Federal Aviation Administration

R&D Review

News Source for the FAA Air Traffic Organization's Operations Planning Research & Development Office

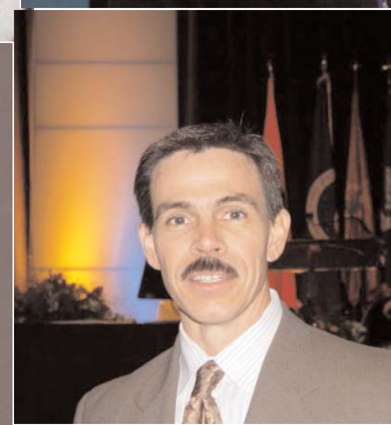
2006 Issue 3

Continuing Airworthiness

in this issue

The Official Welcome

Snapshots from the 2006 Aging Aircraft Conference

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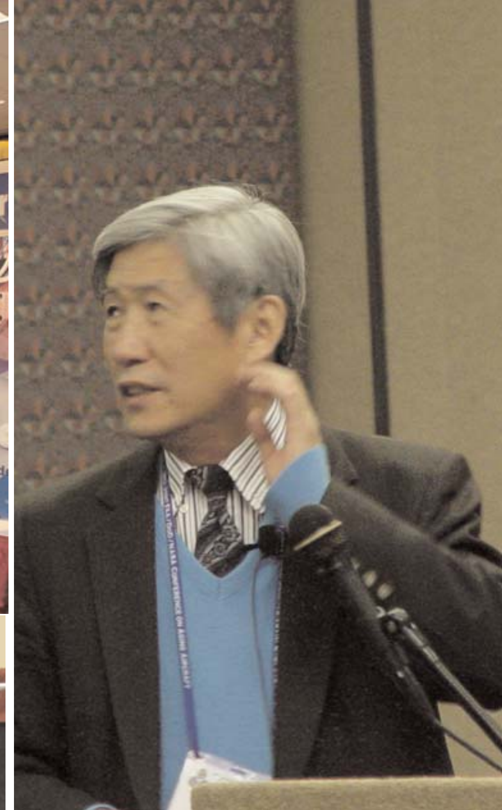


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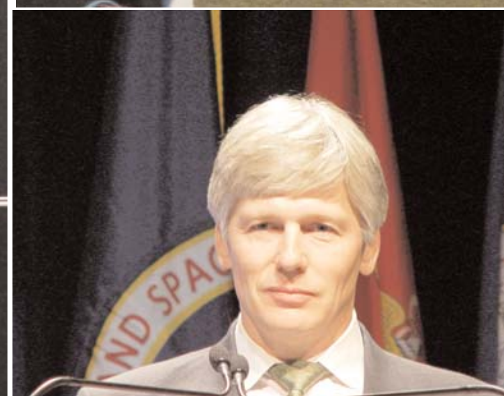

A Captivating Message

A Message from the National Aging Aircraft Continued Airworthiness Research Program Manager

Airplanes are special machines. They have to be. Lives depend on how well and how safely they operate. And, compared with many other machines, aircraft are often expected to operate with uncompromised safety for a remarkably long time. These realities underlie one of the FAA's most important research efforts, the National Aging Aircraft/Continued Airworthiness Research Program.

Aloha Airlines Flight 243 departed routinely from Honolulu on April 23, 1988. Then it suffered an explosive decompression. Although the captain brought the plane down safely at Kahului Airport on Maui, one crew member was killed and many other passengers and crew were injured. This tragedy happened, in part, because the cumulative effects of nearly 90,000 cycles of takeoffs, flight, and landings had invisibly weakened a well engineered machine.

Before the year was out, Congress passed the Aviation Safety Research Act, and the National Aging Aircraft Research Program soon followed. A little more than a year later, the lessons of another tragedy further defined the program. The Number 2 engine of a DC-10 failed in flight and caused the loss of three flight critical hydraulic systems. An undetected material defect was among the many contributing factors and engine research was added to the program. Since then, the scope of the research program has grown to include aging non-structural systems (electrical and mechanical systems). The program also addresses aging aircraft concerns from the rotorcraft and small airplane communities. Though the initial focus of the program was aging aircraft, the research conducted in the program is applicable to the continued airworthiness of all aircraft, as referred to in title of the article.

The National Aging Aircraft/Continued Airworthiness Research Program maintains close working relationships with the FAA Airworthiness Assurance Nondestructive Inspection Validation Center, the Department of Defense Joint Council on Aging Aircraft, the Center for Aviation Systems Reliability, the Engine Titanium Consortium, the National Institute for Aviation Research, the FAA Airworthiness Assurance Center of Excellence, the Center for Aviation Research and Aerospace Technology, and the National Rotorcraft Technology Center. In addition to their FAA components, these institutions combine the resources of all branches of the Department of Defense, NASA, industry, and renowned academic institutions.

The program's stakeholders and research partners encompass the full aviation community. Permanent FAA groups concerned with the nature and direction of aging aircraft research include: the Subcommittee on Aircraft Safety of the Research, Engineering and Development Advisory Committee, the Aviation Rulemaking Advisory Committee, and the Aging Transport Systems Rulemaking Advisory Committee. Every year, researchers, regulators, and manufacturers join others interested in aging aircraft issues at the annual Joint FAA/NASA/DOD Aging Aircraft Conference to exchange ideas, brainstorm solutions, and share knowledge. Preparation for the 2007 Conference is underway. For more information, please see http://www.agingaircraft.utcdayton.com/.

For almost twenty years, the program has performed a vital role in helping the FAA meet its goals in reducing aviation accidents. Representative areas of the program's research and contributions to FAA rulemaking, include prototype aircraft arc-fault circuit breakers, advanced computer models simulating crack growth in aircraft structures, innovative inspection and structural repair technologies and techniques, development of data and methods that support damage tolerance rulemaking, flight loads analyses of civil transport and firefighting aircraft, state-of-the-art technologies for nondestructive inspection of aircraft engine rotating components, technologies that can detect insulation defects in aircraft wiring, innovative rudder control strategies and systems for transport aircraft, and development of risk assessment methods and tools.

We are making significant strides in enhancing aircraft safety. In 2005, for example, our researchers conducted extended fatigue tests on fuselage panels removed from a retired Boeing 727 to study multisite damage; issued handbooks specifying aircraft and aerospace material and fastener properties; developed statistical methods and engineering approaches to predict crack initiation, growth, linkup, and residual strength in aircraft fuselages; developed a prototype, air-coupled, ultrasonic system that works on the composite structures increasingly being used to manufacture aircraft; applied information from digital ▶

flight data recorders to assess the 0.5G limit lateral load criteria for wide-body aircraft; and assessed the ability of nondestructive inspection techniques to detect small cracks in rotorcraft structures.

To enhance the commercial fleet, we have supported FAA rulemaking efforts resulting in approximately 540 airworthiness directives on aircraft structures and 110 on wiring. In fact, the program has been so successful that it no longer needs to function as it was originally formulated. The R&D program is focusing its future plans and applying its expertise to emerging technologies and ensuring continued airworthiness and operational safety. With a three-fold increase in air traffic expected by 2025, we must focus on ensuring this nation's already extraordinary safety record.

This issue of R&D Review highlights some of our ongoing work. In a dynamic aviation environment, the need to keep aircraft safe remains a constant. New materials, manufacturing methods, inspection technologies, and repair techniques are continually introduced into the aviation system. With this diversity, it becomes increasingly important, and challenging, to understand how the aircraft built yesterday, today, and tomorrow will age. The program will continue to support national safety goals by developing the data and tools needed to identify and eliminate or control emerging aircraft potential hazards. The National Aging Aircraft/Continued Airworthiness Research Program has successfully faced high expectations in the past, and it will continue to do so in the future.

Rob Pappas
Manager, National Aging Aircraft/Continued Airworthiness Research Program R&D Review

Wires, Wires, Wires

Electrical Wiring Inspection Systems

Prior to the introduction of electrical systems research into the FAA National Aging Aircraft Research Program (NAARP), aging aircraft research focused primarily on structural and engine issues. The results of the investigations of the TWA-800 and SwissAir-111 accidents initiated and accelerated a highly focused response by the FAA and aviation community, which launched tremendous efforts to study electrical systems' problems and develop a comprehensive and effective response, including the addition of electrical systems research to the NAARP. It became clear that the practice of keeping airplanes in service well past their design service lives required an expanded effort to understand the effects of aging on critical airplane systems and functions.

The Aging Aircraft Electrical Systems Research project is tasked with the research and development of technologies, methods, and data to ensure the continued safe operation of aircraft electrical systems. FAA's electrical systems research began in 1999 with two efforts jointly sponsored by the FAA and the Department of Defense. The FAA teamed with the U.S. Navy to develop arc-fault circuit breakers and with the U.S. Air Force to develop enhanced wire test equipment. In 2000, the Aging Transport Systems Rulemaking Advisory Committee (ATSRAC) asked the FAA to support and chair a working group chartered to investigate the condition of wire on recently retired transport aircraft. The FAA added this work, known as the Intrusive Inspection program, to the electrical systems research program.

The Intrusive Inspection program completed one of the most comprehensive assessments of the condition of electrical wiring on aged airplanes ever performed. Results from this work had an immediate impact on the activities of the ATSRAC and requirements for FAA electrical systems research. The idea that electrical wiring was simply a system of connections between devices began to fade with an emerging recognition that the electrical wiring interconnect system (EWIS) was a complex aircraft system in its own right.

As commercial aircraft age, so do the hundreds of miles of wiring that deliver electrical power and impulses to control critical flight systems. "But the effective age of aircraft wiring," explains Michael Walz, project manager of the FAA Aging Aircraft Electrical Systems Research, "is more a matter of the health of it's insulation than the wire's actual age in years." Wire aging causes wiring insulation to deteriorate, become brittle, and reduce the quality of the insulating material. Many factors contribute to the deterioration of wiring insulation including: vibrations and mechanical stress, moisture, temperature variations, and exposure to chemicals.

FAA Aging Aircraft Electrical Systems Research has sponsored many projects to understand how the EWIS ages and effects the safe transmission of power and signals in an aircraft. These studies have helped the FAA and ATSRAC to develop regulatory measures to improve the safety of aging electrical wiring. The FAA recently proposed a rule and related advisory circulars that revamp how manufacturers and operators design, install, and maintain wiring systems aboard commercial airliners. The notice of proposed rulemaking requires manufacturers to conduct a comprehensive risk assessment of the EWIS throughout the aircraft with consideration given to risk factors within each area of the aircraft that wiring is located. The same requirements are also applicable to all future aircraft alterations and repairs.

To support eventual implementation of the proposed rule, FAA Aging Aircraft Electrical Systems researchers are investigating new methods for inspection of aircraft wiring. The EWIS is one of the most difficult aircraft systems to diagnose, maintain, and repair properly. Wiring bundles often run through inaccessible places, bulkheads, sidewall panels, above false ceilings, and below cabin floors. Wiring problems are often intermittent and sometimes difficult to reproduce. Under these conditions, identifying and locating problems pose a great challenge.

"Traditionally, the principal method of EWIS inspection is visual," says Walz. "This is a painstaking process. Vast stretches of wiring are inaccessible without dismantling the aircraft. Some problem areas are hidden within bundles and beneath clamps. Breaches in insulating materials are sometimes no larger than the head of a pin. What's more, if their insulation is brittle or close to cracking, the moving or dismantling of bundles during inspections can cause increased damage to the other wires in the bundle."

FAA researchers are developing new non-intrusive and nondestructive techniques that can detect and locate wire failures. "We must be proactive in preventing onboard fires and smoke incidents," says Walz. "We have to raise the bar, and identify problems on the ground. We need to provide better tools to help the inspectors locate problems and maintain the EWIS."

The FAA Aging Aircraft Electrical Systems Research team is developing, evaluating, and testing innovative nondestructive inspection (NDI) and nondestructive test (NDT) technologies. The FAA has partnered with other government agencies and the private sector to find new NDI and NDT technologies that show promise in EWIS inspection. Some of these include: Excited Dielectric Test, Micro-Energy High Voltage Technology; Broadband Impedance Measurement; Pulse Arrested Spark Discharge; Tera-Hertz Reflectometry; Aircraft Wiring Integrity Verification using Pseudo-Random Binary Sequence; and Material Indenter Testing Research. ▶

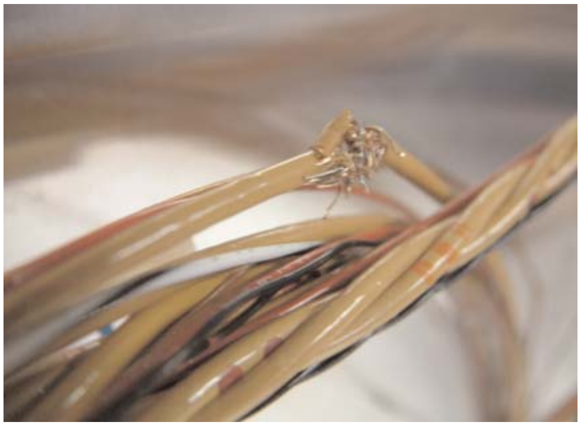

Photo courtesy of the University of Utah Department of Electrical & Computer Engineering.

NDI and NDT technologies continue to evolve creating a need for a standardized method for evaluating these technologies. The FAA tasked its Airworthiness Assurance NDI Validation Center (AANC) to create a standard electrical systems test-bed to accomplish this requirement. The test-bed is used to evaluate NDI and NDT technologies in an apples-to-apples manner. Researchers used the facility to evaluate commercial off-the-shelf NDI and NDT systems. Private sector organizations are free to use the test-bed to conduct research and development of NDI and NDT technologies.

One NDI technique developed by the FAA Aging Aircraft Electrical Systems Research project has been commercialized by Astronics Advanced Electronic Systems Company into in their ArcSafe® test system. This system uses a high voltage, low energy source to locate evidence of insulation breakdown. Developed by Astronics, AANC and the FAA, ArcSafe® identifies and locates an insulation breaches in single conductor power wire in an aircraft. The FAA, while continuing to sponsor inspection technology, is also working on several other techniques to mitigate and reduce the risks associated with EWIS failure.

The FAA, in cooperation with the aviation industry, is developing new risk analysis tools that are applicable both to existing and emerging aircraft. The EWIS RAT™, designed by Lectromec with FAA support, helps analyze hazards, anticipate damage to structures, and reduce the potential of on-board fires. The RAT™ logic and output is based in part on the function, length, and type of every wire on the airplane in conjunction with its proximity to potentially volatile fixtures, such as fuel tanks and hydraulic lines, and its exposure to the elements, as well as failure rates for typical aircraft wiring. Aircraft designers can use the RAT™ to identify problem areas early in the design or modification stage. The RAT™ can also be used to for hazard assessment of EWIS modifications and alterations throughout the operational life of the aircraft.

Prevention of EWIS failures by proper design, inspection, and maintenance are critical to safety, but these measures alone are not a complete solution. FAA Aging Aircraft Electrical Systems Research is investigating methods of mitigating the effects of EWIS failures when they occur. To do this, the FAA undertook research to develop advanced technologies for arc fault detection and arc fault damage mitigation. In partnership with the U.S. Navy, researchers developed fault circuit breaker (AFCB) technologies for single-phase, three-phase, and DC circuits.

Since the completion of the FAA's arc fault single-phase research, most aerospace circuit breaker manufacturers have developed arc fault detection devices. To ensure the safety of these devices, the FAA created the Arc Fault Evaluation Laboratory (AFEL) where the performance of different arc fault mitigation techniques can be evaluated. Located at the William J. Hughes Technical Center, the AFEL is also used to research the characteristics of arc faults and generate data necessary to evaluate EWIS design requirements.

In the AFEL, FAA researchers simulate known aircraft wiring defects and failures to test the real-world effectiveness of in-service and experimental protection devices. Arc fault circuit interrupter technology is evaluated and qualification tests are developed to support the implementation and new advanced power technologies. The AFEL is used to assess damage that occurs during an arcing fault to determine the amount of fault mitigation provided by the protection device. The AFEL is also being used to conduct research on the effects of fault current reduction, insulation materials, and other protection techniques. Safety advancements from this research are applicable to existing aircraft as well as aircraft of the future.

Researchers in government, industry, and academia are exploring the next generation of improvements for aircraft EWIS. New research areas are being studied such as advanced embedded diagnostics, advanced circuit protection technologies, and advanced wire insulation and conductor materials. Some revolutionary approaches involve using carbon nanotube materials as conductors, self-healing wire insulation, and fielding smart wiring that can reconfigure itself in the face of operational problems. FAA Aging Aircraft Electrical Systems Research will be at the forefront of these technologies to assure that FAA safety goals are successfully accomplished. R&D Review

For additional information on the FAA electrical systems research, please visit http://aar400.tc.faa.gov/Programs/AgingAircraft/agingsystems/Electrical%20Systems%20Website/ELECTRICAL%20SYSTEMS.htm.

Mark your Calendar for

Upcoming Events

2007

Aging Aircraft Conference

The 10th Joint DoD/NASA/FAA Conference on Aging Aircraft will be held in Palm Springs, California, April 16-19, 2007. The Conference on Aging Aircraft brings together members of the military and commercial aviation communities for the purpose of disseminating information relevant to the continued airworthiness and sustainability of aging aircraft. Presentations will analyze emerging issues and discuss technical and managerial solutions to age-related problems. The conference draws top researchers from throughout the world and attracts in excess of 1200 attendees and 150 exhibitors.

The conference addresses the full spectrum of aging aircraft topics of interest to aviation professionals, including:

- Engines
- Avionics
- Corrosion
- Fleet Management
- DMSMS/Obsolescence
- Dynamic Components
- Flight Controls & Aging Non-Structural Systems
- Aircraft Loads (Fixed Wing)
- Aging Non-Metallic Materials
- Aging Space Vehicles & Systems
- Structures - Metallic & Composite
- Electrical Wiring Interconnect System

Conference organizers are now soliciting abstracts for papers and presentations. Abstracts must be received by November 3, 2006, contain between 200 and 500 words, and relate to one of the announced conference topics.

Multiple opportunities are available for organizations interested in becoming a conference sponsor. See the conference website for additional information.

Additional information about attending the conference, submitting abstracts, and becoming a sponsor are available on the Internet at:

http://www.agingaircraft.utcdayton.com/index.htm.

New JPDO Director Named

On Wednesday, August 1, 2006, FAA Administrator Marion C. Blakey announced the selection of Charles Leader to be the new Director of the JPDO. Mr. Leader brings a unique and impressive background to his new assignment.

He is a seventeen-year veteran of the U.S. Marine Corps. He is a graduate of Notre Dame University and received an MBA from Harvard University. During the past fifteen years, His experience includes working in research management, technology development, and systems integration, with a focus on aviation and aerospace.

Other R&D News

Allard to Head Human Factors Research and Engineering Program

The FAA has selected Dr. Terry Allard, a veteran NASA scientist and program manager, to direct its human factors research and engineering program. He brings with him a researcher's advanced understanding of how human capabilities and actions affect today's complex aviation environment. Equally important, he is already thoroughly familiar with the established spirit of cooperation among researchers in his former and his new agencies. He will oversee human factor professionals both at FAA Headquarters and the FAA's William J. Hughes Technical Center in Atlantic City, N.J.

"Technology is advancing faster than anyone had expected," says FAA Administrator Marion C. Blakey, who is looking to Dr. Allard to "make sure that humans will be able to keep up with the technology that's coming on line."

An accomplished scientific leader and manager, Dr. Allard served NASA as associate director for human system research and technology, program director for Advanced Space Technologies, and chief of the Human Factors Research and Technology division at NASA Ames, California. He has earned NASA's Outstanding Leadership Medal and major awards from other agencies.

Dr. Allard holds a Ph.D. in psychology and brain science from MIT. He has completed post-doctoral training in neurophysiology, animal behavior and self-organizing systems at the University of California, San Francisco. His writings have appeared in respected journals and he has served on the editorial boards of distinguished professional publications.

COMMENTS ???

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Keeping the Fleet Safe

Fatigue Damage

Typically, manufacturers build commercial airliners to operate safely for at least twenty years or 60,000 cycles of takeoffs and landings. Today's competitive aviation environment forces airlines to demand even more of their equipment. A carrier might spend $50 million for a new Airbus A320, but rebuilding a model it already owns might cost between $4 and $9 million. Aviation industry leaders know they share a daunting challenge with those who use and maintain their products. Together they must find new ways to keep aging aircraft safe and airworthy.

As demands upon aircraft have markedly increased, so too have the R&D efforts of FAA engineers and scientists to identify, prevent, and repair widespread fatigue damage (WFD). A major safety concern for the aging fleet, WFD can be described as the simultaneous presence of cracks at multiple structural locations on an aircraft. Sometimes large and dense enough to lead to structural deterioration, these cracks appear after the airplane is subjected to carrying many loads - and to the related effects of repeated pressurizations and depressurizations. In some cases, emerging multiple WFD cracks are too small to be reliably detected using existing inspection methods. But the cracks can grow together very rapidly, making equipment failure a real possibility between scheduled inspections.

One source of WFD is multiple site damage (MSD). This occurs when areas of fatigue cracks merge within a common structural element such as a large skin panel. This damage also can extend to other parts of the element. Another source of WFD is multiple-element damage characterized by the, simultaneous presence of fatigue cracks interacting across adjacent structural elements such as frames and stringers. Some structural elements are susceptible to either type of damage, or to both types in combination. If undetected, WFD of any type could lead to catastrophic failure.

Because of the small size and often hidden location of WFD, even the best experts in aircraft structures are hard-pressed to predict crack growth or to estimate how much strength remains in affected components. Still, the recent work of FAA researchers has greatly improved the aviation industry's ability to analyze and isolate WFD defects in order to make appropriate repairs. More rigorous numerical methods and simplified engineering approaches are now available from these studies to predict crack initiation, growth and linkup, and residual strength.

Detecting Wide Spread Fatigue Damage

In 1988, the FAA established a broad regulatory program to ensure the structural integrity of aging aircraft. Shortly before, a nearly catastrophic incident had occurred aboard a Boeing 737 flight to Honolulu, Hawaii. Investigations showed that small cracks emanating from multiple rivet holes in a lap joint - an element that joins two parts of the fuselage - had failed. First the glue in the joint had "disbonded." Adjacent rivet holes securing a mechanical fastener placed over the bond then became hot spots for further cracks to develop. These conditions caused a large portion of the fuselage crown to tear apart. Fortunately, the pilot landed the crippled aircraft without further incident.

"The 1988 Aloha Airlines accident opened our eyes to widespread fatigue damage," says John G. Bakuckas, Jr., aircraft structural integrity R&D project manager. "The work of our scientists and engineers has supported the development of more than 500 FAA Airworthiness Directives that address specific airplane structural issues."

As part of its ongoing structural integrity research program, the FAA has teamed with Delta Air Lines, Drexel University, and the FAA Airworthiness Assurance Nondestructive Inspection Validation Center (AANC) at Sandia National Laboratories to conduct the combined destructive evaluation, with extended fatigue testing, of a commercial transport airplane. The investigation centers on WFD initiation and growth in a Boeing 727-232 commercial airliner retired in 1998 near its design service goal of 60,000 flight cycles. Mindful of the fate of the Aloha 737, researchers are gathering knowledge, generating analytical methods, and creating new data reduction approaches to prevent such future damage in the commercial fleet. They also are developing protocols for future evaluations as well as an interactive database that will allow users to conduct parametric studies of teardown data.

Being able to explore beneath the surface of a retired aircraft provides researchers a unique opportunity to test and validate existing as well as emerging nondestructive test methods. Specialists are now documenting inspection findings from various technologies and developing probability-of-detection curves using the teardown data.

FAA Full Scale Aircraft Structural Test Evaluation and Research Facility

 continued from page 9

"This research is helping us verify fatigue damage assessment methods, procedures, and tools," explained Dr. Bakuckas. "We expect results from this program to provide key data to support WFD assessments needed to determine initial operational limits."

Rigorous Testing

Testing is underway on the Boeing 727 aircraft panels. Researchers have removed 11 panels containing lap joints that connect the upper fuselage both in front of and behind the wings. They have already completed a destructive evaluation to characterize multiple-site damage found beneath the surface of seven panels affected with extensive internal cracking. Four of these panels are now undergoing extensive fatigue testing in the FAA Full-Scale Aircraft Structural Test Evaluation and Research (FASTER) Facility located at the William J. Hughes Technical Center in Atlantic City, N.J.

"The FASTER facility can test the large curved panels generally used in aircraft fuselage structures," explains Dr. Bakuckas. "It provides experimental data needed to validate and support analytical methods under development, including WFD predictions, repair analysis and design, and new aircraft design methodologies. The test fixture can simulate the effects of the major modes of loading, including internal pressurization, tensile hoop, longitudinal, frame, and skin shear loads upon an aircraft fuselage when it is submitted to a range of flight conditions. We can apply both quasi-static and long-term durability spectrum loadings in the FASTER facility."

Researchers combined the use of high-magnification visual methods with conventional and emerging nondestructive inspection methods to document the actual baseline condition of the four test sections. These inspections found no damage. The team then fitted the panels with strain gages and conducted quasistatic tests to ensure a proper load introduction. Finally, drawing on the real-time capabilities of the FASTER fixture, they matched applied loads for the fatigue testing with the actual in-service history of the aircraft.

To date, the researchers have completed the testing of two previously stressed panels. After an additional 43,500 simulated flight cycles, they found no cracks in the panel skin test section of the first panel they tested. The post-test destructive evaluation also revealed no undetectable cracks. In view of the extensive amount of cracking found in other joints due to in-service use, this lack of cracks was unexpected. Further examination of the lap joints continued to show encouragingly good overall joint quality.

For the second test panel, researchers applied an additional 120,000 flights beyond its expected lifetime of 60,000 flights. The researchers then inserted artificial cracks in the lap joint, and tested the panel at limit load and proof load levels until a one bay crack developed. They plan to disassemble the lap joints for further evaluation and to reconstruct the crack growth history.

Delta is now performing a quality control check of the research database to ensure its accuracy. Also, the FAA AANC is assessing the usability of a beta version of the database software.

Regulatory Activities

In addition to these research initiatives, the FAA also undertook numerous regulatory actions to address WFD since the Aloha accident. The Agency addressed immediate safety concerns using the Airworthiness Directives process. In 1991, the Aging Airplane Safety Act required mandatory records reviews and airplane inspections after an airplane has been in service for 14 years. The act also required damage tolerance based inspections and procedures. In 1998, the Damage Tolerance requirements in the Federal Aviation Regulations were updated to address WFD. In the update, applicants must demonstrate that WFD will not develop during design service goal through full-scale test evidence.

The FAA has also worked closely with industry in the Aviation Rulemaking Advisory Committee (ARAC) process. In 1993, Airworthiness Assurance Working Group identified those aircraft structures susceptible to WFD in the aging airplane fleet. This same group recommended regulatory action by the FAA to prevent WFD. In 2003, the General Structures Harmonization group harmonized the United States and European damage tolerance requirements and advisory material for WFD.

The most recent regulatory action taken by the FAA addressing WFD is a Noticed of proposed rulemaking issued in April 2006. The objective is to establish operational limits on transport category airplanes to preclude WFD. This is a shared responsibility between the design approval holders and the operators. The design approval holders, which include airplane manufacturers, modification shops and repair stations, are responsible for establishing the operational limits within which WFD will not occur. The operators of the airplane are responsible for incorporating operational limits into their maintenance programs.

The FAA, working with industry and academia, are addressing WFD on several fronts with the goal of preventing the recurrence of any tragedy similar to the 1988 Aloha Airlines incident. R&D Review

For additional information on the FASTER Facility and ongoing tests, please contact Dr. John Bakuckas at john.bakuckas@faa.gov.

The Bureau of Transportation Statistics, a part of DOT's Research and Innovative Technology Administration, reported that the U.S. airlines carried 0.4 percent more domestic passengers and 5.8 percent more international passengers during the first five-month period in 2006 than during the same period in 2005

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Operational Loads

To obtain reliable loads data, FAA researchers are collecting data to determine if the loading spectra being developed for design, test, and structural life analysis of both small and large transports are representative of actual usage.

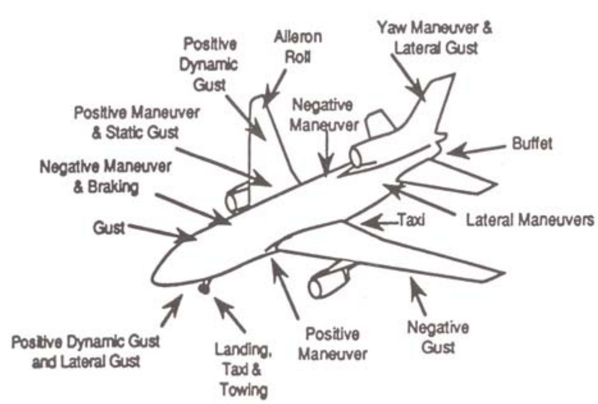
Many aircraft fleets around the world are being operated beyond their intended service life span and in environments more severe than their airframes were designed to accommodate. FAA researchers are working to understand exactly how these realities effect aircraft safety and to eliminate or mitigate associated risk. It is very difficult, however, to quantify and analyze the true global flight environment.

Often, the only feedback operators provide to airframe manufacturers and/or the FAA is a tally of hours flown and landings logged. While these numbers show how many pressurization cycles an airplane has experienced, researchers can only guess at details of how the aircraft has really been used. What kinds of loads have been placed on individual components of the airframe? Have elements such as the wings, tails and flaps been subjected to reasonable or to excess stress during the airplane's total flight history?

The FAA Operational Loads Monitoring R&D project is providing answers to these increasingly important questions. Tom DeFiore, project manager, explains: "The purpose of our work is to characterize typical in-service usage, and provide more realistic design and certification criteria for future generations of airplanes. Concurrently, our research frequently helps to identify or at least shed light on potential operational problems."

New designs such as the Boeing 7E7 and the Airbus A380 stretch old limits and theories about aircraft structure and flight and ground loads. Many of the current airworthiness standards for load criteria were developed prior to deregulation, and, in some cases, prior to the design of wide-body, fly-by-wire and regional jet aircraft. New technology, operating rules and practices, and the anticipation of double the air traffic within ten years pose a real need to validate and continuously update flight load airworthiness certification standards based on actual measured usage.

The FAA researchers are collecting data that can be used to determine if the loading spectra being developed for design, test, and structural life analysis of both small and large transports are representative of actual



Typical Airplane Loads

usage. They are examining how the aircraft structure reacts to flight, maneuver, and environmental loads. As flight speeds and altitudes increase, predicting and analyzing flight loads, and how the airplane reacts to those loads is critical to safe flight.

"Our research found a significant difference in the touchdown lateral acceleration between wide-body airplanes and narrow-body airplanes."

Researchers in DeFiore's project compare operational in-service usage data with design and fatigue loads of typical civil transport aircraft. Since its inception the quantity and quality of usage data obtained from this research has steadily increased to include data from eight different operators, three of which were international airlines. "Our research is fundamental to the FAA's regulatory and certification process, which ensures the continued safety of the civil transport fleet," he explains.

Among the innovative tools used by the project is a video system that collects data on landing impact conditions for both large and small commercial transport aircraft. This system locates from four to seven specially modified video cameras along the edge of the runway to collect the landing images. The cameras feature enhanced vertical resolution (double that of standard video formats) that enables accurate measurement and tracking of aircraft position data. The system also uses digital image processing technology that can position the image to within a fraction of a pixel. As an aircraft passes, the cameras capture sequential video images on an optical laser disk recorder. At a special workstation, technicians then determine the aircraft position as a function of time along with notations of each airplane's model type and registration number. The data reduction system reveals exact landing impact parameters such as sink speed, horizontal velocity, distance from and height over the threshold, bank angle, crab angle, and the like. Using this system, touchdown parameters can be acquired without special instrumentation installed on the aircraft. Researchers have temporarily installed the video landing system at six U.S. and two international airports.

"One of the challenges we face is how to manage the increasing volume of information we are collecting," says DeFiore. "To help us with data analysis and processing, we have turned to the University of Dayton Research Institute (UDRI). FAA-funded researchers at UDRI are responsible for analyzing, processing, and storing our data." Collaborating with aircraft manufacturers and operators, these scientists have designed software that can reduce, analyze, and provide the statistical data the FAA needs to reassess existing certification criteria.

The FAA Operational Loads Monitoring R&D project has supported several certification initiatives. Recently, using in-service data from digital flight data recorders, researchers re-evaluated current 0.5G limit lateral load criteria for wide-body aircraft, particularly the Airbus A380. Airbus had requested a reduction in the 0.5G limit load specified in Title 14 Code of Federal Regulations Part 25.495.

"Our research," says DeFiore, "found a significant difference in the touchdown lateral acceleration between wide-body airplanes and narrow-body airplanes. Also, in general, an aircraft's size and weight significantly affect lateral acceleration. Smaller models, such as the Boeing 737, tend to incur most of their higher lateral acceleration values while turning, probably because of higher speed and landing gear configuration. Heavier airplanes experience lower lateral acceleration while taxiing and tend to have their highest lateral accelerations occur during touchdown and the subsequent rollout."

As a result of this work, the FAA Aviation Rulemaking Advisory Committee for Loads and Dynamics Harmonization recommended a special condition to 14 CFR 25.495 to reduce the ground turning requirement from 0.5G to 0.42G for the Airbus A380. The results of this study are documented in Study of Side Load Factors During Ground Operations (Technical Report DOT/FAA/AR-05/7), which can be found on-line at http://www.tc.faa.gov/its/worldpac/techrpt/ar05-7.pdf. R&D Review

For additional information about FAA operational loads monitoring research, please contact Tom DeFiore at thomas.defiore@faa.gov or see http://aar400.tc.faa.gov/Programs/AgingAircraft/airbornedata/index.htm. You can find all related research reports on this site.

In His Own Words

A Conversation with FAA's Tom DeFiore

Q: Has your entire professional background been in aviation?

A: Yes. I began by working for over 20 years with the Navy on airframe fatigue and flight and ground loads research, similar to the research I'm conducting for the FAA. In 1987, I became an FAA engineer assigned to developing simulations of flight tests and potential accident situations - what the Agency called analytic modeling work. During my first year with the FAA the Aloha accident occurred. My manager at the time recalled my fatigue loads background in my resume, and told me: "You're now working on aging aircraft." I've been working this research ever since.

Q: What are your responsibilities as project manager?

A: First and foremost, I do what's necessary to keep the operational loads monitoring program going. I line up all the necessary support, both internal and external, to get, reduce, analyze, and publish data on typical aircraft usage. Thus far, most of the research and published reports deal with the characterization of the use of large transports. We are now beginning to focus on the usage of commuter carriers, business jets, firefighting aircraft, agricultural operators, and the general aviation fleet.

Q: What does the project entail?

A: We acquire, reduce, and analyze data, which describes the in-service load environment of a wide variety of civil airplane models. We study how much pitching, rolling, and yawing a plane experiences, how hard it touches down, what airspeed and attitude it is flown at, and how much turbulence it encounters. We look at the flight and ground load parameters that we can reliably identify. And, we look for dissimilarity in how different categories of airplanes are used. For example, we once worked with colleagues at the Department of Transportation Volpe National Transportation Systems Center to learn how much noise the reverse thrust systems of various aircraft make after touchdown. We found out that, thrust reverser thrust levels used at U.S. airfields are considerably higher than at European airfields. In addition narrow body airplanes use higher reverser thrust levels than their widebody counterparts.

Q: What are some of the major accomplishments of the research?

A: We have published about 40 technical reports detailing the results of our ongoing research. Some of our research has resulted in proposed changes to certification criteria. We found major differences, for example, in taxi turning between narrow- and wide-body civil transports. I supported the Aviation Rulemaking Advisory Committee (ARAC) Loads and Dynamics Harmonization study, which looked at the lateral loads of taxiing A380 aircraft. Airbus had requested a waiver from CFR 25.495 "Turning" requirement of 0.5G's, and I was able to confirm that heavy, widebody airplanes do not turn nearly as sharply as smaller airplanes. Airbus eventually received a waiver.

Q: What are some of the challenges you have faced?

A: Probably the biggest challenge has consistently been to find airlines willing to participate in our research by providing usage data from their Digital Flight Data Recorder. I'm not looking for regulatory violations, but rather a composite of processed, analyzed results that I can use to characterize an airplane model's loads history. I've had the good fortune of successfully negotiating with eight airlines, three international, to provide data directly to our contractor, the University of Dayton Research Institute (UDRI). Under a nondisclosure agreement, UDRI had previously agreed to not pass on any raw data to the FAA. This restriction was of no consequence since I am only really interested in seeing if aircraft are operated in a manner consistent with its certification and design criteria. When we find discrepancies, we can make a recommendation to modify the certification criteria.

Q: Are you looking for the general ways a particular aircraft is being operated throughout the industry rather than for specifics of how a specific airline operates its planes?

"For me, it was a 'no-brainer.' Being drafted to launch the FAA's Operational Loads Monitoring Program...was repeating my work with the Navy only in a different environment."

A: That's correct. Our reports do not even identify the airline involved, only the model type. We want to know things like common cruise altitudes, flight distances, turbulence, ground impact parameters, so we can characterize details in plots, charts, figures, while at the same time safeguarding all airline-specific raw data. The data we receive from the airlines comes from the flight data recorder, the crash recorder - or, as most people call it, "the black box." Airlines remove all individual flight identification information such as flight number, date and time, pilot name, and anything else, which have the potential to identify a specific flight. We don't need that information for our research.

A little history might help to explain what has been happening. When I worked for the Navy, we knew that there was a flight recorder in every airplane even if it was only a cg Nz recorder. When I started working the Aging Aircraft Research Program, my first questions was: "What data is available from the flight recorder of the Aloha airplane involved in the accident? In other words, what was the recorded usage history?" To my surprise, I was told that only the previous 25 hours was available to help investigate this accident. The complete historical information was gone; moreover this was the case for all models, all operators, all over the world! My Navy experience told me that the FAA should not simply rely on manufacturers usage reports but establish a program to collect its own data on the operational service of aircraft.

When I worked for the Navy, I was responsible for the fatigue and flight loads program for the F-4s in the 1960s, F 14s in the 1970s, and finally F-18s's in the 1980s. For me establishing an operational loads monitoring program for civil aviation was a "no-brainer." Now I'm almost repeating it in a different environment, however the controls and incentives are different. The Navy owned the airplanes and corresponding usage data. Pilots couldn't complain. In civil aviation, though, the regulators don't own the airplanes; manufacturers don't have to cooperate; and operators certainly don't have to share their data. That's really been the challenge - convincing naturally reluctant airlines and manufacturers to share some of their proprietary data.

Q: What advice would you pass along for people considering an aviation career?

A: One had better like it and like your co-workers, because you spend approximately one-third of your 40-year career at work and another third sleeping. As an example, I recently had lunch with the FAA manager who hired me 19 years ago and jokingly told him: "You gave me the impression that I was going to be doing mostly technical work. Yes, I have done some, but most of what I have done has had political overtones!" He said (laughing) that was the only way he could get good people - because once you're here, they've got you.

Q: Forty years ago, what made you choose aviation? And are you happy you did?

A: There's a story to go with that, too. I went to graduate school at University of Pennsylvania's Wharton Schoole, to study economics. However, between the time I graduated from Drexel University and when I started Penn, I did a favor for a professor who had helped me get into Penn. Two students had skipped out after he had promised them to the Navy for the summer. I went to work in the place of one of them and I loved it from the first day. My economics education had dealt heavily in mathematics with the purpose of understanding and making forecasts in a dynamic environment with many interrelated parameters. It turns out, an aircraft operates in a highly dynamic environment as well with lots of interrelated parameters. Consequently, all of the mathematical methods, which I became quite familiar with in graduate school, were equally as applicable to understanding aircraft dynamics. In life, lots of things happen by accident as it did for me. Had I pursued a career in business, I may have ended up rich in a different way (laughs), but I fell in love with aviation and loads. Forty years later, I'm still working at it. R&D Review

Rotorcraft

Rotorcraft Structural Integrity

Approximately 6,500 commercial rotorcraft operate in the United States. Able to function at low speed, hover in place, and maneuver in areas not accessible to other vehicles, these aircraft fill a unique role in aviation. In addition to routine passenger shuttle and other transportation services, rotorcraft are used in demanding missions such as logging, fire fighting, emergency medical transportation, and offshore oil rig support.

Rotorcraft are complex machines that are uniquely operated, subjecting them to extremely high cyclic load frequencies. With the loads imposed on rotorcraft fuselage and rotating components, rotorcraft work relatively harder to fly and accomplish their mission than fixed-wing aircraft do.

When helicopter pilots land and take off from dry, unprepared surfaces, severe dust does more than just compromise their vision - it also puts their engines at risk. Transporting people and supplies to offshore oil platforms constantly expose rotorcraft to a corrosive maritime atmosphere. Sometimes, helicopters used for logging and fire fighting must fly many power cycles in a very short time. These are only some reasons why vital rotorcraft components, elements that cannot fall back on the redundancy such as that of fixed wings - rotor masts, for instance - are flight-critical in all operations.

Responding to domestic emergencies, such as those caused by terrorists or natural disasters, evolving niche applications, growing international markets, and emerging advanced rotorcraft technology will greatly increase the commercial use of helicopters over the next decade. With increased use comes the need for increased operational safety. Rotorcraft Structural Integrity and Safety research is working to reduce rotorcraft fatigue-related failures and better detect the mechanical anomalies that cause structural failure.

Damage Tolerance

The FAA requires that transport category rotorcraft structures function without catastrophic failure after exposure to the repeated high-cycle fatigue loads expected throughout their anticipated operational life. The industry standard that has been used in designing rotorcraft structures for more than 50 years is known as the safe-life method. Using this method, designers can establish the retirement life (number of cycles or flight hours) of rotorcraft structures and rotating components so they can be removed from service before failure. The safe-life method, however, is sometimes less conservative, and the actual fatigue life of a given rotorcraft component sometimes proves shorter than its safe-life rating.

Dy Le, FAA rotorcraft research project manager explains: "To ensure rotorcraft safety, we have launched numerous research efforts. We hope to establish a more reliable method, such as damage tolerance, to complement the safe-life method and require its use through new FAA rulemaking."

The damage tolerance approach assumes that a crack exists in a given rotorcraft component and uses advanced technologies to predict the continued growth of the crack. A reliable model of the fatigue crack growth is determined and is used to develop inspection schedules identify the crack before it reaches a predetermined critical length.

"The damage tolerance approach for fixed-wing aircraft has been well-established as the principal methodology for precluding fatigue failures in many types of structures, including transport aircraft. However," explains Le, "because of the high number of vital components in rotorcraft, and the extremely high cyclic load frequencies to which they are exposed, rotorcraft damage tolerance (RCDT) research and applications are considerably more challenging - and significantly less well-developed - than those in transport aircraft."

To lead the RCDT research, the FAA has developed a RCDT strategic plan with an associated 10-year roadmap. "While the FAA is working closely with the rotorcraft industry, academia, and other government agencies using the new roadmap to develop, validate, and demonstrate the damage tolerance technologies," says Le, "our work is still not easy." The research requires many advanced technologies to compute fatigue crack growth, develop material crack data, determine how rotorcraft are actually being flown, and implement the kinds of inspection methods needed to detect very small cracks.

Health and Usage Monitoring Systems

The FAA researchers are also conducting research to guide the certification of health and usage monitoring systems (HUMS). HUMS systems normally rely upon a combination of airborne data acquisition systems, with sensors strategically installed in various critical locations and ground-based units that process the collected airborne data. HUMS systems are typically used to monitor the rotorcraft operational "health" and to determine how the aircraft are being flown (usage) so that the maintenance can be done accordingly.

Monitoring rotorcraft health can improve their continued operational safety and lower the potential failures. Aircraft usage data are also critical to extending component fatigue life or to determine when maintenance activities should be performed ahead of schedule to remove degrading components.

"Currently, HUMS for health monitoring have been certified on many rotorcraft," explains Le, "but HUMS for age still require extensive research to demonstrate and validate technologies required for full implementation." As a result, the FAA has developed a HUMS R&D strategic plan and 10-year roadmap to validate and demonstrate processes, methodologies, and data for these guidance materials. Using this plan, the FAA has initiated many research efforts with academia, HUMS suppliers, rotorcraft industry, and other government research facilities to support the demonstration and validation of HUMS for usage-related certification purposes. R&D Review

For more information on the rotorcraft structural integrity and safety program, or to access rotorcraft technical R&D reports, please visit http://aar400.tc.faa.gov/Programs/agingaircraft/rotorcraft/.

Propellers

"More than 200,000 propellers on business and general aviation aircraft are generally examined by visual inspection during pre-flight and annual inspections," says Cu Nguyen, a FAA researcher. "Since damage can sometimes be hidden from view, we need to identify appropriate safety parameters that will help us prevent failures before they happen."

Most propeller components in use today are designed using long established safe-life methods to preclude fatigue cracking. The safe-life approach to fatigue evaluation is based on the principle that the repeated loads can be sustained throughout the intended life of a propeller during which there is a low probability that the strength will degrade below its design value because of fatigue.

The event of crack initiation in any given structure is typically defined by the safe-life endurance limit or the fatigue crack growth threshold. There are standard laboratory procedures for generating safe-life endurance limits and the fatigue crack growth threshold.

FAA research shows, however, that these procedures may not be as accurate as once thought. As a result, researchers are now examining whether or not a damage tolerance life cycle management methodology might be a better way to assess propeller life. The introduction of formal damage tolerance methods (based on crack growth prediction and periodic inspections) in the airframe and gas turbine industries suggests investigation of similar approaches for propeller systems.

Propeller systems are vibratory in nature, and therefore accumulate many millions of loading cycles per flight hour. To transition to damage tolerance life cycle management schemes requires a thorough understanding of crack initiation. This is contrary to traditional damage tolerance where a crack is assumed initiated, and growth of the crack is expected to be slow and stable. Because of the high number of loading cycles in a propeller, crack growth is typically fast and unstable.

"Before damage tolerance requirements for propellers can be implemented, we must first scientifically quantify the initiation and subsequent propagation of cracks in propeller systems," explains Nguyen. "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, damage such as corrosion, and the sensitivity of inspection techniques. Damage tolerance assessments and analyses of propeller components require fatigue crack growth properties of propeller primary materials, which are currently unavailable. One objective of our current research is to develop a database containing essential material properties that can be used in propeller damage tolerance assessments and analyses."

The FAA is working closely with NASA to develop a crack growth and fatigue properties database for propeller materials. Currently, NASA and Hamilton Sundstrand are developing fracture mechanics data including fatigue crack growth rates and threshold values for shot-peened coupons and surface crack condition coupons made from propeller alloys. The results of this FAA funded research will be used to determine the feasibility, validity, and application of damage tolerance to the continued airworthiness of existing designs and certification of new designs.

The FAA has also established the Committee of Propeller Damage Tolerance (CPDT). The CPDT is developing detailed plans to address six technical areas critical to successful implementation of propeller damage tolerance. The committee is comprised of small airplane and transport type-certificate holders. The members are working closely with FAA propeller specialists and researchers to address the following priorities:

1. Develop a crack growth and fatigue properties database
2. Characterize threats
3. Identify propeller damage tolerance specific issues
4. Develop specialized fracture mechanics methods
5. Assess nondestructive inspection methods
6. Characterize propeller load spectra

A recent survey conducted by the CPDT to determine the major causes of cracking in propeller systems pointed to corrosion as the most frequent physical damage or proximate cause leading to crack formation. To increase the tolerance of ▶

propeller blades and hubs to the threat of corrosion, the FAA funded a research effort to understand how corrosion leads to cracking and the rate at which corrosion develops under realistic environmental conditions. Researchers are also developing corrosion inspection methods.

Propeller damage tolerant design is dependent upon the availability of appropriate nondestructive inspection (NDI) methods to support periodic inspections of the propeller system. Development of special and advanced NDI methods for propeller system is currently conducted by researchers at the FAA Airworthiness Assurance Nondestructive Inspection Validation Center (AANC) at Sandia National Laboratories in Albuquerque, New Mexico. For more information on the NDI research and development conducted at the FAA AANC please see "*Testing the System"* on page 26. R&D Review

For additional information on this research program, please see http://aar400.tc.faa.gov/Programs/AgingAircraft/etc/FAA_Reports/reports.htm.

In Top Shape

Structural Integrity of Small Airplanes

"The general aviation fleet is very different from the scheduled commercial passenger transport," explains FAA's Michael Shiao, manager of a R&D project that explores how to improve the continued operational safety of small airplanes operated within the commuter and general aviation categories. "The general aviation fleet number is over 210,000 aircraft, and includes corporate jets, air taxis, and air cargo, as well as personal, agricultural, aerobatic, and public use aircraft. Its usage is as diverse as its equipment, ranging from small single-engine planes to the multi-million dollar business jets capable of intercontinental nonstop flights. Approximately sixty percent of this fleet is for personal use, another 20 percent for business. Planes used for instruction, observation, and aerial application make up another 10 percent. What's left is scattered among air taxi, public, and miscellaneous other uses."

The great numbers of small airplanes, their increasing age, their multiple uses, and their diverse design standards make it increasingly challenging for the FAA to ensure the operational safety of general aviation. The average airplane in the fleet is now approximately 35 years old. Because this age could approach 50 by the year 2020, the Agency is working harder than ever to learn just what happens when small airplanes age.

For years, researchers have scheduled comprehensive teardown inspections to monitor the condition of transport category airplanes. The resulting knowledge base has long guided the maintenance of the commercial fleet's structural and systems integrity. Until recently, though, there was no such knowledge base for smaller airplanes. In September 2002, the FAA moved to fill this knowledge gap. The Agency initiated a task to evaluate three aged commuter airplanes. Funded by the FAA, researchers at Wichita State University's National Institute for Aviation Research recently completed the airworthiness evaluation of a well-traveled 1969 Cessna 402A, a 1979 Cessna 402C, and a 1975 Piper Navajo Chieftain.

"Researchers selected these aircraft because they are representative of the small airplane fleet," says Shiao. "Operators primarily used the Cessna 402A for flying Grand Canyon tours, a severe turbulence flight environment. The 402C was used for short island flights along the East Coast, a more corrosive environment with higher-than-normal operational usage. And, the Navajo's multiple owners had operated it for service periods of more than three years each in Alaska, Maryland, Arizona, and Nevada."

For each aircraft, the Wichita State team performed a preliminary survey of its maintenance records followed by routine visual inspections and nondestructive evaluations. Next, they disassembled the plane into its major airframe sections -- wings, horizontal stabilizer, vertical stabilizer, landing gear, forward fuselage, aft fuselage, and cabin -- and examined its system and structural components. Microscopic examinations located cracks and areas of corrosion. Researches assessed the wiring in two phases: the nondestructive inspection and testing phase including general visual inspection, in-situ wiring tests and laboratory tests, and the destructive testing phase including intrusive visual inspection, wiring insulation microscopic inspection, insulation resistance test, circuit breaker test and relay inspection.

"Our objective was to determine if potential continuing airworthiness problems exist for the small airplane fleet due to the aging process," states Shiao. "The project revealed the condition of a typical aged airplane and raised awareness about aging within the general aviation community. Ultimately, though, it will help to guide the future improvements in maintenance and inspection."

The research team has recommended that - based either on service history or damage tolerance analyses - supplemental inspections should be required in the maintenance programs of general aviation airplanes. Furthermore, a comprehensive inspection, in addition to annual inspections, should be performed at a given time as aircraft ages.

As an additional part of its research program, the FAA developed a computer program to analyze the static strength and damage tolerance of certain metallic skin repairs for commuter category airplanes. This user-friendly software, RAPIDC (Repair Assessment Procedure and Integrated Design-Commuter), aids engineers in the design and verification of a damage-tolerant skin repair.

While new commuter-sized airplane designs require damage-tolerance-based inspections programs as part of their certification, other smaller airplanes still use the fatigue safe-life approach for maintenance and certification. FAA report AFS-120-73-2 (Fatigue Evaluation of Wing and Associated Structure on Small Airplane) is in world-wide use for fatigue safe-life certification of most Part 23 airplane designs. First published in 1973, this report needs to be updated to reflect new airplane usage data and new material data for fatigue evaluation and an updated fatigue evaluation procedure is needed to support the Part 23 regulations. The FAA is currently working to establish guidance material for load spectrum generation, generate new fatigue data for various materials and develop a structural-life evaluation methodology for small airplanes.

As airplanes age, a fleet safety management strategy must be developed and implemented. The FAA is committed to data driven solutions for continued airworthiness issues in order to respond to FAA's proactive identification of safety concerns. Since 2004, the FAA Small Airplane Directorate and Shiao have been working together to develop a methodology and a tool for fleet risk assessment and risk management. This methodology was used to determine a risk-based compliance time for two Airworthiness Directives for Cessna 402 wing spar fatigue cracks.

Following the success of this study, a new research task will be initiated in fiscal year 2007 to assess and mange the risks associated with the safe operation of small airplanes. The initiative is expected to develop a methodology and tools that can both identify vital safety issues prior to an accident and allow proactive intervention prior to incidents or accidents. The tools are critical to a systematic review of data when a safety concern surfaces that requires actions for airworthiness assurance. All parties involved need the information they will produce to agree on how to manage or mitigate safety concerns. R&D Review

For more information on FAA's small airplane research, please see http://aar400.tc.faa.gov/Programs/agingaircraft/commuter/index.htm.

Perspective
Talking with Michael Schiao

Dr. Michael Shiao manages FAA R&D on the structural integrity of small airplanes. At his office in the William J. Hughes Technical Center, he recently answered our questions about his program and his role in it.

What is your professional background? Why did you choose a career with the FAA?

I earned my Ph.D. in 1985 from Case Western Reserve University with emphases in probabilistic risk assessment, engineering mechanics, and structural mechanics. For the past 20 years, I have worked with FAA and NASA projects assessing the probabilistic risk of aircraft structures. Maintaining the ability of aircraft to operate safely and reliably under adverse operating environments is a huge task. My work with the FAA challenges my knowledge of engineering mechanics, probabilistic methods and software development, but most importantly, it puts my skills to truly meaningful use.

How long have you been with the FAA?

I have been a technical specialist working in probabilistic risk assessment and structural life assessment here at the Tech Center for the past seven years.

What is your current position?

I manage the FAA's research into the structural integrity of small airplanes. Also, because some important work in my field is not directly under our auspices, I often provide technical advice to colleagues who work for other institutions.

What are some of the challenges you face in this position?

First of all there is the researcher's usual lament - we could always use more money. So I constantly have to look for ways to get the best possible results from the funding available to us. Another challenge involves community perceptions. Even the most promising new technologies often meet some resistance. The researcher's job doesn't end with just finding a better way. Sometimes he has to convince people to give the new technology a chance to prove its usefulness. And finally, a responsible researcher must help to mature a new technology to the point where it can support viable airworthiness certification.

How do you think the Agency and aviation community can overcome these challenges?

Through collaboration, communication, and something akin to salesmanship, we must work with, and stay in touch with, our research colleagues to eliminate waste and duplication of effort. And then, when we are sure we have a valid, well-tested new technology, we must convince skeptics to give it an honest try.

Would you share a recent accomplishment of your program with us?

Until recently, some owners and operators in the general aviation community doubted that aging issues exist in their fleet. With our research for airworthiness evaluation of aging small airplanes, we were able to raise the awareness for the aging concerns. For the small airplane fleet management, we have been able to influence two new Airworthiness Directives to combat the fatigue cracking of wing spars on the Cessna 400 series using a data driven methodology for risk assessment and risk management.

The evaluation of three aged commuter planes has highlighted concerns about, and suggested additional maintenance and inspection techniques and procedures for use with, aircraft of their types. What else might this research suggest to reduce accident and ensure airworthiness?

Again, based largely on our study of wing spar fatigues cracking with the Cessna 400, it seems that combining a data driven risk assessment with sound risk management offers a reasonable proactive approach to maintaining airworthiness and reducing accidents with aging fleets.

What advances do you foresee in your program over the next five to ten years?

A multi-year research project applying the principles of risk assessment and risk management to enhance the continued operational safety of small airplanes program will be initiated in FY 2007.

What made you choose aviation as a career?

I can't imagine a more challenging arena to put my passions for math and physics to meaningful use than working to help maintain the safety of our aging aircraft.

What advice would you share with people considering a career in aviation?

This field is both challenging and rewarding. But you must always be on the lookout for new and better technologies - and you must never be afraid to think outside of the box. R&D Review

Start Your Engines

Engine Safety

"The jet engine, a critical aspect of modern air transport safety, is a complex component," explains Cu Nguyen, FAA engine and propeller research manager. "For continued air safety, we need to understand better how to assess, monitor, and control the health or integrity of engines and propellers and their parts and materials. At the same time, our research program is providing tools to help the aviation industry comply with regulations and is developing advisory information to maintain the airworthiness of engine components."

A disintegrated fan rotor caused the 1989 crash of a United Airlines DC-10 at Sioux City, Iowa. Investigators traced that fatal accident to an undetected material defect - a hard alpha inclusion caused by impurities of nitrogen, oxygen, or both - in the engine rotor material. Since that time, continued airworthiness of engines research has primarily concentrated on improving inspection techniques for jet engine components throughout the engine life-cycle

Ensuring the reliability of rotating engine parts is critical to protecting passengers and crew. In 1992, the FAA began supporting 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. "Since that time, we have made great progress in developing these inspection tools," says Nguyen. "Over the years, engine reliability has improved steadily. Technology advances have cut the failure rate of high-energy rotating components to the lowest rate ever. However, the FAA forecasts that commercial aircraft operations will continue to increase by 3 to 5 percent per year over the next decade. So we still have great challenges ahead of us; reductions in accident rates will be required to keep the absolute number of failures to a minimum."

The ETC is led by Iowa State University and composed of General Electric Aircraft Engines, Pratt and Whitney, and Honeywell. From its inception, it has focused research on production inspection, in-service inspection, and inspection systems capability assessment and validation. Through 1998, titanium billet inspection and in-service titanium disk inspection were the major areas of involvement. The FAA expanded the scope of the ETC to include forgings that use titanium, nickel, and nickel billet.

"One goal of inspection," explains Nguyen, "is to detect anomalous conditions as early in the production process as possible, and to remove defective material before it can result later in a component failure." With this in mind, the ETC has concentrated on the ultrasonic inspection of billets. The billets typically used in the industry are 6 to 14 inches in diameter and 12 to 20 feet long. Conventionally, a single transducer and an immersion tank are used to inspect billets along their diameters. Because the transducer focuses at no specific depth, its sensitivity suffers at all depths.

By focusing transducers at successive depths or zones, ETC research into the multizone inspection system resulted in a fourfold improvement in anomaly detection capability. This 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 approved by the Aerospace Council and Committee K of the Society of Automotive Engineers.

The ETC has also improved technologies to inspect the nickel alloy billets used with engine turbine disks. Manufacturers use nickel alloys in the compressor and turbine stages, where operational temperatures are the highest (800° to 1500°F). ETC scientists have demonstrated that the multizone inspection technique is 31 times more sensitive than the conventional technique in the case of one nickel billet.

When compared to those required for billet inspections, inspection of the forging geometry affords the opportunity to apply the highest sensitivity due to the shorter material paths. The accommodating geometry often has flat sound entry surfaces. ETC researchers have recently completed development of an even more sophisticated inspection based on a technique known as Ultrasonic (UT) Phased Array. They have replaced fixed focus, single element transducers with an array of electronically synchronized ultrasonic transducers that can be focused at various zone depths. "The ability to steer the ultrasonic phased-array probe to points of interest makes it an important tool for aviation inspections," say Nguyen. Recent lab results have demonstrated that the new system UT Phased array provides four times greater sensitivity than current technology. This laboratory system, however, needs further development before it is ready for the production environment.

The objective of engine nondestructive inspection (NDI) is to remove defective material from the production process as early as possible. In August 2004, the FAA and the ETC began research to identify and evaluate advanced nondestructive inspection technologies that maximize the detection of manufacturing induced anomalies (MIA). MIA sometimes occurs during machining of the component (Operations such as drilling, broach-

ing, etc.) and may not be visually detectable. The presence of MIA can negatively impact the expected life and the safety of the component. Subsequent to the 1996 failure of a titanium engine fan disk that resulted in two fatalities, investigators traced the cause of the fan disk rupture to a severely worked material surface layer in one tie-rod bolthole. The fact that this defect occurred during original machining of the disk has intensified interest in research to improve NDI techniques for finding MIAs.

Once in service, engine components operate in a remarkably challenging environment and are sometimes damaged. As a second line of defense, compromised parts must be identified so they can cause no harm. With FAA funding, the ETC has produced a set of tools that can be used either alone or in combination on a wide range of engine models. Items in the suite include a portable Eddy Current (EC) bench scanner prototype, a semi-automated high-speed bolthole scanning system that aids in data acquisition and analysis, a low-pressure rotor rotator, eddy-current arrays, a signal and image processing system, and application-specific probes. Today the EC scanner is commercially available, with over 60 units in use.

Research results also contributed to the development of eddy-current modeling and simulation software needed for the further development of these sophisticated inspection tools. The simulation tools are routinely used by jet engine manufacturers in the design and optimization of inspection techniques.

ETC researchers also want to find better techniques, which are more robust, sensitive, and faster. Current efforts include research into a thermal acoustic technology called vibrothermography. When vibrated, typically by an ultrasonic welding gun, adjacent crack faces rub together. Resulting heat can be detected with an infrared camera. Before this technique is ready for wide use, however, researchers are working to ensure that vibratory excitation itself could not cause cracks to initiate and grow. This technique may possibly replace the fluorescent penetrant inspection (FPI) technique that is presently the most widely used inspection method for surface anomalies of commercial engines. FPI involves many steps with critical parameters and processes. When implemented in a production setting, the effectiveness of the FPI technique is also influenced by human factor and other process control issues. Furthermore, FPI relies on line-of-sight visual access and its effectiveness is limited when inspectors encounter complex geometry features such as deep holes and internal cavities. ETC researchers believe that thermal acoustics technology can successfully address FPI shortcomings.

Enhancing engine life relies on principles of damage tolerance to assess the impact of flaws that might remain undetected prior to the next period of engine service and researchers are studying inspection programs that play an increasingly important role in managing the life cycle and risk of commercial aircraft engines. Highly reliable and sensitive inspection processes can enhance engine life estimates by assuring the absence of any emerging flaws. With the best possible inspection methodologies, it may even be possible to keep engine components safely in service indefinitely. The performance of inspection methods is specified by a curve known as the Probability of Detection (POD). Accurate POD estimates are essential assure the continued airworthiness of aircraft engines.

POD is a measure used to specify the performance of inspection systems. POD estimates are based on experiments using a limited number of flawed test specimens. There are two factors, however, that affect the accuracy of the POD estimate. First, flaws in test specimens are not always fully representative of flaws found in engine materials. Second, POD accuracy will increase by conducting larger and larger sets of experiments. In reality, researchers must work with imperfect test specimens and limit POD experiments to what is practicable. For example, hard alpha flaws in titanium are particularly rare, difficult to simulate, and practically impossible to fabricate in the numbers necessary to accurately estimate the extremes of the POD curves.

To address these POD challenges, the ETC has developed a new methodology that combines information from laboratory data on synthetic flaws, field and/or production data on real flaws, and a sophisticated signal response model to estimate POD. The methodology is the first to link explicitly POD with the fundamental concepts of signal and noise distributions. This methodology has been adopted by some industrial organizations and has laid the foundation for the Model-Assisted POD Working Group, whose researchers have been brought together under the joint support of FAA, Air Force Research Laboratory, and NASA. (For more information on Model-Assisted POD activities see "*Collective Talent - FAA's Center of Aviation Systems Reliability*," page 28.) The ETC is now validating model assisted POD methodologies for new applications and new materials.

Most recently, ETC researchers have applied their insights to the specific problem of updating the Default POD curves for the ultrasonic detection of hard alpha inclusions in titanium billet. This and other POD data appears in FAA advisory circulars guiding the application damage tolerance concepts to high energy turbine engine rotors. R&D Review

Several FAA reports highlight the ETC research completed over the past twelve years. You may see all the documents online at http://actlibrary.tc.faa.gov/.

Nondestructive Inspection

FAA's Inspection Systems Research for Aging Aircraft

The aviation industry faces significant challenges to ensure the continued airworthiness of the aging U.S. fleet. Aircraft flown beyond their intended economic design lives show a susceptibility to widespread fatigue damage and corrosion, conditions that could pose a threat to their structural integrity. To find solutions to these maintenance and inspection concerns, the FAA is conducting a number of inspection and repair research activities as part of its overall continued airworthiness R&D program.

"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 help ensure the continued airworthiness of the U.S. civil fleet," says Dave Galella, manager for the FAA's Inspection System Research projects. "A key part of our effort is having our FAA sponsored researchers work closely with their industry counterparts from the very start of every project."

To facilitate this partnership, the FAA has established two 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 and applied research to advance nondestructive inspection (NDI) technology for civil aviation applications. The second center, the FAA Airworthiness Assurance Nondestructive Inspection Validation Center (AANC), is operated for the FAA by Sandia National Laboratories and is focused on performing validation and technology transfer of successful research endeavors to the aviation community. (Please see related articles regarding CASR and AANC on page 26-29.)

The cooperative work of these partners is paying off through the development and commercialization of several new NDI technologies. In particular, the development of more specific inspection tools and techniques is helping to detect the small fatigue cracks that develop under fasteners and which are associated with widespread fatigue damage, cracks and corrosion hidden within multi-layer structures, and disbonding and delaminations of composite structures.

"Nondestructive testing is used to evaluate the quality and condition of components and materials without altering or destroying them, and with minimal, or preferably no disassembly," explains Galella. "The aviation industry uses a variety of inspection methods to detect flaws in aircraft. The particular method chosen depends on the inspected part's geometry and material, and the type, size, and location of the anticipated defect."

One of the most common methods used to detect cracks and corrosion in aluminum aircraft structures is eddy current inspection. Inspectors use hand-held probes to sense changes of an induced magnetic field in the part being inspected. These changes can be attributed to a number of material properties, including the presence of cracks and corrosion. The probes can detect the locations of surface and subsurface cracks around, for example, the rivets that secure the aircraft 's fuselage skin.

"In one of our early research projects, we assessed the reliability of conventional eddy current methods," says Galella. "The inspection proved to be a reliable means for detecting surface flaws in aluminum aircraft structures. However, as the fleet ages, the detection of defects within multiple layers and at greater depths is becoming more important."

In view of these increasing needs, the FAA has investigated a number of improved inspection methods based on enhanced eddy current technology. Researchers at CASR, for example, have developed a pulsed eddy current inspection system. In contrast to the conventional continuous wave eddy current method, pulsed eddy current induces a broad range of frequencies into the component under test, allowing a thorough inspection of multiple depths in a single pass. Another eddy current-based method is the Magneto Optic Imager, developed by PRI, Inc., and now marketed by Quest Integrated, Inc., provides a real-time view of the induced magnetic fields and perturbations caused by their interactions with discontinuities such as cracks. A third method developed by Jentek Sensors, Inc., makes use of a model based inversion approach that permits independent conductivity and lift-off measurements. Specific advantages of this approach over conventional eddy current include the ability to configure sensor arrays which can be conformable and surface mounted, requires minimal calibration and lift-off compensation, and offers multi-frequency measurements. Still another method developed by IMTT, Inc., with support from the FAA, uses remote field eddy current to penetrate deeper than conventional methods.

These methods, and others, have been tested at the FAA AANC on cracked test panels located there and as part of a project in which a retired B-727 aircraft was inspected with the methods and then destructively characterized to identify the presence of cracks and to quantify the reliability of the NDT methods. A report summarizing these results should be available over the next several months.

Although the predominance of the FAA's Inspection System Research has focused on large civil transport aircraft, several efforts have been aimed at commuter and rotorcraft as well. "Damage tolerance requirements for these aircraft will bring about an increased NDI need for their particular designs and construction," according to Galella. "Our approach is to develop inspection solutions that have applicability to a general inspection challenge, for example, crack detection in a multi-layer stack up such as a wing spar."

One notable project resulted in the development of an eddy current and ultrasonic inspection procedure for the Metro 226/227 wing to detect the presence of cracks in the spar through the lower wing skin. Use of the developed procedure eliminates the need to remove fuel tank sealant and provides for a more thorough, reliable, and cost effective inspection than previous inspection methods. A follow-on study looking at a similar spar stack-up is taking place now with Cessna aircraft.

Similarly, a number of improved inspection methods have been developed and applied to common rotorcraft problems. Currently, NDI capabilities for rotorcraft are essentially limited to the techniques established for fixed wing aircraft. However, unlike fixed wing aircraft, rotorcraft accumulate a very large number of cycle loads in a short time and their ability to hover makes them more weight critical than fixed wing aircraft, requiring the use of thinner and lighter structures. Hence, much smaller cracks must be detected in rotorcraft for the implementation of damage tolerance analysis than current NDI techniques are capable of.

Researchers at the FAA AANC recently collaborated with Bell Helicopter and others in the rotorcraft industry to evaluate NDI capabilities to detect small cracks under button head or raised head fasteners. The FAA and rotorcraft industry identified this as an important near-term need because cracks in high cycle fatigue joints, such as those found in the tail boom and transmission assembly regions, can quickly grow from small initiation lengths to critical lengths in a relatively few number of flight hours.

After a series of evaluations of emerging NDI technologies, researchers are now working with industry to transfer these inspection methods for routine use in rotorcraft maintenance depots. Successful transition will aid the rapid integration of these improved NDI methods in a cost-effective manner.

In addition to traditional metal aircraft, the FAA has been conducting research to improve the inspections of composites and advanced materials for detection and characterization of damage. Look for these activities to be covered in a future edition of the R&D Review. R&D Review

Testing the System

Aging Aircraft Nondestructive Inspection Validation Center

The FAA Airworthiness Assurance Nondestructive Inspection (NDI) Validation Center (AANC) independently tests and evaluates maintenance and repair techniques - both new and newly enhanced - so that innovations can safely be used within the National Airspace System. Established in 1991 at the Sandia National Laboratories in Albuquerque, New Mexico, this FAA-sponsored research facility accurately simulates a typical airline maintenance environment and maintains NDI capabilities applicable to a wide range of aircraft.

Developments in quality control make it possible to ensure the initial and ongoing safety of large manufactured items. Those who build and maintain bridges, buildings, ships, automobiles, and aircraft now use tools like ultrasound, eddy currents, and X-rays to detect hazards such as interior cracks and flaws with no need to disassemble complex assemblies. With many aging aircraft now in operation, and with many new aircraft types scheduled to enter service in the future, the FAA greatly values the efficiency and reliability with which the Center performs its NDI evaluations. Work at the FAA AANC supports the FAA rulemaking process by providing guidance on the content and necessary tools to meet requirements or recommendations of Federal Aviation Regulations (FAR), Airworthiness Directives (AD), Advisory Circulars (AC), service bulletins (SB), supplemental structural inspection documents (SSID), corrosion and prevention and control programs (CPCP), and widespread fatigue damage (WFD) edicts.

Crucial to the FAA AANC validation role is its physical infrastructure. It comprises a 24,000 square foot hangar facility, NDI test equipment and testbeds, and a unique specimen defect library with full-scale, representative sections of selected airframe and engine structures that contain natural or engineered defects in known locations. With these resources, the developers, users, and regulators of aviation equipment can routinely arrange to conduct controlled testing of new inspection procedures and equipment on real aircraft. The facility is also available on a quick-response basis to validate inspection, maintenance, and repair procedures and technologies when critical problems arise in the field. This type of work has included support for the FAA and National Transportation Safety Board on a number of accident investigations. Of equal importance, the FAA AANC has used its infrastructure and expertise to support similar needs within NASA, the Department of Defense, and other private industry endeavors.

The AANC works side-by-side with researchers to investigate the technical and economic benefits of applying promising technologies and procedures to solving many of aviation's most critical problems. But the Center's job does not end in the conceptual stages of research. It has become a respected advisor for the development and transfer of new inspection and maintenance techniques into the field.

Ongoing relationships with other domestic and foreign government programs, NDI equipment manufacturers, airframe and propulsion manufacturers, aircraft maintenance depots, and airline operators allow the Center to serve as a focal point for the FAA National Aging Aircraft Research/Continued Airworthiness Program. Over 150 organizations from around the world have visited the FAA AANC facility and participated in experiments to enhance aviation safety. The list of organizations also includes numerous academic institutions that have used the center as a proving ground for their research. AANC's teaming with these entities has resulted in significant in-kind funding contributions and resource-leveraging for FAA's research program.

Some notable accomplishments of the FAA AANC include:

- Assessed the effects of human factors on the reliability of inspections of high frequency eddy currents in airline facilities. ▶

- Analyzed the reliability and economic viability of a specific eddy current imager. The results showed that, when taking full advantage of the potential time and labor savings associated with implementing the imager, a facility can recoup its start-up costs and generate a positive return in less than a year.
- Assessed the use of ultrasound in detecting wing-area corrosion in DC-9 aircraft. Compared with the costs of tearing wing assemblies apart to inspect them visually, the experimental technology conducts reliable inspections about 15 times faster, at a savings of 94 percent in labor, and with related cost savings of about $9,000 per aircraft.
- Visited aircraft maintenance depots worldwide and conducted extensive in-house testing to quantitatively evaluate the capabilities of conventional and advanced NDI methods to inspect composite structures.
- Performed many routine and "quick reaction" analyses using NDI technologies to inspect and maintain a variety of U.S. Coast Guard aircraft. The ongoing results have encouraged the Coast Guard to purchase NDI testing units for its own use.
- Analyzed and ranked the performance of commercially available, fieldable, and portable scanner systems applicable to nondestructive aircraft inspections. The Center has made a matrix of scanner features and ranking factors available to potential users of competing systems.
- Developed low-cost, yet highly sensitive inspection methods for crack and corrosion detection in rotorcraft to help this industry adopt the damage tolerance approach to helicopter design and maintenance.
- Developed eddy current and ultrasonic procedures to externally inspect commuter aircraft wing spars such as the Metro 226/227 without disassembly and fuel tank sealant removal. These procedures have been included in Fairchild's Supplemental Inspection Documents.
- Applied radiography and ultrasonic NDI techniques to inspect a forward spar fuselage attachment fitting of a Piper PA-25 aircraft. The techniques were further refined to improve their effectiveness, and the results have been incorporated into a revision of the FAA Airworthiness Directive 93-21-12.
- Conducted a benchmark visual inspection reliability experiment with the help of twelve airline inspectors who performed specific inspections tasks on the Center's Boeing 737 testbed aircraft.
- Validated the use of pulsed thermography which has now been approved as an alternative method for inspecting bonded fuselage doublers specified in an AD that addresses over 2000 aircraft.
- In conjunction with the Commercial Aircraft Composite Repair Committee, developed a set of standards to allow for improved pre- and post-repair inspections of both honeycomb and solid laminate structures. These standards are now being referenced in most aircraft manufacturers nondestructive test manuals.
- Completed a Commercial Airplane Certification Process Study that evaluated safety-critical processes associated with commercial airplane certification/operation and produced process improvements to enhance air transportation safety.

Based in part on these accomplishments, a number of accolades have recently been bestowed on the FAA AANC and its staff. In 2003 and 2005, several AANC staff members were named as team recipients of the FAA-ATA NDT Better Way Award, which recognizes efforts by joint industry and government teams to improve the way civil aircraft are inspected. One recognized a team that developed the set of composite reference standards described above and the other for AANC's efforts in evaluating the improved Magneto Optic Eddy Current Imager. In 2006, Sandia National Laboratories presented the AANC with an Employee Recognition Team Award for "producing maintenance, inspection, and repair solutions that address critical airworthiness problems for the FAA, NASA, military, and world aviation community." R&D Review

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Additional information on the Airworthiness Assurance NDI Validation Center can be found at their website: http://www.sandia.gov/aanc/AANC.htm.

Collective Talent

FAA's Center for Aviation Systems Reliability

Through the Center for Aviation Systems Reliability (CASR), the FAA has forged partnerships that bring together some of the best nondestructive inspection (NDI) researchers in the country to benefit the aviation community.

Iowa State University, the founding partner of CASR, has built a strong program based on the collective resources of its earlier established Center for Nondestructive Evaluation. The CASR program deals with the lifetime inspection needs for aviation systems from design to production to operational and in-service use. In addition to Iowa State University, other long standing CASR partners include Wayne State and Northwestern universities. Together, these universities work with the FAA and industry to develop and test dependable, cost-effective inspection tools and comprehensive training materials that meet the needs of airlines, airframe manufacturers, and FAA.

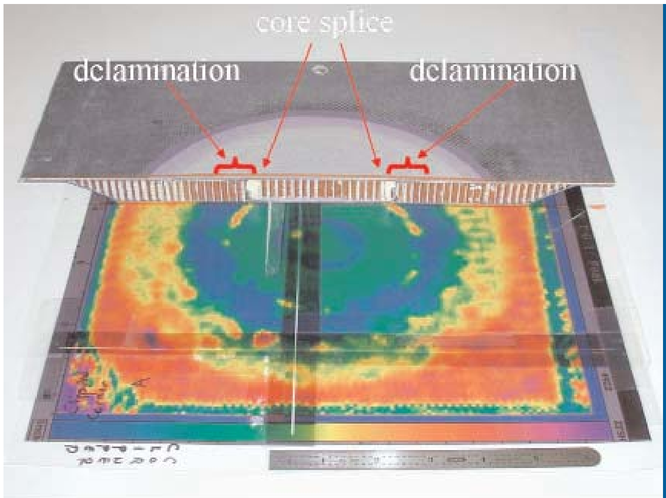
CASR researchers are well grounded in the physics of the inspection process and, in many cases, use an extensive model base that has been established at Iowa State University. Currently the FAA is partnered with the U.S. Air Force and NASA in supporting the Model Assisted Probability of Detection (MAPOD) Working Group. Probability of Detection (POD) is the metric that researchers use to judge the effectiveness of a NDI technique. Typical, they use empirical measurements, which require a large and often expensive sample set. Through the use of physics models, more effective POD studies can be completed, because the models require fewer samples, increasing the use of POD through the reduction in cost. The FAA-funded portion of the program partners Iowa State University with Cessna in the evaluation of eddy current inspection methods and models for airframe components.

Iowa State's expertise in ultrasonic inspection is assisting several airlines with landing gear inspections. In this project, a combination of modeling and experimental design is being used to address the complexities of typical landing gear components. The gear in question is currently inspected with magnetic particle at very short intervals. Upon completion of the ultrasonic procedure, a smaller flaw size should be detectable leading to a safer inspection at less frequent intervals.

State-of-the-art experimental facilities are also a key part of Iowa State's support to the FAA. One project that takes advantage of the experimental capabilities and the data analysis experience is the Fluorescent Penetrant Inspection (FPI) Engineering Studies program. For this program, Iowa State University is partnered with Boeing Commercial Aircraft, Boeing Phantom Works, Delta Air Lines, United Airlines, Rolls Royce, Pratt & Whitney, General Electric Aviation, Honeywell, D&W Enterprises, and Sherwin, Inc., to generate engineering data for the various steps in the FPI process. FPI is a widely used inspection method in which a penetrating fluid containing special dyes is applied to the surface of the part. The fluid enters surface breaking flaws that are clean and dry through capillary action. A series of steps are used to remove the excess fluid from the surface, and then a developer which draws the fluid containing the fluorescent dyes is applied. The part is inspected under black light which exposes the fluorescing cracks. Each of the steps in the FPI process is dependent on the successful execution of previous steps and a variety of parameter combinations are possible. The FAA-funded program is evaluating the various parameters to determine which are most critical to detectability and therefore require more strict controls. The results of the program are being used to update industry specifications such as the SAE - AMS 2647 document. A subset of the team won the 2004 ATA-FAA Better Way Award.

Iowa State researchers have also developed enhancements that have improved traditional inspection methods. By first working closely with the airlines and repair stations, researchers identify need and then design tools to address those needs. An example from the early 1990s was the development of the dripless bubbler, a device which enabled ultrasonic immersion inspection to be performed in a hangar environment. This type of device is now offered as an option on some commercial devices today. More recently, university researchers developed a computer aided tap tester, which quantifies the stiffness of composite structures and provides an image of the damaged locations. This device is commercially available. Today they are working on generic scanning devices that can be combined with hand-held inspection instruments already in use by the airlines. The combination of existing NDI equipment with inexpensive position tracking technology will enable users to generate scanned images which are much more intuitive to interpret. Several beta-site units are in place, including one at United Airlines. Based on the results of this FAA-funded program, the U.S. Air Force and Navy have also funded the university to develop similar applications for military components.

In addition to technology developments, Iowa State University has also produced several educational tools, such as the materials currently used for the NDI course at the FAA Training Academy.



This figure shows a repaired composite test panel that was cross sectioned and compared with the color image which came from an ultrasonic imaging method developed by Iowa State.

Research at Wayne State University has focused on developing and applying thermal imaging techniques to detect a variety of flaws in aircraft. In early efforts at the university, researchers used a pulsed thermography or thermal wave approach to inspect aging aircraft for areas of disbonding of both bonded metal-to-metal joints and skin-to-core inspection of composites. In pulsed thermography, flash lamps are used to heat the part being inspected and an infra-red (IR) camera is used to monitor the heat dissipation at the inspection surface. Depending on how the heat dissipates, an inspector can determine whether a bonded joint has failed. Based on this FAA-funded research, the FAA ha approved the thermal wave imaging technique developed by Wayne State as a general method to inspect all Boeing bonded fuselage doublers. Likewise, the FAA has approved a similar method to assess damage and repairs of composite flight controls and secondary structures.

A more recent area of thermal research developed by Wayne State is called Thermosonics or Sonic IR Imaging. In this method, a short burst of sound energy is introduced into a part being tested as an IR camera views the surface. The sound energy causes localized frictional heating as crack tips (fracture surfaces) and other damage areas such as disbonds and delaminations rub together, causing an increase in temperature that is detectable by the IR camera. In tests conducted to date, thermosonics has shown great promise as a crack detection technique and as a possible replacement or complementary inspection to fluorescent penetrant method. Aging aircraft inspection researchers at Northwestern University have been largely engaged in developing ultrasonic testing procedures to detect cracks and corrosion in multi-layer aluminum aircraft structures. As long as the layers are separated by sealant, ultrasonic sound energy can pass from one layer to the other, enabling defects in any of the layers to be detected. With the help of the FAA Airworthiness Assurance NDI Validation Center (AANC) and industry partners, including airlines and airframe manufacturers, researchers have successfully used this approach several times to detect defects deep in layered structures. In one application for the DC-9, the wing attachment, known as the T-cap, could be inspected for cracks and corrosion externally from the underside of the wing, reducing the inspection time significantly from 800 to 40 man-hours per wing. Additionally, this inspection provided a more sensitive and thorough examination as well. Researchers also developed related applications for the Metro 226/227 commuter airplane, DC-10, and Boeing 777 aircraft. The U.S. Air Force adopted a similar approach to inspect their C-141 wings.

Recent enhancements to the ultrasonic methods at Northwestern have resulted in the development of dry-coupled transducers that transmit and receive sound energy into a test part without the need for a liquid couplant. This allows faster and easier inspections to be accomplished, especially when scanning large areas. Another ultrasonic testing enhancement promoted by Northwestern University researchers is the use of B-scan imaging when using inexpensive hand-held flaw detection instruments. B-scans present the user with more information by providing a cross-sectional view of the part under test - a tool not yet widely used through the industry.

As evidenced by the variety and depth of the various projects, the CASR program has demonstrated their value to the FAA and the aviation industry. R&D Review

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Details of the CASR program are available at http://www.cnde.iastate.edu/faa-casr/index.html.

Mechanical Systems

Mechanical Systems

The Federal Aviation Administrations Flight Controls and Aging Mechanical Systems Project is tasked to develop technologies, technical information, procedures, and practices to help ensure the continued airworthiness of aircraft flight controls and mechanical systems. Under this mission, the project has initiated a variety of research tasks.

A major four part effort is underway to evaluate the current design and pilot use of airplane rudders; this research is known simply as the Rudder Study. For the first task of this research, completed in 2005, researchers conducted an extensive literature review to gather all pertinent information and to further develop the approach to the project. Task II, scheduled for completion in the fall of 2006, is a survey of airline pilots to determine actual pilot experiences, rudder usage, and training. In Task III, completed in 2005, researchers conducted a human-in-the-loop desk-top simulation to provide background information for the development of Task IV, real time piloted simulation.

For Task IV, the FAA will use a high fidelity flight simulator to subject pilots to various flight conditions where rudder use may or may not be necessary. By evaluating pilot responses and analyzing related data, the FAA will determine if corrective actions, such as updated pilot training or rudder design criteria, are necessary.

Additional research tasks designed to ensure the continued safe operation of mechanical systems include the development of a methodology to determine which systems may be in jeopardy of failing. According to project manager Robert McGuire, "The FAA is currently working with aircraft manufacturers to develop a methodology to enable operators to evaluate various mechanical systems to anticipate or prevent failures that may occur with age. However, to do this it is important to keep in mind how aging components and systems interact with new, refurbished, and reconfigured systems and components."

Another research task within this project focuses on single element, dual load path flight control linkages, which contain a primary and a secondary (redundant) load path. These safety-critical control linkages connect various actuators to control surfaces. These parts are designed to last the life of the aircraft. They can be integrated or co-located, but in either configuration the secondary load path may be difficult if not impossible to inspect visually.

"Highly complex mechanical systems, such as the flight control linkages, are subject to failure modes that may be difficult to anticipate," states McGuire. "The FAA uses a fail-safe design concept to certify large transport aircraft systems. This approach is intended ensure that any failure with catastrophic consequence is extremely improbable, and the failure of any system that might reduce the ability of the crew to deal with adverse operating conditions is improbable. Despite certification regulations that require designers to take the probabilities of multiple failures and undetected failures into account, failures can still occur."

In cooperation with Boeing, the research team is assessing single element, dual load path linkages from primary flight control systems on recently-retired Boeing 737 and 747 commercial aircraft. The researchers have identified 21 dual load path linkages, and acquired three of each from the aircraft for testing. At times aided by a fiberscope, they have visually inspected each component in three stages: as installed on the aircraft; after removal and cleaning; and when completely disassembled. The team has looked for any visual signs of erosion, corrosion, excessive wear, cracks, impact damage, or other signs of mechanical degradation, and inspected some components against the manufacturer's specifications. Researchers plan to acquire additional aged dual load path inspection specimens to increase the current database.

The FAA has acquired a vintage Boeing 747-136 and installed it as a mechanical systems test bed the FAA Airworthiness Assurance Nondestructive Inspection Validation Center. Researchers will use this test bed to test and evaluate a variety of mechanical systems. The test bed is available to anyone interested in conducting research or tests on airplane systems.

Future projects may include research into envelope protection for general aviation aircraft, highly integrated flight critical systems architecture, regulatory requirements for fly-by-wire components, and advanced guidance and control safety systems. R&D Review

For additional information on the FAA mechanical systems research program, please visit http://aar400.tc.faa.gov/Programs/AgingAircraft/agingsystems/mechanicalsystems/index.htm.

Hot off the Press!

FAA's Latest Technical Reports

Sean Kelley and George Johnson STATISTICAL TESTING OF AIRCRAFT MATERIALS FOR TRANSPORT AIRPLANE ROTOR BURST FRAGMENT SHIELDING

Fragment barrier systems are being examined and developed for commercial airplanes to prevent accidents as a result of an engine rotor burst failure. To use this system, an understanding of how the existing aircraft materials behave under ballistic impact. The material responses of 0.063, 0.125, and 0.25-in-thick 2024 aluminum, 0.25-in-thick Makrolon® polycarbonate, and sandwich composite panels were investigated under ballistic impact is required. Failure modes were evaluated and ballistic limits obtained for each set of targets. The testing was done in the UC Berkeley Ballistics Laboratory using a gas gun and a powder gun setup with a 1/2-inch diameter chrome steel spherical projectile. This report documents the testing and analysis of the UC Berkeley ballistic testing. The testing yielded excellent results on aluminum, but more data is needed for titanium, composites, and polycarbonate materials.

David Blake DEVELOPMENT OF A STANDARDIZED FIRE SOURCE FOR AIRCRAFT CARGO COMPARTMENT FIRE DETECTION SYSTEMS

This report documents the development and testing of a standardized fire source for cargo compartment fire detection systems. Currently, these fire sources cannot be used in actual certification flight tests. The intent of this work was to define a fire source in terms of heat release rate, mass loss rate, and smoke and gas species production rates, and then devise a safe method to simulate whichever aspect of the fire signature the particular detection system was designed to respond to in the certification tests. This could be done singly or in some combination with smoke generators, heat guns, and the controlled release of actual or surrogate gas species. This report discusses how this fire source is used in a computational fluid dynamics model to predict the transport of smoke, gases, and heat throughout a cargo compartment. The testing concluded that the fire source used in a simulated smoldering fire mode does not produce a fire signature that would be useful in developing multicriteria fire detectors with a better capability to resist false alarms. This report also documents the amount of smoke that would be detectable in various size cargo compartments and the responses of aircraft smoke detectors currently in-use from the simulated smoldering and flaming fires.

Tim Connelly and Chuck Teubert AIRSIDE APPLICATIONS FOR ARTIFICIAL TURF

A study to investigate the considerations and concerns associated with airside applications of artificial turf was conducted using input from the artificial turf manufacturers and by administering and discussing questionnaire surveys via site visits to airports. These site visits were scheduled with some airports that already had installed artificial turf plots and during the installation of artificial turf plots at other airports.

To address the safety concerns and performance expectations of airside artificial turf installations, several tests were done. The majority of the tests performed to date were to quantify the artificial turf product. During the airport surveys, airport personnel were asked what concerns they had with an artificial turf installation. The results of the surveys and discussions with airport personnel indicated that the main reasons for considering artificial turf are for safety, soil erosion mitigation, and foreign object debris reduction. Additional and secondary considerations for the use of artificial turf were found to be abatement of turf management (i.e., low maintenance), jet blast erosion, wildlife control, and visual enhancements. ▶

Hot off the Press!

James W. Patterson INSTALLATION CRITERIA FOR TAXIWAY CENTERLINE LIGHTS

The Federal Aviation Administration (FAA) Advisory Circular (AC) 150/5340-30, "Design and Installation Details of Airport Visual Aids," requires that properly installed taxiway centerline fixtures should, when placed on a taxiway curve with radii between 75 and 399 feet, maintain that three lights are visible from the cockpit, provide information to the pilot on how sharp the curve is, provide the pilot with an indication of how far off the taxiway centerline the aircraft might be, and visually look the same from both directions of travel.

Typically, the FAA type L-852D taxiway centerline fixture is spaced at 12.5 feet when placed on a taxiway curve with radii between 75 and 399 feet. The International Civil Aviation Organization (ICAO) version of the taxiway centerline fixture, which is designed specifically for curved applications, is spaced at 25 feet when placed on the same taxiway curve.

The objective of this research was to determine what would happen if the FAA type L-852D taxiway centerline fixture was placed at a spacing of 25 feet; the same spacing as the ICAO fixture.

Steven M. Summer THE FIRE SAFETY HAZARD OF THE USE OF FLAMELESS RATION HEATERS ONBOARD COMMERCIAL AIRCRAFT

While it is well established that the shipment of a large quantity of flameless ration heaters poses a significant fire safety risk, this report examines the potential hazard associated with the use of these flameless ration heaters in an aircraft cabin and with the accidental activation of them in a confined area aboard an aircraft, such as in overhead storage bins or a cargo compartment.

Tests were performed both with individual Meals, Ready-to-Eat containing flameless heaters in an open environment and multiple Meals, Ready-to-Eat in a confined space to examine their potential hazard. Temperatures in excess of 215 F and violent ignition events were observed. Results from the tests performed confirm that the release of hydrogen gas from these flameless ration heaters is of a sufficient quantity to pose a potential hazard on board a passenger aircraft. R&D Review

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Critical Research for Aviation's Future