NASA CR-134963
OR-14,176

NDE – AN EFFECTIVE APPROACH TO IMPROVED RELIABILITY AND SAFETY – A TECHNOLOGY SURVEY

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(NASA-CR-134963) NDE: AN EFFECTIVE APPROACH TO IMPROVED RELIABILITY AND SAFETY. A TECHNOLOGY SURVEY (MARTIN MARIETTA CORP.) 167 P HC $6.75 CSCL 14D

N76-25577
UNCLAS
G3/38 42212

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
AEROSPACE SAFETY RESEARCH AND DATA INSTITUTE
CLEVELAND, OHIO 44135

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Contract NAS 3-19530
June 1976

1. Report No NASA CR-134963	2. Government Accession No.	3. Recipient's Catalog No. N76-25577
4. Title and Subtitle NDE - AN EFFECTIVE APPROACH TO IMPROVED RELIABILITY AND SAFETY - A TECHNOLOGY SURVEY		5. Report Date June 1976
		6 Performing Organization Code
7. Author(s) James L. Carpenter, Jr. and William F. Stuhrke		8. Performing Organization Report No. OR 14,176
		10. Work Unit No.
9 Performing Organization Name and Address Martin Marietta Corporation Orlando, Florida 32805		11. Contract or Grant No. NAS 3-19530
		13 Type of Report and Period Covered Contractor Report
12 Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D. C. 20546		14. Sponsoring Agency Code

15 Supplementary Notes

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Aerospace Safety Research and Data Institute, Lewis Research Center, Cleveland, Ohio 44135

16 Abstract

This Technology Survey Report is comprised of technical abstracts for about 100 significant documents relating to the nondestructive testing of aircraft structures or related structural testing and the reliability of the more commonly used evaluation methods. Particular attention is directed toward six NDE techniques: acoustic emission; liquid penetrant; magnetic particle; ultrasonics; eddy current; and radiography. The Introduction of the report includes an overview of the state-of-the-art represented in the documents that have been abstracted.

The abstracts in the report are mostly for publications in the period April 1962 through December 1975. The purpose of the report is to provide, in quick reference form, a dependable source for current information on the subject field.

17. Key Words (Suggested by Author(s)) Acoustic Emission Aircraft Structures Analysis Methods Eddy Currents Magnetic Particles NDE Techniques NDI Techniques NDT Techniques Penetrant Inspection Radiography Reliability Ultrasonic Tests		18. Distribution Statement Unclassified - Unlimited	
19. Security Classif. (of this report) Unclassified	20. Security Classif (of this page) Unclassified	21. No. of Pages	22. Price*

* For sale by the National Technical Information Service, Springfield, Virginia 22151

NASA-C-168 (Rev. 6-71)

FOREWORD

This Technology Survey was prepared by Martin Marietta Aerospace under Contract NAS 3-19530. It is one product of a research program initiated by the NASA Lewis Research Center to compile, evaluate, and organize for convenient access information and structural materials limitations. The NASA Aerospace Safety Research and Data Institute (ASRDI) has technical responsibility for the research program. Preparation of this report was under the direction of George Mandel, ASRDI Program Manager.

Many people contributed to the preparation of the report. Their assistance and cooperation are appreciated and gratefully acknowledged. The authors wish to especially acknowledge the interest and assistance of the following individuals: H. Dana Moran, Battelle Memorial Institute; Robert L. Davies and Stanley J. Klima, NASA Lewis Research Center; Michael J. Buckley, Air Force Materials Laboratory; R. Bruce Thompson, Rockwell International Science Center; Paul F. Packman, Vanderbilt University; Harold Berger, National Bureau of Standards; Ward D. Rummel, Martin Marietta Aerospace - Denver; Robert T. Anderson, American Society of Nondestructive Testing; Charles P. Mehrib, Army Materials and Mechanics Research Center; C. Gerald Gardner, Nondestructive Testing Information Analysis Center.

KEY WORDS

Acoustic emission; aircraft structures; analysis methods; critical flaw size; eddy currents; fatigue life; fracture strength; inspection; magnetic particles; material defects; NDE methods; NDE techniques; NDI techniques; NDT techniques; penetrant inspection; radiography; reliability; ultrasonic tests; x-ray inspection

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PREFACE

Since June 1972 the Orlando Division of Martin Marietta Aerospace has supported the NASA Lewis Research Center's Aerospace Safety Research and Data Institute (ASRDI) in an investigation of the mechanics of structural failure and structural materials limitations. A series of technical reports have been produced.

Under Contract NAS 3-16681 an initial Register of Experts for Information on the Mechanics of Structural Failure was published as NASA CR-121200. An updated and enlarged version was published in January 1975 as NASA CR-134754. Its purpose was to give visibility for a listing of recognized experts who might be available for consultation related to the mechanics of structural failure. Contract NAS 3-16680 also produced other products: NASA CR-121201, Register of Sources for Information on the Mechanics of Structural Failure; NASA CR-121202, Bibliography of Information on the Mechanics of Structural Failure; and NASA CR-12199, Thesaurus of Terms of Information on the Mechanics of Structural Failure. The last of these reports is comprised of key words which facilitate access to an ASRDI mechanized data base.

This Technology Survey Report is one of a series of such reports prepared under Contracts NAS 3-17640 and NAS 3-19530. Other technology reports and companion bibliographies include: NASA CR-134760, Life Prediction of Materials Exposed to Monotonic and Cyclic Loading - A Technology Survey; NASA CR-134751, Life Prediction of Materials Exposed to Monotonic and Cyclic Loading - A Bibliography; NASA CR-134752, Fracture Toughness Testing Data - A Technology Survey; NASA CR-134753, Fracture Toughness Testing Data - A Bibliography; NASA CR-134962, Hydrogen Embrittlement of Structural Alloys - A Technology Survey; and NASA CR-134964, Bibliography of Information on Mechanics of Structural Failure (Hydrogen Embrittlement, Protective Coatings, Composite Materials, NDE).

The report is comprised of interpreted abstracts of about 100 key documents related to the nondestructive evaluation (NDE). These documents have been surfaced and selected in a literature search performed between June 1972 and December 1975. Since a significant number of the documents relate to more than one aspect of NDE there are often multiple citations of the same document. All of the documents selected and abstracted for this technology survey report are included in ASRDI's mechanized data base. In addition a majority of the references cited with the abstracted documents are also included in the ASRDI data bank. This affords a significant information resource for the interested researcher.

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The ability to predict the ultimate performance of an item without testing it to failure has been a long-sought goal. Originally this was accomplished by parallel testing. For example a section of rope for a hoist would be tested by loading it to failure and then it was assumed that the rest of the rope would support that same load before failure. Experience and prudence then dictated appropriate reductions in the working loads employing the untested section of rope. Such parallel testing aided both design and production but was of little value in truly qualifying the service life of a large or complex structure. It is obvious for example that testing a nuclear reactor containment vessel to failure is completely out of the question. This and similar challenges have led to the development of a variety of nondestructive evaluation (NDE) techniques. Until recently the trend in this development has been in the testing of new techniques and in the detection of smaller and smaller flaws in structural materials. Today there is increasing emphasis on the proper application of NDE methods and on the reliability of a method in a given application.

This report seeks to summarize the knowledge of NDE methodology, application and reliability as it is presented in the literature of the past decade. The report can only be a contribution toward the establishment of a larger and much needed information base. Nevertheless it is felt that the contribution is substantive and will cause the publication of other related, valuable knowledge. To introduce the abstracts, which form the main body of the report, the authors have prepared an overview of the key contributions of the researchers represented by the abstracts. A significant reference list is offered to substantiate the author's conclusions.

* * * * *

Harold Berger, in his 1975 Mehl Honor Lecture, observed that there are three areas of concern today that tend to force greater use of NDE and to demand improved and more reliable NDE methods (ref.1). These are safety, conservation, and productivity.

The safety concern is not new. For many years design criteria for structures were based on strength properties alone, rarely considering the chance of catastrophic failure at design stress levels at or below the yield strength of the materials involved. The result was brittle fracture and failure, due to some sort of mechanical or metallurgical notch or defect. Classic examples of catastrophic incidents include the Boston molasses tank, Cleveland methane storage tank, World War II Liberty ships and a number of iron bridges. Such events stimulated development of new fracture mechanics methodology and also the requirement for periodic NDE of structures (ref. 2). Even so, as recently as 1969, Dr. Robert C. McMaster accurately pointed out that there are many systems in our society inadequately monitored where a structural failure would result in a major technological disaster (ref. 3). Such a disaster might be failure of a pressure vessel in a larger chemical or petroleum storage facility, or in a large scale transportation system. A smaller but no less significant disaster might be the loss of a fully loaded 747 aircraft due to catastrophic failure of structure. In these or other instances the losses would be in hundreds of millions of dollars, hundreds or thousands of lives and, potentially, irreparable damage to the ecology. The responsibility for preventing these potential disasters lies with those who conceive and create and operate such systems. The NDE practitioner is significant in this equation because he must be able to inspect a structure and certify that it does not contain critical defects. It is also important to note that he is afforded today the ability to calculate critical defect sizes and inspection standards can thus be related directly to design criteria. There is an overall improvement in structural design.

A more recent pressure, related to safety, has been the attention devoted to fixing the legal liability in consumer product damage suits (ref. 4, 5). The potential costs due to a failure which could have been prevented by NDE are considerable. Further the present legal guidelines expect that product integrity will have been assured by the application of the best available current technology.

Conservation is not a new concern but is getting more attention because of economic sensitivities and our growing preoccupation about the availability of materials and energy (ref. 6). Reliable NDE can help reduce our consumption of materials and energy by minimizing the production of faulty materiel, reducing the tendency to over-design, and facilitating the substitution of available, alternative materials for those that are scarce and more costly (ref. 1).

Like conservation, productivity has severe economic implications in our present society. It is of particular concern as our country faces more foreign competition for trade dollars and sees dwindling supplies of raw materials and low-cost, skilled labor. Any technology that can impact this problem is important. The National Materials Advisory Board (NMAB) in a major study has identified NDE as a potentially major asset. Subsequently the NMAB and others have noted that if NDE is to take its proper place in the technical arena there is need for development of an improved quantitative data base and increased reliability in NDE practices (ref. 1, 6).

By the end of World War II, the "big five" NDE methods (liquid penetrant testing, magnetic particle testing, ultrasonic testing, eddy current testing, and x-ray radiography) had reached a significant level of development. These techniques were better defined and found application as the post-war years saw the arrival of jet aircraft, nuclear reactors, rocket-powered ballistic missiles, and spacecraft. At the same time the development of new methods (e.g., thermal and infrared testing) and new applications of old techniques (e.g., acoustic emission testing) were stimulated (ref. 7). The "big five" are still the most used NDE methods. Even so new techniques are finding greater use in selected applications.

Liquid penetrant testing is useful in the detection of surface defects in all types of nonporous materials. It is based on the ability of a liquid to wet the surface to be inspected. Penetrants are either a colored dye or fluorescent indication type and can be water washable or post emulsifiable. The advantages and disadvantages of this method can be briefly summarized. The most important advantage is its relative simplicity and economy. There also is no size or shape limitation. It is, however, dependent on the skill of the operator. It cannot be used for porous materials and special cleaning techniques may be required to remove the penetrant prior to subsequent finishing operations such as plating or painting. In general penetrant inspection is a room temperature process and special inhibitors may be required to prevent corrosive attack by some penetrants of susceptible materials. The sensitivity of the penetrant technique is limited by the ability of the process to distinguish between crack-like flaws and nonsignificant defects such as microporosity, etc. It is useful in determining cracks, porosity, shrink, and other macroscale defects. Advanced penetrant procedures for critical application include use of radioactive tracer in the penetrant system with subsequent exposure to a photographic film to obtain defect indications. A major disadvantage is the need to clean and prepare the surface of the test item prior to application of the penetrant, i.e., most penetrant procedures for critical parts recommend a slight surface etch prior to use of the penetrant (ref. 8).

The magnetic particle method and its more recent derivative, the magnetic field perturbation method, are generally employed for surface and near surface defects. The theory for magnetic particle methods is based on the fact that a flaw or discontinuity in the material when in an external magnetic field will create pseudo poles near the discontinuity. When a magnetic power or liquid containing suspended magnetic particles is applied to the part, these pseudo poles are outlined as a discontinuity. This perturbation will cause the collection of magnetic particles sprinkled on the surface or can be monitored by magnetic field sensor. There are a number of advantages and disadvantages to this technique. First and obviously it is limited to inspecting ferromagnetic materials. Since the largest quantity of structural metals is ferromagnetic (the steels), except in aerospace, this is not too significant a disadvantage. Like the liquid penetrant technique it is substantially dependent upon the skill, experience, and attentiveness of the operator. It is slightly more sensitive to surface flaws than the liquid penetrant technique, and has the further advantage of being sensitive to subsurface flaws of depths up to one-quarter inch.

The major disadvantages of the magnetic field perturbation technique are that geometric discontinuities other than defects may create pseudo poles and large parts cannot be inspected under linear or circular magnetic fields, but must use a hand-held magnetic yoke. The orientation of the flaw should be known and placed perpendicular to the magnetic field for maximum sensitivity. (Cracks whose orientation is parallel to the field will not generate pseudo poles.) In some environments the complexity of data acquisition, processing, and display equipment can be a problem. The principal advantages are: in its most refined form, it is probably the most sensitive method for the detection of surface and shallow subsurface cracks and flaws; it lends itself to automation; and it can be made substantially independent of an operator.

Ultrasound refers to sound waves having a frequency greater than 20 kHz. Audible sound has been used for centuries as a means of testing the quality of articles such as swords, bells and glassware. The use of ultrasound in NDE is less than 40 years old. Of the "big five" NDE methods, only ultrasonics and radiography can reveal flaws which are substantially subsurface. The propagation of ultrasound is a mechanical wave propagation process and can be used with almost all engineering materials that do not disperse an elastic wave too readily. (Concrete ultrasonics is difficult due to the presence of large particles that disperse the acoustic energy.) The major NDE applications of ultrasonics include flaw detection, thickness measurement, and characterization of metallurgical structure. The five principal advantages of ultrasonics are: its ability to penetrate to substantial depths in many important materials; its ability to test from one surface only; its sensitivity in the detection of minute flaws; its comparative accuracy in determining flaw size and depth (especially where the size of the flaw is larger than the diameter of the probe); and its electronic operation which enables rapid and substantially automated inspection. Three significant disadvantages are: When used manually the interpretation of the signals requires technicians of considerable native ability, training, experience, and motivation; it is intrinsically a small area coverage method - larger area coverage requires complex mechanical scanning or the use of numerous transducers in an array; and its use, in general, requires a good, essentially direct mechanical coupling to the article to be tested, a requirement which is often difficult to meet in practice.

Eddy current inspection complements the other standard methods for detection of surface and subsurface flaws, irregularities in material structure, and variations in chemical composition, in metallurgical structure and heat treatment. There are two general types of eddy current probes, the feed through and surface probe. The feed through coil is widely used for high speed automatic inspection of pipe and tubing, and is the major method of inspection of tube, wire and bar. The surface probe is usually designed and used for specific purpose. In general, eddy current methods are not as sensitive to flaws, but they have the advantage of being effective with both ferromagnetic and nonferromagnetic metals. Ultrasonic methods are superior to eddy current methods for detecting flaws located well below the surface; however, eddy current methods do not require mechanical coupling to the specimen as does ultrasonics. Compared with radiographic methods, eddy current techniques are faster but generally not as sensitive to deep subsurface flaws. Some of the inherent limitations of eddy current test methods are: depth of inspection below the material surface is limited depending upon the test frequency; eddy currents are influenced by many material variables, which often yield ambiguous test results; most test instruments must be manned by well trained operators; and the sensitivity of eddy currents is very dependent upon the distance between the probe and the specimen. It is also noteworthy that probe coils are usually not interchangeable from unit to unit.

A radiograph is basically a two-dimensional picture of the intensity distribution of some form of radiation, projected from a source, and which has passed through a material object that partially attenuates the intensity of the radiation. Voids, changes in thickness, or regions of different composition will, under favorable circumstances, attenuate the radiation by different amounts, producing a projected "shadow" of themselves. Three forms of penetrating radiation are presently used in radiography: X rays, gamma rays, and neutrons. Radiographic inspection can be superior to other NDE methods in a number of applications. For example, it can provide a permanent visual representation of the interior of the test object. Under favorable conditions, radiographic inspection as a quality control procedure can conserve time and materials. The more significant advantages of this NDE method are: it enablesdeep penetration; it provides a permanent record; it is good for assembly verification; it can detect subtle changes (0.5%) in thickness or density; it can be used in field or factory. The major disadvantages are: it is the most expensive NDE technique; it can involve a radiation health hazard; it is poor for crack detection (ref. 9).

Acoustic emission is both the oldest and newest technique in the NDE spectrum. As has been mentioned it was employed for centuries to determine quality of swords, bells and glassware. More recently it has been employed to monitor fatigue crack growth (ref. 10) and to evaluate metallurgical texture (ref. 11). It has been proposed for use as a monitor technique to evaluate the remaining life in a cyclic fatigue application where random cyclic loading such as in aircraft is experienced.

Other important techniques for nondestructive testing are either very specialized or still in various stages of development. Thermal and infrared testing is widely employed as a means of flaw detection. It depends on the occurrence of thermal gradients at the surface of the test article, a flaw being an anomoly in the material's thermal conductivity. For bulk metals nondestructive evaluation methods using electrical conductivity, magnetic permeability, or ultrasonics are, as a rule, more sensitive than thermography. For certain structures, however, such as bonded honeycomb, or dielectric materials, thermography is often the method of choice.

A number of developmental techniques employing holography are available. These coherent light techniques make possible the accurate reconstruction from a two-dimensional record or three-dimensional surface. This can be compared with a slightly deformed surface and the nonuniformities can be related to defects. This is potentially a very powerful technique for the determination of strain although the application is quite complex.

Nondestructive evaluation techniques and methods provide information about more than just flaws in materials. In metals NDE has become a vital adjunct to fracture mechanics, both in the laboratory (ref. 12) and in structure tests (ref. 13). A considerable effort is underway to develop quantitative NDE techniques (ref. 14). The developing capabilities of fracture mechanics have increased the requirements for determination of both the size and the geometry of the defect. This has developed from the fracture mechanics philosophy which assumes that alloy materials contain flaws, and uses the concept of flaw criticality to predict the growth of the flaw and hence the eventual failure of the component. The task of NDE is to ensure that all flaws whose size would make them critical to the design are detected and removed from the part prior to use. This requirement is complicated by the need to detect small flaws of differing geometries usually in the most highly stressed location (ref. 8).

Fatigue cracks develop as a result of service and must be found by NDE during periodic inspections. The detection of fatigue cracks and measurements of their size by NDE has been discussed in detail (ref. 15). It was demonstrated that ultrasonic, eddy current, and penetrant inspection methods were applicable and sensitive to detection of small tight cracks. X radiography was the least reliable of the four test methods for detection of tight cracks and should not be considered as a sensitive, reliable method for detection of tight cracks.

The growing use of composite materials for structural purposes has made them the subject of considerable NDE activity. These complex materials have an initial characterization requirement resulting from the distinct nature of the reinforcement matrix system. The volume fraction and orientation of the reinforcement must be known. Radiography has been employed in determining the volume fraction of filamentary reinforcement, the orientation and defects such as broken or crossed over fibers (ref. 16). In addition, neutron radiography has been used to evaluate the degree of interfacial interaction between the filaments and the metal matrix composites (ref. 17).

Adhesive bonding, including honeycomb core systems presents a difficult, but important NDE task. The adhesive is transparent to x radiography, nonconductive (electrically) and acoustically very highly damped. Thermal and infrared techniques have been employed (ref. 18); however, this is an area where further development is required. Neutron radiography may offer distinct advantages in visualizing adhesives.

Ceramic materials have only recently been considered for structural application where the stress state was other than compressive. In these materials NDE achieves paramount importance due to their inherent nonhomogeneity. The potential application of SiC and Si_3N_4 in the rotating hot end of turbine engines has given impetus to these techniques (ref. 19).

The development of aerospace and advanced aircraft technology has placed additional demands on NDE technology. Packman has discussed the interaction of NDE, fracture mechanics and aircraft design (ref. 20). He has shown that current and projected aircraft designs are dependent on the quantitative capability of NDE for flaw characterization. Aircraft design and vehicle performance are limited by the ability to adequately describe the defect structure in the material or structure. It is necessary to know the largest flaw that may be missed. In other aerospace applications many unique inspection applications are being automated to remove the operator bias. One of these is an ultrasonic system for finding cracks under installed fasteners in aircraft (ref. 21). In this case the ability to nondestructively examine for these cracks without disassembly saves considerable time and cost. In addition the removal and subsequent reinsertion of fasteners carries the attendant possibility of further damage to the hole.

The advent of nuclear power plants has put considerable emphasis on the NDE capability, due to the unthinkable nature of a major nuclear power plant accident. Electric utilities have been major users of NDE capabilities over a long period of time (ref. 22). This has ranged from ultrasonic surveys of boiler tube thicknesses to sonic testing of wood poles. One of the more interesting applications in the electrical utility is the use of aerial surveys of high voltage transmission lines using infrared scanning techniques. These scans reveal overheated splices or other defects resulting in localized heating along the transmission system.

A continuing problem in NDE is operator sensitivity. In the 1969 Mehl Honor Lecture the problem was summarized (ref. 23). Hovland stated that "Our No. 1 requirement in most nondestructive testing today then is to require that those performing the tests and those who interpret the test results have a basic level of competency so that we may have a reasonable confidence level in the test results." The American Society for Nondestructive Testing (ASNT) has developed a set of recommended practice for personnel qualification and certification in nondestructive testing. These recommended practices cover seven NDE methods: radiography, ultrasonics, magnetic particle, liquid penetrant, eddy current, neutron radiography, leak testing (ref. 24). The document also contains recommended training course outlines as well as information forming the general framework for an employer's qualifications and certification program.

Technological advances in structural materials and structural designs have created a critical need for more sensitive and more reliable NDE methods. This need has resulted in the conducting of a series of studies, tests and demonstrations that are reliability related.

In 1972 a round robin test series to evaluate the effectiveness of magnetic particle testing was completed (ref. 25). During this well controlled test 24 parts containing a total of 43 flaws were examined by 11 organizations. The flaws were in typical aerospace hardware and proper identification of the flaws involved varying degrees of difficulty. The NDE laboratories used were typical of those in the aerospace community. The testing activities discovered only 47% of the flaws or an average ranging from one organization which found 93% to one which found only 19%. Other disturbing data points emerged from the study. A majority of the NDE laboratories failed to detect flaws that would have definitely resulted in part failure in service. It was also shown that proper use of magnetic particle testing could have increased the scores of those participants who scored 60% or below to 90% or better, i.e., state of the art knowledge was under-applied by all but one of the experiment participants.

As disturbing as the results of this experiment might appear, they do include data and a reference point. As such it is untypical of the posture of the industry. A recent assessment of the NDE literature revealed little quantitative data (ref. 26). This NASA report provided new stimulus in Air Force and NASA efforts to compile, assess, and apply NDE reliability data.

Pertinent work by the Air Force in applying fracture mechanics and nondestructive testing for the establishment of a design criterion was reported in 1968 (ref. 27). The subsequent B-1 bomber contract (F33657-70-C-0800) imposed fracture-critical design analysis and demonstration of detection probability and confidence. The B-1 philosophy has since been formalized in MIL-STD-1530 (1 September 1972), MIL-I-6860C (27 March 1973), and in MIL-A-83444 (2 July 1974). These requirements have also been applied to the A-10 aircraft and are recognized as standard requirements for future Air Force procurements.

NASA, preparing for the Space Shuttle program, approached fracture control/nondestructive testing criteria by systematic evaluation of the state-of-the-art NDE sensitivity and reliability if optimized techniques are applied. Results of this work are reported in three NASA contractor reports (ref. 28, 29, 30) and summarized by Ehret (ref. 31) as shown in Figure 1.

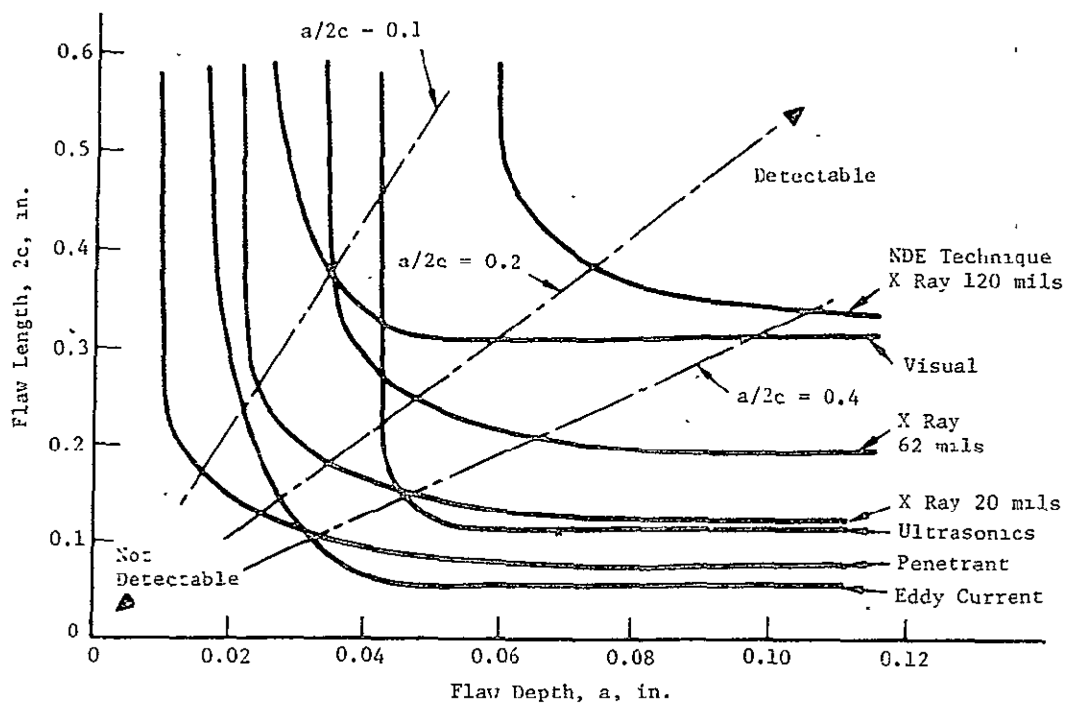

Figure 1. Estimated NDE Capabilities for Flaw Detection

NDE reliability demonstration programs are continuing to generate new and valuable data. Some results of a Martin Marietta Aerospace program to extend attainable inspection reliability data to aluminum alloy weldments and integral stringer-stiffened panel structures were recently reported (ref. 32). Government funded on-going programs include one on crack detection reliability on actual aircraft at the depot level (being done by Lockheed Georgia Company) and one on crack detection reliability on F-111 fatigue tested structures (being done by General Dynamics/Forth Worth). The Rockwell International Space Division is also conducting an NDE demonstration program to qualify the subcontractors who are producing fracture critical hardware for the Space Shuttle Orbiter.

Collection, analysis, and assessment of the data generated in these and similar programs is yet to come. The NASA Lewis Research Center and its contractors have recently completed an investigation and assessment of NDE reliability data (ref. 33). Twenty sets of relevant data were identified, collected, compiled, and categorized. A criterion for the selection of data for statistical analysis considerations was formulated. A model to grade the quality and validity of the data sets has been developed. Data input formats, which record the pertinent parameters of the defect/specimen and inspection procedures, have been formulated for each NDE method. A comprehensive computer program exists to calculate the probability of flaw detection at several confidence limits by the binomial distribution. This program also selects the desired data sets for pooling and tests the statistical pooling criteria before calculating the composite detection reliability. Probability of detection curves at 95 and 50 percent confidence levels have been plotted for individual sets of relevant data as well as for several sets of merged data with common sets of NDE parameters.

In summary, NDE is a developing technology which is in transition due to provide and apply more quantitative information. It is also obvious that the theme of the 35th Fall Conference of the ASNT, "Nondestructive Testing Does Not Cost - It Pays," was timely and a forecast of better things to come.

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29. Anderson, R. T., DeLacy, T. J., and Stewart, R. C., Detection of Fatigue Cracks by Nondestructive Testing Methods, NASA CR-128946 (March 1973).

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31. Ehret, R. M., Fracture Control Methods for Space Vehicles, Rockwell International Report SD-73-SH-0171-1-2 (January 1974) (Contract NAS 3-16765).

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33. Yee, B. G. W., Couchman, J. C., Chang, F. H., and Packman, P. F., Assessment of NDE Reliability Data, NASA CR-134991 (October 1975).

I. STATE OF THE ART REVIEWS AND OVERVIEWS

NONDESTRUCTIVE EVALUATION TECHNIQUE GUIDE
Vary, A. (National Aeronautics and Space Administration, Lewis Research Center, Cleveland, OH)
NASA SP-3079 (1973)

In this guide a total of 70 individual nondestructive evaluation (NDE) techniques is described, each in a standardized single-page format for quick reference. Information is presented in a manner that permits ease of comparison of the merits and limitations of each technique with respect to various NDE problems. An NDE technique classification system is presented. It is based on the system that was adopted by the National Materials Advisory Board (NMAB). The classification system presented follows the NMAB system closely with the exception of additional categories that have been added to cover more advanced techniques already in use. The rationale for the technique description format used in the guide is explained. The format provides for a concise description of each technique, the physical principles involved, objectives of interrogation, example applications, limitations of each technique, a schematic illustration, and key reference material. Cross-index tabulations are also provided so that particular NDE problems can be referred to appropriate techniques.

Comment:

The NASA Centers have recently significantly influenced the development and utilization of NDE technology. The importance of the contribution of this Guide is probably second only to a NASA sponsored development of NDE instruction materials published under contract in 1967-1968 (see Section ID.4 - Handbooks).

Important References

1. McMaster, R. C., Nondestructive Testing Handbook, 2 Vols., Roland Press (1959).

2. Rogers, E. H. and Merhib, C. P., A Report Guide to Magnetic Particle Testing Literature, AD-617758 (June 1965).

3. Sharpe, R. S., Research Techniques in Nondestructive Testing, Academic Press (1970).

4. Liptai, R. G., Harris, D. O., Engle, R. B., and Tatro, C. A., Acoustic Emission Techniques in Materials Research, Int. J. Nondestructive Testing 3, No. 3, 215-275 (December 1971).

5. Stenton, F. G. and Merhib, C. P., A Report Guide to Ultrasonic Testing Literature, AD-689455 (April 1969).

6. Merhib, C. P. and Rodgers, E. H., A Report Guide to Thermal Testing Literature, AD-612043 (August 1964).

Key words: Analysis methods; design guides; detection systems; handbooks; inspection procedures; NDE methods; NDE techniques; NDI methods; NDI techniques; NDT methods; NDT techniques.

NONDESTRUCTIVE TESTING - A SURVEY
Southwest Research Inst., San Antonio, TX
NASA SP-5113 (1973)

Standard and developmental methods for nondestructive evaluation (NDE) are reviewed. The principles involved are discussed and typical applications are given. Advantages and disadvantages are listed, and practical considerations are presented. The first chapter in the document is an introduction by C. G. Gardner. Then follow nine chapters, written by different authors and describing a variety of NDE emthods and techniques. The final chapter, also by Gardner, discusses developmental methods. Each chapter includes a reference list which is expanded in a comprehensive bibliography at the end of the volumes.

Comment:

This document complements NASA SP-3079, providing considerable detailed information on the application and effect of techniques listed by Vary. NASA SP-5113 is also especially useful in that it describes when, where and often how the NASA Centers have made specific contributions to NDE technology.

Key words: Acoustic emission; analysis methods; eddy currents; experimental data; holography; infrared radiation; inspection; leak testing; magnetic particles; magnetic perturbation; NDE methods; NDT methods; NDT techniques; penetrant inspection; radiography; thermal inspection; ultrasonic tests; x ray inspection.

ADVANCED NDE TECHNIQUES
Thompson, D. O. (Rockwell International Corp., Thousand Oaks, CA)
Prevention of Structural Failure - The Role of Quantitative Nondestructive Evaluation, Amer. Soc. Metals, Materials/Metalworking Technol. Series No. 5, 114-145 (1975).

Recent advances and remaining difficulties in finding ways of obtaining all the information that is inherently possible out of an established NDE technique and of obtaining scientific understanding of problems in NDE are discussed, as they relate to quantitative NDE procedures. The subjects include improved techniques for use with ultrasonics that will provide significantly greater quantitative results for adhesive bond strength measurements.

Comment:

This is a detailed offshoot of a very important and continuing research program at the Rockwell Science Center supported by AFML and ARPA. Quantification is the key to a credible NDE reliability program. Useful and current data on ultrasonics/acoustic emission are included in this report.

Important References:

1. Jolly, W. D., The Use of Acoustic Emission as a Weld Monitor, Battelle-Northwest Report BNWL-SA-2727 (September 1969).

2. Tatro, C. A., Acoustic Emission Sensors and Instrumentation, Lawrence Livermore Lab. Report TED-4500, UC-38 (January 1973).

3. Ono, K., Recent Developments in Acoustic Emission as Applied to Welding Defects, UCLA-ENG-7375 (September 1973).

Key words: Acoustic emission; adhesive bonding; bond integrity; failures (materials); material defects; NDE techniques; ultrasonic tests.

NONDESTRUCTIVE EVALUATION - A REPORT OF THE NATIONAL MATERIALS ADVISORY BOARD
National Academy of Sciences - National Academy of Engineering, Washington, DC
Publication NMAB-252 (June 1969)

This five-part report is a vehicle for widely publicizing the now commonly accepted definition for nondestructive evaluation (NDE) and for presenting to government and industry study conclusions and recommendations for application and expansion of the five report subject areas.

Section 1 - Report of the Ad Hoc Committee on Nondestructive Evaluation

Recommendations are made to DOD which would enhance the greater utilization of the potentials of NDE for present and future military systems. An integrated plan is presented which takes into account short- and long-range technical problems, lack of professional manpower, educational requirements, specification deficiencies, and requirements for basic research. Current NDE problems of military, indeed national importance and scope are delineated, and approaches for potential solutions are outlined.

Section 2 - Education and Promotion

In order to produce more well-qualified NDE engineers, American universities must be convinced that NDE is a science relying upon the most advanced knowledge in fields such as physics, materials, and electronics. Then, hopefully, those institutions will incorporate the subject into their curricula and graduate well-qualified and greatly needed NDE engineers. An intensified educational program for technical management is of paramount importance to aid them in implementing their responsibilities. The establishmnet of NDE research centers for and by government is highly recommended.

Section 3 - Information

NDE in its present state is already a highly developed technology. The techniques in use, with an indication of potential applications, are presented in an outline adapted from Materials Advisory Board Report MAB-231-1. Note is made of the fact that NDE technology is extensively documented but over a widely diffused information media - e.g., texts, journals, technical reports, etc. The function of the NDT Information Analysis Center at Watertown, MS is described and suggestions are made for its expansion and for the establishment of other similar centers.

Section 4 - Technical Problem Areas

This panel surveyed the reports of previous MAB committees and inputs from the Army Materiel Command, the Navy and the Technical Cooperative Program. The published problem statements provided representative coverage of Department of Defense needs. Most of the problem areas identified did not require technology expansion but rather acceptance and application of available knowledge related to selecting test parameters, designing tools, defining acceptance levels, and using the NDE technique best suited to a specific task. Problems associated with the use of NDE methods in each of the following areas are discussed: (1) joining; (2) coatings; (3) composite materials; (4) graphites and ceramics; (5) alloy verification; (6) surface cleanliness; (7) residual stress; (8) fatigue; (9) thin materials; and (10) corrosion and stress corrosion.

Section 5 - Special Phenomena

NDE uses many different disciplines to study and evaluate the integrity of materials. As in other scientific areas, great strides continue to be made. However, more cross-fertilization of the disciplines involved, increased knowledge, and improved instrumentation capability offer the prospect of further significant advancement. This special phenomena section includes recommendations for new study areas and offers an extensive bibliography.

Comment:

This report like most NMAB reports is a primary source of information on the subject. It is also particularly significant to the dedicated practitioner since it afforded the first high level and highly respected consensus on the definition for NDE. The Ad Hoc Committee report stated that, "the term nondestructive evaluation (NDE) is considered more appropriate...since: (1) this discipline also requires the evaluation of test results and inspection; (2) the words 'testing and inspection' do not properly imply the theoretical aspects of this field; and (3) the name (nondestructive evaluation) is more succinct and descriptive." Subsequent to 1969 the recommendation of the NMAB Ad Hoc Committee was adopted and publicized by agencies as demonstrated in the two NASA Special Publications cited above (NASA SP-3076 and NASA SP-5113).

Key words: Analysis methods; analysis tools; bibliographies; composite materials; design criteria; design standards; information; inspection standards; material defects; NDE methods; NDE techniques; protective coatings; quantitative analysis; recommended practices; specifications; structural safety.

RESEARCH TECHNIQUES IN NONDESTRUCTIVE TESTING
Sharpe, R. S. (Atomic Energy Research Establishment, Harwell, England)
Academic Press (1970)

This text, edited by R. S. Sharpe, is a collection of 14 papers by different authors which provide particular insight into selected aspects of NDE. As seen below some of the authors are among the more outstanding people in the field of NDE. The chapters are:

1. Acoustic Emission (Hutton and Ord)
2. Ultrasonic Spectroscopy (Gericke)
3. Ultrasound Imaging Systems (Jacobs)
4. Ultrasonic Critical Angle Reflectivity (Becker and Richardson)
5. Ultrasonic Holography (Aldridge)
6. Optical Holography and Coherent Light Techniques (Ennos)
7. Data Handling Techniques (Cox)
8. Direct-View Radiological Systems (Halmshaw)
9. Neutron Radiography (Berger)
10. A Communication Network Approach to Sub-Millimetric Wave Techniques in Nondestructive Testing (Cooper)
11. Multiparameter Eddy Current Concepts (Libby)
12. Pulsed Eddy Currents (Waidelich)
13. Microwave Techniques (Dean and Kerridge)
14. Infrared Techniques (Lawson and Sabey)

Each chapter in the text includes an extensive reference list.

Key words: Acoustic emission; analysis methods; bibliographies; eddy currents; holography; NDT methods; NDT techniques; radiography; ultrasonic imaging; ultrasonic tests.

ON-LINE AUTOMATIC HIGH SPEED INSPECTION OF CARTRIDGE CASES
Coleman, W. J., Reich, F. R., Erickson, M. D., and Kelly, W. S. (Battelle-Northwest, Richland, WA)
ASTM Stand. News 3, No. 3, 31-34 (March 1975)

An automatic inspection and reject system has been developed for a production application to small caliber cartridge cases. It has undergone initial quality assurance testing and will soon go on-line at Frankford Arsenal. This system gages case profile, surface flaws, wall thickness, and vent hole presence. A mechanical handling system coupled with computer control and data acquisition automatically inspects and rejects 5.56 mm cases at the rate of 1200 per minute. Electro-optical techniques are used to inspect case profile, surface flaws, and vent hole presence. Profile monitoring of individual cases at high production line speeds is accomplished with an optical diode array gaging technique. Optical scattering, using a line source and fiber optic receiver system, is used to monitor cartirdge case surface flaws and two optical transducers perform quality assurance inspection of cartridge cases to verify the presence of the primer vent. Eddy current techniques are used to determine wall thickness. Cases are rotated past four elongated eddy current coils to produce a circumferential thickness profile. Information from the multiple inspection units is fed into the data acquisition and control computer. Operator communication with the quality assurance system is via video display, printer output and a computer function keyboard input. Outputs include hourly trend data and throughput alarm conditions to alert the operator when the number of rejected cases exceeds a preset threshold.

Key words: Automation; eddy currents; fiber optics; inspection; inspection standards; material defects; NDI techniques; optical techniques; thickness measurements.

THE ROLE OF NDT IN AN ELECTRIC UTILITY
Collins, R. V. (Detroit Edison Co., MI)
Mater. Eval. 30, No. 8, 174-180 (August 1972)

Applications of nondestructive testing (NDT) in an electrical utility are summarized. In addition to the expected applications during turbine and boiler overhaul periods the author describes NDT techniques used in surveillance programs such as: (1) detection of heart rot in wooden poles; (2) location of overheated electrical connections on overhead lines by aerial survey; (3) leak detection in underground steam lines; and (4) determination of the integrity of large rotor forgings. Currently, three experimental programs are underway to investigate techniques to detect potential boiler tube failures during a scheduled outage period: (1) infrared scanning system, (2) radiation survey to detect chemical reaction between radioactive salts and ID deposits, and (3) comparative analysis of acoustic emission characteristics of corroded and non-corroded tubes.

Comment:

The advent of nuclear power has presented a major challenge to the power industry to develop new and remotely controlled NDT techniques to determine the integrity of structural components in high radiation environments. The author discusses both the technical and economic aspects of this problem.

Key words: Acoustic emission; analysis tools; detection systems; failure prevention; leak testing; material defects; NDT techniques; ultrasonic tests.

NONDESTRUCTIVE TESTING TECHNIQUES FOR FIBERGLASS, GRAPHITE FIBER AND BORON FIBER COMPOSITE AIRCRAFT STRUCTURES

Hagemaier, D. J., McFaul, H. J., and Parks, J. T. (Douglas Aircraft Co., Inc., Long Beach, CA)

Mater. Eval. 28, No. 9, 194-204 (September 1970)

Various NDT methods were evaluated for inspection and evaluation of boron, graphite and glass-fiber composites for aircraft structures. Typical specimens were evaluated using microscopic, fluorescent penetrant, radiographic, ultrasonic and thermochromic test methods. Optical microscopic examination is useful for determination of fiber pattern from the edge of a panel. It was concluded that fluorescent penetrant combined with microscopic examination is a useful tool to determine fiber pattern, fiber gaps, broken fibers, crushed core, and resin-rich areas; and ultrasonic and thermal methods appear to have merit for determining unbonded areas. The results of a literature survey concerning the NDT of composites are presented in abstracted form and indicate significant applications and limitations of various test methods. The direction of future NDT research and development efforts is indicated.

Important References:

1. Tomlinson, R. and Underhill, P., Production Neutron Radiographic Facility for Routine NDT Inspection of Special Aerospace Components, ASNT Spring Conf., Los Angeles, CA (March 1969).

2. Haskins, J. J., and Wilkinson, C. D., Neutron Radiography: Some Applications for NDT, ASNT Spring Conf., Los Angeles, CA (March 1969).

3. Maley, D., Nondestructive Evaluation of Material Properties Through the Use of Thermal Inspection System, AFML-TR-66-192 (1966).

4. Searles, C., Thermal Image Inspection of Adhesive Bonded Structures, Proc. ASNT Symp. NDT of Welds and Joining, Evanston, IL (1968).

5. Schroeer, R., Research on Exploratory Development of Nondestructive Methods for Crack Detection, AFML-TR-67-167-PT1 (August 1967).

6. Padden, H., Fokker Bond Testing of Composites, Proc. AFML Aerospace Conf. NDT of Composite Structures, Dayton, OH (March 1969).

Key words: Aircraft structures; acoustic emission; bond integrity boron fibers; carbon fibers; composite materials; detection systems; evaluation; fiber-reinforced composites; glass fibers; laminates; material defects; NDT methods; NDT techniques; penetrant inspection; radiography; ultrasonic tests; x ray inspection.

NDT TECHNIQUES FOR AIRLINE MAINTENANCE INSPECTION
Weldon, W. J. (American Airlines, Inc., Tulsa OK)
Qual. Prog. 3, 22-24 (November 1970)

Airline maintenance and use of NDT does not lend itself to automated or production line concepts. The range of NDT techniques employed by American Airlines is described. These include ultrasonic, eddy current, magnetic particle, penetrant, and x ray techniques. Due to the considerable expense of aircraft disassembly most inspections are performed on the aircraft. The unique methods and apparatus employed for these inspections in areas often of limited accessibility are described. It is shown that NDT is a valuable and expanding factor in the profit and safety record of todays airlines.

Key words: Aircraft structures; eddy currents; gas turbine engines; magnetic particles; maintenance; penetrant inspection; ultrasonic tests; x ray inspection.

NONDESTRUCTIVE TEST TECHNIQUE DEVELOPMENT FOR THE EVALUATION OF BONDED MATERIALS
Zurbrick, J. R., Proudfoot, E. A., and Hastings, C. H. (Avco Government Products Group, Lowell, MA)
AD-753753 (November 5, 1971)

This report describes a research and development program on NDT techniques for characterizing metallic substrate surfaces. Studies of the relative influence of parametric variables on bond strength have shown the overriding influence of surface free energy as compared with contact angle on prepared substrates. The effective strain value was found to be very complex. Its empirical treatment as if it consists only of uniformly distributed axial strain is a possibly useful solution which permits linking bond strength primarily to surface free energies. Effort was devoted to development of nondestructive, optical, and spectrophotometric techniques for characterizing contaminants which frequency occur on substrate surfaces. Although the most sensitive techniques available were employed, they did not reveal correlations with bond strength variability observed.

Important References:

1. Lockyer, G. E. and Proudfoot, E. A., Development of Nondestructive Tests for the Evaluation of Bonded Materials, AVCO Report AVADT-0123-69-CR (1969).

2. Zurbrick, J. R., Nondestructive Test Technique Based on the Quantitative Prediction of Bond Adhesive Strength, AVCO Report AVSD-0331-70-RR (July 1970).

3. Schmitz, G. and Frank, L., Nondestructive Testing for Evaluation of Strength of Bonded Materials, Contract NAS 8-11456 (September 1965).

4. Zurbrick, J. R., Nondestructive Test Technique Development Based on Quantitative Prediction of Bond Strength, AVCO Report AVSD-0331-70-RR (July 1970).

Key words: Bonding; bond integrity; NDE techniques; NDT techniques; optical techniques; substrates.

ASSURING SATURN QUALITY THROUGH NONDESTRUCTIVE TESTING

Neuschaefer, R. W. (National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, AL)

Mater. Eval. 27, No. 7, 145-152 (July 1969)

The Saturn V space vehicle is briefly described. The organizational responsibilities of NDT groups are discussed as well as the approach to management of research and development activities. Applications of the various nondestructive testing methods employed to evaluate materials and processes used in the manufacture of the various stages and major components are described. Emphasis is placed on a discussion of the special NDT methods and equipment developed to satisfy the unique requirements of the Apollo program. Advancements in the state-of-the-art, including a solid-state, radiographic image amplifier and an RF device suitable for measuring the thickness of nonmetallics on metallic objects, are described.

Important References:

1. Hagemaier, D. J. and Meyer, J. A., Braze Bond Inspection of Open-Face Honeycomb Seals Using Low Viscosity Liquid, Mater. Eval. 26, No. 10, 211-214 (October 1968)

2. Hagemaier, D. J. and Posakony, G. J., Ultrasonic Testing of Melt-Through Welds in Small-Diameter, Thin-Walled Tubing Couplers, Mater. Eval. 26, No. 11, 221-226 (November 1968).

3. Nowakowski, M., X-Ray Television Techniques for Nondestructive Testing, Proc. NASA Technology and Trends Symp., 2nd (1968).

4. Zoller, L. K., Prospectus for NDT in the Saturn and Advanced Space Flight Programs, Mater. Eval. 24, No. 11, 637-640 (November 1966).

5. Musser, C. W., NDT Systems for Establishing Weld Integrity of Space Vehicles, Mater. Eval. 27, No. 2, 42-48 (February 1969).

6. Hannah, K. V., Cross, R. T., and Tooley, W. M., Development of the Ultrasonic Delta Technique for Aluminum Welds and Materials, Contract NAS 8-18009 Technical Report 68-75 (May 15-1968).

Key words: Aerospace vehicles; bond integrity; economic factors; eddy currents; inspection procedures; NDI methods; NDI techniques; penetrant inspection; radiography; ultrasonic imaging; x ray inspection.

RELIABILITY, LIFE PREDICTION AND PROOF TESTING OF CERAMICS
Wiederhorn, S. M. (National Bureau of Standards, Washington, DC)
Ceramics for High Performance Applications, 633-663, Brook Hill Pub. Co., Chestnut Hill, MA (1974)

This paper was originally presented at the AMMRC-sponsored Second Army Materials Technology Conference, Hyannis, MS, 13-16 November 1973. A critical review of the use of proof testing as a design method for assuring the reliability of structural components is presented. The advantage of proof testing over the statistical approach used for design lies in the insensitivity of the proof testing method to the detailed history of handling or processing of structural components. Methods are presented for developing and using proof test diagrams to assure component lifetime after proof testing. Procedures of proof testing and precautions that must be followed during proof testing are discussed. It is stated that if the recommended precautions are followed, proof testing offers a good method for assuring the reliability of structural components subjected to stress.

Important References:

1. Evans, A. G. and Wiederhorn, S. M., Proof Testing of Ceramic Materials - An Analytical Basis for Failure Prediction, NBS Report NBSIR-73-147 (March 1973) (AD-759373).

2. Evans, A. G. and Fuller, E. R., Crack Propagation in Ceramic Materials Under Cyclic Loading Conditions, Met. Trans. 5, 27-33 (1974).

3. Evans, A. G., Fracture Mechanics Determinations, in Fracture Mechanics of Ceramics, 1. Concept, Flaw and Fractography, Plenum Press (1974).

4. Wiederhorn, S. M., Subcritical Crack Growth in Ceramics, in Fracture Mechanics of Ceramics, 2. Microstructure, Materials and Applications, Plenum Press (1974).

5. Evans, A. G., Static Fatigue and Slow Crack Growth in Ceramics, in Ceramics for High Performance Applications, Brook Hill Pub. Co., Chestnut Hill, MA (1974).

6. Evans, A. G. and Wiederhorn, S. M., Crack Propagation and Failure Prediction in Silicon Nitride at Elevated Temperatures, J. Mater. Sci. 9, 270-278 (1974).

Key words: Ceramics; crack propagation; design guides; design procedures; failure mechanisms; life prediction; material defects; NDT methods; proof tests; reliability; statistical analysis; structural analysis.

IC - Effectiveness and Standardization

COST/EFFECTIVENESS IN NONDESTRUCTIVE TESTING
Bogart, H. G. (Magnaflux Corp., New York NY)
Mater. Eval. 26, No. 4, 23A-26A (March 1968)

Some of the benefits of NDT including the role it plays in reliability and safety in modern industry are discussed. Factors which affect the cost of NDT, such as research and development, equipment installation, and operating costs, are included. It is pointed out that the conventional economics of NDT are shifting to a new field where all known factors, tangible and intangible, will be included in an organized fashion in the decision making process. In this paper, originally presented at the 1967 ASNT Fall Conference in Cleveland, OH (16-19 October), the author credits his experience at ICAF as providing inspiration for the paper. There are no references.

Key words: Analysis methods; costs; failure prevention; NDT methods; NDT techniques; safety.

ULTRASONIC REFERENCE STANDARDS KEY TO RELIABLE ULTRASONIC INSPECTION
Ellerington, H. (Automation Industries, Inc., Boulder, CO)
Mater. Eval. 28, No. 11, 251-256 (November 1970).

Ultrasonic inspection procedures are based on the use of reference standards manufactured from carefully selected materials in which calibrated discontinuities have been machined. The proper use of reference standards provides uniform inspection criteria that have significant meaning when used to describe inspection results. This paper describes the numerous types of reference standards being used throughout the industry today and discusses the importance of standards and some of the precautions relative to their use in ultrasonic inspection processes.

Key words: Calibration standards; inspection procedures; NDE methods; NDI methods; ultrasonic tests.

THE NEED FOR A QUANTITATIVE APPROACH TO NONDESTRUCTIVE TESTING
Goldspiel, S. (Naval Applied Science Lab., Brooklyn, NY)
Mater. Eval. 23, No. 5, 224-242 (May 1965)

The author seeks to establish that quantitative NDT techniques must meet 5 requirements: (1) be theoretically feasible; (2) be reproducible; (3) provide foolproof legibility of test indications; (4) test indication must be capable of unique interpretations in terms of fabrication flaws; (5) for quantitative capability there must be a known correlation of test indications with deterioration of engineering performance. Problems raised by these requirements are identified and some suggestions for their solution are given.

Key words: Bibliographies; crack detection; inspection standards; material defects; NDT methods; NDT techniques; quantitative analysis; radiography; specifications; standards; ultrasonic tests.

USING NONDESTRUCTIVE TESTING EFFECTIVELY
Heine, H. J. (Foundry Management and Technology, Cleveland, OH)
Foundry 103, No. 4, 22-29 (April 1975)

Judicious application of nondestructive testing techniques, whether to assure soundness of components or strict adherence to tolerance standards, can reduce both the cost of casting production and scrap percentage effectively. This article is the first of a series that will review and evaluate commonly applied NDT techniques, including liquid penetrants, radiographic methods, magnetic particle testing, ultrasonics, use of eddy current, and others.

(FOR LISTING OF IMPORTANT REFERENCES, KEYWORDS AND A DUPLICATE ABSTRACT, SEE PAGE 129).

THE HUMAN ELEMENT IN NONDESTRUCTIVE TESTING
Hovland, H.
Mater. Eval. 27, No. 12, 13A-15A, 18A-19A (December 1969)

This Mehl Honor Lecture to the 1969 ASNT Fall Conference in Philadelphia, PA discusses the growth in acceptance and application of NDT and some associated problems. Increase in utilization of NDT has brought with it the need to have guidelines in industry by which to train, examine, and evaluate NDT skills. Hovland pays particular tribute to the ASNT program publishing recommended practices for the qualification and certification of NDT personnel. He notes that it is a three-phase program which recommends: (1) three basic levels of qualification; (2) a training course outline for each NDT method; and (3) an examination and testing system whereby applicants could demonstrate their qualifications. Recommendations for administration of NDT personnel certification are also offered. The ASNT document referenced attempts to establish the profile for a qualified NDT operator.

Key words: Human factors; inspection standards; NDI techniques; NDT techniques; recommended practices; test standards.

A MANAGER LOOKS AT NONDESTRUCTIVE TESTING
Kirchner, W. R. (Aerojet-General Corp., Sacramento, CA)
Mater. Eval. 23, No. 6, 271-278 (June 1965)

NDT is extremely critical in the successful manufacture of solid rocket motors. Both the crude stock and the final part must be inspected without damage to its integrity to assure delivery of a safe product to the customer. In this paper some of the equipment used to inspect both completed motors and inert hardware in various stages of fabrication are described. It is shown that the cost of such rigid control of materials and processes is considerable but not too much relative to the alternatives. Major advantages obtained from use of NDT in the missile industry are listed as: (1) maximum developmental and analytical data from a minimum number of test firings; (2) accomplishment of accurate failure analyses; (3) early detection of flaws in components or full-scale motors, permitting corrective action which tends to maintain a higher reliability record for units released in the field; (4) minimized development and production costs, improving competitive position; and (5) providing a final assurance of the quality of production units.

Key words: Aerospace vehicles; analysis methods; cost analysis; costs; design criteria; economic analysis; inspection; NDT methods; NDT techniques; safety criteria.

NONDESTRUCTIVE TESTING HANDBOOK
McMasters, R. C. (Ohio State Univ., Columbus, OH)
The Ronald Press Co., New York, NY (1963)

This well-annotated two-volume work is a basic tool for NDE/NDT practitioners. The broad scope of what is called the science of NDT is demonstrated. The fundamental test methods described range the entire NDT field. Fundamental principles, methods and applications, and equipment and techniques of the tests are described in detail and guides are given for interpreting test results and evaluating the serviceability of the test objects. The handbook seeks to implement development, standardization, and the proper application of NDT. Critical NDT problem areas are discussed. Much of the material is conveyed in terms of problem solving and solutions are stated in terms of the basic physics underlying test methodology.

Comments:

This text is currently under revision to include NDE advances of the past decade. It will continue to be an essential reference for the NDE engineer and manager.

Key words: Analysis methods; crack detection; detection systems; eddy currents; failures (materials); handbooks; inspection; magnetic particles; material defects; NDT methods; NDT techniques; optical techniques; penetrant inspection; radiography; ultrasonic tests; x ray inspection.

NONDESTRUCTIVE EVALUATION TECHNIQUE GUIDE
Vary, A. (National Aeronautics and Space Administration, Lewis Research Center, Cleveland, OH)
NASA SP-3079 (1973)

In this guide a total of 70 individual nondestructive evaluation (NDE) techniques are described, each in a standardized single-page format for quick reference. Information is presented in a manner that permits ease of comparison of the merits and limitations of each technique with respect to various NDE problems. An NDE technique classification system is presented. It is based on the system that was adopted by the National Merits Advisory Board (NMAB). The classification system presented follows the NMAB system closely with the exception of additional categories that have been added to cover more advanced techniques already in use. The rationale for the technique description format used in the guide is explained. The format provides for concise description of each technique, the physical disciplines involved, objectives of interrogation, example applications, limitations of each technique, a schematic illustration, and key reference material. Cross-index tabulations are also provided so that particular NDE problems can be referred to appropriate techniques.

FOR LISTING OF IMPORTANT REFERENCES, KEYWORDS AND A DUPLICATE ABSTRACT, SEE PAGE 17).

NONDESTRUCTIVE TESTING - A SURVEY
Southwest Research Inst., San Antonio, TX
NASA SP-5113 (1973)

Standard and developmental methods for NDE are reviewed. The principles involved are discussed and typical applications are given. Advantages and disadvantag are listed, and practical considerations are presented. The first chapter in the document is an introduction by C. G. Gardner. There follow nine chapters, written by different authors and describing a variety of NDE methods and techniques. The final chapter, also by Gardner, discusses developmental methods. Each chapter includes a reference list which is expanded in a comprehensive bibliography at the end of the volume.

(FOR LISTING OF IMPORTANT REFERENCES, KEYWORDS AND A DUPLICATE ABSTRACT, SEE PAGE 18).

NDE METHODS HANDBOOK SERIES
National Aeronautics and Space Administration (1967-1968)

NASA through a contractor has prepared a series of instructional materials in each of the most widely used NDE methods. A training handbook is provided for each method, together with one or more manuals of the so-called programmed type. These manuals are suitable for self-study, and are designed to lead the student step-by-step to an understanding of the principles, apparatus, and procedures of an NDE method. When used as part of a systematic training program conducted by competent instructors, and including a period of supervised apprenticeship, these materials provide the student with the knowledge and experience necessary for expert application of the method at the technician level. These books are available from the American Society for Nondestructive Testing and are listed below.

1. Anon.: Introduction to Nondestructive Testing, NASA CR-61204 (1968).

2. Anon.: Liquid Penetrant Testing, NASA CR-61205 (1968).

3. Anon.: Magnetic Particle Testing, NASA CR-61206 (1967).

4. Anon.: Ultrasonics: Vol. I - Basic Principles, NASA CR-61209 (1967).

5. Anon.: Ultrasonics: Vol. II - Equipment, NASA CR-61210 (1967).

6. Anon.: Ultrasonics: Vol. III - Applications, NASA CR-61211 (1967).

7. Anon.: Eddy Current: Vol. I - Basic Principles, NASA CR-61207 (1967).

8. Anon.: Eddy Current: Vol. II - Equipment, Methods, and Applications, NASA CR-61208 (1967).

9. Anon.: Radiography: Vol. I - Origin and Nature of Radiation, NASA CR-61212 (1967).

10. Anon.: Radiography, Vol. II - Radiation Safety, NASA CR-61213 (1967).

11. Anon.: Radiography: Vol. III - Radiographic Equipment, NASA CR-61214 (1967).

12. Anon.: Radiography: Vol. IV - Making a Radiograph, NASA CR-61215 (1967).

13. Anon.: Radiography: Vol. V - Film Handling and Processing, NASA CR-61216 (1967).

14. Anon.: Liquid Penetrant Testing: Classroom Training Handbook, NASA CR-61229 (1967).

15. Anon.: Magnetic Particle Testing: Classroom Training Handbook, NASA CR-61227 (1967).

16. Anon.: Ultrasonic Testing: Classroom Training Handbook, NASA CR-61228 (1967).

17. Anon.: Eddy Current Testing: Classroom Training Handbook, NASA CR-61230 (1967).

18. Anon.: Radiographic Testing: Classroom Training Handbook, NASA CR-61231 (1967).

Key words: Analysis methods; detection systems; eddy currents; handbooks; inspection procedures; magnetic particles; NDE methods; NDE techniques; NDT techniques; penetrant inspection; radiography; safety criteria; test equipment; test procedures; ultrasonic tests.

II. TECHNIQUES

FLAW DETECTION AND CHARACTERIZATION USING ACOUSTIC EMISSION
Corle, R. R. and Schliessmann, J. A. (Lockheed Propulsion Co., Redlands, CA)
Mater. Eval. 31, No. 6, 115-120 (June 1973)

A test program was conducted to evaluate acoustic emission techniques for use in detecting flaws during proof testing of rocket motor cases. Steel sheet specimens which contained tight fatigue cracks of various sizes were tested. Selected specimens were inspected by standard radiographic and magnetic particle techniques to determine the sensitivity level of these methods. Each specimen was then loaded to simulate proof testing. An acoustic emission signature was recorded for each specimen during proof testing and was found to be a function of the flaw size. By evaluating the signature, unflawed specimens could be distinguished from flawed specimens and could be ranked on the basis of flaw size, with flaws as small as 0.035 in (0.9 mm) deep being detected. By comparison flaws as large as 0.16 in (4.1 mm) deep and 2.6 in (66 mm) long were not detected by radiographic techniques, and surface flaws as large as 0.1 in (2.5 mm) deep and 0.1 in (2.5 mm) long were not detected by magnetic particle inspection.

Comment:

This test program gave visibility to the severe drawbacks of radiography in detecting sight crack flaws. The demonstration of the sensitivity of acoustic emission during proof testing was particularly significant because it is of the order of magnitude of the K_{IC} critical flaw size for some of these very high strength steels.

Important References:

1. Dunegan, H. L. and Harris, D. O., Acoustic Emission - A New Nondestructive Testing Tool, Ultrasonics 7, 160-166 (July 1969).

2. Dunegan, H. L. and Green, A. T., Factors Affecting Acoustic Emission Response from Matérials, Mater. Res. Stand. 2, No. 3 (1971).

Key words: Acoustic emission; crack detection; detection systems; evaluation; magnetic particles; material defects; NDT techniques; radiography; stress intensity factor.

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DETECTION OF FATIGUE CRACK GROWTH BY ACOUSTIC EMISSION TECHNIQUES

Dunegan, H. L., Harris, D. O., and Tetelman, A. S. (California Univ., Livermore, Lawrence Radiation Lab.)

Mater. Eval. 28, No. 10, 221-227 (October 1970)

It has been well established in tensile tests that acoustic emission is an irreversible process that is associated with plastic deformation. It is also widely recognized that plastic deformation is present at the root of a sharp crack in a structure that is stressed. Acoustic emission tests performed on cracked fracture toughness specimens have confirmed that acoustic emission associated with the plastic zone at the crack tip is also very nearly irreversible for stress intensities at the crack tip of less than one-half the critical stress intensity value required to cause unstable fracture. It is shown in this report how this irreversible feature can be utilized in a practical NDT test on a structure undergoing crack growth due to cyclic loading or other environmental effects. This technique is based on periodic acoustic emission monitoring of a structure as it is loaded back to its proof stress.

Important References:

1. Dunegan, H. L., Harris, D. O, and Tatro, C. A., Fracture Analysis by Use of Acoustic Emission, J. Eng. Fract. Mech. 1, 105-122 (June 1968).

2. Dunegan, H. L. and Harris, D. O., Acoustic Emission - A New Nondestructive Testing Tool, Proc. Annual. Symp. NDT of Welds and Materials Joining, 3rd, Los Angeles, CA (March 1968).

3. Paris, P. C., The Fracture Mechanics Approach to Fatigue, Proc. Sagamore Conf., 10th, Syracuse Univ. Press (1965).

4. Wessel, E. T., State of the Art of the WOL Specimen for K_{IC} Fracture Toughness Testing, J. Eng. Fract. Mech. 1, 77-103 (June 1968).

5. Zackay, V. F., Parker, E. R., Dieter, F., and Busch, R., The Enhancement of Ductility in High Strength Steels, California Univ. Lawrence Radiation Lab., Report UCRL-17455 (March 1967).

6. Tiffany, C. F. and Masters, J. J., Applied Fracture Mechanics, Fracture Toughness Testing and Its Applications, ASTM STP-381, 249-308 (1965).

Key words: Acoustic emission; crack propagation; crack tip plastic zone; detection systems; environment effects; fatigue (materials); fracture strength; fractures (materials); NDT methods; stress intensity factor.

ACOUSTIC EMISSION AS A TECHNIQUE FOR NONDESTRUCTIVE TESTING
Frederick, J. R. (Michigan Univ., Ann Arbor)
Mater. Eval. 28, No. 2, 43-47 (February 1970)

Acoustic emission or noise given off spontaneously by solid materials as a result of stress relaxations within the materials is discussed. The type of stress relaxation of interest in nondestructive testing applications is that which results from either the nucleation or propagation of cracks, or localized microscopic yielding. The range of frequencies and amplitudes of acoustic emission encountered in nondestructive testing applications are described. Some ways in which the amount of acoustic emission depends upon the microstructure of a specimen are shown. Finally, some results of fatigue and fracture studies are presented.

Comment:

A promising method for nondestructive testing and inspection is to observe the acoustic emission from materials when they are stressed. The author notes that such observations can be made equally well on tensile specimens or on manufactured parts. He also states that except for the noise produced by crack nucleation or propagation, the exact mechanisms which cause acoustic emission are not clear. The amount of noise has been shown to be dependent upon microstructure and the level of the applied stress. The technique appears to offer considerable promise for the "in-service" monitoring of critical structures.

Important References:

1. Dunegan, H. L. and Harris, D. O., Acoustic Emission - A New Nondestructive Testing Tool, Lawrence Radiation Lab., Report UCLA-70760 (January 1968).

2. Parry, D. L., Nondestructive Flaw Detection by Use of Acoustic Emission, Phillips Petroleum Co. Report TID-4500 (May 1967).

3. Schofield, B. H., A Study of the Applicability of Acoustic Emission to Pressure Vessel Testing, AFML-TR-66-92 (November 1966).

4. Green, A. T. and Hartbower, C. E., Stress Wave Analysis Technique for Detection of Incipient Failure, Aerojet-General Corp. Report Robert RA/FA-DSR (November 30, 1967).

Key words: Acoustic emission; analysis methods; crack propagation; dislocations (materials); material defects; microstructures; NDT methods.

ACOUSTIC EMISSION
Hutton, P. H. and Ord, R. N. (Battelle Memorial Inst., Richland, WA)
Research Techniques in Nondestructive Testing, Academic Press (1970).

This is the first chapter in a valuable text edited by R. S. Sharpe. (See Section IA5 of this report.) The authors describe acoustic emission (AE) as a phenomenon arising from energy released as a solid material undergoes plastic deformation and fracture. Part of the energy is converted to elastic waves which propagate through the material and can be detected at the materials surface using high sensitivity sensors. AE monitor system requirements and equipment development are discussed in functional blocks - signal analysis, sensor, signal conditioning, and data analysis and readout. Areas of application are also discussed.

Important References:

1. Day, C. K., An Investigation of Acoustic Emission for Defect Formation in Stainless Steel Weld Coupons, Battelle Report BNWL-902 (1968).

2. Fitch, C. E., Acoustic Emission Signal Analysis in Flat Plates, Battelle Report BNWL-1008 (1969).

3. Hutton, P. H., Acoustic Emission in Metals as an NDT Tool, Mater. Eval. 26, No. 7, 125 (1968).

4. Hutton, P. H., Nuclear Reactor System Noise Analysis, Dresden I Reactor, Battelle Report BNWL-867 (1968).

5. Hutton, P. H., Acoustic Emission Detection in the Presence of Hydraulic Noise, Battelle Report BNWL-933 (1968).

6. Jolly, W. D., An In Site Weld Defect Detector, Acoustic Emission, Battelle Report BNWL-817 (1968).

Key words: Acoustic emission; crack analysis; crack detection; crack initiation; crack propagation; detection systems; dislocations (materials); material defects; plastic deformation; NDT methods.

ACOUSTIC EMISSION TECHNIQUES IN MATERIALS RESEARCH
Liptai, R. G., Harris, D. O., Engle, R. B., and Tatro, C. A. (California Univ,, Livermore, Lawrence Radiation Lab.)
Int. J. Nondestruct. Test 3, 215-275 (1975)

A review of the application of emission analysis to evaluate materials properties and defect structure is presented. Topics discussed include fracture toughness and crack propagation, fatigue, plastic deformation, and creep processes in metals, composites, and rock materials. The status of emission techniques as applied to the evaluation of structural integrity is reported. A complete discussion of experimental techniques and data acquisition and processing systems is given. It is concluded that acoustic emission techniques have wide applicability to experimental studies in materials research and to evaluation analysis of structural integrity. Directions of future developments and applications are discussed.

Important References:

1. Dunegan, H. L., Harris, D. O. and Tatro, Fracture Analysis by Use of Acoustic Emission, Eng. Fract. Mech. 1, No. 1, 105 (1968).

2. Engle, R. B. and Dunegan, H. L., Acoustic Emission: Stress Wave Detection as a Tool for Nondestructive Testing and Material Evaluation, Int. J. Nondestruct. Test. 1, No. 1, 109 (1969).

3. Dunegan, H. L. and Harris, D. O., Acoustic Emission - A New Nondestructive Testing Tool, Ultrasonics 7, No. 3, 160 (1969).

4. Gerberich, W. W. and Hartbower, C. E., Monitoring Crack Growth of Hydrogen Embrittlement and Stress Corrosion Cracking by Acoustic Emission, Proc. Conf. Fundam. Aspects Stress Corros. Cracking, Ohio State Univ., Columbus OH (1967).

5. Dunegan, H. L., Harris, D. O. and Tetelman, A. S., Detection of Fatigue Crack Growth by Acoustic Emission Techniques, Proc. Symp. Nondestruct. Eval. Components Mater. Aerospace Weapons Systems, Nucl. Appl., 7th, ASNT and Southwest Research Inst., San Antonio, TX (1969).

6. Harris, D. O., Dunegan, H. L. and Tetelman, A. S., Prediction of Fatigue Lifetime by Combined Fracture Mechanics and Acoustic Emission Techniques, AFFDL-TR-70-144, 459-471 (September 1970).

Key words: Crack propagation; detection systems; fatigue (materials); fracture strength; metallic materials; plastic deformation; structural safety; ultrasonic tests.

AN ACOUSTIC SURFACE WAVE METHOD FOR RAPID, NONDESTRUCTIVE TEXTURE EVALUATION
Tittmann, B. R. and Alers, G. A. (North American Rockwell Corp., Thousand Oaks, CA)
Met. Trans. 3, 1307-1308 (May 1972)

A simple and rapid method for the nondestructive evaluation of texture in metal sheet and plate products of arbitrary thicknesses is described. The method uses impulse techniques to generate and receive Rayleigh waves on thick plates or Lamb waves on thin materials. The technique is applied to titanium alloy sheet and plate materials whose texture was introduced by the rolling process.

Important References:

1. Viktorov, I. A., Rayleigh and Lamb Waves, Plenum Press (1967).

2. Alers, G. A. and Liu, Y. C., Calculation of Elastic Anisotropy in Rolled Sheet, Trans. ASME 236, No. 4, 482-489 (April 1966).

3. Alers, G. A. and Nadler, H., Rockwell Science Center, Technical Report SCTR-71-8 (August 1971).

Key words: Acoustic emission; microstructures; NDE techniques; plates (structural members); sheet metal; titanium alloys; ultrasonic tests.

ULTRASONIC IMAGING SYSTEMS FOR NONDESTRUCTIVE TESTING
Berger, H. (Argonne National Lab., IL)
J. Acoust. Soc. Amer. 45, No. 4, 859-867 (April 1969)

Methods for detecting ultrasonic images are briefly reviewed, and discussed in light of their potential application to nondestructive test problems. In a typical nondestructive test system involving a water immersion tank, the ultrasonic image detector should respond to an ultrasonic intensity of 10^{-2} W/cm^2 or less. This requirement eliminates from consideration a number of detection methods involving photographic, chemical, or thermal mechanisms. Of the remaining image detection systems, only a few have been applied to nondestructive test problems. These include the surface relief technique, the Pohlman cell, and scanning methods involving piezoelectric transducers. The latter method has been most used for image applications, with mechanical movement of the transducer(s) in a C-scan method. Electron scan of a single piezoelectric detector to provide a television presentation is coming into wider use. A description of one such system is given. For a thin, flat inspection object, the system offers good inspection speed, resolution, and sensitivity to inhomogeneities. Thick, irregularly shaped inspection objects present problems because lens systems are involved. Lenses for imaging are not well developed. Also, the use of a lens tends to slow the inspection of a thick object because one must examine the object by focusing at different depths. Pulsed television systems and holographic techniques offer some promise in that area. A new phase-sensitive color television ultrasonic image system offers hope for improved detection of subtle discontinuities.

Comment:

This scholarly and comprehensive report on ultrasonic imaging, the by-product of a research program under the auspices of the Atomic Energy Commission, is still a basic document in ultrasonics. It is heavily annotated - 65 American and foreign references. The author is currently with the National Bureau of Standards, Gaithersburg, MD and is doing pioneer work in neutron radiography (see Section IIC).

Important References:

1. Berger, H. and Dickens, R. E., A Review of Ultrasonic Imaging Methods, with a Selected Annotated Bibliography, Argonne National Lab. Report ANL-6680 (1963).

2. Fry, W. J. and Dunn, F., Ultrasonic Absorption Microscopy and Spectroscopy, Proc. Symp. Phys. Nondestructive Testing, Southwest Res. Inst., San Antonio, TX, 33-57 (1962).

3. Berger, H., A Television System for Ultrasonic Imaging, Argonne National Lab. Report ANL-7042 (1966).

4. Thurstone, F. L., Ultrasound Holograms for the Visualization of Sonic Fields, J. Acoust. Soc. Amer. 42, 1148(A) (1967).

Key words: Detection systems; holography; inspection; instrumentation; material detects; NDT methods; NDT techniques; ultrasonic imaging; ultrasonic tests.

ULTRASONIC REFERENCE STANDARDS KEY TO RELIABLE ULTRASONIC INSPECTION
Ellerington, H. (Automation Industries, Inc., Boulder, CO)
Mater. Eval. 28, No. 11, 251-256 (November 1970)

Ultrasonic inspection procedures are based on the use of reference standards manufactured from carefully selected materials in which calibrated discontinuities have been machined. The proper use of reference standards provides uniform inspection criteria that have significant meaning when used to describe inspection results. This paper describes the numerous types of reference standards being used throughout the industry today and discusses the importance of standards and some of the precautions relative to their use in ultrasonic inspection processes.

Key words: Calibration standards; inspection procedures; NDE methods; NDI methods; ultrasonic tests.

THE USE OF ULTRASONIC SURFACE WAVES TO EVALUATE MAGNETIC INDICATIONS OF SUBSURFACE DEFECTS
Hart, S. D. (Naval Research Lab., Washington, DC)
NRL Memo. Report 2236/AD-723526 (April 1971)

An ultrasonic technique for detecting flaws near the surface in plate material was developed. The technique makes use of pulsed surface waves in a two transducer "pitch-catch" arrangement. This provides greater sensitivity than a single transducer pulse-echo system. The system was used to evaluate magnetic particle indications of near-surface flaws. It was concluded that the magnetic particle indications were non-relevant, being caused by leakage fields at the boundaries of slightly dissimilar metals (welded structures). Examination by ultrasonic surface wave probes revealed no cracks. Dye-penetrant inspection was also negative.

Comment:

The probe combination developed for these tests was acknowledged to be crude and further tests are warranted. These tests required the presence of an extra observer to provide constant vigilance to assure probe-plate surface contact at all times.

Key words: Analysis methods; magnetic particles; material defects; NDI techniques; plates (structural members); test procedures; welded structures.

THE MEASUREMENT OF SURFACE AND NEAR-SURFACE STRESS IN ALUMINUM ALLOYS USING RAYLEIGH WAVES

Martin, B. G. (Douglas Aircraft Co., Inc., Long Beach, CA)

Mater. Eval. 32, No. 11, 229-234 (November 1974)

Experimental work has been conducted on determining the feasibility of using an ultrasonic technique for measuring residual stress in aluminum alloys. It was observed that stress changes Rayleigh-wave velocity slightly (a fraction of 1 percent), and that uniaxial tensile stress decreases velocity and compressive stress increases it. This is in agreement with predictions based on second order elasticity theory. The effect of preferred grain orientation on Rayleigh-wave velocity is of the same order of magnitude as the effect of stress (at least in the elastic range). Also, preferred grain orientation acts in such a manner as to decrease Rayleigh-wave velocity. It was concluded that due to the difficulty of separating the effects of preferred grain orientation and stress, the ultrasonic technique is not practical for measuring residual stress in aluminum alloys, at least not in the alloys 2024-T3 and 7075-T6. However, the technique is applicable to the measurement of applied stress and to the measurement of residual stress in 6061-T6 alloy.

Important References:

1. Martin, B. G., Rayleigh-Wave Velocity, Stress and Preferred Grain Orientation in Aluminum, Non-Destructive Testing - Research and Practice 7, 199 (August 1974).

2. Development of Nondestructive Methods for Determining Residual Stress and Fatigue Damage in Metals, Final Report, Contract NAS 8-20208 (March 8, 1968).

3. Holmes, V., Ultrasonic Measurement of Stress, McDonnell Co. Report R513-716 (1969).

4. Gause, R. L., Ultrasonic Analysis of Cold-Rolled Aluminum, in Nondestructive Testing, Trends and Techniques, NASA SP-5082 (1967).

5. McKannan, E. C., Ultrasonic Measurement of Stress in Aluminum, in Nondestructive Testing, Trends and Techniques, NASA SP-5082 (1967).

Key words: Aluminum alloys; elastic properties; experimental data; experimentation; NDT techniques; Rayleigh waves; residual stress; stress analysis; test equipment; test procedures; ultrasonic tests.

ADVANCED CONCEPTS IN STRUCTURAL MATERIALS AND TESTING, PART 1 - THE APPLICATION OF RANDOM SIGNAL CORRELATION TECHNIQUES TO ULTRASONIC FLAW DETECTION IN SOLIDS
Newhouse, V. L., Furgason, E. S., and Bilgutay, N. M. (Purdue Research Foundation, Lafayette, ID)
AD-782349 (July 15, 1974)

This technical report discusses a Purdue program researching the application of random signal correlation techniques to ultrasonic flaw detection in solids and the development of modulated microstructure heat treatable steel.

Part 1 of the report dealing with the application of random signal correlation techniques to ultrasonic flaw detection in solids consists of applying random signal radar techniques to ultrasonic flaw detection and determining the consequent improvement in range and resolution over existing systems. The accomplishments to date are:

1. A random signal ultrasonic flaw detection system, has been constructed and operated.
2. It has been demonstrated that the resolution of the system is independent of the length of the transmitted signal. This indicates that a much lower peak to average power ratio can be used than is possible with pulse-echo systems.
3. It has been experimentally demonstrated that signals which are 1,000 times too small to be detected by a current pulse-echo system can be used by our system.
4. The smallest flaw that can be viewed by our present system agrees with theoretical calculations and is the order of 0.001 inch.
5. A clutter avoidance scheme has been invented which should permit the system to maintain its demonstrated advantages in an environment containing many detectable flaws.

Comment:

This is an annual report, representative of a series of studies performed under contract and the auspices of ARPA.

The results of the Purdue program have shown that a simple correlation type ultrasound receiver can detect echoes which have at least 8000 times less power than the thermal receiver noise without any noticeable problems due to mechanical vibration or electronic instabilities. Several further orders of magnitude improvement in sensitivity may be possible by simply lengthening the system integration time above the 0.1 sec used in this work and using a larger mark-space ratio for the transmitted signal.

When operating at high resolution, the system described in the report can trade speed for sensitivity by varying the integration time of the correlator output. When examining objects which are expected to contain a very small number of possible flaws, increased speed can be obtained without sacrificing sensitivity, by narrowing the transmitted spectrum, thus enlarging the range cell.

The fact that the system has much greater sensitivity and uses much lower peak to average transmitted power than conventional systems should enable it to greatly extend the size of strongly absorbing objects that can be examined by ultrasound, or to use higher frequencies which are too strongly absorbed to be practical at present, and thus obtain greatly improved resolution. The ability of a random signal correlation system to provide high sensitivity for a given transmitted power also makes it possible to reduce the peak and average power required for a given sensitivity. This feature and the absence of range ambiguity may make the system or similar designs of interest for bio-medical progams, e.g., brain scans, blood flow measurement, etc.

Important References:

1. Krautkramer, J. and Krautkramer, H., Ultrasonic Testing of Materials, Springer, New York, NY (1969).

2. Kennedy, J. C. and Woodmansee, W. E., Signal Processing in Nondestructive Testing, Boeing Report SAOPI-FOI, RB2 (April 25, 1973).

3. Seydell, J. A., Improved Discontinuity Detection in Ceramic Material Using Computer-Aided Ultrasonic Nondestructive Techniques, Proc. Army Mater. Technol. Conf., 2nd (November 1973).

4. Newhouse, V. L. and Bendick, P. J., An Ultrasonic Random Signal Flow Measurement System, J. Acoust. Soc. Amer. (August 1974).

Key words: Acoustic emission; crack detection; detection systems; instrumentation; material defects; NDE techniques; NDI techniques; ultrasonic imaging; ultrasonic tests.

FLAW CHARACTERIZATION: HOW GOOD IS ULTRASOUND?
Posakony, G. J. (Battelle-Northwest, Richland, WA)
Prevention of Structural Failure - The Role of Quantitative Nondestructive Evaluation, Amer. Soc. Metals Materials/Metalworking Technol. Series No. 5, 1-16 (1975)

Problems and limitations encountered when using ultrasonic NDT methods for flaw detection are described. Conditions which influence the ultrasonic sound beams, such as flaw characteristics, surface conditions, and material microstructure which influence the precision of ultrasonic measurements are discussed.

Comment:

This is a current view of the usefulness of ultrasound for NDE and is therefore useful in planning test and inspection activities, especially for large pressure vessels.

Important References:

1. Packman, P. F., Fracture Toughness and NDT Requirements for Aircraft Design, J. Non-Destruct. Test. (Guilford, England), 314-324 (December 1973).

2. Posakony, G. J., Ultrasonic Techniques for Remote Inspection of Nuclear Reactor Vessels, Proc. Conf. Periodic Inspection of Pressure Vessels, London (May 1972).

3. Gericke, O. R., Ultrasonic Spectroscopy, in Research Techniques in Nondestructive Testing, Academic Press, New York, NY (1970).

4. Whaley, H. L. and Cooke, K. V., Ultrasonic Frequency Analysis, Mater. Eval. 28, No. 3, 61 (1970).

Key words: Analysis tools; crack detection; detection systems; material defects; NDT methods; ultrasonic tests.

THE PROPAGATION OF ULTRASONIC WAVES IN CFRP LAMINATES
Reynolds, W. N. and Wilkinson, S. J. (Atomic Energy Research Establishment, Harwell, England)
Ultrasonics, 109-114 (May 1974) (A74-44349)

A survey report is presented of studies of ultrasonic wave propagation in flat carbon fiber reinforced plastic laminates. After summarizing earlier work on uniaxial specimens the authors give more detailed information of testing for two- and three-ply laminates and sandwich structures. The discovery that velocities measured perpendicular to fiber direction show an interesting dependence on porosity of the matrix of the material under test and on the measuring technique used could lead to wider exploitation.

Important References:

1. Markham, M. F., Measurements of the Elastic Constants of Fibre Composites by Ultrasonics, Composites, 1, 145 (1970).

2. Smith, R. E., Ultrasonic Elastic Constants of Carbon Fibres and Their Composites, J. Appl. Phys. 43, 2555 (1972).

3. Reynolds, W. N., Problems of Nondestructive Testing in Carbon Fibres and Their Composites, Proc. Int. Conf. Carbon Fibres, The Plastics Inst., London (1971).

4. Wilkinson, S. J. and Reynolds, W. N., The Propagation of Ultrasonic Waves in Carbon Fibre Reinforced Plastics, J. Appl. Phys. 7, 50 (1974).

5. Elliot, J. G., An Investigation of Ultrasonic Goniometry Methods Applied to Carbon Fibre Composite Materials, AERE Report NDT 64 (1973).

Key words: Carbon fibers; composite materials; fibers; fiber-reinforced composites; laminates; NDI methods; NDT methods; quantitative analysis; ultrasonic tests.

IMPROVEMENT IN CRACK DETECTION BY ULTRASONIC PULSE-ECHO WITH LOW FREQUENCY EXCITATION

Sessler, J. G. (Syracuse Univ. Research Corp., NY)

AD-708747 (May 1970)

A program of analytical and experimental research was conducted to investigate the effect of stress fields on the ultrasonic energy reflected from thin flat cracks in solids. It was established that the amplitude of ultrasonic signals reflected from a crack interface is decreased significantly when a compressive stress field is applied to the region of the crack. Also, within certain limitations, the amplitude is increased with increasing tensile stress. Thus, a crack in compression is more difficult to detect by pulse-echo than an unstressed crack, and the capability of detecting the crack is improved by application of tensile stress.

Comment:

This report is somewhat dated but still provides important basic data. The researchers theorized that it is possible to induce the stress required for improved detection by introducing low frequency sound excitation in the region of the crack. Subsequent to the period of this report, they continued effort to develop and optimize this technique.

Important References:

1. Sessler, J. G. and Weiss, V., Improvement in Flaw Detection by the Ultrasonic Pulse-Echo Technique with Simultaneous Low Frequency Excitation, Syracuse Univ. Res. Corp. Final Report, ARPA Contract N00140-69-C-0121 (November 1969).

2, Frederick, J. R., Ultrasonic Engineering, John Wiley and Sons, Inc., New York, NY (1965).

Key words: Compressive loads; crack analysis; crack detection; detection systems; fracture mechanics; NDE methods; NDE techniques; ultrasonic tests.

RADIOGRAPHIC NONDESTRUCTIVE TESTING
Berger, H. (National Bureau of Standards, Washington, DC)
ASTN Stand. News 3, No. 3, 21-28 (March 1975)

The state-of-the-art in radiography is briefly reviewed and some new ideas are described in sufficient detail to give readers an idea of how and where they may be applied. An extensive list of references provides for quick access to additiona information on techniques of special interest. The traditional use of gamma radiography and x radiography are described including listing limitations and capabilities. High definition by the use of image enhancement techniques including Xeroradiographic and electronic techniques are cited. The use of thermal neutrons with their discrete mass absorption coefficients which permit the imaging of hydrogen and certain organic nonmetallic materials is described in some detail. The high thickness sensitivity of monoenergetic proton radiation is described.

Important References:

1. Halmshaw, R., Physics of Industrial Radiology, Heywood Books, London (1966).

2. Hertz, R. H., The Photographic Action of Ionizing Radiations, Wiley-Interscience, New York, NY (1969).

3. Sharpe, R. S., Industrial Uses of X-Ray Microscopy, J. Royal Microscopical Soc. 86, Part 3, 271-284 (1967).

4. McMaster, R. C. and Hoyt, H. L., Xeroradiography in the 1970's, Mater. Eval. 29, No. 12, 265-274 (1971).

5. Janney, D. H., Hunt, B. R., and Ziegler, R. K., Concepts of Radiographic Image Enhancement, Mater. Eval. 30, No. 9, 195-203 (1972).

6. Vary, A. and Bowles, K. J., Application of an Electronic Image Analyzer to Dimensional Measurements from Neutron Radiographs, Mater. Eval. 32, No. 1, 7-17 (1974).

7. Vary, A., Investigation of an Electronic Image Enhancer for Radiographs, Mater. Eval. 30, No. 12, 259-267 (1972).

8. Cutforth, D. C., Dimensioning Reactor Fuel Specimens from Thermal Neutron Photographs, Nuclear Technol. 18, No. 1, 67-70 (1973).

9. Parish, W. and Pullen, D. A. W., Recent Developments in the Radiography of Highly Radioactive Specimens at AERE Harwell, Brit. J. Nondestructive Testing 7, No. 1, 3-10 (1965).

0. Ryan, M. C., Color Radiography, Mater. Eval. 26, No. 8, 159-162 (1968).

1. Beyer, N. S. and Staroba, J. S., Research and Development in Color Radiography, Mater. Eval. 26, No. 8, 167-172 (1968).

2. McMaster, R. C., Rhoten, M. L., and Mitchell, J. P., The X-Ray Vidicon Television Image System, Mater. Eval. 25, No. 3, 46-52 (1967).

3. Halmshaw, R., Direct-View Radiological Systems, Res. Techniques in Nondestruct. Test., Academic Press, New York, NY (1970).

4. Beal, J. B. and Brown, R. L., Advanced Radiographic Imaging Techniques, Mater. Eval. 31, 133-144 (1973).

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6. Ranby, P. W., Electroluminescent Storage and Display Panels for Radiography, Research Techniques in Nondestructive Testing 2, R. S. Sharpe, Ed., Academic Press, New York, NY 89-119 (1973).

7. Bryant, L. E., Flash Radiography of Electron Beam Welding, Mater. Eval. 29, No. 10, 237-240 (1971).

8. Pullen, D. A. W., High Energy Radiography: A New Technique in the Development of Efficiency and Integrity of Aero Gas Turbine Engines, Mater. Eval. 32, 25-30; 37 (1974).

Key words: Gamma radiation; image enhancement; metallic materials; neutron radiation; NDT methods; NDT techniques; photographic techniques; radiography; x ray inspection.

A QUALITATIVE DISCUSSION OF QUANTITATIVE RADIOGRAPHY
Berger, H. and Motz, J. W. (National Bureau of Standards, Washington, DC)
Prevention of Structural Failure - The Role of Quantitative Nondestructive Evaluation, Amer. Soc. Metals Materials/Metalworking Technol. Series 5, 37-53 (1975).

This report includes a description of the radiographic process, a discussion of some of the quantitative aspects of radiography, and a description of some of the new ideas emerging in radiography. It is concluded that radiography can provide some quantitative NDT results. The method as presently practiced is particularly useful for revealing the size, shape, and location of inhomogeneities which present a thickness or density change on the order of one percent of the object thickness and which cover an area large enough to be resolved. Detection of some types of defects, such as tight cracks, presents problems for radiography because it is often difficult to align the radiation beam so that a detectable change in radiation intensity occurs.

Important References:

1. Ferusic, S., Determination of the Fatigue Strength of Welded Joints with Artificial Flaws by Radiographic Examination, Materialprüefung 15, No. 5, 157-160 (1973).

2. McMasters, R. C. and Hoyt, H. L., Xeroradiography in the 1970's, Mater. Eval. 29, No. 12, 265-274 (December 1971).

3. Vary, A. and Bowles, K. J., Application of an Electron Image Analyzer to Dimensional Measurements from Neutron Radiographs, Mater. Eval. 32, No. 1, 7-17 (January 1974).

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5. Hasenkamp, F. A., Radiographic Laminography, Sandia Labs. SLA-73-0964 (November 1973).

6. Koehler, A. M. and Berger, H., Proton Radiography, in Research Techniques in Nondestructive Testing, 1-30, Academic Press (1973).

Key words: Analysis methods; cracks; detection systems; inspection procedures; material defects; NDI methods; NDT methods; quantitative analysis; radiography; x ray inspection.

THE RADIOGRAPHY OF METAL MATRIX COMPOSITES

Martin, G., Moore, J. F., and Tsang, S. (North American Rockwell Corp., Los Angeles, CA)

Mater. Eval. 30, No. 4, 78-86 (April 1973)

A comprehensive survey was made of the applicability of a wide variety of radiographic methods and variables to metal matrix composites. It was shown that comparatively simple rules for the optimization radiographic parameters allow the definition of filament details down to the resolution of single filament strands in even multilayer composites. For resolution, the type R film was found to be superior to the more rapid type M film, which, however, is quite adequate for most purposes. Densitometry and particularly microdensitometry is applicable to composites with only a few filament layers and may allow determination of width of diffusion layers, relative local spacings, etc. Dynamic radiography of composites under loads requires, in the case of boron or silicon carbide filaments, the availability of high resolution vidicon tubes, but is quite feasible.

Quantitative measurements of absorption or scatter factors are relatively more complex procedures. Results can be obtained, but, because of the influence of a number of factors, such as local filament density variations, existence of surface and interface layers and local thickness variations seem promising only on a comparative basis for sections manufactured by similar methods under similar conditions A number of methods and approaches were worked out and analyzed.

Comment:

The experimenters report experiment design and results of work performed under the auspices of AFML. Specimens were predominantly boron-titanium and boron-aluminum. In addition to standard radiography testing, the use of microradiography and stereo-radiography techniques is presented. The paper provides an excellent summary of the field of investigation not widely available in the open literature.

Important References:

1. Foster, B. E. and Evans, J. W., X-Ray Mass Attenuation Coefficients in the Range of 50 to 150 kVp, Nondestructive Testing (ASNT Journal) 21, 51 (January-February 1963).

2. Brown, W. D., X-Ray Attenuation and Absorption Coefficients, Boeing Co. Report D1-125065-1 (1966).

3. Halmshaw, R., Physics of Industrial Radiology, American Elsevier Co., Inc., New York, NY (1966).

Key words: Composite materials; fiber-reinforced composites; inspection procedures; material defects; metal matrix composites; NDI methods; NDT methods; radiography; x ray inspection.

THE REALM OF INDUSTRIAL X RAY
Schneeman, J. G. (X-Ray Products Corp., Pico Rivera, CA)
Mater. Eval. 38, No. 12, 19A-26A (December 1970)

This was the Lester Honor Lecture for the 30th National Fall Conference of ASNT at Cleveland, OH, October 19-22, 1970. Schneeman, a top expert in the field of radiography, describes the changes and advances in his field over a 50 year period. Of interest and importance is the attention given to radiation safety and the need for good inspection standards and operator certification. There are no specific references.

Key words: Analysis tools; certification; inspection procedures; inspection standards; NDI methods; radiography; safety.

CONCEPTS OF RADIOGRAPHIC IMAGE ENHANCEMENT
Janney, D. H., Hunt, B. R., and Zeigler, R. K. (Los Alamos Scientific Lab., NM)
Mater. Eval. 30, No. 9, 195-203 (September 1972)

Enhancement of radiographic images may be desired for various purposes: accentuation of obscure details, reduction of overall density range, sharpening of selected features for greater certainty of dimensional measurement, suppression of extraneous features, or correction of defects in radiographic technique or equipment. Many of the applications require mathematical concepts of image convolution, Fourier transformation, and spatial frequency filtering which are alien to the training and experience of the practicing industrial radiographer. The motivation for application of these techniques to industrial radiography is examined, and the basic mathematical concepts are discussed by means of qualitative and plausibility arguments. Recourse is made, for pedagogical purposes, to analogies from electrical technology. The types of hardware required and the computer needs for image enhancement by the methods discussed are described. Advantages and disadvantages of various image handling systems are enumetated.

Important References:

1. Lodwick, G. S., Problems Encountered in the Computer Diagnosis of Radiographs, Proc. Two-Dimensional Digital Signal Processing Conf., Missouri Univ., Columbia (October 6-8, 1971).

2. Andrews, H. C., Computer Techniques in Image Processing, Academic Press, New York, NY (1970).

3. Rosenfeld, A., Picture Processing by Computer, Academic Press, New York, NY (1969).

4. Rhodes, Jr., J. E., Analysis and Synthesis of Optical Images, Amer. J. Phys. 21, 337-343 (May 1953).

Key words: Analysis methods; analysis tools; inspection procedures; NDI techniques; NDT techniques; radiography.

THE PRESENT STATE OF NEUTRON RADIOGRAPHY AND ITS POTENTIAL
Berger, H. (Argonne National Lab., Argonne, IL)
Mater. Eval. 30, No. 3, 55 (March 1972)

The present state of the art of thermal-neutron radiography as it relates to industrial application is reviewed. Techniques for performing this type of nondestructive test are well developed and available. Commercial neutron radiographic service can be obtained in several countries. In-house thermal-neutron radiographic facilities in nonnuclear organizations are now going into service. Progress with those facilities will be closely followed as harbingers of the potential growth of thermal-neutron radiography. Some predictions concerning the future of this technique are given.

Comment:

This paper was the 1971 President's Honour Lecture to the Non-Destructive Testing Society of Great Britain on September 9, 1971, in Stirling, Scotland. It is an excellent overview and incorporates research performed by Mr. Berger under the auspices of the U. S. Atomic Energy Commission.

Important References:

1. Whittemore, W. L., Larson, J. E., and Shoptaugh, J. R., A Flexible Neutron Radiography Facility Using a TRIGA Reactor Source, Mater. Eval. 29, No. 5, 93 (May 1971).

2. Shaw, C. B. and Cason, J. L., Portable Neutron Radiographic Camera Using Californium-252, Mater. Eval. 29, No. 2, 40 (February 1971).

3. Berger, H., Neutron Radiography, Elsevier Publ. Co., Amsterdam (1965).

4. Vasilik, D. G. and Murri, R. L., Mater. Eval. 29, No. 6, 130 (June 1971).

5. Halmshaw, R. and Hunt, C. A., Proc. Int. Conf. Nondestructive Testing, 6th (Hanover, Germany), M, 51-62 (1970).

6. Berger, H., Neutron Radiography, in Res. Techniques in Nondestruct. Test., Academic Press, New York, NY (1970).

7. Warman, E. A., Neutron Radiography in Field Use, Mater. Eval. 23, No. 11, 543 (November 1965).

8. Cutforth, D. C., On Optimizing an Sb-Be Source for Neutron Radiographic Applications 26, No. 4, 49 (April 1963).

9. Hagemaier, D., Halchak, J., and Basl, G., Detection of Titanium Hydride by Neutron Radiography, Mater. Eval. 27, No. 1, 193 (January 1969).

0. Rhoten, M. L. and Carey, W. E., Neutron Radiography of Pyrotechnic Cartridges, Mater. Eval. 24, No. 8, 422 (August 1966).

1. Iddings, F. A. and Bostrom, N. A., Neutron Radiography with a Cockcroft-Walton Accelerator, Mater. Eval. 27, No. 10, 215 (October 1969).

2. Breynat, G. and Dubus, M., Utilization of Small Accelerator Neutron Generators in Neutron Radiography, Mater. Eval. 27, No. 10, 220 (October 1969).

Key words: Analysis tools; bibliographies; inspection procedures; neutron irradiation; NDI techniques; NDT techniques; radiography.

EDDY CURRENT TESTING
Anderson, R. T. (General Dynamics/Convair, San Diego, CA)
Prevention of Structural Failure - The Role of Quantitative Nondestructive Evaluation, Amer. Soc. Metals Materials/Metalworking Technol. Series No. 5, 54-67 (1975).

An attempt is made to illustrate the simplicity of eddy current test principles. Some of the applications for eddy current testing are conductivity measurements, geometric measurements, and defect detection. These three applications are discussed. In-service inspection of fatigue cracks is a principal application. The method is effective for detecting small surface cracks. Inspection for radial cracks in fastener holes is common. Stress corrosion cracking and hydrogen embrittlement cracking are other conditions often sought. Sub-surface defects are better detected by other NDT methods, although it is feasible to detect cracks under plating, paints, and other coatings as well as slightly sub-surface defects in bare metals.

Comment:

The author, now with ASNT, appropriately stresses the simplicity of using eddy currents but with a caution as to the limitation of the test technique. It has broad use often without acknowledgement of the needs for improvement in test technique, test data analysis and display.

Key words: Crack detection; detection systems; eddy currents; fatigue (materials); inspection procedures; NDT methods; quantitative analysis; structural safety; surface defects.

OPTIMIZING DEFECT DETECTION IN EDDY CURRENT TESTING
Dodd, C. V., Deeds, W. E. and Spoeri, W. G. (Oak Ridge National Lab., TN)
Mater. Eval. 29, No. 3, 59-63 (March 1971)

A number of curves were prepared that show that the eddy current signal produced by a defect varies as a function of test parameters for various arrangements of the coil and conductor with special emphasis on differential encircling coils. From these curves the optimum parameters can be selected for a particular test.

Important References:

1. Burrows, M. L., A Theory of Eddy Current Flaw Detection, University Microfilms, Inc., Ann Arbor, MI (1964).

2. Dodd, C. V., Solutions to Electromagnetic Induction Problems, Oak Ridge Lab. Report ORNL-TM-1842 (1967).

3. Dodd, C. V., Deeds, W. E., and Luquire, J. W., Integral Solutions to Some Eddy Current Problems, Int. J. Nondestruct. Test. 1, No. 1, 29-90 (1968).

4. Luquire, J. W., Dodd, C. V., Deeds, W. E., and Spoeri, W. G., Computer Programs for Some Eddy Current Problems, Oak Ridge Lab. Report ORNL-TM-2501 (August 1969).

Key words: Crack detection; detection systems; eddy currents; material defects; NDT methods; pipes (tubes); plates (structural members).

PRINCIPLES OF PENETRANTS
Betz, C. E. (Magnaflux Corp., Chicago, IL)
Magnaflux Corp. (1963)

This book is comprised of a compilation representative of the state-of-the-art in penetrants in 1963. It describes materials, techniques, equipment, and the applications (uses) of penetrant testing. It is intended as a source of detailed information. The seventeen chapters include: (1) History of Penetrants; (2) General Considerations; (3) Some Definitions of Terms; (4) Nature and Properties of Penetrants; (5) Nature and Properties of Developers; (6) The Penetrant Method - Factors Affecting Its Operation; (7) Water-Washable Fluorescent Penetrants - Materials and Techniques; (8) Post Emulsifiable Fluorescent Penetrants - Materials and Techniques; (9) Black Light - Its Nature, Sources, and Requirements; (10) Color-Contrast Penetrants - Materials and Techniques; (11) Equipment for Conducting Penetrant Inspection; (12) Detectable Defects; (13) Industrial Applications; (14) Detection of Leaks with Penetrants; (15) Interpretation of Results; (16) Standards and Specifications for Penetrant Inspection; (17) Evaluation of Penetrants, Developers, and Emulsifiers - Specifications and Tests. An index includes a bibliography of 79 citations.

Comment:

This is still a basic reference. There is no later equivalent. The bibliography is dated (before 1962) and must be supplemented by later material.

Key words: Crack detection; inspection procedures; NDI methods; NDT methods; penetrant inspection

THE NEW SCIENCE OF INSPECTION PENETRANTS
Alburger, J. R. (Shannon-Glow, Inc.)
Prevention of Structural Failure - The Role of Quantitative Nondestructive Evaluation, Amer. Soc. Metals/Materials Metalworking Technol. Series No. 5, 17-36 (1975)

This paper includes a review of modern penetrant inspection technology for the purpose of presenting the methods that have been developed to quantify penetrant performance features. Significant improvements which have been made in penetrant products in recent years are mentioned. Considerations which have a significant bearing on the utilization by industry of the new science of inspection penetrants are given.

Important References:

1. Alburger, J. R., Instruments and Test Methods as Employed in an Inspection Penetrant Material Specification, Symp. Nondestructive Evaluation, 9th, San Antonio, TX (April 1973).

2. Alburger, J. R., Signal-to-Noise Ratio in the Inspection Penetrant Process, ASNT Fall Meet., Chicago, IL (October 1973).

3. Alburger, J. R., Dimensionable Transition Effects in Visible Color and Fluorescent Dyed Liquids, Annu. Corp. Instrument Soc. Amer., 23rd, New York, NY (October 1968).

4. Alburger, J. R., Measurement and Control of Penetrant Indication Stability, ASNT Spring Meet., Los Angeles, CA (March 1972)

5. Alburger, J. R., A Closed-Loop Water-Washable Inspection Penetrant System, ASNT Spring Meet., Los Angeles, CA (March 1974)

6. Alburger, J. R., A Simplified Method of Dimensional Sensitivity Measurement for Inspection Penetrants, ASNT Spring Meet. (March 1969).

Key words: Analysis methods; crack detection; detection systems; inspection procedures; material defects; penetrant inspection; surface cracks; surface defects.

IIF - Magnetic Particles

QUANTITATIVE NONDESTRUCTIVE EVALUATION BY THE MAGNETIC FIELD PERTURBATION METHOD

Gardner, C. G. and Kusenberger, F. N. (Southwest Research Inst., Houston, TX)
Prevention of Structural Failure - The Role of Quantitative Nondestructive Evaluation, Amer. Soc. Metals/Materials Metalworking Technol. Series No. 5, 67-85 (1975)

This paper includes a brief review of the magnetic field perturbation (of flux leakage) method of NDE, focusing on the magnetometric approach which lends itself both to quantitative interpretation and automation. The paper is selective rather than comprehensive, the aim being to indicate the general state of development of the method and its potential with respect to use in quantitatively characterizing material defects.

Important References:

1. Lord, W. and Oswald, D. J., Leakage Field Methods of Defect Detection, Int. J. Nondestruct. Test. 4, 249-274 (1972).

2. Foerster, F., New Results of NDT by the Magnetic Leakage Field Method, Nondestruct. Test. 4, No. 4, 154-259 (1971).

3. Luz, H., The Non-Destructive Testing of Bars and Billets for Surface Defects by Magnetic Leakage Methods, Nondestruct. Test. 6, No. 1, 16-24 (1973).

4. Gardner, C. G. and Barton, J. R., Recent Advances in Magnetic Field Methods of Nondestructive Evaluation for Aerospace Applications, Proc. Conf. AGARD, No. 64 - Advanced Technology for Production of Aerospace Engines, 18-1 - 18-9 (1970).

5. Kusenberger, F. N., Ko, W. L., Lankford, Jr., J., Francis, P. H., and Barton, J. R., Nondestructive Evaluation of Metal Fatigue, AFOSR-TR-73-1070 (April 1973).

6. Barton, J. R. and Lankford, J., Magnetic Perturbation Inspection of Inner Bearing Races, NASA CR-2055 (May 1972).

Key words: Fatigue (materials); magnetic perturbation; material defects; NDE methods; quantitative analysis; surface cracks; surface defects.

PRINCIPLES OF MAGNETIC PARTICLE TESTING
Betz, C. E. (Magnaflux Corp., Chicago, IL)
Magnaflux Corp. (1966)

This book covers in detail many technical and practical aspects of magnetic particle inspection. It follows the format and organization of its companion volume Principles of Penetrants. Materials and equipment information are provided in depth. One whole chapter is devoted to the design and use of automatic or special purpose units. The book is composed of 26 chapters which treat each aspect of magnetic particle testing individually.

Comments:

This is a basic reference in the field though there is more current literature. The bibliography is extensive but all pre-1965. An excellent supplement is NASA SP-5113.

Key words: Crack detection; inspection procedures; magnetic particles; NDI methods; NDT methods.

NDT BY ACOUSTO-OPTICAL IMAGING
Aprahamian, R. and Bhuta, P. G. (TRW, Inc., Redondo Beach, CA)
Mater. Eval. 29, No. 5, 112-116 (May 1971)

A new technique, termed acousto-optical imaging, which provides visible images of flaws in optically opaque objects is described. The device uses ultrasonic acoustic waves to look inside the optically opaque objects. The ultrasonic waves are made to enter the body to be inspected and, upon emergence from the object, interact with light from a laser resulting in a real-time optical image of what the sound waves have "seen." The device has overcome many problems, such as eliminating the use of pickup transducers, associated with acoustic imaging devices. This paper describes the device, the principle of operation of the technique and presents the results of laboratory experiments which demonstrate the application of the device to nondestructive testing.

Comment:

This paper, presented at the 30th ASNT Fall Conference, Cleveland, OH (October 1970), provides a brief survey of the field of acoustical holography as well as a description of what the authors describe as a better alternative.

Important References:

1. Jacobs, J. E., Performance of the Ultrasound Microscope, Mater. Eval. 25, No. 3, 41-45 (March 1967).

2. Metherell, A. F., El-Sum, H. M. A., and Larmore, L., Acoustical Holography (1969).

3. Gericke, O. R. and Grubinskas, R. C., Utilization of the Liquid Surface Levitation Effect as a Means of Ultrasonic Image Conversion for Materials Inspection, J. Acoust. Soc. Amer. 45, 872-880 (April 1969).

4. Brenden, B. B., Acoustical Holography as a Tool for Nondestructive Testing, Mater. Eval. 27, No. 6, 140-144 (June 1969).

5. Berger, H., Ultrasonic Imaging Systems for Nondestructive Testing, J. Acoust. Soc. Amer. 45, No. 4 (1969).

Key words: Analysis tools; composite materials; crack detection; material defects; NDT techniques; ultrasonic tests.

NONDESTRUCTIVE HOLOGRAPHIC TECHNIQUES FOR STRUCTURES INSPECTIONS

Erf, R. K., Gagosz, R. M., Waters, J. P., Stetson, K. A., and Aas, H. G.
(United Aircraft Corp., East Hartford, CT)

AFML-TR-74-130 (October 1974)

A study of holographic techniques for the inspection of structures was accomplished. The results relevant to the following six areas are presented: (1) physical environmental effects; (2) surface finish effects; (3) development of suitable techniques for a manufacturing or maintenance environment; (4) maximum strain and strain patterns; (5) crack detection; and (6) NDT. The holographic process is discussed and interferometric holography and the techniques that apply are discussed. Comments on current state of the art and future potential of holographic NDI are presented.

Important References:

1. Stetson, K. A., Moire Method for Determining Bending Moments from Hologram Interferometry, Opt. Tech. 2, 80 (1970).

2. Waters, J. P., Aas, H. G., and Erf, R. K., Investigation of Applying Interferometric Holography to Turbine Blade Stress Analysis, UARL-J990798-13 (February 1970).

3. Leendertz, J. A. and Butters, J. N., An Image-Shearing Speckle-Pattern Interferometer for Measuring Bending Moments, J. Phys. E. (Sci. Instrum.) 6, 1107 (1973).

4. Erf, R. K., Holographic Nondestructive Testing, Academic Press, New York, NY (1974).

Key words: Aircraft structures; analysis tools; composite materials; holography; inspection procedures; NDE methods; NDI methods.

THERMAL AND INFRARED NONDESTRUCTIVE TESTING OF COMPOSITES AND CERAMICS
Green, D. R. (WADCO Corp., Richland, WA)
Mater. Eval. 29, No. 11, 241-248 (November 1971)

This paper describes the application of high-speed thermal and infrared methods to the detection of density differences, cracks, voids and other defects in ceramics and composites. A single-pass induction heating method, made possible with a full-width "paint brush" heating coil, was used in infrared tests on carbon-carbon composites. Unique characteristics of the induction heating make it possible to detect cracks that are perpendicular as well as parallel to the surface of the test specimen. All the materials were also tested using a new low-cost thermal image transducer, and the resolution and sensitivity to defects were determined. Both the infrared method and the thermal transducer method are capable of completing a test on a large area in a few seconds (not including specimen handling time).

Important References:

1. Green, D. R., High Speed, Thermal Image Transducer for Practical NDT Applications, Mater. Eval. 28, No. 5, 97-102 and 110 (May 1970).

2. Green, D. R. and Dixon, N. E., Thermal and Ultrasonic Test Methods for Carbon/Carbon Structures, Proc. Annu. ASME/UNM Symp., 10th, New Mexico Univ. (January 29-30, 1970).

3. Green, D. R., Thermal Surface Impedance for Plane Heat Waves in Layered Materials, J. Appl. Phys. 37, 3095-3099 (July 1966).

4. Green, D. R., Thermal Impedance Method for Nondestructive Testing, Mater. Eval. 25, No. 10, 231-236 (October 1967).

Key words: Ceramics; composite materials; crack detection; detection systems; infrared radiation; inspection procedures; material defects; NDI techniques; NDT techniques.

ADVANCED CONCEPTS OF HOLOGRAPHIC NONDESTRUCTIVE TESTING
Kersch, L. A. (GCO, Inc., Ann Arbor, MI)
Mater. Eval. 29, No. 6, 125-129 and 140 (July 1971)

Holographic interferometry has proven useful for the nondestructive testing of a large class of objects. New and advanced optical techniques show promise of greatly extending the capability of holographic interferometry as a nondestructive testing tool. New optical techniques used to examine laminate structures with greater resolution and flaw detectability are discussed in this paper. It is shown how these new techniques greatly increase the inspection speeds of Holographic Nondestructive Testing (HNDT). In the area of vibrational analysis with holographic interferometry, a technique has been developed which allows the detection of vibrational amplitudes in the order of 10^{-7} to 10^{-8} cm. These concepts are discussed and the nondestructive testing possibilities outlined.

Important References:

1. Wells, D. R., NDT of Sandwich Structures by Holographic Interferometry, Mater. Eval. 27, No. 11, 225-231 (November 1969).

2. Champagne, E. and Kersch, L. A., Control of Holographic Interferometric Fringe Patterns, J. Optical Soc. Amer. 59, 1535A (November 1969).

3. Metherall, A. F., Spinak, S. and Pisa, E. J., Subfringe Interferometric Holography for Linearly Recording Small Displacements, J. Optical Soc. Amer. 59, 1534A (November 1969).

Key words: Analysis tools; detection systems; holography; inspection procedures; material defects; NDI techniques; NDT techniques; optical techniques.

THE CHARACTERISTICS AND APPLICATIONS OF THE SCANNING MICROSCOPE
Kimoto, S. and Russ, J. C. (Japan Electron Optics Lab. Co. Ltd., Tokyo)
Mater. Res. Stand. 9, No. 1, 8-16 (January 1969)

The scanning electron microscope provides information on the topography, composition, and electrical behavior of a variety of solid samples, and density information on thin sections. In presently (1969) available instruments, the resolution of about 200A, combined with great depth of field, is favorably comparable to replica techniques, and the scanning electron microscope avoids the problems of specimen damage on the introduction of artifacts. In addition, it permits the examination of many samples that cannot be replicated, and provides a broader range of information. The scanning electron microscope has found application in diverse fields of study, including biology, materials science, semiconductor technology and many others.

Important References:

1. Oatley, C. W., Nixon, W. C., and Pease, R. F., Scanning Electron Microscopy, in Advances in Electronics and Electron Physics, 21, 181-247; Academic Press, New York, NY (1965).

2. Kimoto, S. and Hashimoto, H., Scanning Electron Microscopy, Symp. Proc., IITRI, 65-78 (1968).

3. Crewe, A. V., The Potentials of Scanning Microscopy, Proc. Electron Microscopy Soc. Amer. 26, 352 (1968).

Key words: Analysis Tools; detection systems; electron microscopy; failure analysis; fractures (materials); metallography; NDE methods; NDE techniques; scanning electron microscopy.

THERMAL AND INFRARED METHODS FOR NONDESTRUCTIVE TESTING OF ADHESIVE-BONDED STRUCTURES
Kutzscher, E. W., Zimmerman, K. H., and Botkin, J. L.
(Lockheed Aircraft Corp., Burbank, CA)
Mater. Eval. 26, No. 7, 143-168 (July 1968)

Thermal and infrared NDT methods of adhesive-bonded aerospace structures are discussed. The design of an active scanning infrared inspection system (SIRIS) for large, panel-shaped components is described. Examples of measuring results are presented.

(FOR LISTING OF IMPORTANT REFERENCES, KEYWORDS AND A DUPLICATE ABSTRACT, SEE PAGE 99)

THE ELECTRON MICROPROBE AS A TOOL IN MATERIALS ENGINEERING
Landis, F. P., Merchant, R. W., and Zemany, P. D. (General Electric Co., Schenectady, NY)
Mater. Res. Stand. 5, No. 5, 219-229 (May 1965)

The design and operation of the electron microprobe are described emphasizing its capabilities and limitations. The qualitative presentation capabilities and the quantitative analysis in the beam scanning mode are described in detail. Examples of the use of the instrument are given, including the analysis of concentration gradients in bonds, phase composition measurement, identification of inclusions, corrosion product analysis, and particle identification.

Important References:

1. Birks, L. S., Electron Probe Microanalysis, John Wiley Interscience Publishers, Easton, PA (1963).

2. Ziebold, T. O. and Ogilvie, R. E., Quantitative Analysis with the Electron Microanalyzer, Analytical Chemistry 35, 621 (May 1963).

Key words: Analysis methods; electron microprobe; material defects; microstructures; NDE methods; NDI techniques; qualitative analysis; quantitative analysis.

ELECTROTHERMAL NONDESTRUCTIVE TESTING OF METAL STRUCTURES
McCullough, L. D. and Green, D. R. (Battelle Pacific Northwest Labs., Richland, WA)
Mater. Eval. 30, No. 4, 78-91 (April 1972)

The electrothermal method is a nondestructive testing technique applicable to metal parts and structures. Welds may be tested for voids, cracks and slag inclusions. Relatively complex machined or cast parts may be tested. Moderate surface waviness does not affect the test.

To apply the electrothermal method, the specimen is subjected to an electrical current pulse to develop a surface temperature distribution that is indicative of internal defects. This distribution is mapped by infrared or other thermal imaging techniques. Defect indications are superimposed upon the normal temperature profile of a good part or weld, but can usually be easilly separated from the normal profile.

Laboratory tests have been made locating voids in welded test bars and weld inclusions in 2 in. (5.08 cm) thick steel plate. Voids and cracks have been detected in turbine blades.

Important References:

1. Green, D. R. and McCullough, L. D., An Electro-Thermal Nondestructive Testing Method, Battelle-Northwest Report BNWL-1273 (December 1969).

2. Greene, D. R., Principles and Applications of Emittance Independent Infrared Nondestructive Testing, Applied Optics 7, 1779-1789 (September 1968).

3. Green, D. R., High Speed Image Transducer for Practical NDT Applications, Mater. Eval. 28, No. 5, 97-102 and 110 (May 1970).

Key words: Crack detection; detection systems; material defects; NDT methods; NDT techniques; stainless steels; structural analysis; structural safety; turbine blades.

III. APPLICATIONS

IIIA - Metals

1. Fracture Mechanics/Flaw Detection

FLAW DETECTION AND CHARACTERIZATION USING ACOUSTIC EMISSION

Corle, R. R. and Schliessmann, J. A. (Lockheed Propulsion Co., Redlands, CA)
Mater. Eval. 31, No. 6, 115-120 (June 1973)

A test program was conducted to evaluate acoustic emission techniques for use in detecting flaws during proof testing of rocket motor cases. Steel sheet specimens which contained tight fatigue cracks of various sizes were tested. Selected specimens were inspected by standard radiographic and magnetic particle techniques to determine the sensitivity level of these methods. Each specimen was then loaded to simulate proof testing. An acoustic emission signature was recorded for each specimen during proof testing and was found to be a function of the flaw size. By evaluating the signature, unflawed specimens could be distinguished from flawed specimens and could be ranked on the basis of flaw size, with flaws as small as 0.035 in. (0.9 mm) deep being detected. By comparison flaws as large as 0.16 in. (4.1 mm) deep and 2.6 in. (66 mm) long were not detected by radiographic techniques, and surface flaws as large as 0.1 in. (2.5 mm) deep and 0.1 in. (2.5 mm) long were not detected by magnetic particle inspection.

Important References:

1. Dunegan, H. L. and Harris, D. O., Acoustic Emission - A New Nondestructive Testing Tool, Ultrasonics 7, 160-166 (July 1969).

2. Dunegan, H. L. and Green, A. T., Factors Affecting Acoustic Emission Response from Materials, Mater. Res. Stand. 2, No. 3 (1971).

Key words: Acoustic emission; crack detection; detection systems; evaluation; magnetic particles; material defects; NDT techniques; radiography; stress intensity factor

X-RAY MAPPING OF FLAWS BY COMPUTER GRAPHICS
Hartmann, F. (North American Rockwell Corp., Downey, CA)
Mater. Eval. 27, No. 8, 169-179 (August 1969)

A new process that gives a three-dimensional picture of the shape and location of invisible discontinuities (gas holes, cracks, etc.) in metallic or nonmetallic materials has been reduced to practice.

Two x ray films of the defective structure are taken from different angles, with a provision for accurate registration between them. A standard wedge of the same composition is x-rayed simultaneously. Density readings, obtained from microdensitometer scans at given intervals are converted into thickness values, with a correction for scattering if necessary. The resulting data are digitzed and put on tape. This is fed into a specially built "shape reconstruction computer," which, by means of a novel superposition algorithm, computes for each scan the cross section of the defect and displays it on its cathode ray tube. Tape feed, computation and photography of the CRT display take only a few seconds. A series of cross sections yields a three dimensional picture.

Samples of sheet aluminum and welds containing defects were analyzed in this manner. Very good agreement was obtained when computer-derived pictures of the shape and location of the defects were compared with photographic enlargements of the sectioned samples.

Important References:

1. Hartmann, F., Three-Dimensional Analysis of Weld Defects, North American Rockwell, Space Division Rpt. SD-67980 (June 1968).

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Key words: Analysis methods; computer techniques; cracks; material defects; NDT methods; radiography; x ray inspection

NONDESTRUCTIVE TESTS AS AN AID TO FRACTURE PREVENTION MECHANICS
Hastings, C. H. (AVCO Corp., Lowell, MS)
J. Franklin Institute 290, No. 6, 589-598 (December 1970).

Meaningful analysis of product strain data or defect allowables requires knowledge of material macrodefects and property gradients. This knowledge can be supplied by NDT during design studies involving brittle materials. An NDT technology, capable of supporting this extension, is rapidly developing, parallel with improvements in stress analysis techniques. The nondestructive, quantitative evaluation of material properties in discrete local volumes of materials and products makes knowledge of properties variability gradients available for more precise, non-statistical analysis of thermomechanical stress behavior. Even in defect-free materials failures may be initiated at sites of property-stress gradients. Recent advances in NDT determination of mechanical properties are reviewed.

Important Reference:

1. Lockyer, G. E., and Proudfoot, E. A., Nondestructive Determination of Mechanical Properties of Refractory Materials, Amer. Ceramics Soc. Bull. 46, 521 (1967).

Key words: Analysis methods; composite materials; failures (materials); fracture mechanics; material defects; NDT methods; NDT techniques.

ADVANCED CONCEPTS IN STRUCTURAL MATERIALS AND TESTING,
PART 1 - THE APPLICATION OF RANDOM SIGNAL CORRELATION TECHNIQUES TO ULTRASONIC FLAW DETECTION IN SOLIDS
Newhouse, V. L., Furgason, E. S., and Bilgutay, N. M. (Purdue Research Foundation, Lafayette, ID)
AD-782349 (July 15, 1974)

This technical report deals with the application of random signal correlation techniques to ultrasonic flaw detection.

(FOR AN EXPANDED ABSTRACT, LISTING OF IMPORTANT REFERENCES, KEYWORDS AND A DUPLICATE ABSTRACT, SEE PAGE 43)

FRACTURE TOUGHNESS AND NDT REQUIREMENTS FOR AIRCRAFT DESIGN
Packman, P. F. (Vanderbilt Univ., Nashville, TN)
J. Non-Destruct Test (Guilford, England), 314-324 (December 1973)

This paper reviews current design concepts of fracture toughness for materials selection and for design where fatigue-crack growth is analyzed under constant amplitude and spectrum loading. It is essential that the lower limit of detection be known with confidence. The materials are then chosen so that the critical flaw size is above this limit. From this knowledge the life of a particular design may be forecast for different conditions of service. The lifetime is influenced by both detection capabilities and changes in service conditions.

Comment:

This paper is particularly useful as a summary of NDT information. It includes tables on the surface flaw size to cause failure in materials of different strength and thicknesses and of detection sensitivities for commercial NDT processes.

Important References:

1. Wood, H. A., The Role of Applied Fracture Mechanics in the Air Force Structural Integrity Program, AFFDL-TM-70-5 (June 1970).

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Key words: Aircraft design; crack propagation; fatigue (materials); fracture strength; life expectancy; materials selection.

FLAW CHARACTERIZATION: HOW GOOD IS ULTRASOUND?
Posakony, G. J. (Battelle-Northwest, Richland, WA)
Prevention of Structural Failure - The Role of Quantitative Nondestructive Evaluation, Amer. Soc. Metals Materials/Metalworking Technol. Series No. 5, 1-16 (1975)

Problems and limitations encountered when using ultrasonic NDT methods for flaw detection are described. Conditions which influence the ultrasonic sound beam, such as flaw characteristics, surface conditions, and material microstructure which influence the precision of ultrasonic measurements are discussed.

(FOR LISTING OF IMPORTANT REFERENCE, KEYWORDS AND A DUPLICATE ABSTRACE, SEE PAGE 44)

THE DETECTION OF TIGHTLY CLOSED FLAWS BY NONDESTRUCTIVE TESTING (NDT) METHODS
Rummel, W. D., Rathke, R. A., Todd, Jr., P. H. and Mullen, S. J. (Martin Marietta Corp., Denver, CO)
MCR-75-212 (October 1975)

Liquid penetrant, ultrasonic, eddy current and x radiographic techniques were optimized and applied to the evaluation of 2219-T87 aluminum alloy test specimens in integrally stiffened panel, and weld panel configurations. Fatigue cracks in integrally stiffened panels, lack of fusion in weld panels, and fatigue cracks in weld panels were the flaw types used for evaluation. 2319 aluminum alloy weld filler rod was used for all welding to produce the test specimens. Forty-seven integrally stiffened panels containing a total of 146 fatigue cracks, ninety-three lack of penetration (LOP) specimens containing a total of 239 LOP flaws and one-hundred seventeen welded specimens containing a total of 293 fatigue cracks were evaluated. Specimen thickness were nominally 0.317 cm (0.125 inch) and 1.27 cm (0.500 inch) for welded specimens and 0.710 cm (0.280 inch) for the integrally stiffened panels. NDT detection reliability enhancement was evaluated during separate inspection sequences in the specimens in the "as-machined or as-welded", post etched and post proof loaded conditions. Results of the NDT evaluations were compared to the actual flaw size obtained by measurement of the fracture specimens after completing all inspection sequences. Inspection data were then analyzed to provide a statistical basis for determining the flaw detection reliability. Analyses were performed at 95% probability and 95% confidence levels and one-sided lower confidence limits were calculated by the binomial method. The data were plotted for each inspection technique, specimen type and flaw type as a function of actual flaw length and depth.

(FOR LISTING OF IMPORTANT REFERENCES, KEYWORDS AND A DUPLICATE ABSTRACE, SEE PAGE 138)

FRACTURE MECHANICS AIRCRAFT STRUCTURAL DESIGN APPLICATION AND RELATED RESEARCH
Wood, H. A. and Tupper, N. (Air Force Flight Dynamics Lab., Wright-Patterson AFB, OH; Air Force Materials Lab., Wright-Patterson AFB, OH)
Proc. Int. Cong. Fracture, 3rd, Munich (April 8-13, 1973)

Fracture control requirements to ensure safety by reducing the probability of catastrophic failure due to undetected damage as instituted by the U. S. Air Force in the design of current and future systems are described. These include various aspects of material and process selection, material procurement and control, NDI and damage tolerance analyses and testing.

Key words: Aircraft structures; analysis methods; crack analysis, crack detection; design criteria; failure prevention; fracture strength; fracture mechanics; life prediction; material defects; NDI methods; NDI techniques; safety criteria; structural safety.

ULTRASONIC SURFACE-WAVE DETECTION TECHNIQUES IN FRACTURE MECHANICS
Ho, C. L., Marcus, H. L., and Buck, O. (Rockwell International Corp., Thousand Oaks, CA).
Exp. Mech. 42-48 (January 1974)

Recent applications of ultrasonic acoustic waves to characterizing fatigue-crack propagation in part-through-crack specimen is discussed. A simple ultrasonic system recently developed is described in detail. Emphasis of the description is paid to the practical aspects of instrumentation and operation of this system which is based on the interaction of cracks with acoustic surface waves. The received signal contains information on the character of a static or a propagating crack. The sensitivity of the system mainly due to its high-resolution power makes it particularly suitable for studying plasticity effects in fatigue-crack propagations. Of special importance, the present technique provides direct, experimental evidence on the crack-closure phenomenon and convenient means for measuring the amount of this closure, together with its associated crack-tip resistance. The significance of these parameters is discussed in terms of analytic predictions based on the residual deformations at the crack tip. Important fracture mechanics quantities discussed, which are obtainable from the surface-wave test data, include: the instantaneous crack geometry and its variations with changing load conditions; the closure and resistance phenomena at the crack tip due to the material ductility, stress relaxations for sustained loads, and environmental effects on moving cracks. To get more general fracture mechanics information, the present ultrasonic system can be simultaneously coupled to acoustic-emission detectors.

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4. Klima, S. J., Lesco, D. J. and Freche, J. C., Ultrasonic Techniques for Detection and Measurement of Fatigue Cracks, NASA TN-D-3007 (September 1965).

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Key words: Aluminum alloys; crack detection; crack growth rate; crack propagation; detection systems; fatigue (materials); fracture mechanics; metallic materials; stress intensity factor; titanium alloys; ultrasonic tests.

IIIA - Metals

2. Fatigue Crack Growth

DETECTION OF FATIGUE CRACK GROWTH BY ACOUSTIC EMISSION TECHNIQUES
Dunegan, H. L., Harris, D. O., and Tetelman, A. S. (California Univ., Livermore, Lawrence Radiation Lab.)
Mater. Eval. 28, No. 10, 221-227 (October 1970)

It has been well established in tensile tests that acoustic emission is an irreversible process that is associated with plastic deformation. It is also widely recognized that plastic deformation is present at the root of a sharp crack in a structure that is stressed. Acoustic emission tests performed on cracked fracture toughness specimens have confirmed that acoustic emission associated with the plastic-zone at the crack tip is also very nearly irreversible for stress intensities at the crack tip of less than one-half the critical stress intensity value required to cause unstable fracture. It is shown in this report how this irreversible feature can be utilized in a practical NDT test on a structure undergoing crack growth due to cyclic loading or other environmental effects. This technique is based on periodic acoustic emission monitoring of a structure as it is loaded back to its proof stress.

Important References:

1. Dunegan, H. L., Harris, D. O., and Tatro, C. A., Fracture Analysis by Use of Acoustic Emission, J. Eng. Fract. Mech. 1, 105-122 (June 1968).

2. Dunegan, H. L. and Harris, D. O., Acoustic Emission - A New Nondestructive Testing Tool, Proc. Annu. Symp. NDT of Welds and Materials Joining, 3rd, Los Angeles, CA (March 1968).

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Key words: Acoustic emission; crack propagation; crack tip plastic zone; detection systems; environment effects; fatigue (materials); fracture strength; fractures (materials); NDT methods; stress intensity factor.

ULTRASONIC DETECTION AND MEASUREMENT OF FATIGUE CRACKS IN NOTCHED SPECIMENS

Klima, S. J. and Freche, J. C. (National Aeronautics and Space Administration, Lewis Research Center, Cleveland, OH)

Exp. Mech. 9, No. 5, 193-202 (1969)

An ultrasonic technique was developed and used to observe the formation and growth of fatigue cracks in notched cylindrical specimens subjected to reverse axial cyclic loading. Fatigue curves of the life-to-initial detectable cracks as well as life-to-fracture were obtained for an aluminum -, a titanium -, and a cobalt-base alloy, as well as maraging steel. Depth of initially detectable cracks ranged between approximately 0.01270 and 0.1016 mm. Curves were also obtained relating ultrasonic system output voltage to crack depth up to 0.762 mm for three materials. These curves were used to demonstrate the capability of the device for monitoring crack growth.

Important References:

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2. Klima, S. J., Lesco, D. J. and Freche, J. C., Application of Ultrasonics to Detection of Fatigue Cracks, Exp. Mech. 6, No. 3, 154-161 (1966).

3. Manson, S. S., Interfaces Between Fatigue, Creep, and Fracture, Int. J. Fract. Mech. 2, No. 1, 327-363 (1966).

Key words: Aluminum alloys; analysis methods; crack detection; crack initiation; crack propagation; cracks; detection systems; fatigue (materials); fatigue tests; fractures (materials); maraging steel; metallic materials; structural safety; titanium alloys; ultrasonic tests.

NONDESTRUCTIVE EVALUATION OF METAL FATIGUE
Kusenberger, F. N., Francis, P. H., Leonard, B. E., and Barton, J. R.
(Southwest Research Inst., San Antonio, TX)
AD-688892/AFOSR-69-1429TR (April 1969)

Investigations of NDI techniques for the early detection and evaluation of fatigue damage in metals have been extended. Photographs of the fatigue evaluation apparatus are shown, and brief descriptions of the ultrasonic, magnetic perturbation, and electric current injection nondestructive techniques are presented. Results obtained using ultrasonic and electric current instrumentations to monitor a stress-cycled Ti-6Al-4V and AISI 4340 specimens are presented and discussed.

Ultrasonic and magnetic perturbation instrumentations were used to monitor many stress-cycled AISI 4340 steel specimens. Magnetic data were accumulated using a very small Hall effect probe and new signal response characteristics were obtained. Reproductions of many ultrasonic and magnetic records are shown; surface photomicrographs showing fatigue microcracks are included. Data are presented that show the lives of AISI 4340 steel specimens can be significantly extended by the local removal of fatigue microcracks.

An analytical theory is proposed for describing the growth of a small surface "microcrack" under uniaxial fatigue loading. The theory is based upon dimensional analysis and uses the stress intensity factor and crack extension force concepts of elastic fracture mechanics. Experimental measurements were made of the growth of surface microcracks, ranging in length from 0.0005 to 0.040 in., in polished specimens of AISI 4340 steel. Good correlation was achieved in comparing the test results with the theoretical predictions. Finally, an approach is indicated for extending the analytical model to the prediction of fatigue failure.

Important References:

1. Manson, S. S. and Hirschberg, M. H., Low Cycle Fatigue of Notched Specimens by Consideration of Crack Initiation and Propagation, NASA TN-D-3146 (June 1967).

2. Kusenberger, F. N., Leonard, B. E., Francis, P. H., Barton, J. R., and Donaldson, W. L., Nondestructive Evaluation of Metal Fatigue, AFOSR Scientific Report, 1967-1968 (April 1968).

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Key words: Crack propagation; detection systems; failures (materials); fatigue (materials); magnetic perturbation; NDI methods; ultrasonic tests.

THE EARLY DETECTION OF FATIGUE DAMAGE
Moore, J. F., Tsang, S., and Martin, G. (North American Rockwell Corp., Los Angeles, CA)
AFML-TR-71-185 (September 1971)

This is the final technical report in a program directed toward the development of NDT methods for the detection of early fatigue and fracture damage in metallic materials. The program was based on an interdisciplinary approach designed to interrelate the factors of early fatigue damage with measurable physical phenomena. NDT methods were evaluated in terms of their potential detection and measurements capability of the observed fatigue-related effects and damage as determined by studies of fatigue evaluation tests. Based on the analysis, the following NDT methods were selected for detailed evaluation for static and in-process measurement of fatigue damage: exoelectron emission; acoustic emission; and ultrasonic surface wave attenuation and velocity.

Comment:

This report summarizes effort initiated under ARPA sponsorship in 1968. AFML was the contracting supervisor - Contract F33615-68C-1706, ARPA Order 1244. A significant conclusion resulting from these studies is that fatigue is essentially a surface layer phenomenon and, as such, is influenced by environment. It was concluded that the development of methods for assessing the extent of fatigue damage to a structure should be based on the correlation of actual fatigue life data with surface layer depth affected by the physical phenomena changes. The general approach taken in this study was that of determining (1) the depth of fatigue-mechanism-affected layers as a function of fatigue life, (2) the depth sensitivity of various inspection methods, and (3) a correlation between the two. Investigations for determining the actual fatigue mechanisms operative at the affected layer can involve a fairly considerable investigation, and this program concentrated on limited surface analysis in terms of the depth of the affected area and basic metallographic observations. In addition to contract references there is a bibliography of more than 50 citations including those from the French, Russian, German and British literature.

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Key words: Acoustic emission; analysis methods; crack detection; detection systems; exoelectron emission; fatigue (materials); fractures (materials); microstructures; NDT methods, NDT techniques; quantitative analysis; surface cracks; ultrasonic tests.

DETECTION OF CRACKS UNDER INSTALLED FASTENERS
Raatz, C. F., Senske, R. A., and Woodmansee, W. E. (Boeing Commercial Airplane Co., Seattle, WA)
AFML-TR-74-80 (April 1974)

The objective of this program was the development of a reliable method of detecting cracks under installed fasteners, emphasizing improvement of the ultrasonic shear wave method. The program included the implementation of the developed method into a system suitable for on-line inspection of aircraft. The development method was in four main areas: (1) ultrasonic fastener-hole scanning techniques; (2) display of test information; (3) identification of transducer requirements; and portable-scanner design. Ultrasonic shear-wave sound paths were identified for detection of fastener hole cracks in such diverse locations as upper and lower hole edges and base of countersink, and for test configurations of straight, countersunk, and taper shank holes 4.76 to 12.7 cm in diameter in aluminum, steel, and titanium alloys 3.8 to 19 mm thick. The influence on crack detection of surface finish, interface sealant, crack configuration, and corrosion was assessed. Two methods of data display were developed, both using circular display of ultrasonic test information on storage oscilloscope.

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Key words: Aircraft structures; aluminum alloys; crack detection; corrosion; eddy currents; fatigue (materials); NDI methods; NDI techniques; plates (structural); reliability; safety; structural safety; titanium alloys; ultrasonic tests.

A MECHANIZED EDDY CURRENT SCANNING SYSTEM FOR AIRCRAFT STRUTS
Reeves, C. R. (Lockheed-Georgia Co., Marietta)
Mater. Eval. 31, No. 3, 48-52 (March 1973)

This paper describes the design and operation of a mechanized eddy current defect detection system used for scanning internal cylindrical surfaces. The single coil scanning apparatus traces a helical path. Cracks as small as 0.050 in. (1.27 mm) long by 0.020 in. (0.508 mm) deep can be reliably detected at scan rates up to 140 sq in. (910 sq cm) per minute. A unique electronic, audio/visual indicator is incorporated into the portable eddy current inspection system to provide recognizable defect indications at high speeds. A description of two specific applications on aircraft landing gear components is presented with data on operating parameters. A number of potential uses for this system are also discussed.

Key words: Aircraft structures; aluminum alloys; crack detection; detection systems; eddy currents; inspection procedures; NDI methods; NDI techniques; reliability; surface cracks.

THE DETECTION OF FATIGUE CRACKS BY NONDESTRUCTIVE TESTING METHODS
Rummel, W. D., Todd, Jr., P. H., Frecska, S. A. and Rathke, R. A.
(Martin Marietta Corp., Denver, CO)
NASA CR-2369 (February 1974)

X-radiography, penetrant, ultrasonic, eddy current, holographic, and acoustic emission techniques were optimized and applied to the evaluation of 2219-T87 aluminum alloy test specimens. 118 specimens containing 328 fatigue cracks were evaluated. The cracks ranged in length from 1.27 cm to 0.018 cm and in depth from 0.451 cm to 0.003 cm. Specimen thicknesses were nominally 0.152 cm and 0.532 cm and surface finishes were nominally 32 and 125 rms and 64 and 200 rms, respectively. Specimens were evaluated in the "as milled" surface condition, in the chemically milled surface condition and, after proof loading, in a randomized inspection sequence. Results of the nondestructive test (NDT) evaluations were compared with actual crack size obtained by measurement of the fractured specimens. Inspection data were then analyzed to provide a statistical basis for determining the threshold crack detection sensitivity (the largest crack size that would be missed) for each of the inspection techniques at a 95 percent probability and a 95 percent confidence level.

Important References:

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Key words: Aluminum alloys; analysis methods; crack detection; crack initiation; critical flaw size; detection systems; eddy currents; fatigue (materials); NDE methods; NDT techniques; testing methods; ultrasonic tests; x ray inspection.

THE APPLICATION OF ACOUSTIC EMISSION TECHNIQUES TO FATIGUE CRACK MEASUREMENT

Singh, J. J., Davis, W. T., and Crews, Jr., J. H. (National Aeronautics and Space Administration, Langley Research Center, Langley Station, VA

NASA TN-D-7695 (October 1974)

The applicability of acoustic emission techniques to measure fatigue cracks in aluminum specimens was investigated. It is shown that a summation type of acoustic emission law can be applied to the slow crack growth region and may be used to verify the crack length changes. However, variables such as the metallurgical and physical treatment of the specimen can affect the level of acoustic activity of a fatigue specimen. It is therefore recommended that the acoustic emission technique be supplemented by other NDE methods to obtain quantitative data on crack growth.

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Key words: Acoustic emission; aluminum alloys; crack propagation; detection systems; fatigue (materials); material defects; NDE methods; NDE techniques.

INVESTIGATION OF ACOUSTIC EMISSION DURING FATIGUE LOADING OF COMPOSITE SPECIMENS

Williams, R. S. and Reifsnider, K. L. (Virginia Polytechnic Inst. and State Univ., Blacksburg)

J. Compos. Mater. 8, 340-355 (October 1974)

Strain and load controlled fatigue tests were run on boron-aluminum and boron-epoxy angle-plied specimens. Acoustic emission data were recorded using a gating technique that eliminated most extraneous noise. Various material parameters were monitored during the test. A good correlation between acoustic emission and damage extent and propagation was obtained. This was evidenced by an apparent first order linear relationship between dynamic compliance and totalized acoustic emission. A basis for an energy based failure model is formulated and discussed.

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4. Corten, H. T., Fracture Mechanics of Composites, Fracture 7, 675 (1972).

Key words: Acoustic emission; aluminum alloys; analysis methods; boron fibers; composite materials; crack detection; crack growth rate; epoxy resins; fatigue (materials); fatigue tests; fiber-reinforced composites; ultrasonic tests.

3. Stress Corrosion

NONDESTRUCTIVE DETECTION AND EVALUATION OF STRESS CORROSION CRACKING
Carter, J. J. (Melbourne Univ., Parkville, Australia)
Proc. Tewksbury Symp. Fracture, Effects of Chemical Environments of Fracture Processes, 3rd, Melbourne, Australia (June 4-6, 1974)

Stress wave emission is compared with conventional methods of NDI as a means of detecting and evaluating stress corrosion cracking. The methods explored are described briefly and their advantages and limitations outlined. In the case of stress wave emission, some experimental results are included, as well as a brief review of appropriate literature. It is concluded that, for the present, stress wave analysis can usefully complement but not replace the older inspection methods. Complete evaluation of stress corrosion cracking requires additional knowledge from other fields such as fracture mechanics and materials engineering.

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Key words: Acoustic emissions; crack initiation; crack propagation; detection systems; eddy currents; environment effects; fracture strength; magnetic particles; material defects; metallic materials; NDI methods; NDI techniques; penetrant inspection; radiography; stress corrosion cracking; stress wave emission; ultrasonic tests.

ACOUSTIC EMISSIONS AND STRESS-CORROSION CRACKING IN HIGH-STRENGTH ALLOYS
Tucker, T. R. and Fujii, C. T. (Naval Research Lab., Washington, DC)
AD-785009 (August 1974)

The usefulness of acoustic emission data, i.e., stress wave emission (SWE), to studies of stress-corrosion cracking (SCC) of high strength alloys was explored. Single-edge-notched, precracked cantilever specimens were used to study the stress-corrosion-crack growth and SWE characteristics of a high-strength stainless steel and a titanium alloy. SWE data correlate reasonably well to crack growth measurements by conventional beam deflection techniques for high-strength stainless steel but is too insensitive for reliable detection of crack extension in the titanium alloy. The use of SWE data to define the energetics of discrete cracking events is currently beyond the capabilities of existing equipment and analytics.

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4. Hartbower, C. E., Reuter, W. G, and Crimmins, P. P., Mechanisms of Slow Crack Growth in High Strength Steels and Titanium, AFML-TR-67-26 (1969).

5. Beachem, C. D., A New Model for Hydrogen Assisted Cracking, Met. Trans. 3, 437 (1972).

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Key words: Acoustic emission; analysis tools; crack growth rate; crack propagation; detection systems; fracture mechanics; NDE techniques; NDT techniques; stainless steels; stress corrosion; stress corrosion cracking; stress wave emission; titanium alloys.

STRESS-CORROSION CRACK DETECTION AND CHARACTERIZATION USING ULTRASOUND
Weil, B. L. (Lockheed-Georgia Co., Marietta)
Mater. Eval. 27, No. 6, 135-139, 144 (June 1969)

Stress-corrosion cracking is a complicated mechanism involving: (1) sustained surface tensile stresses; (2) an alloy and temper susceptible to this phenomenon; and (3) a corrosive atmosphere. Described is the development of a nondestructive test technique following the occurrence of a stress-corrosion failure in a ring support structure of 7075-T6. Configuration of the part and concealment of the area of surface tensile stresses under a glass-resin structure dictated that a shear wave technique be used to detect and characterize the stress-corrosion cracks. Test frequencies, types of search unit and various couplants were investigated to determine optimum sensitivity and resolution with minimum attenuation. Test techniques were developed with concern for location of probe, angle of refracted wave and amplitude of discontinuity indication. To simulate discontinuities, machined standards with areas related to cracks of various locations, sizes, depth and angles were evaluated. Characterization was finally optimized through development of standards with induced stress-corrosion cracks of various sizes, locations, depth and angles propagated by submitting sections of the part to acidified salt spray while under a residual tensile stress of 80 percent of the yield stress. Information was correlated using data from both the ultrasonic and metallographic evaluation of these specimens.

Key words: Analysis tools; aluminum alloys; corrosion; cracking (fracturing); detection systems; inspection procedures; inspection standards; NDT methods; stress corrosion cracking; ultrasonic imaging; ultrasonic tests.

CORROSION CRACKING OF METALLIC MATERIALS, PART II - ACOUSTIC EMISSION EXPERIMENT AND THEORY

Fontana, M. G. and Graff, K. F. (Air Force Materials Lab., Wright-Patterson AFB, OH)

AD-751529/AFML-TR-72-102-PT-2 (August 1972)

The aspects of acoustic emission associated with the theory of the stress waves emitted from cracking and the experimental measurement of the acoustic emission pulses are reported. In the theoretical phase of the work, a survey of the applicable literature in the area of stress waves from moving cracks is reviewed. Certain simple theoretical arguments pertaining to the energy release from an increment of crack growth are reported. In the experimental phase, an evaluation of a number of ultrasonic NDT transducers for acoustic emission work was carried out and an optimum transducer selected. A complete acoustic emission test system was then constructed and several tests performed by the conclusion of the project.

Important Reference:

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Key words: Acoustic emission; corrosion; cracking (fracturing); crack propagation; fracture tests; NDT methods; NDT techniques; ultrasonic tests; wave propagation.

4. Residual Stress

THE MEASUREMENT OF SURFACE AND NEAR-SURFACE STRESS IN ALUMINUM ALLOYS USING RAYLEIGH WAVES
Martin, B. G. (Douglas Aircraft Co., Inc., Long Beach, CA)
Mater. Eval. 32, No. 11, 229-234 (November 1974)

Experimental work has been conducted on determining the feasibility of using an ultrasonic technique for measuring residual stress in aluminum alloys. It was observed that stress changes Rayleigh-wave velocity slightly (a fraction of 1 percent), and that uniaxial tensile stress decreases velocity and compressive stress increases it. This is in agreement with predictions based on second order elasticity theory. The effect of preferred grain orientation on Rayleigh-wave velocity is of the same order of magnitude as the effect of stress (at least in the elastic range). Also, preferred grain orientation acts in such a manner as to decrease Rayleigh-wave velocity. It was concluded that due to the difficulty of separating the effects of preferred grain orientation and stress, the ultrasonic technique is not practical for measuring residual stress in aluminum alloys, at least not in the alloys 2024-T3 and 7075-T6. However, the technique is applicable to the measurement of applied stress and to the measurement of residual stress in 6061-T6 alloy.

Important References:

1. Martin, B. G., Rayleigh-Wave Velocity, Stress and Preferred Grain Orientation in Aluminum, Non-Destructive Testing - Research and Practice 7, 199 (August 1974).

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5. McKannan, E. C., Ultrasonic Measurement of Stress in Aluminum, in Nondestructive Testing, Trends and Techniques, NASA SP-5082 (1967).

Key words: Aluminum alloys; elastic properties; experimental data; experimentation; NDT techniques; Rayleigh waves; residual stress; stress analysis; test equipment; test procedures; ultrasonic tests.

NONDESTRUCTIVE MEASUREMENT OF RESIDUAL STRESSES IN METALS AND METAL STRUCTURES
Masubushi, K. (Battelle Memorial Inst., Columbus, OH)
AD-467033/RSIC-410 (April 30, 1965)

This Redstone Scientific Information Center report presents a state-of-the-art survey of the nondestructive measurement and evaluation of residual stresses produced in metals and metal structures. This report is concerned primarily with residual stresses produced during the fabrication of structures made of high-strength aluminum alloys.

Discussions are presented in four sections which provide the following: (1) fundamental information on residual stresses that is needed to understand measurement techniques; (2) review of methods of measuring residual stresses, including stress-relaxation techniques, x ray diffraction technique, the ultrasonic technique, the hardness technique, and the cracking techniques; (3) measurement of residual stresses during fabrication of metal structures (methods of measuring residual stresses and typical experimental data are described); and (4) selection and use of appropriate measurement techniques and evaluations of results.

On the basis of findings obtained during this survey, recommendations are given for future research on nondestructive measurement of residual stresses produced during fabrication of metal structures.

Comment:

This is a basic document on the NDE of residual stress in metal structures. Though most of the 141 references cited are pre-1962 and some are dated by technology, they represent a comprehensive search of the British, German, and Japanese literature in addition to that of the United States.

Important References:

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2. Vaughan, D. A. and Crites, N. A., Measurement of Stress by X-Ray Diffraction, Prod. Eng. 34, No. 20 (September 1963).

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4. Yoshida, T. and Hirano, K., Measurement of Residual Stress in Weldments by X-Ray Diffraction Method, J. Jap. Weld. Soc. 33, No. 7, 533-537 and 538-543 (1964).

5. Bolstad, D. A., Davis, R. A., Quist, W. E. and Roberts, E. G., Measuring Stress in Steel Parts by X-Ray Diffraction, Metal Prog. 84, No. 1, 88-124 (1963).

Key words: Aluminum alloys; cracking (fracturing); experimental data; high strength alloys; NDE methods; NDE techniques; residual stress; ultrasonic tests.

AN ACOUSTIC SURFACE WAVE METHOD FOR RAPID, NONDESTRUCTIVE TEXTURE EVALUATION
Tittmann, B. R. and Alers, G. A. (North American Rockwell Corp., Thousand Oaks, CA)
Met. Trans. 3, 1307-1308 (May 1972)

A simple and rapid method for the nondestructive evaluation of texture in metal sheet and plate products of arbitrary thickness is described. The method uses impulse techniques to generate and receive Rayleigh waves on thick plates or Lamb waves on thin materials. The technique is applied to titanium alloy sheet and plate materials whose texture was introduced by the rolling process.

(FOR LISTING OF IMPORTANT REFERENCES, KEYWORDS AND A DUPLICATE ABSTRACT, SEE PAGE 39)

C. 2

5. Analysis of Composition

INTERNAL STANDARD METHOD FOR THE RAPID IDENTIFICATION OF METALS BY ATOMIC ABSORPTION SPECTROPHOTOMETRY
Deak, C. K. (Frankel Co., Inc., Detroit, MI)
Mater. Res. Stand. 10, No. 11, 12-13 and 36-37 (November 1970)

Identification of metals using instruments based on the physical properties of the metals, spot checks, or spectroscopy are not always accurate or sensitive. Atomic absorption spectrophotometry can solve many difficult metal problems. Two rapid methods not requiring weighed specimens are discussed. Small specimens are dissolved in a suitable acid. The solutions are diluted until the desired elements are in a well readable concentration range for the instrument. The concentrations are compared to the concentration of the matrix, and the percentages are calculated using the internal standard method.

Key words: Analysis tools; atomic absorption; chemical composition; detection systems; NDE methods; NDE techniques; qualitative analysis; quantitative analysis.

REVIEW OF RECENT WORK IN THE RAPID IDENTIFICATION OF STEELS
Pasztor, L. C., Raybeck, R. M., and Dulski, T. R. (Jones and Laughlin Steel Corp., Pittsburgh, PA)
Mater. Res. Stand. 10, No. 8, 8-11 and 32-35 (August 1970)

The major published work on the identification of metals is described. The following general areas are covered: (1) subjective: organoleptic approaches, including fracture and spark testing; (2) chemical: including metal surface reactions, drop solution (microchemical), spot, and printing tests, paper substrate, ion exchange, and chelometric methods; and (3) instrumental methods: including special spectroscopic approaches; such as magnetic, eddy current, thermoelectric, triboelectric and ultrasonic techniques.

Important References:

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2. Meinke, W. W., and Scribner, B. F., Eds., Trace Characterization - Chemical and Physical, NBS, Washington, DC (1967).

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4. Zall, D. M. and Bolander, E. H., In Situ Identification of Alloys - Spot Testing Alloys for Submarine Construction, Mater. Protection 6, No. 7, 37-38 (July 1967).

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Key words: Analysis methods; detection systems; metals; NDE methods; NDE techniques.

RAPID NONDESTRUCTIVE IDENTIFICATION AND COMPARISON OF METALS

Schmid, D. M. and Wolf, J. E. (Techalloy Co., Inc., Rahns, PA; Techalloy Illinois, Inc., Union, IL)

Mater. Res. Stand. 10, No. 11, 14-15 (November 1970)

Metal identification by electrical interrogation is discussed. The measurement equipment was originally designed for continuous comparison and identification of in-process wire, but has proved useful for laboratory identification work for testing other forms such as heavy rod, narrow width strip, tubing and small parts. The instrument's sensing element consists essentially of two cylindrical coils arranged in a balance transformer configuration. When a metal specimen is inserted into a coil, the effective permeability is altered and a change in output voltage from the particular coil is observed.

Key words: Chemical composition; detection systems; electrical tests; inspection procedures; metallic materials; NDE methods; NDE techniques.

SIGNATURE COMPARISON TECHNIQUE FOR RAPID ALLOY SORTING WITH A RADIOISOTOPE EXCITED X-RAY ANALYZER

Sellers, B. and Brinkerhoff, J. (Panametrics, Inc., Waltham, MA)

Mater. Res. and Stand. 10, No. 11, 16-18 (November 1970)

A new operational technique for rapid identification of metal alloys has been developed. Unlike standard x ray analysis procedures requiring accurate quantitative assay of specific elements to effect the identification, the method utilizes a signature comparison technique involving a number of known standards. An inherent feature of the technique is that a set of two numbers is generated for each element which is characteristic of a specific alloy. Use of these two numbers as a dual entry signature on a plot utilizes the fact that the fluorescent x ray emission from a particular characteristic element in the alloy not only depends on the concentration of that element but also is related to the character of the matrix material itself. By using more than one characteristic element as the basis for identification, additional sets of numbers are generated which, taken together, become positively indicative of a specific alloy. Results are presented which were obtained from a portable analyzer that uses a radioisotope source to excite fluorescent x rays in the alloy. The instrumentation retains the principal advantage of x ray inspection; that is, it is nondestructive and, in addition, inexpensive, fast and easy to use. Also, little or no specimen preparation is required. Rough castings as well as rod and bar stock can be tested if a reasonably smooth surface of several square centimeters area is available. Specific successful applications reported include identification of nickel- and aluminum-base alloys.

Key words: Analysis tools; aluminum alloys; composite materials; detection systems; NDI techniques; nickel alloys; x ray inspection.

NONDESTRUCTIVE DETERMINATION OF FATIGUE CRACK DAMAGE IN COMPOSITES USING VIBRATION TESTS

DiBenedetto, A. T., Gauchel, J. V., Thomas, R. L. and Barlow, J. W.
(Washington, Univ., St. Louis, MO)

J. Mater. 7, 211-215 (June 1972)

The vibration response of glass reinforced epoxy and polyester laminates was investigated. The complex modulus and the damping capacity were measured as fatigue crack damage accumulated. Changes in the Young's modulus as well as the damping capacity correlated with the amount of crack damage. The damping was especially sensitive to debonding of the reinforcement from the resin matrix. Measurement of these vibration response changes shows promise as a means to nondestructively test the structural integrity of filament-reinforced composite structural members.

Important References:

1. Lifshitz, J. M. and Rotem, A., Determination of Reinforcement Unbonding of Composites by a Vibration Technique, J. Compos. Mater. 3, 412-423 (July 1969).

2. Schultz, A. B., Warwick, D. N., DiBenedetto, A. T., Gauchel, J. V. and Thomas, R. L., Non-Destructive Determination of Composite Material Properties Using Vibration Tests, NASA Report Contract NGR-26-008-063 (May 1971).

Key words: Crack initiation; composite materials; epoxy resins; fatigue (materials); fatigue tests; fiber-reinforced composites; NDT methods; vibration tests.

THERMAL AND INFRARED NONDESTRUCTIVE TESTING OF COMPOSITES AND CERAMICS

Green, D. R. (WADCO Corp., Richland, WA)

Mater. Eval. 29, No. 11, 241-248 (November 1971)

This paper describes the application of high-speed thermal and infrared methods to the detection of density differences, cracks, voids and other defects in ceramics and composites. A single-pass induction heating method, made possible with a full-width "paint brush" heating coil, was used in infrared tests on carbon-carbon composites. Unique characteristics of the induction heating make it possible to detect cracks that are perpendicular as well as parallel to the surface of the test specimen. All the materials were also tested using a new low-cost thermal image transducer, and the resolution and sensitivity to defects were determined. Both the infrared method and the thermal transducer method are capable of completing a test on a large area in a few seconds (not including specimen handling time).

(FOR LISTING OF IMPORTANT REFERENCES, KEYWORDS AND A DUPLICATE ABSTRACT, SEE PAGE 60)

NONDESTRUCTIVE TESTING TECHNIQUES FOR FIBERGLASS, GRAPHITE FIBER AND BORON FIBER COMPOSITE AIRCRAFT STRUCTURES

Hagemaier, D. J., McFaul, H. J., and Parks, J. T. (Douglas Aircraft Co., Inc., Long Beach, CA)

Mater. Eval. 28, No. 9, 194-204 (September 1970).

Various nondestructive test (NDT) methods were evaluated for inspection and evaluation of boron, graphite and glass-fiber composites for aircraft structures. Typical specimens were evaluated using microscopic, fluorescent pentrant, radiographic, ultrasonic and thermochromic test methods. Optical microscopic examination is useful for determination of fiber pattern from the edge of a panel. It was concluded that fluorescent penetrant combined with microscopic examination is a useful tool to determine fiber pattern, fiber gaps, broken fibers, crushed core, and resin-rich areas; and ultrasonic and thermal methods appear to have merit for determining unbonded areas. The results of a literature survey concerning the NDT of composites are presented in abstracted form and indicate significant applications and limitations of various test methods. The direction of future NDT research and development efforts is indicated.

Important References:

1. Tomlinson, R. and Underhill, P., Production Neutron Radiographic Facility for Routine NDT Inspection of Special Aerospace Components, ASNT Spring Conf., Los Angeles, CA (March 1969).

2. Haskins, J. J. and Wilkinson, C. D., Neutron Radiography: Some Applications for NDT, ASNT Spring Conf., Los Angeles, CA (March 1969).

3. Maley, D., Nondestructive Evaluation of Material Properties Through the Use of Thermal Inspection System, AFML-TR-66-192 (1966).

4. Searles, C., Thermal Image Inspection of Adhesive Bonded Structures, Proc. ASNT Symp. NDT of Welds and Joining, Evanston, IL (1968).

5. Schroeer, R., Research on Exploratory Development of Nondestructive Methods for Crack Detection, AFML-TR-67-167-PT1 (August 1967).

6. Padden, H., Fokker Bond Testing of Composites, Proc. AFML Aerospace Conf. NDT of Composite Structures, Dayton, OH (March 1969).

Key words: Aircraft structures; acoustic emission; bond integrity; boron fibers; carbon fibers; composite materials; detection systems; evaluation; fiber-reinforced composites; glass fibers; laminates; material defects; NDT methods; NDT techniques; penetrant inspection; radiography; ultrasonic tests; x ray inspection.

THE RADIOGRAPHY OF METAL MATRIX COMPOSITES

Martin, G., Moore, J. F., and Tsang, S. (North American Rockwell Corp., Los Angeles, CA)

Mater. Eval. 30, No. 4, 78-86 (April 1972)

A comprehensive survey was made of the applicability of a wide variety of radiographic methods and variables to metal matrix composites. It was shown that comparatively simple rules for the optimization radiographic parameters allow the definition of filament details down to the resolution of single filament strands in even multilayer composites. For resolution, the type R film was found to be superior to the more rapid type M film, which, however, is quite adequate for most purposes. For highest resolution, microfilms should be used. Densitometry and particularly microdensitometry is applicable to composites with only a few filament layers and may allow determination of width of diffusion layers, relative local spacings, etc. Dynamic radiography of composites under loads requires, in the case boron or silicon carbide filaments, the availability of high resolution vidicon tubes, but is quite feasible.

Quantitative measurements of absorption or scatter factors are relatively more complex procedures. Results can be obtained, but, because of the influence of a number of factors, such as local filament density variations, existence of surface and interface layers and local thickness variations seem promising only on a comparative basis for sections manufactured by similar methods under similar conditions. A number of methods and approaches were worked out and analyzed.

(FOR LISTING OF IMPORTANT REFERENCES, KEYWORDS AND A DUPLICATE ABSTRACT, SEE PAGE 49)

ULTRASONIC INSPECTION OF A BORON/EPOXY-ALUMINUM COMPOSITE PANEL
Mool, D. and Stephenson, R. (Boeing Co., Seattle, WA)
Mater. Eval. 29, No. 7, 159-164 (July 1971)

This investigation was undertaken to determine the inspectability of a boron/epoxy-aluminum panel; the panel consisted of a ten-ply unidirectional boron/epoxy laminate adhesively bonded to aluminum face sheets. The ability of through-transmitted ultrasound to detect and identify defects introduced into a test panel was assessed. Ultrasonic C-scans obtained at 5, 10 and 15 MHz adequately showed such defects. Although defect delineation was sharper with increasing frequency, low amplitude made signal processing difficult at 15 MHz. Defects definitely identified included: (1) delaminations at any depth in the panel; (2) missing and added boron/epoxy plies; (3) missing adhesive layer; (4) resin variations; and (5) misaligned filament. It was concluded that the through-transmission ultrasonic technique was an effective inspection method for this particular composite system.

Important References:

1. Anon, Recommended Practice for Selecting Nondestructive Testing Methods for Reinforced Thermosetting Plastics, Mater. Res. Stand., 37 (July 1968).

2. Mool, D., Testing of Composite Compatibility Laminates, Unpublished Boeing Development Report (January 1970).

3. Zurbrick, J. R., Development of Nondestructive Tests for Quantitatively Evaluating Glass Fiber Reinforced Laminates, AFML-TR-67-170 (December 1967). Available as AD-825951.

4. Zurbrick, J. R., Development of Nondestructive Tests for Predicting Elastic Properties and Constant Volume Fractions in Reinforced Plastic Composite Materials, AFML-TR-68-233 (February 1969).

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Key words: Adhesive bonding; analysis tools; boron fibers; composite materials; epoxy resins; inspection procedures; laminates; material defects; NDI methods; panels (structural); ultrasonic tests.

THE PROPAGATION OF ULTRASONIC WAVES IN CFRP LAMINATES
Reynolds, W. N. and Wilkinson, S. J. (Atomic Energy Research Establishment, Harwell, England)
Ultrasonics, 109-114 (May 1974) (A74-44349)

A survey report is presented of studies of ultrasonic wave propagation in flat carbon fiber reinforced plastic laminates. After summarizing earlier work on uniaxial specimens the authors give more detailed information of testing for two- and three-ply laminates and sandwich structures. The discovery that velocities measured perpendicular to fiber direction show an interesting dependence on porosity of the matrix of the material under test and on the measuring technique used could lead to wider exploitation.

(FOR LISTING OF IMPORTANT REFERENCES, KEYWORDS AND A DUPLICATE ABSTRACT, SEE PAGE 45)

CORRELATION AND ANALYSIS OF ULTRASONIC TEST RESULTS IN EVALUATING REINFORCED RESIN LAMINATES
Schultz, A. W. (AVCO Corp., Lowell, MA)
Mater. Res. Stand. 7, No. 8, 341-345 (August 1967)

Correlations between ultrasonic longitudinal bulkwave velocity and density, and between elastic modulus and velocity have been experimentally determined for carbon fabric-phenolic resin laminated fabrications. A comparison of the experimental results with those from mathematical analysis indicates that the analysis can be used to predict correlation variability and characterize the correlations themselves with good accuracy. One valuable quantity determinable from these two correlations is Poisson's ratio. Although the results of the analysis are not new, the method used is unique, provides insight into materials evaluation, and can be applied to other materials and correlations.

Key words: Analysis methods, composite materials; fiber-reinforced composites; laminates; modulus of elasticity; NDT methods; predictions; resin bonded composites; ultrasonic tests.

INVESTIGATION OF ACOUSTIC EMISSION DURING FATIGUE LOADING OF COMPOSITE SPECIMENS
Williams, R. S. and Reifsnider, K. L. (Virginia Polytechnic Inst. and State Univ., Blacksburg)
J. Compos. Mater. 8, 340-355 (October 1974)

Strain and load controlled fatigue tests were run on boron-aluminum and boron-epoxy angle-plied specimens. Acoustic emission data were recorded using a gating technique that eliminated most extraneous noise. Various material parameters were monitored during the test. A good correlation between acoustic emission and damage extent and propagation was obtained. This was evidenced by an apparent first order linear relationship between dynamic compliance and totalized acoustic emission. A basis for an energy based failure model is formulated and discussed.

(FOR LISTING OF IMPORTANT REFERENCES, KEYWORDS AND A DUPLICATE ABSTRACT, SEE PAGE 82)

LOW VOLTAGE AND NEUTRON RADIOGRAPHIC TECHNIQUES FOR EVALUATING BORON FILAMENT METAL MATRIX COMPOSITES
Holloway, J. A., Stuhrke, W. F., and Berger, H. (Air Force Materials Lab., Wright-Patterson AFB, OH; Argonne National Lab., IL)
AFML-TR-67-193 (February 1968)

Low voltage (5 to 50 KVCP) and neutron radiographic techniques are described for characterizing boron filament/metal matrix composites. Broken, misaligned, and unevenly spaced filaments detected with these techniques in multilayer boron/metal matrices are reported. The applicability of microdensitometry is demonstrated for detecting the relative degree of the interaction between and metal matrix as a function of heat treatment using monolayer boron filaments in an electrodeposited nickel matrix. The metallurgical properties of this interaction are discussed. The effect of time-temperature exposure, residual stress, and filament spacing on the mechanical properties of the composite is considered.

Important References:

1. Alexander, J. A., Research on Boron Reinforced Metal Matrix Composites, AFML-TR-67-101 (June 1967).

2. Martin, G. and Moore, J. F., Research and Development of Nondestructive Testing Techniques for Composites, AFML-TR-66-270 (February 1967).

3. Berger, H., Neutron Radiography, Elsevier Pub Co., Amsterdam (1965).

Key words: Boron fibers; composite materials; failures (materials); fiber-reinforced composites; metal matrix composites; NDE methods; NDI methods; neutron irradiation; radiography.

THERMAL AND INFRARED METHODS FOR NONDESTRUCTIVE TESTING OF ADHESIVE-BONDED STRUCTURES

Kutzscher, E. W., Zimmermann, K. H., and Botkin, J. L.
(Lockheed Aircraft Corp., Burbank, CA)

Mater. Eval. 26, No. 7, 143-168 (July 1968)

Thermal and infrared NDT methods of adhesive-bonded aerospace structures are discussed. The design of an active scanning infrared inspection system (SIRIS) for large, panel-shaped components is described. Examples of measuring results are presented.

Important References:

1. Alzofon, F. E., The Relative Contributions of Emissivity and Thermal Conductivity in Nondestructive Testing, Trans. of Infrared Sessions, ASNT Spring Conf. (1965).

2. Sachs, H. L., Infrared Physics, Argonne Lab. Report 6515, Proc. Symp. Phys. Nondestruct. Test., 2nd (October 3-5, 1961).

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Key words: Adhesive bonding; aircraft structures; analysis methods; composite materials; infrared radiation; material defects; NDI methods; NDT methods; thermal inspection.

NON-DESTRUCTIVE TESTING OF BONDED JOINTS
Norris, T. H. (Hawker Siddley Aviation, Ltd., Hatfield, England)
Non-Destruct Test (Guilford, Engl.) 7, 335-339 (December 1974)

This paper deals with the production aspects of controlling the manufacturing and testing of adhesive bonded primary aircraft structures. Whilst recognizing the requirement for in-service testing, the problems encountered are somewhat different and should be treated as a separate issue.

Key words: Adhesive bonding; aircraft structures; bond integrity; inspection; joints (junctions); material defects; reliability; structural safety.

NONDESTRUCTIVE TESTING FOR EVALUATION OF STRENGTH OF BONDED MATERIALS
Schmitz, G. and Frank, L. (General American Transportation Corp., Niles, IL)
NASA CR-67983 (September 1965)

The theoretical and experimental investigation of various techniques for nondestructively testing for bond strength are described. Existing nondestructive test techniques are mainly effective for detecting complete lack of bond in adhesively bonded structures. Techniques investigated included: acoustic emission, bond line electrical parameters, strain sensitive coatings, and ultrasonic attenuation as a function of bond stress. The ultrasonic emission of a bond line under stress was found to be a reliable indication of bond strength. A definite need was found for a widely applicable bond stress method.

Important References:

1. Gonzalez, H. M. and Cagle, C. V., Nondestructive Testing of Adhesive Bonded Joints, Pacific Area Nat. Meet., 4th, (October 4, 1962).

2. Arnold, J. S., Development of Nondestructive Tests for Structural Adhesive Bonds, WADC Tech. Report 54-231, Part 3 (April 1965).

Key words: Acoustic emission; adhesive bonding; detection systems; NDT techniques; ultrasonic tests.

PRACTICAL PROBLEMS RELATED TO THE THERMAL INFRARED NONDESTRUCTIVE TESTING OF A BONDED STRUCTURE

Sneeringer, J. W., Hacke, K. P., and Roehrs, R. J.
(McDonnell Aircraft Co., St. Louis, MO)

Mater. Eval. 29, No. 4, 88-92 (April 1971)

Infrared nondestructive testing provides a rapid and reliable method for the detection of anomalies in an adhesively bonded structure. There are, however, a number of practical problems encountered in the evaluation of a bonded structure, such as boron composite/aluminum honeycomb sandwich. Included in this discussion are surface effects, such as emittance and reflectance; internal structural effects, such as changing cross section in the product, and the effects of instrumentation sensitivity. Images of boron composite/aluminum honeycomb sandwich are presented and discussed to illustrate the problems in evaluating the results.

Important References:

1. Brown, S. P., Cholesteric Crystals for Nondestructive Testing, Proc. ASNT Symp. on NDT of Welds and Materials Joining (1968).

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4. Maley, D. R., Two Thermal Nondestructive Testing Techniques, Automation Industries Report TR-65-25 (August 1969).

5. Searles, C. E., Thermal Image Inspection of Adhesive Bonded Structure, Proc. ASNT Symp. on NDT of Welds and Materials Joining (1968).

Key words: Adhesive bonding; composite materials; infrared radiation; material defects; NDT methods; NDT techniques; thermal inspection.

NONDESTRUCTIVE TEST TECHNIQUE DEVELOPMENT FOR THE EVALUATION OF BONDED MATERIALS
Zurbrick, J. R., Proudfoot, E. A., and Hastings, C. H. (AVCO Government Products Group, Lowell, MA)
AD-753753 (November 5, 1971)

This report describes a research and development program on nondestructive testing (NDT) techniques for characterizing metallic substrate surfaces. Studies of the relative influence of parametric variables on bond strength have shown the overriding influence of surface free energy as compared with contact angle on prepared substrates. The effective strain value was found to be very complex. Its empirical treatment as if it consists only of uniformly distributed axial strain is a possibly useful solution which permits linking bond strength primarily to surface free energies. Effort was devoted to development of nondestructive, optical, and spectrophotometric techniques for characterizing contaminants which frequently occur on substrate surfaces. Although the most sensitive techniques available were employed, they did not reveal correlations with bond strength variability observed.

(FOR LISTING OF IMPORTANT REFERENCES, KEYWORDS AND A DUPLICATE ABSTRACT, SEE PAGE 24).

RELIABILITY, LIFE PREDICTION AND PROOF TESTING OF CERAMICS
Wiederhorn, S. M. (National Bureau of Standards, Washington, DC)
Ceramics for High Performance Applications, 633-663, Brook Hill Pub. Co., Chestnut Hill, MA (1974)

This paper was originally presented at the AMMRC-sponsored Second Army Materials Technology Conference, Hyannis, MA, 13-16 November 1973. A critical review of the use of proof testing as a design method for assuring the reliability of structural components is presented. The advantage of proof testing over the statistical approach used for design lies in the insensitivity of the proof testing method to the detailed history of handling or processing of structural components. Methods are presented for developing and using proof test diagrams to assure component lifetime after proof testing. Procedures of proof testing and precautions that must be followed during proof testing are discussed. It is stated that if the recommended precautions are followed, proof testing offers a good method for assuring the reliability of structural components subjected to stress.

(FOR LISTING OF IMPORTANT REFERENCES, KEYWORDS AND A DUPLICATE ABSTRACT, SEE PAGE 26)

DEFECT DETECTION IN HOT-PRESSED Si_3N_4
Kossowsky, R. (Westinghouse Research Labs., Pittsburgh, PA)
Proc. Army Mater. Technol. Conf., 2nd, Hyannis, MA
(13-16 November 1973)

The types of defects found in commercial hot-pressed Si_3N_4 are identified and described. X ray radiography, ultrasonic, and dye-penetrant detection techniques are discussed. It is shown that high-density defects such as metallic particles can be detected by x ray radiography but not by ultrasonic methods. On the other hand, cavities, low-density areas, and low-density defects, which are difficult to detect by x ray techniques, could be identified by ultrasonic detection. Finally, examples of defect detection in structural components are shown.

Important References:

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3. McLean, A. F., Fisher, E. A., and Bratton, R. J., Brittle Materials Design, High Temperature Gas Turbine, Interim Report, 1 January 1973 to 30 June 1973, Contract AMMRC-CTR-73-32 (September 1973). Also available as AD-914451L.

Key words: Ceramics; failure prevention; inspection procedures; material defects; NDI methods; NDT methods; neutron irradiation; penetrant inspection; radiography; ultrasonic tests; x ray inspection.

PULSED ULTRASONIC MEASUREMENTS IN CERAMIC MATERIALS AT HIGH TEMPERATURES
Fate, W. A. (Ford Motor Co., Dearborn, MI)
In Ceramics for High Performance Applications, 687-695, Brook Hill Pub. Co., Chestnut Hill, MA (1974)

Experimental methods for megacycle frequency, pulsed ultrasonic measurements at high temperatures are reviewed. Elastic-property data recently obtained for silicon nitride, silicon carbide, and a lithium-aluminum-silicate glass-ceramic are presented.

Key words: Analysis methods; ceramics; elastic properties; high temperature; instrumentation; ultrasonic tests.

IMPROVED DISCONTINUITY DETECTION IN CERAMIC MATERIALS USING COMPUTER-AIDED ULTRASONIC NONDESTRUCTIVE TECHNIQUES
Seydel, J. A. (Michigan Univ., Ann Arbor)
Ceramics for High Performance Applications, 697-709, Brook Hill Pub. Co., Chestnut Hill, MA (1974)

Previous efforts at testing hot-pressed Si_3N_4 ceramics with pulse-echo ultrasonics indicated that current ultrasonic systems do not have sufficient sensitivity and resolution to detect the expected material discontinuities. The ultrasonic sensitivity is limited by electrical noise from the ultrasonic transducer and amplifiers and by ultrasonic reflections from the random microstructure of the test piece. The ultrasonic resolution is limited by the restricted frequency response of the ultrasonic transducer. Three data processing techniques are described which improve the sensitivy and resolution of the ultrasonic system. Feasibility experiments demonstrating the effectiveness of these data processing techniques on nonceramic materials are discussed.

Key words: Ceramics; computer techniques; detection systems; material defects; NDI methods; NDI techniques; NDT methods; ultrasonic tests.

INVESTIGATION OF ACOUSTIC EMISSION FROM CERAMIC MATERIALS
Graham, L. J. and Alers, G. A. (Rockwell Science Center, Thousand Oaks, CA)
AD-745000 (May 1972)

The frequency content, amplitude distribution, and rate of occurrence of acoustic emissions generated in model ceramic materials were determined. Single crystal MgO and glass, used as models of a ductile and a brittle ceramic, were mechanically loaded by three different means to produce rapid crack growth, controlled slow crack growth, and plastic deformation in both four-point bending and by cyclic bending at 100 cycles per second. A method was developed for easily determining the frequency spectrum of a single acoustic emission over the frequency range of 1 kHz to 3 MHz. A video tape recorder was modified and used in conjunction with broadband transducers and amplifiers to record the acoustic emissions on magnetic tape and then play them back in "stop action" into a standard frequency spectrum analyzer. The main results of the tests with the model materials were that no acoustic emissions were detected before rapid crack growth commenced or during slow crack growth in glass. Rapid crack growth produced acoustic emissions which had characteristic features in their frequency spectra which seemed to depend on the size of the crack produced. Acoustic emissions were generated and were easily detected during plastic deformation of single crystal MgO in four-point bending and were also observed to occur at the stress maxima during cyclic fatigue loading of this material. The frequency spectra of these emissions was very much like those produced by a ductile metal.

Important References:

1. Romrell, D. M., and Bunnell, L. R., Acoustic Emission Monitors Crack Growth in Ceramic, Battelle Memorial Institute Report BNWL-SA-3064 (March 1970).

2. Gatti, A., Mehan, R. L., and Noone, M. S., Development of a Process for Producing Transparent Spinel Bodies, Naval Air Systems Command Contract N00019-71-C-0126 (December 1971).

3. Stokes, R. J., Dislocation Sources and the Strength of Magnesium Oxide Single Crystals, Honeywell Research Center Report HR-62-251 (January 1962).

4. Langitan, F. B., and Lawn, B. R., Hertzian Fracture Experiments on Abraded Glass Surfaces as Definitive Evidence for an Energy Balance Explanation of Auerbach's Law, J. Appl. Phys. 40, No. 10, 4009-17 (September 1969).

5. Mikosza, A. G., and Lawn, B. R., Section and Etch Study of Hertzian Fracture Mechanics, J. Appl. Phys. 42, No. 13, 5540-5 (December 1971).

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8. Graham, L. G., Frequency Analysis of Acoustic Noises During Fatigue Testing of the EBOR Nuclear Reactor Pressure Vessel, North American Rockwell/ Science Center Report SCTR-72-6 (April 1972).

Key words: Acoustic emission; ceramics; crack growth rate; crack propagation; cyclic loads; detection systems; fatigue (materials); laboratory tests; plastic deformation; test procedures.

IV, EFFECTIVENESS, STANDARDIZATION, AND UTILIZATION

NONDESTRUCTIVE TESTING OF BRAZED ROCKET ENGINE COMPONENTS

Hagemaier, D. J., Adams, C. J., and Meyer, J. A. (Rocketdyne, Canoga Park, CA)

Weld. J. (Miami, Fla.) 47, 789-792, 795-801 (October 1968)

This paper describes and illustrates radiographic, ultrasonic, thermographic, and leak-test methods and techniques used to nondestructively evaluate the quality of various brazed liquid propellant rocket engine components and assemblies.

It was found that the nondestructive testing of brazed assemblies falls into three categories: (1) radiography to determine braze-alloy flow; (2) ultrasonic and thermal-paint testing to detect lack of bonding; and (3) penetrant and gas tests to detect leaks.

Some unique techniques and equipment have been developed for inspection of complex assemblies. A description of the most interesting applications and results is given in this paper.

Important References:

1. Iacobellis, S. F., Liquid Rocket Engines: Their Status and Their Future, AIAA Paper No. 66-828, Boston, MA (1966).

2. Symp. NDT Stainless Steel Brazed Honeycomb Structures, Soc. NDT Publication No. 100, Evanston, IL (July 1959).

Key words: Aerospace vehicles; brazed structures; leak testing; NDE methods; NDE techniques; NDT methods; NDT techniques; penetrant inspection; radiography; ultrasonic tests.

NONDESTRUCTIVE TESTING TECHNIQUES FOR FIBERGLASS, GRAPHITE FIBER AND BORON FIBER COMPOSITE AIRCRAFT STRUCTURES
Hagemaier, D. J., McFaul, H. J., and Parks, J. T. (Douglas Aircraft Co., Inc., Long Beach, CA)
Mater. Eval. 28, No. 9, 194-204 (Spetember 1970)

Various NDT methods were evaluated for inspection and evaluation of boron, graphite and glass-fiber composites for aircraft structures. Typical specimens were evaluated using microscopic, fluorescent pentrant, radiographic, ultrasonic and thermochromic test methods. Optical microscopic examination is useful for determination of fiber pattern from the edge of a panel. It was concluded that fluorescent penetrant combined with microscopic examination is a useful tool to determine fiber pattern, fiber gaps, broken fibers, crushed core, and resin-rich areas; and ultrasonic and thermal methods appear to have merit for determining unbonded areas. The results of a literature survey concerning the NDT of composites are presented in abstracted form and indicate significant applications and limitations of various test methods. The direction of future NDT research and development efforts is indicated.

(FOR LISTING OF IMPORTANT REFERENCES, KEYWORDS AND A DUPLICATE ABSTRACT, SEE PAGE 94)

ASSURING SATURN QUALITY THROUGH NONDESTRUCTIVE TESTING
Neuschaefer, R. W. (National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, AL)
Mater. Eval. 27, No. 7, 145-152 (July 1969)

The Saturn V space vehicle is briefly described. The organizational responsibilities of NDT groups are discussed as well as the approach to management of research and development activities. Applications of the various nondestructive testing methods employed to evaluate materials and processes used in the manufacture of the various stages and major components are described. Emphasis is placed on a discussion of the special NDT methods and equipment developed to satisfy the unique requirements of the Apollo program. Advancements in the state-of-the-art, including a solid-state, radiographic image amplifier and an RF device suitable for measuring the thickness of non-metallics on metallic objects, are described.

(FOR LISTING OF IMPORTANT REFERENCES, KEYWORDS AND A DUPLICATE ABSTRACT, SEE PAGE 25).

NON-DESTRUCTIVE TESTING OF BONDED JOINTS
Norris, T. H. (Hawker Siddley Aviation, Ltd., Hatfield, England)
Non-Destruct Test (Guilford, Engl.) 7, 335-339 (December 1974)

This paper deals with the production aspects of controlling the manufacturing and testing of adhesive bonded primary aircraft structures. Whilst recognizing the requirement for in-service testing, the problems encountered are somewhat different and should be treated as a separate issue.

Key words: Adhesive bonding; aircraft structures; bond integrity; inspection; joints (junctions); material defects; reliability; structural safety.

FRACTURE TOUGHNESS AND NDT REQUIREMENTS FOR AIRCRAFT DESIGN
Packman, P. F. (Vanderbilt Univ., Nashville, TN).
J. Non-Destruct. Test. (Guilford, Engl), 314-324 (December 1973).

This paper reviews current design concepts of fracture toughness and NDT in fracture control programs for advanced aircraft. The dual role of fracture toughness for materials selection and for design where fatigue-crack growth is analyzed under constant-amplitude and spectrum loading. It is essential that the lower limit of detection be known with confidence. The materials are then chosen so that the critical flaw size is above this limit. From this knowledge the life of a particular design may be forecast for different conditions of service. The lifetime is influenced by both detection capabilities and changes in service conditions.

(FOR LISTING OF IMPORTANT REFERENCES, KEYWORDS AND A DUPLICATE ABSTRACT, SEE PAGE 70).

A MECHANIZED EDDY CURRENT SCANNING SYSTEM FOR AIRCRAFT STRUTS
Reeves, C. R. (Lockheed-Georgia Co., Marietta)
Mater. Eval. 31, No. 3, 48-52 (March 1973)

This paper describes the design and operation of a mechanized eddy current defect detection system used for scanning internal cylindrical surfaces. The single coil scanning apparatus traces a helical path. Cracks as small as 0.050 in. (1.27 mm) long by 0.020 in. (0.508 mm) deep can be reliably detected at scan rates up to 140 sq in. (910 sq cm) per minute. A unique electronic, audio/visual indicator is incorporated into the portable eddy current inspection system to provide recognizable defect indications at high speeds. A description of two specific applications on aircraft landing gear components is presented with data on operating parameters. A number of potential uses for this system are also discussed.

Key words: Aircraft structures; aluminum alloys; crack detection; detection systems; eddy currents; inspection procedures; NDI methods; NDI techniques; reliability; surface cracks.

NDT TECHNIQUES FOR AIRLINE MAINTENANCE INSPECTION
Weldon, W. J. (American Airlines, Inc., Tulsa, OK)
Qual. Prog. 3, 22-24 (November 1970)

Airline maintenance and use of NDT does not lend itself to automated or production line concepts. The range of NDT techniques employed by American Airlines is described. These include ultrasonic, eddy current, magnetic particle, penetrant, and x ray techniques. Due to the considerable expense of aircraft disassembly most inspections are performed on the aircraft. The unique methods and apparatus employed for these inspections in areas often of limited accessibility are described. It is shown that NDT is a valuable and expanding factor in the profit and safety record of today's airlines.

(FOR LISTING OF IMPORTANT REFERENCES, KEYWORDS AND A DUPLICATE ABSTRACT, SEE PAGE 24).

INFRARED PYROMETER FOR TEMPERATURE MONITORING OF TRAIN WHEELS AND JET ENGINE ROTORS
Wiederhold, P. R. (Comstock and Wescott, Inc., Cambridge, MA)
Mater. Eval. 32, No. 11, 239-243 and 248 (November 1974).

The infrared radiation pyrometer for non-contact temperature measurements of hot spots on rapidly rotating objects, such as turbine blades of operating jet engines, is discussed. The infrared optical pyrometer described makes such measurements while mounted at a convenient distance from the rotating object.

Important Reference:

1. Rohy, D.A., Duffy, T. E., and Compton, W. A., Radiation Pyrometer for Gas Turbine Blades, SAE Paper No. 720159, 10-14 (January 1972).

Key words: Detection systems; gas turbine engines; infrared radiation; NDE methods; NDE techniques; optical techniques; pyrometers.

DETECTION OF CRACKS UNDER INSTALLED FASTENERS
Raatz, C. F., Senske, R. A., and Woodmansee, W. E. (Boeing Commercial Airplane Co., Seattle, WA)
AFML-TR-74-80 (April 1974)

The objective of this program was the development of a reliable method of detecting cracks under installed fasteners, emphasizing improvement of the ultrasonic shear wave method. The program included the implementation of the developed method into a system suitable for on-line inspection of aircraft. The development method was in four main areas: (1) ultrasonic fastener-hole scanning techniques; (2) display of test information; (3) identification of transducer requirements; and (4) portable-scanner design. Ultrasonic shear-wave sound paths were identified for detection of fastener hole cracks in such diverse locations as upper and lower hole edges and base of countersink, and for test configurations of straight, countersunk, and taper shank holes 4.76 to 12.7 cm in diameter in aluminum, steel, and titanium alloys 3.8 to 19 mm thick. The influence on crack detection of surface finish, interface sealant, crack configuration, and corrosion was assessed. Two methods of data display were developed, both using circular display of ultrasonic test information on storage oscilloscope.

(FOR LISTING OF IMPORTANT REFERENCES, KEYWORDS AND A DUPLICATE ABSTRACT, SEE PAGE 79)

SIGNIFICANT REDUCTION IN UTILITY MAINTENANCE COSTS THROUGH ULTRASONICS
Collins, R. V. (Detroit Edison Co., MI)
Mater. Eval. 24, No. 2, 109-110 (February 1966)

Nondestructive testing has become an important phase of maintenance operations at the power plants of the Detroit Edison Company. During turbine and boiler overhauls, most of the major nondestructive testing methods are included as an integral part of the scheduled maintenance program. The present status of nondestructive testing in the company has been achieved by a diligent effort to inform management and supervisory personnel of the test principles involved, and the economic advantage offered by the various methods. As a result, numerous examples can be cited whereby maintenance costs have been significantly reduced through the use of NDT techniques.

The purpose of this paper is to describe, briefly, an example which emphasizes the economic advantage of using ultrasonic techniques. This example concerns 30-year inspections of boilers, and illustrates how mutual understanding and cooperation between city authorities and company representatives resulted in significant dollar savings to the company, as well as improving the quality of the boiler inspection. The test procedures employed were straightforward applications of ultrasonic test principles.

Comment:

Cost reduction in the inspection of boilers through the use of ultrasonic NDT is discussed. Previous visual methods of inspection proved costly because it was required to remove the insulation from the parts in question. This insulation, which had become dry and brittle after many years of use had to be replaced with new insulation. By using ultrasonics, labor cost for removal and installation of insulation and the cost of new insulation was reduced to a minimum. Ultrasonic methods were used to measure the wall thickness of drums, headers, and tube ends. This was done from the inside surface, eliminating the need for removing insulation. In addition to thickness measurements, gross laminar flawa and embrittlement cracks were also detected.

Key words: Costs; economic factors; effects; inspection; maintenance; material defects; NDI methods; pressure vessels; ultrasonic tests.

THE ROLE OF NDT IN AN ELECTRIC UTILITY
Collins, R.V. (Detroit Edison Co., MI)
Mater. Eval. 30, No. 8, 174-180 (August 1972)

Applications of NDT in an electrical utility are summarized. In addition to the expected applications during turbine and boiler overhaul periods the author describes NDT techniques used in surveillance programs such as: (1) detection of heart rot in wooden poles; (2) location of overheated electrical connections on overhead lines by aerial survey; (3) leak detection in underground steam lines; and (4) determination of the integrity of large rotor forgings. Currently, three experimental programs are underway to investigate techniques to detect potential boiler tube failures during a scheduled outage period: (1) infrared scanning system, (2) radiation survey to detect chemical reaction between radioactive salts and ID deposits, and (3) comparative analysis of acoustic emission characteristics of corroded and non-corroded tubes.

(FOR LISTING OF KEYWORDS AND A MORE COMPLETE ABSTRACT, SEE PAGE 22).

IVC - Design/Analysis

QUANTITATIVE CAPABILITIES OF ACOUSTIC EMISSION FOR PREDICTING STRUCTURAL FAILURE

Dunegan, H. L. (Dunegan/Endevco, San Juan Capistrano, CA)

Prevention of Structural Failure - The Role of Quantitative Nondestructive Evaluation, Amer. Soc. Metals, Materials/Metalworking Technol. Series No. 5, 86-113 (1975)

The combination of acoustic emission and linear fracture mechanics can provide quantitative information regarding structural failure. This report shows that for certain situations acoustic emission techniques can be used to accurately estimate the stress intensity factor at a growing crack, and therefore provide predictive information regarding structural failure. The importance of locating defects in large structures is also stressed, and a multiple-channel computer system is described for accomplishing this function. The ability to locate a growing defect, coupled with the ability to quantify the growth rates with fixed sensors (no scanning required) places acoustic emission in the forefront of new techniques for the prevention of structural failure.

Important References:

1. Dunegan, H. L., Harris, D. O., and Tatro, C. A., Fracture Analysis by the Use of Acoustic Emission, Eng. Fract. Mech. 1, 105-112 (1968).

2. Dunegan, H. L. and Tetelman, A. S., Characterization of Hydrogen Embrittlement Cracking by Use of Acoustic Emission Techniques, Eng. Fract. Mech. 2, No. 4, 387-402 (June 1971).

3. Gerberich, W. W. and Hartbower, C. E., Monitoring Crack Growth of Hydrogen Embrittlement and Stress Corrosion Cracking by Acoustic Emission, Proc. Conf. Fundamental Aspects of SCC, Ohio State Univ., Columbus (1967).

4. Magnani, N. J., Acoustic Emission and Stress-Corrosion Cracking of U-4-½ Wt. % Nb, Exp. Mech. 13, No. 12, 526-530 (December 1973).

5. Dunegan, H. L. and Harris, D. O., Detection of Fatigue Crack Growth by Acoustic Emission Techniques, Mater. Eval. 28, No. 10, 221-227 (October 1970).

6. Harris, D. O., Dunegan, H. L., and Tetelman, A. S., Prediction of Fatigue Lifetime by Combined Fracture Mechanics and Acoustic Emission Techniques, AFFDL-TR-70-184, 459-471 (1970).

Key words: Acoustic emission; cracking (fracturing); critical flaw size; design procedures; detection systems; failures (materials); fracture strength; hydrogen embrittlement; inspection procedures; material defects; plastic deformation; quantitative analysis; stress corrosion cracking; structural failure; structural safety.

USING NONDESTRUCTIVE TESTING EFFECTIVELY
Heine, H. J. (Foundry Management and Technology, Cleveland, OH)
Foundry 103, No. 4, 22-29 (April 1975).

Judicious application of nondestructive testing techniques, whether to assure soundness of components or strict adherence to tolerance standards, can reduce both the cost of casting production and scrap percentage effectively. This article is the first of a series that will review and evaluate commonly applied NDT techniques, including liquid penetrants, radiographic methods, magnetic particle testing, ultrasonics, use of eddy current, and others.

(FOR LISTING OF IMPORTANT REFERENCES, KEYWORDS AND A DUPLICATE ABSTRACT, SEE PAGE 129)

THE PHILOSOPHY OF NONDESTRUCTIVE TESTING AS AN ADJUNCT TO THE DESIGN PROCESS AND PRODUCT ANALYSIS
McFaul, H. J. (Douglas Aircraft Co., Inc., Long Beach, CA)
Mater. Eval. 30, No. 4, 18A-22A (April 1972)

The fundamental relationship of NDT to aircraft design and reliability is described. The resulting simplification of an effective maintainability program through the use of NDT methods for predictive fatigue life analysis and in-service monitoring is also discussed. It is concluded that aircraft being produced today owe their success in reliability to: (1) initial good design; (2) critical examination of part services by applicable NDT methods; (3) realistic fatigue life studies of the entire aircraft; its systems and individual components, and (4) design for realistic but conservative maintenance. For the cost of large aircraft to remain competitively commensurate with their service value, the applications of NDT must be justified and not indiscriminately applied.

Key words: Aircraft design; crack detection; critical flaw size; design criteria; design procedures; NDT methods; reliability analysis.

NONDESTRUCTIVE TESTING FOR EVALUATION OF STRENGTH OF BONDED MATERIALS
Schmitz, G. and Frank, L. (General American Transportation Corp., Niles, IL)
NASA CR-67983 (September 1965).

The theoretical and experimental investigation of various techniques for nondestructively testing for bond strength are described. Existing nondestructive test techniques are mainly effective for detecting complete lack of bond in adhesively bonded structures. Techniques investigated included: acoustic emission, bond line electrical parameters, strain sensitive coatings, and ultrasonic attenuation as a function of bond stress. The ultrasonic emission of a bond line under stress was found to be a reliable indication of bond strength. A definite need was found for a widely applicable bond stress method.

(FOR LISTING OF IMPORTANT REFERENCES, KEYWORDS AND A DUPLICATE ABSTRACT, SEE PAGE 100).

FRACTURE MECHANICS AIRCRAFT STRUCTURAL DESIGN APPLICATION AND RELATED RESEARCH
Wood, H. A. and Tupper, N. (Air Force Flight Dynamics Lab., Wright-Patterson AFB, OH; Air Force Materials Lab., Wright-Patterson AFB, OH)
Proc. Int. Cong. Fracture, 3rd, Munich (April 8-13, 1973).

Fracture control requirements to ensure safety by reducing the probability of catastrophic failure due to undetected damage as instituted by the U. S. Air Force in the design of current and future systems are described. These include various aspects of material and process selection, material procurement and control, NDI and damage tolerance analyses and testing.

(FOR LISTING OF IMPORTANT REFERENCES, KEYWORDS AND A DUPLICATE ABSTRACT, SEE PAGE 72).

COMPUTERIZED INFORMATION RETRIEVAL - FOR NONDESTRUCTIVE TESTERS A NONDESTRUCTIVE MEMORY
Bridges, W. H. and McClung, R. W. (Oak Ridge National Lab., TN)
Mater. Eval. 27, No. 9, 199-204 (September 1969)

An Information Center was formed at the Oak Ridge National Laboratory to store and allow systematic retrieval of the rapidly growing literature on the subject of nuclear fuel technology. Such a subject is very broad, encompassing materials, methods, management, economics, operational characteristics and testing. Since all methods of NDT are, or may be, applicable to the technology, much of the NDT literature is within the scope of the Information Center. Bibliographic information and abstracts entered into a large computer together with appropriate keywords may be manipulated to recall anything from very general bibliographies to information on a very specific question. The types of retrieval and experience with the computerized information system will be discussed.

Important References:

1. Pilloton, R. L., NUFTIC, An Information Center on Nuclear Fuel Technology, ORNL-TM-1358 (March 1966).

2. Staats, H. N., Data Extraction in Nondestructive Testing, Nondestruct. Test. 15, No. 1, 44-46 (1957).

3. Bridges, W. H. and Pilloton, R. L., A Thesaurus of Keywords on Nuclear Fuel Technology, ORNL-TM-1285 (November 1965).

4. Buchanan, J. R. and Hutton, F. C., Analysis and Automated Handling of Technical Information at the NSIC, Nuclear Safety 8, 95-102 (1966-1967).

Key words: Bibliographies; computer techniques; information; test procedures.

X-RAY MAPPING OF FLAWS BY COMPUTER GRAPHICS
Hartmann, F. (North American Rockwell Corp., Downey, CA)
Mater. Eval. 27, No. 8, 169-179 (August 1969)

A new process that gives a three-dimensional picture of the shape and location of invisible discontinuities (gas holes, cracks, etc.) in metallic or nonmetallic materials has been reduced to practice.

Two x ray films of the defective structure are taken from different angles, with a provision for accurate registration between them. A standard wedge of the same composition is x rayed simultaneously. Density readings obtained from microdensitometer scans at given intervals are converted into thickness values, with a correction for scattering if necessary. The resulting data are digitized and put on tape. This is fed into a specially built "shape reconstruction computer," which, by means of a novel super-position algorithm, computes for each scan the cross section of the defect and displays it on its cathode ray tube. Tape feed, computation and photography of the CRT display take only a few seconds. A series of cross sections yields a three-dimensional picture.

Samples of sheet aluminum and welds containing defects were analyzed in this manner. Very good agreement was obtained when computer-derived pictures of the shape and location of the defects were compared with photographic enlargements of the sectioned samples.

(FOR LISTING OF IMPORTANT REFERENCES, KEYWORDS AND A DUPLICATE ABSTRACT, SEE PAGE 68).

DATA ANALYSIS AND CORRELATION WITH DIGITAL COMPUTERS - NONDESTRUCTIVE TESTING
Mann, Jr., L. and Young, M. H. (Louisiana State Univ., Baton Rouge)
AD-876922 (1970)

The feasibility of using the digital computer to discern differences in analog signals obtained by tapping bars of different sizes and shapes was established. The ability of the system to differentiate between heat treated and non heat treated bars was demonstrated. A formula to predict these changes was evolved. Attempts to adopt the program to the hybrid computer were made with considerable success. It is anticipated that these efforts will culminate in an on-line, real-time, computerized NDT system.

Efforts were initiated to determine the sensitivity of the computer program to discern slight changes in dimensions and the degree of stress to which a steel bar is or has been subjected.

Key words: Computer programs; detection systems; NDT methods; NDT techniques; statistical analysis; x ray inspection.

ULTRASONIC DATA ANALYSIS USING A COMPUTER

Sachs, R. D., Elkins, J. D., and Smith, J. H. (Union Carbide Corp., Oak Ridge, TN)

Mater. Eval. 30, No. 6, 121-125 and 135 (June 1972).

A digital computer was used to analyze the data obtained from the ultrasonic inspection of a weld. The computer was interfaced to a standard ultrasonic flaw detector and to the scanning mechanism. The computer automatically determined the size of a flaw and its location on the test part as the test was conducted semiautomatically.

Important Reference:

1. Elkins, J. D., Sachs, R. D., and Austin, L. A., An Investigation of Ultrasonic Data Analysis Using a Multichannel Analyzer or Equivalent Circuitry, Union Carbide Corp., Oak Ridge, TN (December 1969).

Key words: Analysis methods; computer programs; computer techniques; data; inspection procedures; NDI techniques; NDT techniques; ultrasonic tests; welded structures.

IVE - Standardization

ULTRASONIC REFERENCE STANDARDS KEY TO RELIABLE ULTRASONIC INSPECTION
Ellerington, H. (Automation Industries, Inc., Boulder, CO)
Mater. Eval. 28, No. 11, 251-256 (November 1970).

Ultrasonic inspection procedures are based on the use of reference standards manufactured from carefully selected materials in which calibrated discontinuities have been machined. The proper use of reference standards provides uniform inspection criteria that have significant meaning when used to describe inspection results. This paper describes the numerous types of reference standards being used throughout the industry today and discusses the importance of standards and some of the precautions relative to their use in ultrasonic inspection processes.

Key words: Calibration standards; inspection procedures; NDE methods; NDI methods; ultrasonic tests.

THE HUMAN ELEMENT IN NONDESTRUCTIVE TESTING
Hovland, H.
Mater. Eval. 27, No. 12, 13A-15A, 18A-19A (December 1969).

This Mehl Honor Lecture to the 1969 ASNT Fall Conference in Philadelphia, PA discusses the growth in acceptance and application of NDT and some associated problems. Increase in utilization of NDT has brought with it the need to have guidelines in industry by which to train, examine, and evaluate NDT skills. Hovland pays particular tribute to the ASNT program publishing recommended practices for the qualification and certification of NDT personnel. He notes that it is a three-phase program which recommends: (1) three basic levels of qualification; (2) a training course outline for each NDT method; and (3) an examination and testing system whereby applicants could demonstrate their qualifications. Recommendations for administration of NDT personnel certification are also offered. The ASNT document referenced attempts to establish the profile for a qualified NDT operator.

(FOR LISTING OF KEYWORDS AND A DUPLICATE ABSTRACT, SEE PAGE 28).

CORRELATION AND ANALYSIS OF ULTRASONIC TEST RESULTS IN EVALUATING REINFORCED RESIN LAMINATES
Schultz, A. W. (AVCO Corp., Lowell, MA)
Mater. Res. Stand. 7, No. 8, 341-345 (August 1967).

Correlation between ultrasonic longitudinal bulkwave velocity and density, and between elastic modulus and velocity has been experimentally determined for carbon fabric-phenolic resin laminated fabrications. A comparison of the experimental results with those from mathematical analysis indicates that the analysis can be used to predict correlation variability and characterize the correlations themselves with good accuracy. One valuable quantity determinable from these two correlations is Poisson's ratio. Although the results of the analysis are not new, the method used is unique, provides insight into materials evaluation, and can be applied to other materials and correlations.

(FOR LISTING OF IMPORTANT REFERENCES, KEYWORDS AND A DUPLICATE ABSTRACT, SEE PAGE 97)

CONSIDERATIONS FOR ESTABLISHING ULTRASONIC TEST ACCEPTANCE STANDARDS
Sinclair, N. (General Dynamics Corp., Groton, CT)
Mater. Eval. 25, No. 5, 118-125 (May 1967).

Weld-defect characteristics which govern the failure of a pressure vessel are examined, and ultrasonic methods for determining these characteristics are discussed. Assuming that data on slow crack-growth rate and critical crack size for the inception of catastrophic failure are available, a method for establishing ultrasonic acceptance standards is presented. Ultrasonic weld-inspection acceptance standards presently in use are presented for comparison.

Important References:

1. Lovelace, J., Luini, L. and Cook, D., Ultrasonic Inspection of Hull Butt Welds, Final Report Contract NObs-90445 (January 14, 1966).

2. Greenberg, H., An Engineering Basis for Establishing Radiographic Acceptance Standards for Porosity in Steel Weldments, ASME Paper 64-WA/MET-3, ASME Annu. Meet. (1964).

Key words: Acceptance criteria; inspection standards; material defects; NDI methods; NDI techniques; pressure vessels; radiography; ultrasonic tests; welded structures.

SERVICE CORRELATION - THE KEY TO SUCCESSFUL NONDESTRUCTIVE TESTING
Smiley, R. W. (Naval Polaris Missile Facility Pacific, Bremerton, WA)
Mater. Res. Stand. 6, No. 3, 149-154 (March 1966).

A nondestructive testing system for the Polaris missile is described. There are six successful steps for a good NDT program: select those attributes that must be examined, try known NDT techniques on selected attributes to see if they will show what we want to see, verify validity of techniques, establish the effect on performance of measurable anomalies, select best NDT techniques, and eliminate redundant NDT tests after production has started. Seven common pitfalls to be avoided in the development of a NDT program are listed.

Comment:

This paper was originally presented in a Symposium on NDT Methods for the Aerospace Industry, held during the Fifth Pacific Area National Meeting of ASTM, Seattle, WA, November 5, 1965. The author makes a well-organized case relating NDT to hardware reliability. Significant to the purpose of this Technology Survey is what the author describes as the "Seventh Pitfall" to be avoided in the development of an NDT program. This pitfall is identified as "the failure to require that NDT and reliability personnel predict the performance of hardware they have inspected." This requirement was found "to be an extremely useful management tool, since it provides a strong incentive for the NDT and reliability personnel to refine and sharpen their techniques and to replace subjective analysis with an objective measurement wherever possible."

Key words: Acceptance criteria; inspection procedures; inspection standards; material defects; NDI techniques; NDT techniques; reliability analysis.

ON-LINE AUTOMATIC HIGH SPEED INSPECTION OF CARTRIDGE CASES

Coleman, W. J., Reich, F. R., Erickson, M. D., and Kelly, W. S.
(Battelle-Northwest, Richland, WA)
ASTM Stand. News 3, No. 3, 31-34 (March 1975)

An automatic inspection and reject system has been developed for a production application to small caliber cartridge cases. It has undergone initial quality assurance testing and will soon go on-line at Frankford Arsenal. This system gages case profile, surface flow, wall thickness, and vent hole presence. A mechanical handling system coupled with computer control and data acquisition automatically inspects and rejects 5.56 mm cases at the rate of 1200 per minute. Electro-optical techniques are used to inspect case profile, surface flaws, and vent hole presence. Profile monitoring of individual cases at high production line speeds is accomplished with an optical diode array gaging technique. Optical scattering, using a line source and fiber optic receiver system, is used to monitor cartridge case surface flows and two optical transducers perform quality assurance inspection of cartridge cases to verify the presence of the primer vent. Eddy current techniques are used to determine wall thickness. Cases are rotated past four elongated eddy current coils to produce a circumferential thickness profile. Information from the multiple inspection units is fed into the data acquisition and control computer. Operator communication with the quality assurance system is via video display, printer output and a computer function keyboard input. Outputs include hourly trend data and throughput alarm conditions to alert the operator when the number of rejected cases exceeds a preset threshold.

Key words: Automation; eddy currents; fiber optics; inspection; inspection standards; material defects; NDI techniques; optical techniques; thickness measurements.

NONDESTRUCTIVE TESTING OF BRAZED ROCKET ENGINE COMPONENTS
Hagemaier, D. J., Adams, C. J., and Meyer, J. A. (Rocketdyne, Canoga Park, CA)
Weld J. (Miami, FL) 47, 789-792, 795-801 (October 1968)

This paper describes and illustrates radiographic ultrasonic, thermographic, and leak-test methods and techniques used to nondestructively evaluate the quality of various brazed liquid-propellant rocket engine components and assemblies.

It was found that the nondestructive testing of brazed assemblies falls into three categories: (1) radiography to determine braze-alloy flow; (2) ultrasonic and thermal-paint testing to detect lack of bonding; and (3) penetrant and gas tests to detect leaks.

Some unique techniques and equipment have been developed for inspection of complex assemblies. A description of the most interesting applications and results is given in this paper.

(FOR LISTING OF IMPORTANT REFERENCES, KEYWORDS AND A DUPLICATE ABSTRACT, SEE PAGE 23).

ASSURING SATURN QUALITY THROUGH NONDESTRUCTIVE TESTING
Neuschaefer, R. W. (National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, AL)
Mater. Eval. 27, No. 7, 145-152 (July 1969)

The Saturn V space vehicle is briefly described. The organizational responsibilities of NDT groups are discussed as well as the approach to management of research and development activities. Applications of the various nondestructive testing methods employed to evaluate materials and processes used in the manufacture of the various stages and major components are described. Emphasis is placed on a discussion of the special NDT methods and equipment developed to satisfy the unique requirements of the Apollo program. Advancements in the state-of-the-art, including a solid-state, radiographic image amplifier and an RF device suitable for measuring the thickness of non-metallics on metallic objects, are described.

(FOR LISTING OF IMPORTANT REFERENCES, KEYWORDS AND A DUPLICATE ABSTRACT, SEE PAGE 25).

AUTOMATED CRACKED NUT SORTING WITH EDDY CURRENT NDT
Niskala, J. H. and Carson, R. D. (Lamson and Sessions Co., Cleveland, OH; Automation Industries, Inc., Ann Arbor, MI)
Mater. Eval. 27, No. 7, 153-158 (July 1969)

An automated system has been developed for the inspection and sorting of nuts at the rate of 100 parts per minute or greater. The system has been designed to accommodate a variety of nut shapes and sizes with minor tooling changeover and set-up adjustment. The multistation system utilizes eddy current NDT instrumentation to detect forging cracks, seams, bursts, quench cracks, etc., on both the bearing surfaces and crown surfaces of nuts. In addition, the system employs an automated plugging station to check the internal condition of tapped threads and, in the case of self-locking nuts, the presence of the locking element.

A description of the machine design, eddy current instrumentation, system operating features including defect detection capability, operating speed and inspection reliability is presented. This system is thought to be the first of its kind and represents an important contribution to volume production capability for inspecting high-quality, high-strength, high-reliability fasteners--important in automotive, aerospace and other industries.

Key words: Automation; detection systems; eddy currents; inspection procedures; material defects; NDI techniques; NDT techniques; reliability.

A MECHANIZED EDDY CURRENT SCANNING SYSTEM FOR AIRCRAFT STRUTS
Reeves, C. R. (Lockheed-Georgia Co., Marietta)
Mater. Eval. 31, No. 3, 48-52 (March 1973)

This paper describes the design and operation of a mechanized eddy current defect detection system used for scanning internal cylindrical surfaces. The single coil scanning apparatus traces a helical path. Cracks as small as 0.050 in. (1.27 mm) long by 0.020 in. (0.508 mm) deep can be reliably detected at scan rates up to 140 sq in. (910 sq cm) per minute. A unique electronic, audio/visual indicator is incorporated into the portable eddy current inspection system to provide recognizable defect indications at high speeds. A description of two specific applications on aircraft landing gear components is presented with data on operating parameters. A number of potential uses for this system are also discussed.

(FOR LISTING OF IMPORTANT REFERENCES, KEYWORDS AND A DUPLICATE ABSTRACT, SEE PAGE 111).

INFRARED PYROMETER FOR TEMPERATURE MONITORING OF TRAIN WHEELS AND JET ENGINE ROTORS
Wiederhold, P. R. (Comstock and Wescott, Inc., Cambridge, MA)
Mater. Eval. 32, No. 11, 239-243 and 248 (November 1974)

The infrared radiation pyrometer for non-contact temperature measurements of hot spots on rapidly rotating objects, such as turbine blades of operating jet engines, is discussed. The infrared optical pyrometer described makes such measurements while mounted at a convenient distance from the rotating object.

(FOR LISTING OF IMPORTANT REFERENCES, KEYWORDS AND A DUPLICATE ABSTRACT, SEE PAGE 112).

COST/EFFECTIVENESS IN NONDESTRUCTIVE TESTING
Bogart, H. G. (Magnaflux Corp., New York, NY)
Mater. Eval. 26, No. 4, 23A-26A (March 1968)

Some of the benefits of NDT including the role it plays in reliability and safety in modern industry are discussed. Factors which affect the cost of NDT, such as research and development, equipment installation, and operating costs are included. It is pointed out that the conventional economics of NDT are shifting to a new field where all known factors, tangible and intangible, will be included in an organized fashion in the decision making process. In this paper, originally presented at the 1967 ASNT Fall Conference in Cleveland, OH (16-19 October) the author credits his experience at ICAF as providing inspiration for the paper. There are no references.

Key words: Analysis methods; costs; failure prevention; NDT methods; NDT techniques; safety.

SIGNIFICANT REDUCTION IN UTILITY MAINTENANCE COSTS THROUGH ULTRASONICS
Collins, R. V. (Detroit Edison Co., MI)
Mater. Eval. 24, No. 2, 109-110 (February 1966)

Nondestructive testing has become an important phase of maintenance operations at the power plants of The Detroit Edison Company. During turbine and boiler overhauls, most of the major nondestructive testing methods are included as an integral part of the scheduled maintenance program. The present status of nondestructive testing in the Company has been achieved by a diligent effort to inform management and supervisory personnel of the test principles involve, and the economic advantage offered by the various methods. As a result, numerous examples can be cited whereby maintenance costs have been significantly reduced through the use of NDT techniques.

The purpose of this paper is to describe, briefly, an example which emphasizes the economic advantage of using ultrasonic techniques. This example concerns 30-year inspections of boilers, and illustrates how mutual understanding and cooperation between City authorities and Company representatives resulted in significant dollar savings to the Company, as well as improving the quality of the boiler inspection. The test procedures employed were straight forward applications of ultrasonic test principles.

Comment:

Cost reduction in the inspection of boilers through the use of ultrasonic NDT is discussed. Previous visual methods of inspection proved costly because it was required to remove the insulation from the parts in question. This insulation, which had become dry and brittle after many years of use had to be replaced with new insulation. By using ultrasonics, labor cost for removal and installation of insulation and the cost of new insulation were reduced to a minimum. Ultrasonic methods were used to measure the wall thickness of drums, headers, and turf ends. This was done from the inside surface, eliminating the need for removing insulation. In addition to thickness measurements, gross laminar flaws and embrittlement cracks were also detected.

Key words: Costs; economic factors; effects; inspection; maintenance; material defects; NDI methods; pressure vessels; ultrasonic tests.

USING NONDESTRUCTIVE TESTING EFFECTIVELY
Heine, H. J. (Foundry Management and Technology, Cleveland, OH)
Foundry <u>103</u>, No. 4, 22-29 (April 1975)

Judicious application of nondestructive testing techniques, whether to assure soundness of components or strict adherence to tolerance standards, can reduce both the cost of casting production and scrap percentage effectively. This article is the first of a series that will review and evaluate commonly applied NDT techniques, including liquid penetrants, radiographic methods, magnetic particle testing, ultrasonics, use of eddy current, and others.

Important Reference:

1. McMaster, R. C., <u>Nondestructive Testing Handbook</u>, Ronald Press (1959).

Key words: Castings; costs; design criteria; eddy currents; inspection standards; magnetic particles; NDT methods; penetrant inspection; radiography; ultrasonic tests.

THE HUMAN ELEMENT IN NONDESTRUCTIVE TESTING
Hovland, H.
Mater. Eval. 27, No. 12, 13A-15A, 18A-19A (December 1969)

This Mehl Honor Lecture to the 1969 ASNT Fall Conference in Philadelphia, PA discusses the growth in acceptance and application of NDT and some associated problems. Increase in utilization of NDT has brought with it the need to have guidelines in industry by which to train, examine, and evaluate NDT skills. Hovland pays particular tribute to the ASNT program publishing recommended practices for the qualification and certification of NDT personnel. He notes that it is a three-phase program which recommends: (1) three basic levels of qualification; (2) a training course outline for each NDT method; and (3) an examination and testing system whereby applicants could demonstrate their qualifications. Recommendations for administration of NDT personnel certification are also offered. The ASNT document referenced attempts to establish the profile for a qualified NDT operator.

Key words: Human factors; inspection standards; NDI techniques; NDT techniques; recommended practices; test standards.

A MANAGER LOOKS AT NONDESTRUCTIVE TESTING
Kirchner, W. R. (Aerojet-General Corp., Sacramento, CA)
Mater. Eval. 23, No. 6, 271-278 (June 1965)

NDT is extremely critical in the successful manufacture of solid rocket motors. Both the crude stock and the final part must be inspected without damage to its integrity to assure delivery of a safe product to the customer. In this paper some of the equipment used to inspect both completed motors and inert hardware at various stages of fabrication are described. It is shown that the cost of such rigid control of materials and processes is considerable but not too much relative to the alternatives. Major advantages obtained from use of NDT in the missile industry are listed as: (1) maximum developmental and analytical data from a minimum number of test firings; (2) accomplishment of accurate failure analyses; (3) early detection of flaws in components or full-scale motors, permitting corrective action which tends to maintain a higher reliability record for units released in the field; (4) minimized development and production costs, improving competitive position; and (5) providing a final assurance of the quality of production units.

Key words: Aerospace vehicles; analysis methods; cost analysis; costs; design criteria; economic analysis; inspection; NDT methods; NDT techniques; safety criteria.

AN ASSESSMENT OF EDUCATION IN NONDESTRUCTIVE TESTING - PRESENT STATUS AND THE FUTURE NEEDS (Parts 1 and 2)
Serabian, S. (Lowell Technological Inst. Res. Foundation, MA)
Mater. Eval. 27, No. 4, 14A-20A and 30A-33A (April 1969); Mater. Eval. 27, No. 5, 18A-20A, 22A-24A, and 29A-30A (May 1969)

This paper discusses the present (1969) status of educational programs available to the field of nondestructive testing. The prime source of the material for the paper is a survey by the Educational Council of the American Society for Nondestructive Testing. It was noted that the programs available are directed to a wide assortment of personnel working in the sciences and engineering fields on both the professional and technician levels. The teaching facilities can be categorized as those emanating from industry, government, professional socities and the full spectrum of the formal educational institutions: i.e., from the vocational high school to the undergraduate and graduate curricula of the colleges. The objectives, teaching methods and needs of each teaching facility are presented and form a datum plane to reference recommendations for improving the teaching of nondestructive testing. It is concluded that there is a continuing and critical need for more and better NDT education to meet the demands of industry and government.

Important References:

1. Anon., One Year Old - Your Educational Council, Mater. Eval. 25, No. 10, 11A (October 1967).

2. Anon., The Pressure Builds for Nondestructive Testing: Codes, Liability, Education, Welding, Design and Fabrication, 52 (February 1968).

Key words: Analysis methods; education; NDI methods; NDT methods; NDT techniques.

AN INVESTIGATION OF THE EFFECTIVENESS OF MAGNETIC PARTICLE TESTING
Gulley, Jr., L. R. (Air Force Materials Lab., Wright-Patterson AFB, OH)
AFML-MX-73-5 (October 1973)

This paper describes a program to sample the effectiveness in NDI of a group of organizations to obtain some insight into the level of application of magnetic particle testing technology. A selection of 24 parts with known detectable flaws was circulated to eleven organizations for examination. The average participant detected only 47 percent of the flaws existing in the parts. Sophisticated equipment and a clean, well-organized work area do not necessarily indicate that effective magnetic particle inspection will be conducted. Flaw size appeared to be not as important a variable as is technique and such variables as bath concentration and field strength. Flaw size could not be related to frequency of detection because, frequently, improper orientation of the part in the magnetic field did cause flaws as long as 3/8 inch to be missed. The opinion is ventured that more proper application of magnetic particle testing could have increased the scores of those participants with 60 percent or below to 90 percent or above; i.e., state-of-the-art knowledge was under-applied by all but one of the participants.

Important References:

1. Anon., Results of Magnetic Particle Inspection Detection Capability NDI Demonstration Program, TFD-72-768, North American Rockwell, Los Angeles, CA (June 1972).

2. Anon., Evaluation and Optimization of NDT Techniques for Flaw Detection in D6AC Steel, FZM-5795, ARL-General Dynamics - Fort Worth, TX (August 1972).

3. Anon., Eddy Current Measurement of Magnetic Flux Density, AFML-TR-72-115 (November 1972).

Key words: Aircraft structures; crack detection; detection systems; engineering standards; inspection standards; magnetic particles; material defects; NDI methods; NDI techniques; reliability.

PRACTICAL SENSITIVITY LIMITS OF PRODUCTION NONDESTRUCTIVE TESTING METHODS IN ALUMINUM AND STEEL

Southworth, H. L., Steel, N.W., and Torelli, P. P. (Boeing Commercial Airplane Co., Seattle, WA)

AFML-TR-74-241 (March 1975)

This report describes the work accomplished during an 18-month program conducted to evaluate the sensitivity capabilities of current state-of-the-art NDI methods. The methods included magnetic particle, penetrant, eddy current, ultrasonic, and radiographic. These capabilities were demonstrated in response to varied surface flaws and were statistically defined in terms of probability and confidence of detection. This was accomplished with differing specimen configurations in two representative aircraft structural alloys and for both laboratory and production inspections.

Two innovative approaches to the development and fabrication of controlled, reproducible surface discontinuities in the inspection test specimens were reported. The primary approach was to place electrodischarge machined (EDM) slots in grooved specimen blanks and to subsequently compress these blanks to close the slots by permanent, plastic deformation. The blanks were then machined to configurations of varying degrees of complexity. The second approach utilized the combined effects of controlled introduction of hydrogen into the specimen surface and the presence of residual or applied stresses. The development of the methodology and the fabrication of the numerous and varied specimens are described in sufficient detail to allow duplication.

Repeated inspections of all specimens were performed both in the laboratory and in production areas to provide a statistically meaningful data base for each of the NDI methods. A broad variety of equipment, technique differences, and skills, within the confines of accepted practice and specification control, was included to accurately represent industry practice. Selected specimen discontinuities were further investigated, including destructive examinations, to characterize and confirm the flaw geometries. Using the test results in a statistical analysis, the sensitivity capabilities of the five NDI methods were determined in terms of 0.90 probability of detection with 95 percent confidence for a given flaw size. Comparative capabilities such as between laboratory and production inspections, methods, and flaw types are shown for differences of significance. The test data and statistical analysis results are detailed in this report.

Comment:

This is one report of a series of public releases on a very active and valuable reliability program. Another and recent presentation, "Reliability of Conventional NDE Methods for Surface Flaws" by Torelli and Southworth, was made to the October 1975 ASNT Fall Meeting in Atlanta, GA. Information from the use of reliable surface flaw detection techniques is necessary as an essential data base in the application of fracture, mechanics concepts to structural designs. The study program described is making a significant contribution toward this end.

Important Reference:

1. Fletcher, E. E. and Elsea, A. R., Hydrogen Movement in Steel - Entry Diffusion and Elimination, DMIC Report 219 (June 1966).

Key words: Calibration standards; crack detection; detection systems; eddy currents; inspection procedures; inspection standards; laboratory tests; magnetic particles; NDI methods; penetrant inspection; radiography; reliability; statistical analysis; ultrasonic tests.

EVALUATION OF THE RELIABILITY AND SENSITIVITY OF NDT METHODS FOR TITANIUM ALLOYS

Lord, R. J. (McDonnell-Douglas Corp., St. Louis, MO)

AFML-TR-73-107 (March 1973)

A program to improve NDT techniques and to determine the detection capability of the improved NDT techniques is being sponsored by the Air Force. Several penetrant inspection parameters have been investigated. The minimum penetrant dwell time required to detect a variety of discontinuities was found to be 10 minutes for water washable (Group V) fluorescent penetrant and 20 minutes for post-emulsifiable (Group V) fluorescent penetrant. The minimum penetrant bleed-out time was 5 minutes for each. Either a dry powder or nonaqueous wet developer was preferable for both penetrant systems over aqueous wet developer or no developer at all. The maximum emulsification time for the post-emulsifiable penetrant system was less than 3 minutes. Overwashing during the removal of excess penetrant was found to occur as a function of water spray pressure and water temperature for both post-emulsifiable fluorescent penetrant and water washable penetrant systems. Future work will be conducted to improve ultrasonic, eddy current, penetrant, and radiographic testing. A full size Ti-6Al-4V ingot has been melted for use in the future NDT capability portion of the program. The melting procedure was intentionally altered to induce Type I and Type II alpha stabilized defects. The ingot has been converted to 9 inch billet, 6 inch billet, and, finally, bar and plate. The remaining billet material will be converted to forgings. Ultrasonic and radiographic inspections were made of the ingot, 9 inch diameter billet, and 6 inch diameter billet. A number of indications were present indicating that the segregates survived the ingot conversion. During the ultrasonic inspections of the ingot and billet, the effectiveness of the inspections was increased by using shear wave as well as longitudinal wave.

Important References:

1. Grala, E. M., Characterization of Alpha Segregation Defects in Titanium 6Al-4V Alloy, AFML-TR-68-304 (1968).

2. Sattler, F. J. and Matay, I. M., Advanced Nondestructive Testing Techniques for Titanium Billets and Ingots, AFML-TR-70-118 (June 1970).

3. Abbott, N. S., Effect of Mechanical Processing Upon Penetrant Inspection Sensitivity, TIS Number CP020GF012.20, Report MDC A1181, McDonnell Aircraft Company (June 1971).

Key words: Crack detection; detection systems; magnetic particles; material defects; NDT methods; penetrant inspection; radiography; reliability; titanium alloys; ultrasonic tests.

RELIABILITY OF DEFECT DETECTION IN WELDED STRUCTURES
Packman, P. F., Malpani, J. K., Wells, F., and Yee, B. G. W. (Vanderbilt Univ., Nashville, TN; General Dynamics/Fort Worth, TX)
Interim Report, AFOSR Contract F44620-73-C-0073 (1975)

An analysis has been made of the ability of several NDI procedures to reliably detect surface fatigue cracks. It is shown that the ability of penetrant systems of aluminum and titanium is over 90 percent for cracks whose surface length is greater than 0.939 mm in length and decreases for cracks less than this value. The probability of detection of these cracks, given that the crack is present, has been determined at 90, 95, and 99 percent confidence factors. The conditional probabilities associated with an error call have also been developed. For this analysis four outcomes were defined as follows: (1) the detection of a crack that is present; (2) the missing of a crack that is present; (3) the detection of a crack that does not exist (false call); and (4) the verification that a part does not contain a flaw. Using Bayes theorem; the conditional probabilities have been established in terms of a material quality factor, an error probability ratio, and a success probability ratio. The results of two inspectors, one with a 6 percent error probability, and the other with a 36 percent error probability, have been examined.

Comment:

The continuing investigations referenced in this report are adding significantly to the data base needed to apply fracture mechanics concepts more effectively in designs of aluminum and titanium alloys. The use of Baysian statistical analysis provides a new look in analysis methods.

Important References:

1. Wood, H. A., The Role of Applied Fracture Mechanics in the AF Structural Integrity Program, AFFDL-TM-70-5 (June 1970).

2. Packman, P. F., Fracture Toughness and NDT Requirements for Aircraft Design, J. Nondestruct Test. (Guilford, England), 314-324 (December 1973).

Key words: Aluminum alloys; cracking (fracturing); detection systems; eddy currents; inspection procedures; magnetic particles; material defects; NDI methods; penetrant inspection; reliability; titanium alloys; ultrasonic tests; welded structures; x ray inspection.

ASSESSMENT OF NDE RELIABILITY DATA
Yee, B. G. W., Couchman, J. C., Chang, F. H., and Packman, P. F. (General Dynamics/Fort Worth, TX; Vanderbilt Univ., Nashville, TN)
NASA CR-134991 (October 1975)

Twenty sets of relevant NDT reliability data have been identified, collected, compiled, and categorized. Three relevant on-going programs are being monitored for future usage. A criterion for the selection of data for statistical analysis considerations has been formulated. A model to grade the quality and validity of the data sets has been developed. Data input formats, which record the pertinent parameters of the defect/specimen and inspection procedures, have been formulated for each NDE method. A comprehensive computer program has been written and debugged to calculate the probability of flaw detection at several confidence limits by the binomial distribution. This program also selects the desired data sets for pooling and tests the statistical pooling criteria before calculating the composite detection reliability. Probability of detection curves at 95 to 50 percent confidence levels have been plotted for individual sets of relevant data as well as for several sets of merged data with common sets of NDE parameters.

Comment:

This report describes the results of twelve months work in the most focused NDE reliability study yet. The investigators have essentially limited their analysis results to aluminum structures and to data input obtained from three NASA contracts. Data availability was a key consideration. The methodology appears to be useful for analysis of most structural configurations. There is an obvious need to expand the evaluated data base to encompass a variety of materials in a variety of configurations. This contract was a big first step.

Important References:

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2. Rummel, W. D., Todd, Jr., P. H., Frecska, S. A., and Rathke, R. A., The Detection of Fatigue Cracks by Nondestructive Test Methods, NASA CR-2369 (February 1974).

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Key words: Analysis methods; computer programs; data; eddy currents; inspection procedures; magnetic particles; mathematical models; NDE methods; NDI methods; NDT methods; penetrant inspection; probability statistics; radiography; reliability; statistical analysis; ultrasonic tests.

THE DETECTION OF TIGHTLY CLOSED FLAWS BY NONDESTRUCTIVE TESTING (NDT) METHODS
Rummel, W. D., Rathke, R. A., Todd, Jr., P. H. and Mullen, S. J. (Martin Marietta Corp., Denver, CO)
MCR-75-212 (October 1975)

Liquid penetrant, ultrasonic, eddy current and x radiographic techniques were optimized and applied to the evaluation of 2219-T87 aluminum alloy test specimens in integrally stiffened panel, and weld panel configurations. Fatigue cracks in integrally stiffened panels, lack of fusion in weld panels, and fatigue cracks in weld panels were the flaw types used for evaluation. 2319 aluminum alloy weld filler rod was used for all welding to produce the test specimens. Forty-seven integrally stiffened panels containing a total of 146 fatigue cracks, ninety-three lack of penetration (LOP) specimens containing a total of 239 LOPflaws and one-hundred seventeen welded specimens containing a total of 293 fatigue cracks were evaluated. Specimen thickness were nominally 0.317 cm (0.125 inch) and 1.27 cm (0.500 inch) for welded specimens and 0.710 cm (0.280 inch) for the integrally stiffened panels. NDT detection reliability enhancement was evaluated during separate inspection sequences in the specimens in the "as-machined or as-welded", post etched and post proof loaded conditions. Results of the NDT evaluations were compared to the actual flaw size obtained by measurement of the fracture specimens after completing all inspection sequences. Inspection data were then analyzed to provide a statistical basis for determining the flaw detection reliability. Analyses were performed at 95% probability and 95% confidence levels and one-sided lower confidence limits were calculated by the binomial method. The data were plotted for each inspection technique, specimen type and flaw type as a function of actual flaw length and depth.

Comment:

This 187 page contract (NAS9-13578) report is comprised mainly of data, in tabular and graph format, detailing experiments using the four NDT methods cited. It provides an essential augmentation of the limited quantitative information base. The quantitative assessment of selected NDT methods extends the base begun under contract NAS9-12276 and provides a valuable input to the NDT reliability studies conducted under Contract NAS3-18907.

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Key words: Analysis methods; crack initiation, crack propagation; detection systems; eddy currents; fatigue (materials); flaw detection; material defects; NDT methods, NDT techniques; penetrant inspection; statistical analysis; ultrasonic tests; x ray inspection.

THE DETECTION OF FATIGUE CRACKS BY NONDESTRUCTIVE TESTING METHODS
Rummel, W. D., Todd, Jr., P. H., Frecska, S. A. and Rathke, R. A.
(Martin Marietta Corp., Denver, CO).
NASA CR-2369 (February 1974)

X radiography, penetrant, ultrasonic, eddy current, holographic, and acoustic emission techniques were optimized and applied to the evaluation of 2219-T87 aluminum alloy test specimens. 118 specimens containing 328 fatigue cracks were evaluated. The cracks ranged in length from 1.27 cm to 0.018 cm and in depth from 0.451 cm to 0.003 cm. Specimen thicknesses were nominally 0.152 cm and 0.532 cm and surface finishes were nominally 32 and 125 rms and 64 and 200 rms respectively. Specimens were evaluated in the "as milled" surface condition, in the chemically milled surface condition and, after proof loading, in a randomized inspection sequence. Results of the NDT evaluations were compared with actual crack size obtained by measurement of the fractured specimens. Inspection data were then analyzed to provide a statistical basis for determining the threshold crack detection sensitivity (the largest crack size that would be missed) for each of the inspection techniques at a 95 percent probability and a 95 percent confidence level.

(FOR LISTING OF IMPORTANT REFERENCES, KEYWORDS AND A DUPLICATE ABSTRACT, SEE PAGE 80).

DETECTION OF FATIGUE CRACKS BY NONDESTRUCTIVE TESTING METHODS
Anderson, R. T., Delacy, T. J., and Stewart, R. C. (General Dynamics/Convair, San Diego, CA)
NASA CR-128946 (March 1973)

This program is specifically directed toward the objective of defining the reliability of NDT methods to detect fatigue cracks of various sizes in 2219-T87 aluminum plate and sheet. The performance of these tests was measured by comparing the flaws detected against the flaws present. The principal NDT methods utilized were radiographic, ultrasonic, penetrant, and eddy current. Holographic interferometry, acoustic emission monitoring, and replication methods were also applied on a reduced number of specimens. Generally, the best performance was shown by eddy current, ultrasonic, penetrant, and holographic tests. Etching provided no measurable improvement, while proof loading improved flaw detectability. Data are shown that quantify the performances of the NDT methods applied.

Key words: Aluminum alloys; analysis methods; crack detection; crack initiation; cracks; fatigue (materials); NDE methods; NDT methods; reliability; structural safety; ultrasonic tests.

AUTHOR INDEX

This Index lists the name of each author, or co-author of a document that is abstracted in this report and also the names of the authors or co-authors of all important references cited with the abstracts. Authors of documents that are abstracted are identified by an asterisk (*).

KEY WORD INDEX