Research and Development

Highlights
2002

U.S. Department of Transportation
Federal Aviation Administration

Airport and Aircraft Safety R&D Division
William J. Hughes Technical Center
Atlantic City International Airport, New Jersey 08405

FOREWORD

As the nation's premier research organization for aviation technology, the Federal Aviation Administration's (FAA) aircraft research and development (R&D) program has made significant contributions to assure the safety, efficiency, and cost-effectiveness of the national aviation system. Today that system is under heavy pressure to keep pace with rising traffic demand, needs for essential safety and security improvements, airspace user requirements for more flexible and efficient air traffic management operations, and demands for further mitigation of the environmental impacts of aircraft operations. To meet these future challenges, the FAA employs a comprehensive research, engineering, and development program that assures all available resources remain customer-focused and targeted on the highest priority activities.

The fundamental mission of the FAA is to foster a safe and efficient air transportation system. With respect to safety, the FAA's goal is to establish an operating environment that promotes an error-free system that produces no accidents or fatalities. The mission of the Airport and Aircraft Safety R&D Program is:

> *To provide a safe global air transportation system by developing technology, technical information, tools, standards, and practices to promote the safe operation of the civil aircraft fleet.*

This report contains highlights of the major accomplishments and applications that have been made by Airport and Aircraft Safety researchers and by our university, industry, and government colleagues during the past year. The highlights illustrate both the broad range of R&D activities supported by the FAA and the contributions of this work in maintaining the safety and efficiency of the national aerospace system. The report also describes some of the Division's most important research and testing facilities, considered to be some of the most scientifically advanced in the world. For further information regarding this report, contact Mr. Jason McGlynn, jason.mcglynn@faa.gov, Technical Publications Editor, AAR-400, FAA William J. Hughes Technical Center, Atlantic City International Airport, NJ 08405, (609) 485-6420.

Chris C. Seher
Director

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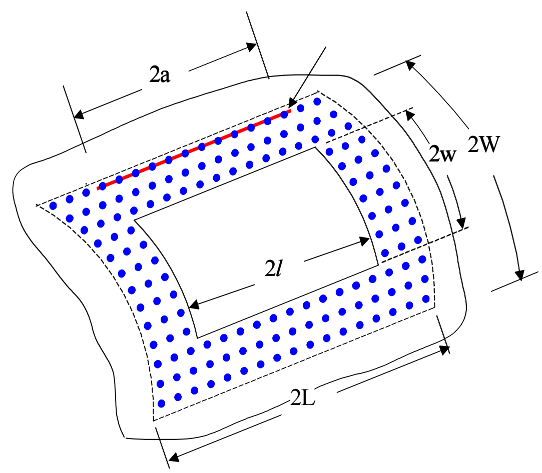
Structural Integrity



Airborne Data Monitoring Systems

The Code of Federal Regulations (CFR), Aeronautics and Space, Airworthiness Standards are replete with loads criteria, much of which were generated prior to deregulation and in some cases prior to the design of both wide-body and fly-by-wire civil aircraft. With the existence of (1) new technology, (2) newer operating rules and practices, and (3) the anticipation of double the air traffic within 10 years, a need exists to develop and implement a system to continuously validate and update the operational flight and ground loads airworthiness certification standards based on actual measured usage.

A research program that provides a continuous supply of new in-service operational loads data is needed to ensure the appropriateness of the certification process for structural strength and fatigue life and to identify changes in service usage trends. New flight loads data needs to be collected for major airplane configurations including twin engine on wing, twin engine in rear, wide bodies, airplanes with digital flight controls, regional jets, turboprops, and general aviation. Substantial quantities of large transport landing loads data, principally touchdown vertical velocity, are also needed for a wide variety of airports and airplane model types (see figure 1).

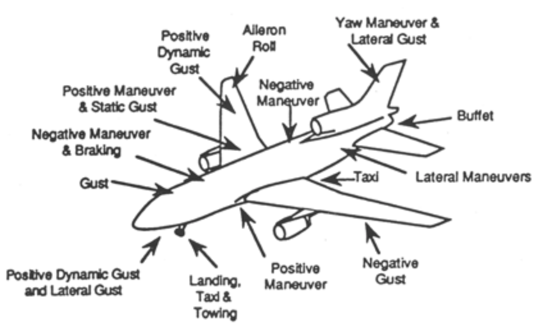


Figure 1. External Loads Imposed on a Commercial Aircraft

By taking advantage of newer technologies and improving, as well as enhancing, both the data acquisition and analysis process, safer and more optimally designed transports will continue to be made possible in the future.

The Federal Aviation Administration has re-established an Operational Loads Monitoring Program, which includes both flight and landing loads data collection on civil transports. The FAA Technical Center's landing data acquisition facility is shown in figure 2.

Figure 2. FAA Technical Center's Video Landing Survey Facility

Technical Support for Aviation Rulemaking Advisory Committee (ARAC) Loads and Dynamics Harmonization Working Group: The FAA Operational Loads Monitoring team provided specialized operational loads data and analysis to ARAC to develop recommendations for the following certification criteria for the A-380 airplane: (1) 14 CFR 25.473 Ground Load Conditions, Limit Descent Velocity at Design Limit Landing Weight and (2) 14 CFR 25.495, "Turning," Limit Side Load Factors.

Sink speed data at touchdown, collected during video landing parameter surveys at JFK International, Honolulu International, and Heathrow International, were merged into a single database and presented to the ARAC for assessing whether (or not) to increase the limit load design sink speed of 14 CFR 25.475 above the stated 10-ft/sec level for the new generation of super-heavy, wide-body airplanes. Speculation at this time is that, based on these data, the ARAC harmonization membership will vote to retain the 10-ft/sec limit sink speed for the A-380, while at the same time strongly recommending a sink speed fatigue spectrum at or near to the MIL-A-8863 values shown in figure 3.

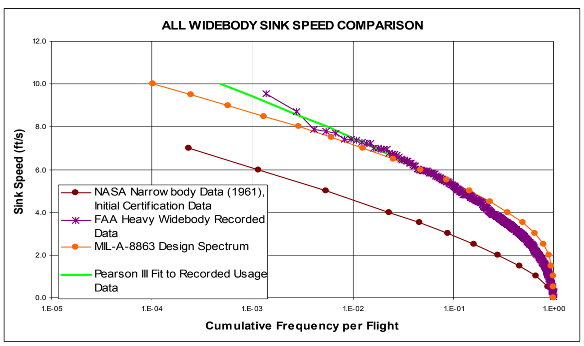


Figure 3. Comparison of Sink Speed Frequency per Flight for all Surveyed Wide-Body Aircraft

The ARAC subcommittee was also tasked to assess the suitability of using the 0.5-g ground turning lateral load as specified in 14 CFR 25.495 for the planned Airbus A-380 airplane. The FAA researchers acquired and processed ground turning side loads data from B-737, A-320, MD-82, B-767, and B-747 airplanes to determine if a correlation existed between airplane size and ground turning lateral acceleration. The technical paper "Development of a Normalization Procedure for Lateral Load Factors Due to Ground Turning" written by the University of Dayton Research Institute (UDRI) under FAA funding clearly indicated that there existed a significant trend for lower lateral acceleration during ground turn for the airplanes with the larger landing gear. Consequently, the results from this research assisted the ARAC subcommittee to recommend a special case of 0.42-g lateral acceleration certification limit load replacing the 0.5-g limit for ground turns. The ARAC subcommittee will continue to investigate subject usage data and corresponding UDRI research results to determine if a rule recommendation should be made to correlate lateral limit load certification criteria to airplane size and landing gear geometric configuration.

A-320 Data Report: The FAA published an operational loads monitoring report DOT/FAA/AR-02/35, "Statistical Loads Data for the Airbus A-320 Aircraft in Commercial Operations." This report presents flight and ground loads data obtained from 56 Airbus A-320 aircraft representing 10,066 flights and 30,817 hours of airline operations from one U.S. carrier. The onboard data collection system for the Airbus A-320 (see figure 4) consists of a Digital Flight Data Acquisition Unit (DFDAU), a Digital Flight Data Recorder (DFDR), and an Optical Quick-Access

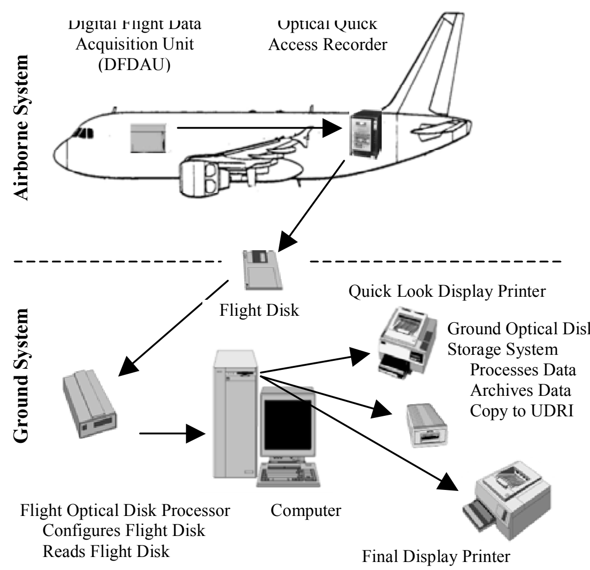


Figure 4. Operational Flight Loads Data Monitoring System

Recorder (OQAR). The DFDAU collects sensor signals and sends parallel data signals to both the DFDR and the OQAR. The OQAR is equipped with an optical disk, which can store up to 300 hours of flight data, whereas the DFDR uses a 25-hour loop tape. The optical disk is periodically removed from the OQAR and forwarded to the ground processing station.

Statistical data are presented on the aircraft's usage, flight and ground loads data, and systems operations. The data presented in this report provide information about the accelerations, speeds, altitudes, flight duration and distance, gross weights, speed brake/spoiler cycles, thrust reverser usage, and gust velocities encountered by the Airbus A-320 during actual operational usage. These statistical data provide the FAA, aircraft manufacturers, and the operating airline with the information that is needed to assess how the A-320 aircraft is actually being used in operational service versus its original design or intended usage. These data are used by the FAA to (1) evaluate existing structural certification criteria, (2) improve requirements for the design, evaluation, and substantiation of existing aircraft, and (3) establish design criteria for future generations of new aircraft. The aircraft manufacturer uses these data to assess the aircraft's structural integrity by comparing the actual in-service usage of the A-320 aircraft versus its originally intended design usage.

While current program research efforts are tailored primarily to support the FAA and the aircraft structural design community in evaluating design criteria related to the strength, durability, and damage tolerance of the basic airframe structure, much of the data that are available, when provided in meaningful statistical formats, can provide the aircraft operator with some valuable insight into how his aircraft and aircraft systems are being used during normal flight and ground operations.

Gust Specialists Workshop: The FAA conducted a Gust Specialists workshop that brought together over 40 international specialists to review the results of a number of recently completed research studies and to propose and discuss new research. The Statistical Discrete Gust approach was selected as the most appropriate procedure for modeling the gust response for aircraft with nonlinear control systems. One final workshop to document this process will be linked with a future ARAC meeting during the spring of 2003.

Operational Loads Monitoring Website: An improved website has being established that more fully describes subject research and will permit the downloading of electronic copies of all loads technical reports. Website address is: http://aar400.tc.faa.gov/aar-430/airborne-data/

Thomas DeFiore, AAR-480, (609) 485-5009

Statistical Loads Data for the Airbus A-320 Aircraft

University of Dayton, under contract to the FAA, completed the collection and analysis of over 10,000 flights of A-320 aircraft in commercial operation. The data, representing 30,817 hours of aircraft operation by a single U.S. operator, include flight and ground loads and operational data including accelerations, speeds, altitudes, flight duration and distance, gross weights, speed brake/spoiler cycles, thrust reverser usage, and gust velocities.

The Airbus A-320 is the first subsonic commercial aircraft equipped with fly-by-wire control throughout the entire flight envelope, and the first aircraft to have sidestick controls instead of the standard control column and aileron wheel. The fly-by-wire system controls ailerons, elevators, spoilers, flaps, leading-edge devices, engine thrust, and rudder and tail surface trim. The flight control system incorporates features that will not allow the aircraft's structural limits to be exceeded regardless of pilot input.

The airline data collection and editing system consists of two major components: (1) the data collection system installed onboard the aircraft and (2) the ground data editing station. The onboard collection system consists of a Digital Flight Data Recorder and Optical Quick Access Recorder (OQAR). The OQAR is equipped with an optical disk that can store up to 300 hours of flight data. The ground editing consists of a data integrity check and routine removal of any nonessential information deemed sensitive by the airline.

The 118 statistical data formats presented in the final report "Statistical Loads Data for the Airbus A-320 Aircraft in Commercial Operations," DOT/FAA/AR-02/35, published in April 2002, provides the FAA, airlines, and aircraft manufacturers with a detailed characterization of the A-320s in-service usage. The statistical data presented in the report demonstrated that the operational ground and airborne usage of the A-320 aircraft is similar to other large transports such as the Boeing 767, 737, and the MD-82/83 aircraft. However, there were instances, such as shown in figure 1, where the A-320 appeared to be operating very close to or slightly in excess of its structural and operational limits.

Thomas DeFiore, AAR-480, (609) 485-5009

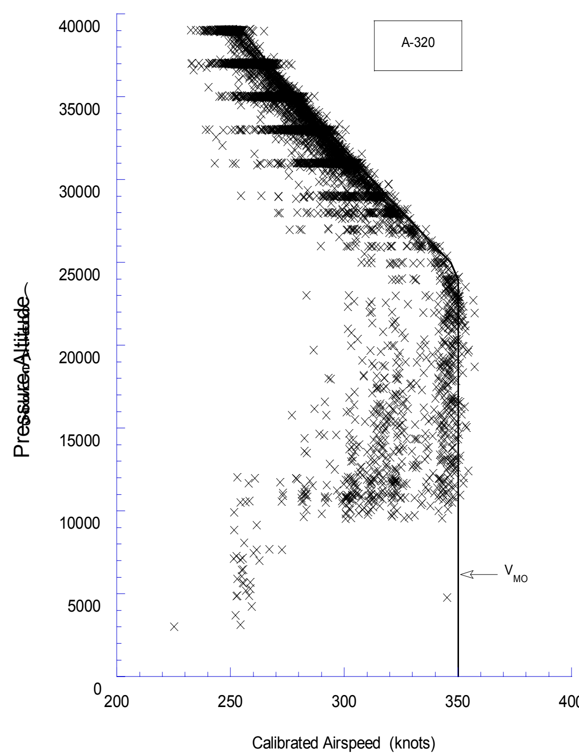


Figure 1. A-320 Aircraft Operational Data, Maximum Calibrated Airspeed and Coincident Altitude, All Flight Phases

Composite Material Control and Standardization

The material properties of composite structures are manufactured into the structure during the manufacturing process. Material procurement and processing specifications used to produce composite materials must contain sufficient information to ensure that critical process parameters are identified. This will assure production reliability of composite materials and adherence to expected part performance standards. Due to the wide variety of composite structures now emerging for certification, control of the materials is rapidly becoming a vital issue with respect to the overall assurance of safety.

In recent years, NASA, the FAA, and industry have worked together to develop a cost-effective method of qualifying composite material systems by sharing central material qualification databases such as MIL-HDBK-17 and the Advanced General Aviation Transport Experiment (AGATE). Through these shared databases, a manufacturer can select an approved composite material system to fabricate parts and perform a smaller subset of testing to a specific application (see FAA technical report "Material Qualification and Equivalency for Polymer Matrix Composite Material Systems," DOT/FAA/AR-00/47).

For materials to be accepted into these shared databases, all materials are required to be:

- Manufactured in accordance with a material specification that imposes control of the key physical, chemical, and mechanical properties.
- Processed in accordance with a process specification that controls key processing parameters.

Currently, the guidelines for creating the material and process specifications are not available as a single reference source. The information is spread between numerous technical reports, general industry knowledge, and lessons learned on individual programs. See figure 1 for a typical documentation process for certification.

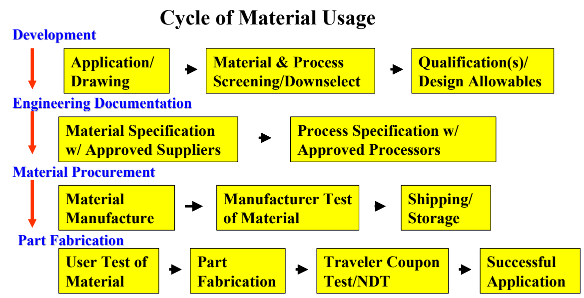


Figure 1. Life Cycle for Composite Materials

To assist the effort to standardize engineering protocol, the FAA has identified the essential information required for the development of composite material procurement and processing specifications. The current focus is on polymer matrix prepreg composite materials such as carbon/graphite and glass. This will be expanded as other material and process combinations emerge.

The research is focused towards promotion of standardized material procurement and processing specifications. The objective of this project is to develop standard specification requirements that will meet the FAA's needs for accepting material procurement and processing specifications as part of a certification program. The research will establish a set of controls and tests on the production and fabrication process of composite materials to assure that a consistent and reliable product is produced and accepted for use in aviation applications. The project goals are:

- To greatly reduce the number of material and process specifications for identical composite material systems by using shared databases.

- To enhance the safety of composite structures by establishing guidelines for material and process specifications that will control key characteristics and produce stable properties.

- To eliminate the extra design costs associated with duplicative composite material testing and producing material and processing documentation requirements.

All criteria for materials procurement specifications and material fabrication specifications were identified based on known quality assurance methodology. Advanced technology areas were recognized that require quality assurance method development. These include additional manufacturing and fabrication process controls, and advanced inspection methodologies to consistently and reliably control composite products.

Material specification information includes recommendations and guidelines for basic fiber, matrix, and cured component characteristics; chemical, mechanical, and physical properties; safety and health information; transportation, storage, and handling; and testing including type, number, and frequency of tests. Processing information includes recommendations for fabrication method control and environmental conditions, inspection criteria at each operation, storage and handling throughout the process, process controls, materials, test specimen construction and processing, personnel qualifications, and tool proofing control.

Two draft documents with the recommended information and criteria for inclusion in composite materials procurement and processing documents were generated this year. These documents were a collection of the experiences of a group of industry composite professionals and FAA composite specialists. The two drafts were developed through the efforts of AAR-450 under a contract to Wichita State University.

A workshop to solicit industry comments from material suppliers and original equipment manufacturers was held in August 2002. The workshop was the first step towards creating a proposed policy and rulemaking by the Small Airplane Directorate. The participants critiqued two drafts of recommendations and guidelines to develop material and process specifications for composite materials.

The comments on the two draft documents will be addressed before they are published as:

“Guidelines and Recommended Criteria for the Development of a Material Specification for Carbon Fiber/Epoxy Unidirectional Prepregs,” DOT/FAA/AR-02/109

“Guidelines for the Development of Process Specifications, Instructions, and Controls for the Fabrication of Fiber-Reinforced Polymer Composites,” DOT/FAA/AR-02/110

Curtis Davies, AAR-450, (609) 485-8758

Bulging Effects on Longitudinal Cracks in Lap Joints of Pressurized Aircraft Fuselage

Longitudinal cracks in pressurized aircraft fuselage structures are subjected to complex stress and displacement fields resulting in nonlinear out-of-plane deformations. The response of such cracks is characterized by large out-of-plane deformations or bulging of the surfaces of the crack, as illustrated in figure 1. The so-called bulging effect can significantly elevate the stress-intensity factor (SIF) at the crack tip and reduce the residual strength. One way to measure the bulging effect is by the bulging factor, which is the ratio of the SIF of a longitudinal crack in the curved fuselage to the SIF for the same crack in a flat panel. The damage tolerance design philosophy requires determination of realistic stress state in the vicinity of cracks in airframe fuselage structure. However, most studies of bulging effects are for idealized unstiffened shells. Few studies have been conducted to study the significance of bulging effects on cracks in lap joints of aircraft fuselage structure and the consequence of not including these effects in the stress predictions and subsequent damage tolerance analysis. An area of particular concern is the critical rivet row in a longitudinal lap splice joint, 1 of the 16 critical areas identified by the Airworthiness Assurance Working Group as having the potential for multiple-site fatigue crack initiation.

A study was undertaken to examine the effects of bulging of a mid-bay crack in the critical row of a longitudinal lap splice joint. A typical three-rivet row lap joint configuration, which contained a mid-bay crack in the critical rivet row, was analyzed. The bulging factors were calculated using a nonlinear finite element analysis. The SIF at the crack tip was calculated using the Modified Closure Integral method. Parametric studies were done to examine the effects of crack length, applied pressure, and stiffening elements (stringers and frames) on the bulging factor.

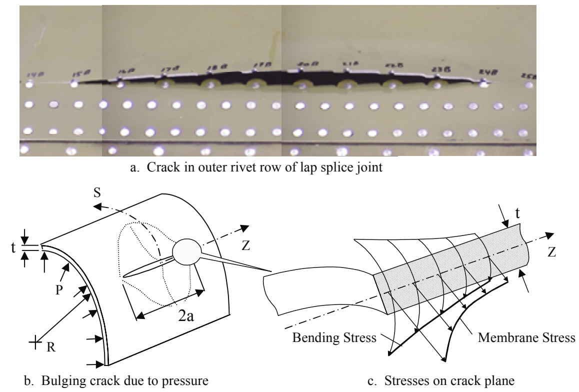


Figure 1. Crack Bulging Phenomena

In general, results show that the bulging phenomenon occurred in the typical longitudinal lap joint considered, even with stiffening elements. Figure 2 shows representative results from the study. For the configurations analyzed, bulging factors were the highest for the unstiffened case and were reduced with each additional stiffening element. In all cases, the lap joint provided some stiffening effect, reducing the bulging factor compared to the baseline case.

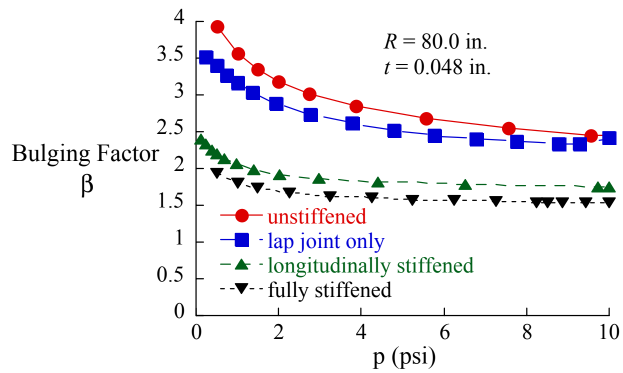


Figure 2. Bulging Factor for the Configurations Analyzed

For short cracks (cracks much smaller than the stringer spacing), a near-constant response was obtained for the bulging factor as a function of the applied pressure. The presence of the stiffeners only slightly reduced the bulging factor for the shorter cracks. The cracks were too small and too far from the stringers to be affected by the stiffening elements. For longer cracks, the bulging factor varied nonlinearly as a function of the applied pressure, and the presence of the stiffeners significantly reduced the bulging factor.

John Bakuckas, AAR-450, (609) 485-4784

Initiation and Distribution of Fatigue Cracks in a Fuselage Lap Joint Curved Panel

A study was conducted on the formation and evolution of multiple-site damage (MSD) emanating from the rivet holes in the lap joint of an initially undamaged full-scale fuselage curved panel subjected to fatigue loading. The experimental work was conducted at the Full-Scale Aircraft Structural Test Evaluation and Research (FASTER) facility located at the Federal Aviation Administration William J. Hughes Technical Center, Atlantic City International Airport, New Jersey. The objective of this test was to characterize initiation, distribution, and linkup of MSD cracks. Quasi-static tests were conducted first to ensure a proper load introduction to the panel. Test results showed a large bending deformation locally along the critical outer rivet row in the lap joint area. The experimental data were compared to predictors made using geometrically nonlinear finite element analyses.

The curved panel was subjected to a fatigue loading with a marker band spectrum. During the fatigue test, rivets in the panel were periodically inspected for cracks using a nondestructive eddy-current system and by visual inspection. High eddy-current signals were recorded at rivets along the critical outer rivet row of the lap joint prior to visual detection of skin cracks. The typical damage development in the outer row of the lap joint is illustrated in figure 1 with a series of photographic images. The full-load cycle number at which each image was taken is also shown in the figure. Damage in the rivet was first observed in the form of a rivet head crack.

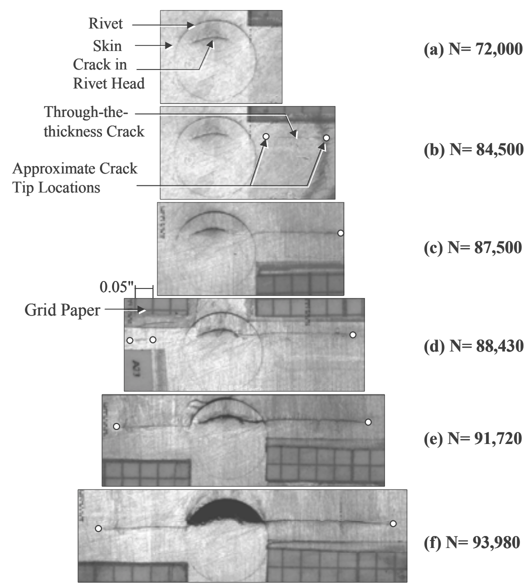


Figure 1. Crack Growth Process in Outer Critical Rivet Row

Subsequently, the crack grew along a curved path that seemed to follow the perimeter of the rivet stem, figure 1(a). Water leakage from this crack indicates that it was a through-the-thickness crack. It is noted that the loading used in this study is much higher than what a fuselage would experience during normal service conditions. The rivets are not designed to sustain such high fatigue loads. Thus, it is believed that the rivet head crack initiated at the rivet shank-countersink interface due to the stress concentration in that area and propagated upwards to the surface. As the fatigue test continued, a through-the- thickness crack appeared on the right side of the rivet. The through crack grew in both directions and eventually linked up with the rivet hole, figure 1(c).

At a later stage, another through-the-thickness crack appeared on the left side of the rivet, figure 1(d). This crack also grew in both directions and linked up with the rivet hole, figure 1(e). Finally, the rivet head crack propagated to the edge of the rivet hole and joined the other two cracks to form a major crack that cuts through the rivet itself, figure 1(f). A similar damage evolution process was observed at the rivets in the outer row. Other MSD cracks were observed at rivets holding the shear clips to the skin at the shear clip cutouts located at the frame stringer intersections.

Crack growth rates were calculated for two sets of MSD cracks, results agreed very well with those from other similar studies. Results obtained in this study, although for longer crack lengths and different joint and panel configurations, follow the trend of the data very well, as shown in figure 2. This indicates that the fatigue cracks from the three different studies grew at similar rates.

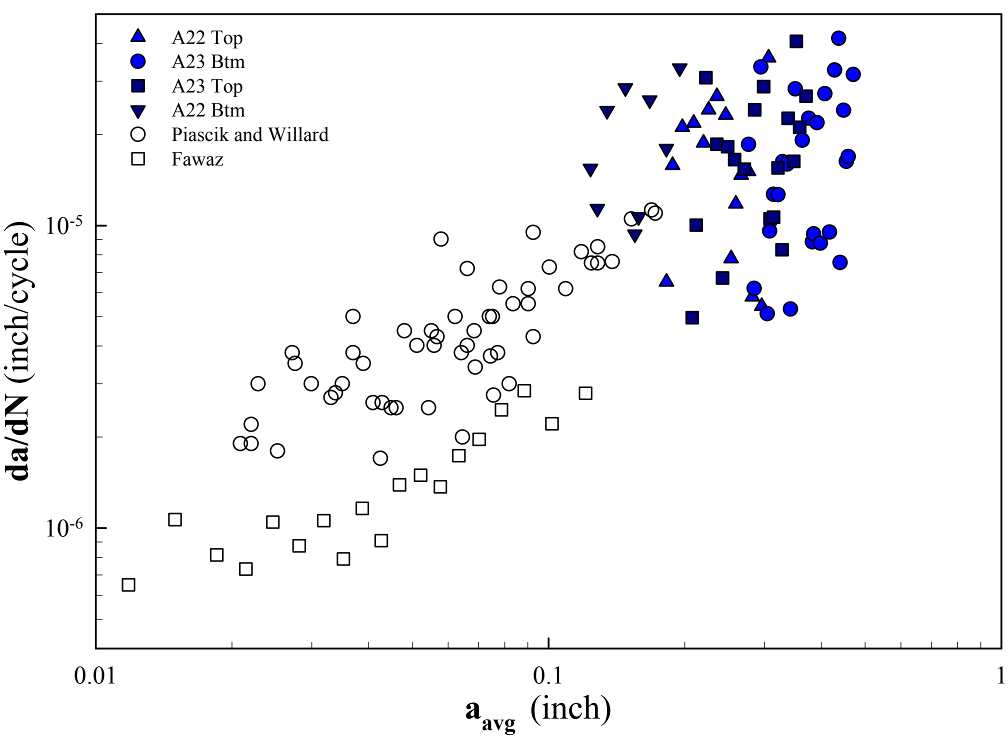


Figure 2. Fatigue Crack Growth Characteristics

These MSD cracks eventually linked up to form a large lead crack as shown in figure 3. In the figure, a schematic is provided of the crack path along the outer rivet row between frames 2 and 3. The first crack linkup occurred between rivets designated A22 and A23 after 106,217 cycles. The lead crack then grew very rapidly. After 107,448 pressurization cycles, the MSD evolved into a 16″ two-bay crack through rivets designated A17 and A27.

The panel was then subjected to quasi-static pressurization up to failure to measure the residual strength. The panel failed catastrophically at 17.8 psi pressure along the outer rivet row exhibiting no crack turning (flapping) or arrest capability. As shown in figure 4, the crack grew across five frames designated F2 through F6. In addition, frames 3, 4, and 5 were fractured. Data from this test will be used to calibrate and validate methodologies to assess widespread fatigue damage (WFD). Posttest fractographic studies will be conducted to reconstruct and map the crack growth histories.

John Bakuckas, AAR-450, (609) 485-4784

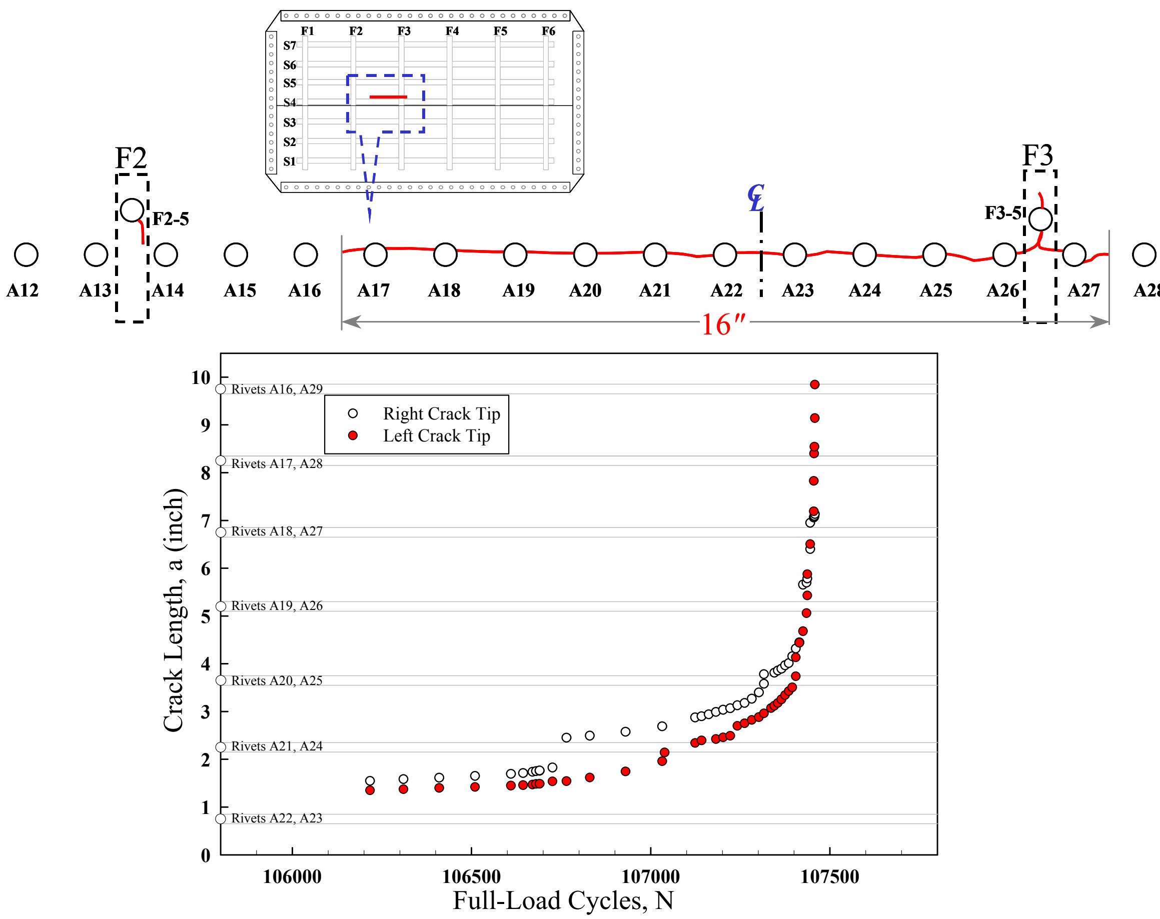


Figure 3. Lead Crack Length as a Function of Fatigue Cycles

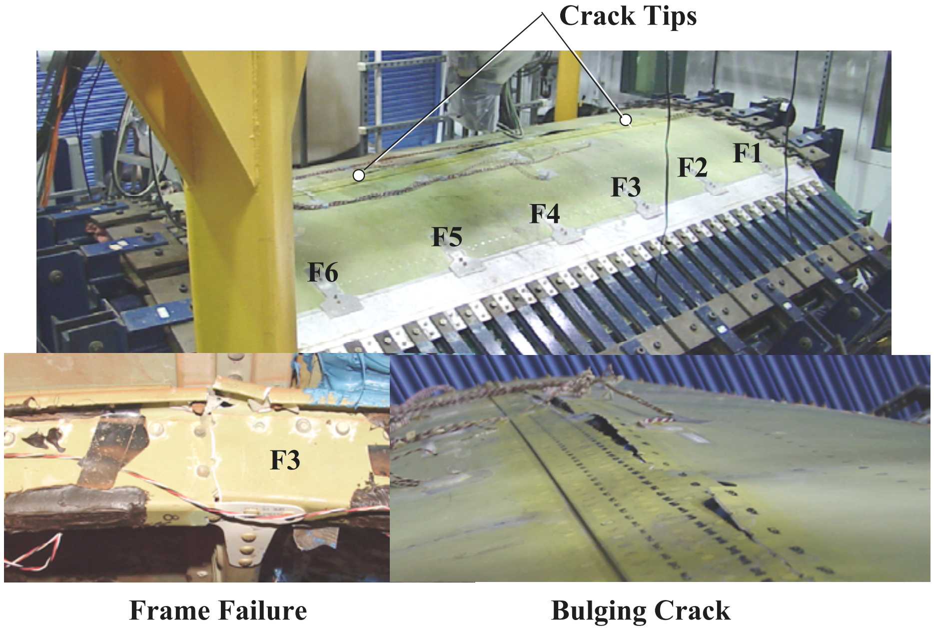


Figure 4. Failed Panel With Final Crack

Metallic Materials Properties Development and Standardization (MMPDS)

The Military Handbook, "Metallic Materials and Elements for Aerospace Vehicle Structures," (MIL-HDBK-5), is a source of material strength properties and design values that are generally accepted as meeting the FAA 14 CFR Parts 23/25/27/ 29.613 requirements because of its rigorous standards. It also contains extensive information and data for other material properties and characteristics, such as fracture toughness strength, fatigue strength, creep strength, rupture strength, fatigue-crack propagation rate, and resistance to stress corrosion cracking.

MIL-HDBK-5 has evolved significantly over the years. Its predecessor was first published in 1937 as Army-Navy-Commerce Handbook 5 (ANC5). The United States Air Force (USAF) assumed the primary responsibility of continuing development in 1954 and, subsequently, the name of the book was changed to MIL-HDBK-5 in 1956. MIL-HDBK-5 has been continuously updated to incorporate new methodologies, add new material properties, and update existing ones. This continuing effort has enabled the Handbook to keep up with technology development and maintain up-to-date information for materials used by industry.

Detailed guidelines for statistical analysis of data were incorporated into the Handbook in 1971, which established standardized procedures for data requirements and analyses based on available statistical methods. The statistical procedures were further developed in 1984 to allow proper treatment of skewed data. As part of its continuing development, a major update of fracture toughness was completed in 1987. As digital information technology has become available and increasingly simple to use, the Handbook was distributed on CD-ROM in 1997.

In the past, the USAF had taken the lead in managing this effort and maintained a contract with Battelle Columbus Laboratory for specific technical and managerial functions, with 80% of the funds from the USAF and 20% from the FAA. However, due to recent USAF policy not to invoke or maintain military specifications or standards, USAF funding for the support of the handbook development ended in 1999. The FAA felt that the continuation of MIL-HDBK-5 was critical for certification and continued airworthiness of commercial aircraft and took the lead in supporting this effort.

As core research requirement within the FAA, the Metallic Material Properties Development and Standardization (MMPDS) document is the continuation of and replacement for MIL-HDBK-5. During fiscal year 2002, the FAA and USAF underwent a transition, which will insure the integrity MIL-HDBK-5 is maintained in the MMPDS. An interagency agreement between the FAA and the USAF has transferred the historical archives to the FAA and the MIL-HDBK-5 has been completely transitioned to the MMPDS document. On April 22-25, 2002, the FAA William J. Hughes Technical Center hosted the First Metallic Materials Properties Development Standards (MMPDS) and the 101st MIL-HDBK-5 Coordination Meetings. The meeting was well attended with over 50 participants.

The FAA considers the Handbook critically important to the FAA mission in certification and continued airworthiness and will continue to fund the core activities as required to maintain the Handbook's continued existence. The FAA will continue the process working closely with the industry and other government agencies to develop the MMPDS, continuing to provide periodic updates. The MMPDS will replace the MIL-HDBK-5 as the standard for static properties of metallic materials for the aviation industry.

John Bakuckas, AAR-450, (609) 485-4768

Rotorcraft Usage Monitoring and Validation of HUMS Advisory Circular

To conduct a Functional Hazard Assessment of a Health and Usage Monitoring System (HUMS), Bell Helicopter, Inc., under FAA funding, performed a fault tree analysis of the commercial off-the-shelf (COTS) HUMS installed on a Bell Model 412 helicopter. The FAA Rotorcraft Directorate will use the analysis results to support the Draft HUMS Advisory Circular (AC) issued by the FAA in 1999. The draft AC provides industry guidance to obtain airworthiness approval for HUMS installation, credit validation, and instructions for continued airworthiness for the full range of HUMS applications on rotorcraft.

Using HUMS, operators can monitor onboard critical helicopter components such as engines, rotor, rotor controls, drive train, and fatigue life-limited structures. HUMS offers potential benefits in enhanced safety, reduced maintenance costs, and improved operating efficiency. HUMS can be used for health monitoring to track rotor balance, assess engine performance, and aid in performing mechanical diagnostics. HUMS can be used for usage monitoring to monitor exceedance and operation and structural usages. HUMS can also be used for logistic interface and information management.

A HUMS can consist of a variety of onboard sensors and data acquisition systems. The acquired data may be processed onboard the rotorcraft or on a ground station (or a combination of both), providing the means to measure against defined criteria and general instructions for the maintenance staff and/or flight crew for intervention. Currently, the FAA has not certified or approved any HUMS for use in commercial operation.

The basic COTS HUMS used in this research project for usage monitoring consisted of:

- A centralized data acquisition and a processing unit called the HUMS Processing Unit (HPU). The HPU acquires data; converts analog, digital bus, and discrete inputs into digital form; preprocesses the data; provides display output to the HUMS Display Panel (HDP); provides continuous usage parameter data to the personal computer (PC) memory card interface for storage; and provides data access for the ground support equipment Data Retrieval Unit. HPU performs continuous built-in-testing (BIT) on the system elements.

- A set of sensors and transducers to provide signals to the HPU through wiring harnesses. Many signals are provided to the HPU by connecting existing aircraft systems via harnesses to the aircraft.

- A HUMS Display Panel mounted in the cockpit that displays operational information to the pilots. Inside the HDP, there are two PCMCIA type II card slots that can accommodate FLASH memory cards for continuous usage parameter data. The HDP contains the BIT and sends the results to the HPU.

The ground station used in this project consisted of a COTS PC with a tape backup system, a PCMCIA card slot, and a printer.

The certification process begins with the declared application intent and a determination of the resultant criticality. The declared intent should specify whether this application is for credit and if it adds to, replaces, or intervenes in maintenance practices or flight operations. When the declared intent is for credit, the end-to-end criticality for such an application should be determined and used as an input to establish the integrity criteria. If the declared intent is for noncredit, it may be certified as long as it can be shown that the installation of the equipment will not result in a hazard to the aircraft. Therefore, the criticality describes the severity of the result of a HUMS application failure or malfunction. A functional hazard assessment (FHA) defines the criticality by considering the effect that the HUMS application can have on the safety of the aircraft. Compliance with the criticality level established by the FHA in the HUMS AC must be demonstrated.

The fault tree, as shown in figure 1, was developed to support the functional hazard analysis and focused on the usage monitoring aspect of the HUMS. The fault tree presents a top-down analysis of the usage monitoring system. The analysis starts with the worst-case condition, i.e., a fatigue life-limited part being left in service too long. This is considered a potential catastrophic failure condition. The fault tree analysis shows the potential faults, which could be the cause(s) of the catastrophic failure condition, and how to prevent or compensate for each cause.

Dy Le, AAR-450, (609) 485-4636

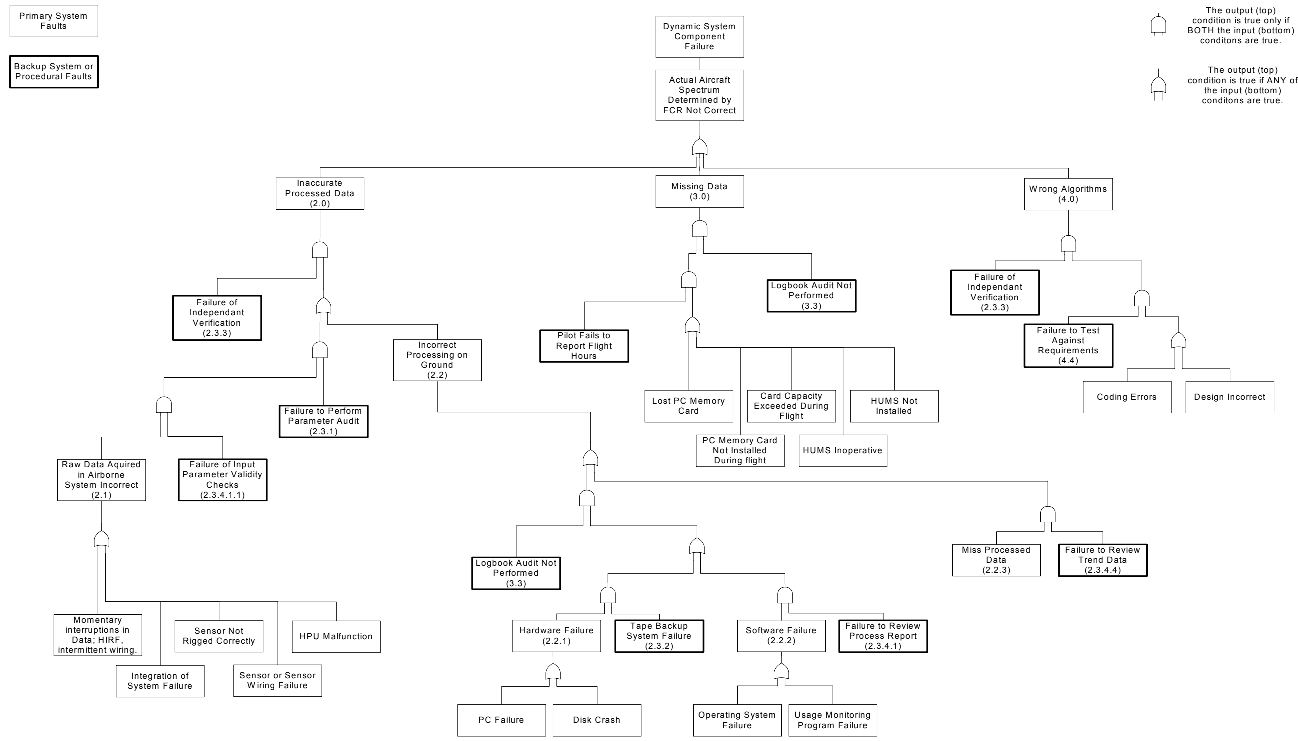


Figure 1. Fault Tree Analysis for HUMS Usage Credits

Mini-Health and Usage Monitoring Systems Concepts in Collecting Usage Spectrum for Fatigue Life Determination

A research task was undertaken to study the effectiveness of a mini-health and usage monitoring systems (HUMS) concept, compared to a complete HUMS, in collecting rotorcraft usage spectrums for determining the fatigue life of rotorcraft components. In this task, four previously developed usage spectra: the certification spectrum, the Utility Mission in Morgan City (UMMC) spectrum, the Atlanta Short Haul Mission (ASHM) spectrum, and the Gulf Coast Mission (GCM) spectrum, were used. The four spectra were originally developed using a complete HUMS. The certification mission spectrum was used as the base line spectrum for all comparisons.

Three simplified or mini-HUMS concepts were investigated. Each concept reduced the number of sensors and therefore reduced the complexity and the cost of the system by recording selected conditions and parameters (e.g., altitude, normal acceleration, airspeed, vertical velocity, and roll angle).

- Concept 1 records altitude only and applies an altitude breakdown to the certification spectrum. Thus, concept 1 was essentially an altimeter recorder. This would be equivalent to producing two certification data sets, one for below 3000 ft and another for at or above 3000 ft to account for the altitude effects on fatigue lives. The fatigue life calculations were reprocessed with the above altitude assumptions for all three mini-HUMS concepts.

- Concept 2 records altitude, normal acceleration, airspeed, and vertical velocity. Using these parameters, the amount of time the aircraft is in level flight is determined. The time in level flight was compared to the time in level flight for the certification spectrum at various air speeds. The remaining percentage time from the certification mission was factored to account for the difference in level flight time between the certification spectrum and the actual spectrum as recorded by the HUMS unit. The factored certification spectrum would then be used for the percentage time for all conditions other than level flight. Concept 2 assumes the helicopter is flown at the certification gross weight breakdown. As with concept 1, the actual altitude breakdown recorded by the HUMS unit is used.

- Concept 3 records altitude, normal acceleration, airspeed, vertical velocity, and roll angle. Using these parameters, it can be determined if the aircraft is in level flight, turning, or pulling up; the amount of time in these conditions is calculated. The percentage of time in level flight, turns, and pullups at various airspeeds is compared to the time in level flight, turns, and pullups at various airspeeds for the certification spectrum.

In the table below, the fatigue lives for the selected principal structural elements (PSEs) are shown. Shown first is the currently recommended fatigue lives with no altitude breakdown, then the fatigue lives using the three different mini-HUMS concepts along with fatigue lives using the complete HUMS package.

Summary of Fatigue Lives Using Mini-HUMS and Complete HUMS

Life Calculation Method	REPHASE LEVER Fatigue Life (Hrs)	COLLECTIVE LEVER Fatigue Life (Hrs)	MAIN ROTOR SPINDLE Fatigue Life (Hrs)	MAIN ROTOR YOKE Fatigue Life (Hrs)
- Certification Spectrum - No Altitude Breakdown - Certification Gross Weight Breakdown	**5000**	**10,000**	**10,000**	**5,000**

Concept \ HUMS Mission Profile	GCM	ASHM	UMMC	GCM	ASHM	UMMC	GCM	ASHM	UMMC	GCM	ASHM	UMMC
Mini HUMS Concept 1 - Certification Spectrum - Mission Altitude Breakdown - Certification Gross Weight Breakdown	**12,910**	**80,320**	**21,030**	**20,730**	**45,170**	**27,607**	**19,000**	**33,090**	**23,563**	**5,760**	**5,460**	**5275**
Mini HUMS Concept 2 - Certification Spectrum but with actual Level Flight from Mission Spectrum - Mission Altitude Breakdown - Certification Gross Weight Breakdown	**16,176**	**53,604**	**31,547**	**30,972**	**56,341**	**45,097**	**23,445**	**20,480**	**35,185**	**11,045**	**5,250**	**11,826**
Mini HUMS Concept 3 - Certification Spectrum but with actual Level Flight, Turns & Pullups from Mission Spectrum - Mission Altitude Breakdown - Certification Gross Weight Breakdown	**40,592**	**21,031**	**34,799**	**32,415**	**72,364**	**46,654**	**33,103**	**22,678**	**32,506**	**9,814**	**3,735**	**9486**
Complete HUMS Package - Mission Spectrum (including unrecognized) - Mission Altitude Breakdown - Mission Gross Weight Breakdown	**24,610**	**15,620**	**20,850**	**27,410**	**174,220**	**34,830**	**28,840**	**32,810**	**18,850**	**26,510**	**4,760**	**20,030**

The mini-HUMS and the complete HUMS all use the mission altitude breakdown. Compared to the currently recommended fatigue lives with no altitude breakdown using the certification spectrum, the fatigue lives using the three mini-HUMS concepts are, in general, significantly greater. The only PSE where this is not the case is the main rotor yoke using the ASHM mission.

The table shows that for the collective lever, main rotor spindle, and main rotor yoke, in general, the mini-HUMS fatigue lives are reasonably close to or substantially lower than the complete HUMS fatigue lives for the ASHM and GCM spectrums. For the UMMC spectrum, the mini-HUMS gives lives that are higher than the lives using the complete HUMS package for the rephase lever, the collective lever, and the main rotor spindle. However, for the main rotor yoke, the mini-HUMS lives are lower than those for the complete HUMS. For the rephase lever with the ASHM spectrum, the mini-HUMS gives fatigue lives that are substantially higher compared to the complete HUMS package. This is also true for the GCM when comparing mini-HUMS concept 3 to the complete HUMS package.

These results show that a mini-HUMS system can, in some instances, generate fatigue lives that are significantly higher than those generated by the more accurate complete HUMS package. To account for this, it may be necessary to assign a life extension limit to the part if a mini-HUMS system is to be used. For example, with a mini-HUMS system, the fatigue life of the part could not be extended beyond 200% of the recommended fatigue life using the certification spectrum, as published in the manufacturers fatigue life report. Further work is needed to establish such guidelines.

Dy Le, AAR-450, (609) 485-4636

Repair of Transport Aircraft Using Composite Doublers

Bonded composite doublers offer airline maintenance facilities a cost-effective way to safely extend the lives of their aircraft. Instead of riveting multiple-steel or -aluminum plates to repair an aircraft, it is now possible to bond a single boron-epoxy composite doubler to the damaged structure. However, before this advanced aircraft repair technique could be accepted for commercial use, uncertainties surrounding the application, nondestructive inspection (NDI), and long-term endurance of composite doublers had to be addressed.

The FAA's Airworthiness Assurance NDI Validation Center (AANC) has completed an experimental project where composite repair doublers were installed on in-service commercial aircraft. The project validated a family of generic composite patches to be used to repair various types of damage to metallic structures caused by dents, dings, lightning strikes, corrosion grind outs, and certain cracks in nonpressurized areas. The project also identified necessary guidance data needed to assure the continued airworthiness of composite doublers.

In conducting this program, the AANC focused their attention only on the DC-10/MD-11 aircraft and worked collaboratively with FedEx, Boeing Long Beach, and Textron Specialty Materials. To a large extent, the project built upon a foundation established during a previous project where the AANC worked with Delta Airlines to validate the use of a composite reinforcement on an L-1011 doorframe corner.

In the current project, the first composite patches were installed to repair impact damage on two FedEx aircraft in July 2000. Those installations marked the first use of bonded composite doublers as permanent repairs for skin damage in a U.S.-operated commercial aircraft. To date, repairs have been installed using a phosphoric acid-anodized surface preparation method, although future efforts will investigate a simpler procedure using Sol-Gel. After each installation, the doublers were inspected using AANC-developed ultrasonic inspection procedures. The inspections ensured that there were no interply delaminations or disbonds between the composite patch and the underlying metallic structure. As part of the project, the inspections were conducted after 30 days, 6 months, and 1 year of service after installation. After 1 year, the inspection of the doubler was coordinated into the airplanes' heavy maintenance or D-check schedule.

One key element of the experimental project was to demonstrate that aircraft maintenance personnel could be trained to install and inspect the composite doubler repairs. As a result, workers from the FedEx composite and NDI shops were key participants in the repair installation and inspection. AANC personnel gradually reduced their role in the composite doubler installations until FedEx personnel were able to safely apply and inspect them without supervision. Overall, seven composite doubler repairs were installed on FedEx aircraft and, to date, each has successfully passed the applied NDI tests.

The project included developing the appropriate technical data that can be used in an FAA advisory circular on installing and inspecting composite repairs. The data needed to develop a Boeing Material Specification to formally adopt the material allowables for the boron-epoxy composite material was also formulated. The adoption of the material allowables is the last step necessary before a revision can be made to the manufacturer's Structural Repair Manual (SRM). The ultimate outcome of this project is to have composite doubler repairs conveniently specified in the manufacturer's SRMs.

Future users of this technology are all the airlines and maintenance depots that currently apply metallic repairs. Industry interest in using composite doubler repair has grown considerably since the results from this study have shown that the finished doublers are lighter in weight, corrosion resistant, stronger, and faster to install than a typical riveted aluminum plate repair.

Figures 1 and 2 show examples of the installation and inspection of a composite doubler repair on a FedEx DC-10 aircraft.

David Galella, AAR-480, (609) 485-5784

Figure 1. Composite Doubler During Cure Cycle

Figure 2. Ultrasonic Inspection of Repair

Innerlayer Crack Experiment

Investigators from the FAA's Airworthiness Assurance Nondestructive Inspection Validation Center (AANC) recently completed an experiment to assess the reliability of a sliding probe eddy-current procedure for its effectiveness in finding second- and third-layer cracks in certain Boeing 737 lap splice joints. The task was undertaken at the request of the FAA's Seattle Aircraft Certification Office.

The experiment used well-characterized test panels that simulated the lap splice joint shown in figure 1. Each test specimen consisted of one mock doubler, four mock tear straps, and two aluminum skins riveted together with a 3-inch overlap that included the doubler. Fatigue cracks were grown in the aluminum sheets and placed in the lower skin, requiring inspection through either 0.072 or 0.080 inch of combined upper skin and doubler material. The spacing of the tear straps was varied to simulate manufacturing tolerances. Since the tear straps create a major source of noise for the eddy-current inspection, the number of tear straps per unit length of lap splice was doubled for this experiment. The fatigue cracks were created from starter notches at select locations. The lower skin panels were then cycled until the desired length of crack was reached. The starter notches were then removed by drilling the final holes for fastener installation. Individual eddy-current signals were verified to simulate signals from aged aircraft. Cracks were of varying lengths and some of the rivet locations had cracks emanating from both sides of the rivet hole. In total, there were 360 rivet sites to inspect as part of the experiment.

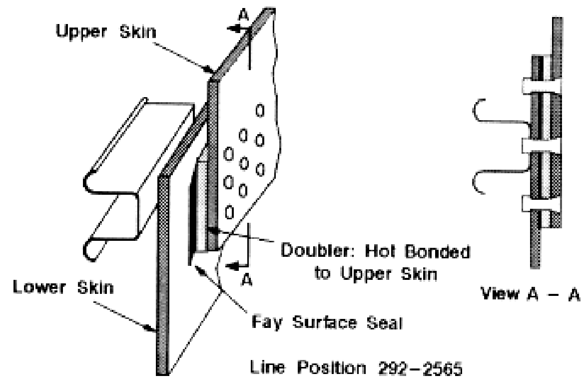


Figure 1. Boeing Lap Splice Joint Configuration

The AANC researchers traveled with the test panels to eight different inspection facilities where 56 inspectors participated in the experiment. Inspectors were asked to conduct the inspections following Boeing's procedure 53-30-11 using the eddy-current instruments and probes available at their facilities.

The results from the experiment are shown in the probability of detection curves in figure 2.

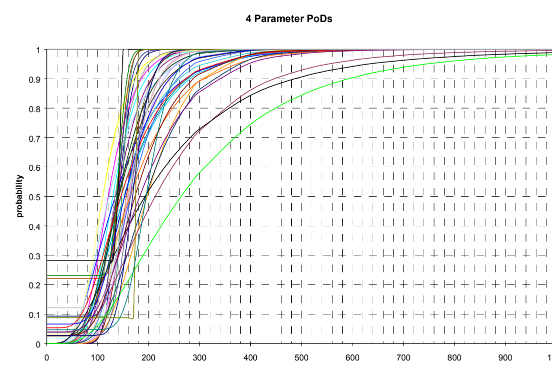


Figure 2. Probability of Detection Curves for 56 Inspectors

Analysis conducted to date has revealed several observations. First, as is often the case, there was substantial inspector-to-inspector variation in this experiment. This variation indicates that fundamentally different inspections are being carried out from one inspector to another. Many of the inspectors failed to closely follow the Boeing procedures and only a few implemented the checks that were included in the procedures to give better inspections in the presence of tear straps. Second, many of the inspectors only used an absolute threshold of the maximum signal height and did not include calls based on signal loop width, as called for in the Boeing procedure. Third, many of the inspectors did not use a nonconducting straight edge to aid in keeping the sliding probe centered over the rivets, a factor which can mask crack signal indications.

FAA certification personnel and Boeing NDI procedure developers were briefed on these findings and will take them into consideration when issuing revisions and future lap splice inspection procedures.

David Galella, AAR-480, (609) 485-5784

Effects of Surface Preparation on the Long-Term Durability of Composite Bonded Joints

The long-term durability of adhesively bonded composite joints is critical to modern aircraft structures, since bonding is being adopted more frequently as an alternative to mechanical fastening. The advantages of bonding over mechanical means of fastening include higher stiffness, more uniform load distribution, cleaner aerodynamic lines, part consolidation, elimination of holes in adherends (thereby reducing stress concentrations and increasing load-bearing area), and less labor. The surface preparation of the adherends is critical to bond performance and affects initial strength, long-term durability, fracture toughness, and failure modes of bonded joints.

Inadequate surface roughening, environmental effects, possible chemical contamination, and other mechanical and chemical factors can prevent adhesives from bonding properly to composites, resulting in interfacial failures. These failures can occur at loads well below those of properly bonded joints that fail cohesively. Other interfacial failures occur over time in service as joints are exposed to harsh environments, such as elevated temperature and humidity, which do not affect well-prepared adherends. FAA research is intended to provide greater insight and extensive data to support increased application and confidence in bonded structures.

This study focuses on the effects of peel plies, release films, release fabrics, grit blasting, and environmental exposure; these not only have significant mechanical and chemical effects on bond integrity but are also relevant to aviation manufacturing processes. In this study, two potential factors were evaluated, with focus on the following:

- Effects of possible chemical contamination from release fabrics, release films, and peel plies during adherend cure.
- Chemical and mechanical effects of abrasion on the fracture toughness and failure mode.

The relative importance of each of the two factors in contributing to the bond strength and durability were determined. These results can be used to provide manufacturers with bonding guidance and to assist the FAA with certification procedures.

Nondestructive testing included X-ray photography of crack fronts, energy dispersive spectroscopy (EDS), X-ray photoelectron spectroscopy (XPS), surface chemistry analyses, and scanning electron microscope (SEM) imaging of prepared surfaces. Nondestructive microscopy and spectroscopy tests revealed chemistry and morphology features that explained the destructive test results. Smooth and fluorine-contaminated surfaces were neither chemically nor mechanically acceptable, although blasting created rough, less-contaminated surfaces. Results illustrate that release agents deposited on adherend surfaces during their cure cycle prevented proper adhesion.

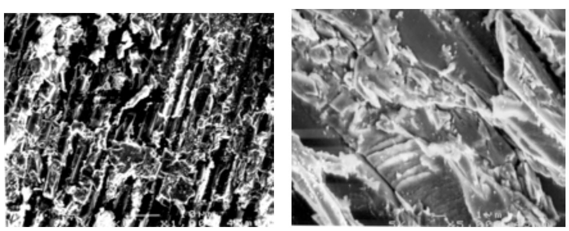
Among the various nondestructive test methods used to evaluate prebond surfaces, SEM and XPS provided excellent information, while EDS revealed very little. SEM images could be used for qualitative morphological assessments to provide feedback on abrasion, peel ply removal, and other morphology-modifying processes. XPS revealed accurate chemical assessments of surfaces, aiding in correlation of specific elements to bond performance, especially failure mode. Because EDS examines chemical composition deeper than XPS does, EDS did not detect differences even between grossly different surface preparations. Finally, the X-ray photography was a useful tool in understanding crack front behavior in these opaque joints, justifying the optical tick mark measurement methods used in most of the tests for the given specimens.

Strength and fracture tests were performed on paste and film adhesive joints, and microscopy and chemical analyses were conducted on sample adherends. Because there were difficulties and variations in processing the paste adhesive, film adhesive was used for the majority of the tests in this study. The film adhesive removed several possible variables such as bond thickness and adhesive distribution. Additionally, film adhesive is more typical of commercial aviation bonded structures and its use, in addition to paste, broadens and generalizes the results of the tests.

Four release materials were tested during this program. Three different versions of the same polyester cloth were used. They were a scoured and heat set (NAT), very low porosity (VLP), and super release blue (SRB). VLP is mechanically finished through calendering. In the proprietary calendering process, the cloth is passed between several pairs of heated rollers that compress the material, reducing its porosity and flattening out the cloth's fibers. The use of VLP results in less resin bleed into the peel ply during cure. This improves releasability without the chemical agents that impede secondary bonding. SRB release fabric is a version that has an inert, heat-stabilized, cross-linked siloxane polymer finish. The fourth material was a release film, fluorinated ethylene propylene (FEP).

Grit-blasted FEP samples performed the worst of the four (see figure 1), preceded by blasted SRB and VLP, with blasted NAT specimens producing the highest strength, see figure 2. NAT specimen shear strength was increased only slightly from blasting. SRB surfaces were rough but contaminated heavily with silicon, indicating that chemistry is at least as important as morphology. Blasting improved SRB surfaces greatly, even though they still produced unacceptable bonds in the destructive tests. VLP and NAT surfaces were contaminant free but the VLP surfaces were not as textured as the NAT surfaces, indicating that a difference in surface morphology does lead to different bond qualities, even if the chemistry is identical.

Blasted VLP and NAT surfaces had improved morphology but little chemistry change, which resulted in increased performance in all of the destructive tests, proving the benefits of surface roughening. While mechanical abrasion did improve their fracture toughness and lowered their contamination greatly, the test values did not reach the levels of samples that were not contaminated before bonding, and the interfacial modes of failure did not always change to desirable modes.



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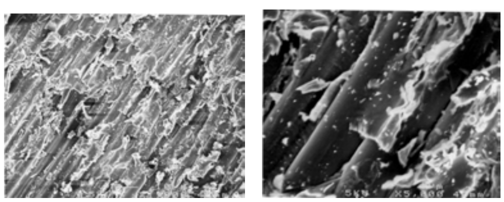
FEP, blast
Matrix morphology extremely jagged & random
Carbon fiber orientation visible but fibers unbroken

Figure 1. SEM Images of Surfaces Cured Against FEP Release Film and Blasted



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NAT, blast
Peel ply fiber impression no longer visible
Carbon fiber pattern exposed but fibers apparently not broken
Matrix extremely broken and jagged

Figure 2. SEM Images of Surfaces Cured Against NAT Peel Ply and Blasted

Because each combination of materials can produce different chemical and mechanical bonding conditions, it was impossible to provide a single set of bonding rules. Every adhesive and adherend's exact chemical composition is proprietary, further hindering attempts to apply specific test data to other adhesive designs. Therefore, bonded joints that use similar materials cannot be assumed to perform like their counterparts, and even minor batch-to-batch material variations can change bonding performance significantly. Therefore, not only should all joint combinations be tested before production, but all incoming materials must also be tested as part of a continuous quality assurance program for adhesive bonding fabrication for aviation applications.

The results and trends of the study can be used as bonding guidelines and to increase awareness of potential surface preparation problems. Distinctions between peel plies, release fabrics, and release films apply to any bonding application, though the exact results will certainly vary greatly based on a specific product. Release fabrics and release films left bond-inhibiting contaminants, while peel plies did not. The extremely smooth surface created by a release film provided a poor mechanical interface, while the textures from peel plies and release fabrics were better suited to bonding. Likewise, effects of grit blasting were similar but not identical between the different joints tested. Grit blasting, if performed carefully at parameters similar to those used in this research, is strongly recommended for all bonding operations for its chemical and morphological benefits.

Curtis Davies, AAR-450, (609) 485-8758

Impact Damage in Composite Sandwich Structures

It is well established that impact damage in composite sandwich structures is a serious threat to maintaining structural integrity, particularly under compression loading. The industry's response to this threat has been to inflict impact damage that is barely visible on the structure and demonstrate by testing that the structure can withstand ultimate static load and one lifetime of spectrum loads. This approach has several difficulties.

1. The selection of impactor diameter can change the visibility characteristics dramatically. Small diameter impacts will be much more visible than blunt impacts. The industry standard of using 1-inch-diameter impactors may not be conservative. The indent damage can also spring back, making it invisible.

2. The determination of what energy level is needed to create visible damage in a full-scale structure is hard to ascertain from small coupon tests.

3. The visibility criterion results in many unnecessary repair actions during maintenance because the operator does not know the effect of the damage on strength but only knows that all visible damage must be structurally repaired.

4. The visibility criterion penalizes designs that are damage resistant through the use of tougher material or better design configuration. For instance, thicker facesheets and heavier core densities would tend to force such designs to have ultimate load levels at very low strains. This latter practice can lead to heavy, but fortunately, safe designs.

To address these difficulties, the FAA has invested in a sizeable research program in characterization, analysis, and testing of impact-damaged sandwich structures. The research was spurred by using sandwich structure in small general aviation airplanes, where new certification approaches had to be developed and by the maintenance difficulties encountered by airline companies on older commercial aircraft parts.

Results reported in 2001 indicated that reduction in compression strength due to an impact event could be as much as 60% with the greatest reductions for damages that were not visible and inflicted by a blunt impactor. The test data showed that the visual inspection methods are very misleading and that other damage metrics, such as internal planar damage size, need to be considered for evaluating the severity of impact damage.

To determine how accurately the current field inspection techniques (FIT) can measure internal damage, a comparison study was performed on both honeycomb and foam sandwich panels that were impacted by a 3-in.-diameter impactor. Wichita State University was the principal investigator; they made the panels, did through transmission ultrasonic inspections, and destructively inspected some panels. The FAA Nondestructive Inspection Validation Center (AANC) at Sandia National Laboratories did field inspections using the manual impact tap hammer, the instrumented tap tester, and the mechanical impedance analysis (MIA). The effectiveness of each technique was evaluated by comparing the damage metrics to those found by the through transmission ultrasonic C-scan method. The latter was found to give good results when compared to destructive inspections, at least for the honeycomb core panels. The effects of facesheet stiffness and core density (honeycomb and foam cores) on the detectability of the field inspection techniques were examined as part of the study.

Tap testing can be classified into mechanical and acoustical. In the acoustical tap testing, the characteristic resonant sound emanating from the tap test is analyzed by the human ear. The audible resonant sound will depend on the sandwich local impedance and tap mass or hammer characteristics. The damaged region is characterized by a dull (dead) sound, which can be attributed to the decreased participation of the higher frequency modes. In the present investigation, the Mitsui Woodpecker Automated Tap Tester and the manual tap test hammer (Airbus design) were used to identify the impact damage in sandwich panels.

In the mechanical tap testing, the impact (tap) force is measured using an accelerometer mounted behind the impactor. The magnitude of the force and impact duration will depend on the constitutive properties of the sandwich components, impact energy, and impactor properties. The duration of impact (period) has been reported to be rather insensitive to the magnitude of the peak impact force for sandwich panels, which ensures repeatability. However, the impact duration will be significantly altered when the local stiffness of the sandwich structure is reduced due to the presence of damage. This change in impact duration is used to identify damage in sandwich structures. The V-95 Bondcheck was the technique of choice for honeycomb panels and was used as a baseline for foam core panels. In addition, MAUS C-Scan apparatus was used in the MIA mode for foam core sandwich panels. This system adds scanning capability to the MIA mode and eliminates the need to inspect the panels at discrete locations.

The capability of FITs to find internal damage in honeycomb core sandwich panels was evaluated by comparing the average of all the normalized planar damage sizes for each facesheet type. The results are summarized and plotted as a function of the number of (90/45) ply groups in the facesheets in figure 1. The error bars shown in the same figure correspond to one standard deviation about the respective mean value. From the figure, it can be observed that the FITs perform better with thinner facesheets. However, relatively higher scatter was observed for thinner facesheets. As the facesheets get thicker, the contribution of the core to the local stiffness (flexural) decreases, especially at the edge of the damage region. Thus, the facesheet tends to mask the core damage underneath, reducing the effectiveness of FITs, which relies on either the mechanical or the acoustical impedance of the sandwich panel.

A similar capability evaluation of FITs for foam core sandwich panels was performed. The results are summarized and plotted as a function of the number of (90/45) ply groups in the facesheets in figure 2. The error bars shown in the same figure correspond to one standard deviation from the mean value. Unlike in the case of honeycomb core sandwich panels, the Mitsui Woodpecker performs comparatively poorly with respect to the manual (acoustic) tap tests, especially as the facesheet gets thicker. This implies that the acoustic impedance of foam core sandwich panels is relatively more sensitive to impact damage.

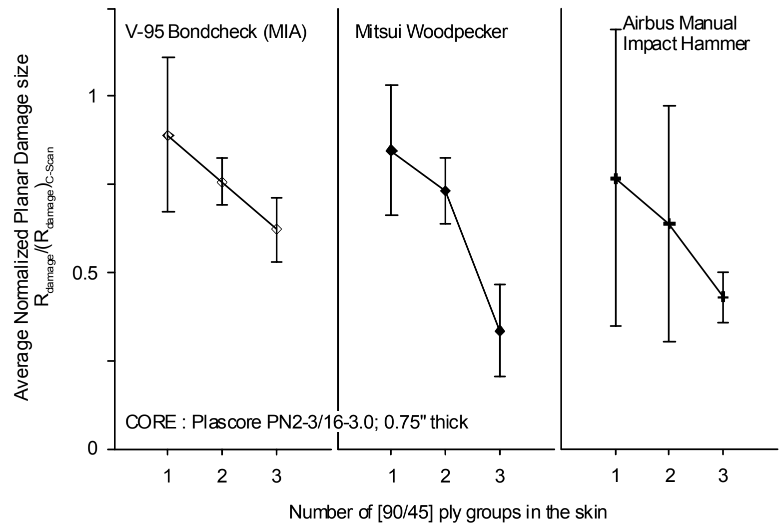


Figure 1. Average Normalized Damage Size for Sandwich Panels With Different Facesheet Configurations, With 0.75″ Thick, 3.0 lb/ft^3 Honeycomb Cores Only

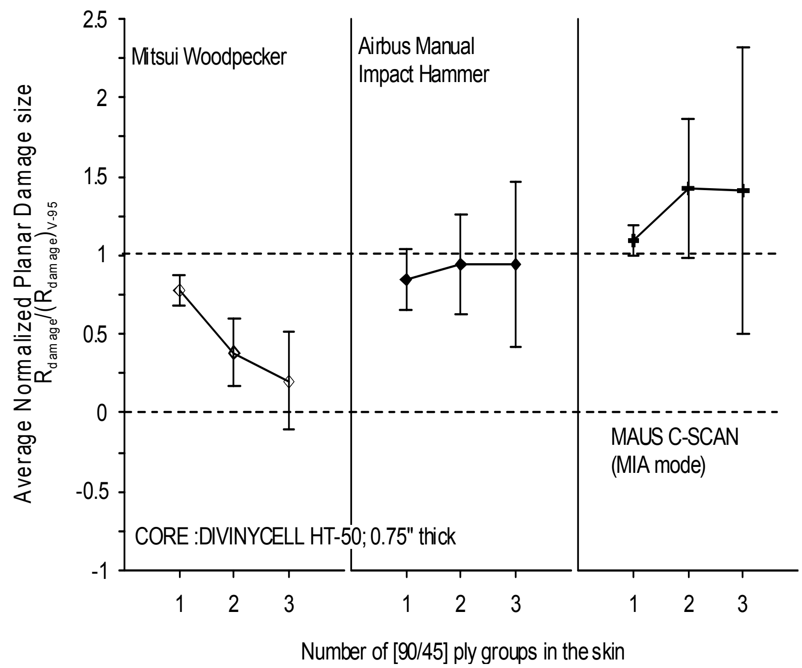
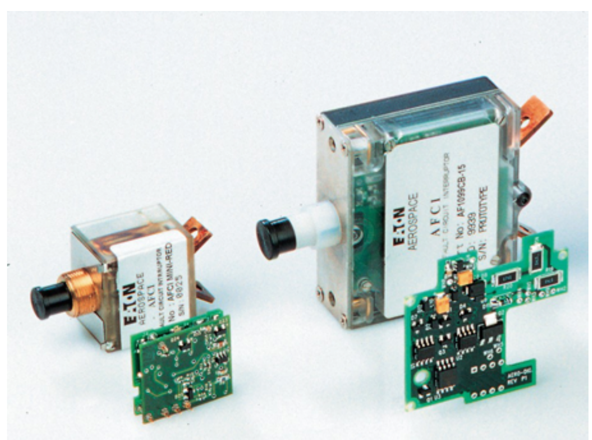


Figure 2. Average Normalized Damage Size for Sandwich Panels With Different Facesheet Configurations, With 0.75″ Thick, 2.6 lb/ft^3 Foam Cores Only

Based on the experimental results, it can be concluded that the detection of impact damage in honeycomb and foam core sandwich panels cannot be accomplished to the same level of accuracy using a single field inspection technique. The experimental data suggests that the impact damage in honeycomb core sandwich panels can be better detected by a technique that measures the local stiffness of the sandwich. The damage in foam core panels can be better assessed with a technique relying on the measurement of acoustic impedance. The trends observed for foam core panels may be biased by the normalization procedure due to the inability to corroborate the damage size using destructive sectioning. The research performed calls into question the field inspection methods used by airlines and repair stations. These methods may be still used but will need correction factors.

Peter Shyprykevich, AAR-450, (609) 485-4967

Mechanical and Electrical Systems Reliability and Integrity



Development and Validation of the Excited Dielectric Test Technique for Aircraft Electrical System Nondestructive Inspection

In April 2000, the FAA issued a broad agency announcement to support the development of advanced testing and inspection systems, technology, and techniques that characterize and identify material flaws in aircraft wiring. Of specific interest to the FAA and industry were test methods that can be used to detect the presence of nicked and chafed insulation.

In response to this announcement, CM Technologies Corporation proposed a new test technology, known as the Excited Dielectric Technique (EDT). CM Technologies asserted that the lumped impedance associated with a material flaw in aircraft wiring could be manipulated (i.e., made to increase or decrease) using an alternating current stimulus or an electrical forcing function. Furthermore, if the impedance of a material flaw were manipulated during a time domain reflectometery (TDR) test, the material flaw would appear more pronounced on the resultant TDR signature. A contract was awarded to CM Technologies in October 2000 to develop the concept for measuring flaws in wire insulation.

The EDT method exploits the basic property of polar insulation materials that some small amount of current will flow through all insulation materials when exposed to an alternating electric field. The magnitude of the current varies with the frequency of the applied electric field. In a polar insulation material, there is a frequency at which a maximum current occurs (usually less than 1 Hz for most materials). As a practical consideration, this current is often expressed in terms of the phase angle, δ, between the applied voltage and the resultant current. The tangent of δ is known as the dissipation factor (DF).

The other aspect of the EDT test method is TDR. Aircraft wiring can be modeled as a classical transmission line (i.e., a continuous structure of resistors, inductors, and capacitors). Assuming this model, the electrical characteristics of the wire (e.g., impedance, capacitance, DF, and resistance) can be thought of as distributed elements. TDR has been shown to be extremely effective in measuring the distributed characteristics of wiring.

The EDT method is based on the combination of DF and TDR measurement theory. An alternating electric field, known as a forcing function, is applied to the wire under test at a frequency that creates the maximum DF. A TDR signature is acquired and stored under this excitation. The frequency of the forcing function is then changed, and a second TDR signature is acquired and stored. The signatures are then compared and areas where the signatures separate represent the wire's weakest insulation. Polyimide and cross-linked ethylene tetraflouroethylene (ETFE) were the insulation materials studied under this research effort.

Laboratory evaluation of the technique, figure 1, was completed at the William J. Hughes Technical Center in March 2002. Field-testing of a system based on the EDT method was performed on a DC-9 aircraft prior to lab evaluation.

The following is a summary of the important results of this project:

- The theory associated with EDT was proven and demonstrated in the lab and in the field.

- The EDT method can detect and locate a variety of defect types including abrasions, fluid contamination, and thermal degradation. Slight damage to the wire's insulation is more easily detected when contaminates are also present.
- The EDT method has demonstrated that no historical data (i.e., baseline TDR signatures) are required for the technique to be effective.
- Expert data interpretation can be used but automated analysis is needed to advance the technology.

Figure 1. CM Technologies EDT Prototype

More EDT and materials testing is needed using other insulation types to better understand the effects that various defect types have on the electrical properties of a wire. Further development of the EDT technique is required before it can be introduced into service. However, the results of this project validate the theory of the approach and have identified the improvements necessary to develop a field-ready system. The Office of Naval Research and the Naval Air Systems Command has awarded a follow-on contract to CM Technologies to continue development of the EDT system, including the incorporation of signal analysis software and to produce deployable EDT units.

Robert Pappas, AAR-480, (609) 485-6181

Use of COTS Software and Hardware in Airborne Systems

Using commercial off-the-shelf (COTS) software and hardware in airborne systems has the potential to (1) offer significant cost savings for small aircraft and rotorcraft, (2) reduce project development time and the associated cost, and (3) increase aircraft safety if lower cost systems could be shown to be safe and would allow the replacement of older, less capable systems. However, there is substantial concern in the aerospace industry whether methods are available or could be found for evaluating COTS used in airborne systems. Moving maps, graphical weather, situational awareness, and cockpit display of traffic information could be used in general aviation applications if efficient methods of assessing COTS were available. To address these concerns, the Flight Safety Research Branch published a report that provided significant information for use in the development of regulatory guidance on COTS software and hardware employed in flight controls and avionics systems. The report, prepared under contract with United Technologies Research Center, is titled "Study of Commercial Off-The-Shelf (COTS) Real-Time Operating Systems (RTOS) in Aviation Applications," DOT/FAA/AR-02/118.

COTS RTOS provides a variety of services to application software within a system. As RTOS services and capabilities grow in complexity, it is clear that they have an increased influence on the overall system performance and, as such, should have consideration in the overall System Safety Assessment.

The report takes a detailed look into the safety and certification issues of using a COTS RTOS in aviation applications. RTOS attributes are detailed and their safety-related properties are discussed along with considerations to address when integrating a COTS RTOS with an application in an aviation system.

Certain characteristics of RTOSs used in aviation applications are detailed in this report. Historically, aviation-based computing systems have used a federated design approach that can effectively isolate functions with respect to system criticality. However, in more recent years, manufacturers are integrating many of these functions into single computing systems with possibly different levels of criticality. RTOSs have become the central computing resource to manage these functions, and for this reason, RTOSs in integrated modular avionics (IMA) require a high level of scrutiny. The RTOS and the associated partitioning, both spatially and temporally, of such IMA systems is important to maintain effective software level separation. The challenge is to design a partitioning solution that enables the exchange of information between partitioned functions and controlled access to other shared resources (such as I/O devices), while keeping the partitioned functions largely autonomous and unaffected by other functions.

Typical COTS software components are used in low-risk applications and many have been developed without considering the safety aspects of the software. However, if this software is to be used in airborne systems, the COTS product must be scrutinized to determine its ability to meet the intent of objectives found within RTCA/DO-178B, Software Considerations in Airborne Systems and Equipment Certification. It is difficult to access a COTS product's development and verification documentation, if any were produced, to substantiate compliance with DO-178B. However, some products are being developed specifically for the airborne market, albeit the selection is limited, it is growing. Additionally, there are other methods of compliance; however, they are difficult and rely on the regulator's ability to understand the alternate method and to apply some amount of subjective evaluation that the methods meet the intent of DO-178B objectives or provide equivalent levels of confidence.

Charles Kilgore, AAR-470, (609) 485-6235

Use of Software Service History in Certification

The Flight Safety Research Branch published a handbook and a report on how the method of product service history may be used to gain certification credit for airborne software applications. These are applications that (1) were developed in the past and could have been developed for other domains, (2) have been previously certified for use in lower criticality aviation applications, or (3) have been certified to earlier versions or different standards than those currently used. This research effort collected and analyzed what is known and understood about applying product service history and then synthesized the data into a handbook for use in the aircraft certification process. Refer to figure 1 for a description of the overall research effort design. The handbook was published as DOT/FAA/AR-01/116, “Software Service History Handbook.” The report, DOT/FAA/ AR-01/125, “Software Service History Report,” made recommendations to close the gaps in the existing guidance of DO-178B and Title 14 of the Code of Federal Regulations and made several recommendations for new guidance. The most important recommendation was to eliminate the inconsistencies in DO-178B between the use of service history and the prohibition of software reliability use in the assessment of system safety. These recommendations will be used as policy and guidance in the aircraft certification service. These documents should place more consistent expectations on applicants, something that has generally been shown to help control costs associated with certification.

Charles Kilgore, AAR-470, (609) 485-6235

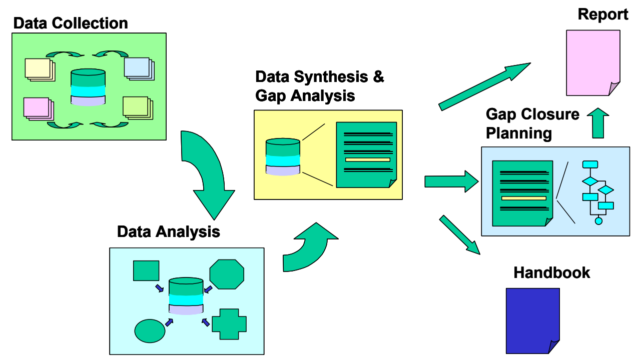


Figure 1. Overall Software Service History Research Effort Design

Object-Oriented Technology in Aviation

Object-oriented technology (OOT) uses object-oriented (OO) languages in a computer programming environment that is radically different from the environment engendered by a procedural language, such as FORTRAN. Instead of providing the two distinct elements of data and procedures to provide a step-by-step list of procedures to follow in solving the problem at hand, OO languages define the objects and the relationship between the objects and let the computer figure out how to find the answer to a given problem. The objects are independent, each having its own characteristics and ways of interacting with other objects. In effect, the object behaves like a computer; it is capable of receiving messages from other objects, storing information, and manipulating the information in limited ways. Within the objects, methods, which are found in the receiving object, are the specific procedures needed to carry out a named manipulation called for by a transmitting object. The objects are arranged in a class structure, which is an abstract data type with its associated operations. An attribute is a component used for defining the class structure. Further, the programmer can use objects to perform tasks without having to understand the mechanics of each object’s performance. If needed, the programmer can change the details contained in an object and can create objects to perform new tasks.

The OO language is well suited for writing complicated programs that control computer systems onboard aircraft. Each component of the aircraft computer system can be represented as an object, such as the software that controls a control surface in a fly-by-wire system. If the software that controls the control surface needs to be replaced, other software objects will not be affected.

OOT has been used since the beginning of Simula 67 in 1967. Simula 67 evolved from the original Simula language developed for simulations. OOT has been extensively used throughout the non-safety-critical software and computer-based systems industry (e.g., the various window-based graphical user interface icon-based operating systems, applications, and the Internet). This technology is touted as solving many of the problems seen in software production through the reduction of complexity in the development of software, and the potential for massive reuse and adaptation of previously developed software (e.g., objects) and patterns. In particular, the compilers and development environments for object-oriented programming generate a large amount of code automatically. There is also a large market of support tools, object libraries, and training to support OOT. In response to this movement, there is interest in moving OOT into the commercial airborne software and systems domain. However, as with any new technology, there are concerns and issues relating to its adoption within safety-critical systems.

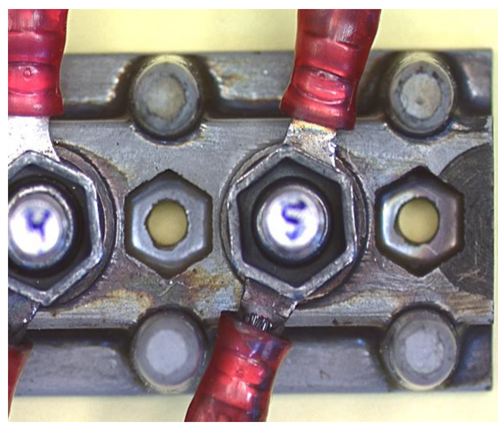
To pursue the implementation of OOT in aviation, a workshop was held on April 9-11, 2002. NASA, the FAA, and key industry representatives participated in the workshop, where the topics of Single Inheritance and Dynamic Dispatch; Multiple Inheritance; Reuse and Dead/Deactivated Code; Tools; Templates; Inlining; Type Conversion; and Operator Overloading were addressed. In each of these eight areas, a position paper was matured through review and discussion, and additional issues were documented as they arose. Numerous recommendations and changes were implemented in each paper. The papers will be finalized and implemented into a handbook to be distributed at the second workshop planned for March 2003.

In parallel with the efforts for the workshops, an OOT report titled, “Issues Concerning the Structural Coverage of Object-Oriented Software,” DOT/FAA/AR-02/113, was published. The report provides information to international certification authorities to assist with the implementation of FAA policy and guidance for the use of OOT to develop software for commercial airborne computer-based systems. The research focuses on the aspects of structural coverage that are impacted by the use of OOT. Structural coverage is used within DO-178B as one of the adequacy measures for the requirements-based testing of software for commercial airborne computer-based systems. However, neither DO-178B nor RTCA/DO-248B (Final Report for Clarification of DO-178B, which contains supplementary material to DO-178B) addresses OOT. Therefore, the OOT report provides needed information in the area of structural coverage of object-oriented software.

Specifically, the report identifies issues concerning the effect of certain features of OOT on structural coverage. These issues can concern a specific OOT feature; its implementation within the programming languages Ada95, C++, and Java; or the monitoring of the feature/implementation by structural coverage analysis tools.

Charles Kilgore, AAR-470, (609) 485-6235

Propulsion Systems



ASTM Test for Octane Rating General Aviation Piston Engines

Because of the 1990 Clean Air Act Amendments, the Environmental Protection Agency (EPA) no longer allows gasoline that contains lead to be produced. However, since an unleaded fuel suitable for general aviation aircraft has not been developed yet, the EPA made an exemption, allowing the oil companies to continue to produce 100 low-lead fuels. To develop a new fuel that is both safe and efficient, manufacturers will need to know what standards the fuel needs to meet.

For more than 10 years, FAA researchers in the William J. Hughes Technical Center's Unleaded Aviation Gasoline Program have been active participants in the industrywide effort to develop an unleaded aviation gasoline for spark ignition piston aircraft engines. The Coordinating Research Council (CRC) High Octane Unleaded Aviation Gasoline Subcommittee was formed from aircraft user groups, engine manufacturers, airframe manufacturers, petroleum producers, specialty chemical companies, laboratories, universities, and regulatory agencies to facilitate this effort. Replacing the current leaded fuel requires extensive testing in many different areas including performance issues, fuel specifications (e.g., distillation curves, vapor pressure, content), and materials compatibility. The CRC subcommittee identified the motor octane requirement of the current engine fleet as the initial fuel development target. To this end, the Airport and Aircraft R&D Division located at the FAA William J. Hughes Technical Center, as an independent engine test facility, was tasked with determining the octane rating of four engines known to be the most sensitive to octane rating. A fuel that met the octane requirement of these engines would then satisfy the octane requirement of the overwhelming majority of the piston engine fleet.

The consensus of the CRC committee was that a universal engine octane rating procedure be developed, including knock detection and analyses methods. The goal was to ensure consistency of data between separate test facilities.

The FAA personnel used their extensive experience in testing piston aircraft engines to develop a test procedure for the octane rating of naturally aspirated aircraft engines. The procedure was designed to determine the minimum motor octane required so knocking does not occur. The procedure specifies environmental conditions, engine operating temperatures and pressures, engine power settings, fuel blending and handling procedures, knock detection instrumentation, and a process for determining combustion instability levels. The parameters of the test were defined to simulate the most severe engine conditions that would be experienced in flight. After reviewing tens of thousands of cylinder pressure waveforms generated in their test facility, FAA researchers were able to develop a numerical analysis technique to quantify the combustion instability of an individual cylinder pressure cycle.

Two standard procedures were developed based on the FAA work: a standard procedure for octane rating normally aspirated aircraft engines and a standard procedure for turbocharged aircraft engines using unleaded reference fuels. The procedures were distributed to the CRC members for comment and review. After some iteration, the final procedures were agreed upon.

Since any future unleaded fuel would eventually require an ASTM standard, the FAA procedures for octane rating naturally aspirated and turbocharged aircraft engines with unleaded reference fuels were submitted to ASTM. Previous ASTM standards dealt with octane rating leaded fuels using leaded reference fuels. The final procedures were modified and circulated to the ASTM D-2 subcommittee on aviation fuels for their comments. Major comments were addressed and the procedures then went to ASTM for balloting. Negative votes were addressed and were either incorporated into the procedure or rectified with the voter. The normally aspirated standard practice was accepted and assigned ASTM D 6424-99. Currently, the turbocharged procedure is in the ASTM balloting process.

Stewart Byrnes, AAR-460, (609) 485-4499
David Atwood, AAR-460, (609) 485-4986

Enhanced Turbine Rotor Material Design and Life Methodology

Despite the current rigorous safe-life design approach for failure-critical rotating components, the commercial service experience of turbine-powered aircraft has shown that material and manufacturing anomalies can reduce the structural integrity of critical rotating components and increase the risk of failure (see figure 1).

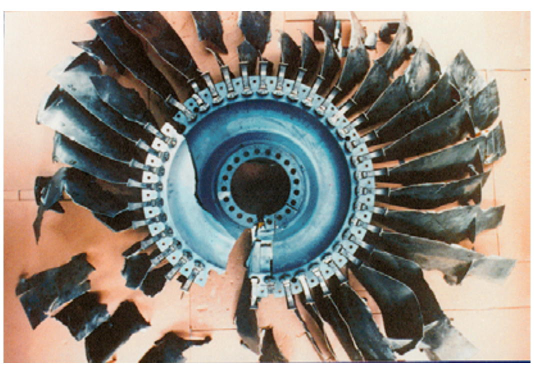


Figure 1. Reconstructed Stage 1 Fan Disk From the No. 2 Engine of a DC-10 That Crashed at Sioux City, Iowa, on July 19, 1989, Caused by a Material Anomaly Produced During Melting

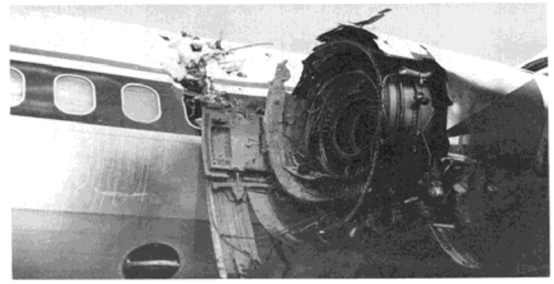
A recent Advisory Circular (AC) 33.14-1, “Damage Tolerance for High-Energy Turbine Engine Rotors,” introduces an enhanced rotor life management process and a new element, known as damage tolerance, to the engine manufacturers existing design and life management process.

The enhanced process, detailed in AC 33.14-1, establishes a new standard for rotor design and life management of all titanium rotor components in new aircraft turbine engines. The new approach is a probabilistic fracture mechanics-based assessment process with the corresponding damage tolerance design targets. The engine manufacturers will use this new design philosophy to evaluate the acceptability of all future titanium rotor designs and life management plans.

The software tool Design Assessment of Reliability With Inspection (DARWIN) was developed by Southwest Research Institute (SwRI) under an FAA grant specifically to support this new design process. DARWIN is a probabilistically based damage tolerance design code used to determine the risk of fracture of turbine engine rotor disks containing undetected material anomalies. The DARWIN software integrates finite element stress analysis results, fracture mechanics-based life assessment for low-cycle fatigue, material anomaly data, probability of anomaly detection, and inspection schedules to determine the probability of fracture as a function of applied operating cycles. The code also indicates the regions of the disk most likely to fail and the sensitivity of the risk to inspection schedules.

The previous versions of DARWIN focused on the presence of the melt-related defect known as hard alpha found in titanium alloys. Version 4.0 of DARWIN includes new capabilities for probabilistic life prediction of rotor disks subjected to manufacturing and maintenance-induced surface damage. Figures 2(a) and 2(b) show failures due to an abusively machined bolthole. The primary focus of the current version is on cracks that initiate at surfaces and corners associated with boltholes. Version 4.0 includes a number of new features to allow the user to directly define zone dimensions, stresses, temperatures, and stress gradients associated with surface damage problems.

Joseph Wilson, AAR-460, (609) 485-5579



(a)

(b)

Figure 2. (a) Uncontained Engine Failure and (b) Separated Stage 1 Fan Disk From an MD-88 That Aborted Takeoff at Pensacola, FL, on July 6, 1996, Caused by an Abusively Machined Bolthole

Uncontained Engine Debris Damage Assessment Model (UEDDAM) Version 1.1 Released

A second Interagency Agreement with Naval Air Warfare Center Weapons Division (NAWCWD) China Lake was signed in FY02. The existing tasks were expanded to continue the work started under Uncontained Engine Debris Damage Assessment Model (UEDDAM) and new tasks were added such as engine disk crack detection. Figure 1 shows a typical engine disk failure debris layout. Figure 2 shows how a typical spray pattern of debris would exit a turbine engine from a compressor disk failure.

In FY02 NAWCWD and their support contractor, Service Engineering Company, delivered version 1.1 of UEDDAM.

Figure 1. Uncontained Engine Fan Disk Debris

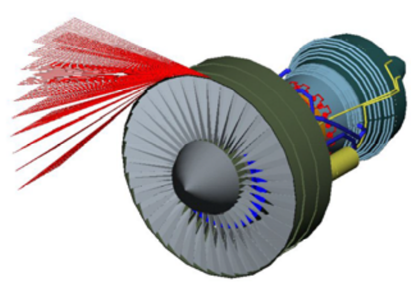


Figure 2. Uncontained Engine Failure Model

This code will help industry comply with a proposed revision to AC 20-128 currently in development by FAA rulemaking. Both of Boeing's commercial divisions have conducted initial evaluations of the vulnerability assessment tools in UEDDAM under contract from NAWCWD. Resulting recommendations will improve the tools' ability to assess aircraft safety to the uncontained engine debris threat.

As a result of the Fourth Uncontainment Workshop (March 2000), NAWCWD started developing generic models of a business jet and a commercial transport aircraft. Results were presented at the Aviation Rulemaking Advisory Committee (ARAC) Propulsion and Power Industry Harmonization Working Group (PPIHWG) meetings held in June 2001, October 2001, and July 2002.

The UEDDAM vulnerability assessment tools automate the analysis and allow airframe design trade studies to be performed. UEDDAM enhances the safety of commercial aircraft by providing the means to critically examine the threat posed by uncontained engine debris and determines steps that can be taken to mitigate the threat (see figure 3).

The uncontainment research effort has produced several reports that are the result of years of effort in support of developing the revisions to AC 20-128, "Design Precautions for Minimizing Hazards to Aircraft From Uncontained Turbine Engine and Auxiliary Power Unit Rotor Failure." A compact disc with all reports was distributed at the 29th ARAC meeting in October 2001.

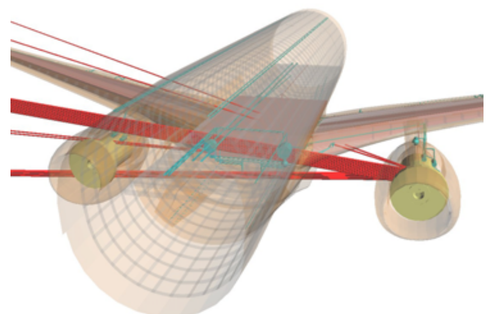


Figure 3. UEDDAM Disk Burst Analysis

The ballistic testing is summarized in a series of reports DOT/FAA/AR-01/27 "Engine Debris Fuselage Penetration Testing, Phase I and II." A draft report for the generic twin transport airplane has been delivered along with the code. This code is currently being evaluated by the U.S. Navy, the U.S. Air Force, and Boeing Commercial Airplane Group.

Donald Altobelli, AAR-460, (609) 485-5940

Improved Barriers to Turbine Engine Fragments Phase II Completed

Over the years, several civil aircraft accidents with catastrophic consequences have occurred when fragments from in-flight engine failures damaged critical aircraft components. To reduce the probability of such incidents in the future, the FAA is sponsoring research to develop and apply advanced technologies and methods for mitigating the effects of uncontained engine bursts. The largest fragments, like the compressor disc segment from the Sioux City accident, would not be stopped by improved barrier materials. However, the loss of all hydraulic systems in that accident was attributed to smaller debris liberated by the failure rather than a direct hit by the large piece. Under FAA funding, SRI International has completed an evaluation of the ballistic effectiveness of fabric structures made from advanced polymers and has developed a computational ability to design fragment barriers.

SRI evaluated the ballistic response of fabrics to fragment impact, explained the phenomenology of fabric deformation and failure using quasi-static penetration tests, and measured the tensile properties of yarns and fibers. Figures 1 and 2 show model printouts from this work. SRI focused on three commercially available high-strength polymer materials—PBO (Zylon), aramid (Kevlar), and polyethylene (Spectra).

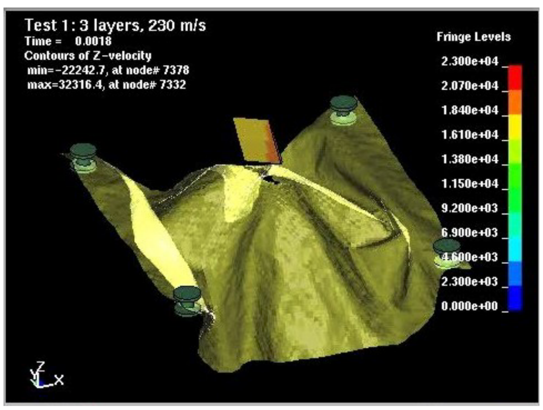


Figure 1. Simplified Model—Ballistic Simulation

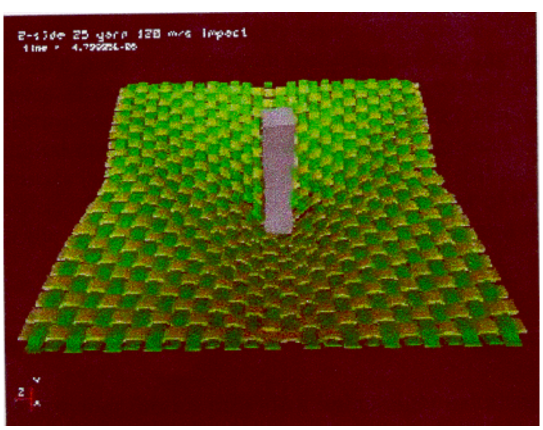


Figure 2. Model of Fabric Impact by Debris

The FAA research on armor barriers for uncontainment has produced a series of reports that documents the progress made in modeling and designing armor fabric barriers to protect aircraft systems from the majority of fragments liberated from an uncontained engine failure. The majority of fragments are relatively small and can be defeated with ballistic fabrics in combination with the existing structure.

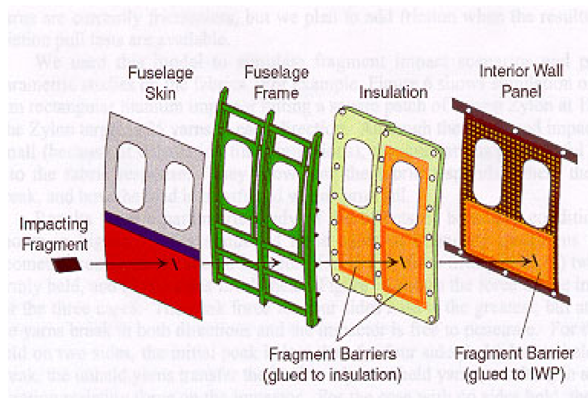


Figure 3. Armor Fabric Installation Schematic

Published reports from this work (including Parts IV and V published in 2002) are titled "Improved Barriers to Turbine Engine Fragments," DOT/FAA/AR-99/8, Part I through V. Parts IV and V complete the planned work and includes extensive testing and analysis on fabric attachment methods. This research included a full-scale test of fabrics in an aircraft structure, which is described in report DOT/FAA/AR-99/71, "Full-Scale Tests of Lightweight Fragment Barriers on Commercial Aircraft."

The research included full-scale testing of fabric barriers at both Naval Air Warfare Center Weapons Division and SRI International. Figure 3 shows how the fabric barrier was attached to the aircraft fuselage. During full-scale testing a fan blade fragment weighing 0.37 pound was shot at a fuselage wall containing three layers of Zylon fabric. The initial velocity was 622 feet per second, and the Zylon stopped the fragment in the wall (see figure 4). Additional aircraft fuselage testing concentrated on fabric attachment problems and solutions. This work was summarized in DOT/FAA/ AR-99/8 III, "Improved Barriers to Turbine Engine Fragments: Interim Report III," published in 2001.

Figure 4. Fan Blade Fragment Stopped in Interior Wall Panel

To allow for the end user to design fabric barriers with reasonable computer time, SRI converted the detailed model to a simplified shell model.

Currently, there are two programs being conducted that are working to transfer the technology from the fabric barrier research to commercial use. The University of California Berkeley is currently working with SRI International and Boeing to develop fuselage barriers, while Arizona State University is currently working with SRI and Honeywell Engines to develop improved engine containment.

Donald Altobelli, AAR-460, (609) 485-5940

Copper-Sulfur Deposits on the Fuel Quantity Indication System and Attendant Wiring, Phase II Completed

The Airport and Aircraft Safety R&D Division located at the FAA William J. Hughes Technical Center has been responding to a National Transportation Safety Board (NTSB) recommendation (NTSB A-98-037) to conduct research on copper-sulfide deposits found on Fuel Quantity Indicating Systems (FQIS). The latest NTSB recommendation, A-00-107, which supersedes A-98-037, states, "Require the development and implementation of corrective actions to eliminate the ignition risk posed by silver-sulfide deposits on fuel quantity indication system components inside fuel tanks." Figure 1 shows a center fuel tank FQIS terminal block.

Phase II of this research was completed in 2002 by a team led by SRI International, including University of Dayton Research Institute, and Arizona State University.

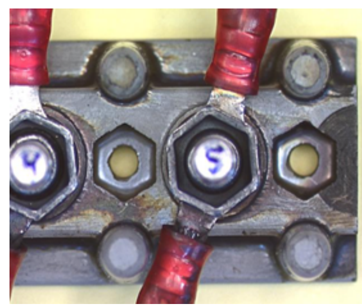


Figure 1. FQIS Terminal Strip With Deposit

Significant results of the work are:

- Conductive deposits can cause fuel indication errors when silver, copper, and cadmium-sulfide deposits are wet with condensation.
- Silver-sulfide deposits can be readily made in the laboratory between two terminals in the presence of electricity, water, and commercial jet fuel.
- Deposit formation differs somewhat with the content and type of sulfur in jet fuel.

- Deposits bridging electrical wires can ignite fuel with resistive heating when sufficient power is available.

- Laboratory testing has demonstrated flashes and glowing spots with low amperage.

The complexity of the aircraft environment is not easily duplicated in the laboratory. Testing at SRI has shown natural deposit growth via condensation on FQIS terminal blocks to be very slow. This laboratory observation agrees with service experience; however, only a few examples have been found in the fleet. For the laboratory tests, water and fuel droplets were applied to bridge the conductors.

The Transport Airplane Directorate has identified silver sulfide as a hazard in Special Federal Aviation Regulation (SFAR) 88 Guidance Material. Papers on this research were presented at the FAA International Aircraft Fire and Cabin Safety Research Conference in October 2001.

William Emmerling, AAR-460, (609) 485-4009

Inspection Development for Nickel Billet

In November 2001, the Engine Titanium Consortium (ETC)—an FAA-funded consortium comprised of General Electric, Honeywell, Iowa State University, and Pratt & Whitney—completed initial testing of a new ultrasonic inspection system for nickel alloys used in jet engines. These tests, demonstrated to the billet manufacturers at the GE facility in Cincinnati, revealed that the new inspection system, which is based on the ETC's multizone ultrasonics for titanium billet, has improved sensitivity to material anomalies that can reduce the durability of critical rotating components.

Using the new system, ETC researchers, working together with billet manufacturers, will inspect 25,000 pounds of Waspaloy and 75,000 pounds of Inconel 718, two of the most common alloys used for high-temperature rotating components such as turbine disks, by February 2003. Figure 1 shows a multizone inspection system with five transducers, each focused on a different depth along a radius of the circular cross section of the billet. As the billet spins, each transducer sweeps an annular section with greater precision than the existing conventional system, which relies on a single transducer to inspect along the entire radius.

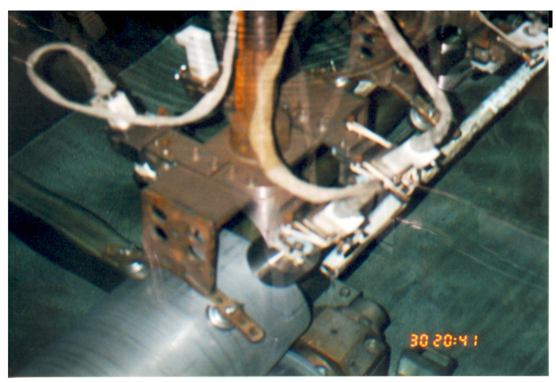


Figure 1. Nickel Billet Ultrasonic Inspection

The original program goal was to develop and validate an inspection system with the capability of finding flaws of a cross-sectional area four times smaller than what can be found by conventional systems. As shown in figures 2 and 3, this goal was substantially exceeded. While conventional inspection of Inconel 718 is capable of detecting a flaw that is the size of a flat bottom hole (FBH) with a diameter of 1/32-inch (#2 FBH), the new system is, in some zones, capable of detecting a 1/128-inch diameter flat bottom hole (#1/2 FBH). In no case is the new system's inspection of Inconel 718 billet less sensitive than a #1 FBH (1/64-inch-diameter flat bottom hole)—a six-fold improvement over the conventional system. For Waspaloy, the conventional two-transducer inspection is calibrated to detect a #5 FBH (5/64-inch flat bottom hole), while the new inspection system is capable of finding a #1 FBH.

The new inspection system is designed to handle billets up to 10 inches in diameter.

Paul Swindell, AAR-480, (609) 485-8973

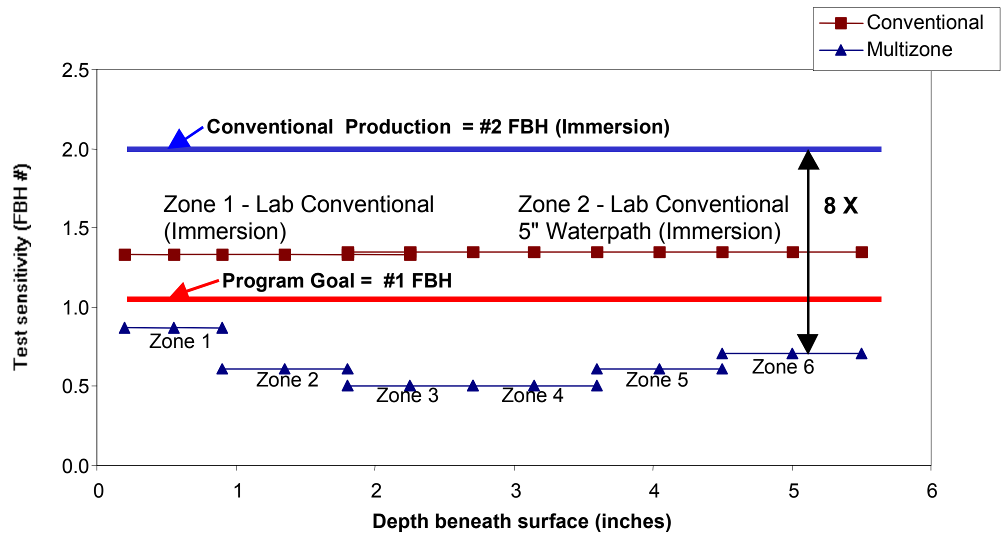


Figure 2. Comparison of Conventional and Multizone Inspection of Inconel 718 10″ Diameter Billet

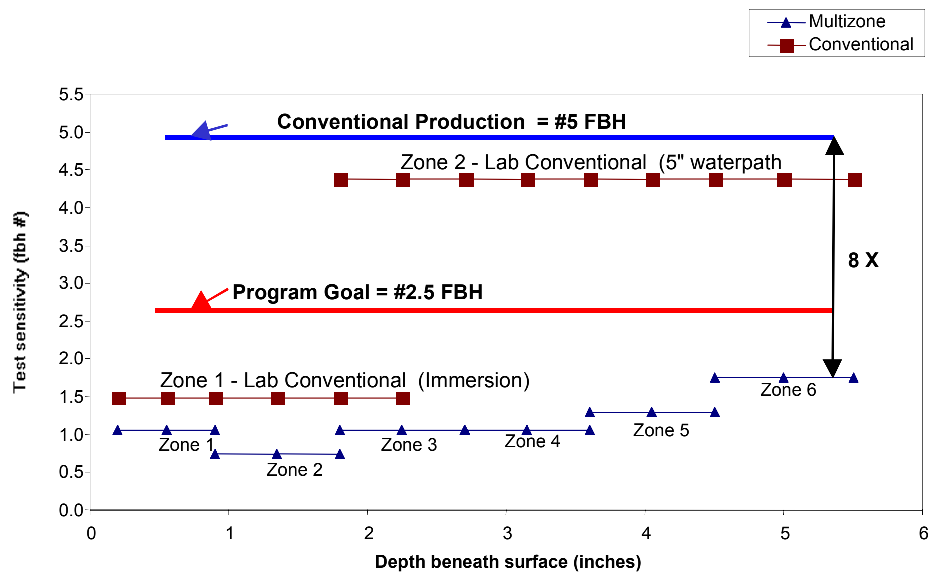
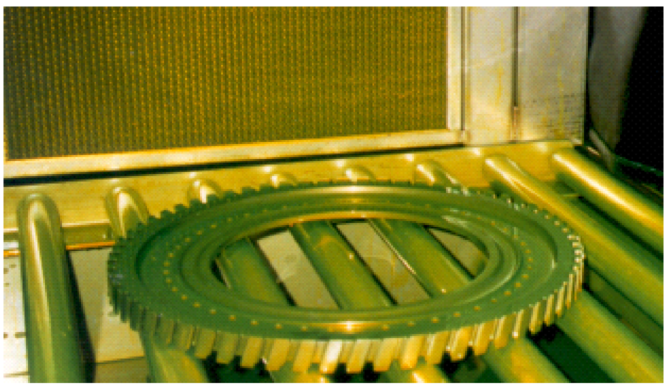


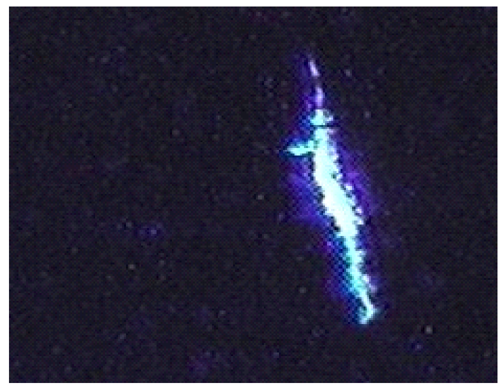
Figure 3. Comparison of Conventional and Multizone Inspection of Waspaloy 10″ Diameter Billet

Engineering Studies of Cleaning and Drying Process for Fluorescent Penetrant Inspection

Fluorescent penetrant inspection (FPI) is a widely used inspection method for detecting surface cracks in engine and airframe components. Most parts will receive an FPI as part of the production process while the parts are still in a pristine condition. For critical engine hardware, components will also be inspected during their service life, which includes the additional challenge of field-generated conditions. Figure 1(a) shows a part to which the penetrant has been applied. The penetrant solution enters the defect, excess penetrant is removed from the surface, and a developer is applied to draw the penetrant back out of the flaw so it is more readily visible to the inspector under blacklight. Figure 1(b) shows an example of a crack indication.



(a)



(b)

Figure 1. (a) Typical Engine Part With Fluorescent Penetrant Solution Applied to the Part and (b) Example of the FPI Response of a 60-mil Crack Captured Using Digital Imaging as Part of the FPI Studies

For the penetrant process to be effective, the part must be clean and dry, i.e., the crack must be open to the surface and empty of contaminants so the penetrant can enter the flaw. Contaminants can include service-induced conditions such as oxide, soot, scale, or coke and varnish conditions that are generated at high temperatures. Contamination can also come from the processes used to prepare the part for inspection, e.g., fluids or blast media from the cleaning processes. In recent years, the requirements for improved environmental protection have led to modifications in the cleaning processes used in preparation for FPI. Because of these changes, engineering data is needed to understand the impact of the various cleaning and drying processes being used. Starting in February 2000, the Engine Titanium Consortium (ETC) evaluated two approved drying methods and a range of chemical and mechanical cleaning methods. The project was completed in July 2002.

The primary effort of the program focused on comparisons of oven and flash drying methods and the evaluation of the effect of eight chemical and six mechanical cleaning methods on FPI response. A set of samples that contained low-cycle fatigue cracks ranging from 20 to 150 mils, with most being in the 60 to 80 mil range, were produced in titanium and nickel. Samples were baselined at Iowa State University where FPI brightness was measured and digital images of the ultraviolet indications were captured. Following the laboratory characterization, the samples and measurement equipment were shipped to Delta Airlines' engine maintenance facility in Atlanta, Georgia. Three separate 1-week studies were conducted at the Delta facility. Delta provided access to their cleaning, drying, and fluorescent penetrant inspection facilities for these studies, a major contribution to the program. After the cleaning process and prior to FPI, the parts are dried using either an oven dryer like the one shown in figure 2(a) or by flash dry as shown in figure 2(b). Flash dry involves placing the part in water at a temperature of 150° to 200°F, allowing the part to come to temperature, and then removing the part to allow the water to flash from the surface. A comparison of the two methods was completed and led to the conclusion that for the crack sizes and temperatures evaluated in the study, there are no statistical differences between the two methods. Additional efforts to understand the effect of part size, i.e., thermal mass, on the inspection sensitivity are needed. Data for the two methods are shown in figure 3.

(a)

(b)

Figure 2. (a) Oven Dryer That Contains Three Furnaces and (b) Flash-Dry Tank Used to Process Components Prior to FPI

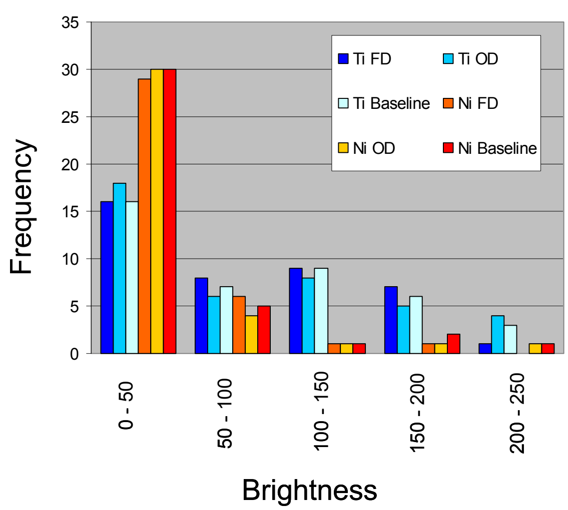


Figure 3. Brightness Histograms Comparing Flash Dry and Oven Dry Results to the Baseline Brightness for Titanium and Nickel Samples

A range of chemical cleaning methods, including aqueous and alkaline cleaning processes, were used to evaluate their effectiveness to remove oil; service coatings such as antigallant compound and high-temperature sealant; and baked-on contamination such as oxide, scale, varnish, and soot. In addition, six mechanical-blasting processes were evaluated: plastic media, wet glass bead, aluminum oxide at three grit sizes (500, 320, and 240), and walnut shell. The purpose of the cleaning studies was to determine if cleaning methods were effective in removing the contaminants and whether those cleaning processes had an impact on the FPI response. The results indicated that some of the cleaning methods were effective for the range of contaminants, but in some cases, the FPI indications were reduced. As an example, using wet glass bead led to surface changes and reduction in FPI response, including no FPI indication in some samples. An example of the results for one sample of a nickel specimen is shown in figure 4. The photograph on the far left shows the sample surface of a pristine crack. The top center image shows the baseline FPI response for the sample. The indication was not found after wet glass bead but was partially restored after alkaline cleaning. The right image shows the final surface condition. Based on the results of this research, it is recommended that wet glass bead not be used prior to FPI. Further details and conclusions of the study will be published as a final report in 2003. Continued assessment of the FPI process is underway in an FAA program being performed by Iowa State University.

Paul Swindell, AAR-480, (609) 485-8973

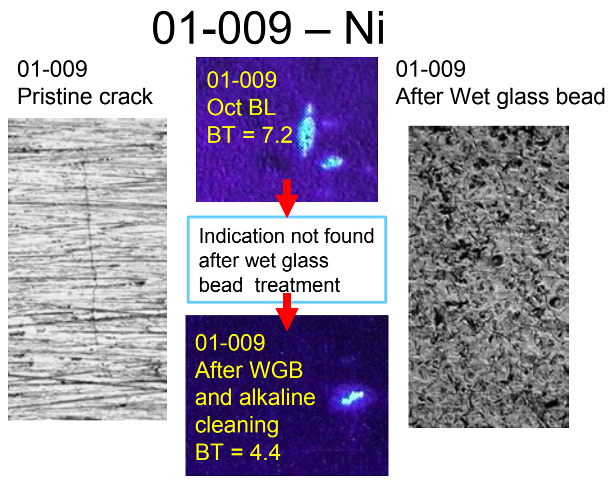


Figure 4. Results for Nickel Sample 01-009

Safety of Flight

Commercial Airplane Certification Process Study Initiative

The current high level of safety in the commercial aviation system has only been made possible by making continuous improvements in many areas, e.g., aircraft certification, flight operations, and continued airworthiness. As part of this continuous improvement effort, the FAA initiated a study of the aircraft certification processes that was applied in the U.S. Commercial Airplane Certification Process Study (CPS). Emphasis was placed on processes that interface with airplane continued airworthiness and operation activities. The review was intended to be separate, but complementary to the FAA's Safer Skies effort. Safer Skies is an initiative that identifies and prioritizes safety intervention strategies based on past safety problems, i.e., problem focused, whereas the CPS was intended to identify future certification process improvement opportunities through a detailed review of existing processes, i.e., process focused. The scope of the study was intended to focus on the processes that provide technical data to the certification, maintenance, and operation activities during the airplane's lifecycle.

To meet the objectives of CPS, a 34-member team comprised of representatives from government (FAA, NASA, and DoD), industry (airlines, manufacturers, etc.), a national research laboratory, and foreign and domestic consultants was assembled, with AAR-400 providing the research support. The CPS team met formally 15 times, approximately 1 week per month. Some subgroups met between the formal meetings. An enormous amount of information was analyzed during the study, including:

- 68 case studies of accidents and incidents
- 42 presentations
- 12 interviews
- 10 historical reports

Through multiple screening processes, five focus areas were identified:

- Safety Assurance Processes
- Aviation Safety Data Management
- Maintenance, Operations, and Certification Interface
- Major Repairs and Modifications
- Safety Oversight Processes

In the team's final report, released in March 2002, 15 findings and 2 observations resulted from the in-depth review of the five areas listed above. In addition, there were four common areas identified that appeared to connect the findings and observations:

- Information Flow: Barriers to critical information flow may exist
- Human Factors: Failure of the human-machine interface
- Lessons Learned: Significant safety issues learned through accident and incident analysis
- Accident Precursors: Significant incidents that are indicators of a serious service problem requiring intervention in order to prevent an accident

Other significant issues raised included:

- Many of the accidents reviewed during the CPS effort also followed one or more previous incidents that had not been effectively acted upon.

- There was a lack of awareness often due to a failure to view the incident at an airplane level rather than a system level.

- An airplane-level safety perspective allows the interface areas to be most apparent, such as human factors considerations, and failure assumptions.

- An airplane-level safety perspective is achieved through training and experience and is enhanced by lessons-learned knowledge. There is a need to emphasize better communication, i.e., cross discipline understanding of operation and maintenance by certification personnel and certification by operation and maintenance personnel.

- Traditional relationships among regulators and industry have, in some cases, limited the ability to identify and act on accident precursors. Inter- and intraorganizational changes are needed to facilitate more open exchange of information and regulatory solutions alone cannot achieve desired results.

As a follow-on to the CPS effort, teams consisting of both government and industry experts are being assembled. These teams will investigate each of the findings and observations and determine the appropriate strategy required to remedy or improve the situation. Phase two of this effort is scheduled to start in late summer 2002. The final report can be found at http://aia-aerospace.org/issues/subject/faa/faa_cert_study.pdf.

John Lapointe, AAR-490, (609) 485-8173

Dependence of Aerodynamic Effects of Ice on Aircraft Wing Geometry

The aerodynamic efficiency of an aircraft wing can be seriously affected by ice accretions, which disrupt the normal smooth airflow over the wing. The severity of these aerodynamic effects (loss of lift, increase in drag) depends not only on the ice accretion, but on the aerodynamic characterisitics of the wing cross section (airfoil). Furthermore, the importance of the size and location of the accretion varies with the characteristics of the airfoil. Recent accidents and incidents in icing conditions have underscored the need for a systematic study of the sensitivity of different airfoil types to ice accretion and of the most critical ice shape locations for different types of airfoils. As part of the certification process, aircraft are flown with simulated ice shapes affixed to their wings to determine if the aircraft can fly safely with ice that may accrete during actual operations.

In response to these and related concerns, the FAA has sponsored a long-term research investigation at the University of Illinois at Urbana-Champaign (UIUC). The program includes aerodynamic testing in the UIUC tunnel and in the low-pressure turbulence tunnel (LTPT) at the NASA Langley Research Center in Hampton, Virginia, as well as extensive computational fluid dynamics investigations.

An important conclusion of the investigation is that the severity of the aerodynamic penalty of the ice is strongly dependent on the geometry of the airfoil as reflected in its pressure distribution and lifting characteristics. The NACA 23012 is an airfoil of a type widely used on piston and turbopropeller airplanes.[*] Much of the lift on the NACA 23012 is generated on the forward portion of the airfoil, which tends to be very sensitive to ice and experiences the greatest lift penalties when the ice is located close to, but downstream of, the point of minimum pressure on the upper surface. The NLF 0414, a natural laminar flow airfoil for which the lift is more evenly distributed over the airfoil, experiences less severe, though still very significant, penalties due to ice. The most critical ice location is aft of that for the NACA 23012, and the sensitivity to the location of the ice is much less pronounced. An airfoil with intermediate characteristics, such as the NACA 3415, exhibits intermediate characteristics with the simulation supercooled large droplet ridge-type accretion. Figure 1 compares the geometries of the three airfoils. Figure 2 shows the maximum lift coefficient ($C_{l,\max}$) for the three airfoils without simulated ice (the straight lines at the top) and with simulated ice at locations specified by *x/c*, where *x* is the location of the simulated ice and *c* is the chord (the line from the leading to the trailing edge) of the airfoil. (Thus, *x/c* = 0.20 means that the simulated ice covers about 20% of the wing from the leading edge back.) The NACA 23012 suffers the largest penalty at *x/c* = 0.12, where the maximum lift coefficient is less than 0.3 (a penalty of well over 75%). However, the the maximum lift coefficient then increases for simulated ice shapes closer to the leading edge. For the other two airfoils, the penalty is not as severe, around *x/c* = 0.12, but then the maxium lift steadily declines as the ice shape is moved back.

James Riley, AAR-470, (609) 485-4144

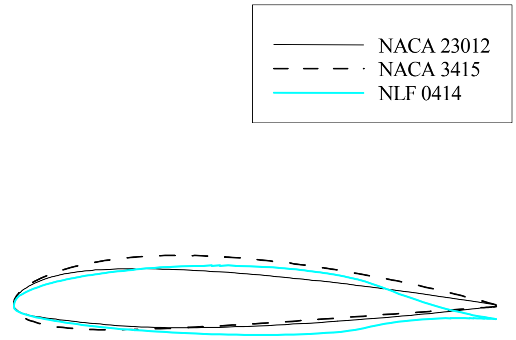


Figure 1. Comparison of the Three Airfoil Geometries

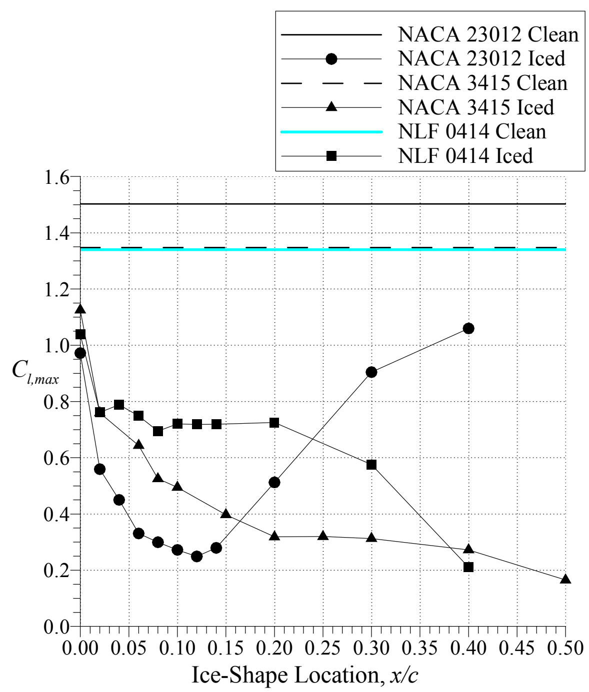


Figure 2. Summary of Maximum Lift Effects From a Simulated Ice Accretion Located at Various Chordwise Locations

[*]Abbott, I.H. and von Doenhoff, A.E., Theory of Wing Sections, Dover Press, 1959.

FAA Holdover Time Guidelines for Aircraft Ground Deicing

The Airport and Aircraft Safety R&D Division continues to support research and development efforts directed toward enhanced safety during aircraft ground operations in conditions conducive to aircraft icing. One mainstay of this effort is the investigation and development of Holdover Time (HOT) guidelines as shown below, for use by the world's airlines during freezing precipitation conditions for aircraft ground operations prior to takeoff. The HOTs present information on the time of effectiveness of various types of deicing and anti-icing fluids for various weather conditions. Each year, deicing fluid manufacturers develop new fluid formulations which typically exhibit superior performance capabilities than current fluids. Although, historically, these deicing fluids have used glycol to impede the freezing of precipitation on aircraft surfaces, a recently introduced fluid employed a glucose-lactate-based combination that exhibited more environmentally friendly characteristics than glycol-based fluids. The Flight Safety Branch, in conjunction with other authorities and fluid manufacturers, participated in investigating and assessing the performance of these new fluid formulations. These new formulations were evaluated and their time of effectiveness substantiated for conditions of frost, snow, freezing fog, freezing drizzle, freezing rain, and rain on a cold-soaked wing. The results of these investigations were incorporated into complete sets of HOT guidelines for all types of deicing fluids and are used by the world's pilots, dispatchers, deicing operators, and other aviation specialists.

This information is made available through an FAA Flight Standards Information Bulletin for Air Transportation (FSAT) entitled "FAA-Approved Deicing Program Updates." The FSAT for winter icing season 2002-2003 presents test results on over 20 Type I, Type II, and Type IV deicing and anti-icing fluids. The HOT guidelines were coordinated with industry during an international meeting in Europe. The FSAT also presents other key information including infrared deicing, use of visibility tables in estimating snowfall intensities for HOT determination, forced air deicing systems, deicing fluid dryout, interpretation and usage of Type I fluid HOT guidelines, new technologies, and other topics. The FSAT was placed on the AFS-200 website (www.faa.gov/avr/afs/fsat/) for use by world's airlines during the upcoming winter.

Charles Masters, AAR-470, (609) 485-4135

FAA TYPE II Holdover Time Guideline

OAT		SAE Type II Fluid Concentration Neat-Fluid/Water (Vol. %/Vol. %)	Approximate Holdover Times under Various Weather Conditions (hours: minutes)						
°C	°F		Frost*	Freezing Fog	Snow◆	Freezing Drizzle***	Light Freezing Rain	Rain on Cold Soaked Wing	Other‡
above 0	above 32	100/0	12:00	0:35-1:30	0:20-0:55	0:30-0:55	0:15-0:30	0:05-0:40	CAUTION: No holdover time guidelines exist
		75/25	6:00	0:25-1:00	0:15-0:40	0:20-0:45	0:10-0:25	0:05-0:25	
		50/50	4:00	0:15-0:30	0:05-0:15	0:05-0:15	0:05-0:10	CAUTION: Clear ice may require touch for confirmation	
0 to –3	32 to 27	100/0	8:00	0:35-1:30	0:20-0:45	0:30-0:55	0:15-0:30		
		75/25	5:00	0:25-1:00	0:15-0:30	0:20-0:45	0:10-0:25		
		50/50	3:00	0:15-0:30	0:05-0:15	0:05-0:15	0:05-0:10		
Below -3 to -14	Below 27 to 7	100/0	8:00	0:20-1:05	0:15-0:35	**0:15-0:45	**0:10-0:25		
		75/25	5:00	0:20-0:55	0:15-0:25	**0:15-0:30	**0:10-0:20		
Below -14 to -25	Below 7 to -13	100/0	8:00	0:15-0:20	0:15-0:30				
Below -25	below -13	100/0	SAE Type II fluid may be used below –25 °C (-13 °F) provided the freezing point of the fluid is at least 7 °C (13 °F) below the OAT and the aerodynamic acceptance criteria are met. Consider use of SAE Type I when SAE Type II fluid cannot be used.						

14 CFR Part 145 Repair Station Analysis Model

Title 14 of the Code of Federal Regulation (CFR) Part 145 defines repair stations as those facilities that perform maintenance and/or alterations on airframes, powerplants, propellers, and/or appliances. In the U.S. aviation industry today, the bulk of maintenance is outsourced, primarily to repair stations. In the past, the major carriers conducted up to 90% of their maintenance in-house. During the 1990s, the major air carriers started relying on contracted maintenance, repair, and overhead facilities (e.g., repair stations) for their maintenance support. Today, approximately 45% of maintenance of the major carriers is contracted to outside vendors.

Due to the rapidly changing environment in the aviation maintenance arena, changes in the repair station business practices and advances in aircraft technology, it has become increasingly difficult to administer the repair stations based on the existing FAA regulations and associated systems. Research, sponsored by Flight Standards Service (AFS), initially involved developing functional and business models to yield the safety-critical data needed by AFS personnel in providing the required oversight of certificated repair stations. The research provided input into the development of a model that indicates potential problems using existing information. Emphasis was given to the System Safety business approaches that AFS is embracing. The research required interviews of aviation safety inspectors (ASIs), a survey of industry, an exploratory analysis of systems with respect to FAA regulations, study and input from related efforts by other entities, and inputs from Subject Matter Experts (SMEs).

The Analysis Model was developed and a prototype was presented at the Repair Station Expert Panel meeting held on October 30 – November 1, 2001. The model was approved for development and implementation in the FAA's Safety Performance Analysis System (SPAS) in FY02. AAR-490 was responsible for writing the Software Requirements Specification (SRS) based on the Analysis Model prototype. The software specifications for the second version of the 14 CFR Part 145 Analysis Model were delivered in February 2002. AAR-490 met the Flight Standards requirement to deliver a prototype and specifications for a production version of an analysis model that could be applied to both FAA-certificated domestic and foreign repair stations.

The Analysis Model provides a means to inform FAA ASIs of potentially important situations regarding the repair stations. The model will also expedite their activities in certification, recertification, surveillance, and investigation by providing them readily accessible information from a variety of data sources and by highlighting important information and trends. The primary objectives of the Repair Station Analysis Model are to identify repair stations that may need a greater safety analysis, highlight potential analysis areas, and to identify those areas that could further improve the analysis model as new data is collected. The overall Analysis Model has four components: Stability, Investigation, Complexity, and Oversight. Each component is comprised of a set of factors and uses an algorithm to create individual performance measures.

From this research, AFS will be able to:

- Proactively respond to maintenance-related issues to enhance safety

- Enhance understanding of current requirements reflecting the changing Repair Station environment
- Establish a baseline for repair station process and supporting information systems
- Improve data collection mechanisms
- Improve data quality and standards and data sharing
- Improve guidance and training material
- Provide better analysis tools for oversight and decision making

Kathy Fazen, AAR-490, (609) 485-4100

Survey of Aviation Maintenance Technical Manuals

Until recently, little attention has been paid to the way written procedures that are used to develop and revise aircraft maintenance technical data affect the users of that data. Studies of maintenance problems have tended to focus on the actions of the mechanic, job culture, and work procedures. More recently, attempts have been made to document the source of maintenance errors and improve maintenance procedures. One of the identified contributing causes of errors is the documentation used to guide maintenance tasks. As a result, efforts have been made to establish guidelines for the design of maintenance job aids. A question that remains is, how do the procedures that manufacturers use to develop maintenance data contribute to user error?

The Survey of Aviation Maintenance Technical Manuals was a three-phase research effort (1) to examine the procedures used by the industry to develop maintenance manuals, (2) to document the problems encountered by users of these documents, and (3) to identify ways in which human factors principles can be used to improve the development of these documents.

Phase 1 surveyed the procedures used within the aviation industry to develop maintenance technical data. A cross section of manufacturers was surveyed regarding company policy, communication, data tracking, user feedback, and error reduction efforts. Some of the human factors issues identified in this phase were related to the document development process used by manufacturers. They included the reactive rather than proactive use of user evaluations, the limited use of user input and procedure validation, no systematic attempts to track error, and lack of standards for measuring document quality. The survey is documented in “Human Factors Survey of Aviation Technical Manuals Phase 1: Manual Development Procedures,” DOT/FAA/AR-01/43.

During Phase 2, a written survey was conducted to solicit information about user perception of errors in current manuals, usage rates, general manual quality, and suggestions for manual improvement. The information from the surveys was supplemented with interviews of technicians responsible for maintenance of a wide variety of Code of Federal Aviation Regulations (CFR) Part 25 aircraft. Technicians were queried about technical manual usage rates, manual errors, general manual quality, potential safety impact of manual problems, and suggestions for manual improvement. The results showed that the accuracy and quality of technical manuals are rated as being good but had poor usability. The results are documented in “Survey of Aviation Technical Manuals

Phase 2: User Evaluation of Maintenance Documents," DOT/FAA/AR-02/34.

During Phase 3, recommendations were identified that address a number of shortcomings in how manufacturers develop aircraft maintenance documentation. The recommendations included (1) manufacturers and operators work to facilitate communication between the technicians submitting change requests and the technical writers making the changes to ensure prompt feedback regarding actions to be taken, (2) maintenance procedures be validated by technicians using standard human factors techniques, (3) industry cooperation in developing a system akin to the Maintenance Steering Group to identify maintenance procedures that should be systematically validated, and (4) manufacturers should maintain databases with a history of user-reported errors, feedback to the user, and actions taken. The results from Phase 3 were published December 2002, "Survey of Aviation Technical Manuals Phase 3: Final Report and Recommendations," DOT/FAA/AR-02/123.

In response to the findings and recommendations of this research effort, an Associates of Arts (AA) degree program was established at local Wichita area colleges with coordination from WSU. The AA program was developed as a result of a joint venture between local aircraft manufacturers (Raytheon, Lear, and Cessna), educational institutions (Wichita Area Technical College and Wichita State University), the Wichita Chamber of Commerce, and a consulting business (Entrepreneurial Foundations, LLC). This joint venture led to the development of certificate and degree programs for aviation technical writers. Through the collaborative efforts of this group, it will provide an environment for teaching the necessary skills of technical writing, as well as aircraft systems operation and maintenance procedures. Classes began in the fall of 2002.

Cristina Tan, AAR-490, (609) 485-8168

Continuing Analysis and Surveillance System (CASS) Research

A joint FAA/NTSB study of a series of maintenance-related air carrier accidents occurring during the 1950s found that, in some cases, the primary causal factor of the accidents was the air carrier maintenance program itself. The maintenance program was incapable or ineffective in preventing the equipment failure that led to the accident. In other cases, the maintenance program was determined to be effective in terms of failure prevention, but maintenance personnel failed to do the required maintenance tasks or failed to complete the task correctly.

In response to these findings, in 1964, the FAA introduced Title 14, Code of Federal Regulations (CFR), Parts 121.373 and 135.431, which require air carriers to establish a Continuing Analysis and Surveillance System (CASS) to evaluate, analyze, and correct deficiencies in the performance and effectiveness of their inspection and maintenance programs.

Although 14 CFR Parts 121.373 and 135.431 require air carriers to establish and implement CASS, the existing guidance and CASS regulations do not provide a model for what an effective CASS should include.

As a result, clear guidelines on how an effective CASS should be established and monitored are not available to the FAA inspectors and air carriers. On December 12, 2001, the Department of Transportation Inspector General Office released a report titled "Oversight of Aircraft Maintenance, Continuing Analysis and Surveillance Systems" in which it recommended that the FAA establish clear and expanded guidance for CASS.

The Aircraft Maintenance Division (AFS-300) asked the Risk Analysis Branch (AAR-490) to initiate a research task to develop guidelines and models for CASS. The guidelines and models should assist air carrier personnel and FAA inspectors in establishing, implementing, and monitoring CASS more effectively. The research should also produce guidance materials that could be used to develop an Advisory Circular for CASS.

Between January and April 2002, the research team conducted 28 on-site interviews with 23 Part 121 and 135 air carriers, along with three trade associations (Air Transport Association, Regional Airline Association, and National Air Carrier Association) and the Joint Aviation Authorities of Europe. The interviews were conducted using a generic questionnaire guideline developed by the FAA research team. The questionnaire was designed to foster discussions on CASS functionality and compliance. The research team also conducted interviews with various FAA organizations and Flight Standard District Offices (FSDO) for their input and perspective on CASS.

Based on the results of the interviews and a review of the CASS requirements, the CASS models and guidance were developed.

In summary, the responsibility for CASS remains with the air carrier. Each air carrier's CASS must consist of the following functions:

- Surveillance
- Analysis
- Corrective action
- Follow-up
- Controls

Surveillance represents the function through which the air carrier can determine how its maintenance and inspection programs are performing. This surveillance is followed by a report of findings, which is then analyzed to determine what the root causes of the findings are. Comprehensive fixes are subsequently developed to address the findings. Finally, follow-up and surveillance audits are scheduled to verify that each corrective action was effective. Together, these functions form a closed-loop system that allows the air carrier to monitor the quality of its maintenance.

In addition to the analysis of surveillance data, another part of this CASS function is the collection and analysis of mechanical performance data. The air carrier's personnel compile the analyzed data of active failures for reporting purposes so that management can make decisions. Many air carriers perform this function through elements such as their FAA-approved reliability program that monitors mechanical failures (active failures). In contrast, the CASS surveillance function seeks to uncover latent failures through the identification of improper processes or procedures so they can be corrected.

Through this research effort, it was determined that an effective CASS should go beyond a monitoring function and seek to continually improve the quality of the air carrier's maintenance through a closed-loop system. Each air carrier's CASS should include interrelated elements that are, at a minimum, composed of:

- Competent personnel
- Documented procedures
- Proper/adequate materials
- Adequate tools (comprehensive audit checklists, computers, Coordinating Agency for Supplier's Evaluation (CASE))
- Proper equipment
- Suitable facilities
- Proper software controls
- Effective CASS audit procedures
- An independent auditing organization

There are many characteristics of CASS that contribute to make it an effective system, for example:

- Proper auditor qualifications
- Well-defined role and scope of outside audits
- Adequate resource determination

Michael Vu, AAR-490, (609) 485-8143

Improving Weather-Related Airworthiness Standards

The regulations and requirements for the design and safe operation of aircraft are contained in the Code of Federal Regulations (CFR), Title 14 (Aeronautics and Space), Chapter I (Federal Aviation Administration). Parts 23-29 of that chapter contain airworthiness standards for airplanes and rotorcraft. These standards include requirements for the design of ice protection equipment for aircraft seeking airworthiness certification for flight in icing conditions. This is a necessity for transport and commuter aircraft, which carry passengers for revenue.

Ice protection equipment (typically heated wings on jet airplanes and inflatable tubes on the front of the wings on propeller-driven airplanes) must be capable of preventing or removing ice that would form during flight in icing conditions. The range of icing conditions to be expected was explored by research flights undertaken in the late 1940s. The results now appear as icing design envelopes in Appendix C of 14 CFR Parts 25 and 29. These envelopes display the ranges of pertinent cloud variables (water concentration, droplet sizes, temperature, and altitude) that may be encountered in most natural icing conditions in flight. These are the variables that engineers need for computing the rate, extent, and depth of possible ice accumulations on aircraft surfaces and components.

While these envelopes have proved satisfactory for designing adequate ice protection systems, it has always been difficult to relate flight test data to them because of the way the envelopes are drawn. This has caused considerable confusion, discussion, and nonuniformity of application over the years.

This problem was investigated in the Flight Safety Research Section (AAR-470), and an interesting solution was developed. It was found that the problem could be solved by redrawing the envelopes in terms of other variables. This results in equivalent envelopes that are much more versatile and useful than before. Now, design points and data from test flights, icing wind tunnels, and even computer simulations can be plotted easily on the envelopes and compared to one another in ways that were not possible before. New variables, such as icing rate, icing severity, and total accumulations can also be plotted. Moreover, by entering the basic envelope coordinates into a computerized spreadsheet, the graphing capabilities of the software modernizes the envelopes and allows them to be tailored to specific needs. Finally, redrawing the envelopes allows four of the six original graphs in Appendix C to be replaced by just one graph, thus simplifying the appendix and reducing its size.

The details and results of this study have been published in the FAA technical report DOT/FAA/AR-00/30, "Icing Design Envelopes (14 CFR Parts 25 and 29, Appendix C) Converted to a Distance-Based Format," by Richard K. Jeck (April 2002). This report is available from the Flight Safety Research Section, AAR-470, Federal Aviation Administration, William J. Hughes Technical Center, Atlantic City International Airport, New Jersey, 08405.

Richard Jeck, AAR-470, (609) 485-4462

Continued Electromagnetic Protection Integrity of Aircraft and Systems

The Airport and Aircraft Safety R&D Division, in conjunction with the National Institute for Aviation Research at Wichita State University, Cessna Aircraft Company, Raytheon Aircraft, QinetiQ Research, and the European Aircraft Electromagnetic Compatibility (EMC) Research Council, completed a series of research tasks related to shield degradation of aircraft wire bundles for high-intensity radiated fields (HIRF) and lightning protection.

Phase I – Task 1, Shield Degradation Testing of Aircraft Wire Bundles: Five sets of shielded wire bundles (two harnesses) with connectors, backshells, and termination boxes attached to ground-plane aluminum panels (see figure 1) were built to simulate an aircraft structure. These panels were subjected to varying conditions of vibration, temperature and altitude, salt spray and humidity, and mechanical degradation.

Figure 1 shows a photograph of a 36″ by 30″ by 0.25″ aluminum panel used to simulate an aircraft structure. Bolted to the panel at the middle of each end is a 4″ by 3″ cable termination box. A thin 6″ by 6″ aluminum plate, bent in the middle to form an L-shaped bracket, is bolted to the center of the panel. Receptacles for connectors are attached to each termination box and to each side of the center bracket. A 36″ long wiring harness, consisting of 12 shielded and 12 unshielded wires (No. 22 gauge) attached to connectors with backshells, is connected to each termination box and to the center L-bracket, forming two loops. Individual wire conductors are tied directly to ground in the right termination box, whereas, in the left termination box, the wire conductors are terminated to ground through 10-kilohm resistors.

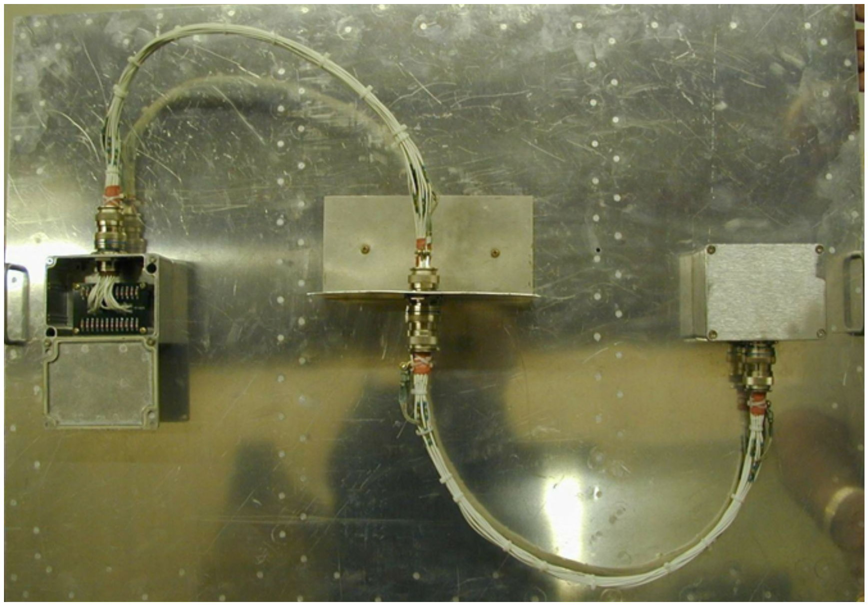


Figure 1. Termination Boxes, Shielded Wire Bundles, and Aluminum Ground-Plane

Figure 2 shows a plot of the average total loop resistance (in units of milliohms) for the five test types (baseline, vibration, temperature and altitude, salt spray and humidity, and mechanical). A loop resistance of approximately 9 milliohms was observed for the baseline, increasing only slightly for both the vibration test (~10 milliohms) and the temperature and altitude test (~10.4 milliohms). Larger increases were observed for both the salt spray and humidity test (12 milliohms) and mechanical degradation test (16 milliohms). Visual degradation was also observed on the test panels that were subjected to the salt spray and humidity test and to the mechanical degradation test.

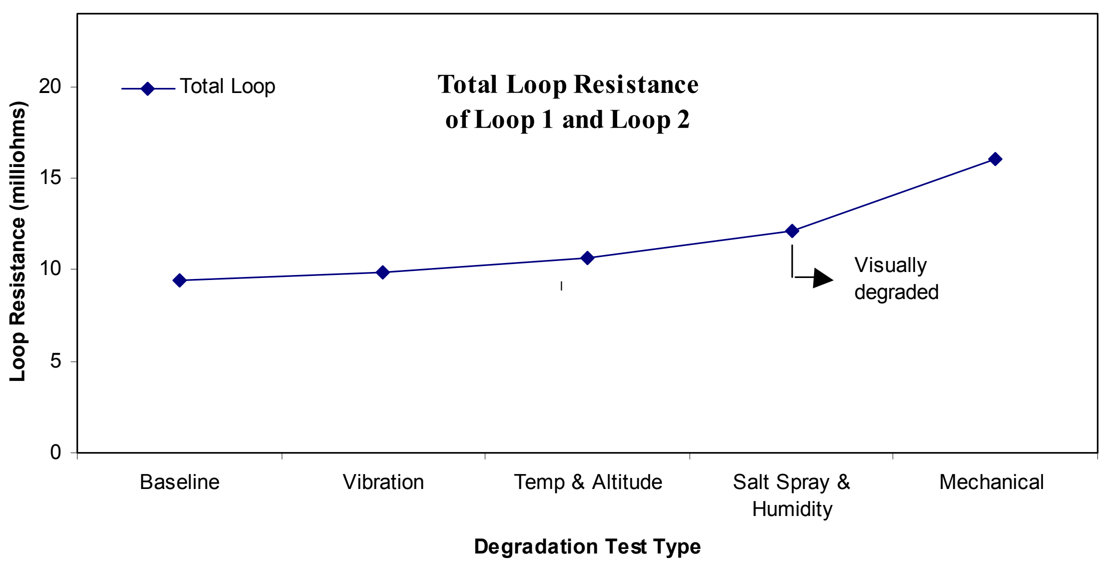


Figure 2. Average Degradation in Total Loop Resistance Due to Various Degradation Mechanisms

Figure 2 shows the average variation in loop resistance for each test condition. The loop resistance should be as low as possible; therefore, any increase in loop resistance would indicate a decrease in lightning and HIRF protection.

Surprisingly, the increase in loop resistance from vibration testing for this type of backshell was less than from either temperature or altitude testing. These results are highly dependent on the type of connector and backshell used. Tests conducted with long-barreled backshells, designed for better HIRF protection, are likely to fail even at medium levels of vibration testing.

Mechanical degradation caused the largest change as expected. A mechanical degradation is a malfunction in a physical component such as a ground shield or a connector backshell. Many times a mechanical failure, such as a loosened backshell, can be observed visually. Degradation tests indicated that the loosened backshells of harness connectors could significantly cause an increase in the loop resistance of the wiring harness.

Phase I – Tasks 2 and 3, Shield Degradation of In-Service Aircraft Wire Harnesses: The loop resistance of the Full Authority Digital Engine Control (FADEC) wiring harnesses of four newly manufactured aircraft was compared with the loop resistance of the same harnesses of ten similar aircraft ranging from 0.7 to 4.4 years of service and having 300 to 3000 flight hours.

Figure 3 shows a plot of FADEC harness loop resistance (in units of milliohms) for in-service aircraft as a function of years of service. Data is shown for 0.0 to 4.4 years of service. The average loop resistance for newly manufactured aircraft was observed to be slightly less than 8.0 milliohms. The harness resistance values increased to 9.0 milliohms at 2.4 years of service. Larger values were observed after 4 years of service (12.2 milliohms). A linear regression of the data showed a correlation factor of 0.944 between harness resistance and years of service.

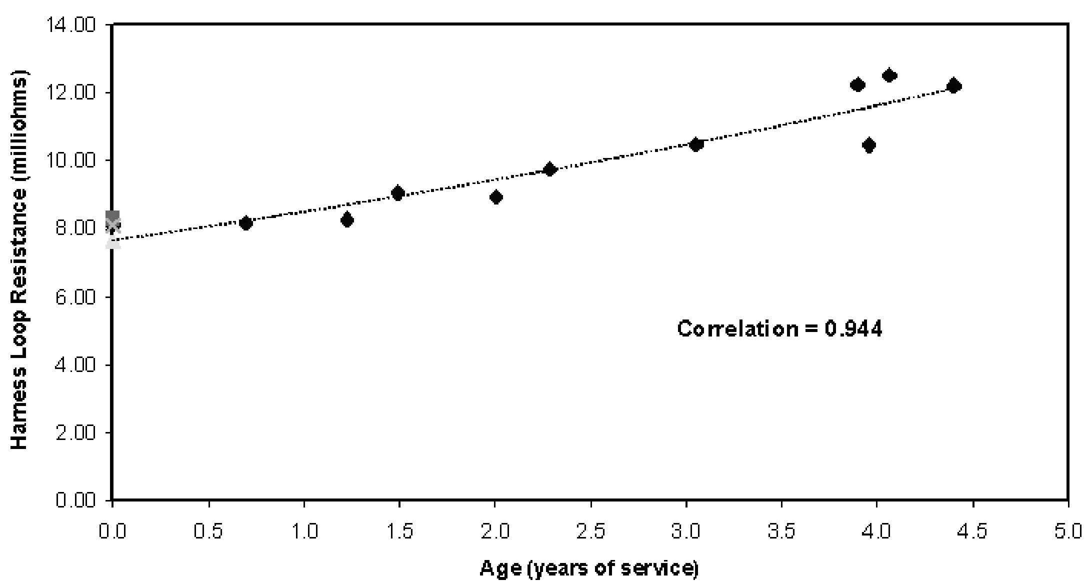


Figure 3. Loop Resistance of FADEC Harnesses as a Function of Aircraft Age

Figure 4 shows a plot of FADEC harness loop resistance (in units of milliohms) for in-service aircraft as a function of flight hours. Data is shown for 0.0 to 3000 flight hours. The average loop resistance for newly manufactured aircraft was observed to be slightly less than 8.0 milliohms. Aircraft with 1000 flight hours had observed harness resistance values of 8.27 and ~12.5 milliohms. Aircraft with ~2200 flight hours had resistance values ranging from 9.05 to 10.45 milliohms. Values as large as 12.2 milliohms were observed for aircraft with 2500 and 3000 flight hours. A linear regression of the data showed a correlation factor of 0.767 between harness resistance and aircraft flight hours. The data for obtaining these results are shown in tables 1 and 2.

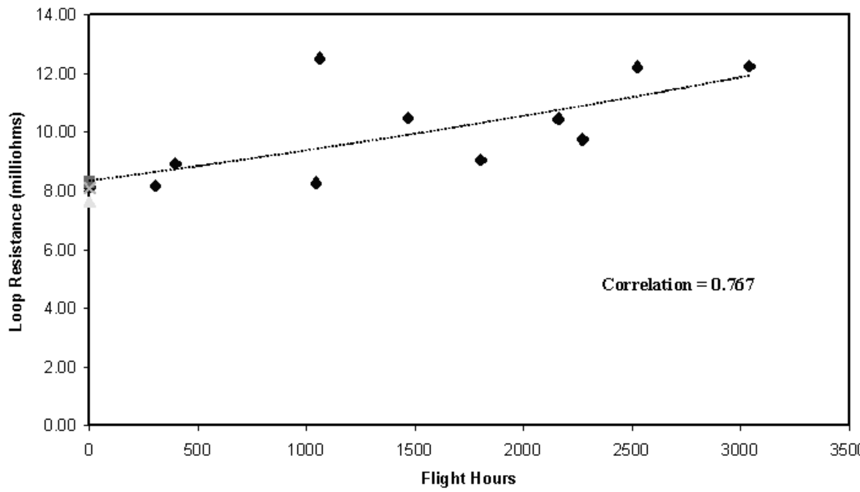


Figure 4. Loop Resistance of FADEC Harnesses as a Function of Aircraft Flight Hours

Table 1. Loop Resistance Measurements on FADEC Wire Bundles of New Production Aircraft

Aircraft Serial No.	New Aircraft	**101**	**102**	**103**	**104**
Field Survey Date		7/26/2001	4/16/2001	4/17/2001	4/17/2001
Left Engine	Blue Bundle	7.76	7.52	7.32	7.8
	Yellow Bundle	8.68	8.78	7	8.7
Right Engine	Blue Bundle	7.42	7.75	7.4	7.5
	Yellow Bundle	8.62	9.03	8.81	8.39
Average		8.12	8.27	7.63	8.10

Table 2. Loop Resistance Measurements on FADEC Wire Bundles of In-Service Aircraft

Aircraft Serial No.	**001**	**002**	**003**	**004**	**005**	**006**	**007**	**008**	**009**	**010**
Airworthiness_Date	2/17/97	6/7/97	6/27/97	9/2/97	7/1/98	3/31/99	5/21/99	11/24/99	3/2/00	11/7/00
Field Survey Date	7/13/01	5/22/01	7/20/01	7/26/01	7/20/01	7/13/01	5/22/01	5/22/01	5/24/01	7/20/01
A/C Age (Yrs.)	4.4	4.0	4.1	3.9	3.1	2.3	2.0	1.5	1.2	0.7
Flight Hours	2523	2161	1062	3041	1467	2273	396	1803	1045	305
Left Engine:										
Blue Bundle	13.06	12.22	12.55	15.56	10.71	8.51	9.73	8.89	7.32	7.53
Yellow Bundle	14.74	12.06	11.48	10.85	10.98	9.38	8.7	9.3	8.57	8.01
Right Engine:										
Blue Bundle	9.73	8.81	40.52*/12.50	11.4	9.73	11.05	8.38	9.45	7.41	8.02
Yellow Bundle	11.34	8.72	13.51	11.18	10.5	10.06	36.9*/8.955	8.56	9.79	9.1
Average	12.22	10.45	12.51	12.25	10.48	9.75	8.94	9.05	8.27	8.17

The FADEC harness controls the critical functions of each jet engine. Therefore, a redundant harness (comprised of a blue and a yellow bundle) is connected to each engine. The loop resistance of all four harnesses was measured and recorded for each airplane. The data from newly manufactured aircraft appear in table 1. The data recorded from in-service aircraft was recorded in table 2. For the data plotted in figure 3 (years in service) and figure 4 (aircraft flight hours), the average loop resistance of the four cables was used because the value was deemed the best representation of the current status of the engine cables. A low loop resistance of approximately 8.0 milliohms was desired.

Phase I – Task 4, Lightning Strike Database Analysis: Lightning strike reports from 96 different aircraft over the most recent 5-year period were analyzed to determine the effect of the level of HIRF and lightning protection design and implementation. Figure 5 shows a bar graph of the number of lightning strike reports filed for nine different types (models) of business jet aircraft over the last 5 years. The aircraft were grouped into three categories according to the level of lightning and HIRF protection that was installed at the time of manufacture (no protection, avionics only protection, and full-system protection). For each aircraft type, a bar graph was drawn for the total number of lightning strike reports filed, the number of electrical failures that were sustained, and the number of incidences when only temporary electrical interference (no damage) was reported. The graph shows that fully protected aircraft suffered significantly fewer incidences of interference and indirect-effects damage, when compared to lightning strike reports of lesser-protected aircraft.

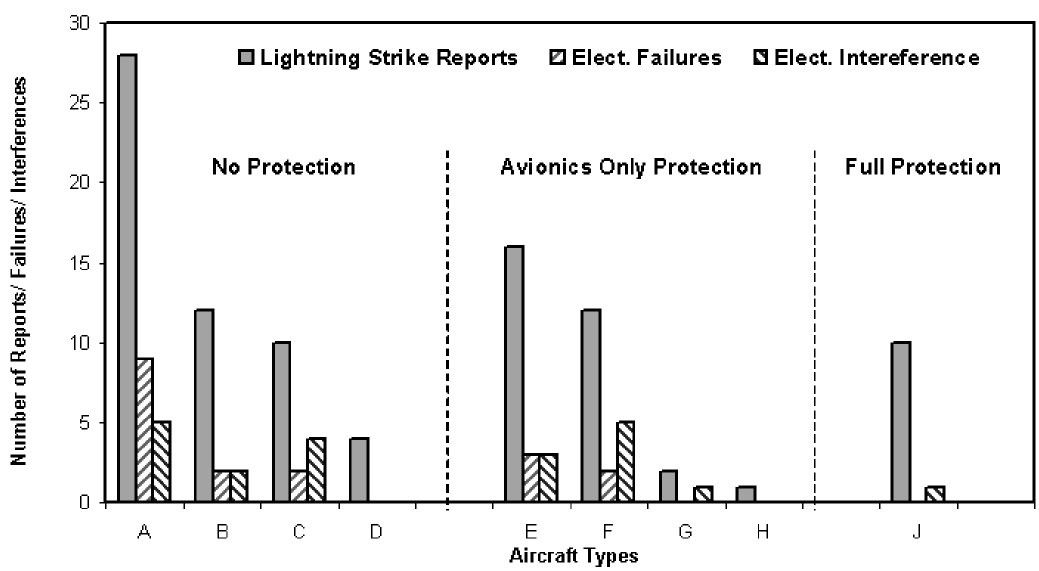


Figure 5. Electrical Failures and Electrical Interferences by Aircraft Model

Results were divided into three categories: aircraft with no protection, avionics only protection, and fully protected aircraft. Figure 5 shows the number of lightning strikes reported for various types of aircraft and the number of resulting electrical failures and electrical interferences. The aircraft (represented by the letters A, B, C, D, E, F, G, H, and J) represent a wide spectrum of business jet aircraft that have reported lightning strikes. Results showed that physically larger aircraft (A, E, and J) were more likely to be struck by lightning than smaller aircraft (B, C, D, F, G, and H), possibly because larger aircraft are more likely to be flown through inclement weather than smaller aircraft. The number of failures and interferences due to lightning strikes were significantly reduced by increasing the level of protection built into the aircraft. Lightning strikes on the radome were the most common. Indirect-effects damage is graphed in figure 5, showing the difference in temporary interference versus equipment or system failure. Fully protected aircraft suffered significantly less interference and no permanent failures for the reports studied.

Phase II – Task 2, Analysis of Loop Resistance Variation With Loosened Backshells: Degradation tests from Phase I, Task 1, indicated that loosened backshells of harness connectors could cause a significant increase in the loop resistance of the wiring harness. But how loose can the backshell become before the loop resistance rises to an unsafe value? Figure 6 shows a plot of the increase of wire bundle loop resistance (in units of milliohms) when the backshells of the harness connectors are loosened by a number of angular degrees. The plot shows very little change in loop resistance when the backshell becomes visually loose (5 degrees) on two different harnesses (from 80 to 82 milliohms for Loop 1 and 70 to 71 milliohms for Loop 2). The backshells were loosened by a 45-degree turn before they became hand loose. At this point, the resistance of Loop 1 had increased from 80 to 91 milliohms, and the resistance of Loop 2 had increased from 70 to 74 milliohms.

When the backshells were loosened a quarter turn (90 degrees), the resistance of Loop 1 rose to 98 milliohms, and the resistance of Loop 2 rose to 92 milliohms. When the backshells were loosened beyond 90 degrees, the loop resistance rose significantly (beyond 300 milliohms) and became unstable (out of range of the measuring instrument).

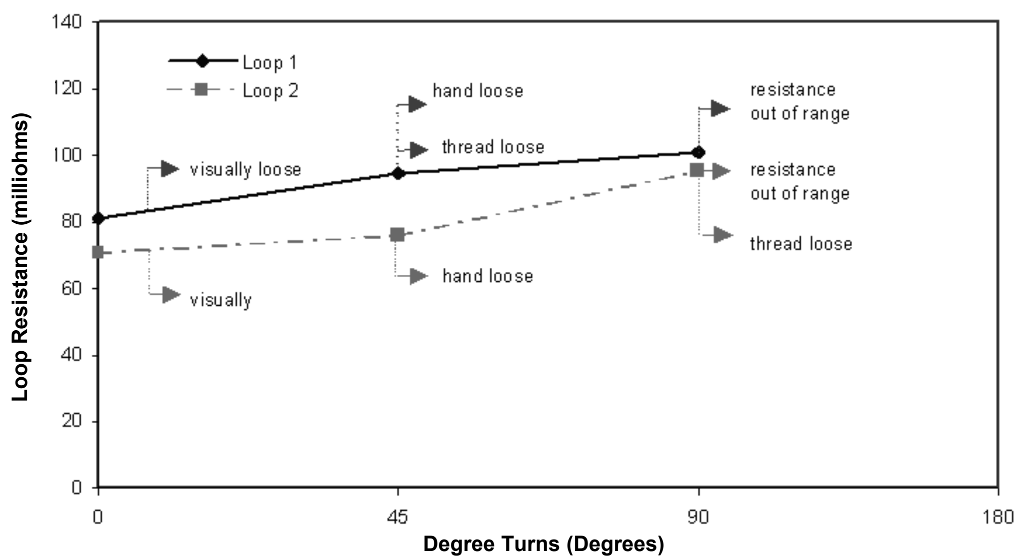
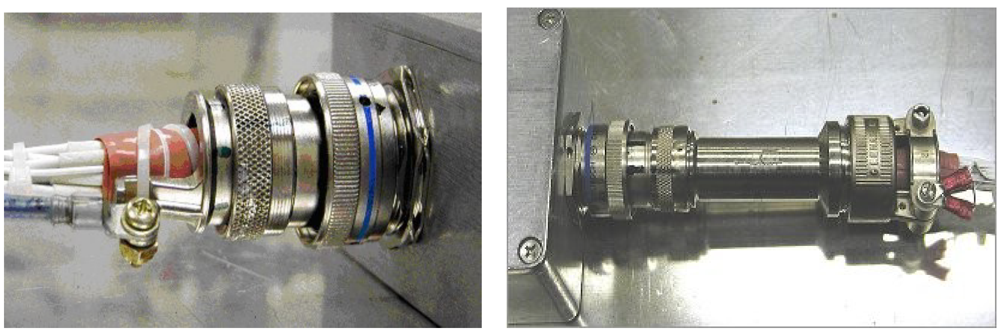


Figure 6. Backshell Loosening by Degree Turns

In summary, figure 6 shows the increase in loop resistance as the backshell of a wiring harness connector is loosened by hand in varying amounts by turning. These tests verified that the backshell could look like it was loose and be loosened by manual hand turning before significant changes in loop resistance were measured. Loops 1 and 2 results, shown in figure 6, are individual loops that make up the entire wiring harness fastened to termination boxes on the ground-plane panel, simulating an aircraft structure.

Figures 7(a) and 7(b) show photographs of two different backshell configurations.

Figure 7(a) shows a short-barreled backshell mounted on a connector where the wire shields from individual wires are stripped back and bolted to a common post outside the backshell. By comparison, figure 7(b) shows a long-barreled backshell mounted on the same type of connector. In this case, the wire shields are soldered to individual wires inside the long backshell, which cannot be seen or visually inspected. The shield wires exit from the rear of the backshell and are bolted to a common post on the end of the backshell.



(a) (b)

Figure 7. Comparison Photographs of a Short- and Long-Barreled Backshell

Our studies have found that different backshells used in business jet aircraft vary widely in their HIRF characteristics, ease of visual inspection, and changes when subjected to vibration, humidity, and contamination. A comprehensive investigation of a variety of different backshells is recommended because significant variance was found with different connector types. Results from these investigations are being incorporated into recommended specifications and guidance documents for the protection of aircraft electrical and electronic systems from electromagnetic hazards.

Anthony Wilson, AAR-470, (609) 485-4500

Fire Safety

2001 International Aircraft Fire and Cabin Safety Research Conference

The Third International Fire and Cabin Safety Research Conference, sponsored by the FAA, European Joint Aviation Authorities (JAA), Transport Canada Civil Aviation, Japanese Civil Aviation Bureau, and Civil Aviation Safety Authority Australia, was held in Atlantic City, NJ, on October 22-25, 2001. Over 400 people attended the tri-annual conference that was hosted by the Fire Safety Branch, AAR-440. The conference was a follow-up to the International Fire and Cabin Safety Research Conference held in November 1998. The objective of the conference was to apprise the aviation community of recent, ongoing, and planned research activities in the areas of aircraft fire and cabin safety since the November 1998 Conference. Each attendee was given a compact disk (CD) containing technical reports published by the regulatory authorities, covering the subject area since the November 1998 Conference.

The conference was comprised of presentations and discussions in the areas of fire safety (including materials flammability, fuselage burnthrough, halon replacement, fuel tank explosion, and advanced materials), crash dynamics, evacuation, and operational issues. Of the 129 presentations, 15 were made by Fire Safety Branch personnel on the following R&D subjects:

- Past accomplishments and current program
- Burnthrough test method
- Correlation of heat release rate in the OSU and Cone Calorimeters
- FTIR toxic gas analysis
- BPC polymers
- Heat release capacity
- Electrical wiring flammability
- Hidden fire program
- Testing of insulation tapes and hook and loop
- Cargo smoke detector test standards development
- Ground-based inerting of a 747SP center wing tank
- Onboard oxygen analysis system
- Jet fuel vapor ignition experiments at reduced oxygen levels
- Engine nacelle halon replacement
- Cargo water mist

The conference proceedings, consisting of the 129 papers and presentations, were published on a CD (DOT/FAA/AR-02/49) and distributed to the attendees.

The fourth triennial conference is scheduled to be held in Lisbon, Portugal, and will be hosted by the JAA.

Richard Hill, AAR-440, (609) 485-5997

Options for the Use of Halon Agents for Aircraft Fire Suppression

The FAA is completing a program to determine performance criteria and certification methods with the objective of developing minimum performance standards (MPSs) for nonhalon fire-extinguishing and suppression systems onboard aircraft. This program is being performed in cooperation with the Joint Aviation Authorities in Europe, the Civil Aviation Authority in the United Kingdom, and Transport Canada Aviation. The International Halon Replacement Working Group (IHRWG) was established by the FAA and cooperating agencies to provide input for the program. Participants included aviation regulatory authorities, other government agencies involved in research and development, airframe manufacturers, airlines, industry associations, manufacturers and suppliers of fire protection equipment and agents, and researchers.

The Task Group on Halon Options was established as one of several task groups within the IHRWG. The Halon Options Task Group was initially assigned to review chemical options to halons and published a report in February 1995 and an updated report in September 1996.

Subsequently, the focus of the IHRWG was recently expanded to include all system fire protection research and development for aircraft. The name of the group was changed to the International Aircraft Systems Fire Protection Working Group. The Halon Options Task Group completed the report "Options to the Use of Halons for Aircraft Fire Suppression Systems—2002 Update," DOT/FAA/AR-99/63, in February 2002. This report is an update of a 1996 report that was written in the early stages of the assessment of halon options. This report provides a current reference of all the issues and concerns relating to using halon options for aircraft fire suppression.

The report was prepared by the Halon Options Task Group of the International Aircraft Systems Fire Protection Working Group, which was chaired and administered by AAR-440. Participants included aviation regulatory authorities, other government agencies involved in research and development, environmental regulatory authorities, airframe manufacturers, airlines, industry associations, manufacturers and suppliers of fire protection equipment and agents, and researchers.

This report provides an up-to-date summary of the chemical, physical, toxicological and environmental properties, and considerations for the use of available fire suppression agents. It also discusses the fire-extinguishing performance and the current regulatory status (toxicological and environmental, as well as aviation regulations) of the halon options.

This report also summarizes available fire suppression technologies that could be considered as halon substitutes for the four major aircraft onboard applications: (1) engine nacelles, (2) hand-held extinguishers, (3) cargo compartments, and (4) lavatory protection. The technologies are discussed and the applicability of each is assessed for the four primary applications. The minimum performance standards are presented for each major aircraft onboard application. Fire tests conducted using halon options for these four major aircraft onboard applications were reviewed, with successes and failures noted.

The options are divided into two groups: replacements (halocarbon agents) and alternatives (all other options). Halocarbon agents as well as alternatives (i.e., foams, water sprinklers, dry chemicals, carbon dioxide, loaded stream, water misting systems, fine particulate aerosols, inert gases, solid propellant gas generators, and combination and new foam agents) are discussed.

During preparation of this report, draft versions were updated and posted on an Internet site to permit review, comment, and recommendations by working group members and others. Manufacturers were also informed of the Internet posting, allowing them to review and comment on discussions of their products.

Louise Speitel, AAR-440, (609) 485-4528

Proposed Flammability Test for Airline Blankets

The FAA recently proposed a flammability test standard for airline blankets based on work completed by the Fire Safety Branch, AAR-440. Currently, there is no FAA flammability requirement for airline blankets. A proposed Technical Standard Order (TSO) C1582, "Flammability Test Method for Airline Blankets," was issued by the Aircraft Certification Service, the Technical Programs and Continued Airworthiness Branch, AIR-120, and may be commented upon by the public until June 7, 2002. It is available on the following website: http://av-info.faa.gov/tso/tsopro/prosed.htm.

Research to examine the flammability of airline blankets and develop a test standard was initiated after a serious incident with a fire in an overhead stowage bin. The fire occurred shortly after push back from the loading gate and was extinguished by crewmembers and all passengers were safely evacuated. It was determined that the primary source of fuel for the fire was the polyester airline blankets. Tests showed that the blankets were easily ignited with a match, causing rapid flame propagation. Consequently, the NTSB recommended that the FAA develop flammability test criteria for blankets supplied to the airlines.

Although not required by FAA regulations, some airlines require from their vendors that the blankets meet a flammability standard, usually the vertical Bunsen burner test prescribed in FAR 25.853.

The flammability of airline blankets was evaluated by conducting a series of large-scale fire tests. Typical blankets were folded or crumpled into a ball and subjected to an ignition source, either a match or cigarette. It was shown that the 100% fire-retardant (FR) wool and 100% FR modacrylic blankets exhibited the greatest resistance to ignition. Conversely, a 100% polyester-warped knit blanket failed the full-scale match test. The 60% wool/40% acrylic, 100% acrylic, and 100% wool blankets were also flammable and burned completely or significantly when ignited with a match. None of the blankets tested could be ignited with a cigarette. Full-scale tests demonstrated that some blankets were fire resistant and others were relatively flammable. Thus, improvements in blanket fire performance were needed and achievable.

To readily and consistently evaluate the flammability of airline blankets, a small-scale fire test standard was required. Four test methods were evaluated and compared with full-scale fire test results: (1) single-ply vertical test, (2) single-ply horizontal test, (3) four-ply vertical test, and (4) four-ply horizontal test. The four-ply horizontal test method provided the best correlation with full-scale match tests and produced consistent (repeatable) test results. Moreover, it was a more realistic assessment because the blankets are usually folded when stored in the aircraft stowage bins.

The four-ply horizontal test method is a relatively simple test configuration. Each test blanket is folded in half and then folded again, resulting in an 11-inch-square, four-ply test specimen. The test specimen is subjected to a Bunsen burner flame placed under the geometric center of the test specimen for 12 seconds (see figure 1). To pass the proposed test method, the average flame time for all the specimens tested must not exceed 15 seconds and any flaming drippings must be extinguished within 5 seconds.

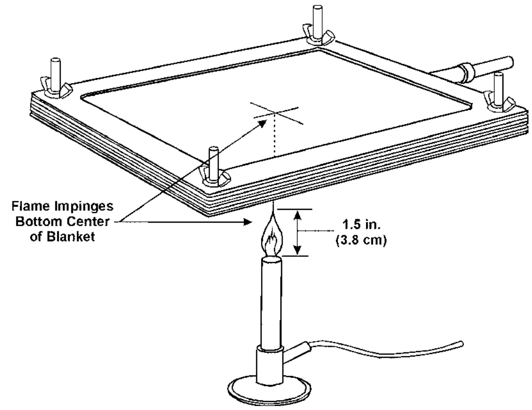


Figure 1. Horizontal Test Fixture With Four-Ply Blanket Sample

The proposed TSO provides a means of FAA approval of fire-resistant airline blankets.

Patricia Cahill, AAR-440, (609) 485-6571

New Fire Suppression System Evaluated

Currently, commercial aircraft employ Halon 1301, an extremely effective extinguishing agent, to protect against cargo compartment fires. However, by international agreement, halon is no longer being produced because it is a chemical that depletes the stratospheric ozone layer. The availability of halon is diminishing, and there may be use restrictions. The effectiveness of a new fire suppression system, employing water mist for initial fire knockdown and nitrogen for inerting against a deep-seated fire, was evaluated during full-scale cargo compartment tests using a series of standard cargo fire scenarios (see figure 1). The test showed that the hybrid water mist and nitrogen system met the minimum performance standard for nongaseous halon replacement agents developed recently by the Fire Safety Branch, AAR-440. Additionally, after putting out the fire, cargo compartment temperatures were found to be lower than with halon, and the weight of water consumed was less than the weight of the halon that would have been needed to extinguish the test fires.

Figure 1. Testing of the Water Mist System

The test program was initiated by a recommendation from the International

Aircraft System Fire Protection Working Group, chaired and administered by AAR-440. Comprised of government and industry fire safety specialists, the working group recommended two halon replacement systems for FAA testing: pentafluoroethane and water mist/nitrogen gas. Tests completed with pentafluoroethane were disappointing because the agent did not consistently suppress cargo fires, there were anomalous test results, and the agent would require an unacceptable large weight penalty. Although not fully tested, a water mist/nitrogen system has a number of significant advantages: environmentally friendly, nontoxic, and readily abundant agents.

A water mist/nitrogen gas system would potentially have two additional major safety advantages. First, the nitrogen gas could be available from an onboard inert gas generation system (OBIGGS), which is used to inert fuel tanks to protect against an explosion. The dual application of nitrogen for fuel tank inerting and cargo compartment fire suppression would significantly offset the weight and cost of an OBIGGS. Second, water for cargo compartment fire protection could also be used for a cabin water spray system, which in past FAA full-scale fire tests was shown to be capable of providing a significant increase in postcrash fire survivability.

The water mist/nitrogen gas system was evaluated in the 130-foot-long, wide-body fuselage test article located at the Full-Scale Fire Test Facility, Building 275. Its effectiveness was examined against four cargo fire scenarios: bulk-load fire, container fire, surface burning fire, and aerosol can explosion. Each fire test scenario was repeated five times for a total of 20 tests. The performance of the water mist/nitrogen system was impressive. Peak cargo temperatures were reduced by 35%-60% compared to the halon system. The quantity of water required ranged from 22-73 pounds, as compared to 80 pounds of halon that would be needed.

The test results are documented in final report DOT/FAA/AR-01/121, "The Evaluation of Water Mist With and Without Nitrogen as an Aircraft Cargo Compartment Fire Suppression System."

John Reinhardt, AAR-440, (609) 485-5034

FAA Transfers Fire Safety Technology

The heat release rate in flaming combustion is the single most important parameter describing the fire hazard of a material in an enclosure such as a room or an aircraft cabin. For this reason, the FAA requires a heat release rate test (FAR 25.853(a-1)) for large area aircraft cabin interior materials. Heat release rate testing is done in a fire calorimeter using samples cut from commercial and production materials. Figure 1 shows typical results from a fire calorimeter for flaming heat release rate versus external heat flux (fire size). The slope of the line in figure 1 is the sensitivity of the material to fire size, which is called the heat release parameter (HRP). The intercept in figure 1 is the intrinsic heat release rate of the material at zero heat flux HRR_0 and its sign and magnitude determine the ignition resistance of a plastic, i.e., whether it will continue burning or self-extinguish after the removal of the Bunsen burner flame. Plastics will self-extinguish in isolated flame (flammability) tests if $HRR_0 < 125$ kW/m^2.

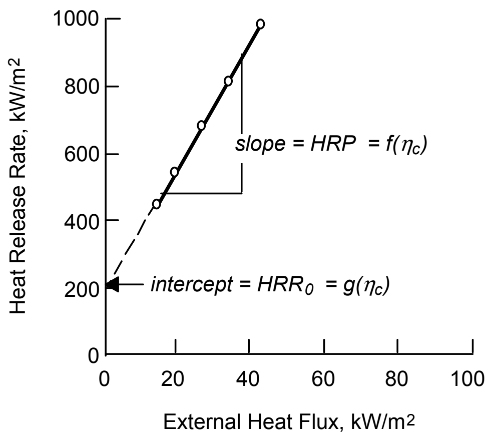


Figure 1. Typical Fire Calorimetry Data for Heat Release Rate in Flaming Combustion Versus External Heat Flux (Fire Size)

While flaming heat release rate (e.g., figure 1) is the best indicator of the fire hazard of a material, only a small fraction of the 16 billion pounds of flame-retardant plastics sold worldwide are required to pass a heat release rate test. Instead, the majority of commercial plastics used in consumer electronics, electrical equipment, and public transportation are only required to exhibit ignition resistance, i.e., they must self-extinguish after removal of a Bunsen burner flame rather than continue to burn. Fire calorimeter testing of heat release rate and Bunsen burner tests of flammability each require a minimum of several kilograms of material from which to fabricate replicate test specimens. Multikilogram quantities of commercial plastics and compounds are readily available, but such large quantities are not available for research materials that are only produced in gram quantities in chemical laboratories. Thus, research scientists need a screening test that is capable of predicting the fire behavior and flammability of the gram-sized samples of new, potentially fire-resistant plastics that could be used in aircraft interiors and consumer applications.

To address the need for a rapid flammability screening test and to accelerate the discovery of new ultra-fire-resistant plastics, the Department of Transportation's Federal Aviation Administration was awarded U.S. Patent 5,981,290 on November 9, 1999, for the Microscale Combustion Calorimeter. On December 19, 2000, the DOT/FAA filed a second patent for an improved and simplified Heat Release Rate Calorimeter for Milligram Samples that uses a computer algorithm to eliminate the need for a mass loss rate measurement during the test. This improvement reduced the cost of the microscale combustion calorimeter by a factor of 2 and reduced the typical test time from over an hour to less than 5 minutes. The devices are collectively referred to as pyrolysis-combustion flow calorimeters (PCFCs) and were developed by the FAA and Galaxy Scientific Corporation researchers at the William J. Hughes Technical Center's Airport and Aircraft Safety R&D Division, Fire Research Program. Figure 2 shows the current PCFC. The PCFC test produces a repeatable and quantitative value for the fire hazard potential of a material called the heat release capacity η_c, which has units of Joules per gram per degree Kelvin (J/g-K). The heat release capacity is directly related to the HRP and the intrinsic heat release rate (HRR_0) measured in fire calorimetry tests, as indicated by the generalized functional dependence of these parameters on η_c in figure 1.

Figure 2. FAA Pyrolysis-Combustion Flow Calorimeter

The PCFC was evaluated as a small-scale screening test for fire and flammability for use by the plastics industry to rapidly and economically evaluate gram quantities of new flame-retardant formulations. The Underwriters Laboratory test UL 94, Sections 2 and 3, is the predominant standard for flammability of plastics. In the UL 94 test, thin strips of plastic are ignited by a Bunsen burner in a vertical (V) or horizontal (H) orientation and ranked according to their horizontal-burning rate (HB) or time to self-extinguish after removal of the flame (V-2, V-1, V-0). Flammability decreases in the order: HB, V-2, V-1, V-0, with a V-0 rating the de facto U.S. industry standard for plastics. The UL 94 test is expensive to use as a screening tool for research because a large amount (kilograms) of the material must be compounded and extruded into standard test bars for testing, and the pass/fail results provide no quantitative information that can be used to develop new formulations.

Figure 3 is a plot of the UL 94 ranking of commercial plastics (vertical axis) versus their heat release capacity (horizontal axis), the latter measured in the FAA pyrolysis-combustion flow calorimeter (see figure 2) using 1-milligram samples. A sharp decrease in flammability is observed in figure 3 as an abrupt transition from self-propagating (HB) to self-extinguishing (V-0) behavior at a heat release capacity of about η_c = 300 J/g-K corresponding to $HRR_0 < 125$ kW/m^2 (see figure 1). This small-scale predictive capability prompted the Dow Chemical Company of Midland, MI, to seek and obtain a nonexclusive (site) license from the FAA/DOT on August 6, 2001, for the use of the Heat Release Rate Calorimeter for Milligram Samples. This is the first license of DOT/FAA-owned technology by either the Department of Transportation or the Federal Aviation Administration. Dow Chemical is using the microcalorimeter to develop more fire-resistant plastics for consumer electronics and electrical equipment. This is one way that FAA-licensed technology is being used by industry to improve public safety.

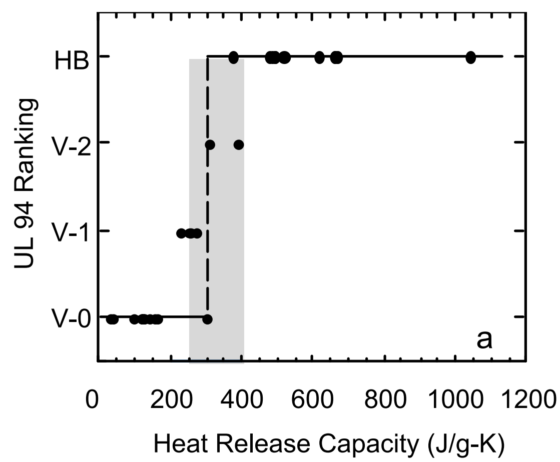


Figure 3. UL 94 Flammability of Plastics Versus Their Heat Release Capacity Measured in the PCFC. Self-Extinguishing (V-0) Behavior is Observed for η_C < 300 J/g-K

The hazard of a material in a fire, i.e., the slope of the heat release rate versus heat flux curve (HRP) in figure 1 is directly related to η_c so the PCFC should also be able to measure fire hazard. For this reason the FAA was asked to use the PCFC as a forensic tool in the investigation of a major fire-related commercial aircraft accident where only miniscule (gram-sized) samples of cabin materials could be obtained from the wreckage. Figure 4 shows that the fire behavior or heat release parameter in flaming combustion (vertical axis) is accurately predicted by the heat release capacity measured in the PCFC (horizontal axis) using the functional form HRP = 0.25 $\eta_c^{3/5}$. The PCFC results were used to estimate the fire hazard of salvaged aircraft cabin materials and to help ascertain their role (if any) in the accident.

Richard Lyon, AAR-440, 609-485-6076

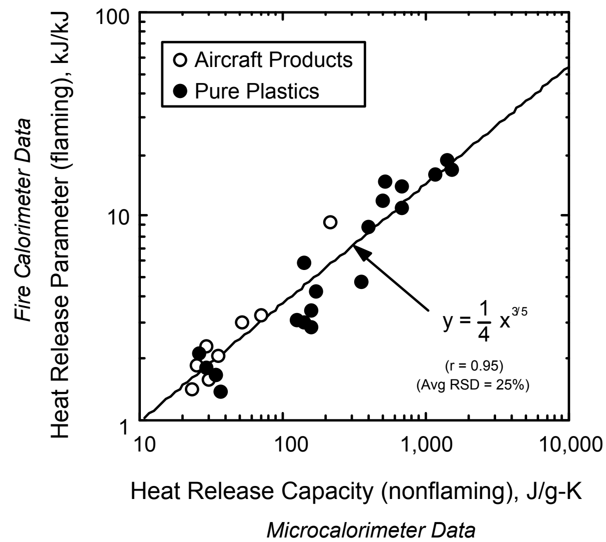


Figure 4. Correlation of Fire Calorimetry Data for Heat Release Parameter (100-gram samples) With PCFC Data for Heat Release Capacity (1-milligram samples)

Airport Technology

Completion of Full-Scale Traffic Testing on Initial NAPTF Test Pavements

Traffic testing of the initial nine test pavements (test items) at the National Airport Pavement Test Facility (NAPTF) was completed in early FY02. Loads were applied to test items with low-strength subgrade flexible stabilized base construction (LFS), low-strength subgrade flexible conventional construction (LFC), high-strength subgrade flexible stabilized base construction (HFS), and high-strength subgrade flexible conventional construction (HFC). Results of NAPTF traffic tests are significant, since they will be incorporated by the FAA into the new airport pavement design standards that will be applicable to next-generation heavy commercial aircraft, including the Boeing 777 and Airbus A-380.

The NAPTF was completed in 1999 and dedicated in April of that year. Traffic testing of the six flexible (asphalt) and three rigid (concrete) test items began in February 2000. The primary objective of the tests was to subject the test pavements to simulated heavy multiaxle aircraft traffic and to observe the number of vehicle passes before structural failure of the pavements. The two carriages of the NAPTF test vehicle (figure 1) were configured to simulate taxi loads from a six-wheel B-777 main gear (carriage on the left side of the photograph) and a four-wheel B-747 main gear (carriage on the right side), respectively. In this way, the relative performance of the various pavements under these gear configurations could be compared. A secondary objective was to collect data from the approximately 1000 sensors embedded in the pavements for use in analysis.

Figure 1. Wheel Loading Carriages

The two test items constructed on a medium-strength subgrade (designated MFS and MFC) exhibited clear structural failures after repeated passes of the load vehicles. For these test items, the ultimate failure was characterized by deep rutting (approximately 6 inches) in the center of the load path, along with visible upheaval of the pavement structure at the fringes of the load path (figure 2). This type of failure is indicative of shear flow in the subgrade, a conclusion that was supported by posttraffic investigations. Two other flexible pavement test items constructed on low-strength material (LFS and LFC) exhibited incomplete failures (i.e., the pavement structure showed significant damage after repeated traffic loading, although ultimate shear failure of the subgrade did not occur). Flexible test items constructed on high-strength subgrade material (HFS and HFC) showed no signs of failure after repeated traffic.

Figure 2. Failed Asphalt (Flexible) Pavement

For the three rigid (concrete) pavement test items, failure was defined as a shattered slab condition, i.e., the concrete slabs are broken into multiple pieces. Although this final condition was attained in traffic loading for all three test items (LRS, MRS, and HRS), posttraffic investigations revealed that, in most cases, the cracks were due to the curling up of the slab corners that occurred before the tests began. When the traffic testing started, breaks occurred in the corners because of the pretest deformation rather than from the fatigue damage. This damage mechanism needs to be considered in analyzing the rigid pavement results.

Throughout the tests, the pavements were continuously monitored at regular intervals using visual surveys, nondestructive testing methods, and pavement profiling. After the traffic was stopped, posttraffic investigations were performed. Trenches were dug to expose the layers of pavement for direct visual inspection of the damaged structure. Monitoring and posttraffic testing provided extensive documentation that will be valuable in the analysis of the tests.

Data from the traffic testing at the NAPTF is available via the Internet in a searchable database. For additional details see the next article, National Airport Pavement Test Facility Database.

Gordon Hayhoe, AAR-410, (609) 485-5198

National Airport Pavement Test Facility Database

Traffic testing at the NAPTF resulted in the accumulation of a vast quantity of test data. These data were primarily collected from approximately 1000 sensors embedded in the test pavements but also included pavement profiles and nondestructive pavement test (falling-weight deflectometer (FWD)) results. To store and retrieve the data reliably, the Airport Technology R&D Branch designed and built a relational database using the Structured Query Language (SQL) Server 7.0 system. The database is searchable over the Internet, providing convenient access to the NAPTF data (see figure 1).

Some sections of the database have been accessible over the Internet for about a year, but the full database, including dynamic sensor data from flexible (asphalt) test pavements, came on-line starting in June 2002. Searchable records are grouped into three main categories:

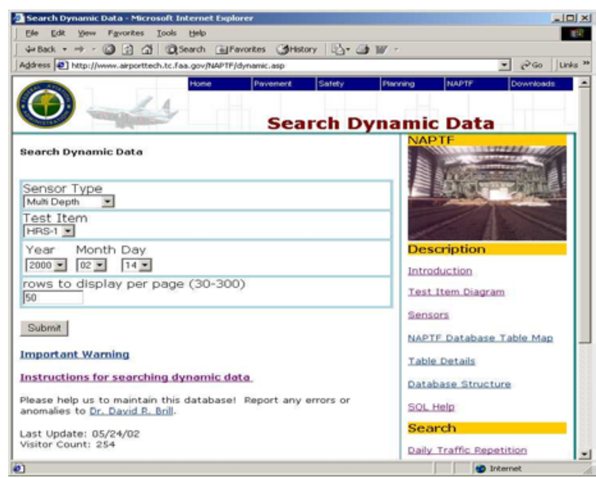


Figure 1. NAPTF Database Internet Search Form

- Static data. Static sensor readings are taken at regular hourly intervals. This category includes environmental sensors such as temperature and moisture gages.

- Dynamic data. Dynamic sensor readings are triggered by the movement of the vehicle and record the pavement's response to dynamic loads. This category includes the embedded strain gages, deflection sensors, and pressure cells.

- Other data. This category covers FWD results, pavement profile data, and pavement condition reports.

Using SQL commands, it is possible for an Internet user to retrieve specific subsets of data, e.g., concentrating on a particular test pavement, sensor, or range of dates. For less experienced database users, the most frequently used searches have been implemented on web forms.

In addition to the standard static, dynamic, and custom data search forms, background information on the NAPTF testing and instructions on how to use the database are available on the web site. These web-based materials include maps of the database showing the tabular structure of the database and the fields and data types associated with each table. A Daily Traffic Repetition table was created that summarizes the month-by-month and day-by-day testing schedule for each test pavement. By referring to this table, users can find the particular dynamic data they are looking for.

The NAPTF database has been completely populated, and its current statistics are as follows:

Static Data Records:	2,478,550
Dynamic Data Records:	11,018,340
Total Size of Database:	25 Gigabytes

Between April 12 and July 16, 2002, the NAPTF database was visited 58,136 times. The URL is: http://www.airporttech.tc.faa.gov/NAPTF/.

David Brill, AAR-410, (609) 485-5198

2002 FAA Airport Technology Transfer Conference

The 2002 FAA Airport Technology Transfer Conference was held on May 5-8, 2002, at the Tropicana Hotel in Atlantic City, NJ. The theme of the 2002 Conference was "Trends in Airport Technology for the New Millennium." Over 200 attendees from 12 countries participated in this international conference, which focused on the development of technology and its application to airports. The Conference included internationally recognized keynote speakers, technical presentations, and industry exhibitors. Invited conference speakers included The Hon. Frank A. LoBiondo, Member of the U.S. House of Representatives (New Jersey 2nd Dist.), The Hon. Marion Blakey, Chairman of the NTSB, Dr. Anne Harlan, Director of the FAA William J. Hughes Technical Center, Ms. Arlene Feldman, the FAA Eastern Region Administrator, and Mr. Spencer Dickerson, Executive Vice President of the American Association of Airport Executives (AAAE). AAAE was also a co-sponsor of the Conference.

Conference participants presented over 65 technical papers during the first two days. Technical sessions were divided into two tracks, focusing on airport pavements and airport safety. Airport pavement technology presentations by FAA and contractor support personnel highlighted the work that is being accomplished at the National Airport Pavement Test Facility. In addition, faculty and students of the FAA Center of Excellence for Airport Technology at the University of Illinois at Urbana-Champaign made presentations in areas ranging from airport pavement modeling to airport wildlife hazard mitigation. The conference proceedings were published on CD-ROM and are available from the AAAE.

David Brill, AAR-410, (609) 485-5198

Airport Pavement Marking Evaluation for Reducing Runway Incursions

The FAA Office of Aviation Research, Airport Technology Research and Development Branch is conducting research aimed at reducing the potential of runway incursions and incidents by making airport pavement markings more visible for pilots and vehicular operators. In one project, completed this year, the effect of widening airport pavement markings to enhance their recognition was evaluated. A series of airport pavement marking variations were installed at the Atlantic City International Airport. Subject pilots were given the opportunity to view these variations and to express their opinions.

This effort was directed specifically toward:

- Evaluating which runway holding position marking was most effective.
- Evaluating which Instrument Landing System/Microwave Landing System (ILS/MLS) holding position marking was most effective.
- Evaluating which nonmovement area marking was most effective.

Standard markings are 6-inch-wide paint stripes. For the evaluation, standard 12-inch- and 24-inch-wide stripes with various spacings were tested in the runway holding position markings and in nonmovement areas. Evaluations were conducted on the various width paint stripes, with and without the ILS/MLS. ILS/MLS facilities are a highly accurate and dependable means of navigating to the runway in instrument flight rating (IFR) conditions. When using the ILS/MLS, the pilot determines aircraft position primarily by reference to instruments. The ILS/MLS consists of:

- a localizer transmitter,
- a glide path transmitter,
- an outer marker (which can be replaced by an NonDirectional Beacon (NDB) or other fix), and
- an approach lighting system.

The ILS/MLS provides the lateral and vertical guidance necessary to fly a precision approach, where glide slope information is provided. A precision approach is an approved descent procedure using a navigation facility aligned with a runway, where glide slope information is given. When all components of the ILS system are available, including the approved approach procedure, the pilot may execute a precision approach.

Results from the evaluation showed the pilots preferred the runway holding position marking incorporating the 12-inch stripes over the marking with the standard 6-inch stripes. Pilots also preferred the ILS/MLS holding position marking incorporating the 24-inch paint stripes with 48-inch spacing. The pilots preferred the nonmovement area marking incorporating the 12-inch stripes.

A summary of the results found during the evaluation was published in Technical Note DOT/FAA/AR-TN01/2, “Airport Pavement Marking Evaluation for Reducing Runway Incursions,” February 2001.

Holly Cyrus, AAR-411, (609)-485-4887

Fiber-Optic Runway Distance Remaining Sign Evaluation

A research task was undertaken to install and evaluate three fiber-optic runway distance remaining (RDR) signs at a major air carrier airport and compare the performance of the fiber-optic sign to traditional sign units in both day- and nighttime and in low- and high-visibility conditions. In addition, any other characteristics of the sign units that make them different from traditional signs, such as lamp-out indicators and simple design construction, would be identified. Most importantly, the results of this effort would identify those modifications to FAA Advisory Circulars that will be required to include provisions for use of fiber-optic signs on airports. The research effort was conducted in response to a request from the Office of Airport Safety and Standards, AAS-1.

An initial evaluation, conducted in 1996 at the Atlantic City International Airport (ACY), New Jersey, revealed that fiber-optic distance remaining signs provided a significant enhancement over the standard sign units currently installed at ACY and other airports throughout the country. To validate this finding, an in-service evaluation was conducted at the Greater Pittsburgh International Airport.

Signs were installed for a 1-year period at the Greater Pittsburgh International Airport. During the year, questionnaires were distributed to local pilots. The questionnaire responses showed that 93% of the pilots thought the signs were very effective and 79% of them thought the signs were better than the traditional RDR signs. Subject responses used terms such as sharper, clearer, and stood out better frequently to explain the differences between the older conventional signs and the fiber-optic units (see figure 1).

Figure 1. Fiber-Optic Runway Distance Remaining Sign at Night

The sharper appearance of the sign legend is more clearly visible during low-visibility conditions, a characteristic that was also noted during the initial testing of the fiber-optic sign at ACY. Results were published in Technical Note DOT/FAA/AR-TN01/103, "Evaluation of Fiber-Optic Runway Distance Remaining (RDR) Signs."

James Patterson, AAR-411, (609) 485-4989

In-Pavement Runway Guard Lights at Chicago O'Hare International

A research effort was undertaken to investigate operational problems resulting from the installation of in-pavement runway guard lights (RGL) at entrances to runways at Chicago O'Hare International Airport (ORD). Specifically, pilots exiting the runways at locations where flashing yellow RGLs were located had reported seeing a considerable amount of light reflecting from the recessed fixtures, to the extent that several pilots halted short and informed air traffic control that they were concerned about possibly entering a construction area. They believed the dim yellow lights were those from small yellow construction barricades. At least one major carrier lodged a formal complaint about this visible light being reflected in the runway direction. This led the airport authorities to temporarily suspend operation of the in-pavement RGLs at ORD. Figure 1 illustrates the reflected light generated by the fixture.

Figure 1. In-Pavement L-852G Runway Guard Light With Reflection on Pavement

Personnel from AAR-411 conducted rough photometric testing of various L-852G light fixtures at the FAA William J. Hughes Technical Center and spoke with manufacturers who produce the fixtures.

The investigation determined that the reflected light was being caused by a combination of factors. The fixture used in these types of installations, as produced by all major airport lighting manufacturers, projects a significant amount of light below the horizontal level of the fixture (negative angles of 2 to 3 degrees). The fixtures are also installed so that the light shines directly on the vertical wall (or, in some cases, slope) of the saw cut hole, creating an even more intense rearward reflection. Additionally, the row of yellow lights in the RGLs is configured so that alternate lights are pulsed on and off to provide a so-called wigwag attention-getting signal. Unfortunately, the reflections as viewed from the rear can very easily be perceived as being random flashing, the signal normally projected by battery-powered, unsynchronized yellow construction area warning lights.

Two possible solutions were formulated: (1) redesigning the L-852G light fixtures so that no light would be projected below 1 degree or (2) changing the flash pattern of the system, thus eliminating the random flashing appearance created from the rear side of the installation.

While the most effective remedy for the reflection problem would be the redesigning of the fixture, it would also be the most difficult and expensive to implement. Initial discussions with fixture manufacturers showed that they may be reluctant to pursue such a modified fixture because of the low-market demand for such fixtures. There are simply not enough inset runway guard installations to warrant the development of a custom fixture. It was then determined that changing the flash pattern would be the best solution.

To investigate the possibility of varying the flash pattern, an additional evaluation was conducted at O'Hare to determine if an alternate flash pattern would provide the desired solution. On the evening of November 19, 2001, the original investigative team of representatives from the FAA Great Lakes Region and from the FAA Technical Center, along with pilots from American Airlines and representatives of other interested organizations, met at O'Hare to conduct an evaluation of the proposed simultaneously flashing lighting configuration.

As a result of the evaluation, it was determined that the U.S. should change its specification for the system and standardize the inset runway guard light configuration as a transverse array of simultaneously flashing yellow lights instead of the current configuration in which every other light flashes alternately. This would eliminate the possibility of confusion with construction barricade warning lights while still retaining the unique and bold flashing characteristics that the system was originally designed to produce.

The findings of this investigative effort have been submitted for publication as an FAA technical note.

James Patterson, AAR-410, (609) 485-4989

Ground Vehicle Lighting Evaluation

The purpose of this research effort was to determine the feasibility of developing supplementary airport vehicular lighting that would readily identify ground vehicles cleared by air traffic control for operation within the active runway area. Such lighting would be displayed only during the period that the cleared vehicle is physically within the critical runway area. The research was done in response to a request from the FAA Office of Airport Safety and Standards, AAS-1.

An evaluation was conducted at the FAA William J. Hughes Technical Center, Atlantic City International Airport, New Jersey. Numerous vehicles were fitted with modified light bars (see figure 1) so that the supplemental lights could be observed in operation. The various beacon colors, flash patterns, flash speeds, and light bar arrays were evaluated during the course of the task. In addition, surveys were taken at other airports to determine which type of vehicle lighting they were using.

The evaluation showed that the supplemental lighting concept, while very intriguing, was not feasible for implementation. It was found that there are no colors available that are unique enough to identify the vehicles on the runway, as all colors available for vehicle lighting already have functions in the airport environment. It was also found that if two lights (amber and an added colored light that could either be red, blue, green, or white) were used, they would need to be spaced approximately two feet apart to ensure that the lights did not blend when they flashed in unison. The lights would need to be mounted vertically, one above another, to make both lights visible from 360 degrees.

Figure 1. Vehicle With Test Light Bars

An FAA technical note titled "Development of Airport Active Runway Vehicle Lighting," which will be published soon, provides a summary of the results found during the evaluation and suggested that the concept of using cleared vehicle lights not be pursued, due to the requirement for complex lighting devices and the potential problem caused by improper operation.

James Patterson, AAR-410, (609) 485-4989