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FEDERAL AVIATION ADMINISTRATION AGING AIRCRAFT NONDESTRUCTIVE INSPECTION RESEARCH PLAN

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SUMMARY

This paper highlights the accomplishments and plans of the Federal Aviation Administration (FAA) for the development of improved nondestructive evaluation (NDE) equipment, procedures, and training. The role of NDE in aircraft safety and the need for improvement are discussed. The FAA program participants, and coordination of activities within the program and with relevant organizations outside the program are also described.

BACKGROUND

Airplanes built prior to 1978 were designed to the fail safe principles, but with no specific damage growth or damage tolerance requirements. Since 1978 all new transport aircraft are required to be damage tolerant. Newly designed aircraft must be designed as damage tolerant and aircraft designed before the regulation was promulgated are required to have manufacturer defined programs to make them damage tolerant. Succinctly, the damage tolerance philosophy states: cracks are expected to occur; the structure must tolerate "small" cracks; and cracks must be detected before they become "large". In order to implement this regulation, manufacturers were required to define inspection programs for each of the "probable location and modes of damage". Some key points to note: cracks are expected to occur; cracks are expected to grow unacceptably large if not detected; and damage tolerance requires reliable crack detection.

Although the inspection system has generally worked well, aging aircraft are straining it. Presently, about 30% of the transport category fleet is greater than 20 years old. It is estimated that by the year 2000, greater than 60% of the transport category fleet will be more than 20 years old. Several issues have arisen which cause concern.

- Multiple Site Damage (MSD) - numerous, small, interacting cracks
- Unpredicted Crack Sites - cracks in unexpected, and therefore uninspected places
- Inaccessible Areas - areas which are difficult to inspect due to lack of access

The concern over MSD has led to mandated terminating actions to replace rivets and increased inspection intervals. These actions are extremely costly to the industry. A more reliable means of detecting inaccessible second layer cracks and corrosion is needed, especially as regards to repair patch configurations. In addition, the commuter fleet has come under increased awareness of crack detection and corrosion reliability needs. Visual inspection continues to be the predominant, most practical choice for aircraft inspections in the field. Therefore, high priority and great emphasis must be placed on enhanced and augmented visual inspection techniques. Especially in the commuter fleet application, NDI developments must be noncomplex and inexpensive to be cost effective and implementable. Due to these pressures on the detection system, improved inspections are required. Input from airframe manufacturers confirms that in general, equipment and procedures currently in use should be improved such that smaller defects are detected, any indications are well documented, and disturbances are eliminated so that the false alarm rate is low.

Each of six factors that affect airworthiness assurance: corrosion; fatigue and fracture; maintenance and repair; flight loads; human factors; and nondestructive inspection (NDI) are subprograms of the overall Federal Aviation Administration (FAA) National Aging Aircraft Research Program (NAARP). Inspection is the vehicle that identifies damaged aircraft, and sends them back for repair, as shown in Figure 1. Other elements of the system can be improved to slow the rate at which deterioration occurs. However, inspection is the only element which can immediately improve the safety of the system by finding non-airworthy aircraft.

The term NDI denotes the means for establishing the quality or integrity of materials and structures without impairing or affecting their end use. To this end, NDI has provided the basis for essential quality assurance and maintenance inspection criteria in the aircraft industry. NDI methods are used to supplement basic visual inspection to: avoid costly tear down in gaining access to hidden structure; provide early detection of defects before they reach critical size; and obtain additional information. In many situations, there is no practical alternative to NDI procedures. NDI procedures are mandatory for some structural inspections to support supplemental structural inspection programs and to support service bulletin and airworthiness directive call outs. The six most commonly used NDI methods are: visual; eddy current; radiographic; ultrasonic; penetrant; and magnetic particle. Their applications and possible new technology improvements are listed in Figure 2.

PROGRAM MANAGEMENT

The NDI portion of the NAARP predicates that improvements must be made to existing inspection techniques and devices, and research and development efforts should be directed towards new and emerging technologies, so as to meet the challenge of more reliable detection capabilities. The objectives for the NDI program are derived directly from the concerns about the current system, as exemplified by the factors which led up to the Aloha accident. These objectives are closely aligned with the priorities defined by the Air Transport Association in 1988. The FAA program seeks to improve crack detection reliability, develop capabilities for scanning broad areas of the structure to detect damage, develop means to reliably detect and differentiate various forms of corrosion, develop techniques for measuring bond quality and bond strength, and identify inspection protocols that would ensure consistently high inspector performance.

The program is making use of several resources to achieve the objectives. These resources have been integrated into a single management structure, as depicted in the attached Figure 3, to assure: a mix of near, mid, and long term research; integration of knowledge from organizations outside the FAA's purview; allocation of funds to most efficiently reach program objectives; and mechanism for encouraging and integrating innovative technologies.

To this end, an Aging Aircraft NDI Working Group (AANWG) consisting of NDI experts from government, industry and academia has been established. AANWG was specifically set up to advise the program office about the technical merit of various ideas which may be proposed. The FAA National Resource Specialist (NRS) advises the program office on the direction of the program and chairs the AANWG group.

In addition, the National Aeronautics and Space Administration (NASA) which has run a large in-house NDI program for some time, primarily oriented towards the space shuttle, has agreed to maintain a close liaison between the two agencies through a formal memorandum of understanding which assures that projects are complimentary, with little overlap. A two way flow of technical information has been established benefiting both organizations. For example, workshops are being planned for joint sponsorship by the FAA and NASA this winter on topics like infrared imaging and ultrasonics. NASA will continue to focus on basic research in NDI, especially in the area of broad or large area aircraft inspection techniques, while the FAA program addresses continued airworthiness issues.

Because of the diversity of the overall nondestructive inspection requirements, the FAA will utilize the abilities of various technology centers in support of the different program tasks. A continuing effort is underway to identify and integrate universities and research institutes into our program structures to help execute the NAARP. Iowa State University, Sandia National Laboratory, Lawrence Livermore National Laboratory, Harwell Laboratory, and Carnegie-Mellon University have all so far been selected for inclusion to the Program. Starting in FY-93, the Program budget requests provide the funding necessary to fully integrate these and possibly several more participants into the integrated Program structure.

RECENT ACCOMPLISHMENTS

Iowa State University has established a Center for Aviation Systems Reliability (CASR) with congressionally directed funds to pursue applied basic research in support of the FAA Aging Aircraft Research Program through a consortium which includes Northwestern and Wayne State Universities. The purpose of this group is to focus specialized university talents on application of NDI fundamentals to concepts which could be developed, implemented and integrated into the aircraft inspection system. Initial projects and tasks have been defined for CASR in the areas of characterization of adhesive bonds, large scale inspection technique development, neural nets and expert systems, in-situ sensor development, characterization of materials, and image analysis for future system automation.

In FY-91, $3M was obligated to the CASR to begin work on the above tasks through an interagency agreement with the Department of Energy (DOE). An additional $3M has been transferred to DOE by the FAA and negotiations are underway with the CASR for defining tasks from the CASR for a Congressionally directed $1.5M laboratory expansion design to assure that specialized university talents in basic research and education and training as related to aging aircraft problems are applied in the long term NDI program.

Sandia National Laboratory, in support of the FAA Aging Aircraft Research Program, has established an aging aircraft NDI Development and Demonstration Center (AANC) through a consortium led by Sandia National Laboratories which includes Science Applications International Corporation (SAIC) and New Mexico State University. Their role is to develop concepts which come from CASR/NASA research, and to demonstrate and evaluate new technologies. "Hands-on" experience for field personnel will be afforded, important for transferring technology to the field.

Technology transfer will be accomplished by choosing proven or emerging NDI technologies capable of solving current aircraft inspection problems, adapting them for field inspection, verifying their capabilities, and transferring them to the aircraft industry.

In August, $3.4M in congressionally directed funding initiated the efforts at Sandia National Laboratories for FY-91 and FY-92. The major task being undertaken by Sandia with this initial funding is to determine how well current equipment and procedures being used in the field can find cracks of a given size under a given set of circumstances. Work to determine probability of detection (POD) has been done at major aircraft manufacturers, including recently, Boeing Commercial Airplane Company. However, the experiments have been performed in a quasi-laboratory setting, and have not taken into account the problems of environmental and human factors influencing POD (such as physical access difficulty and boredom). Also, no attempt has been made to optimize instrumentation and procedures. Three pilot projects have been identified by the FAA: POD of cracks in lap joints in transport aircraft; POD of cracks in commuter aircraft inspection scenarios; and POD of visual inspection of cracks.

These projects are looking at eddy current, and/or visual inspection as a process to be analyzed under field conditions. The analysis will determine the probability that inspectors could find appropriately sized cracks and make suggestions for improving the inspections. The five year agreement created with Sandia establishes a long term NDI prototype instrumentation and technique validation facility supported by: maintaining a library of characterized samples for use in technique validation; developing and operating test beds for NDI technique development and validation; and developing and maintaining a standard data base for validation test data.

Harwell Laboratory is assisting Sandia in establishing a validation tool which can quantitatively and independently assess the effectiveness and reliability of newly developed and existing inspection methodologies. A specific objective of the work by Harwell will be to quantify the effects of human factors on the probability of detection of cracks. The work will measure human responses when required to perform repetitive inspections, and under varying work conditions.

FAA Technical Center in-house efforts have been directed at identifying areas in commercial aviation where emerging NDI techniques can be a cost-effective replacement for existing inspection procedures that are time consuming, labor intensive, and not totally reliable. Under a Cooperative Research and Development Agreement with Henson Aviation, a shearographic demonstration inspection of portions of specific interest of the fuselage of a Boeing 737-200 was performed at the carrier's repair station at Winston-Salem, North Carolina. The demonstration indicated potential advantages of shearography over currently used ultrasonic inspection techniques for detection of disbonds in the fuselage, and reduced down-time of the aircraft with concommitant reduced inspection costs. USAir Express engineers present during test and evaluation have concurred with our draft findings based on carrier provided data that shows the potential of saving hundreds of labor hours and up to three days of aircraft down-time per inspection compared with respective times listed in pertinent Service Bulletin. Additional demonstrations on commuter type fuselage have been scheduled on a DeHavilland DHC-7 with USAir Express in December.

A magneto-optic imaging device based on unconventional eddy current excitation and a new method of extracting the desired flaw information, using a magneto-optic sensor to form images of flaws directly and in real time over relatively large areas, was evaluated for detection of cracks around rivet holes. Concurrently, Boeing, Douglas, and American Airlines also evaluated the device and American has received limited approval from the FAA for specific rivet inspection procedures. The Technical Center will work with the manufacturer to further evaluate the technique on additional fuselage applications such as second layer crack and corrosion detection.

A subcontracted JT8D series engine flight safety review was completed, which identified reliability problems through actuarial analysis of causes of in-flight shutdowns and engine removals. Development is ongoing for enhanced NDI procedures for the identified troublesome components with the cooperation of Pratt and Whitney engineers. Further development of critical components for CF6 and JT3D engines requiring enhanced NDI procedures is underway.

NEAR TERM DEVELOPMENTS

In order to assimilate additional industry expertise in NDI procedures and techniques into the Program, we are currently working on contracting mechanisms which can expedite the process for input from the private sector. In addition, several agencies within the United States and foreign governments posses strong NDI talent and are pursing research of their own. It is expected that valuable cross-fertilization will result from cooperative agreements being established with these agencies.

For example, Lawrence Livermore National Laboratory (LLNL) has developed dual band infrared imaging methods and unique image correction algorithms for detection and characterization of subsurface geologic features. They have proposed to apply these methods for broad area scanning of airframes to provide early warning of subsurface flaws. These methods developed at LLNL provide high sensitivity through improved signal to noise and separation of surface emissivity effects from true thermal patterns. They will be working in cooperation with General Electric Aircraft Engine Company NDI specialists on a companion study to determine the feasibility of detecting low cycle fatigue cracks in aluminum airframe skins with infrared imaging.

The most widely used technique for field inspection of aircraft is visual inspection or enhanced visual inspection using dye penetrant or magnetic particles. Since this is the most widely used inspection technique, any improvement in this area would have a major impact on inspection quality. A number of areas of enhanced visual or optical inspection are being considered for quality. A number of areas of enhanced visual or optical inspection are being considered for accelerated development and evaluation:

1. Detection of surface waviness conditions such as "pillowing" caused by corrosion may be enhanced by structured light, moire, or D-Sight (a simple optical arrangement involving a source of light and a retro-reflective screen).

2. A process using spectroradiometrics, employing color filters with optical devices such as glasses or borescopes, to detect colors associated with corrosion products.

3. Application of commercially available borescope and fiberscope technology to aircraft fuselage inspection behind skins through a removed rivet for corrosion detection.

In FY-91, a feasibility study was initiated at Carnegie-Mellon University in Pittsburgh, PA to design and develop robotic tools to assist the aircraft inspector and to automate the collection, archiving and post-processing of inspection data. Upon successful establishment of the feasibility of large-scale robotic inspection systems for use by major inspection and repair facilities this fall, Carnegie-Mellon will be funded to initiate their long range goal of robotic system or systems development to perform routine aircraft inspection tasks that are currently done manually. These robotic tools will be designed in coordination with guidance and recommendations provided by USAir maintenance and inspection experts from their Pittsburgh facility, so that the end results will be readily acceptable to aircraft maintenance hanger personnel.

Current FAA training programs including a two week training course, "Nondestructive Testing," which is used for training of both engineers and inspectors are being reviewed for possible updating to include technological advances, such as new NDI equipment and inspection procedures now being used by the aviation industry. A survey has been prepared in cooperation with the Flight Standards Service (AFS) and is being distributed to appropriate field personnel. Field data will also be gathered in visits to AFS selected sites in subject areas involving evaluation of non-destructive testing methods, choice of appropriate methods, application of individual methods, limitations and surveillance of methods. A final report will be prepared this spring that summarizes compilation of the survey data, field site analysis and evaluation of the training program. This will include recommendations for any necessary revisions to existing Academy training courses as well as suggestions for new training efforts.

In addition, development of a training video that provides instruction in nondestructive inspection of civil transport and commuter airlines for corrosion detection is underway. The videotape presentation will incorporate an in-service field demonstration of NDI equipment and techniques currently used by commercial operators and independent repair/maintenance facilities in inspection of civil transport and commuter airplanes. Techniques to be included are visual inspection, radiography, ultrasonic and eddy current techniques as they apply to corrosion evaluation and detection. A draft video presentation package will be available in January for AFS review.

To further develop, in all NDI program areas, the best evolution of technology into practical commercial aviation applications, an International NDI Workshop, with that theme, will be sponsored by the FAA, NASA, Navy, Air Force, and we hope the Air Transport Association at Albuquerque, New Mexico, from May 18 to May 20, 1992. A second theme will be encouraging airframe and engine manufacturers, transport and commuter air carriers, repair and maintenance stations, and any other potential users, to tell us what their respective needs and perceptions are for improved NDI.

CONCLUSION

In the past six months, the NDI portion of the Aging Aircraft Program has been thoroughly coordinated with the Airworthiness Assurance R&D Working Group (AATF) and various FAA Regulations and Compliance Offices through a series of briefings and personal contacts. In the area of engine inspection (New England Directorate) and small airplane category problems (Central Region Directorate) in particular, there has been a major redirection of tasks within the NDI Program to accommodate their respective requirements.

The NDI Program has been structured and is managed to ensure that: meaningful issues are identified; R&D tasks are selected to address these issues; maximum use is made of technologies developed elsewhere; innovative R&D is encouraged and integrated; useful products are derived from the R&D; and R&D products are delivered to the people who can make a difference in aviation safety.

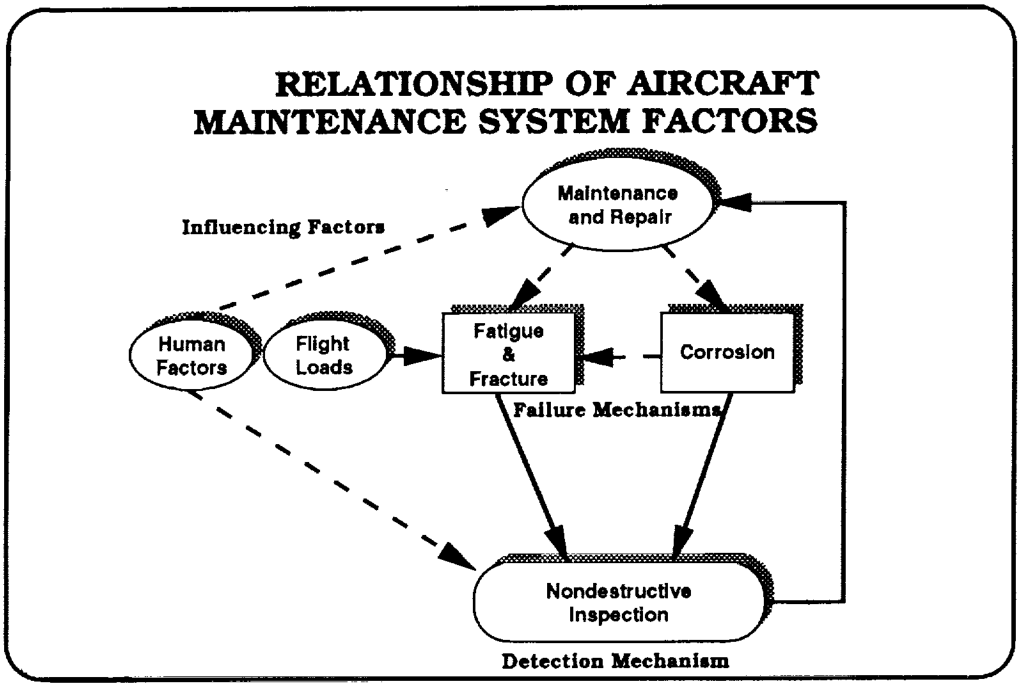

Figure 1.

NONDESTRUCTIVE INSPECTION IN COMMERCIAL AVIATION

Current Techniques	Common Tasks	Shortcomings	Potential New Technologies
Visual	Airframe Cracks	Poor reliability Small cracks not seen False calls due to scratches	Broad Scan Systems Improved visual techniques Visual assistance equipment
	Corrosion	Requires good visual access	Inaccessible area NDI Neutron Radiography Corrosion monitoring
Eddy Current	Airframe Cracks	Hard to interpret signals Small cracks near fasteners hard to "see" Time consuming for large areas Surface must be accessible Metals only	Auto signal interpretation Signal processing, advanced ultrasound Broad Scan Systems
	Corrosion (thickness measurement)	Thinning only - early phases undetected Requires access False calls due to thinning	Neutron Radiography Corrosion monitoring
Ultrasound	Disbond (void) detection	Many disbonds, e.g. lap joint "kissing disbonds", have no voids, are not detected. Rqs skilled set up & interpretation	Laser Holography Infrared Thermography Advanced Ultrasound
	Corrosion (thickness measurement)	Thinning only early phases undetected Rqs surface access Rqs skilled set up & interpretation False calls due to thinning	Neutron Radiography Corrosion monitoring
	Airframe Cracks	Thinning only early phases undetected Rqs surface access Rqs skilled set up & interpretation False calls due to thinning	Automation Auto signal interp Signal processing Broad Scan Systems
Radiography	Airframe Cracks ("buried")	Rqs skilled set up & interpretation Directional-geometry dependent Rqs 2 sided access Radiation hazard	CAT Scan Back Scatter Radiography
Magnetic Particle	Landing gear cracks, stress corrosion	Ferromagnetic (steel) only Surface must be accessible Directional, geometry dependent Demagnetization required	Advanced Ultrasound CAT Scan
Penetrant	Engine Cracks	Surface cracks only Reliability Time consuming	Improved Engine NDI Microsensors

Figure 2.

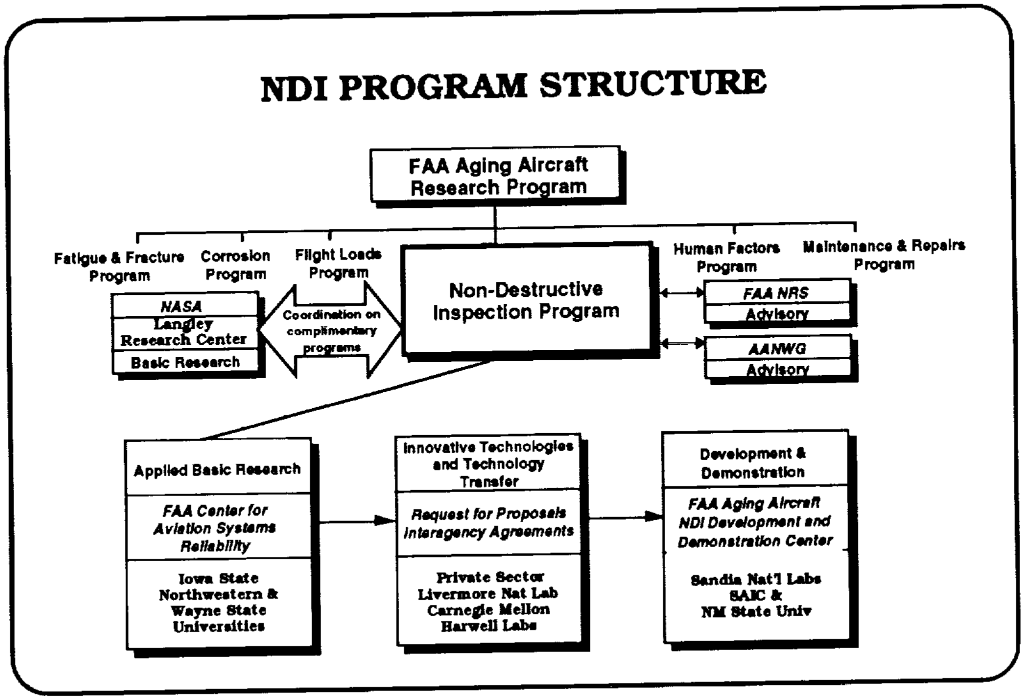
NDI PROGRAM STRUCTURE
FAA Aging Aircraft Research Program
Fatigue & Fracture Program
Corrosion Program
Flight Loads Program
Human Factors Program
Maintenance & Repairs Program
NASA
Langley Research Center
Basic Research
Coordination on complimentary programs
Non-Destructive Inspection Program
FAA NRS
Advisory
AANWG
Advisory
Applied Basic Research
FAA Center for Aviation Systems Reliability
Iowa State
Northwestern &
Wayne State
Universities
Innovative Technologies and Technology Transfer
Request for Proposals
Interagency Agreements
Private Sector
Livermore Nat Lab
Carnegie Mellon
Harwell Labs
Development & Demonstration
FAA Aging Aircraft NDI Development and Demonstration Center
Sandia Nat'l Labs
SAIC &
NM State Univ

Figure 3.