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INSPECTION OF AGING AIRCRAFT - A MANUFACTURER'S PERSPECTIVE

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SUMMARY

Douglas in conjunction with operators and regulators has established interrelated programs to identify and address issues regarding inspection of aging aircraft. These inspection programs consist of: Supplemental Inspection Documents, Corrosion Prevention and Control Documents, Repair Assessment Documents, and Service Bulletin Compliance Documents. In addition, airframe manufacturers perform extended airframe fatigue tests to deal with potential problems before they can develop in the fleet. Lastly, NDI plays a role in all these programs through the detection of cracks, corrosion, and disbonds. However, improved and more cost effective NDI methods are needed. Some methods such as magneto-optic imaging, electronic shearography, Deffracto-Sight, and multi-parameter eddy current testing appear viable for near-term improvements in NDI of aging aircraft.

INTRODUCTION

After an airplane enters service, on going inspection and maintenance of its structure are essential to ensure a continuous high level of safety. These maintenance programs are specified and approved by the certifying agencies. However, these aircraft will eventually reach an age where an increase in corrosion and fatigue cracking can be expected (Fig. 1). Industry and airworthiness experts recognize that an additional structural inspection program, which would supplement the existing operator maintenance programs, is necessary for aging aircraft.

Manufacturers, operators, and regulators have been studying the question of how to assure the structural integrity of aging aircraft since 1978. In that year the British CAA published criteria for a structural audit on aging aircraft. The FAA published similar requirements in 1981. Both of these documents directed the development of Supplemental Inspection Documents (SIDs). The SIDs are intended to extend the routine maintenance program in order to detect predicted but heretofore undetected fatigue damage in older aircraft before it became a safety problem. Accordingly, about 1983, DAC and the operators established an Industry Steering Committee (ISC) to oversee the development of SIDs for each of its aircraft models.

The SIDs identify the principal structural elements (PSEs) on each aircraft. A PSE is defined as "a structural part of assembly of parts whose failure, if it remained undetected, could lead to loss of the aircraft". SIDs also identify the inspection methods and procedures associated with each PSE. Briefly, this is an inspection program to supplement or adjust existing structural inspection programs, as required, to ensure the continued safety of older aircraft.

The primary areas of concern are aircraft that have exceeded their original design life goals, shown in Figure 1. There is a significant number of Douglas built aircraft in this category and definite steps have been taken to ensure the adequacy of the maintenance in all areas. Douglas, with the cooperation of airlines, regulators, and NDT equipment manufacturers, has established five interrelated programs to identify and address issues regarding inspection of aging aircraft. These five programs are:

1. Supplemental Inspection Documents
2. Corrosion Prevention and Control Documents
3. Aging Aircraft Repair Assessment Documents
4. Service Action Requirements Program
5. Life Extension Fatigue Tests

DESIGN SERVICE-LIFE GOAL

Douglas' initial design goals are set to an equivalent economic life of 20 years. To meet this requirement, Douglas designs and builds each aircraft for a minimum average useful life of 40 years. This is done by selecting design stress levels, materials, and design features that provide all requisite conditions. The airframe is designed to provide relatively crack-free structure under normal operating conditions for the service-life goal of the airplane.

In the development of any new aircraft, the design concept is evaluated in test programs that range from small details to the full-scale article. Tests are performed both to satisfy regulatory requirements and to ensure that the design goals of the structure are met. Testing begins early in the design process on structural details of portions of the aircraft. Various design concepts are evaluated for structural strength, fatigue life, and damage detectability. The evaluation process identifies the design concepts that meet the design goals. Full-scale portions of the airplane are placed in test fixtures and fatigue tested, using cycle-by-cycle and flight-by-flight loading, for at least two projected lifetimes. If premature failures are encountered during this phase of testing, the design is modified and service bulletins are issued to correct deficiencies in any delivered aircraft. At Douglas, at least one lifetime of fatigue testing is completed before an aircraft enters commercial service.

SUPPLEMENTAL STRUCTURAL INSPECTION PROGRAM

Douglas has developed a SID program based on fleet-leader-operator sampling. During the sampling, inspections are carried out on a PSE-by-PSE basis. Symmetrical structure results in two samples, left and right, per aircraft. For sampling purposes, one or both sides of the aircraft may be inspected. It is important to note that each PSE always stands by itself; i.e., inspection start points, inspection intervals, etc., are generally different for each PSE.

The Douglas SID inspection program is established from statistical probabilistic concepts based on a log-normal distribution of having and detecting a crack. These concepts are based on each PSE's fatigue-life estimate, its damage tolerance characteristics, and the NDI method. The basic concepts are illustrated in Figure 2. In the sampling program, the aircraft are to be inspected before they exceed the fatigue-life threshold, N_{TH}, with inspections starting at $N_{TH}/2$.

After a PSE exceeds N_{TH}, the interval between inspections is a function of the NDI method used and the crack growth and residual strength characteristics of the PSE. The interval is set to equal ΔN_{di} (Figure 2) divided by 2. ΔN_{di} is the time for a crack to grow from a discoverable length, a_{det}, to the instability length, a_{inst}, which is the crack length that would produce instability failure due to limit load application. ΔN_{di} is divided by 2 in order to provide two opportunities to detect the crack after it has reached a detectable length and before it reaches the instability length.

The Douglas SIDs were completed and released as follows:

- DC-8, January 1986
- DC-9, June 1986
- DC-3, May 1988 (after 50 years of service)
- DC-10, January 1989
- DC-6, March 1991
- The DC-7 and MD-80 SIDs are presently being developed.

CRACKS VS NOTCHES

For eddy current inspection, simulated structure is fabricated with electrical discharge machining (EDM) notches of different sizes. The notched specimens are then used to develop preliminary procedures and determine the detectable flaw size as it applies to each PSE. The detectable flaw size is assumed to be equivalent to the size of the EDM notch used in setting up the instrument. However, some questions were raised concerning the validity of this procedure. To answer these concerns, both Douglas and Boeing engineers performed a series of eddy current tests where they compared the responses from fatigue cracks and EDM notches in aluminum specimens. The results in Figure 3 showed good agreement between cracks and notches of similar sizes in aluminum specimens.

CORROSION PREVENTION AND CONTROL DOCUMENTS

Corrosion is generally considered a bigger maintenance problem than fatigue cracking. Hence, the original equipment manufacturers (OEMs) prepared Corrosion Prevention and Control Documents for each model aircraft. These documents are used to establish a Corrosion Prevention and Control Program for older (by age) aircraft. Operators are required to apply a CP and CP on all aircraft that reach or exceed the Baseline Program Implementation Age for each corrosion task. The responsibility to establish, maintain, monitor, and regulate the program within the guidelines lies primarily between the operators and their regulatory agencies, with the OEM participating as technical advisor when requested. The program is intended to inspect all primary structures as well as all items that are susceptible to corrosion in a given zone. Each aircraft is broken down into zones with specific inspection tasks within each zone. Visual inspection is the primary detection with NDI being used for detection in non-accessible areas.

Each operator is also given a copy of a Corrosion Control Handbook (MDC K0805). This handbook describes methods for detection, removal, and prevention of corrosion. The handbook contains a rather large section on the use of NDI methods for detection of various forms of corrosion (Figure 4).

Corrosion assessment is broken down into three "Levels":

Level 1. Is local and can be re-worked within limits.
Is local and exceeds limits but caused by non-typical event.
Light corrosion between inspections but now exceeds limits due to cumulative blend-out and requires repair.

Level 2. Occurs between inspections; exceeds limits, requires repair.
Widespread between inspections and requires blend-outs less than limits.

Level 3. Exceeds limits; potential airworthiness concern.

The Corrosion Prevention and Control Documents for DC-8, DC-9/MD-80, and DC-10 were released to operators in the Spring of 1990. In addition to the general guidelines, which are the same for each model, the specific documents identify Service Bulletins and chapters in the Maintenance Manual and Structural Repair Manual concerning corrosion issues for that model aircraft.

REPAIR ASSESSMENT DOCUMENTS

Numerous repairs have been made on aircraft structure. The majority of these repairs meet the minimum standards for strength but some do not meet the current standards for resistance to fatigue and corrosion.

The concern that existing repairs should be reviewed for damage tolerance requirements and may need special inspections/replacement to ensure structural integrity resulted in efforts by Model Task Groups (MTGs) to develop an operator usable system to evaluate repairs on aircraft. Because of the enormous scope of this effort it was decided that guidance material be developed which would cover the review of a majority of existing aircraft repairs. Repair assessment guidelines have been prepared to cover each airplane model and are scheduled to be completed in phases. The Model Task Groups have been working on the guidelines for Phase I (Fuselage Pressure Shell) for about two years. Final completion for Phase I is expected some time in 1992.

In addition, an industry-operator task force is in the process of making recommendations to the FAA on the subject of repairs and the damage tolerance analysis required to certify the repair for a given life. Once completed, this information will be provided in the model specific Structural Repair Manual (SRM).

The Primary objectives of the Repair Assessment Program are:

1. To provide a practical methodology in the form of guidance material (based on damage tolerance principles) that will allow a majority of existing repairs to be evaluated by operators without complex analysis.

2. To direct the repair evaluation process towards showing that an installed repair which replaces the strength and durability of the original structure is found damage tolerant if the existing inspection levels are adequate.

3. To develop a repair evaluation process such that it will identify when and what supplemental inspections (threshold, method, interval) are required.

Nondestructive inspections may be required in the repair assessment process to identify the following concerns:

- o Is the repair or surrounding structure damaged?
- o Are the fasteners less than or equal to 1/8 inch diameter?
- o What is the thickness of the repair?
- o Is the repair material, Al, Ti, or stainless steel?

The NDI techniques for answering the above questions are contained in the model specific SRMs. Basically, the repair materials are identifiable using eddy current conductivity testing. Plating thickness is determined by using ultrasonic thickness testing. Fastener diameters are identified by either removing one of the fasteners or by X-ray radiographic inspection. It is very difficult to determine the difference in shank diameter for 1/8 and 3/32 inch fasteners because their head diameters are almost equal.

Four categories of repairs have been developed to define structural maintenance requirements:

Category - A	Satisfy damage tolerance requirements. No inspection required.
Category - B	Meet design certification but must be periodically inspected to satisfy damage tolerance requirements.
Category - C	Temporary nature requiring periodic inspection and replacement at a certain time limit.
Category - D	Do not meet design requirements and must be upgraded or replaced before further flight.

It has been shown that repairs can degrade the overall fatigue quality of the basic structure. It has also been shown that the most critical locations for future fatigue damage are in the basic skin at the first attachment row in the doubler. Because the doubler covers a possible crack in the basic skin, visual inspection becomes impossible until the crack grows past the edges of the doubler. Hence, Douglas engineers developed ultrasonic shear wave inspection to detect skin cracks under the doubler and low frequency eddy current techniques to detect skin cracks through the doubler. These procedures are contained in the Structural Repair Manuals for use by operators.

In the present program, all repairs in the fuselage pressure vessel will be evaluated using a Repair Categorization Questionnaire.

SERVICE ACTION REQUIREMENTS PROGRAM

In this program, the Model Task Groups (MTGs) evaluated all structure-related service bulletins to determine which service actions should be recommended for termination from special repetitive inspections and to determine the thresholds for incorporation of the structural modification which terminates the special inspections.

The DC-8, DC-9, and DC-10 MTGs reviewed more than 4,700 structure-related service bulletins dated through December 1988. This phase of the program was completed between October 1988 and December of 1989. A total of 159 of the 4,700 service actions were selected for incorporation by the terminating action, which eliminated the repetitive inspection process. It is expected that closing action for these service items will be required within 4 years of the effective date of the airworthiness directive (AD) or by the prescribed "closeout" life, whichever occurs later. The closeout life established for each service action is either the test supported life or the time when there is a significant possibility of missing a crack through inspection.

Current task group activity is concentrating on structure-related service bulletins released between January 1989 and November 1990.

A nondestructive test engineer was a member of each task group who provided improved or updated NDI procedures to those bulletins deemed necessary to obtain a more reliable inspection.

EXTENDED AIRFRAME FATIGUE TESTING

In the original design of an aircraft, the usage of the aircraft is estimated on a 20-year economic life and a specific utilization. These estimates are based on the structural design requirements and the customer's anticipated use of the aircraft. The original fatigue goals based on these initial estimates and the fatigue test that was conducted to verify the design may at some point not adequately shelter the aircraft in the fleet. At this point a new fatigue test of the structure is appropriate to characterize the fatigue behavior of the aircraft. The new fatigue test, as it surpasses the original test life, will reveal new problem areas that have not developed in service. This allows the manufacturer to deal with potential problems before they can develop in the fleet.

In 1981, Douglas purchased DC-9 No. 3, a 15-year-old aircraft which had accumulated more than 66,500 landings. The aircraft was stripped of all interior items and the structure was thoroughly inspected. The structure was found to be remarkably free of fatigue cracks and corrosion. Defective areas were either repaired or marked for evaluation during the test.

The fuselage shell was pressure-cycled to a total of 208,000 flights, including flights in service as well as in test. Selected areas of the structure were periodically evaluated by NDI techniques during the test. Upon completion of the test, an extensive detailed tear-down inspection of the fuselage structure was conducted. More than 8,000 fastener holes were checked for cracks in 22 feet of fuselage lap splices. The specimens were cleaned, etched, and visually inspected at 5X magnification. Some 6,000 attachments were removed from the right wing and inspected using eddy current bolt-hole techniques. Then, coupons were removed from the wing and empennage and fatigue tested. Results of the test showed that the DC-9 structure was capable of achieving a life of 104,000 flights, free from widespread fatigue cracking.

As part of the MD-80 certification, the pylon and aft fuselage structure was tested to 3 lifetimes (150,000 flights), and the aft pressure bulkhead was tested to more than three lifetimes (183,000 flights). Numerous radiographic and eddy current inspections were conducted during the aft pressure bulkhead fatigue test. More recently, the DC-10 horizontal tail assembly underwent a spectrum loaded fatigue test to validate fatigue preventive modifications in the rear spar area.

NDI RESEARCH AND DEVELOPMENT

The FAA's National Aging Aircraft Research Program Plan describes planned research efforts designed to enhance aircraft safety through a better understanding of airframe structural performance and maintainability. The program includes studies on nondestructive inspection (NDI) methods, techniques, and practices with emphasis on reduction of inspection costs without affecting reliability. The NDI program will focus on detection of fatigue cracks, debonding, and corrosion.

Improvements in NDI technology continue through the cooperative efforts of researchers, engineers, and technicians. To that end, the engineers at Douglas have looked for emerging NDI technology which could be used almost immediately for on-aircraft inspections. Following is a description of five promising NDI methods:

Low-Frequency Eddy Current Testing

Nondestructive Inspection (NDI) programs consistently show that eddy current inspection is very reliable in detecting small, tight fatigue cracks. Because of these findings, eddy current testing became the primary crack detection method used in Douglas aging aircraft inspection programs (ref. 1). High frequency (above 10 kHz) eddy current testing is used to detect surface cracks. Low frequency (100 Hz to 10 kHz) eddy current testing is used to detect subsurface cracks in aluminum aircraft structure. The lower the test frequency, the deeper the eddy currents propagate in the structure.

Douglas NDT engineers, in conjunction with equipment manufacturers, have been developing the low-frequency eddy current technology for the past decade. Most of the developments were in the areas of improved portable impedance plane instruments that operate at low frequencies, driver/receiver probes, and applications and limitations of this technology.

In-service inspection techniques are available for detecting cracks in aircraft using a driver/receiver sliding-probe eddy current system for improved hole inspection, without removing the fasteners. Better crack sensitivity and reliability are obtained when using the sliding-probe system (see Figure 5).

The author is presently evaluating multi-parameter eddy current to improve the signal-to-noise response obtained in many practical applications. Multi-parameter eddy current testing expands the capabilities of the eddy current method. Today's instrumentation is capable of operating at two or more test frequencies, displaying multiple channels of data, exciting more than one coil configuration, and combining or mixing raw data channels to generate new data channels. These tools of multi-parameter testing can provide more information about the test piece as well as decreased inspection time.

Magneto-Optic Eddy Current Imager

PRI Instrumentation has recently developed a new inspection technology called "magneto-optic/eddy current imaging"(ref. 2). This technology makes it possible to generate real-time images of defects, such as fatigue cracks and corrosion. An imaging system based on magneto-optic principles has been developed that is capable of inducing eddy currents in the frequency range from 1.6 to 100 kHz. At the higher frequencies, the instrument can image and detect small, tight cracks near rivets on the outer surface of aluminum aircraft skins (Figure 6). At lower frequencies, the instrument can detect an image of second layer cracking and some types of corrosion in aluminum.

The advantages of this new visually-based technique include increased inspection speed, more intuitive and easily interpreted inspection information, elimination of false calls, elimination of the need for paint removal, and the ability to document results with videotape of 35mm cameras.

The author witnessed the development of the MOI (by Gerald Fitzpatrick) for the past few years and provided cracked samples for evaluation of the prototype unit. Douglas is presently approving the MOI for use in surface crack detection in conjunction with DC-10 SID inspections at American Airlines.

Electronic Shearography

Shearography brings the sensitivity of holographic interferometry to the detection of skin-to-core unbonds and deep unbonds in both honeycomb and foam sandwich structures during fabrication inspection. Similar structures can be inspected for disbonds caused by in-service stresses.

Unlike holographic interferometry, shearography is a real-time technique that is all electronic and insensitive to environmental vibration and ambient light. As with holography, an appropriate stressing technique is required to allow a sub-surface flaw to induce a strain concentration on the surface of the part. This may be achieved using vacuum, thermal, or pressure. To detect water in honeycomb structures, microwave excitation is used as a stressing technique. For composite structures, the primary stressing techniques are thermal loading for detecting delamination or impact damage and pressure reduction (vacuum) loading for detecting unbonds/disbonds. Disbonds in fuselage lap joints are easily detected by pressurizing the aircraft.

Electronic shearography was invented by Professor Y. Y. Hung at Oakland University in 1982 and licensed exclusively to Laser Technology, Inc. Shearography uses a laser to illuminate an area on the test part for inspection. Figure 7 shows a schematic diagram of a typical shearography system. The laser beam is introduced to the test part through a fiber-optic cable. The output is an image-processed video display in color, which can show both size and shape of subsurface defects as well as qualitative measures of depth.

John Tyson of Laser Technology, Inc., reported successful detection of corrosion, disbonds and cracks in aluminum aircraft structure (ref. 3). Further studies are being conducted by LTI under funding by the FAA. The author continues to follow the successful results obtained by LTI and is looking for applications for this technology in both fabrication inspection of composites and in-service inspection of aircraft structure for disbonds, corrosion, and cracks.

Diffracto-Sight or D-Sight

Diffracto-Sight or D-Sight (developed by Diffracto Ltd. of Windsor, Ontario, Canada) is a patented method of visualizing surface distortions, depressions, or protrusions as small as $10\mu m$. It is a real-time technique that is particularly applicable to rapid inspection of large surfaces. Komorowski of the National Aeronautical Establishment of the National Research Council of Canada suggested using this technique to inspect composite structures for "barely visible impact damage" (BVID). Computer-based image processing has been applied to D-Sight images. An image from a previous inspection can be directly compared to current results for quick identification of areas where changes in surface features have occurred.

The optical setup for D-Sight consists of a light source, a retroreflective screen, and the object being inspected (Figure 8). The surface being inspected must be reflective. Both flat and moderately curved surfaces can be inspected using this method (ref. 4).

The D-Sight effect can be explained using geometric optical principles. If a flat surface with an indentation is inspected, the light striking the indentation is deflected. It then strikes the retroreflective screen at a point removed from the light rays reflected from the area surrounding the indentation. The retroreflective screen attempts to return all these rays to the points on the inspected surface from which they were first reflected. However, the screen, consisting of numerous glass beads, returns a cone of light to the surface. This imperfection of the retroreflective screen creates the D-Sight effect. By backlighting the defect, the technique increases the light intensity on one side of the indentation and reduces it on the opposite side.

Douglas currently has a D-Sight setup and is evaluating a variety of flawed specimens to determine applications for both fabrication and in-service inspections. We are also working with Omar Hageniers of Diffracto in helping to advance this exciting technology. Presently, this technique has proven successful for detection of surface abnormalities such as impact damage, waviness, buckles, dents, and flaws such as corrosion bulging, and cracks.

Computerized Ultrasonic Test Simulation (CUTS)

Ultrasonic shear-wave (angle beam) inspection has been used routinely for detection of subsurface cracks in aircraft structure especially adjacent to fasteners. To develop an in-service ultrasonic inspection technique, the NDT engineer has an actual size cross-sectional view of the aircraft structure with the crack position accurately located. Working backwards from the crack position, he determines the required angle of refracted sound and the position of the search unit on the external surface of the test part. This technique development exercise requires proper calculation of the refracted wave and considerable time in making the drawings. To improve this situation, Douglas engineers programmed a personal computer with Snell's equations for reflection and refraction of sound in a number of materials having different sound propagation velocities.

To insure that a particular part will be properly inspected, the path of the ultrasonic beam within the part must be known. However, when a beam impinges upon the surface of a part it refracts and reflects within the part. For parts of complex geometry, it is often difficult and time consuming to calculate the paths of these refracted and reflected beams. For each location and incident angle of the transducer, calculations are made to determine if the refraction of the incident beam will intersect the area of interest within the specimen or part. Manual calculations can take considerable time, but the CUTS software performs these calculations in real time. Therefore, as the user repositions the transducer he/she instantly sees the results in real time of the new transducer position and/or angle.

The CUTS software models wave behavior in parts made of isotropic, homogenous materials. The software was written utilizing FORTRAN and "C" programming languages. First, the user inputs the name of the file containing the part geometry, then he/she selects the material that the part is made from. The program draws the part on the screen and places an icon representing the ultrasonic transducer (search unit) near the part at an initial incident angle of 45 degrees. This incident angle is set with a velocity of sound in acrylic (for contact testing) and a velocity in water (for immersion testing). Transducer incident angles are measured with respect to the negative y-axis. Now the user is able to move the transducer icon around the part and observe the effects of the different incident angles and locations in real time. (See Figure 9).

The CUTS program has been useful for developing ultrasonic techniques for in-service inspections especially on parts with complex geometries. It has also been useful for determining where unwanted reflections are generated within the part.

CONCLUDING REMARKS

The purpose of the FAA's Aging Aircraft Research Program is to assure that aircraft are adequately inspected and maintained in an airworthy condition as they are operated up to and beyond their original design life objectives. Douglas, in conjunction with operators, manufacturers, and regulators continues to develop and improve criteria and control programs for protection of the aging aircraft fleet. This protection is provided by the mandated SID, Corrosion Assessment, Repair Assessment, and Service Bulletin compliance programs. In addition, the fleet is also protected by the manufacturers' extended airframe fatigue testing programs and the industries' improvements in NDI technology.

REFERENCES

1. Hagemaier, D. J.: Nondestructive Testing of Aging Aircraft. Proceedings, 2nd Annual Intl. Conference on Aging Aircraft, Oct. 1989.

2. Shih, W. C. L., et al: Aircraft Inspection with the Magneto-Optic/Eddy Current Imager - A New Technology. PRI Instrumentation, Torrance, CA. Sept. 1991.

3. Tyson, J. II: Advanced Shearography Inspection of Commercial Aircraft Structures. Laser Technology, Inc. Norristown, PA., Sept. 1991.

4. Hageniers, O. L.: D-Sight Applications for the Aerospace Industry. Diffracto, Windsor, Ontario, Canada, Sept. 1991.

Aircraft	Launch Date	Service-life Goal	
		Flight Hours	Landings
DC-8	1959	50,000	25,000
DC-9	1965	30,000	40,000
DC-10	1971	60,000	42,000

- Design Goal - Economic Life of 20 Years
- Useful Life - Minimum Average of 40 Years

Figure 1. Design Service-Life Goal

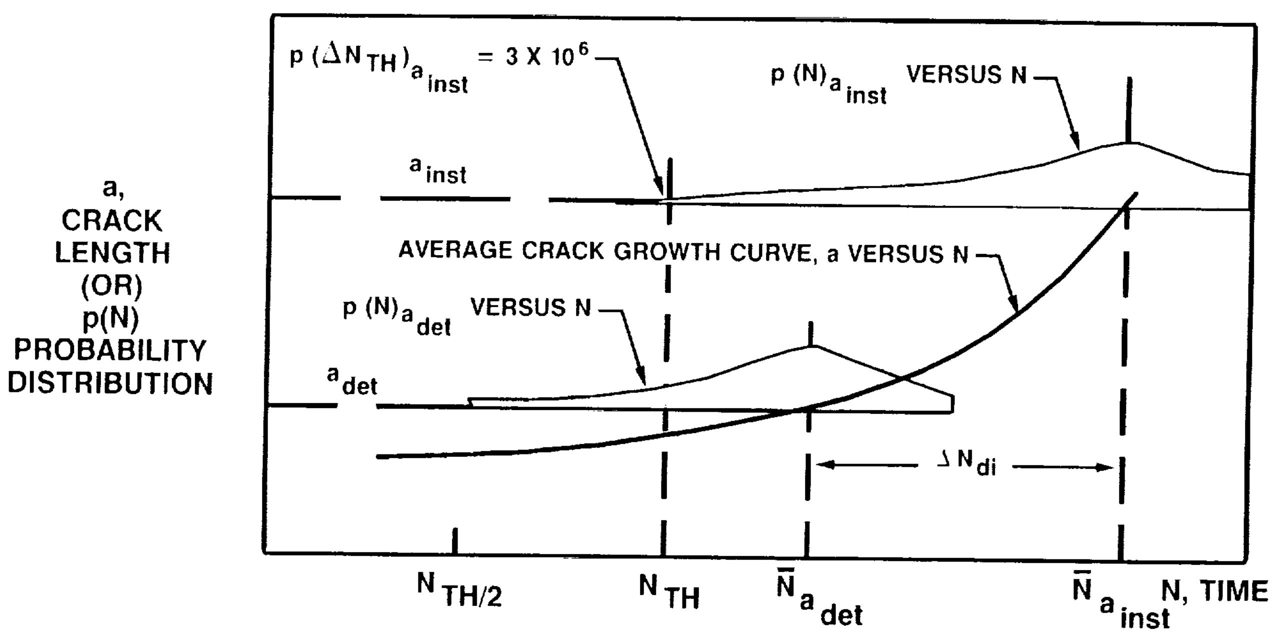


Figure 2. **DURABILITY, DAMAGE TOLERANCE, AND STATISTICS FOR PROBABILITY CONCEPTS**

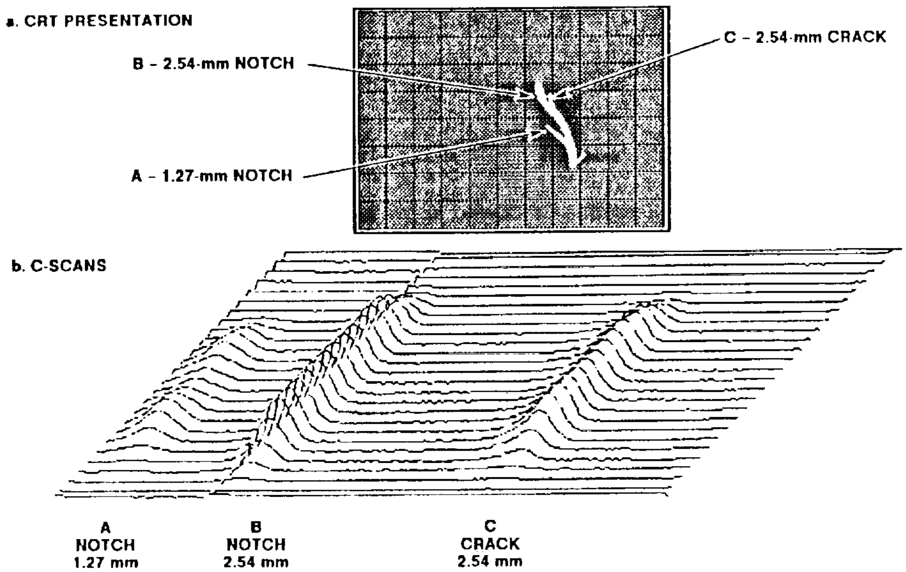


Figure 3. Eddy Current Results for Small Notches and Crack

DETECTION METHODS	EQUIPMENT					
	SIZE	MOBILITY	AUTOMATED	SPEED	COST	AVAILABILITY
VISUAL	SMALL	GOOD	NO	FAST	LOW	YES
TAP TEST	SMALL	GOOD	POSSIBLE	FAST	LOW	YES
ULTRASONIC	MEDIUM	GOOD	POSSIBLE	MODERATE	MODERATE	YES
EDDY CURRENT	SMALL TO MEDIUM	GOOD	POSSIBLE	MODERATE	MODERATE	YES
X-RAY RADIOGRAPHY	MEDIUM TO LARGE	FAIR	NO	SLOW	HIGH	MOST SHOPS
NEUTRON RADIOGRAPHY	LARGE	POOR	NO	SLOW	VERY HIGH	RARE
*ACOUSTIC EMISSION WITH HEAT	MEDIUM	FAIR	NO	MODERATE	MODERATE	VERY FEW SHOPS

*PARTS MUST BE REMOVED FROM AIRCRAFT FOR TEST.

Figure 4. Rating of Test Methods

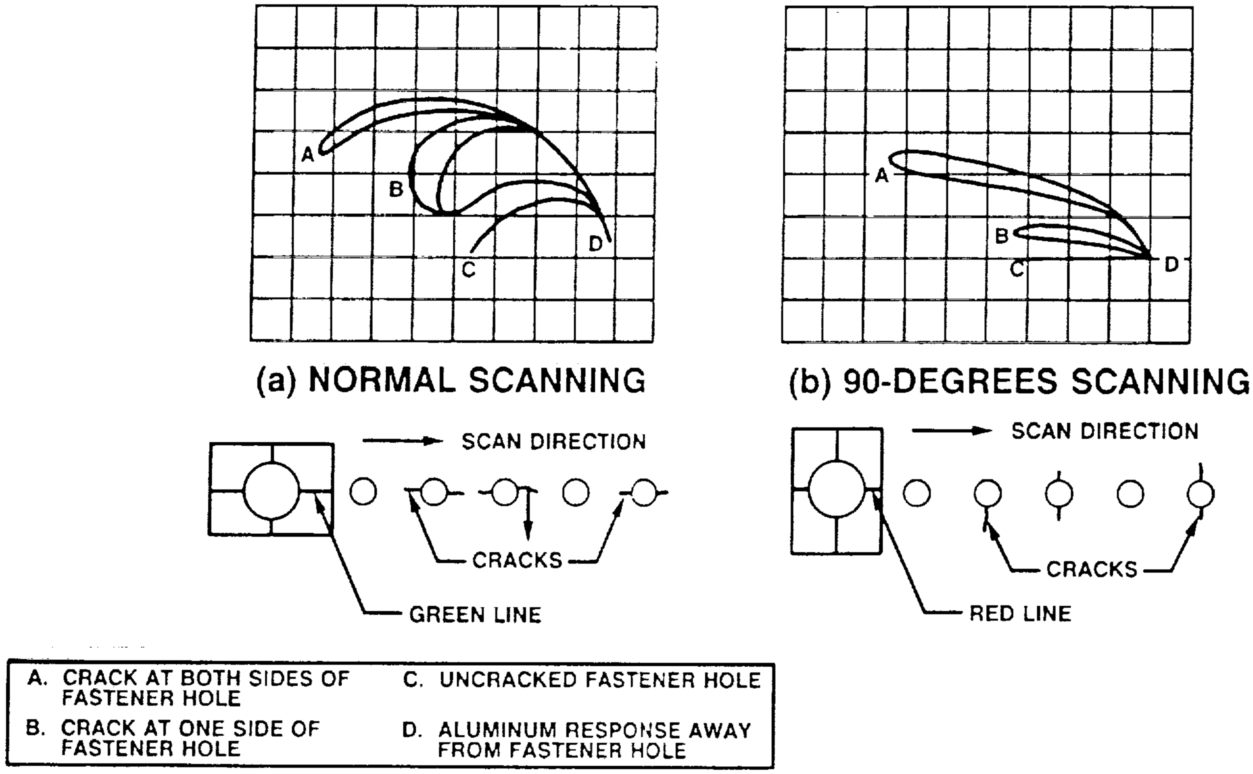
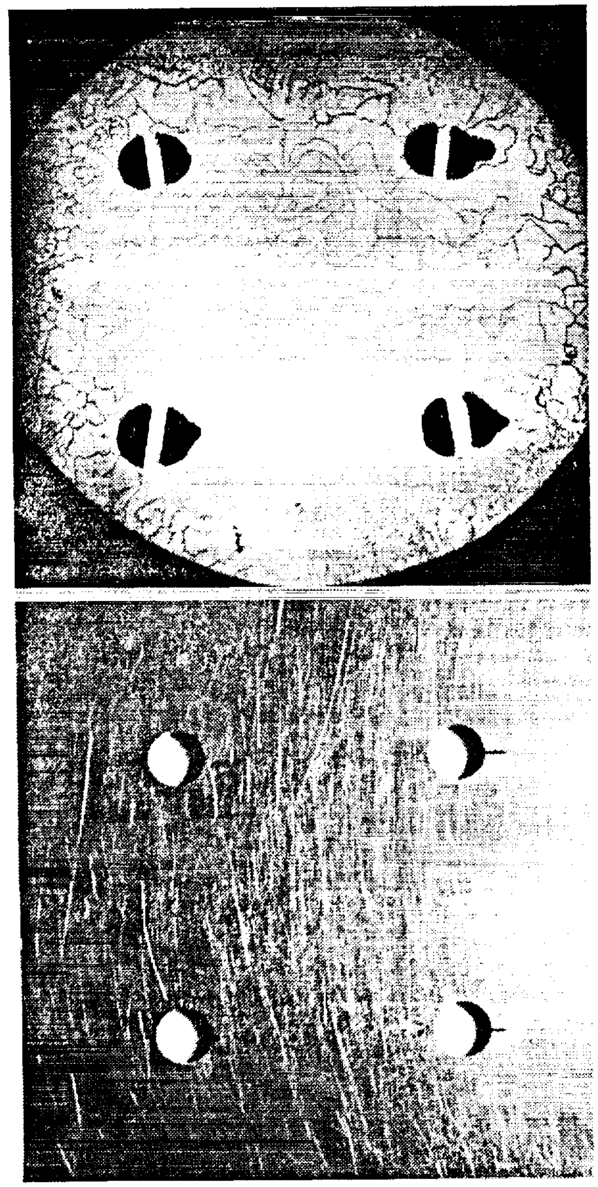


Figure 5. Sliding Probe System for Fastener Hole Crack Detection

(a)



(b)

Figure 6. (a) Magneto-optic eddy current image. (b) Photo of the test piece. This 0.06" thick aluminum panel contains four 0.25 inch diameter holes with 0.020, 0.040, 0.060, and 0.080 inch long EDM notches emanating from them. The order is counterclockwise beginning with the 0.02" long EDM notch in the upper left hand corner of (a) and (b).

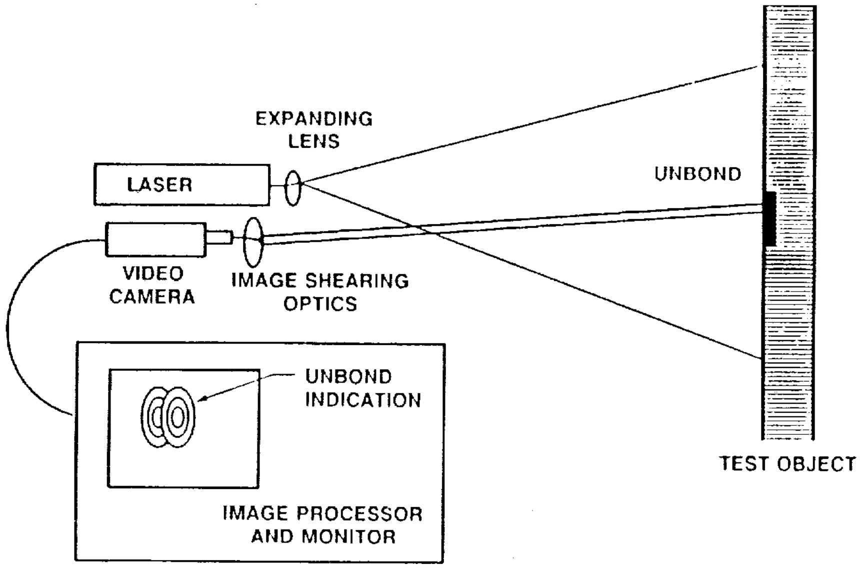


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Figure 7. Schematic Diagram of Electronic Shearography

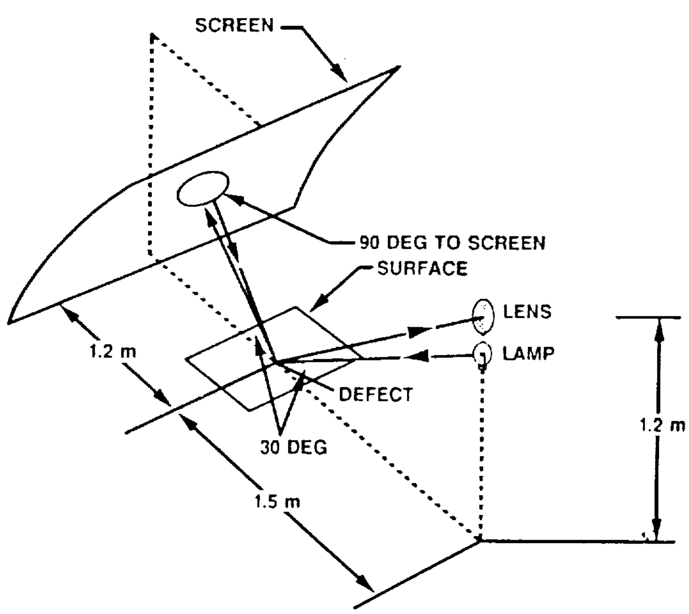

Figure 8. Diffracto-Sight Optical Setup

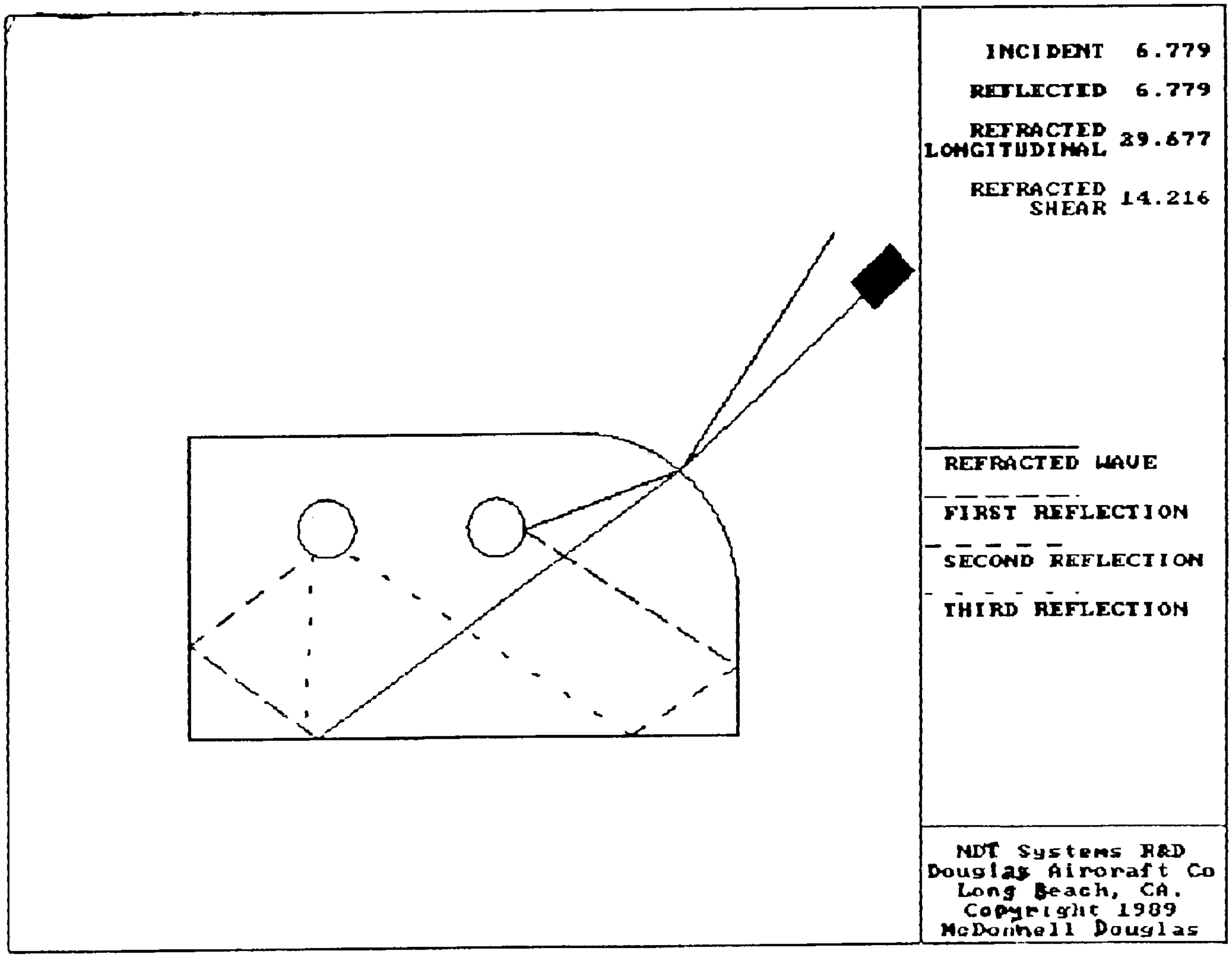

Figure 9. Computerized Ultrasonic Test Simulation (CUTS)