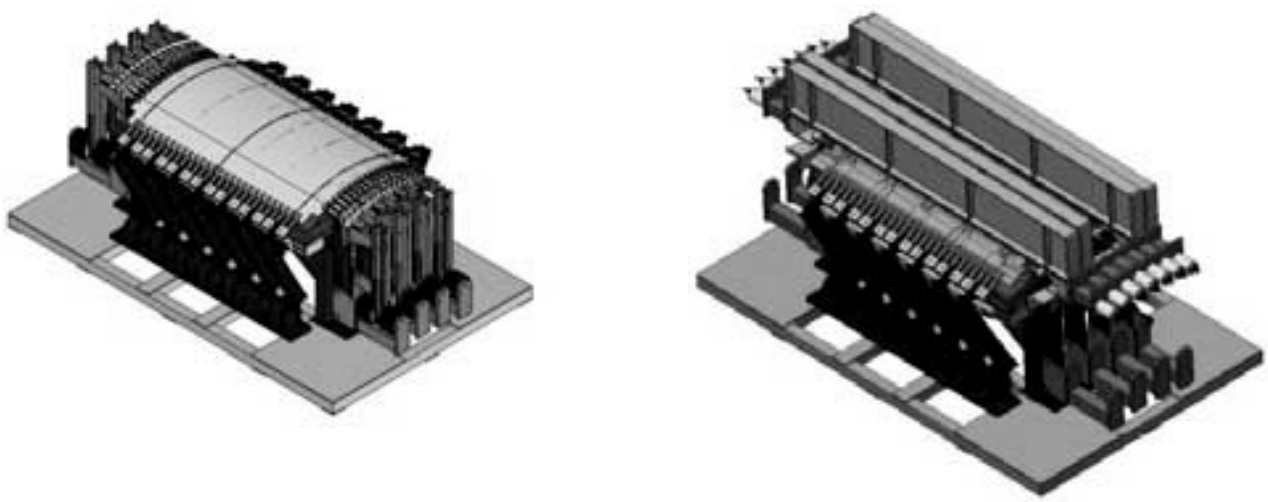


Figure 2 - Modification of FASTER Fixture for Enhanced Axial Load Capacity

load capacity required to meet anticipated catastrophic failure loads.

The test program included loading and inspections of the panel (1) as-built, (2) with barely visible impact damage (BVID), and (3) with discrete source damage (DSD) in the form of a two-bay saw cut. Researchers used various mature and developmental NDI methods to monitor and record the extent of damage, including high-resolution visual, digital image correlation, acoustic emission, thermography, and ultrasound.Test results indicate that the PRSEUS concept is effective in arresting damage growth and in improving the load carrying capacity as illustrated in Figure 3.

The panel was capable sustaining loads exceeding the design ultimate load with a severe initial damage state consisting of a two-bay notch with the central stiffener severed. The overall load-deflection response history appears in Figure 3, indicating the load levels at which damage initiation was first observed, damage containment was maintained, and when final failure occurred. Damage initiation was first observed at 70 percent of the design limit load (DLL). Damage was contained within a two-bay region up to 157 percent of DLL. Figure 4 is a photograph of the panel after failure. The two-bay-notch region is in red. The PRSUES concept was effective in containing damage within these region with applied loads up to 157 percent DLL. Further load was required to progress the damage and eventually cause the panel to fail, which occurred at loads exceeding 200 percent DLL. These test results further demonstrate the damage containment features of the PRSEUS concept and suggest its appropriateness for future flight vehicles.

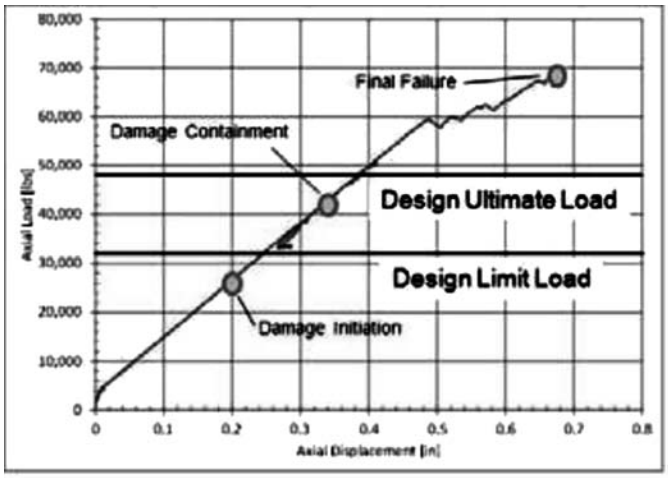


Figure 3 – Load-Deflection Response Indicating PRSEUS Concept Effective in Containing Damage and Enhancing Load-Carrying Capability

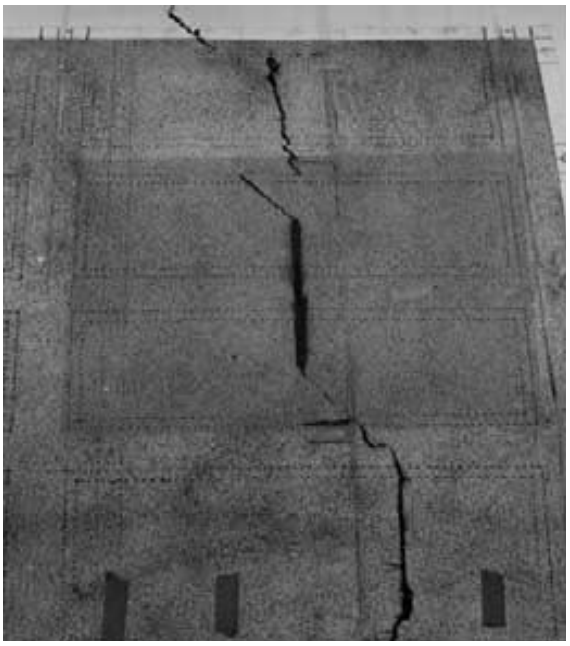


Figure 4 – Panel After Failure

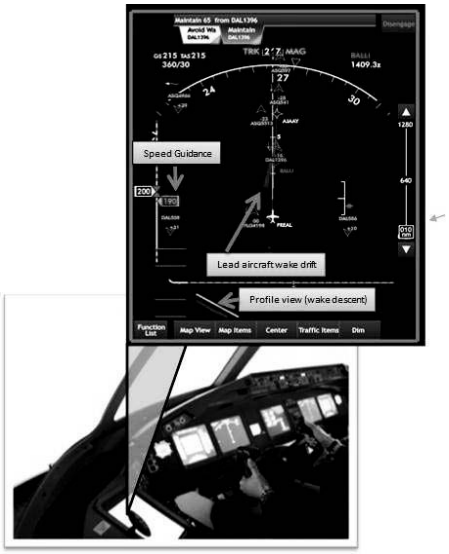
SEPARATION ASSURANCE

A reduction in accidents and incidents due to aerospace vehicle operations in the air and on the ground

Wake Turbulence Avoidance Automation:

Aircraft naturally generate air turbulence patterns, known as wakes, which can be hazardous to trailing aircraft, particularly for operations on airport approach and departure where aircraft are often closely spaced. While current separation standards are safe, as NextGen concepts move toward increasing en route and terminal throughput, wake turbulence separation may become a limiting factor in the pursuit of capacity improvements. Better knowledge of the probable location of wakes—for both air traffic controllers and pilots—could help provide safe separation from wake turbulence while avoiding unnecessary restrictions to operations.

In FY 2011, a CAASD research project was able to use existing research and algorithms to estimate wake characteristics using aircraft and meteorological data as inputs. FAA researchers used this capability to drive displays of wake information on the pilot CDTI. When combined with other advanced technologies, like ADS-B, this led to improved situational awareness, safety, and capacity. Three scenarios conducted in the laboratory demonstrated the feasibility and benefits of incorporating wake information into a CDTI. First, with a strong headwind, the capability decreased the inter-arrival time between successive aircraft over the baseline (i.e., no wake display) scenario. Second, with a strong crosswind, the wake tool decreased inter-arrival time even more than the headwind case, even when heavy aircraft were in the lead. Third, researchers tested a timed paired departure scenario where the trailing aircraft had to start its departure from a closely spaced parallel runway in less than 30 seconds to depart behind a heavy aircraft safely. These laboratory-based feasibility demonstrations supported the value proposition and provided useful feedback on the concepts.



This image illustrates the research concept for improving wake vortex awareness and response using a cockpit display of traffic information.

Future research will focus on expanding the benefits analysis to incorporate the capacity and delay impact of using these wake displays in selected NextGen operations at a broad range of airports. Improvements to the wake displays identified during the FY 2011 simulations will be implemented and an FAA-provided wake model, if available, will be incorporated into the CDTI. Researchers will conduct demonstrations and discussions with interested FAA and aviation industry stakeholders to gain additional feedback and to identify potential work areas that could benefit from this research. Moreover, researchers will explore additional applications of the display of wake information, including other capacity-enhancing concepts, incorporation of wake-avoidance alerts, and improvements to the NAS to make wake prediction more accurate. (CAASD)

Analysis Of Deviations During Simultaneous Independent Approaches:

The FAA initially developed standards for conducting simultaneous, independent approaches to two parallel runways in the 1960s. During the late 1980s and the 1990s, the FAA developing standards for closely spaced simultaneous approaches using the Precision Runway Monitor (PRM) and dual and triple simultaneous approaches using the PRM using standard radars in conjunction with standard green displays and the color Final Monitor Aid (FMA) display. The safety analysis for simultaneous approaches was based on controllers preventing collisions after one aircraft deviated or blundered off final approach. Although blunders did occur, there were little or no data available to estimate either their severity or their rate of occurrence.

At the request of the FAA, CAASD researchers monitored radar, arrival, and weather data at 12 airports from FY 2008 to FY 2011 with the objective of estimating the number of simultaneous approaches, the number of deviations from final during these approaches, and the severity of the deviations. Researchers investigated only simultaneous approaches conducted in less than visual approach conditions (they did not consider dependent instrument approaches and visual approaches). When a deviation event occurred, CAASD requested voice data from the facility to verify that the deviation was not the result of approved controller or pilot action, such as a side-step maneuver or a runway change.

Over a three-year period, CAASD investigated more than 1.4 million simultaneous approaches at 12 US airports, and observed 60 deviations of aircraft from their final approach courses that penetrated or nearly penetrated a No Transgression Zone (NTZ). See Table 1 for a summary. The data collection is ongoing into FY 2012.

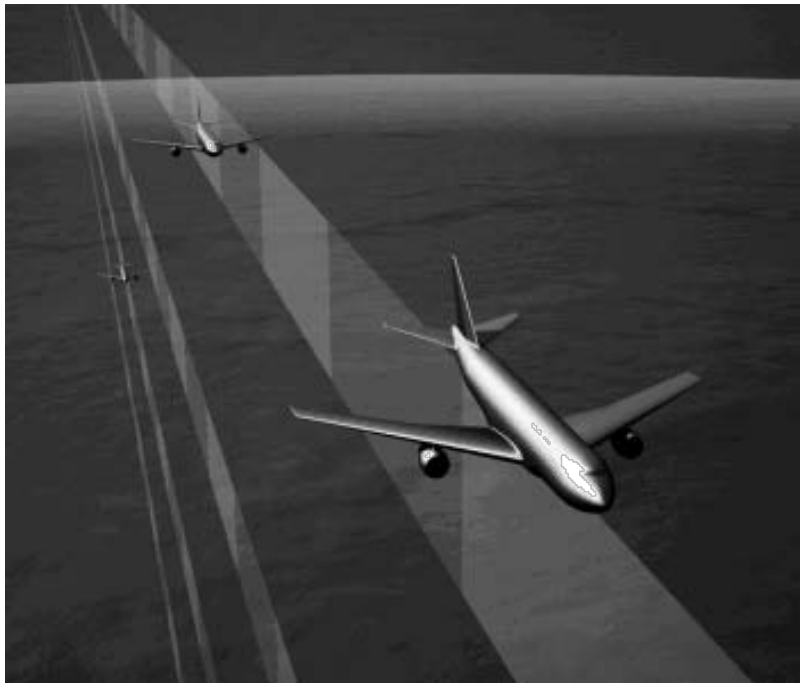
Because of this data collection, the FAA can demonstrate that the rate and severity of deviations from final approach during simultaneous independent approaches is much less than was assumed in earlier analysis. Researchers are using the results of the study in current analyses of approaches, potentially to reduce the required spacing between parallel runways or to reduce the equipment and procedures required for the approaches, such as a requirement for a PRM. (CAASD)

Table 1

Severity (degrees deviation)	FY 2008 Penetrations	FY 2009 Penetrations	FY 2010 Penetrations	FY 2011 (6/30/2011) Penetrations	Total	Penetrations/ Approach	Approaches/ Penetration
< 10°	12	9	4	6	31	2.21E-05	45,174
10–19°	2	6	4	6	18	1.29E-05	77,800
20–29°	0	4	1	4	9	6.43E-06	155,600
30–39°	0	0	0	1	1	7.14E-07	1,400,396
> 40°				1	1	7.14E-07	1,400,396
Total	14	19	9	18	60	4.28E-05	23,240
Approaches	405,035	380,168	353,622	261,571	1,400,396		

Severity and Rate of NTZ Penetrations during FY 2008–FY 2011 (June 2011) FY 2008/09/10/11 (Voice Data Available for Almost all Penetrations)

Initial R&D Plans For ADS-B Applications And Instrument Procedures:



Screen capture showing ADS-B precision satellite-based surveillance.

The FAA's NextGen – Self-Separation Human Factors Program has defined more than two dozen research projects to support its objective. Developed in FY 2011, these R&D plans outline the human factors efforts required for successful implementation of NextGen Operational Improvements, specifically for reduced and delegated separation applications. Key planned products include: (1) descriptions of research and operational experience for each of the application areas; (2) technical information in specialized topic areas such as flight crew training for advanced NextGen flight deck automation; (3) identification of human factors challenges posed by the current implementation of charted and electronic depictions of Area Navigation (RNAV)/Required Navigation Performance (RNP) instrument procedures processes that enhance safety, increase capacity, improve efficiency, and reduce the environmental impact of aviation; (4) low visibility taxi charts; and (5) the Navigation Reference System, a precursor waypoint grid system enabling trajectory operations under NextGen. Anticipated outputs include:

- Defining the potential impact and human factors issues due to new technologies such as enhanced vision, synthetic vision, and electronic flight bags on separation activities.
- Defining human factors technical information needed to support development of standards, procedures, and training by Flight Standards to implement plans for reduced aircraft separation and recovery to classic air traffic operations due to abnormal events.
- Developing procedures and training needed to implement new roles and responsibilities for pilots and controllers during delegated separation operations.
- Defining human and system performance requirements for separation activities, e.g., spacing, merging, and passing.
- Developing and applying error management strategies and risk mitigation factors to reduce automation-related errors associated with enhanced separation operations.
- Developing human factors criteria for successful use of flight deck performance monitoring and decision support tools as they relate to enhanced separation maneuvers such as spacing, merging, and passing. In addition, researchers will are working to determine how conformance alerts are communicated and resolved between flight deck and ground monitors, for example in Trajectory Based Operations, and in RNAV/RNP approach and departure operations (NextGen – Self-Separation Human Factors)

Situational Awareness

Common, accurate, and real-time information of aerospace operations, events, crises, obstacles, and weather

Wayfinding And Signing Guidelines For Airport Terminals And Landside:

ACRP – Capacity is developing a handbook for airport operators containing up-to-date wayfinding and signing guidelines for the airport terminal and landside. The handbook facilitates the safe and efficient movement of passengers within each airport and from one airport to another through the uniform application of guidelines. Guidelines address the following areas: (a) terminal, including concourses/gates, ticketing/check-in, security checkpoints, Federal inspection services, baggage claim; (b) curbside/ground transportation; (c) parking; and (d) on-airport roadways/off-airport access roads. (ACRP)

SYSTEM KNOWLEDGE

A thorough understanding of how the aerospace system operates, the impact of change on system performance and risk, and how the system impacts the nation

Resource Guide To Airport Performance Indicators:

According to a recent airport industry association capital-needs survey, airport capital investment needs are approaching $20 billion annually. Individual airports, state and local agencies, and the FAA depend on individual, case-by-case engineering cost studies and the bid process when estimating, planning, and budgeting for airport capital-improvement projects. Additionally, the engineering, planning, and finance staff at airports do not always have sufficient project-development experience or sufficient information to prepare valid capital cost estimates. In response to this need, ACRP – Capacity developed a user-friendly, interactive, construction cost-estimating model and associated database for airport capital projects along with an implementation guidebook. Projects covered by this research include both airside and landside subject areas. Landside subject areas include the following: airfield, terminal, service and maintenance facilities; runway construction, extension, and rehabilitation; utilities and other infrastructure; security improvements and enhancements; and other airport development projects. The cost-estimating model allows user customization to address industry standards as well as unique local and regional cost factors. In addition, the model is able to respond to particular characteristics of airport projects and import readily available commercial construction information databases or services, where feasible. (ACRP)

Compilation And Analysis Of Economic And Operational Data For Airport Benchmarking Purposes:

Benchmarking is the process of identifying best practices in a particular organization or industry and using measures to track performance against an organizational or industry level of quality or excellence. Benchmarks have multiple purposes. For example, one could use benchmarks to measure progress within a particular organization or to compare performance among similar or competing organizations. Airport operators have frequently used benchmarks to measure financial and operational performance. Recently, airport operators have also used benchmarks to relate levels and types of commercial services with customer satisfaction. To advance the airport industry's knowledge and use of benchmarking, ACRP – Capacity designed, built, and implemented a secure, expandable, database-driven Web application that allows the hierarchical entry and extraction of airport operational, financial, and other data for meaningful performance comparisons with a predetermined and customizable peer group over time. The Web application offers a single data-entry point, assists users in determining and selecting airport peer organizations for various performance comparisons, and provides preformatted reports, including report forms required by FAA and airport-industry trade associations. (ACRP)

Understanding Airport Water Quality Issues Impacting Capacity Enhancements:

Enhanced airport capacity can provide environmental benefits by helping to eliminate congestion in the air and on the ground. Implementing those capacity improvements, however, must go jointly with the need to address environmental issues, including potential water resource impacts. There has been a pressing need to better understand the water resource issues that airports face and how these issues affect the timeliness of project approvals, real project costs, and implementation of proposed projects or programs. In response to this need, ACRP – Capacity created guidance that allows airport operators and planners to recognize the potential effects that capacity enhancement activities may have on water resources. The guidance is in the form of a handbook that identifies issues and requirements relating to water resources, including quality and quantity, wetlands, and groundwater, that may affect the environmental review process linked to airport capacity improvements. The guidebook also describes the potential effects of inadequately addressing these issues and requirements and develops strategies that airports can employ to implement improvements in a timely and cost-effective manner while also protecting water resources. (ACRP)

Airport Impacts From Proposed Firefighting Standards:

ACRP – Safety produced a report that compares the current FAA requirements for Aircraft Rescue and Fire Fighting (ARFF) to recently proposed National Fire Protection Association (NFPA) and ICAO standards. The report provides a financial analysis of the operational costs for airports to comply with the NFPA and ICAO standards compared to the costs associated with the current FAA requirements, including assessments and discussions on the following: the initial cost to implement or start-up these new standards; the continuing cost to provide services; the implications for cost, by size of airport, (cost per enplaned passenger, CPE); and the general implications these costs may have on air service to the community. The report also provides a financial analysis of the infrastructure and equipment costs for airports to comply with the proposed NFPA and ICAO standards where they differ from the costs associated with the current FAA requirements; provides an analysis of the cost and benefits of NFPA and ICAO standards compared to the cost and level of safety currently required; and examines if there are increased operational costs associated with NFPA or ICAO standards and the possible impacts that such costs may have on small airports and their ability to retain and attract new commercial air service. (ACRP)

Ramp Incident Data From Selected Large And Medium Hub Airports:

ACRP – Safety designed a database, available to the airport industry, containing airport and airline ramp incident data. FAA researchers conducted a survey of large and medium hub airports to obtain statistically significant data that is easily sortable by type of incident, cost, injury, and equipment damage. (ACRP)

Research On The Transmission Of Disease In Airports And On Aircraft:

ACRP – Safety planned and conducted a public symposium that features invited presentations on the status of research on or related to the transmission of disease on aircraft and/or in airports. The purpose of the symposium was to provide an opportunity for the research community to share data, models, and methods; discuss findings and preliminary conclusions of ongoing research; and identify gaps to inform future research projects. Specifically, the symposium examined the following: (1) the status of research on—or related to—the transmission of disease on aircraft and in airports; (2) the potential application of research results to the development of protocols and standards for managing communicable disease incidents in an aviation setting; and (3) areas where additional research is necessary. An individually authored summary, including synopses of presentations at the symposium, has also been prepared. In addition to facilitating discussion within the research community, this event provided other participants from the public sector (such as Federal agencies and State and local agencies, including public airports) and the private sector (such as airlines, consultants with expertise in the various facets of airport emergency response) an opportunity to learn about current research and to consider ways that future research might be conducted and funded. (ACRP)

Risk Assessment Of Proposed ARFF Standards:

ACRP – Safety conducted additional research of the proposed industry ARFF standards by expanding the analysis of historical accident data within the context of specific NFPA and ICAO changes to ARFF staffing, reduction in ARFF response time, increase in the airport area to be served within the response time, and increase in ARFF equipment. Specifically, the research analyzed the extent to which NFPA and ICAO ARFF standards may be expected to reduce fatalities and/or mitigate serious injuries associated beyond FAR Part 139 requirements with aircraft accidents on or directly adjacent to airport property. (ACRP)

Airport Apron Management And Control Programs:

Recent studies by the Government Accountability Office (GAO) on airport apron operations in the United States recommended that the FAA work with the aviation industry to develop a mechanism to collect and analyze data on ramp accidents and, if the analysis shows it is warranted, to develop a strategic plan aimed at reducing accidents involving workers, passengers, and aircraft in the ramp area. In response to these studies, and given that there is no clear consensus on the best and most efficient approach for improving apron safety, this research effort performed a study of the methods other countries use to regulate or manage apron safety at airports within their jurisdictions (such as those detailed in ICAO Annex 14, Paragraph 9.5.1). Researchers analyzed the results and used those results to produce a comprehensive report that compares and evaluates the safety benefits of airport apron management and control programs in countries that regulate airport apron operations under ICAO, with those programs and services at similar types of airports in the United States. (ACRP)

Integrated Economy-Wide Modeling:

NextGen has the potential to affect the US economy beyond the air transport industry. For example, productivity gains for cargo and passenger carriers are also realized as productivity gains to businesses that ship or move passengers via air. To date, most benefit studies have not attempted to capture this potential. In 2011, CAASD researchers completed work on a capability to connect operational modeling of congested NAS resources to the functioning of the US economy. Congestion creates inefficiency and higher costs for air carriers; costs that are transmitted to the rest of the economy via business and leisure travelers and air cargo shippers. The ability to model consistently the relationship between efficiency gains in the NAS and the broader national economy opens the door to answering or informing a variety of important questions, such as: How much will delays cost the US economy in 2020 if NextGen fails to be implemented? How much does a one-percent increase in system-wide capacity benefit the economy? What impact does how NextGen is funded have on its potential for economy-wide benefits?

The research was done in collaboration with Monash University, whose US Applied General Equilibrium (USAGE) model is already in widespread use by US Government agencies and has a high degree of industry detail. The USAGE model is based on the Computable General Equilibrium (CGE) model and models numerous components of the economy. The research enhanced the USAGE model in several ways to make it suitable for analyzing economy-wide impacts originating from the air transport industry. One of the most important of these modifications was the development of a method for using the economic concept of decreasing returns to scale to put NAS congestion into economic terms. Initial inputs for the NAS operational side of this relationship were drawn from a *system-wide* Modeler, though the capability is flexible and can work from the output of other NAS-level models.

By connecting operational models of the NAS to the US economy using a CGE approach, economic impacts can be calculated at the broader economy level (variables like gross output, gross domestic product, impact on import and export) through industry-level activity (industries who ship by air, serve air travelers, or produce components of air transport). Compared to economic impact assessment via input and output modeling, the use of a CGE framework provides a more robust way to assess these economic connections—one that is dynamic across time and includes price effects. This approach should help account for stakeholder impacts rarely captured to date, and should provide additional context for the broader value of potential NextGen efficiency gains. (CAASD)

World Leadership

Globally recognized leadership in aerospace technology, systems, and operations

Boeing 787 And Boeing 747-8 Series Aircraft Successfully Integrated Into The NAS:

- **Boeing 787 Series Aircraft:** The FAA and the EASA worked together to certify the Boeing 787, and assumed responsibility for determining the wake separations that the global air navigation services providers would apply to the aircraft. A joint FAA-Boeing task group was formed and provided EASA its recommendations, and upon EASA acceptance, the FAA transmitted these recommendations to the ICAO. Based on those recommendations, ICAO issued guidance to its member states in 2011. (NextGen—Wake Turbulence)

- **Boeing 747-8 Series Aircraft:** To determine wake separations of the new aircraft, the FAA formed a joint steering group with EASA, EUROCONTROL, and Boeing. In the absence of any data to the contrary, the steering group provided interim guidance that the B-747-8 should have a wake separation from other aircraft, which would be greater than the ICAO prescribed standard for Heavy wake category aircraft. In 2007, Boeing decided to conduct a flight test to acquire wake turbulence data to use as the primary basis for establishing wake separation standards for the 747-8 series. Boeing designed a flight test program, which the FAA/EASA work group approved, and they successfully completed testing in 2010. Based on the test program data and other wake turbulence data collected by the NextGen – Wake Turbulence research program and associated analytical and statistical models, the FAA/EASA task group determined in 2011 that the Boeing 747-8 series aircraft should be classified as a Heavy wake category aircraft, which would not require any additional wake separation distance than that provided for other like-category aircraft. Thereafter, the working group provided its recommendation to ICAO. In August 2011, ICAO transmitted guidance on Boeing 747-8 wake separations to its member states based on the working group's recommendations. (NextGen – Wake Turbulence)

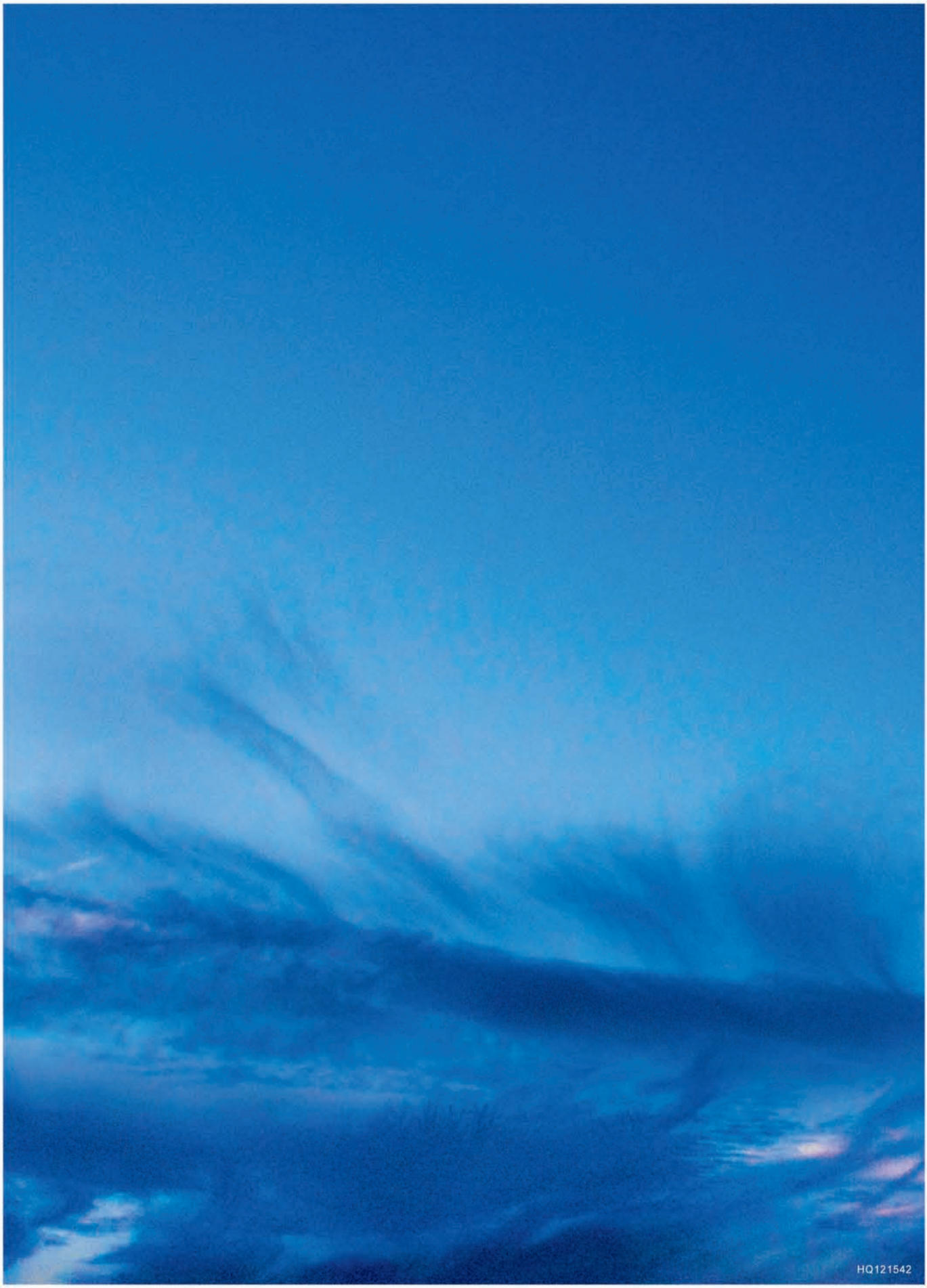
This work also supports R&D Goal 1– Fast, Flexible, and Efficient.

Acronym List

AAFEX II	Alternative Aviation Fuel Experiment II
AAMRWS	Aircraft Accident Medical Review Workflow System
AC	Advisory Circular
ACER	Airliner Cabin Environment Research
ACRP	Airport Cooperative Research Program
ADS-B	Automatic Dependent Surveillance–Broadcast
AEDT	Aviation Environmental Design Tool
AGL	Above Ground Level
ANAC	Agência Nacional de Aviação Civil (Brazil)
APM	Automated People Mover
ARC	Aviation Rule Making Committee
ARFF	Aircraft Rescue and Fire Fighting
ARTCC	Air Route Traffic Control Center
ATA	Air Transport Association
ATC	Air Traffic Control
BVID	Barely Visible Impact Damage
C&V	Current Ceiling and Visibility
C2	Command and Control
CAA	Civil Aviation Authority (UK)
CAAS	Civil Aviation Authority of Singapore
CAASD	Center for Advanced Aviation System Development
CAMI	Civil Aerospace Medical Institute
CASA	Civil Aviation Safety Authority (Australia)
CDA	Continuous Descent Approach
CDQM	Collaborative Departure Queue Management
CDS	Collaborative Departure Scheduling
CDTI	Cockpit Displays of Traffic Information
CFR	Code of Federal Regulations
CGE	Computable General Equilibrium
CIP	Current Icing Products
CLEEN	Continuous Lower Energy, Emissions, and Noise
CMC	Ceramic Matrix Composite
CSPR	Closely Spaced Parallel Runways
CSTA	Chief Scientific and Technical Advisors
CVA	Ceiling and Visibility Analysis
CVM	Comparative Vacuum Monitoring
DHS	Department of Homeland Security
DIWS	Document Imaging and Workflow System
DLL	Design Limit Load
DOD	Department of Defense
DRG	Design Review Group
DSD	Discrete Source Damage
EASA	European Aviation Safety Agency
EDMS	Emissions Dispersion Modeling System
EDR	Eddy Dissipation Rate
EFB	Electronic Flight Bag
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAA-AANC	The FAA's Airworthiness Assurance Nondestructive Inspection Validation Center
FASTER	Full-Scale Aircraft Structural Test Evaluation and Research
FE	Finite Element
FIP	Forecast Icing Products
FLM	Front Line Managers
FLM QRG	Front Line Manager Quick Reference Guide
FMA	Final Monitor Aid
FOD	Foreign Object Debris
FSRL	Feedstock Readiness Level
FSTG	Flammability Standardization Task Group
GA	General Aviation
GAO	Government Accountability Office
GE	General Electric
GSG	Government Steering Group
HAP	Hazardous Air Pollutant
HART	Human Automation Relationship Taxonomy

HITL	Human In The Loop
HRJ	Hydrotreated Renewable Jet
IASFPWG	International Aircraft Systems Fire Protection Working Group
ICAO	International Civil Aviation Organization
IDRP	Integrated Departure Route Planning
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
INM	Integrated Noise Model
ISG	Industry Steering Group
IT	Information Technology
LOS	Level of Service
LOSA	Line Operations Safety Audit
LSTC	Livermore Software Technology Corporation
MCC	Microscale Combustion Calorimeter
MIT/LL	Massachusetts Institute of Technology's Lincoln Laboratory
MMPDS	Metallic Materials Properties Development and Standardization
MOPS	Minimum Operational Performance Standards
NARP	National Aviation Research Plan
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NDI	Nondestructive Inspections
NEPA	National Environmental Policy Act
NFPA	National Fire Protection Association
NiCD	Nickel Cadmium
NIRS	Noise Integrated Routing System
NOAA	National Oceanic and Atmospheric Administration
NOx	Nitrogen Oxide
NTSB	National Transportation Safety Board
NTZ	No Transgression Zone
O&D	Origin and Destination
OEM	Original Equipment Manufacturer
OPD	Optimized Profile Descent
OSED	Operational Services and Environmental Definition
PBPK	Physiologically Based Pharmacokinetic
PC	Polycarbonate
PCT	Potomac Consolidated TRACON
PHMSA	Pipeline and Hazardous Material Safety Administration
PM	Particulate Matter
PMA	Parts Manufacturer Approvals
PRM	Precision Runway Monitor
PRSEUS	Pultruded Rod Stitched Efficient Unitized Structure
PVC	Polyvinylchloride
R&D	Research and Development
RNAV	Area Navigation
RNP	Required Navigation Performance
RTM	Revenue Ton-Miles
SAE	Society of Automotive Engineers
SAFO	Safety Alert for Operators
SHM	Structural Health Monitoring
SIP	State Implementation Plan
STBO	Surface Trajectory Based Operation
TARGETS	Terminal Area Route Generation, Evaluation, and Traffic Simulation
TBL	Towbarless
TCAS	Traffic Alert and Collision Avoidance System
TFDM	Tower Flight Data Manager
TFM	Traffic Flow Management
TMC	Traffic Management Coordinator
TRACON	Terminal Radar Approach Control
TSA	Transportation Security Administration
TSO	Technical Standard Order
UAS	Unmanned Aircraft Systems
USAGE	US Applied General Equilibrium
v-ATD	Virtual Anthropomorphic Test Device
VBB	Vertical Bunsen Burner
VFR	Visual Flight Rules
WJHTC	William J. Hughes Technical Center

The NARP, related appendices, and the *R&D Annual Review* may be found online at:
www.faa.gov/go/narp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