



# Federal Aviation Administration's **R&D Review**

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Quarterly Newsletter of FAA's Office of Aviation Research

Volume 1, Issue 4

## **SPECIAL ISSUE ON AGING AIRCRAFT**

### **A Message from the Manager of FAA's Aging Aircraft Research Program**

While manufacturers of today's large commercial transports originally anticipated that their aircraft would remain in service for twenty years, accumulating 60,000 flights or cycles, many aircraft are currently being flown longer than this anticipated service objective. This extension of service has occurred for a variety of reasons.

In today's market, a new large transport aircraft can cost more than \$50 million. A new jet has attractive qualities, such as increased fuel economy, but it might take years or even decades for an investment in a new aircraft to show a return. Refurbishing an older aircraft, however, can cost as little as \$4 million.

As the fleet ages, the challenge for the aviation community is to maintain a high standard of safety in an economic environment that is intensely competitive. The FAA, in partnership with the aviation community, is leading

the way in ensuring the safety of the commercial fleet.

This special issue of *R&D Review* highlights the FAA's Aging Aircraft Research Program, discussing our challenges, successes, and partnerships, as we work to enhance aviation safety.

In 1988, the FAA established a broad regulatory program to ensure the structural integrity of aging aircraft following the near catastrophic structural failure of a 737 inflight to Honolulu, HI. To support this program, the Agency also established an aggressive research and development program focused on maintaining the airworthiness of high-time, high-cycle aircraft. In 1998, the FAA expanded its regulatory and research programs to address aircraft electrical and mechanical systems.

Because it is critical that government, industry, and academia work together to meet the aging

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*Conducting Critical Research  
for the Future of Aviation*



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This years' conference was dedicated to the memory of Dr. Jack Lincoln.

aircraft challenge, in November, the FAA, DoD, and NASA hosted the 6th Annual Joint FAA-DoD-NASA *Conference on Aging Aircraft* in San Francisco, CA. Over 800 leaders from government, academia, and the aviation industry attended this conference, which was designed around four issue-focused panel groups. Nearly 100 technical papers, 50 posters, and over 50 exhibitors provided information on aging aircraft challenges and solutions.

The conference provided an important forum allowing those concerned about the nation's aging aircraft fleet to interact with their colleagues and strengthen partnerships while

reaffirming our on-going commitment to ensure the safety of the flying public.

For more information on the conference, please read the article in this issue entitled, *Coming Together to Meet the Challenge*.

On a personal note, I want to thank all of you who have supported and continue to support the FAA's efforts to ensure the continued safe and cost effective operation of our aging aircraft. I especially want to thank those of you who participated in and helped organize this year's conference.

I also want to extend an invitation for you to join us at next years' Joint FAA-DoD-NASA Conference on Aging Aircraft, September 8-11, 2003, at the Hyatt Regency in New Orleans, LA. A comprehensive guide to next year's meeting, as well as information on how to obtain the 2002 conference proceedings can be found on-line at: [www.galaxyscientific.com/agingaircraft2002](http://www.galaxyscientific.com/agingaircraft2002).

Christopher Smith, Manager  
Aging Aircraft Research and Development Program

**Remember to visit the website:  
[www.galaxyscientific.com/agingaircraft2002](http://www.galaxyscientific.com/agingaircraft2002)  
for information on next years' FAA-DoD-NASA  
Conference on Aging Aircraft, in New Orleans, LA**

# Ensuring Safety from Roll-Out to Retirement

## FAA's Aging Aircraft R&D Program

The relatively long service histories of many aircraft in the nation's commercial fleets, combined with high replacement costs, pose significant challenges to those responsible for providing reliable and safe air operations in an era of extreme fiscal constraints.

Older aircraft can be more susceptible to structural problems associated with fatigue and corrosion. For example, in April 1988, an Aloha Boeing 737 aircraft experienced an inflight structural failure of the forward upper portion of the passenger cabin while at cruising altitude. Analysis showed that a series of initially very small fatigue cracks had developed at rivet sites in the fuselage skin joints. These almost undetectable cracks quickly merged into longer cracks, causing the residual strength of the structure to drop below the critical level.

design features. Inspectors subsequently found that this "multiple site cracking" was not constrained to just one design feature in one model of aircraft, but was present in other models and other design features with repeated details. The FAA immediately issued airworthiness directives requiring inspection and modification of eleven model aircraft affected by this age-related problem.

That Aloha accident, more than anything else, was responsible for the creation of the FAA's National Aging Aircraft Research Program. This program's original focus spanned the technology areas of structural modeling, fatigue and fracture, corrosion morphology, nondestructive inspection, and flight loads analysis. The Agency's goal is to provide the technology to predict, detect, and mitigate structural deterioration before it becomes a safety hazard.

Though the Aloha accident was the impetus for the FAA's Aging Aircraft Program, visionary management used the opportunity to identify and address potential problems before they could emerge as true threats to aviation safety. In particular, the FAA concluded that improvements to large commercial transports should be leveraged to initiate similar improve-



ments in commuter aircraft and helicopters. At the time of the Aloha accident, neither class of aircraft used the more sophisticated damage tolerance concept for design and maintenance.

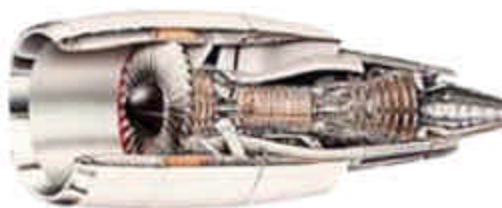
Much of the work in the area of commuter damage tolerance involves the relatively straightforward application of large transport damage tolerance concepts to commuter aircraft. Rotorcraft, however, present some additional challenges. Because of their very different use profiles (unpressurized, short-duration flights at low altitude) and because of their exposure to high-cycle fatigue associated with rotor dynamics, the application of damage tolerance to rotorcraft requires additional research and development.



Identification of this disturbing phenomenon in one aircraft model compelled the FAA to inspect other aircraft with similar

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The FAA's research focus has steadily expanded over the years. A year after the Aloha accident, the fan disk on the number two engine of a DC-10 disintegrated resulting in loss of all hydraulics. The pilots managed to crash land the aircraft saving 171 of the 282 passengers and crew. The accident resulted in the establishment of the Titanium Rotating Components Review Team and subsequently the Engine Titanium Consortium (ETC). Since its start, the ETC has managed to improve billet inspection sensitivity by a factor of 4 and has made substantial improvements in the techniques used for in-service inspection.

In the summer of 1996, a TWA B-747 exploded over the Atlantic shortly after take-off from New York's Kennedy Airport. The National Transportation Safety Board determined that the prob-



able cause of the accident was an explosion of the center wing fuel tank resulting from ignition of the flammable fuel-air mixture in the tank.

The source of ignition energy for the explosion could not be determined with certainty but, of the sources evaluated by the investigation, the most likely was a short circuit outside of the fuel tank that allowed excessive voltage to enter it through electrical wiring associated with the fuel quantity indication system. As a result, non-structural systems has become a major research area of the continuing National Aging Aircraft Research Program.

Today the FAA's aging aircraft research is focused on:

- The development of analytical methodologies to predict the onset of wide spread fatigue damage and residual strength of aircraft structures.
- The development and validation of nondestructive inspection techniques to detect and quantify damage in the forms of corrosion, cracking, disbonding, and material processing defects.
- The analysis of flight data to support the development and validation of airworthiness standards for aircraft structures and systems.
- The development of maintenance and repair requirements and procedures for airframes and systems.

- The development of information, technologies, and techniques to ensure the continued safe operation of aircraft electrical and mechanical systems.

Much of the structural integrity work focused on large transport aircraft applications is undertaken at the FAA's William J. Hughes Technical Center. Here, several state-of-the-art computer workstations enable researchers to develop and exercise methodologies to predict the strength and durability of aircraft structure. These researchers also have at their disposal a full scale test facility capable of subjecting large fuselage panels to typical fatigue loading. Results from these full-scale tests are used to validate structural life prediction methodologies and give insight into new failure modes.

Work in the inspection system research project is conducted primarily at two affiliate centers, the Center for Systems Reliability (CASR) and the Airworthiness Assurance Nondestructive Inspection Validation Center (AANC).

CASR, established in 1990 at Iowa State University, is developing innovative inspection techniques to solve the unique inspection challenges facing commercial aviation. AANC, established in 1991, at Sandia National Labs in Albuquerque, New Mexico, provides the FAA

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# Coming Together to Meet the Challenge

## *Aging Aircraft Conference Highlights Mature Programs and New Challenges*

***"We will rise to the challenge and continue to make air travel the safest transportation system in the world."***

It has been more than a decade since aging aircraft issues emerged as a serious threat to aircraft safety and readiness. While there has been much progress in the development of solutions, there is still much to be done. For example, structural analysis methodologies have improved significantly, but a full understanding of the development and growth of widespread fatigue damage still eludes us.

Corrosion continues to plague aircraft being kept in service well past their anticipated service lives. Composite materials hold the promise of greater structural performance, but these materials are also showing signs of age degradation. Inspection technology is more sensitive and more reliable, but cracks and other degenerative failures are beginning to emerge in hidden or difficult to inspect areas.

While these structural issues linger, a new challenge has emerged. Aircraft systems, par-

ticularly electrical interconnect systems, are showing signs of degradation. Building on lessons learned in the aging structures programs, the aviation community came together quickly and effectively to address these systems issues.

Aircraft arc-fault circuit breakers are now a reality and the FAA's Aging Transport Systems Rulemaking Advisory Committee is poised to recommend rule-making addressing wire system design and maintenance. Nevertheless, wire degradation mechanisms are not fully understood and testing and inspection techniques are far from mature.

The Sixth Joint FAA/DoD/NASA Aging Aircraft Conference, held in San Francisco, September 16-19, 2002, provided a forum to discuss the many aging aircraft challenges, as well as identify new challenges requiring government and industry attention.

It became abundantly clear at the conference that the aviation community cannot rest on past successes. Attendees agreed that it is critical that they develop and validate new and more capable methodologies and technologies. The aviation community must also tailor these methodologies and technologies



to address emerging threats. And, they must address fleet implementation issues; make our solutions more practical and cost effective; and ensure solutions have broad applicability and more flexibility to address smaller aircraft, rotorcraft, and engines.

Participants at this year's conference agreed that they must persevere in concluding this very important work. As Peggy Dido, vice president, Engineering and Technical Support, United Airlines, pointed out, "aging



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effects . . . can impact any airline at any time. We must assure continued airworthiness of all aircraft." Nick Sabatini, FAA associate administrator for regulation and certification, explained that the commercial fleet is getting older; as of July 2002, the average age of the fleet was 12.8 years. Emphasizing the need to ensure the safety of the fleet, Sabatini discussed the FAA's recent and ongoing rulemaking efforts that will require the concerted effort of the entire aviation community to implement effectively.

This year's ambitious conference agenda included papers on: aging structures; aging systems; economics of aging aircraft; and research and development efforts for aging aircraft. Participants at this annual conference shared their expertise, research findings and shared information on the air-worthiness and sustainability of aging aircraft. Subject matter experts analyzed emerging issues and discussed solutions to age-related aircraft problems, for both the civilian and military fleets.



The conference marked the first time that panel discussions were included with the concurrent paper and poster sessions. Panel participants included: Aubrey Carter, Delta Airlines; John DeLisi, NTSB; Dominique Chevant, Airbus; Randy Boren, Northwest Airlines; Edward Keating, RAND; Aaron Gelman, Northwest University; and Amos Hoggard, The Boeing Company. The panels this year were: *Commercial Aviation's Efforts to Mitigate the Threat of Structural Degradation*; *The Economics of Aging Aircraft*; *Using University R&D to Support the Practical Need of the Aviation Community*; and *Commercial Aviation's Efforts to Mitigate the Threat of Deteriorated Subsystems*.

Partnership was a large theme of this year's conference, as many participants talked about shared future success. Brig. Gen. Rosanne Bailey, director of the Aeronautical Enterprise Program Office, Wright-Patterson Air Force Base, remarked at the plenary session, "We must jointly cope with aging aircraft." She explained that the challenge for government and industry is to "expand collaboration," stating, "We all succeed together."

Colonel Mike Carpenter (Aging Aircraft Division, Wright Patterson Air Force Base), providing a keynote lunch-



eon speech and serving as a panel member, reinforced General Bailey's comments about the need for the aviation community to work together.

John Goglia, NTSB, also echoed this partnership sentiment, saying, "We will rise to the challenge and continue to make air travel the safest transportation system in the world." ■

Remember to visit the website: [www.galaxyscientific.com/agingaircraft2002](http://www.galaxyscientific.com/agingaircraft2002) for information on next years' FAA-DoD-NASA Conference on Aging Aircraft, in New Orleans, LA

# Venerable Advisors Set to Retire

## *TOGAA Awarded Administrator's Gold Medal*

At the Sixth Annual FAA/NASA/DoD Aging Aircraft Conference, Nick Sabatini, FAA Associate Administrator for Regulation and Certification, acting on behalf of the FAA Administrator, presented the members of the Technical Oversight Group on Aging Aircraft (TOGAA) with the FAA's Award for Superior Achievement.

The award, also known as the *Administrator's Gold Medal*, acknowledges TOGAA's exceptional public service, dedication, and superior achievements. For nearly fifteen years, the distinguished members of TOGAA have dedicated themselves to assisting the FAA in attaining the goals and objectives of the FAA Aging Aircraft Program.

Realizing that it would benefit from independent advice and technical guidance of industry, government, and academic experts regarding aging aircraft issues, the FAA created TOGAA after the 1988 Aloha Airlines accident. Upon its creation, TOGAA immediately began providing essential guidance in five specific areas related to transport airplanes:



Some of this year's award recipients and family members.

- (1) Service Bulletins to maintain structural integrity;
- (2) Corrosion Protection and Control Program;
- (3) generic structural maintenance program guidelines;
- (4) Supplemental Structural Inspection Documents; and
- (5) Damage tolerance of repairs.

The agency later expanded this role to include reviews of damage tolerance research and rulemaking efforts for transports, aging issues for commuters, rotorcraft, engines, propellers, and cargo conversion modifications.

Lead first by Chairman, Dr. Jim Mar, then his successor Mr. Ernie Bryan, and now current Chairman, Mr. Chuck Tiffany, TOGAA has provided outstanding guidance and support for the FAA's Aging Aircraft Program. Because of the work of these staunch advocates of aircraft safety, the aviation community has been able to implement essential changes to aircraft design, certification, and maintenance practices. Thanks to TOGAA's unrelenting advocacy, the same philosophy is now being incorporated into regulations governing commuters, rotorcraft, and turbine engines. Collectively, these achievements have significantly enhanced aircraft safety and are, by any reasonable measure, truly exceptional accomplishments for a group of experts who are reportedly retired.

After sending a final report to Nick Sabatini this past fall, TOGAA officially dissolved. In keeping with 15 years of advocacy, individual members have expressed their intent to stay in touch with their colleagues in the aviation community. ■

# Ensuring the Airworthiness of Aircraft Systems

## *Aging Mechanical and Electrical Systems Research*

Worldwide accident data from 1959 through 1996 indicates that up to 3 percent of all accident causal factors, or 30 percent of airplane-related accident causal factors may be attributable to nonstructural systems.

To address concerns about the safe operation of aircraft electrical and mechanical systems over time, researchers in the FAA's Aging Nonstructural Systems Research Program are developing technology and techniques to ensure the continued safe operation of aircraft as the average age of commercial airplanes currently in service increases.

This research addresses:

- the degradation of electrical interconnect components and systems;
- hydraulic and pneumatic components and systems; and
- mechanical control linkages, cables, and actuators.

Researchers are also examining the effects of how aging components and systems interact with new, refurbished, and reconfigured systems and components. The products from this research are being used in support of pending and new regulatory action and to facilitate

compliance with existing and new regulations.



Current initiatives include the development of an aging systems test and validation infrastructure; an assessment of wire degradation mechanisms and limits; an assessment of the adequacy of visual inspection; the development of wire inspection and testing technologies and techniques; and the development, test, and validation of aircraft arc-fault circuit breakers.

In establishing the Nonstructural Systems Research Program the FAA has committed to the principal that a fully effective research program must be based on service data analysis and tear-down evaluations.

FAA safety researchers are currently studying both in-service and retired commercial airliners in the first systematic effort to look at the state of aircraft wiring. Their data shows that wire degradation and failure could

have multiple causes, and are not solely related to age.

For additional information on the FAA's Aging Nonstructural Systems Research Program, go to: <http://aar400.tc.faa.gov/Programs/agingaircraft/agingystems/index.htm>. ■

## Stay Tuned

Electrical interconnect system integrity is currently one of the FAA's highest priorities for aircraft safety, but the agency remains mindful of potential threats to other aircraft systems.

In a proactive effort to ensure that aircraft near the end of their service lives remain safe and reliable, FAA researchers are developing technology and techniques to ensure the continued safe operation of mechanical, hydraulic, and pneumatic systems.

The FAA already has a full scale test-bed aircraft at the Aging Aircraft Nondestructive Inspection Validation Center in Albuquerque, NM. Initial research will include: destructive assessment of un-inspectable flight control linkages; an analysis of rudder control design and operation; and an analysis of enhance fail-safe jack-screw designs. ■



# New Circuit Breakers Technology Improves Safety

## Arc-Fault Circuit Breaker Can Prevent Fires and Other Critical Failures

The FAA and National Transportation Safety Board (NTSB) have reported hundreds of potential hazardous incidents of smoke in aircraft cabins and cockpits, and such incidents are likely to increase with the aging of the in-service aircraft fleet. Recent aviation mishaps focused investigators on the problems of aging aircraft wiring, specifically, hard-to-detect arcing faults. In fact, FAA, NTSB and the Transportation Safety Board of Canada investigations cited electrical systems arcing as one likely cause of the cabin fire and crash of Swissair Flight 111 and the explosion and crash of TWA Flight 800. Similar, less catastrophic events, have occurred in commercial transport and military aircraft fleets worldwide.

Civilian and military aircraft contain hundreds of miles of wire, much of it inaccessible once the aircraft is assembled. The wire is routed throughout the airplane in a series of bundles with clamps and connectors creating the electrical pathway through the aircraft. As newer airplanes add wiring to accommodate additional avionics and in-flight entertainment equipment, the sheer mass of stranded copper

that is routed through terminal connectors is growing rapidly.

**“Recent aviation mishaps focused investigators on the problems of aging aircraft wiring, specifically hard-to-detect arcing faults.”**

When the protective sheath of insulation on a wire cracks, tears, or is rubbed off by chaffing and the conductor is exposed, the potential for a short circuit or arc exists. A short circuit occurs when electricity takes an unintended path. For example, condensation or other conductive material sometimes found on wire bundles can bridge the gap between a wire conductor and an adjacent metal surface. When electrical current follows the unintended path to the metallic structure, a short circuit can cause overheating and possibly a fire. Power wiring in aircraft is protected by circuit breakers that detect overloads and continuous short circuit.

Currently, thermal circuit breakers in most aircraft are not unlike those found in most household circuit breaker fuse boxes. They are designed to protect the wiring from overheating associated with

overload or short circuit conditions. They generally do not protect against small sparks that can occur when aging, frayed wires somehow become stressed to the point that arcing occurs between individual wires or between the wire harness and the aircraft structure.

Unlike a short circuit, electrical arcing is intermittent and occurs when high current spikes cross an air gap, emitting sparks that include molten material that is instantly vaporized in the high-energy discharge and produces extreme localized heat. What looks to the naked eye to be a continuous arcing event is really a chaotic series of individual arcs.

“Mechanical wear, environmental effects and thermal stress on



Hendry/Texas Instruments arc fault circuit breaker.

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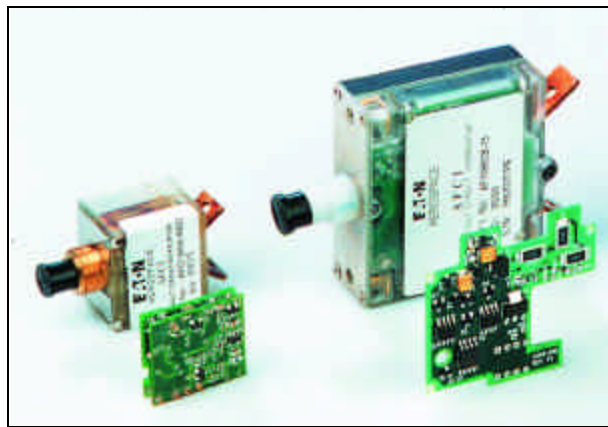
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wiring insulation in all types of aircraft may result in intermittent electrical arcs," explains Rob Pappas, manager of the FAA's Aging Electrical Systems Research program. "Although intermittent, the nature of electrical arcing produces very hot localized temperatures. The arcing, however, might not expend enough energy for the circuit breakers or fuses to heat up sufficiently so that they trip or remove power from the circuit quickly enough to avoid serious damage to the electrical wiring. In addition, left unmitigated, the arcing can ignite flammable materials in the vicinity of the arc."

To avoid the potential catastrophe that arcing could create, the FAA, in cooperation with the Naval Air Systems Command and industry, has developed a new form of circuit protection technology that is capable of sensing an electrical arc along a wire and opening the circuit, greatly reducing the threat of an electrical arc fire.

Pappas explains, "The arc fault circuit breaker uses sophisticated algorithms and integrates this protection together with thermal

circuit breaker technology. This combination preserves the current level of thermal overload protection and adds arc fault detection that detects arcing in the wiring and then rapidly de-



Eaton arc fault circuit breaker.

energizes the circuit. This combination of thermal and arc fault protection will protect the wiring from overloads and arc faults and will reduce the probability of fire and/or smoke." Because more aircraft wiring is packed in tight bundles and hidden from plain view, remote detection is considered a particularly important safety feature.

Arc-fault circuit interrupter technology will mitigate the consequence of wire failure without requiring the redesign of aircraft circuitry. This calls for a device sensitive to arc faulting that still meets all performance and design specification of existing circuit breakers.

With FAA and Navy funding, two such prototype alternating current arc fault circuit breakers have been developed and successfully flight-tested on the FAA's B-727 and a Navy C-9.

The FAA and the Navy, in cooperation with the aviation and electronic industries are working together to develop a common performance specification for the arc fault circuit breaker, and some forms of this circuit breaker are now available for procurement for use in both civilian and military aircraft to lessen the risks posed by aging wiring.

The FAA and Navy researchers are also now developing a miniaturized version that will better integrate into an aircraft's wiring system, as well as a 28VDC and 115V/3-phase arc fault breakers. The FAA plans to have the 28VDC and 115V/3-phase ready for flight testing in FY-2004.

For additional information on the arc fault circuit breaker or on the FAA's aging electrical systems research program, please visit the Internet at <http://aar400.tc.faa.gov/Programs/agingaircraft/agingsystems/electricalsystems/index.htm> ■

# Inspection Systems Research

## *New Technologies Meeting the Challenge*

**"The FAA's Inspection System Research effort is making good strides in developing and validating new and improved inspection technologies and maintenance practices that can be used to ensure the continued airworthiness of the U.S. civil fleet."**

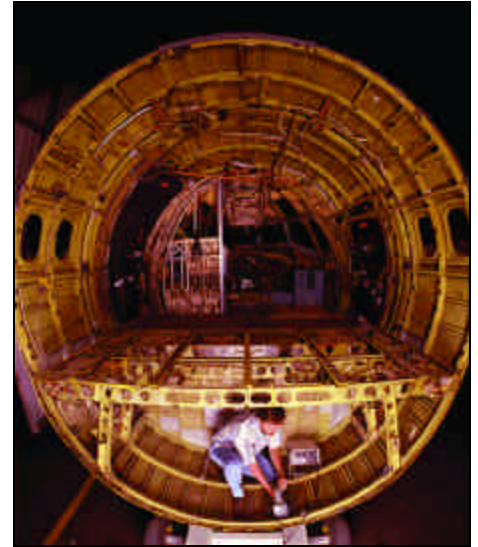
The aviation industry faces significant age-related challenges to ensure the continued airworthiness of the U.S. fleet. Aircraft flown beyond their intended economic design lives have shown a susceptibility to widespread fatigue damage and corrosion that could pose a threat to their structural integrity.

More specific inspection needs for aging aircraft include the detection of fatigue cracks under fasteners, small cracks associated with widespread fatigue damage, cracks and corrosion hidden within multi-layer structures, and disbonding and delamina-

tions of composite structures. Instances of structural failures point to the need for increased reliability of inspection methods.

To find solutions to maintenance and inspection concerns, the FAA has been conducting inspection and repair research activities as part of its overall National Aging Aircraft Research Program (NAARP).

"The FAA's Inspection System Research effort is making good strides in developing and validating new and improved inspection technologies and maintenance practices that can be used to ensure the continued airworthiness of the U.S. civil fleet," says Dave Galella, manager for the FAA's Inspections Systems Research activities. "A key part of any effort in this area is having our FAA sponsored researchers work closely with the industry from the very start of every project."



To facilitate this partnership, the FAA has established research centers to concentrate the collective knowledge and expertise of industry, academia, and government. One of these centers, the Center for Aviation Systems Reliability (CASR) is charged with conducting basic research in the development of inspection techniques. Another, the Aging Aircraft Non-destructive Inspection Validation Center (AANC), operated for the FAA by Sandia National Laboratories, is focused on performing validation and technology transfer of successful research endeavors to the aviation community.

The cooperative work of these partners has paid off through the implementation of several new technologies into the field.

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### **New Inspection Development for Aviation Industry: Pulsed Eddy Current Technique**

A variety of nondestructive inspection (NDI) methods are currently used to detect flaws in aircraft. The particular method chosen depends largely on the inspected component's geometry, material, expected defect location, defect type and size, and inspection cost. An often-used method to detect cracks and cor-



rosion in aluminum structures is the eddy current inspection (ECI).

This inspection, used routinely, has proven to be a cost effective means for detecting surface and near-surface flaws in aluminum aircraft structures. However, as the fleet ages and new inspection requirements are discovered, the detection of defects within multiple layers and at greater depths is becoming more important. Detection and quantification of hidden corrosion has also risen in priority for the commercial and military sectors.

Given the need for improved crack and corrosion detection, the FAA funded the development of a method that addresses limitations of conventional eddy current inspections. Investigators at Iowa State University developed a pulsed eddy current system as part of the FAA Center for Aviation Systems Reliability. In contrast to the conventional continuous wave eddy current method, pulsed eddy current induces a broad range of frequencies into the component under test. This has the advantage of inspecting multiple depths in a single pass, a more cost effective and thorough approach. Researchers have worked with several industry

partners in the development of this technology, including testing specific applications. This has included measurements of bond-line thickness variations in specimens supplied by Cessna and participation in a "blind" round robin corrosion experiment.

Researchers revealed the advantages of the pulsed eddy current approach in a recent demonstration of the system to industry at the Air Transport Association Nondestructive Testing Forum, held in Houston, TX, October 1 - 3, 2002.

### **New Tool to Improve Safety: Replacement for the Coin Tap Method**

The coin tap test method has a long history of being a simple, low cost, and reasonably effective means for inspecting adhesively bonded metal structures and composite parts of aircraft. Tap tests are usually used for the detection of voids, disbonds, and delaminations in structures based on their acoustic response to a tap. Qualitatively, a tap on a structurally sound region produces a characteristic resonant sound whereas a tap on a defective or damaged region will produce a dull or dead sound.

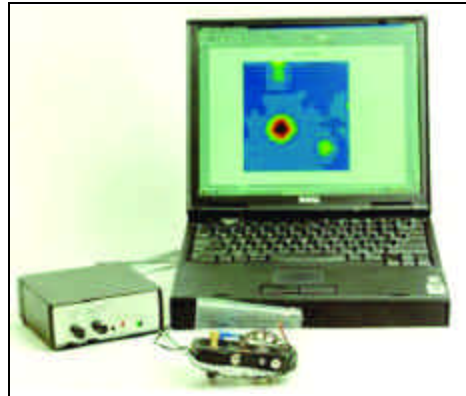
In aircraft inspection, a tap test is usually applied when the composite part shows visual indications of damage or there is rea-

son to suspect subsurface damages. A strictly manual tap test relies on the human ear to discriminate between the sound of a good region and a defective region. This is subjective, operator dependent, and susceptible to false calls, especially in a noisy environment. It is also often difficult to ascertain the size, shape and severity of flaws or damages.

Funded as part of the FAA's Airworthiness Assurance Center of Excellence (AAEC) program, Iowa State University has developed a Computer Aided Tap Tester (CATT) for the inspection of damage, flaws, and repairs in sandwich structures on aircraft, including both composite and aluminum honeycomb sandwiches. The CATT system provides C-scan images depicting local part stiffness that can be used to reveal the size, shape, and severity of the defective or damaged area. The system has the advantages of being operator independent, portable and easy to use.

The system actually measures the time of contact between an accelerometer and the surface of the test component. A novel magnetic cart is used for maneuvering the accelerometer by hand across a surface. As the cart is pushed, a wheel containing permanent magnets forces the accelerometer to contact the surface at a predetermined lin-

ear distance, for example, every centimeter. The impact duration and position for each tap is recorded by a portable laptop computer and Microsoft Excel software is used to produce a C-scan image of the inspected area.



Based on a simple spring model, to which a wide variety of sandwich components on aircraft were found to conform, the time of contact image is then converted into an image of the local stiffness. The image of local stiffness reveals not only the presence of defects or damages, but also the normal substructures and reinforcements.

The CATT system was evaluated quantitatively for its sensitivity and range of applications using composite standards from the Commercial Aircraft Composite Repair Committee (CACRC). Using

these standards, the stiffness measured by the tap test is compared to that obtained directly from a mechanical loading test; the relationships were found to be quite accurate.

The system has also been tested in more than 15 field trials at airline maintenance facilities, military depots and Original Equipment Manufacturers on a variety of composite and aluminum sandwich structures. Field test results using the CATT have been obtained for a wide array of applications including repairs on composite rotor blades, engine fan cowlings, trailing edge flaps, aluminum heater blankets, petal door, pylon fairing and impact damages in foam-cored composites.

For additional information on the FAA's inspection research program, please go to <http://aar400.tc.faa.gov/Programs/agingaircraft/ndi/index.htm>. ■



## RAPIDly Changing Structural Repair Design

The effect of structural repairs on aircraft integrity is a critical issue effecting continuing airworthiness and operational safety. When durability and fail-safety are essential, aircraft engineers use sophisticated damage tolerance methodologies (DTA). While DTA is the prevailing approach for aircraft design engineers, maintenance engineers responsible for quickly returning damaged aircraft to service, have often relied on less sophisticated methodologies. To enable and facilitate the use of DTA in aircraft repair, the FAA, working with the U.S. Air Force, has designed the Repair Assessment and Integrated Design (RAPID) computer tool, providing users with an automated tool to perform damage tolerance analysis.

RAPID is a simple, fast, and user friendly PC software tool that augments guidance in aircraft manufacturer's structural repair manual by performing automatic static strength and damage tolerance analysis. RAPID consists of two major components: a graphical user interface (GUI) that provides schematic representation of repair options, material choices with automatic selection of properties, and structured data entry; and computational tools that automatically perform static strength and damage tolerance analysis.

As part of its aging aircraft research program, the FAA is working with the aircraft industry to develop practical techniques to provide a continuing structural integrity assessment of aircraft in the domestic commuter fleet. Factors such as fatigue and corrosion are time and usage dependent and, if left uncorrected, will degrade the integrity of the airframe to unsafe levels.

To assist the small airplane industry in complying with the Aging Airplane Safety Final Rule, requiring the use of damage tolerance-based inspection programs on airplanes with multi-engine and 10 or more passengers used in scheduled operations (operation within the state of Alaska is exempt), FAA researchers enhanced RAPID for use on commuter aircraft. RAPID for Commuters, RAPIDC, was developed to provide technical assistance to the small airplane operators and repair shops performing damage tolerance analysis of fuselage skin repairs of small airplanes.

RAPIDC is an automated static strength and damage tolerance analysis tool for skin repairs and antenna installations. It includes an advisory system that provides repair guidelines and cautions about possibly inappropriate design features. An extensive material and fracture parameter database eliminates the need for handbook reference and reduces the possibility of erroneous data entry. This software can be downloaded from the Internet at: <http://aar400.tc.faa.gov/RAPID/>.

In FY 2002, the FAA released the latest version of RAPIDC (Version 1.2). This version includes a built-in finite element module, an automatic finite element mesh generator, a load spectrum generator, and static and damage tolerance analysis modules for fuselage skin repairs and antenna installations. The built-in finite element module is used to determine fastener load transfer of mechanically fastened multiple layers. The automatic mesh generator greatly facilitates finite element model preparation.

The types of fuselage skin repairs that can be assessed by the RAPIDC program are rectangular, square and circular doublers, as well as complicated configurations for lap joint and butt joint repairs. The built-in doubler configurations for antenna installations include circular, square, elliptical, and teardrop shapes. Sausage shapes can also be analyzed using RAPIDC.

For additional information on RAPID, please visit:  
<http://aar400.tc.faa.gov/Programs/agingaircraft/RAPID/index.htm>. ■

# Collecting Critical Data

## Operational Loads Monitoring Program

"Many of today's airplanes are being flown beyond their original intended service lifetimes," explains Tom DeFiore, FAA's Program Manager for Flight/Ground Loads. "The only feedback the FAA and the airframe manufacturers receive from operators is the number of flight hours and landings, which for commercial transports define the pressurization cycles and, thus, the major loads on the pressure hull. The loading history on the rest of the aircraft, i.e., wing, tail, flaps, controls, etc., which is dependent on flight operations, is assumed, but is largely unconfirmed."

As a part of its Aging Aircraft Research, the FAA has recently reestablished its Operational Loads Monitoring Program. This program is an important element of the Agency's aggressive aircraft safety research, which provides the technical basis for airframe certification requirements as well as the ongoing development of new technologies to help ensure the safe operation of transports, commercial, and general aviation aircraft.

"Researchers in the Operational Loads Monitoring Program are conducting critical research necessary to characterize the typical service loads environment expe-

rienced by aging aircraft and are developing new technologies to enhance the analysis and presentation of this information," according to DeFiore. "This proactive research helps the FAA and industry identify potential operational problems, and is instrumental in helping the agency meet its safety goals."

The FAA's program focuses on the collection and analysis of data, which will provide the technical basis for load criteria found in the Code of Federal Regulations, Aeronautics and Space, Airworthiness Standards. This research is a fundamental element of the FAA's regulatory and certification process and is necessary to confirm the continued safety and airworthiness of the civil transport fleet.

The most important task being undertaken by researchers is the ongoing collection and analysis of aircraft load usage data from a variety of airplane models, including large transports, commuters, and general aviation aircraft in typical usage environments. The program goal is to collect data equivalent to one *design lifetime* for any particular model.

By collecting and analyzing large amounts of data from aircraft,

aviation safety researchers can:

- determine if the loading spectra being developed for design and test of both small and large transport aircraft are representative of actual usage;
- develop structural design and certification criteria for future generations of commercial aircraft; and
- provide in-service usage data for manufacturers service life assessment and extension programs.

Agency researchers have been using optical quick access recorders (OQAR) to acquire much of the flight data. These recorders are providing the FAA with a new, versatile, and powerful research tool to promote flight safety through flight operational loads monitoring. The recorders operate independent of the aircraft's flight data and cockpit



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voice recorders, sample hundreds of flight parameters, and can store large amounts of data on laser disks for future replay and analysis.

"In 1993, the FAA pioneered the use of optical quick access recorders for flights loads data collection," explains Tom DeFiore. "The agency worked with USAirways to obtain a Supplemental Type Certificate to install a prototype recorder on one of its B-737/400 airplanes. The OQAR collected data on a total of 593 flights.

Those preliminary results seemed to indicate that some existing Federal Air Regulations (FARs), especially those dealing with the aircraft's exposure to gusts, were no longer valid. However, considerable additional data are needed to substantiate this finding. More important was the fact that through subject research, the FAA now had the capability to access the continued suitability of much of the technical data published in the FARs."

As a result of that early effort, the FAA is has been collecting additional recorder data over a number of years to develop a reliable database of operational load parameters, to update/validate the FARs, and to provide reliable fatigue and damage tolerance loads data.

Because landings can pose a particularly high level of stress to any aircraft landing gear and support structure, the FAA is using video recordings to collect information (sink speed, pitch and roll at touchdown, etc.) at a number of highly trafficked airports. To date, the FAA has completed six video landing parameter surveys at John F. Kennedy International Airport, Washington Reagan National Airport, Honolulu International Airport, London City Airport, Philadelphia International Airport and London Heathrow.

For these surveys, agency researchers are using a multiple camera system to acquire video images at airplane touchdown, digitize the video images and use the airplane geometry and digitized images to calculate the parameters, which describe the landing contact conditions.

Wind conditions are acquired using anemometers and landing weight is provided by the airlines. These data are subsequently used by the aviation industry as input to the various analytic models, which determine the effect of the measured landing impact data on airframe structures and landing gear systems of a wide variety of aircraft types.

Researchers are particularly concerned about the flight loads impact on landing gear. To obtain information needed to assist in making key regulatory decisions, agency researchers have established a permanent video landing loads facility at the Atlantic City International Airport.

Over the next several years, researchers will be collecting and characterizing the landing contact data from this facility for a







wide variety of aircraft types and weather conditions. In addition to regularly scheduled commercial traffic at the airport, a substantial number of Air Force tankers, cargo aircraft, and passenger transports use the airport. Airframe manufacturers are also welcome to bring their flight test planes to this facility for landing parameter data collection.

Turbulence creates stress on the overall aircraft structure. While most turbulence can be avoided by simple changes in altitude, sometimes this is not possible because of traffic or weather conditions. As a result, the FAA, NASA, the military, and industry are examining the effects of constant turbulence on aircraft.

To accurately assess the affect of turbulence, FAA researchers are cross-referencing information from the Digital Flight Data Recorder, or the black box, with measurable structural changes. Researchers are also collating available turbulence data from NASA, the military, and industry to determine the sufficiency of such data. The FAA will initiate a

new effort to collect specific turbulence data if necessary.

In another critical project, Agency researchers are reanalyzing existing B-737, B-767 and B-747 data to get coincident longitudinal and incremental vertical load factors for ground maneuvering. Ground turn (lateral load factor) data for B-737, B-767, and B-747 models will be compared to determine if the exceedance of lateral load factors during ground maneuvers decreases with increasing airplane weight or size.

Researchers plan to conduct a series of ground maneuvers that generate lateral force on a four-main-gear test aircraft. Using a data acquisition system connected to strain gages on the landing gear and multi-axis accelerators near the aircraft center of gravity, the researchers will collect high

sample rate data. The ground maneuvers will include S turns and runway turn-offs at various speeds and on various runway surfaces, slopes, and crowns.

The data from this and other tests will be used to characterize the rudder usage and lateral acceleration experience observed during the initial climb phase of flight, and to determine airplane descent rates and total air temperature profiles during descent as criteria to develop systems designs to reduce flammability of fuel tanks.

Additional information on the Operational Loads Monitoring Program as well as research results can be found on-line at <http://aar400.tc.faa.gov/Programs/agingaircraft/airbornedata/index.htm>. For additional information, please contact Tom DeFiore at [thomas.defiore@faa.gov](mailto:thomas.defiore@faa.gov). ■

## JUST A MINUTE



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# Partnering for Success

## Center of Excellence for Airworthiness Assurance

The FAA established the Airworthiness Assurance Center of Excellence (AACE) in September 1997. The FAA created this multi-institutional, multi-disciplinary team to address research, development, education, and technology transfer in the area of airworthiness assurance and aircraft safety. This Center currently has 28 university members across the country, working with over 50 industry partners.

The Center provides research in support of new aviation systems and continued airworthiness of existing aircraft. Research activities include:

- Advanced Materials
- Crashworthiness
- Damage Tolerance for Propellers
- Inspection, Maintenance and Repair
- Propulsion and Fuels
- Software and Digital System Safety
- Structural Integrity and Flight Loads
- Validation and Technology Transfer

Major research efforts of the Center have been focused on aging aircraft related issues.

Since its inception, the Center, matching the FAA's investment dollar for dollar in grants and with substantial industry contributions in contracts, has yielded significant accomplishments in aging aircraft research.

### INSPECTION RESEARCH

Inspection plays a critical role in the lifecycle of aviation components and systems. Given the critical role of inspection technology to safety, inspection research plays a prominent role in the AACE research portfolio. Key elements of the inspection research program are undertaken in conjunction with the Center for Aviation Systems Reliability (CASR) and the Airworthiness Assurance Nondestructive Inspection (NDI) Validation Center (AANC), and the Engine Titanium Consortium (ETC).

#### Infrared (IR) Detection of Ultrasonically Excited Cracks

Preliminary research by Wayne State University has resulted in promising developments in the use of infrared technology to detect fatigue cracks. The advantage of this method is its ability to view relatively large inspection areas and image



even small cracks with very high signal-to-noise ratios. Ultimately, this effort seeks to develop a component inspection technique.

#### Use Of Composite Doublers To Repair Aircraft Structures

FAA research has confirmed that composite doublers installed under proper conditions can provide safe, damage tolerant, and potentially low cost aircraft repair. The results from this ongoing research are providing data on the damage tolerance capabilities of composite doublers, specific design certification, and validation of inspection techniques. Recently Center of Excellence researchers, partnered with The Boeing Company and Federal Express, successfully completed a Pilot Repair Program for DC-10 aircraft, which will be incorporated into the DC-10 Structural Repair

Manual. This research will also produce an FAA Advisory Circular to direct the use of this technology.

### Commuter NDI Program

Northwestern University and Fairchild are currently working with the FAA's Airworthiness Assurance NDI Validation Center to develop an inspection technique to identify cracks in the lower wing spar of the SA226 & SA227 Fairchild aircraft. Researcher investigated two different techniques, an ultrasonic method developed at Northwestern University and an eddy current method used by the Airworthiness Assurance NDI Validation Center. The proper merging of these two NDI techniques makes the inspections easier to perform, less costly, and more reliable than the existing methods specified in the Supplemental Inspection Document. This work also resulted in the development of inspection procedures and calibration standards.

## AIRFRAME STRUCTURAL INTEGRITY

### Transport Category Airplanes

Mississippi State University is currently examining the behavior of riveted joints of aircraft structures. Under this study, researchers are working to measure and establish the magnitude and distribution of the residual stresses in the produc-

tion-quality holes. Previous studies have indicated that testing results of laboratory-prepared test specimen were different than fatigue lives from actual production-quality holes.

Researchers plan to conduct fatigue tests on specimens made of 2024-T3 aluminum with both production-quality and polished holes. Fatigue-life analysis on production-quality and polished holes will be made using small-crack theory and the residual-stress distribution measured or assumed from trial-and-error procedures. This research will result in an assessment on the influence of machining residual stresses and rivet installation on the fatigue behavior of aircraft structural joints and its impact on the prediction of widespread fatigue damage.

Purdue University is working with the FAA to study the fatigue crack growth from countersunk fastener holes. Although the countersink is a common source of cracking in aircraft joints, its complex three-dimensional geometry has limited advancement of stress intensity factor solutions needed for fracture mechanics evaluation of crack growth. For this task, researchers are conducting fatigue tests on transparent polymer specimens, which will



enable the situ measurement of shape and size of fatigue crack developed. Experimental data will be used to evaluate theoretical predictions based on available solutions for this common crack configuration. Results of this study will enable existing solutions to be modified and extended as needed.

### Small Airplanes

Wichita State University has partnered with Cessna Aircraft Company and the CapeAir/Nantucket Airlines to provide insight into the condition of a typical aged airplane and determine if there exists a correlation between its maintenance history and current condition from a safety of flight perspective. Researchers hope to document these findings in a summary report for use in future investigation of fleet wide issues and determine if additional research is required to address specific problems observed. As for the long-term goals, the anticipated

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## NEW RESEARCH LAB FOR AACE PARTNER



On October 15, FAA Administrator Marion Blakey and Congressman Todd Tiahrt helped Wichita State University officials announce the opening of a new \$1.1 million Aging Aircraft Research Laboratory at Wichita State's National Institute for Aviation Research.

Research conducted in the 3,000 square foot lab will focus on the integrity of aging small airplanes in commuter service.

Two commuter-class airplanes have been identified for the initial investigation. The first aircraft is a 1969 402A airplane manufactured by Cessna Aircraft Company. The second aircraft will be a Cessna 402C, one of a fleet of 49 airplanes in cur-

rent service by CapeAir of Hyannis, MA. Both aircraft have more than 20,000 flight hours logged and are currently certified and registered. These particular airplanes were chosen because of the design commonality with other small twin class commuter airplanes. Generic findings from the research on these planes will apply to all general aviation models regardless of manufacturer.

The aircraft will be disassembled to research and evaluate the degradation of wiring and the structural, electrical, hydraulic and mechanical systems. Researchers will also evaluate existing maintenance procedures and standard inspection practices for general aviation aircraft to determine if these methods adequately address the concerns for aging aircraft.

Funding for this research program came from the FAA, Kansas Technology Enterprise Corporation (KTEC) and the University. Cost-sharing partners, CapeAir, which will partially donate one of the aircraft, and Cessna Aircraft Co. of Wichita will provide associated labor and technical support throughout the program. Please visit <http://www.coe.faa.gov/aace/index.htm>



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research output will provide critical information to develop guidance material for aging small airplanes.

## Rotorcraft

Researchers from the University of California - Los Angeles are studying the fracture and fatigue behavior of typical rotorcraft structural materials. Through this work, researchers will generate the elastic-plastic stress-strain relation to failure of 1.8 mm thick 7075-T7351 aluminum, as well as the elastic-plastic stress-strain relation to failure of 8.1 mm thick 2024-T351 aluminum. In addition, crack growth data for various rotorcraft structural materials are being generated. This work directly supports the on-going efforts by the FAA to adopt damage tolerance method to rotorcraft applications to further ensure the safety of rotorcraft operations.

## SOFTWARE AND DIGITAL SYSTEM SAFETY

### Assessment of Software Development Tools for Safety Critical Real-Time Systems

Embry-Riddle Aeronautical University is investigating a number of software tool suites to determine if the benefits promised are actualized. The objective of this research is to identify the assessment criteria for the evaluation, and ultimately qualification, of real-time software development tools from the system/ software safety perspective. Work includes: review of the existing tools used for real-time

safety critical software development; identification of tool functionalities and categories; definition of tool assessment criteria; and the selection of candidate tools for experiments.

### Safety and Certification Approaches for Ethernet-based Aviation Databases

Arizona State University, partnered with the Honeywell Corporation, is leading research which is examining the certification and safety issues of Ethernet as an aviation database. Researchers will propose the methods and techniques to address any issues identified.

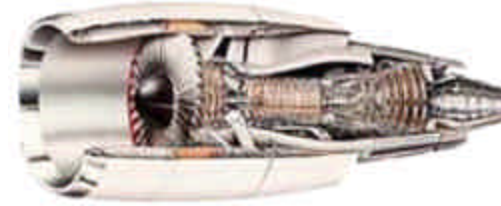
### Flight Critical Data Integrity Assurance for Ground-based COTS

Arizona State University and United Technologies Research Corporation. Investigations are studying how data, critical to the safe operation of an aircraft, can be effectively protected from abnormal operation of ground-based commercial-off-the-shelf (COTS) components in both hardware and software. This research also supports the FAA Rotorcraft Directorate, which evaluates such technology as part of the Health Usage Monitoring Systems (HUMS) for rotorcraft.

### Real-Time Scheduling Analysis

The New Jersey Institute of Technology is investigating the practical use of Deadline Monotonic Scheduling algorithm for periodic, real-time tasks. The

research will look at the deadline monotonic analysis techniques used in real-time operating systems (RTOSs) to identify analy-



sis technique concerns and to develop acceptance criteria and/or guidelines for this technology.

## AIRCRAFT CATASTROPHIC FAILURE PREVENTION PROGRAM

### Explicit Finite Element Analysis Modeling of Multi-Layer Composite Fabric For Gas Turbine Engines Containment Systems

Arizona State University has partnered with Honeywell Engineers and SRI International to apply computer program, DYNA-3D fabric modeling techniques to analyze airframe protection barriers in the event of uncontained engine failures. Researchers hope to develop a generic engine containment ring model that Honeywell Engines can use to increase reliability and safety.

For additional information on the work of this FAA Center of Excellence, please contact: Dr. Catherine A. Bigelow, Deputy Program Director [cathy.bigelow@faa.gov](mailto:cathy.bigelow@faa.gov). ■

# Bridging the Gap

## Centers of Excellence Joint Annual Meeting

The FAA Centers of Excellence (COE) industry affiliates, The Boeing Company, Cessna, Bombardier-Learjet and Raytheon, and university partner, Wichita State University, joined the FAA Office of Airport and Aircraft Safety R&D, and the Central Region in co-hosting the COE 2nd Annual Joint Meeting in Wichita, KS, October 21- 24.

The event drew over 235 participants from across the nation. Guest speakers included CEOs and industry affiliates, FAA senior managers Norm Fujisaki and Chris Seher, and members of the COE for Airport Technology (formerly Airport Pavement), the COE for Airworthiness Assurance (AAACE), the COE for General Aviation (CGAR), and the COE for Operations Research (NEXTOR).

Manufacturing plant tours were conducted for more than 200 participants. Panel discussions among VPs, CEOs, industry co-hosts, and academic partners provided in-depth technical reviews during the breakout sessions.

Again this year, COE students presented their work at a poster session, and had the opportunity to meet with industry executives to discuss their research and career goals. Senior executives

representing industry served as poster session evaluators and presented model airplanes to the top four students.

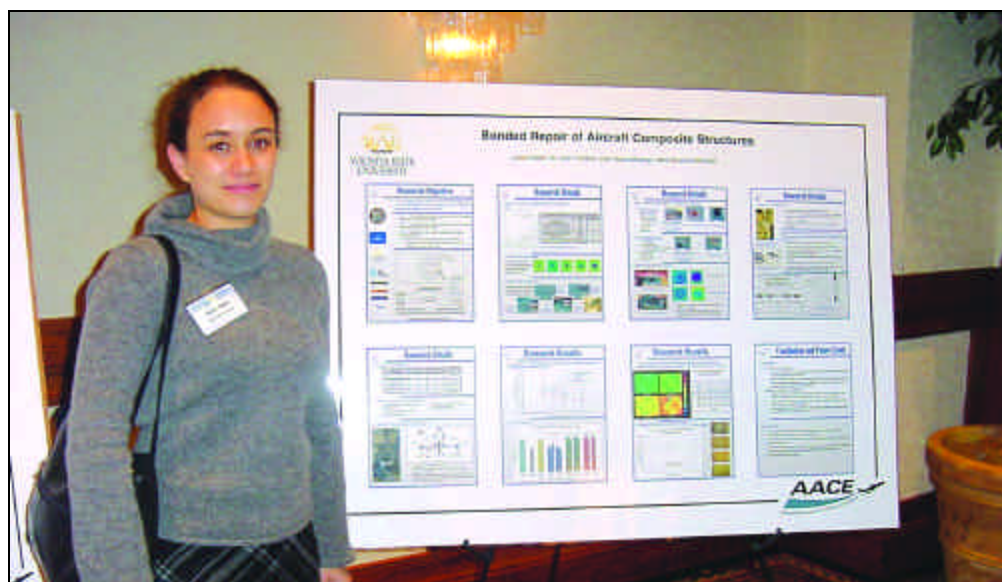
### *The FAA's Air Transportation Centers of Excellence Program bridges the gap between government, academic, and industry researchers.*

COE industry affiliates and academic partner, Wichita State University funded the event along with the Airport and Aircraft Safety R&D Division, AAR-400. COE Program Managers, Technical Monitors, Principal Investigators, project

sponsors, industry representatives and others interested in COE activities attended the 3-day event. Proceedings are being posted on the FAA Air Transportation Centers of Excellence website.

Embry-Riddle Aeronautical University and their industry affiliates are planning to co-host the COE 3rd Joint Meeting this November. Information and registration details will be available on the COE website.

For further information about the COE Program, contact Patricia Watts, FAA COE Program Director, at [patricia.watts@faa.gov](mailto:patricia.watts@faa.gov), telephone: 609-485-5043, or visit the COE website at [www.coe.faa.gov](http://www.coe.faa.gov). ■



Lamia Salah, Wichita State University student, and her poster on "Bonded Repair of Composite Airframe Structures."

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with the capability to conduct rigorous independent validation of emerging inspection and maintenance technologies and methodologies. Both organizations are part of the larger Airworthiness Assurance Center of Excellence (AACE).

Just as maintenance and inspection methodologies must be based on accurate structural analysis, structural analysis must, in turn, be based on accurate assessment of aircraft loads. FAA researchers have established projects to monitor both flight and ground loads on aircraft. Landing loads data is collected and processed at the Technical Center, while sensitive flight loads data is forwarded from individual airlines to the University of Dayton Research Institute for analysis and reporting.

More recently Technical Center researchers have begun collecting data in support of aircraft systems evaluation and certification.

FAA Aging Aircraft Research project managers are also developing improvements to billet and forging inspections of material destined to become critical turbine engine parts. These inspections, together with improved in-service inspections, will substantially reduce the possibility of uncontained engine failure associated with the disintegration of critical rotating parts.

The FAA-sponsored Engine Titanium Consortium is developing sophisticated ultrasonic inspection systems for pre-service volumetric inspection and enhancing state-of-the-art eddy-current systems for in-service surface inspection. The Engine Titanium Consortium is comprised of the Iowa State

University, General Electric, Pratt & Whitney, and AlliedSignal Engines.

The Agency's rotorcraft structural integrity research is focused on two activities. Researchers are providing critical input to an Advisory Circular on health and usage monitoring system certification criteria for rotorcraft. They are also using damage tolerance methods to establish inspection intervals for existing and new rotorcraft designs.

These are just some examples of the research efforts being conducted under the FAA's National Aging Aircraft Research Program. In part because of this research, the United States air transportation system continues to be one of the safest and most advanced in the world. For more information visit <http://aar400.tc.faa.gov/Programs/agingaircraft/index.htm> ■



# Full Scale Fuselage Panel Testing

## FAA's Full-Scale Aircraft Structural Test Evaluation and Research Facility

Widespread fatigue damage (WFD) and multiple site damage (MSD) have been identified as some of the most potent threats to airworthiness found in aging aircraft. Research over the past 10 years has identified many of the processes leading to this damage and has modeled the failure process by which arrays of MSD cracks link up with leading cracks to cause overall failure.

Widespread fatigue damage in a structure is characterized by the simultaneous presence of cracks at multiple structural components where the cracks are of sufficient size and density that the structure will no longer meet its damage tolerance requirement.

To ensure that the residual strength of an aging aircraft is not degraded below limit levels because of WFD, predictive methodologies to identify the onset of WFD during the operational life of an airplane have been developed. The methodologies are currently being verified by test data from coupon tests, sub-scale component tests, full-scale tests, and service experience.

As part of these research efforts, the FAA opened the Full-Scale Aircraft Structural Test Evaluation and Research (FASTER) facility. Completed in 1998, the facility is capable of testing full-scale curved panel specimens under conditions rep-

resentative of those seen by an aircraft in actual operation. Researchers are using FASTER to test full-scale curved, stiffened panels under pressure, biaxial, and shear loading conditions. The data obtained from the tests are being used to validate the FAA's analytical models.

Developed under contract with The Boeing Company, the test system features a unique adaptation of mechanical, fluid, and electronic components capable of applying pressurization, longitudinal, hoop, and shear loads to a curved-panel test specimen. A graphical interface allows the operator to control the loads, speed, and type of test desired.

Data acquisition from strain, load and, pressure transducers, among others, is displayed on color monitors in real time as well as stored for off-line analysis. A remote video system is integrated with the test rig to track and record crack propagation and measure crack opening during the testing of the curved panels.

Researchers can monitor all testing at the state-of-the-art facility by using sophisticated video equipment. The video

The FAA recently initiated a 3-year project with Delta Airlines that involves the destructive evaluation and extended fatigue test of a retired passenger aircraft near its design service goal. Sections removed will be representative of aircraft structure susceptible to widespread fatigue damage.

The state of MSD will be advanced through extended fatigue testing using the FASTER facility and then assessed through nondestructive inspection and destructive evaluation. The extended fatigue testing will provide data to calibrate and validate prediction methodologies and will aid in evaluating the sensitivity and effectiveness of standard and emerging inspection technologies to detect small cracks.

The data generated from this effort will be used to calibrate and validate WFD assessment methods. This data will be compared with data obtained from the analysis of a real structure with natural fatigue crack initiation and accumulation of other environmental and accidental damage-induced small flaws that are representative of commercial transport use over an extended period of time (20-30 years).

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# Engine Titanium Consortium Nears Completion of Phase II Research

In 1991, the Titanium Rotating Components Review Team, formed in response to a serious accident caused by the disintegration of a fast-rotating engine fan disk, recommended the development of an improved inspection processes for manufacturing quality control and in-service inspection. In response, the FAA chartered the Engine Titanium Consortium (ETC) to develop reliable and cost-effective methods for detecting cracks, inclusions, and imperfections in titanium alloys used in engine applications. The ETC is led by Iowa State University, partnered with General Electric Aircraft Engines, Pratt and Whitney, and Honeywell.

Since its inception in late 1992, the ETC has remained focused on three major task areas: Production Inspection; In-service Inspection; and Inspection Systems Capability Assessment and Validation. Through 1998, most of the efforts in these three program areas were focused on titanium billet inspection and in-service titanium disk inspection. The success of those efforts led the FAA to re-charter the ETC with a new focus on titanium forgings and nickel billet and nickel forgings. These Phase II efforts should be completed in mid 2003.

## Production Inspection

One goal of inspection is to detect anomalous conditions as early in the production process as possible, thereby removing defective material before subsequent processing steps result in reduced inspectability and higher costs.

With this in mind, the ETC has focused on ultrasonic inspection of billets. Typical billets in use by the industry range from 6 to 14 inches in diameter and 12 to 20 feet in length. The conventional practice is to inspect billets in an immersion tank using a single transducer to inspect along the diameter of the billet. Because the transducer does not focus at any specific depth, its sensitivity at all depths suffers.

By inspecting at successive depths or zones with focused transducers, the multizone system developed by the ETC has a four-fold improvement in anomaly detection capability. To date three billet production locations have inspected over 10 million pounds of titanium billet using this advanced technique. The new inspection technique decreases the possibility of engine failure due to undetected flaws and increases the reliability and efficiency of inspection procedures for engine critical



components. An industry-wide ultrasonic billet inspection specification, based on the new technique, has been developed and has been approved by the Society of Automotive Engineers (SAE) Committee K and the SAE Aerospace Council. An even more sophisticated inspection technique, using an array of synchronized ultrasonic transducers, is being evaluated for inspection of very large diameter billets and complex forgings.

While Phase I focused almost exclusively on small to moderately large titanium billet, Phase II work will result in improvements to the inspection of larger diameter billet and disk forgings. Phase II is also adapting the inspection technologies developed in phase I for application to nickel alloys used for engine turbine disks and other high temperature application.

## In-Service Inspection

While the objective of nondestructive inspection is to remove

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defective material from the production process as early as possible, once components are placed in-service, service-induced damage must be identified and controlled. The ETC Phase I in-service inspection task was designed to produce a series of generic tools that can be used either alone or together on a wide range of engine models. Items in the tool suite include a portable eddy-current instrument and portable bench scanner, a data acquisition and analysis system, a low-pressure rotor rotator, eddy-current arrays, a signal and image processing system, and application specific probes. This effort also resulted in the development of eddy-current modeling and simulation software necessary for the further development of these sophisticated inspection tools.

The Phase II follow-on activities include the development of standards for high-speed bolt holes scanning, and an evaluation of the effectiveness of the cleaning and drying process in preparation for fluorescent penetrant inspection.

### **Inspection Systems Capability Assessmen And Validation**

The evaluation of inspection reliability plays an increasingly important role in the life and risk management of commercial aircraft engines. The application of

damage tolerance to enhance lifing methodologies requires an assessment of the nature and size of flaws that might remain undetected prior to service introduction.

A highly reliable and sensitive inspection process can enhance life estimates by guaranteeing the absence of flaws that could become critical during the life of the component. In some cases it may even be possible to maintain a component in service indefinitely based on periodic inspection.

Key to making this damage tolerance philosophy work is a reliability measure called the probability of detection (POD). The POD is used in conjunction with estimates of flaw distribution and crack growth rates to ensure that the probability of a component failing in service is infinitesimally small.

Standard methods of determining the adequacy of inspection systems often involve the generation of POD estimates based on experiments with a limited number of flawed specimens. These methods are not appropriate if the flawed specimens are not fully representative of actual flawed material or if the desired POD is extremely high. In particular, hard alpha flaws in titanium are quite rare but

potentially catastrophic.

Unfortunately these subsurface defects are also very difficult to simulate and practically impossible to fabricate in the numbers necessary to accurately estimate the extremes of the POD curves. To address this problem the ETC is developing a new methodology that combines experimental data, field data, and a sophisticated signal response model to estimate POD. The methodology is the first to explicitly link POD with the fundamental concepts of signal and noise distributions.

Phase II activities includes the adaptation and validation of the methodology for new applications and new materials. This task will introduce new issues associated with complex surface geometry and material anisotropy.

For more information visit <http://aar400.tc.faa.gov/Programs/agingaircraft/etc/index.htm> or contact Paul Swindell at [paul.swindell@faa.gov](mailto:paul.swindell@faa.gov). ■



# Rotorcraft Community Embraces Damage Tolerance Methods

In response to the FAA's goal of reducing the fatal accident rate by a factor of five, the FAA Rotorcraft Directorate has commissioned several research activities supporting pending rules aimed at reducing structural and mechanical problems caused by fatigue of rotorcraft structural and dynamic components.

The success of damage tolerance methodologies for managing fatigue-related degradation of fixed-wing aircraft has provided an excellent starting point, but these methodologies must still be adapted to circumstances unique to rotorcraft. Rotorcraft airframe structures and dynamic components are subject to high cyclic stresses in practically every regime in flight. In addition, the spectrum of rotorcraft usage, which has always been far more diverse than that of most fixed-wing aircraft, is becoming even more unpredictable.

In 1999, the Rotorcraft Industry Working Group (RCWG) completed an in-depth review of the current rotorcraft fatigue and damage tolerance approaches under the direction of the FAA and the Technical Oversight Group for Aging Aircraft (TOGAA). TOGAA reviewed the RCWG's final report, *Rotorcraft Fatigue and Damage Tolerance* and recommended to the FAA

that a damage tolerance philosophy, if practical, should be used in the design and certification of rotorcraft structural components. Safe life should be permitted only where it can be shown that damage tolerance design is not practical. As a result, the FAA has initiated a rulemaking process to revise FAR 29.571, Fatigue Evaluation, to include damage tolerance requirements.

There are two major challenges in making damage tolerance work for rotorcraft. First is the adaptation of fatigue crack growth analysis methodologies to very high cycle fatigue. This requires a greater understanding of crack initiation and small crack growth and well as crack growth at relatively low stress levels. Complicating this problem further is the very complex

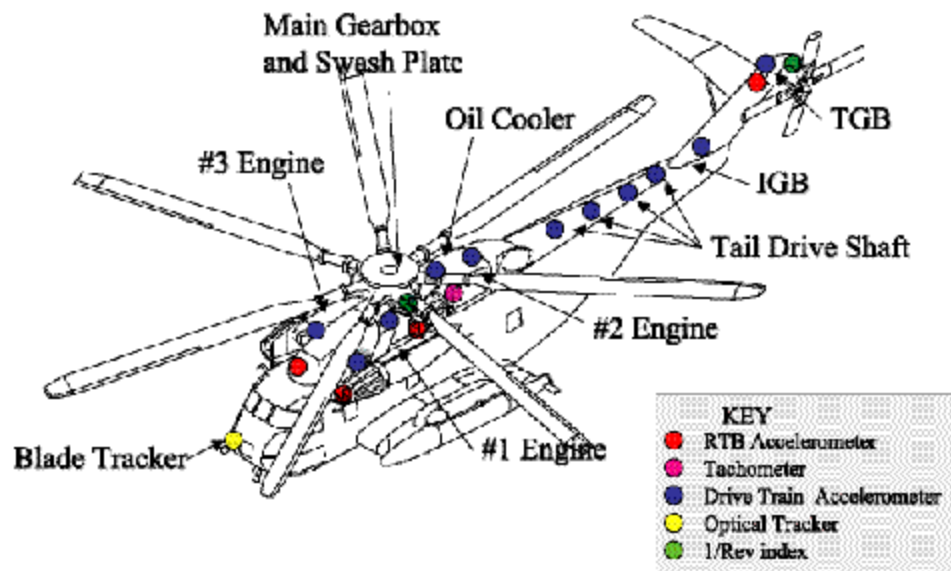
loading and stresses seen by many fatigue-critical rotorcraft components. FAA researchers working in collaboration with the U.S. rotorcraft industry and academia, are conducting much of this very basic fatigue research. FAA-supported software products such AGILE are capable of dealing with small, arbitrarily shaped and warped, intrinsic, fabrication and service-induced cracks.

## Helicopter Dynamic Component Fatigue Crack Growth Modeling and Analysis

The second challenge to the application of damage tolerance to rotorcraft is establishing a means to foresee and forestall

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### HUMS Sensor Inputs



## Full Scale Fuselage Panel Testing *continued*

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system automatically tracks and records the crack growth and has a very high zoom range to be able to cover the entire test panel and to be able to zoom to the narrow field

of view required to observe the crack tip behavior.

For additional information regarding the FASTER Facility please contact John Bakuckas, Jr., at (609) 485-4784. ■



## Rotorcraft Community *continued*

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pending failure. Because fatigue-critical parts can accumulate tens of thousands of cycles per hour of operation, it may not be practical to physically inspect components for cracks at predetermined intervals based on an assumption of assumed worst cases stresses.

Health and Usage Monitoring Systems (HUMS) provide the capability to monitor critical systems and components including engines, rotor and controls, drive

train, and fatigue-life limited structures. HUMS can make application of a damage tolerance maintenance program more effective by directing maintenance actions to areas suspected of have having endured harsh use or other insult. The end result is enhanced safety, reduced maintenance costs, and improved operating efficiency.

FAA researchers are working with their counter parts in the DoD to adapt very sophisticated and expensive military versions of

HUMS to commercial rotorcraft. A few currently available commercial systems can provide very useful data to aircraft operators, but that data is not reliable enough to serves as the basis for an FAA approved maintenance program. Furthermore commercial aviation has an extremely low tolerance for the relatively high false alarm rate of many current systems.

FAA researchers are also working with industry to determine whether commercial off-the-shelf software can be certified as sufficiently reliable and robust to support a HUMS-based damage tolerance maintenance program.

The HUMS research that the FAA has been conducting will enable the revision of an Advisory Circular for Airworthiness Approval of HUMS. This Advisory Circular will contain certification requirements for the installation and operation of HUMS supporting an approved maintenance program. It will also discuss the specification of and proper response to HUMS on-board advisories and warnings. ■

### Damage Tolerance for Propellers Too!

The FAA is initiating a rulemaking process to implement damage tolerance requirements for propellers.

The effectiveness of the damage tolerance analysis depends on several factors that include fatigue crack growth data, initial crack sizes, effects of shot-peening and cold working, and inspection techniques. Damage tolerance assessments and analysis of propeller components require fatigue crack growth properties of propeller primary materials, which are currently unavailable.

A FAA research project will develop a database containing essential material properties that can be used in propeller damage tolerance assessments and analysis.