Applications of Aerospace Technology in Industry

A TECHNOLOGY TRANSFER PROFILE

NONDESTRUCTIVE TESTING

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APPLICATIONS OF AEROSPACE TECHNOLOGY IN INDUSTRY

A TECHNOLOGY TRANSFER PROFILE

NONDESTRUCTIVE TESTING

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PROFILE HIGHLIGHTS

Today's manufacturers are continually confronted by demands for increasingly complex products, systems, and materials that, at the same time, must be safer and more reliable. As a result, nondestructive testing is being used more and more to assure the integrity of manufactured products, to control production processes, to better understand raw materials, and to predict failure of major structures after they are in service.

In many of NASA's programs, where failure often means disaster, extremely high quality and reliability are fundamental considerations. In the course of meeting such requirements, NASA has affected virtually every dimension of the nondestructive testing field, from the design and application of test equipment to the training of NDT specialists. To enhance the transfer of such new NDT technology to nonaerospace users, the Space Agency has actively promoted its dissemination through publications, special conferences and technical societies. As a result, innovations which have their roots in the space program are helping to make safer and more reliable earthbound products.

INTRODUCTION

Nondestructive testing (NDT) is, by definition, the evaluation of a part or system without impairing its usefulness. While certain techniques for nondestructive testing existed prior to 1920, the installation of the first radiographic laboratory at the Watertown Arsenal is commonly recognized as the birth of the NDT field. At Watertown, X-rays and photographic film provided man's first glimpse at the world within a solid material.

Today almost all known forms of energy and energy-detecting devices serve to probe engineering materials nondestructively. Items are observed, smelled, felt, measured, X-rayed, magnetized, vibrated, acoustically excited, and heated all in the name of NDT. No one form of energy nor any one NDT method is the answer to all or even a large portion of the nondestructive testing needs. Each technique has its limitations and the methods usually compliment rather than compete with one another. In some cases it is even necessary to develop special NDT methods along with the products to which they will be applied.

Underpinning the rapid growth of the NDT field is the ever-present demand for improved quality in the products purchased by government, industry and consumers. When finished hardware becomes so expensive that not even a single component can be routinely sacrificed to estimate quality and reliability, or so critical that each must be thoroughly inspected prior to and during use, nondestructive evaluation becomes technically necessary and economically wise.

With these constraints as a backdrop, it is no surprise that the space program has played a major role in the recent growth of NDT. In this profile NASA's contributions to the major growth trends in the field are studied in Section II. To set the stage for this study, Section I provides a brief overview of the NDT field. Sections III and IV focus on the ways in which people outside the space program acquire and use NASA-generated NDT technology.

SECTION I. AN OVERVIEW OF THE NONDESTRUCTIVE TESTING FIELD

For several years prior to World War II, nondestructive testing (NDT) techniques and equipment skirted the edge of industry. Industrial management of the 1920's and 30's viewed the concepts and systems of NDT as costly curiosities not yet adaptable to large-scale, automated manufacture. It was felt that the systematic testing of materials, components, and products without impairing their usefulness was somewhat of a luxury and that periodic destructive tests were ample. As a result, the science of NDT lingered in the laboratories until the early 1940's.

Like so many other technologies, NDT received a great impetus from World War II, and during those years it was actually formalized into a science with the establishment of the American Industrial Radium and X-Ray Society. This organization later evolved into the American Society for Nondestructive Testing (ASNT). The Society now consists of more than 5,000 members, as well as 75 corporate members, and publishes several books and a monthly journal, Materials Evaluation.

With the added impetus of continued military development--the Korean conflict, the Vietnam War--and a large-scale U.S. space effort, NDT has undergone considerable expansion since the 1940's. Within the past decade, for example, rapid advances in materials technology and increasingly stringent aerospace and commercial specifications have moved NDT out of its singular role of quality control, into a new and still expanding role as a diagnostic and predictive tool to be used in all phases of design, development, test and field evaluation.

What techniques and systems now comprise NDT? How much of a transition has been made from laboratory to manufacturing plant? What industries and applications offer the greatest potential for NDT use? How large is the market for NDT equipment, and at what rate is it growing? What does the future hold for NDT?

NDT Techniques

True to its definition as a science which probes materials or objects in a manner that will not impair their future usefulness, NDT most commonly includes radiography, ultrasonics, eddy current, magnetic particles and dye penetrants (see Attachment I). Recent advances in the discipline include infrared, microwave, acoustic emission, real-time X-ray and neutron imaging, acoustic and laser holography, and liquid crystals. Ultrasonic and radiographic methods are typically used for in-depth analysis; while holography, eddy current, magnetic particles, and thermal methods are used for the detection and identification of near surface anomalies.

Applications of NDT

Although some of the newer NDT concepts are presently beyond the workaday use of manufacturers, nonetheless, NDT has made significant inroads into inspection of products after use as well as into automated, mass manufacture. Table 1-1 summarizes the application areas, along with functions and examples of NDT.

TABLE 1-1. APPLICATIONS, FUNCTIONS, AND EXAMPLES OF NDT*

AREAS OF APPLICATION	FUNCTION PERFORMED	EXAMPLES
Research & Development	Evaluating materials, components and parts; comparing and evaluating fabrication and assembly techniques; data acquisition.	Measuring fatigue in metals, detecting cracks in welds, and non-bonds in bonded materials.
Process Control	Measuring process variables and providing control information.	Radioisotope thickness gauging.
Quality Control	Detecting and locating anomalies in materials, defective parts, etc; detecting and locating fabrication and assembly defects; evaluating the production process.	Poor adhesive bonding, cracks in welds, contaminated transistors, non-uniform porosity in metals.
In-Service Evaluation	Detecting flaws, defects, wear and deterioration of items in field use without major disassembly.	Locating corrosion inside gas tanks, detecting moisture in bonded wing structures on aircraft, etc.

* Source: Research Triangle Institute, 1968.

Quality control applications are by far the dominant factor. In the steel industry, for example, there is a heavy concentration of production-line NDT systems. This is not surprising in view of the fact that considerable NDT research has been done in metals and that the amount of available data on metals properties and behavior is extensive.

Typical of NDT uses in manufacture is an installation at Armco Steel Company in Middletown, Ohio, producer of steel pipe. Here, a fluoroscopic system provides 100 percent inspection of spiral-welded pipe at the rate of 20 to 40 feet per minute. The plant has operated this system 24 hours per day, 7 days per week, beginning early in 1971. Other users of similar systems include American Bridge Company in Orange, Texas, which operates four NDT units on a production-line basis; A. O. Smith, Houston, Texas, makes use of five such systems; Bethlehem Steel in Steeltown, Pennsylvania uses three systems (Johnson, 1971).

While the plastics industry has not yet made broad use of NDT methods in process control, a San Diego firm, Tetrahedron Associates, Incorporated, has developed a dielectrometer that measures molecular weight changes in thermosetting resins during cure. As the resin is heated and reaches its gel point and final cure, these changes are tracked dielectrically to within one or two seconds. A press operator can then determine the optimum point at which to close the press by reading the condition of the resin. In later development, Tetrahedron joined forces with Pasadena Hydraulics, Incorporated, Pasadena, California, one of the largest producers of laminating presses in the United States. By using its dielectrometer to control a laminating press, Tetrahedron provided laminators with a press that cycled according to the condition of the material rather than any prearranged processing schedule. The result is relatively void-free laminates and more efficient use of resin. Raytheon Company reported a 25 percent reduction in scrap using the dielectrometer in circuit-board production.

Other examples, taken from the files of ASNT, illustrate the benefits that have been gained by users of NDT (Johnson, 1971):

- Bridge engineers have found that by using the new, exotic, high-strength steels and welding the members together instead of using rivets, they can save 20 percent in the amount of steel used. But these new steels are nondestructively tested when they are made, and the welds are radiographed on the job. Arthur L. Elliott, chief bridge planning engineer for the

California Division of Highways, reported savings of five million pounds of steel in a bridge where 27 million pounds of the metal was used. And it is a better bridge because the welded steel is working almost up to its capacity, thanks to NDT.

- An airline saved $1,500 per jet aircraft by using X-rays to test the honeycomb structure inside the wings, according to Captain Paul J. Slayden, Eastern Airlines' director of quality control.

- Destructive test specimen costs amounting to $180,000 a year have been saved by Northrop Norair, according to E. C. Bennett, chief of Norair's Quality Division.

- National Airlines saved some $210,000 in 1968 by the increased application of nondestructive testing techniques to the maintenance of its aircraft fleet.

The Market for NDT

The net result of NDT's partial transition from the laboratory to the manufacturing plant is a burgeoning business, estimated in 1967 at $6 billion yearly in terms of wages, equipment, and maintenance by John A. Reynolds, vice president and technical director of Picker Corporation, a leading producer of NDT equipment (Johnson, 1971). When asked to describe the current size of the U.S. market for NDT equipment, Ralph E. Turner, director of Industrial Trade Relations, Radiography Markets Division, Eastman Kodak Company, and president of ASNT, provided the market analysis illustrated in Table 1-2.

TABLE 1-2. PROJECTED MARKET GROWTH FOR NDT EQUIPMENT*

	1968	1973	Average Growth
Radiography	$38,000,000	$ 65,000,000	17%
Ultrasonics	25,000,000	65,000,000	21
All Other Methods	20,000,000	50,000,000	20
TOTALS	$83,000,000	$180,000,000	20%

* Source: Turner, 1971.

The growth rate, of course, is dependent upon many factors. Among the most important are:

- The appearance and acceptance of any new and improved products.

- The acceptance of NDT in many applications is dependent on codes and specifications (bridges, pipelines, automobiles, etc.), legal aspects (such as the manufacturer's responsibility for his products), the military situation, and the state of the economy.

- The acceptance of NDT as a quality control tool, which implies that a strong educational effort is a requirement.

Assuming favorable market conditions continue, to what new industries will NDT equipment and supplies be sold and why? And what deterrents are there likely to be to future growth even under satisfactory market conditions?

Dr. Robert C. McMaster, professor of welding engineering at Ohio State University, author of a nondestructive testing handbook, and a well-known authority on NDT, believes that the consumer products industries eventually will find the greatest need for such equipment. "With new government regulations and consumer pressures for improved product performance and safety coming on the scene," explains McMaster, "manufacturers of aircraft, automobiles, railroad equipment, and chemicals will have to install such devices to protect the consumer and themselves. There has been great interest expressed by insurance companies in NDT systems particularly as claims and the cost of product replacement rises sharply" (McMaster, 1971).

Protecting the lives of personnel using hazardous products is a key reason for increased use of NDT, according to Carlton H. Hastings, Space Systems Division, Avco Corporation, Lowell, Massachusetts. "The emergence of hazardous products, such as the supersonic transports, nuclear power plants, and high-speed trains point to the need for NDT to protect the public at large. Factors that will deter the growth of NDT in certain areas are the lack of knowledge about certain techniques--such as ultrasonics--and the high cost of NDT" (Hastings, 1971).

Turner sees specific limitations in certain methods as obstacles to progress. "One deterrent to progress in the use of ultrasonics, for example," says Turner, "is the fact there is only a crude image system as opposed to the sophisticated imagery of X-ray. On the other hand, X-ray suffers from lengthy time necessary for access to data (from 10 to 15 minutes)."

McMaster, Hastings, and Turner, three of the top authorities in NDT today, agree that ultrasonics holds the greatest potential for growth. Portability, lack of danger from radiation, and capability for great depth of penetration are some of the reasons cited for ultrasonics' healthy outlook. Ultrasonics experts feel that closed-loop production machines using ultrasonic monitors may eventually make it possible to produce potentially hazardous products safely and with great reliability.

Although most of the newer, more sophisticated NDT methods--such as holography, acoustic emission, and neutron radiography--are thought of as too costly or unwieldy, the intense need for quality control devices in industry is producing some noteworthy exploration. In the tire industry, for example, stiffening federal regulations and standards have caused producers to seek out NDT as a means of exerting tighter control over production procedures (Business Week, 1971).

Trends and Projections

Against this backdrop of increasing equipment sales and increasing awareness of the need for NDT equipment by industry, new and significant trends are emerging. One of the most important is the ability inherent in acoustic emission techniques for predicting failure of systems. Machine Design magazine, in a comprehensive article on NDT, explained this trend: "It has been known for years that deforming materials make noise because of the generation of stress waves. But it is only recently that this sound could be used to detect flaws. The flaws (in welding) can be detected about 20 to 45 seconds after the weld is made and produce identifiable emissions for about 20 minutes afterward. The technique has been applied successfully to resistance, gas-tungsten arc, and submerged arc welding" (Lavoie, 1969). This development has implications across the entire spectrum of industries, especially those where equipment or structural failures produce catastrophic consequences.

Another trend that offers the promise of continued growth for NDT comes in the form of a stern challenge. George Martin, program manager for materials and producibility, North American Rockwell Corporation, told a 1969 Air Force conference on NDT of plastic/composite structures, "We see NDT results, but we don't know what they mean in terms of properties. Good NDT is determining properties, not defects. In metals, we have tremendous empirical knowledge from the hounding of holes--finding cracks and determining their effect. We need a shortcut for composites." Other comments coming from this conference indicate that NDT must be coupled to design--should influence it, not compromise it (Wessling, 1969).

Just as the steel industry now makes use of eddy current methods and fluoroscopic techniques in on-line mass production techniques, so will the composites field depend upon other emerging types of NDT for its eventual mass manufacture evolution. First, as with metals, design parameters must be established through NDT, and then the equipment can be changed to monitor and control manufacturing processes.

Conclusion

Three factors point the way to healthy NDT growth. First, the promise already demonstrated by NDT methods as on-line quality control devices suggests that these systems will continue to evolve into the manufacturing world. Second, industry is further heartened by the emergence of equipment to develop a better understanding of raw materials and their influence on the production process. Third, the ability to recognize incipient failure in structures is a powerful tool that will find new application in areas where failure has serious economic or human costs. With these three key factors in operation, it is apparent why vigorous growth is forecast for the NDT field. Basic to it all, however, is a general acceptance of the need for greater product quality and safety, particularly as systems and materials grow more complex, expensive and hazardous.

Section II examines the ways in which the U.S. space program is contributing to these important societal needs.

SECTION II. NASA CONTRIBUTIONS TO THE FIELD OF NONDESTRUCTIVE TESTING

NASA has maintained a crucial interest in the techniques and equipment for nondestructive testing, and with good reason--without NDT, the total space effort could not have enjoyed such a high degree of achievement. As a result, nondestructive testing is one of the most important technologies to experience significant growth through the space program.

While NASA and its contractors frequently used commercially available, off-the-shelf NDT equipment, many new techniques had to be developed to solve the unique problems confronting aerospace engineers. The range of technical contributions by NASA is found to cut across the entire spectrum of activity in the field of nondestructive testing; NASA personnel and contractors have produced innovations ranging from improvements to traditional techniques, such as radiography and ultrasonics, to the implementation of advanced new techniques such as neutron radiography, acoustic emission and holography.

Space Program Applications of NDT

Engineers are continually challenged by the conflicting demands associated with aerospace applications. Designs featuring minimum safety factors must be balanced by the quality and reliability requirements for man-rated systems of amazing complexity and sophistication. The conflicts arising from this "have your cake and eat it too" situation were addressed by an Agency-wide, quality assurance policy established in October 1961. In implementing this policy, nondestructive testing techniques were heavily relied upon for assessing the integrity of basic materials and for the in-process discovery of material and fabrication deficiencies. In most cases, destructive or proof-testing methods were found to be inappropriate for technical and economic reasons (Weiss, 1971). The following discussion provides a perspective on the broad use of NDT in the space program.

Materials evaluation. New materials and new concepts for materials considered for use in the space effort were required to be compatible with the hostile environments associated with space flight--for example, temperature extremes ranged from the fiery heat of propellant combustion and capsule reentry into the earth's atmosphere,

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to the numbing cold of cryogenic propellant storage and transfer. To determine material properties and discover defects in these materials, nondestructive testing was used throughout their development.

Materials joining. The problems of joining materials for aerospace use is a story in itself. The first stage of the Saturn V booster (S-IC) requires more than 5,000 feet of welds, all of which are 100 percent radiographically inspected in at least two views. Approximately 20,000 feet (almost 4 miles) of 70 mm radiographic film are used during the inspection of each booster. Since conventional radiographic techniques were found to be expensive, slow, and hazardous to personnel, NASA, in cooperation with the Boeing Company, developed a semi-automatic radiographic system to inspect the Saturn welds rapidly and safely. Total man-hours required for exposing, processing, and reviewing film were reduced by 50 percent. In addition, this new equipment reduced the radiation hazard to the point where technicians may work within 10 feet of an X-ray unit instead of the previous 50 feet, thereby reducing the total time the work area must be cleared (Neuschaefer, 1969). The fact that not a single flight or ground test failure has been caused by a defective weld is evidence of the importance of such NDT techniques.

Another perspective on NASA's interest in NDT is expressed by the immense effort associated with nondestructive testing on the Saturn V vehicle. Table 2-1 illustrates the major NDT activities.

TABLE 2-1. SATURN V NONDESTRUCTIVE TESTING*

NDT REQUIREMENTS	APPROXIMATE MAGNITUDE	
X-Ray of Fusion Welds	1.5	Miles
X-Ray of Castings and Forgings	100	
X-Ray of Transistor and Diodes	5,000	
Ultrasonic Inspection of Welds	0.4	Miles
Ultrasonic Inspection of Adhesive Bonds	1,350	$Ft.^2$
Ultrasonic Inspection of Tubing	5	Miles
Eddy Current Inspection of Tubing	6	Miles
Dye Penetrant Inspection of Welds	2.5	Miles
Sonic Inspection of Adhesive Bonds	5,776	$Ft.^2$

* Source: Zoller, 1966.

These statistics apply only to the vehicle itself and do not include the tremendous number of NDT tests required for support equipment (Musser, 1969).

Safety factor. Weight is one of the fundamental considerations in spacecraft and launch vehicles design; it presently costs about \$1,000 to place a single pound of payload into earth orbit (Normyle, 1970). As a result, engineers are continually confronted with the tradeoffs of a safe design at a minimum weight. The design safety factor, to a large degree, represents the uncertainty associated with material quality, strength properties, and tolerance to inherent defects. By providing useful information about properties and flaws, nondestructive testing has played a vital role in the reduction of Apollo/Saturn design safety factors and, thereby, increased the scientific and exploratory capability that would be built into the vehicle.

Quality assurance. Probably the greatest role for NDT in the space program has been to assure the reliability and quality of hardware that simply must not fail. A single crack in a metal, a flaw in an electronic component, a defective seal, or a warp in a structural member could produce catastrophic consequences. At stake are human lives, millions of dollars and national prestige. Furthermore, the parts, components, and systems that must function properly for a successful mission number in the hundreds of thousands. Nondestructive testing has been instrumental in the attainment of preestablished quality and reliability levels upon which designs have been based. This is one of the basic consequences of the NASA quality assurance policy.

NASA Contributions to NDT

NASA's pervasive utilization of nondestructive testing has produced numerous technological and economic contributions to the field. As illustrated in Attachment IV, NASA has been deeply involved in the preparation of training manuals, miniaturization of equipment, improving resolution and sensitivity of test instrumentation, and many other aspects of NDT. The remainder of this section will be devoted to selected NASA contributions to two new technologies emerging in the NDT field: predicting service life and automated systems. Attachment II, by contrast, focuses on singular NASA innovations acknowledged because of their individual technological and economic significance.

<u>Predicting service life.</u> Nondestructive testing is evolving beyond the simple identification of flaws and becoming an integral part of the overall evaluation of materials. Even the name has been changed to the more encompassing concept of nondestructive evaluation (NDE). This new identity is best illustrated by considering its role in predicting incipient failure and eventually useful service life.

Interest in predicting service life for electronic components has intensified as electronic systems have become more complex and pervasive. The overall reliability of these systems is dependent upon the singular reliability of individual components. Thus, the need for safe and reliable performance of aircraft, power distribution systems, and spacecraft, as well as many consumer products, demands guaranteed reliability of individual components. Routine functional tests offer little possibility of predicting service life; destructive tests on a sampling basis only add a probabilistic dimension to the evaluation. As a result, interest has turned to nondestructive testing techniques.

In 1964 the Boeing Company, a NASA contractor, procured an automated infrared test station for checking electronic components and assemblies. Initial use of the system was to establish a "normal" infrared pattern along with allowable deviations from that pattern for selected electronic assemblies. Because of variable surface emissivities, the testing effectiveness was limited, and Martin Marietta Corporation was given a NASA contract to develop a constant emissivity coating for electronic components and printed circuit boards. Working with manufacturers as well as in house, Martin found a dozen suitable coatings. Infrared testing of electronic components, assemblies, and microcircuits has gained wide application as a direct result. Not only is component quality assured, but the technique has successfully detected misapplied semiconductors, located problems in module design and pinpointed heat pockets.

Accurate prediction of service life for aerospace structures is far more difficult. In fact, one trend that is emerging emphasizes continuous monitoring of structures rather than predictive testing. A notable exception to this trend, however, is evident in the proof-testing of pressure vessels. At one time a practice of questionable value, the proof pressure test is becoming one of the most reliable nondestructive techniques for assuring safe operating life. NASA experiences during recent years have shown that the use of NDT and pressure testing guided by fracture mechanics principles can insure that there are no flaws of sufficient size to cause failure during the service life of a pressure vessel (Tiffany, 1970). The implication for traditional NDT inspection is that accept/reject criteria are now more rationally based on critical flaw sizes, not on the assumed capability of inspection equipment (Weiss, 1971). The significance of this development is that such structures no longer need be scrapped because of the presence of harmless flaws, and undetected flaws need not be an operational concern.

Many costly and tragic structural failures could be avoided if systems were available for continuously monitoring structures for incipient failure. Although this statement is fundamental and obvious, it nonetheless describes a very elusive objective which has been sought for years (Dau, 1971). Consider the following experiences of a major oil company during a recent six-month period:

- A large carbon steel pressure vessel developed 139 cracks after only a few weeks of operation.

- A stainless steel weld overlay inside a 265-ton reactor cracked during hydrostatic testing.

- Several Hastalloy-lined pressure vessels were lost through corrosion failure.

Yet all of these pressure vessels were designed, fabricated, and inspected in accordance with requirements of the ASME Boiler and Pressure Vessel Code (Ebert, 1970).

Failures of major structures such as bridges, aircraft, and ships, although infrequent, are catastrophic events. Because of their critical nature, such structures receive periodic inspection and maintenance aimed at assuring safe operation, yet failures occur. The need for continuous monitoring of critical structures is now present; it can be expected to endure and eventually result in the widespread application of systems which predict remaining service life.

Of the several techniques appropriate to assessing structural integrity, acoustic emission holds the greatest promise for broadening this needed capability. The technique has been used to detect flaws in welds, stress-corrosion cracking, hydrogen embrittlement, and failure in bonded materials. In a review article for Materials Research and Standards it was concluded that:

> The utilization of acoustic emission in assessment of structural integrity is also in its infancy. Great progress has been made in the study of pressure vessels, primarily in initial evaluation before they are put into service. Proof testing and continuous monitoring of a wide variety of structures can be visualized: structures such as pressure vessels, pipelines, airplanes, buildings and bridges could be amenable to acoustic emission techniques. In-process monitoring of welding, rolling, solidification of casting, and other fabrication techniques is also conceivable. This list of possible future applications could be greatly extended, but it should be apparent now that the application of acoustic emission to problems of practical importance has only begun and that this technique has great potential (Liptai and Harris, 1971).

Some of the earliest development work with acoustic emission was undertaken by NASA. Lacking suitable NDT equipment for determination of adhesive bond strength in honeycomb structures, NASA initiated a program aimed at developing such equipment in 1964. An ultrasonic emission detector and methods of equating signal level to mechanically imposed stresses in bonded structures were developed. As a result of this work, the bond strength of adhesively joined structural members can now be qualitatively assessed (Beal, 1967).

Although it will continue to be used for fault finding, the most promising and most difficult application for acoustic emission is predicting failure. When a solid material undergoes plastic deformation, energy is released. Part of the energy is converted to elastic waves which can be detected at the material surface using conventional, high-sensitivity ultrasonic sensors, thereby recording an acoustic signature of the event. Several features of acoustic emission make it ideal for monitoring structures for incipient failure. First, plastic deformation is detected immediately after it occurs, thus facilitating rapid analysis of the event. Second, the system can be conveniently monitored remotely, with only the sensors required to be near the emission source. Third, the source of the signal can be accurately pinpointed and then related to its stress environment.

One of the major technical problems limiting the application of acoustic emission to prediction of incipient failure is that of energy signature identification. In the case of aircraft and nuclear reactors, for example, a myriad of acoustic energy sources are operating continually. Pumps, valves, and flow turbulences all act to provide a noise environment from which the desired signal must be discriminated. A solution to this problem may be found in the pioneering work that the Jet Propulsion Laboratory has done in signal and image enhancement.

The problems of correcting various photometric, geometric, and frequency response distortions from spacecraft television cameras are akin to the problems of identifying and classifying acoustic emissions from a part under stress within an otherwise "noisy" environment. In the early days of the Ranger's TV transmissions from the moon, JPL engineers and scientists received data that contained more noise than desired signal. In dealing with the problem, computer techniques were successfully developed to retrieve the desired signals from the background noise.

Automated systems. The driving force behind the growth of automated NDT is the market demands for higher quality and better performing products at lower cost. Translated to the manufacturer, these demands mean production processes must be faster, have better control over end-product characteristics, and minimize the human labor element. The rapidly growing interest in automated processes is representative of thinking which emphasizes prevention rather than detection and cure. The ultimate goal is optimum process control that assures complete product quality and thereby redefines the need to perform inspection.

Automatic control systems are conveniently classified as either closed-loop or open-loop systems. The most desired principle of operation is the closed-loop system, because the true state of the process output is continually monitored and adjusted when deviations from programmed performance occur. The key to closed-loop control is a "feedback" signal for comparison with a command signal. Open-loop systems are then characterized by the absence of a feedback signal. It is in the output measurement and feedback that NDT principles will play a vital role in the achievement of optimum process control.

The pursuit of optimum manufacturing control is an evolutionary process, which requires several incremental advances to the state-of-the-art. The first stage beyond straight manual inputs is semi-automated systems incorporating both manual and machine inputs. This stage is typically followed by fully automated production processes that, because of inherent weaknesses, continue to require limited inspection. An outgrowth of this progression is automation of inspection techniques. The final stage combines the technologies of automated production along with automated inspection to provide optimum system control. Several industries have been successful in automating production, but only a few firms have successfully automated the inspection function.

Attempts to automate the inspection function have seen data storage techniques become widespread. Typically, these types of systems perform a nondestructive inspection and record the results for subsequent interpretation by highly skilled technicians or engineers. This type of open-loop system has been employed extensively by NASA. The semi-automatic system for radiographic inspection of Saturn welds, described earlier, is an example of such a system.

A second NASA contribution to testing technology was the outgrowth of a problem posed by an unusual hardware configuration. A mechanized ultrasonic scanning system for evaluating welds was developed after commercially available radiographic equipment was deemed unsatisfactory. Manual ultrasonic testing was painfully slow, and the size of the tanks precluded the use of immersion test methods. At the heart of this NASA-developed system is an ultrasonic water column probe, which contains an ultrasonic transducer enclosed within a water-filled cylinder. The benefits of automated inspection are dramatically illustrated by this system. Scanning speeds have been increased from 12 feet per hour to 300 feet per hour, and a higher degree of reliability has been achieved.

A third NASA development is particularly interesting because of its contributions to both trends--automated systems and predicting service life. An ultrasonic system has been developed to automatically detect and record the propagation of a fatigue crack. Fatigue refers to the failure of materials under the action of repeated stresses. By monitoring the growth of fatigue cracks and knowing the stress environment of a part, it is possible to predict accurately remaining service life for a part.

The NASA-developed system employs an ultrasonic reflection technique to monitor the leading edge of a propagating fatigue crack.

A piezoelectric transducer, which is water-coupled to a test specimen, generates an ultrasonic beam that is partially reflected from the crack tip and partially reflected from a reference reflector plate. The transducer's position is automatically adjusted until the amplitudes of the two reflected signals are equal. Growth of the crack causes an imbalance in the amplitude of these reflected signals and produces an error voltage. This error signal activates a servo-motor, which moves the transducer until the signals are balanced again. This displacement of the transducer is then used to measure the advance of the crack.

The most difficult problem in achieving fully automated, closed-loop control is the generation of a useful signal to feedback to a controller. Even with today's sophisticated equipment, highly trained technicians are often required to interpret test results. Furthermore, this interpretation tends to be more qualitative than quantitative.

Several NDT techniques appear to offer promise in this area. Common techniques such as eddy current, ultrasonics, and magnetic leakage flux have enjoyed modest success when used to provide a go/no go decision in systems involving a continuous transfer of parts through an NDT test station; however, infrared, liquid crystals, and microwaves seem to offer the most promise for automated systems of the future.

A noteworthy contribution to the state-of-the-art of automated welding has been developed by a NASA contractor. This system promises to provide in-process, closed-loop control of welding operations. Martin Marietta Corporation initially developed the system for inspecting microwelds on electronic assemblies. However, the system can be modified to provide continuous control of the welding process itself. The development of an instrument which measures the infrared energy generated in a weld as it is produced is the key to the invention. By comparing this energy to predetermined maximum and minimum limits, the system provides an accept/reject decision for the welds. To provide control for the shape of the weld pulse and thereby ensure optimum weld strength, the system would incorporate a computer which is programmed with a predetermined infrared energy profile. The measured infrared energy would then be compared with this profile. Differences between the measured and programmed profile would initiate changes in the welding current aimed at eliminating these differences. This achievement is at the leading edge of automated welding technology and shows the way that closed-loop NDT systems will emerge in industrial practice in the future.

Conclusion

This section has related some of the technical contributions made by NASA to two significant trends in the NDT field. Attachment II, by contrast, offers an in-depth view of selected NASA contributions to the field. This attachment, together with Section III, provides a picture of NASA's technical influence in the NDT community and demonstrates the pervasiveness of the nonaerospace interest in the space program's NDT effort.

SECTION III. DISSEMINATION OF NASA CONTRIBUTIONS

Among technology-generating, mission-oriented federal government agencies, NASA has played a leading role in transferring nondestructive testing technologies to other sectors of the American economy. The first important step in this transfer process involves making potential nonaerospace users of the technology aware of the inventions and innovations that occur. This awareness must be achieved in such a way that potential users can understand the NASA contributions and grasp their economic significance. The question of how NASA has tried to link up technology generators with potential innovators in the private sector is the subject of this section. In particular, the formal publications used by NASA will be reviewed, along with a brief examination of a NASA-sponsored NDT symposium and contractor links with technical societies. No attempt is made to describe or evaluate the other diverse ways (e.g., participation in NDT technical meetings, writing articles for technical journals, personal consulting) that NASA researchers have used to initiate the technology transfer process.

Formal Publications

NASA has developed an extensive formal publication program which nondestructive testing specialists both within and outside of the space program have found useful in their work. Table 3-1 shows the number of different titles related to nondestructive testing in specific NASA document categories published from 1962 through 1971.

TABLE 3-1. NASA PUBLICATIONS PRESENTING SPACE PROGRAM CONTRIBUTIONS TO THE NONDESTRUCTIVE TESTING FIELD: 1962-1971

YEAR OF PUBLICATION	TYPE OF PUBLICATION: Contractor Reports	Tech Brief*	Technical Memorandum	Technical Note	Other	TOTALS
1971	14	23	4	0	9	50
1970	25	26	11	2	21	85
1969	19	16	9	3	14	61
1968	31	15	7	2	4	59
1967	41	24	6	0	2	73
1966	29	14	9	1	2	55
1965	15	3	5	1	0	24
1964	8	0	1	0	1	10
1963	3	0	1	0	1	5
1962	1	0	1	1	0	3
TOTALS	186	121	54	10	54	425

* Tech Brief titles related to nondestructive testing technology are presented in Attachment III.

These NASA-funded publications, taken collectively, report a broad range of space program contributions to the nondestructive testing field. A representative view of the scope of NDT technologies flowing from NASA research and development can be gained by examining Tech Briefs published during the past seven years. Tech Briefs are representative in the sense that they are used to announce many, though not all, of the innovations resulting from Space Agency research activities. Since 1965, 121 Tech Briefs on NDT have been prepared and disseminated.

To better examine their relevance to the nondestructive testing field, the Tech Brief titles in Attachment III have been arranged under five headings: ultrasonics, radiography, chemical and spectrographic analysis, other NDT techniques, and general handbooks. Data in Table 3-2 indicate that almost two-fifths of the Tech Briefs fall into the first three categories. These data also show that while NDT research has been conducted system-wide in NASA, Marshall Space Flight Center in-house and contractor personnel generated a majority (55 percent) of the Tech Briefs. This center has special responsibility for the development of launch and flight hardware.

TABLE 3-2. TECH BRIEF CATEGORY BY ORIGINATING NASA FIELD CENTER

TECHNICAL CATEGORY	NASA FIELD CENTER					
	MSFC	MSC	LERC	SNPO	Other	TOTALS
Ultrasonics	12	3	1	3	2	21
Radiography	13	3	2	0	1	19
Chemical and Spectrographic Analysis	1	1	2	0	4	8
Other Nondestructive Testing Techniques	28	6	3	3	19	59
General Handbooks	12	0	0	2	0	14
TOTALS	66	13	8	8	26	121

The relevance of technology reported in these Tech Briefs to nondestructive testing problems outside of the space program is partially evident in the number of requests which have been made for Technical Support Packages (TSP's) related to the Tech Briefs. During the last four years, persons interested in obtaining additional technical information on NDT made 5,663 TSP requests. The data presented in

Figure 3-1 demonstrate that those TSP requesters wanted information in all five of the technical categories. The fact that general handbooks were so popular is related directly to the broad scope of technologies presented in them. Since their scope is general, they appeal to a much larger audience. In the case of the eight chemical and spectrographic analysis Tech Briefs, 1,063 of the 1,162 requests were for TSP 70-10520, "Nondestructive Spot Tests Allow Rapid Identification of Metals," making it one of the most popular Tech Briefs published. Because of its singular importance, the technology described in this document is analyzed in Attachment II of this presentation; some of the ways the spot test has been used outside of the space program are presented in the "NDT Spot Test for Metal Identification" Transfer Example Summary in Attachment IV. Requests for TSP's fell below the proportionate production of Tech Briefs in the "other NDT techniques" category, primarily for two reasons: either the technique is completely described by the Tech Brief and no TSP request is necessary, or the techniques described are useable only in highly specialized situations.

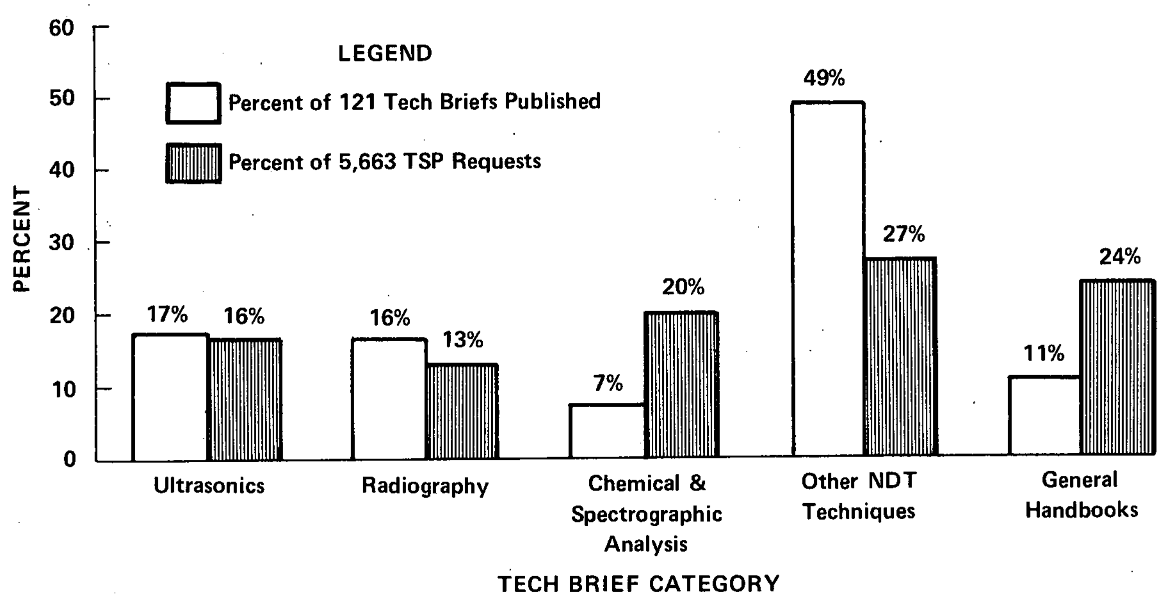

Figure 3-1. Comparison of TSP Requests Associated With Five Categories of Tech Briefs Reporting NASA Contributions to the Nondestructive Testing Field.

Other Dissemination Activities

In addition to its various publications programs, NASA has disseminated information concerning its new NDT technologies through other special mechanisms. Of particular interest are a professional symposium, cooperative links between NASA contractors and professional NDT organizations, and the creation of a Special Publication on NDT.

Nondestructive testing symposium. In 1966, NASA sponsored a national symposium specifically designed to acquaint nondestructive testing specialists with technical developments having nonspace application potential. The meeting, "Second Technology Status and Trends Symposium," was held on October 26-27, 1966, at the Marshall Space Flight Center in Huntsville, Alabama. Approximately 150 people from private industry, federal and state government agencies, research institutes and universities attended. NASA experts described a broad representative spectrum of space program contributions to nondestructive testing: axial transverse laminography; ultrasonic techniques for testing composite materials, residual stresses in aluminum, and welds in aluminum; an X-ray television system; a fast scan infrared microscope for microelectronic components; and liquid crystal applications. The proceedings of the symposium were published in 1967 as NASA Special Publication 5082, Nondestructive Testing: Trends and Techniques. Several symposium participants have made subsequent attempts to use the NDT techniques described in the conference and the proceedings. The transfer experiences of four organizations represented at the symposium--Alcoa, the University of Missouri, the Tennessee Valley Authority, and Automation Industries--are presented in Attachment IV of this presentation (see "1966 Nondestructive Testing Symposium" Transfer Example Summary).

NASA contractors work through technical organizations. The American Society for Nondestructive Testing (ASNT) serves as a source for eleven training handbooks which were compiled and written by General Dynamics/Convair, under contract to Marshall Space Flight Center. These handbooks are also available in microfiche and hardcopy from the National Technical Information Service (NTIS). As encyclopedias of NDT information, they are the most complete and comprehensive set of manuals ever offered for the training of technicians who must apply nondestructive testing techniques. The eighteen volumes contain more than 4,600 pages of material on liquid penetrant, magnetic particle, ultrasonic, eddy current and radiographic testing.

Thirteen of the volumes offer programmed instruction (self study), whereas the other five are designed for classroom training and reference purposes. Philip D. Johnson, managing director of ASNT, estimates that 1,400 sets of the first thirteen volumes and 1,840 sets of the second five volumes have been sold through ASNT to companies and individuals all over the world.

In cooperation with the Knowledge Availability Systems Center (KASC), which is operated under NASA contract at the University of Pittsburgh, Materials Engineering magazine offers a series of abstracts on a wide range of reports on engineering materials and processes coming out of the space program. The "Nondestructive Testing" package contains thirty-eight abstracts of reports covering the range of NDT techniques along with descriptions of several critical NDT applications. Of the more than three dozen packages available, "Nondestructive Testing Methods" has been extremely popular among nonaerospace technologists, generating almost 300 requests.

NASA contractors create special publications. Performing under a NASA contract, Southwest Research Institute in San Antonio, Texas conducted an intensive study of nondestructive testing spanning a period of over two years. The purpose of this study was to assemble, in a single volume, state-of-the-art information which would be useful to practicing NDT engineers as well as engineering students. A large part of this effort was devoted to explaining basic physical principles and illustrating nonaerospace applications of NASA-generated technology. The results of this effort will be published as a NASA Special Publication during the latter part of 1972.

Conclusion

Establishing meaningful communication links between the generators of NDT techniques in NASA and potential nonaerospace adopters of those techniques is the significant first step in the technology transfer process. Once those links have been forged, whole new chains of events leading ultimately to commercial applications of the technologies can be developed. Thus, the dissemination of NDT technology by NASA and its subsequent acquisition by nonaerospace organizations bring the transfer process to life. To illustrate what happens in the private sector after the technology is obtained, Section IV presents specific information concerning non-NASA application activities associated with the use of NASA Tech Briefs.

SECTION IV. A TRANSFER PROFILE

After reviewing the variety of NASA publications related to nondestructive testing issued from 1962 through 1971 in Section III, the next step is to see how these documents are used by NDT specialists working outside the space program. This will illustrate the role such documents play throughout the technology transfer process and also indicate the different ways NASA contributions to the NDT field have been applied by industrial firms.

Transfer Stages Concept

Before describing specific details of the applications activities associated with nondestructive testing technology, it will be useful to first examine the different stages through which such activities pass. Once this idea is clarified, it will be used to place specific examples of technology transfer in an appropriate frame of reference.

Any specific transfer of a technology may be described as a series of related activities that progress through four different stages. Figure 4-1 illustrates this "transfer stages" concept.

1	2	3	4
Initial Awareness and Review	Engineering Evaluation	In-House Use or Market Testing	Full-Scale Marketing

Figure 4-1. Four Stages in the Technology Transfer Process.

Stage one is characterized by an initial awareness on the part of a potential innovator working in the private sector of the existence of a new technology generated for space program purposes. During this transfer stage, the potential innovator may search for additional information concerning the technology in order to determine its relevance to his interests. Stage two involves specific attempts to adapt the new technology to fit the requirements of the private sector. These attempts usually involve laboratory tests and evaluations. A transfer experience progresses into stage three under one of two conditions: either an industrial firm begins to use the adapted technology in its own operational activities (e.g., processing), or a firm begins to market-test prototype versions of the adapted innovation. Only those firms with plans to market a technology ever progress into the fourth transfer stage. In that stage, a commercial firm promotes the diffusion of an adapted technology in the private sector.

Adaptation activities, in which a public sector-generated technology is shaped to fit requirements in the private sector, span across the first three transfer stages. It is important to note that technology originating in the public sector cannot emerge as a force affecting diffusion throughout the second sector until adaptation by a private sector firm is complete.

Survey of TSP Requesters

To determine how NASA-generated nondestructive testing technology has been used outside of the space program, a survey of the 5,378 requesters of Technical Support Packages (TSP's) was conducted. Approximately 40 percent of those individuals received a mail questionnaire six months after they requested the TSP. In addition, to gain an insight on the influence of time in the technology transfer process, another sample of TSP requesters (209) was selected for questionnaire follow-up one year or more after they had received the TSP. All requesters were asked to describe how they had used the information they received.

A total of 1,467 questionnaires were completed and returned. Of those TSP requesters contacted in the six-month survey, 1,383 responded; of those contacted after one year or more, 84 returned the questionnaire.

A profile showing the different transfer activities identified in the survey of TSP users is presented in Figure 4-2. Data in the figure indicate the existence of a significant time factor in the relative progress of each transfer through the various stages of transfer activity. This factor is further illustrated by the following examples and those presented in Attachment IV.

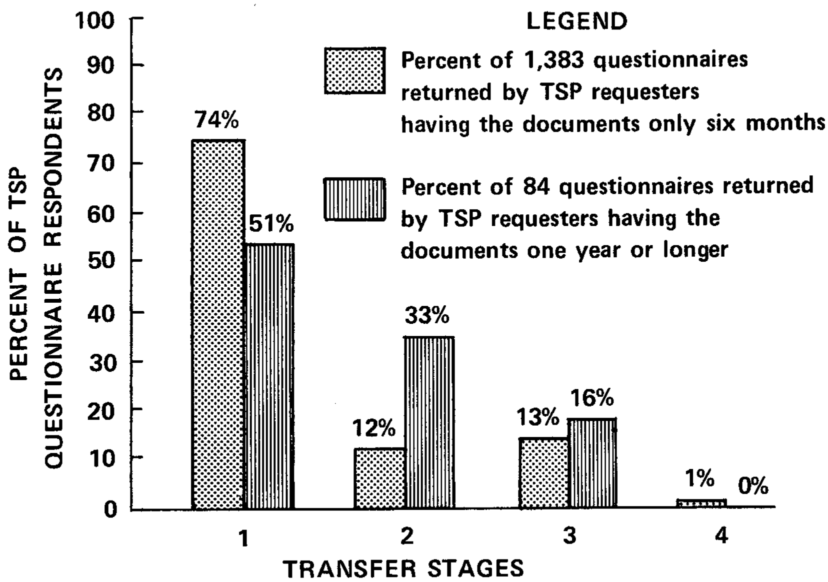

Figure 4-2. Transfer Profile of 1,467 Persons Using TSP's Related to the Nondestructive Testing Field Showing Two Groups: (a) TSP Users Having the Documents Just Six Months, and (b) TSP Users Having the Documents One Year or Longer.

A stage one transfer example which illustrates that a TSP requester's requirements may be satisfied in the awareness stage is one involving the National Business Aircraft Association, Incorporated (NBAA) in Washington, D.C. The NBAA is an association of companies which operate aircraft as an adjunct to their normal business. The association staff provides state-of-the-art information and technical assistance to member companies for the purposes of increasing efficiency and reducing costs. As part of this function, the staff circulated the TSP describing nondestructive testing for brazed components (TB 68-10394) to the NBAA technical committee and to aircraft maintenance personnel of member companies. (See "Nondestructive Testing of Brazed Components" Transfer Example Summary in Attachment IV.)

NASA's announcement of the development of a mechanized ultrasonic scanning system has stimulated a great deal of interest among NDT specialists. One case, demonstrating stage two transfer activities, involves the F. Yeager Bridge and Culvert Company in

Port Huron, Michigan. The company evaluated the technique and plans to use the system as soon as improved methods are developed for interpreting test results. The company fabricates steel bridges for the Michigan Highway Department, which currently requires X-ray testing of bridge welds so that the results may be interpreted objectively. (See "Mechanized Ultrasonic Scanning System" Transfer Example Summary in Attachment IV.)

Another stage two example, Metal Improvement Company in Carlstadt, New Jersey, illustrates how NASA technology may require further development for the requester's application. The TSP described only the concept of a simple, nondestructive measurement of residual stresses in metals (TB 68-10378). Company engineers are considering adapting the NASA method for measurement of the residual stresses introduced in metal components by shot peening. The company does shot peening as a commercial service to improve surface fatigue life of the component. If the engineering evaluation provides satisfactory results and the method is adopted, the company will have greatly improved the service and its saleability since the information is usually required by customers. (See "NDT Measurement of Residual Stress" Transfer Example Summary in Attachment IV.)

Approximately 13 percent of the respondents in the six-month survey and 16 percent of those in the longer than one year survey indicated their transfer activities had progressed into stage three. In many cases, the nature of the technology itself limits the transfer process in the third stage. A case illustrating this point involves the Portland, Maine division of E. W. Bliss Company, which is using the NASA spot test (TB 70-10520) to identify metal alloys from which it produces parts for jet engines and fire fighting equipment. The primary application is in verifying stock material which may become mixed in the stockroom. The company has developed its own set of known comparison samples and estimates that the spot test procedure has eliminated the need to purchase more than $9, 500 worth of spectrographic equipment and reference samples. (See "NDT Spot Test for Metal Identification" Transfer Example Summary in Attachment IV.)

By contrast, another transfer example can be cited that shows how some companies are laying the groundwork for successful stage four activities in stage three. Lodding Engineering, a division of Thermo-Electron Corporation in Auburn, Massachusetts, is proceeding with the development of a new product based on a TSP which described an ultrasonic method of stress analysis (TB 67-10428). The firm's engineers had been experimenting with methods for nondestructively measuring residual stresses when they learned of the new technique. Visits to Marshall Space Flight Center convinced them that the principles embodied in the NASA technology could be applied to a new product. Subsequent development work yielded two portable prototype instruments which work well on aluminum alloys but provide only qualitative data on ferrous alloys. Although redesign efforts are underway to improve the instrument's capability on ferrous alloys, the current model will be marketed by June 1972 in the price range of $5,000 to $10,000. Market prospects are quite good, and development costs will probably be recovered in the first year. The product is expected to replace the use of strain gages in many applications. (See "Ultrasonic Measurement of Residual Stresses" Transfer Example Summary in Attachment IV.)

The survey revealed that a few companies are currently engaged in stage four transfer activities. One of these firms, Metro Physics, Incorporated in Santa Barbara, California, is marketing a fiber optics device, which it developed under NASA contract, to detect surface irregularities. The invention, described in Tech Brief 69-10152, permits taking a large number of discrete dimensional measurements with a single setting and an accuracy on the order of micro inches. Great interest in the instrument has been shown by machine tool manufacturers since it can check contours and measure critical part dimensions, surface flatness and finish, holes, and deflection. To date only custom-built units have been sold, but Metro will soon begin mass production of the device as a result of the response to a recent advertising campaign. This will significantly reduce the present price of $1,200 and greatly increase its marketability. (See "Fiber Optics Detect Surface Irregularities" Transfer Example Summary in Attachment IV.)

In contrast to the cases cited above, a firm may terminate transfer activities in any stage due to a variety of reasons. Atomics International, a division of North American Rockwell Corporation in Canoga Park, California, is an example of termination in stage two. The company was evaluating prototypes of a solid-state radiographic image amplifier panel for application in its in-house testing of a product when the product line was discontinued. Atomics International has no further plans to use the NASA technology. (See "Solid State Imaging Device" Transfer Example Summary in Attachment IV.)

Conclusion

Seven transfer examples have been cited to illustrate the wide range of activities in which persons outside of the space program have attempted to apply NDT technology developed by or for NASA.

These examples illustrate the fact that many of NASA's contributions to nondestructive testing technology are directly related to nonaerospace requirements. At the same time, they show that progress through the various stages depends on a time-consuming integration of many technical and socio-economic factors; this is true even in cases where the technology appears to offer substantial benefits to the recipient organizations.

SECTION V. A FOCUS ON ISSUES

While almost all forms of energy can be used in nondestructive testing, the discovery of new techniques is an infrequent occurrence. The vast majority of NDT contributions tend to incrementally advance the total knowledge base in the field by building on previous innovations. It is in this building block fashion that the relative importance of most NDT innovations can best be understood.

NASA contributions to the advancement of the NDT field have been examined in the context of two important trends which are emerging in the manufacturing arena. Using this selective treatment, it is possible to see how major change is most often effected through an almost endless stream of incremental advances. Thus, by considering that only a fragment of the NASA effort in NDT has been illustrated here, it is possible now to understand that the Space Agency is contributing in fundamental ways to progress in this important field.

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ATTACHMENT I

A BRIEF DESCRIPTION OF COMMON NONDESTRUCTIVE TESTING METHODS

Any physical, chemical, mechanical, or other test method can, under the proper conditions, qualify as a nondestructive test. There is a group of test methods, however, that are the most commonly utilized NDT techniques--radiography, ultrasonics, liquid penetrants, magnetic particle and eddy current. The principle of operation and relative merits of each is discussed in this section.

Radiography

Probably the best known means of nondestructive testing, radiography includes a number of different techniques--X-rays, gamma rays, neutrons, radiation backscatter, fluoroscopy and others. All of them, however, are basically alike: a penetrating beam of radiation passes through an object. As it does, different sections of the object, as well as discontinuities, absorb varying amounts of radiation so that the intensity of the beam varies as it emerges from the object. Figure I-1 illustrates how this variation is detected and recorded on film or otherwise to provide a "picture" of the inside of the object.

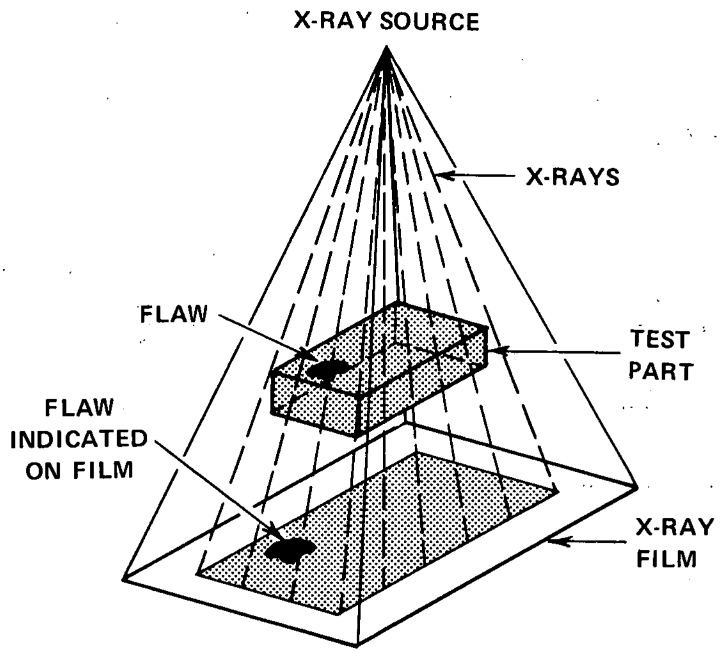


Figure I-1. Flaw Detection Using Radiography

Relative merits of radiography. Almost any material can be radiographed. The shape of a flaw can be viewed, and approximate depth can be determined with special techniques. Films are relatively expensive, and processing can require considerable time. Special precautions are necessary to avoid hazards from radiation. Radiography is often used to check or confirm results of other tests. Internal flaws can be detected in items that are not excessively thick.

For fluoroscopy, contrast is poorer and thickness of test items more limited than for film radiography. However, results are immediately available; thus faster testing and testing of moving items is possible. Fluoroscopy is sometimes used as a "gross" inspection technique, followed by film radiography for better resolution of indicated flaws (U.S. Army, 1970).

Ultrasonics

Ultrasonics, like radiography, includes a number of different techniques. In the two most basic methods, a beam of ultrasonic energy is directed into the specimen; and either the energy transmitted through it or the energy reflected from interfaces within it is indicated. Inspection is accomplished because the ultrasonic beam travels with little energy loss through homogeneous material except when it is intercepted and reflected by discontinuities in the elastic continuum. Figure I-2 illustrates two basic techniques applied to internal flaw dection: (a) the flaw is detected by the decrease of transmitted energy at the receiver; (b) it is detected by energy reflected to the receiver.

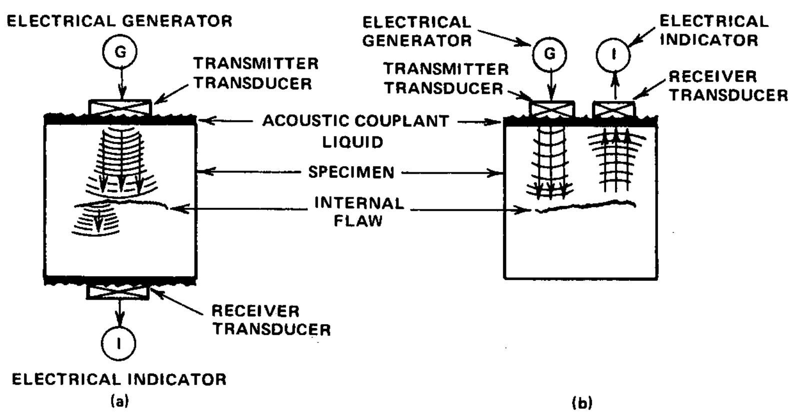


Figure I-2. Basic Testing Methods: (a) Flaw Detected By Decrease of Energy at Receiver; (b) Flaw Detected By Energy Reflected to Receiver. [Source: McMaster, 1959.]

Relative merits of ultrasonics. Ultrasonics is a valuable inspection means for testing smooth-surfaced, fine-grained materials, especially steel and aluminum products. Considerable thicknesses can be tested from any accessible surface; however, liquid couplants are required between the test item and test instrument transducer. Items can be tested with oil-type couplants or immersed in water. Flaw location and depth can be approximately determined, and automation is common. Complex-shaped test items are sometimes impossible to test adequately, as are rough surfaces, large-grained materials and fiber-reinforced composites. Some items must be tested from various directions to insure that flaws oriented in all directions are detected. The principal advantages are that fine cracks a considerable distance from the transducer can be detected, and results are immediately available (U.S. Army, 1970).

Liquid Penetrant

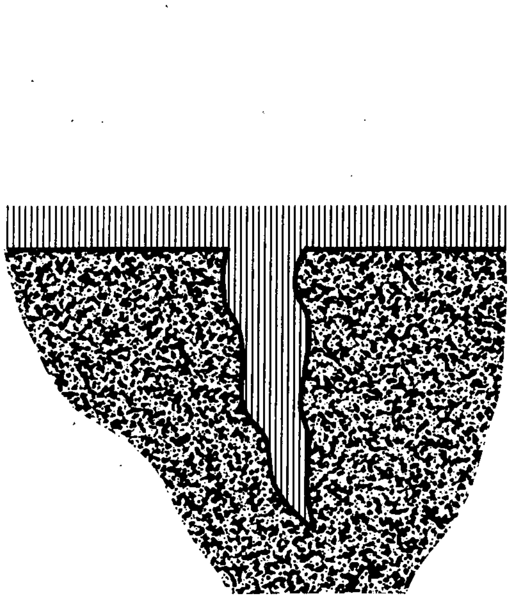
Penetrant inspection is one of the simplest and most commonly used NDT techniques. Figure I-3 illustrates the principle involved.

Relative merits of liquid penetrant inspection. This method can be used to test practically any material regardless of physical characteristics and geometry. It can also be used as a leak test by checking the opposite side of a test item for bleed-through of the penetrant. This technique is limited to surface cracks only and requires a clean surface free of contaminants. Furthermore, penetrant removal after a test can be problematic (U.S. Army, 1970).

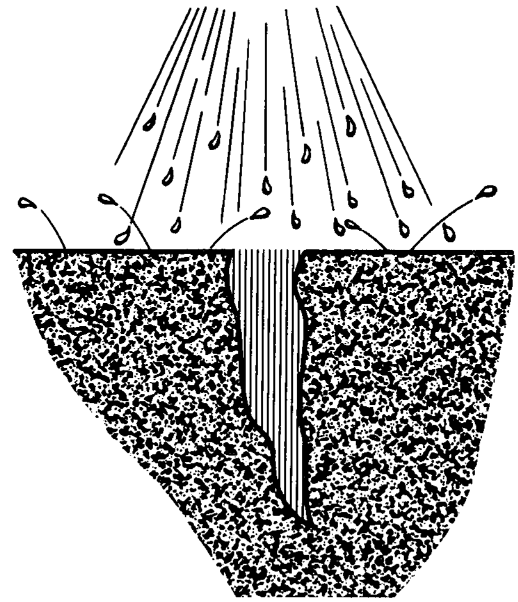
Magnetic Particle

Like liquid penetrant inspection, magnetic particle techniques are relatively easy and simple to use. They are almost completely free from any restrictions as to size, shape, composition, and heat treatment, as long as a part can be magnetized. There are essentially three basic steps in using the technique:

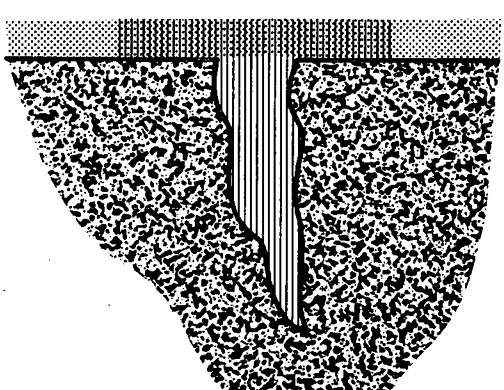
1. Establish a suitable magnetic field in the test object.
2. Apply magnetic particle to the surface of the object.
3. Examine the test object for accumulation of the particles and interpret the pattern.



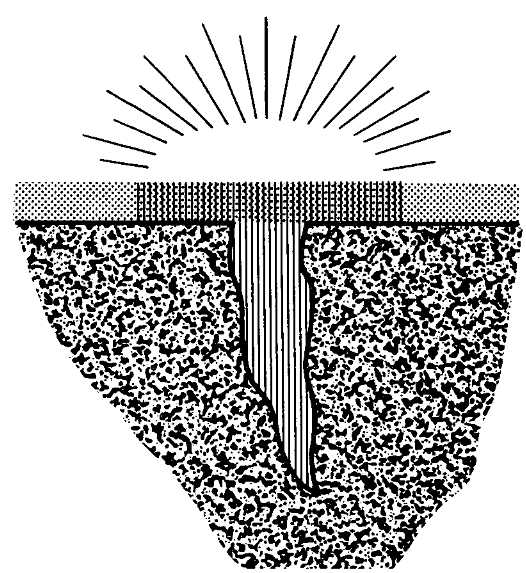
Following Application, Liquid Penetrant on Surface Seeps into Crack.



Water Spray Removes Penetrant From Surface But Not From Cracks and Pores.



Developer Acts as a Blotter to Draw Penetrant from Crack.



Black Inspection Light Causes Fluorescent Penetrant to Glow in Dark.

Figure I-3. Liquid Penetrant Inspection. [Source: McMaster, 1959.]

A crack in a part distorts the magnetic lines of force and creates poles on either side of the crack, thus causing a buildup of particles. Figure I-4 illustrates the phenomena for a crack in a bar magnetic.

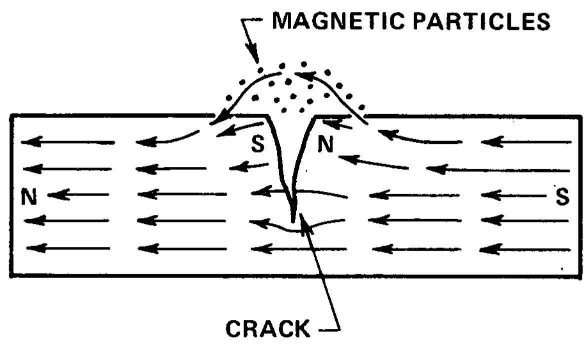


Figure I-4. A Crack in a Bar Magnet Creates Magnetic Poles Which Attract Magnetic Particles. [Source: McMaster, 1959.]

<u>Relative merits of magnetic particle inspection</u>. Magnetic particles can be used to detect almost all kinds of surface flaws as well as those just below the surface. Surface plating and/or contamination does not greatly affect results, as it does with liquid penetrants. This technique can only be used on ferromagnetic materials, and parts must be demagnetized after the test (U.S. Army, 1970).

<u>Eddy Current</u>

Within the broad spectrum of electronic test methods involving the interaction of magnetic fields and circulating currents, the most widely applied technique is eddy current testing. Eddy currents are induced in a test item by means of coils carrying high frequency AC current. Special instruments identify flaws by detecting distortions in the resulting magnetic fields.

<u>Relative merits of eddy current testing</u>. This method is capable of inspecting large quantities rapidly and is easily adapted to automation. Nonmetallic contaminants do not affect results significantly. Testing speeds can be high because of the inherently high exciting frequencies, and direct contact with the test item is not required.

Eddy currents can be used on electrically conductive material only. The method is sensitive to geometry and limited to simple shapes, unless complicated scanning systems are employed. Quantitative assessment of flaw shape and size is difficult to make (U.S. Army, 1970).

ATTACHMENT II

SELECTED NDT DEVELOPMENTS THAT HAVE RESULTED FROM NASA-SPONSORED RESEARCH

The field of nondestructive testing is extensive both in its technological dimensions and its applications. Sections I and II have provided an indication of the breadth of the NDT field, along with the pervasiveness of NASA contributions to the field. This attachment, by contrast, focuses on three specific innovations to provide an in-depth look at selected NASA contributions. The nondestructive spot test, the solid state image amplifier, and the ultrasonic Delta technique have been chosen for special investigation because of their relation to the trends discussed in Section II, as well as for their technological significance.

Chemical Spot Test

The need for a reliable system to rapidly identify incoming raw materials provided a NASA Langley Research Center innovator with the impetus for development of a chemical spot test. Since composition of materials is fundamental to the ultimate utility of fabricated parts, raw materials are commonly inspected for conformance to engineering specifications. Furthermore, the selection of subsequent machining and joining procedures is integrally dependent upon knowledge of material properties.

The spot test technique developed by NASA applies the principles of qualitative chemical analysis to identify metals and alloys. Groups of substances are first isolated, then split into subgroups, fractions of subgroups, and finally a single metal or alloy. The information is presented in flow chart form as illustrated in Figure II-1.

Tests are performed by adding a few drops of a test reagent to an extremely small particle of the unknown material. Conclusions relative to identification of the unknown are drawn from the resulting, unique reactions to the reagents. These reactions are manifested as distinct color changes, which are produced when the appearance or disappearance of phases and their boundaries cause changes in the absorption of light. Although all tests are qualitative, semiquantitative conclusions can be drawn by conducting simultaneous tests on a specimen with known chemical composition.

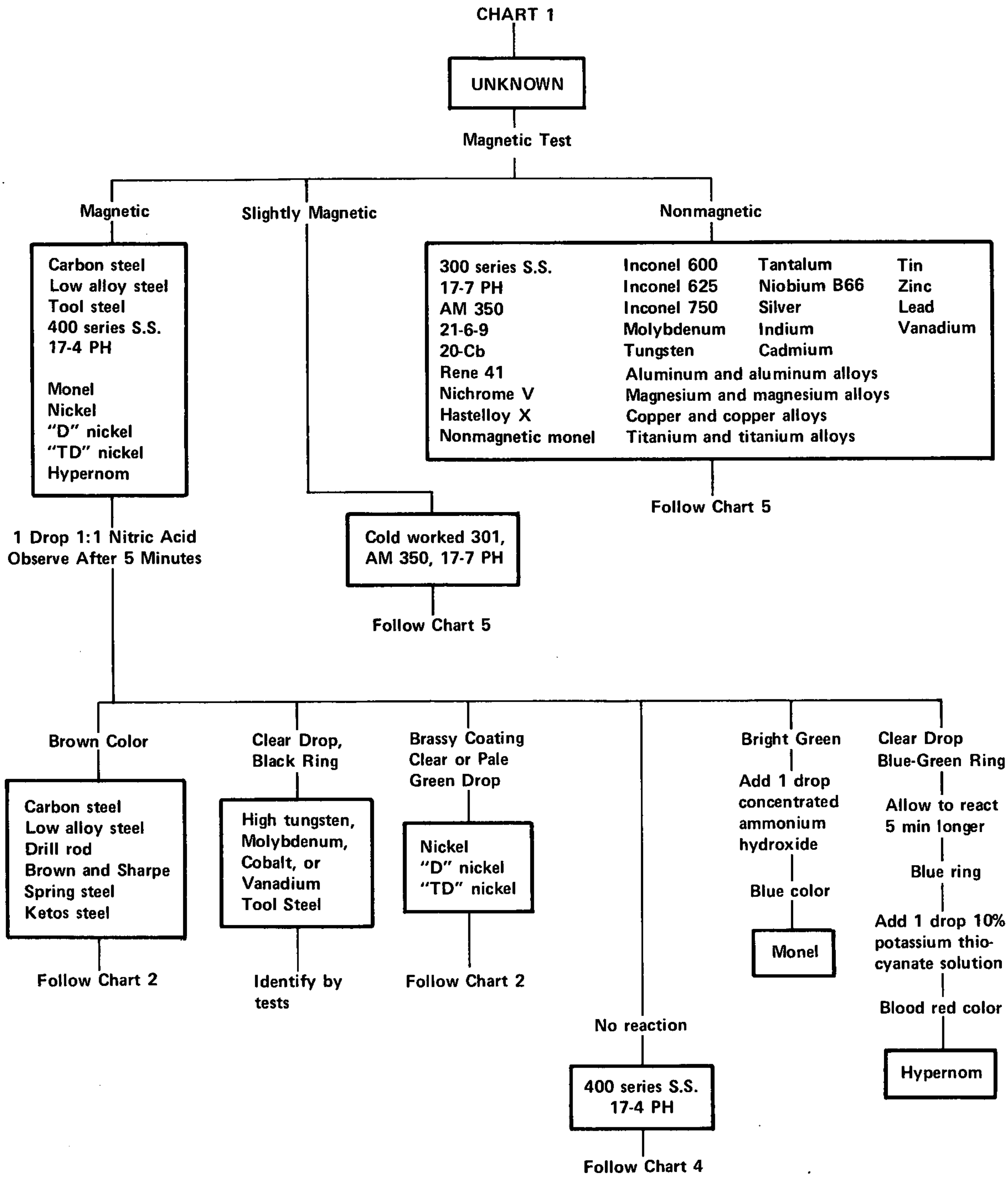


Figure II-1. Identification of Metals and Alloys Using the Procedure Outlined in the Technical Support Package for Tech Brief 70-10520. [Source: Wilson, 1970.]

The use of qualitative chemical analysis to determine the composition of unknown materials is not new. However, the chemical spot test developed by NASA is noteworthy because of two contributions. It first reflects a fundamental effort in aggregation of previously fragmented information. The information is presented in a compact, useable form that requires no special skills for implementation. Second, a refined capability to accurately identify alloys is reflected in many of the tests.

The significance of the NASA contribution can be best described by a single word--practical. The myriad of applications for identification of unknown materials include receiving inspection, periodic inventory checks, separation of mixed lots, tracing misidentified parts, periodic checks of parts in process, and field identification of critical components. All of these applications require a quick and inexpensive means for materials identification. Spectroscopic analysis generally requires a laboratory environment, expensive equipment and skilled operators. The chemical spot test developed by NASA, however, has many features which illustrate its usefulness:

- Low cost. A complete kit including equipment and reagents costs less than $500. Test time required to identify an unknown metal is less than 30 minutes.

- Easy to use. A master kit can be completely portable for on-line or on-site testing. No special training or expertise is required to perform tests.

- Comprehensive. The procedures cover all common metallurgical elements--aluminum, copper, magnesium, nickel, titanium and steel. Over 150 metals and alloys can be accurately identified.

- Nondestructive. Tests can be performed on a small area of a part or on an amount of metal equivalent to that removed by a single stroke of a smooth file.

Information on the technology transfer activity associated with the NDT spot test is presented in the "NDT Spot Test for Metal Identification" Transfer Example Summary in Attachment IV.

Solid State Radiographic Image Amplifier

As evidenced by its popularity, radiography is an extremely important and powerful nondestructive testing tool. However, because it is one of the oldest NDT techniques and its limitations have become traditional, radiography has entered a state of maturity, which is characterized by a modest growth rate when compared to other NDT techniques. Ultrasonics, for example, is expected to grow more rapidly because it offers advantages such as portability, rapid results, safety to personnel and low cost operation. Thermal and infrared techniques feature inexpensive real time testing. Furthermore, this pattern is typical of other growing techniques in the nondestructive testing field. Undoubtedly then, any rejuvenation of radiography can only be accomplished by technological innovations which provide these kinds of traits.

The NASA-developed, solid state radiographic image amplifier is just such an innovation. This device converts input radiation into an electric current, amplifies the current, and then excites an electroluminescent material to form an image on a flat, lightweight panel. The image obtained is comparable in quality to that achieved using radiographic film. When permanent records are desired, the image can be photographed. This unique development promises to remove the burdensome weight of film processing from the shoulders of radiographic techniques, and thereby open up an entirely new horizon of applications.

Principle of operation. Fundamentally, the image amplifier employs a photoconductive (PC) layer and an adjacent electroluminescent (EL) layer in a sandwich configuration. The rather unique properties of PC and EL materials provide the basis of operation for the radiographic image amplifier. Photoconductive materials exhibit an increase in electrical conductivity when they absorb electromagnetic radiation (X-rays for example), whereas, electroluminescent materials emit light upon the application of an electric field.

Figure II-2 illustrates the basic electronic circuit for a PC-EL display. An AC voltage is applied across the series-connected PC and EL elements. This voltage is divided between the elements according to their impedance ratio. In the unexcited condition the PC's voltage is high because its resistance is high. This condition causes the voltage across the EL to be low and thereby produces a very low light output. When the PC is exposed to electromagnetic radiation, however, its resistance decreases, the voltage across the EL element rises, and a light pattern (B out) of the input energy (X inp) is produced.

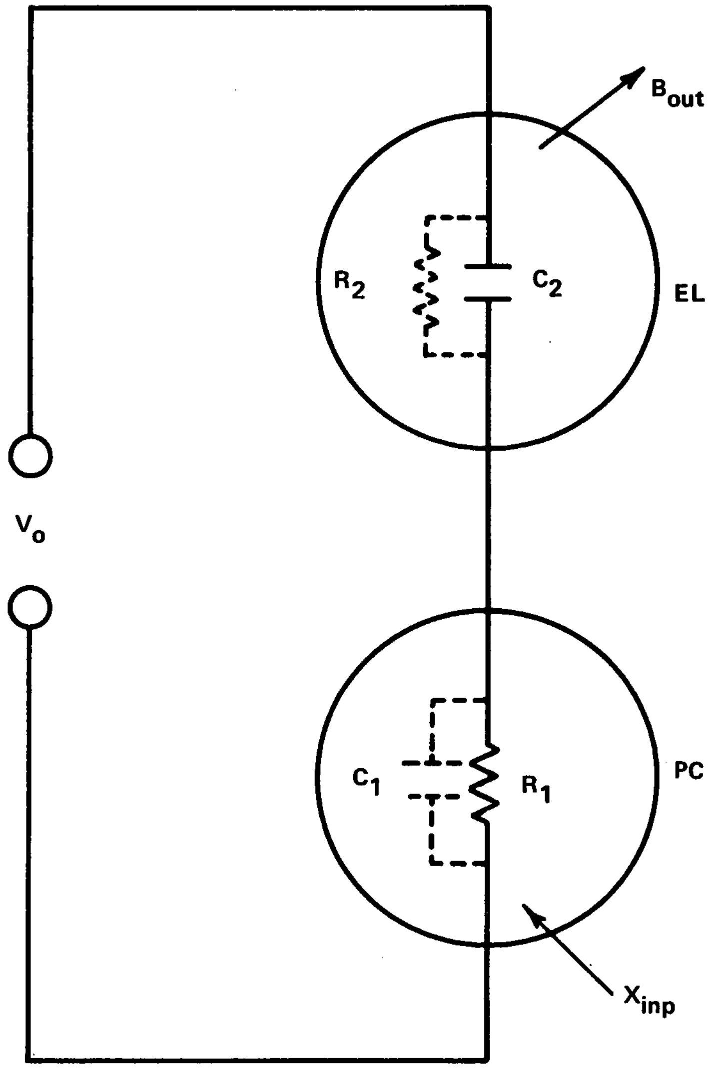


Figure II-2. Basic Circuit of PC-EL Type Light Intensifiers. [Source: Szepesi, 1969.]

A continuous-layer, sandwich-type construction has been demonstrated to be the best way to fabricate solid-state image intensifiers (Szepesi, 1971). Several options are available, depending on performance and application requirements. Because of a radiation hazard to personnel, NASA's primary area of interest has been directed to image storage panels. Storage panels can be irradiated while test personnel are located in a safe area, then studied after the radiation source is de-energized. Nonstorage panels are illuminated only during exposure to radioactive energy sources, requiring a lead glass view port and shielding.

Construction of the storage panel is illustrated in Figure II-3. The function of each layer is further discussed:

- Glass substrate. The glass serves as the foundation upon which subsequent layers are assembled.

- Tin-oxide coating. The glass is coated with tin-oxide to provide electrical contact with the EL material.

- Electroluminescent material. The EL layer is embedded in a high-dielectric constant plastic and sprayed onto the coated glass. The thickness of the EL layer is between one and two thousandths of an inch.

- Photoconducting layer (ZnO). A plastic embedded zinc-oxide layer is bladed on the EL layer. Typical thicknesses range between eight and ten thousandths of an inch. The fine-grained ZnO powders have excellent storage properties and are capable of reproducing half-tones.

- Gold (Au) electrode. A gold film is evaporated on the PC layer to facilitate electrical lead wire attachment.

To summarize, incident radiation causes increased electrical current flow in a photoconducting material. This current is used to excite an electroluminescent material and thereby produce an illuminated image of the radiation energy pattern. Incident electromagnetic energy is converted into a light output suitable for viewing. Proper selection of optoelectronic characteristics of the PC and EL materials produces amplification of the input energy.

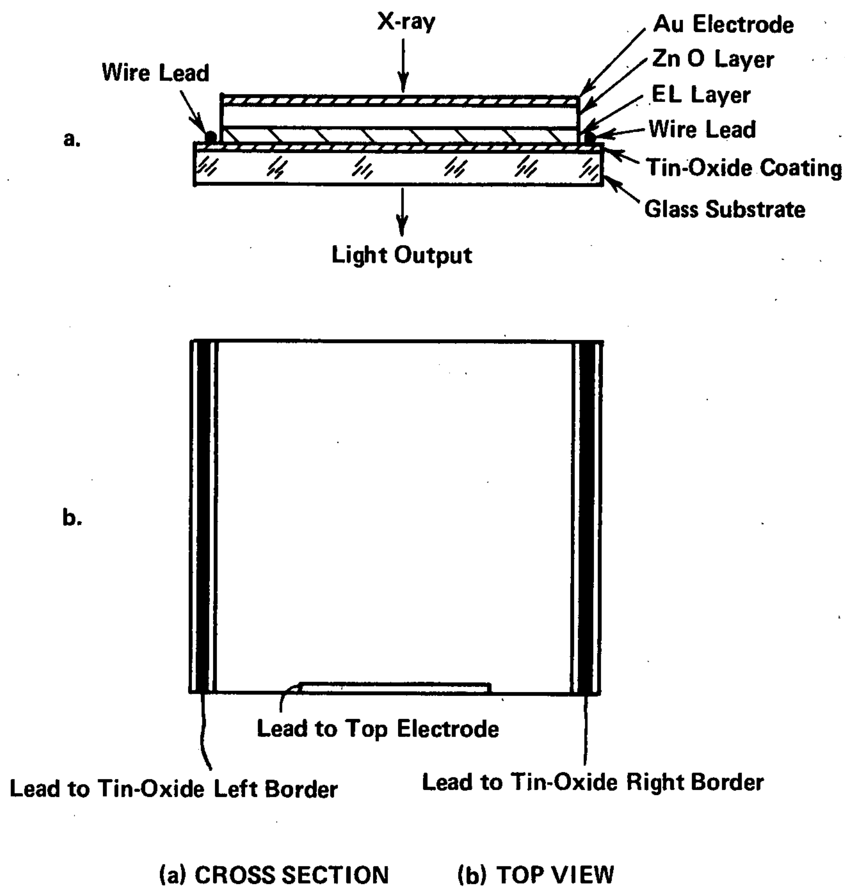


Figure II-3. Construction of Storage Radiographic Amplifier Screens on Glass Substrates. [Source: Szepesi, 1969.]

NASA technological contribution. Interest in direct imaging and image amplification is probably nearly as old as radiography itself; however, the history of the PC-EL sandwich-type panel traces back to 1952, when a German scientist, Dr. Stürmer, applied for the first patent related to the subject. The German patent application was quickly followed by three others (an Australian and two American applications) in the same year. Since then over a hundred patents proposing a large variety of construction techniques, materials, and applications have been awarded (Szepesi, 1969).

Because of serious limitations in available materials, these devices remained primarily a laboratory curiosity for almost 17 years. The requirement of high PC-EL capacitance ratio was primarily responsible for stunting the growth of direct image amplifiers. Thus, the commercial availability of high-dielectric constant plastics represented a truly significant break-through in the development of solid state image intensifiers.

NASA's interest in the concept began shortly after the discovery of the high-dielectric constant plastics. The NASA role can be best summarized as that of bringing the PC-EL imaging concept from a laboratory curiosity to a useful engineering tool. The work was performed by the Westinghouse Electronic Tube Division under direction of engineers at Marshall Space Flight Center. Table II-1 illustrates the performance improvements that have been realized during the NASA/Westinghouse program.

TABLE II-1. SOLID STATE IMAGE AMPLIFIER PERFORMANCE IMPROVEMENTS RESULTING FROM NASA DEVELOPMENT EFFORTS*

PERFORMANCE PARAMETER	STATE-OF-THE-ART	
	Before NASA	After NASA
Resolution	40 lines/inch	300 lines/inch
Contrast	8-10%	2%
Luminous Gain	1	100
Brightness		3-4X

* Source: Brown, 1971.

NASA's concentration of effort directed to radiographic applications is of noteworthy significance, since most other development efforts have been aimed at amplifying input light energy. Early attempts to develop radiographic intensifier panels fell short because of the numerous, conflicting performance demands. However, by cascading two panels, each of which satisfies a group of requirements, all the requirements could be met. One panel features high contrast and sensitivity along with fast rise time, while a second panel is addressed to the requirements of storage and fast erasure-time. Furthermore, cascading of panels significantly reduces the X-ray exposure required for suitable image production. For example, a combined basic PC-EL panel with a light sensitive Thorn panel* requires only 1/350 of the X-ray intensity of a single PC-EL panel.

Applications for the radiographic image amplifier. Continued development of the solid state image amplifier is being pursued by Westinghouse for numerous commercial applications. Among these applications are industrial radiography, where film costs can be significant; medical radiography, where, as in mobile X-ray units, rapid interpretation and reduced exposure are desirable; and veterinary applications, where portability of equipment is imperative for on-site diagnosis. Additional information on the "Solid State Imaging Device" is presented in a Transfer Example Summary in Attachment IV.

Ultrasonic Delta Technique

The many features offered by ultrasonic NDT are largely responsible for the intense and rapidly growing interest in this technique. Users of ultrasonics for flaw identification can employ inexpensive and portable equipment while realizing benefits such as rapid testing, immediate test results and high sensitivity. Furthermore, the method is not limited by material thickness and is suited to automated processing applications.

Even with these advantages, ultrasonic techniques fall short of becoming the universal NDT tool. For example, evaluations utilizing the traditional techniques of pulse-echo, angle beam, and shear wave are limited to the detection of defects which lie in a preferred orientation. In addition, skilled operators are required; and also, permanent records are not normally available. To overcome these limitations Automation Industries, Incorporated developed an ultrasonic Delta technique, which gets its name from the characteristic triangular positions of the search units used to perform the tests. The outstanding feature of the Delta technique is its ability to function regardless of defect orientation. Other ultrasonic methods, as well as radiographic techniques, require the excitation energy to strike the flaw in a

* Manufactured by Thorn Electrical Industries, Enfield, England.

perpendicular or near perpendicular manner in order to obtain a defect signature. As a result, in many critical NDT applications, inspection must be performed from two directions. The Delta technique incorporates the advantages of ultrasonics, along with the added benefits of rapid scanning, low cost testing and providing permanent records. The ability to acquire information on flaw characteristics without concern over test orientation, however, represents the significant advancement to the state-of-the-art.

Principle of operation. Ultrasonic NDT is based on the characteristic of discontinuities to attenuate or scatter an ultrasonic wave propagating through a material. An electromagnetic transducer first generates sound waves in a part by converting electrical energy into mechanical energy. The waves propagate without disturbance until encountering a flaw or a test piece surface. Knowledge about a part allows reflections from flaws to be discriminated from surface reflections. A receiving transducer converts reflected acoustic energy into electrical energy, thus facilitating observation of the event.

The Delta technique represents a departure from conventional ultrasonic methods. Previously, ultrasonic systems were exclusively interested in the primary mode of wave propagation; secondary modes represented unwanted test signal noise. In contrast, the Delta technique utilizes these secondary modes to obtain information about defect size and orientation. Figure II-4 illustrates the fundamental principles of the Delta technique. As with many emerging innovations, the development and application of this technique has proceeded without a rigorous mathematical proof of the concept.

An explanation of the Delta phenomena was developed from classical energy equations and empirical laboratory data. To aid in the analysis of the Delta phenomena certain terms have been defined:

- Transmitted Beam - The transmitted beam is the longitudinal wave originating at the transmitter search unit and incident upon the part surface at a specified angle.

- Transmitted Shear Beam - The transmitted shear beam is the refracted shear wave propagating in the part as a result of the transmitted beam striking the part surface. The angle of incidence between the transmitted beam and the part surface is beyond the critical angle for transmission of longitudinal energy into the part.

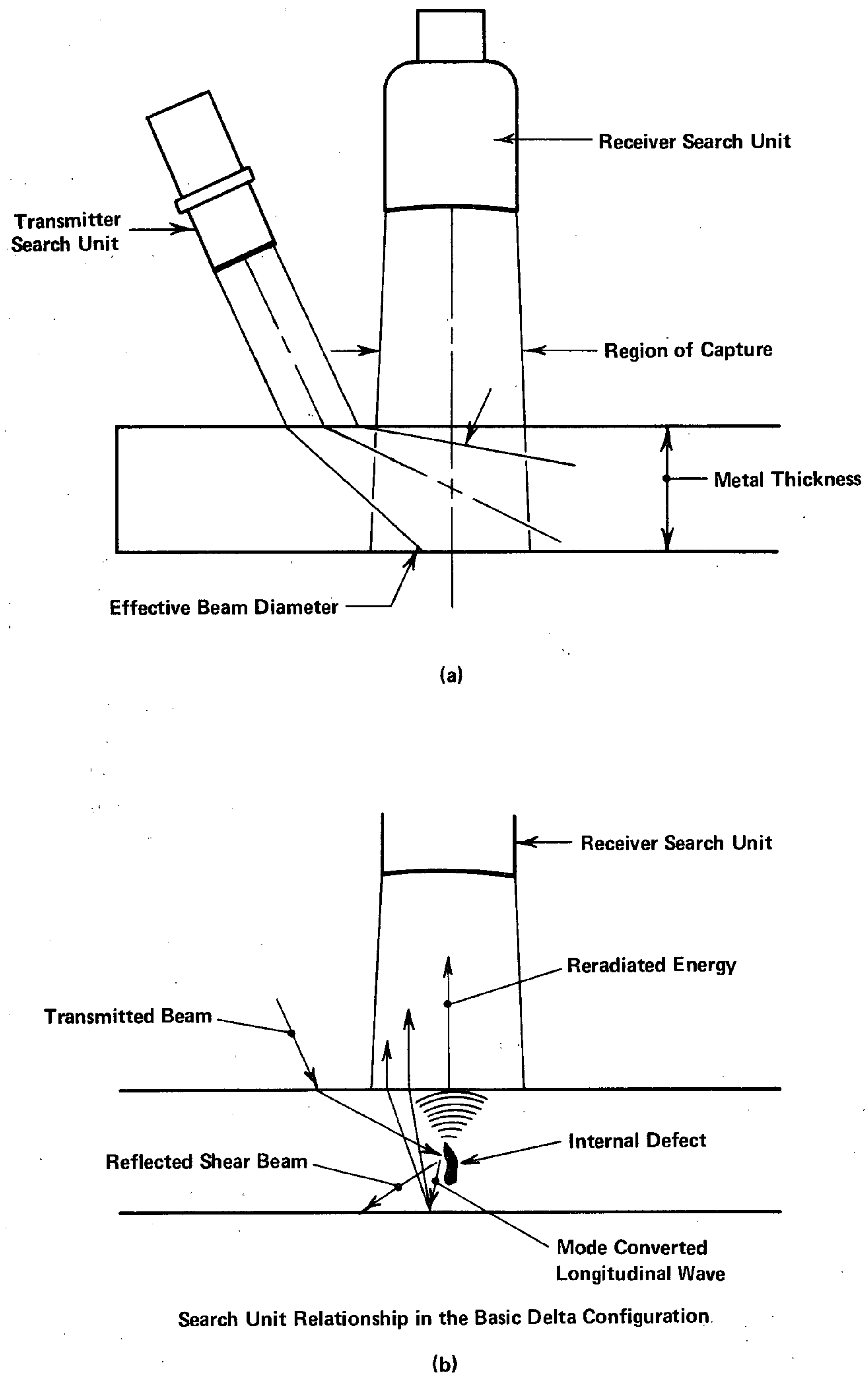


Figure II-4. Fundamental Principles of the Delta Technique. [Source: Hannah, 1968.]

- Interface - The surface forming the boundary between two adjacent media of different acoustical impedance is the interface.

- Redirected Energy - Any energy propagating in the part in a direction different from that of the transmitted shear beam is redirected energy. Redirection is caused by an interaction between the transmitted shear beam and an interface. Redirected energy can be reflected, mode converted or reradiated energy.

- Mode Conversion - Mode conversion is the change of ultrasonic energy from one mode of propagation to another as a result of striking an interface. Ultrasonic energy will propagate in an elastic media in three principle modes: longitudinal, shear and surface.

- Reradiated Energy - An omnidirectional, coherent ultrasonic wave generated at an interface as a result of interface excitation caused by an impinging ultrasonic beam is reradiated energy.

When the transmitted beam strikes an interface it can split into three distinct modes of redirected energy. All three types are used for flaw detection: (1) a reflection of the transmitted shear beam, (2) a mode-converted longitudinal beam, and (3) a reradiated sound beam. The net result of these modes of propagation is a fanlike redirection of the transmitted sound beam. This fanlike spray of redirected energy minimizes the influence of flaw orientation.

In summary, the Delta technique ultrasonically illuminates a part in one direction and views it from another direction. A defect in the part acts as an energy reradiator similar to the way radar signals are reradiated from a flying aircraft (Posakony, 1971).

History of development. A brief review of the history of the development of the Delta technique is presented for two reasons. First, it illustrates the multi-organizational interest in the phenomena; and second, it sets the stage for delineating NASA's contribution to the overall development.

Interest in the technique grew out of the inability of conventional ultrasonics to detect randomly oriented defects. This shortcoming led to an in-house investigation of the technique by Automation Industries, Incorporated. The discovery that the Delta phenomena produced far more information than conventional ultrasonic systems led to extensive research work aimed at understanding the physics of the phenomena and improving the capabilities of the technique. From the original application to flat plates, the technique was then applied to weldments. Feasibility of the technique for weld inspection was established under a program performed for the Martin Marietta Corporation. This work was followed by three Air Force contracts for the development of an ultrasonic system to provide isometric views of defects in metals and welds, as well as correlate the three-dimensional ultrasonic scanning system with standard immersion techniques. A lack of definition of certain types of defects, especially when Delta results were compared to radiographs, led to an additional research study sponsored by the Bureau of Ships. The objective of the program was to study the physics of sound energy as it propagates into a weld specimen and determine the directions of the redirected energy. This information was then used to refine the Delta method (Posakony, 1966).

Up to this point, engineering effort on the Delta phenomena was appropriately confined to laboratory investigation. This activity set the stage for NASA's entrance into the evolving Delta development. Faced with one of the greatest technical challenges of the space program--the need to detect tight lack of penetration (LOP) in welds--NASA turned to the Delta technique for a solution. The problem occurred where weld passes made on each side of joined parts did not penetrate sufficiently to completely fuse the parts. The difficulty arose because shrinkage stresses caused the edges of the plates to become so tightly abutted that radiography and conventional ultrasonics could not detect the flaw. The problem was ultimately solved using opaque additives on the edges of the plates and thereby enhancing the LOP in radiographic images. Nevertheless, Marshall Space Flight Center continued with the development of the Delta technique for other applications because it had demonstrated a significant improvement over conventional ultrasonics (Neuschaefer, 1969).

NASA contribution. The NASA contribution to the overall development was to transform the Delta technique from a laboratory tool into a reliable inspection method for production weld evaluation. A development program was performed in two phases: the first was directed to an analytical and empirical study of the Delta phenomena for aluminum alloys, combined with a test and evaluation program to establish Delta operating parameters for these alloys. The second phase included the design, fabrication, and evaluation of a Delta wheel and manual Delta probe for inspecting aluminum butt welds.

Tests demonstrated that the Delta technique successfully detected weld defects of primary concern in 2014 and 2219 aluminum alloy weldments at inspection rates of 50 feet per hour. Results of this study are summarized in Table II-1. As the table illustrates, substantial improvements in test method reliability were demonstrated for all flaw types, but especially for lack of penetration, lack of fusion and microfissure defects.

TABLE II-1. COMPARISON OF OVERALL NDT RESULTS*

Flaw Types	Delta Inspection Correlation With Destructive Tests	Conventional Ultrasonic 60° Angle Beam Correlation With Destructive Tests	Radiography Correlation With Destructive Tests
Lack of Penetration	73%	50%	37%
Lack of Fusion	98%	45%	84%
Porosity > 0.010"	92%	100%	83%
Porosity < 0.010"	49%	17%	37%
Cracks	90%	75%	60%
Micro-fissuring	100%	0%	14%

*Source: Hannah, 1968.

<u>Significance of the Delta technique</u>. The Delta technique represents added capabilities to NDT technology in two significant ways. First, the method works regardless of flaw orientation, resulting in lower cost, and a faster, more reliable ultrasonic inspection is achieved. Second, the phenomena have the potential to completely characterize a defect. Ultimately an ultrasonic picture can be made from an insonified** part. From this picture, defect characteristics such as size, shape, and type can be determined. This information would then allow a determination of the critical nature of a flaw as well as facilitate predictions of remaining service life. Transfer activity associated with the technology is discussed in the "Ultrasonic Delta Technique" Transfer Example Summary in Attachment IV.

** Insonify is a coined word which indicates the dosage of ultrasonic energy. It is comparable to the level of intensity of radiation in radiographic testing.

ATTACHMENT III

TECH BRIEF EXHIBIT

Technical Category	Tech Brief Number	Tech Brief Title
Ultrasonics	66-10178	Fatigue Cracks Detected and Measured Without Test Interruption
	66-10220	Ultrasonic Recording Scanner Used for Nondestructive Weld Inspection
	66-10289	Ultrasonic Hand Tool Allows Convenient Scanning of Spot Welds
	66-10544	Ultrasonic Quality Inspection of Bonded Honeycomb Assemblies is Automated
	66-10577	Ultrasonic Water Column Probe Speeds Up Testing of Welds
	67-10127	Calibrating Ultrasonic Test Equipment for Checking Thin Metal Strip Stock
	67-10428	Ultrasonics Used to Measure Residual Stress
	67-10486	Ultrasonic Hand Tool Allows Convenient Diagnostic Scanning of Bone Integrity
	67-10542	Plastic Shoe Facilitates Ultrasonic Inspection of Thin Wall Metal Tubing
	67-10620	Ballpoint Probe Gives Optimum Results in Ultrasonic Testing
	68-10004	Development of Mechanized Ultrasonic Scanning System
	68-10379	Automatic System Nondestructively Monitors and Records Fatigue Crack Growth
	69-10402	Nondestructive Testing of Welds on Thin-Walled Tubing
	69-10404	Generation of Sonic Power During Welding
	70-10055	Immersed Ultrasonic Inspection of High Acoustical Attenuative Structures
	70-10118	Acoustic Vibration Test Detects Intermittent Electrical Discontinuities
	70-10397	Nondestructive Sonic Testing of Adhesive-Bonded Composites
	70-10514	Ultrasonic Detection of Flaws in Fusion Butt Welds

TECH BRIEF EXHIBIT (Continued)

Technical Category	Tech Brief Number	Tech Brief Title
Ultrasonics (Continued)	71-10045	Ultrasonics Used for High-Precision Nondestructive Inspection of Brazed Joints
	71-10227	Ultrasonic Scanning System for In-Place Inspection of Brazed-Tube Joints
	71-10486	Instrument Accurately Measures Stress Loads in Threaded Bolts
Radiography	65-10110	Magnets Position X-Ray Film for Weld Inspection
	66-10307	Commercial Film Produces Positive X-Ray Photo in Ten Seconds
	66-10327	Inflatable Holding Fixture Permits X-Rays To Be Taken of Inner Weld Areas
	67-10005	Digital Computer Processing of X-Ray Photos
	67-10008	Polaroid Film Helps Locate Objects in Inaccessible Areas Quickly
	67-10216	Electron Beam Welder X-Rays Its Own Welds
	67-10337	Low-Energy Gamma Ray Inspection of Brazed Aluminum Joints
	67-10391	Method Prevents Secondary Radiation in Radiographic Inspection
	67-10564	Mechanized X-Ray Inspection System for Large Tanks
	68-10343	X-Ray Film Holder Permits Single Continuous Picture of Tubing Joint
	68-10363	Improved Radiographic Image Amplifier Panel
	69-10418	Radiographic Threshold Detection Levels of Aluminum Weld Defects
	69-10553	Use of Medical and Dental X-Ray Equipment for Nondestructive Testing
	70-10189	Reference for Radiographic Film Interpreters

TECH BRIEF EXHIBIT (Continued)

Technical Category	Tech Brief Number	Tech Brief Title
Radiography (Continued)	71-10206	Interpretation of Aluminum-Alloy Weld Radiography
	71-10226	Multilayered Printed Circuit Boards Inspected by X-Ray Laminography
	71-10438	Radiographic Inspection Specifications for Electronic Components
	71-10439	A Multiple-Plate, Multiple-Pinhold Camera for X-ray and γ-ray Imaging
	71-10492	Optimized Techniques and Requirements for Computer Improvement of Structural Weld Radiographs
Chemical and Spectrographic Analysis	66-10305	Simple, Nonstructive Test Identifies Metals
	70-10057	Mass Spectrometer Detects High Molecular Weight Components
	70-10402	Improved Photoionization Mass Spectrometer
	70-10471	Apparatus for Simultaneous Ion Counting and Current Recording in Mass Spectrometry
	70-10520	Nondestructive Spot Tests Allow Rapid Identification of Metals
	70-10661	Spectral Emission Measurement of Igneous Rocks Using a Spectroradiometer
	71-10009	Fast Peak Selector for Mass Spectrometer
	71-10359	Simplified Procedure for Emission Spectrochemical Analysis
Other Non-destructive Testing Techniques	65-10107	Crack Detection Method is Safe in Presence of Liquid Oxygen
	65-10265	Weld Leaks Rapidly and Safely Detected
	66-10028	Portable Self-Powered Device Detects Internal Flaws in Tubular Structures

TECH BRIEF EXHIBIT (Continued)

Technical Category	Tech Brief Number	Tech Brief Title
Other Non-destructive Testing Techniques (Continued)	66-10131	Surfactant for Dye-Penetrant Inspection Is Insensitive to Liquid Oxygen
	66-10341	Ultrasonic Emission Method Enables Testing of Adhesive Bonds
	66-10574	Nondestructive Test Method Accurately Sorts Mixed Bolts
	66-10587	Quality Control Criteria for Acceptance Testing of Cross-Wire Welds
	66-10652	Rocket Engine Vibration Accurately Measured by Photography
	67-10116	Detection of Entrapped Moisture in Honeycomb Sandwich Structures
	67-10121	Portable Fixture Facilitates Pressure Testing of Instrumentation Fittings
	67-10286	Liquid Crystals Detect Voids in Fiber-glass Laminates
	67-10333	Braze Joint Quality Tested Electro-magnetically
	67-10403	Wear Studies Made of Slip Rings and Gas Bearing Components
	67-10430	Study Made of Acoustical Monitoring for Mechanical Checkout
	67-10431	Camera Lens Adapter Magnifies Image
	67-10482	Surface-Crack Detection by Microwave Methods
	67-10645	Eddy Current Probe Measures Size of Cracks in Nonmetallic Materials
	68-10002	Gage Monitors Quality of Cross-Wire Resistance Welds
	68-10021	Optical System Facilitates Inspection of Printed Circuit Boards
	68-10183	Detection and Location of Metallic Objects Imbedded in Nonmetallic Structures
	68-10246	Miniature Pressure Transducer for Stressed Member Application
	68-10333	Automatic, Nondestructive Test Monitors In-Process Weld Quality

TECH BRIEF EXHIBIT (Continued)

Technical Category	Tech Brief Number	Tech Brief Title
Other Non-destructive Testing Techniques (Continued)	68-10347	Improvement in Recording and Reading Holograms
	68-10364	Nondestructive Test Determines Over-load Destruction Characteristics of Current Limiter Fuses
	68-10378	Nondestructive Method for Measuring Residual Stresses in Metals, a Concept
	68-10511	Rocket Engine Analog Simulation
	69-10059	Reidentifying Hardware After Loss of Serial Number
	69-10142	Improved Combustion Chamber Optical Probe
	69-10152	Surface Irregularities Detected by Flare Inspection Instrument
	69-10226	Camera Mount for Close-Up Stereo Photographs
	69-10464	Nondestructive Determination of Cohesive Strength of Adhesive-Bonded Composites
	69-10663	Fine-Line Sensitivity for Holographic Interferograms
	69-10700	Long Range Holographic Contour Mapping Concept
	69-10756	Seismographic Recording of Large Rocket Engine Operation
	70-10012	Sonic Impedance Technique Detects Flaws in Polyurethane Foam Spray-On Insulation
	70-10027	A Method for the Visual Detection of Holes in Thin Polymeric Films
	70-10033	A Simple Tester Provides Resonant Frequency Measurements of Ferrite Devices
	70-10084	Electrical Resistance Determination of Actual Contact Area of Cold Welded Metal Joints
	70-10123	Holographic Stress Analysis

TECH BRIEF EXHIBIT (Continued)

Technical Category	Tech Brief Number	Tech Brief Title
Other Non-destructive Testing Techniques (Continued)	70-10215	Inorganic Bonding of Semiconductor Strain Gages
	70-10263	A Proposed Laser Measurement System for Determining Surface Contour
	70-10266	Motor Brush Wear Measured with Strain Gages
	70-10292	Noncontacting-Optical-Strain Device
	70-10326	Strain Gage Load Measuring Device: A Concept
	70-10466	Nondestructive Assessment of Penetration of Electron-Beam Welds
	70-10533	Electronic Flaw Simulator for Eddy Current Probe Calibration
	70-10630	Bonding of Strain Gages to Fiber Reinforced Composite Plastic Materials
	70-10654	Holographic Analysis of Thin Films
	70-10716	Electronic Strain-Level Counter
	71-10021	Study of Second Breakdown in Power Transistors Using Infrared Techniques
	71-10022	Design and Development of a Fast Scan Infrared Detection and Measurement Instrument
	71-10103	Methyl Alcohol Used as Penetrant Inspection Medium for Porous Materials
	71-10129	Locating Tube Blockage That X-Ray Cannot Detect
	71-10194	Predicting Service Life Margins
	71-10208	Nondestructive Testing of Adhesive Bonds by Nuclear Quadrupole Resonance Method
	71-10258	Study of Nondestructive Techniques for Redundancy Verification
	71-10452	Precision, Triple-Parameter, Non-destructive-Test System for In-Process Microwelding

TECH BRIEF EXHIBIT (Continued)

Technical Category	Tech Brief Number	Tech Brief Title
Other Nondestructive Testing Techniques (Continued)	71-10507	Nondestructive Testing of Bond Integrity in Foam Insulation/Aluminum Composites
	71-10513	Optical Inspection Tool for Interior Surfaces of Fluid Lines
	71-10534	Multifrequency Laser Beams for Holographic Contouring
General Handbooks	67-10195	Weld Procedure Produces Quality Welds for Thick Sections of Hastelloy-X
	67-10374	Handbooks Describe Eddy Current Techniques Used in Nondestructive Testing of Metal Parts and Components
	67-10533	Study of Stress Corrosion in Aluminum Alloys
	67-10574	Nondestructive Testing Techniques Used in Analysis of Honeycomb Structure Bond Strength
	68-10391	Training Manuals for Nondestructive Testing Using Magnetic Particles
	68-10394	Nondestructive Testing of Brazed Rocket Engine Components
	69-10108	Handbooks for Nondestructive Testing Using Ultrasonics
	69-10278	Instruction Manuals for Liquid Penetrant Nondestructive Testing
	69-10366	Instrumentation for Nondestructive Testing of Composite Honeycomb Materials
	69-10730	Effects of High-Pressure Hydrogen on Storage Vessel Materials
	70-10715	Strain Gage Installation Manual
	71-10156	Instruction Manuals for Radiographic Nondestructive Testing
	71-10271	Qualifications and Certification of Nondestructive Testing Personnel

ATTACHMENT IV

Summaries of Technology Transfer Reports Involving NASA–Generated Nondestructive Testing Technology

SUMMARY OF TECHNOLOGY TRANSFER REPORTS INVOLVING
NASA-GENERATED NONDESTRUCTIVE TESTING TECHNOLOGY

NASA CONTRIBUTIONS	TRANSFER STAGES							
	1		2		3		4	
	Cont.*	Term.	Cont.	Term.	Cont.	Term.	Cont.	Term.
ULTRASONICS								
• Mechanized Ultrasonic Scanning System			21897**					
			54934					
• Ultrasonic Delta Technique							59201	
Ultrasonic Hand Tool					15139			
• Ultrasonic Measurement of Residual Stress					31840			
RADIOGRAPHY								
• Radiographic Film Reference					49702			
• Solid State Imaging Device				21588	20501			
					58901			
CHEMICAL AND SPECTROGRAPHIC ANALYSIS								
• NDT Spot Test For Metal Identification					44538			
					44636			
					44768			
					45010			
					47012			
					47074			
					47744			
					48880			
					66874			
OTHER NONDESTRUCTIVE TESTING TECHNIQUES								
• NDT Measurement of Residual Stress			27106	26855	26854			
			54932					
• 1966 Nondestructive Testing Symposium					56301			
					56302			
					57802			
					57803			
• Fiber Optics Detect Surface Irregularities							30502	
• Optical Strain Measuring Device			53850					
• Sonic Impedance NDT				48782				
• Infrared Scanner for Nondestructive Testing					57574		70001	
GENERAL HANDBOOKS								
• Nondestructive Testing Manuals					5170		53871	
					6706			
					27624			
					27634			
					27642			
					27744			
					31534			
					40622			
					53789			
• Nondestructive Testing of Brazed Components	24833		24342					
			27305					
• Nondestructive Testing of Honeycomb Structures					4303			
• Strain Gage Installation Manual					51572			
					51950			
					52304			

* The action status, continuing or terminated, of transfer cases at the time DRI-PATT contacted users. Cases are classed as terminated when (a) no further adaptation or adoption is contemplated, (b) a better technical alternative has been found, or (c) continued transfer activity is not economically feasible.

** Numbers in columns refer to PATT case numbers.

MECHANIZED ULTRASONIC SCANNING SYSTEM
TECHNOLOGY TRANSFER EXAMPLE SUMMARY

Nondestructive testing in the inspection of welds usually involves X-ray or ultrasonic methods. In space vehicles, the range of material thicknesses encountered limits the usefulness of radiography for detecting lack-of-fusion and lack-of-penetration flaws. Using ultrasonics to inspect the flaw content of welds in booster stages and propellant tanks has been inhibited by the necessity of submerging the test weld in water or providing a water flush over the inspection surface.

Raymond Evans and J. A. MacDonald of Marshall Space Flight Center designed and developed a mechanized ultrasonic scanning system, publicized in Tech Brief 68-10004. Their instrument is built around a water column probe that eliminates the need for submerging or flushing the test specimen. The probe is a transmitter and receiver consisting of an ultrasonic transducer enclosed in a water filled cylinder. The lower end of the cylinder is covered with a rubber diaphragm that seals the unit and permits transmission of the ultrasonic beam to the weld. The system consists of the probe, an ultrasonic flaw detection unit, a recording unit, and special tooling to move the probe along the inspection surface at a rate in excess of one inch per second.

The F. Yeager Bridge and Culvert Company in Port Huron, Michigan (54934) plans to use the system as soon as better techniques are developed for interpreting test results. The company fabricates steel bridges for the Michigan Highway Department. The Department currently requires X-ray testing of bridge welds because the results may be interpreted objectively. The portability and recording features of the ultrasonic scanner are attractive to Yeager Bridge; considerable savings are anticipated from its use.

Engineers at De Laval Turbine, Incorporated in Trenton, New Jersey (21897) have evaluated the system and found it to be satisfactory for the company's needs if a suitable method or in-house expertise can be developed to interpret the ultrasonic test results. A company spokesman reported that the NASA system is potentially a more efficient way to conduct quality control testing of De Laval's products such as compressor wheels.

Control Numbers

Tech Brief Number: 68-10004
NASA Center: Marshall Space Flight Center
PATT Case Numbers: 21897, 54934
TEF Number: 380
Date of Latest Information Used: July 8, 1971

ULTRASONIC DELTA TECHNIQUE

TECHNOLOGY TRANSFER EXAMPLE SUMMARY

Marshall Space Flight Center (MSFC) sought a nondestructive testing technique to rapidly inspect butt welds in aluminum alloys and detect the lack of weld penetration not readily seen in the radiographs. With the increasing demands for high vehicle reliability, low cost, sensitive techniques, and automated testing, only a nondestructive test system having exceptional capabilities could achieve the level of defect detection required by MSFC. Since welding is an essential part of fabrication of space vehicles, accurate nondestructive evaluation of weldments requires use of the most advanced methods that are available. The Delta technique, an ultrasonic weld inspection technique developed by the Research Division of Automation Industries, Incorporated in Boulder, Colorado (59201), offered much promise for accomplishing the weld inspection requirements of MSFC. This technique was developed to detect randomly oriented weld defects. In the laboratory, the Delta technique had been used successfully for detecting these defects. The company was awarded a NASA contract (NAS 8-18009) in 1967 to transform the Delta technique from a laboratory tool into a reliable inspection method for production weld evaluation.

The Delta technique uses two or more transmitting transducers which introduce ultrasonic sound energy into the material being investigated at an angle that produces shear-wave energy in the material; for welds it is introduced into the adjacent parent material. The sound propagates in the material until it strikes an interface, which is anything differing in acoustic impedance from the parent material and interrupting the propagation pattern of the sound beam. The interface may be an inclusion, crack, or absence of weld penetration or fusion. At the interface the sound energy may be (1) simply reflected; (2) converted in mode from shear to longitudinal; or (3) reradiated. Experiments have shown the occurrence of this latter phenomenon; in concept the defect acts as a new source of the sound energy. Any energy redirected from the defect can provide information about the defect. The energy received at the receiving search unit (RSU) conveys information to either an oscilloscope or a printout about the defect, regardless of which path it followed to get there. The RSU is usually focused for increase in the angle of capture of the redirected energy. In thinner materials the lengths of the various paths are so short that they give the appearance of almost simultaneous occurrence; in thicker materials the various paths and modes can be separated and identified. The nature and operation of two Delta configurations, the Delta Wheel and the Delta Manipulator, are described in the TSP for Tech Brief 70-10514.

The contracted development at Automation Industries produced an operational Delta technique and equipment which detected the weld flaws of primary concern in aluminum alloys at inspection rates of 50 feet per hour and did so with greater accuracy than radiography. Destructive analysis of 18 feet of weldment tested showed that about 80 percent of total defects were detected by the Delta technique, whereas only 36 percent were caught by radiography.

Since the NASA contract was completed, Automation has been producing similar equipment for similar applications. Approximately 25 companies have purchased the Delta Manipulators for $790.00 each. A single company may have as many as 100 of these units since they are the key to using the Delta technique. NDT experts report that the Delta technique was immediately used to replace standard ultrasonic methods in many applications as soon as the first descriptions of its operational capabilities were published (Automation's report in 1968, NASA CR-61952). Many users fabricated their own version of the Manipulator for in-house use with standard transducers.

Control Numbers

Tech Brief Number:	70-10514
NASA Center:	Marshall Space Flight Center
PATT Case Number:	59201
TEF Number:	387

Date of Latest Information Used: August 9, 1971

ULTRASONIC HAND TOOL

TECHNOLOGY TRANSFER EXAMPLE SUMMARY

The Boeing Company, under contract to Marshall Space Flight Center, has invented a portable, electrically-powered ultrasonic hand tool for rapid scanning of spot weld discontinuities in small, inaccessible places. The unit consists of an ultrasonic search unit attached to a solenoid in a housing assembly which includes the scanning motor. The solenoid is fitted with a recording stylus in contact with pressure sensitive paper to provide a read-out of the results. In operation, the front end of the scanner is placed on the area being examined. The spiral scanning motion of the ultrasonic search unit is recorded as a spiral pattern on the pressure sensitive paper. Weld discontinuities will appear as breaks in the spiral pattern.

Moragne Machine and Manufacturing Corporation in Freeport, Texas (15139) is using several copies of the hand tool, which were fabricated in-house, to inspect welds on equipment produced by the company for industrial use. Dr. Moragne, company president, has used this and other NASA TSP's as the basis for an extensive investigation of ultrasonics. His investigation has produced several inventions: a patented ultrasonic precipitator to clean air in the Houston Astrodome; a carbon black plant and a fire brick plant; and a welding method in which the work piece is vibrated ultrasonically to produce a superior weld. Dr. Moragne attributes approximately $3.5 million of increased sales to his use of the NASA technology. This is, in part, indirect since he includes all benefits which have evolved from his reading the TSP.

Control Numbers

Tech Brief Number:	66-10289
NASA Center:	Marshall Space Flight Center
PATT Case Number:	15139
TEF Number:	386

Date of Latest Information Used: July 12, 1971

ULTRASONIC MEASUREMENT OF RESIDUAL STRESS

TECHNOLOGY TRANSFER EXAMPLE SUMMARY

Metal machining and assembly processes can produce residual stress which can cause fatigue failure. Residual stress levels inside a metal are difficult to analyze, although surface residual stress can be analyzed by X-rays, and dynamic surface stresses are observable with strain gage and photostress techniques.

In 1967, R. W. Benson & Associates, Incorporated, under contract to Marshall Space Flight Center, developed an ultrasonic method for stress analysis in which the patterns of wave propagation inside the metal provide a basis for analysis. The method involves mounting two Y-cut crystals with their axes of vibration at right angles. The crystals generate and receive signals, and the degree of stress in the metal is revealed by timing the phase shift between the two signals. Stresses within the metal can be measured with this method by varying the signal frequency. The penetration depth of a surface wave is approximately one wavelength, so that deeper penetration can be achieved by using lower frequencies. This method was described by NASA in Tech Brief 67-10428.

Lodding Engineering, a division of Thermo-Electron Corporation in Auburn, Massachusetts (31840), is proceeding with development of a new product based on the Tech Brief. The firm's engineers had been experimenting with methods of nondestructively measuring residual stresses when they learned of the new technique. Visits to Marshall convinced them that the principles embodied in the NASA technology could be applied to a new product. Subsequent development work yielded two portable prototype instruments which work well on aluminum alloys but provide only qualitative data on ferrous alloys. The instruments give essentially instantaneous results under field conditions as opposed to at least an hour of preparation time for the strain gage techniques. Although redesign efforts are underway to improve the instrument's capability on ferrous alloys, the current model will be marketed by June 1972 in the price range of $5,000 to $10,000.

Market prospects are quite good, and development costs will probably be recovered during the first year. The product is expected to replace the use of strain gages in many applications.

Control Numbers

Tech Brief Number: 67-10428
NASA Center: Marshall Space Flight Center
PATT Case Number: 31840
TEF Number: 316
Date of Latest Information Used: March 23, 1972

RADIOGRAPHIC FILM REFERENCE

TECHNOLOGY TRANSFER EXAMPLE SUMMARY

When radiography is used for nondestructive testing, the resulting image must be interpreted to discover flaws in the test object. An improved "Reference for Radiographic Interpreters" (RRI) was compiled at North American Rockwell Corporation under contract to Marshall Space Flight Center. It provides a wider variety of X-ray film examples for each weld defect than are available in other X-ray film references. The RRI also contains examples of film quality, stainless steel welded tubing and acceptable weld conditions. The film slides are one inch by two inches and are contained in loose-leaf, celluloid folders for easy viewing. The slides are identified by a number, which can then be referenced to the summary sheet in the RRI for a detailed description of the particular discrepancy shown on the film strip. An interpreter who desired to familiarize himself with weld radiographs would view a numbered X-ray slide and make an evaluation of the observed defects. This evaluation would then be compared with the standard given in the summary sheet for that particular slide. The RRI was announced by NASA in Tech Brief 70-10189.

Quality control engineers at American Standards, Incorporated in Franklin Park, Illinois (49702) frequently use the RRI to evaluate X-rays of temperature sensors which are produced by the company. Prior to receiving the NASA reference, this quality control evaluation was based on less thorough references and required more time to complete. The sensors are used by customers in boilers, reactors, and laboratory equipment where safety requires a very stringent quality control.

Control Numbers

Tech Brief Number: 70-10189
NASA Center: Marshall Space Flight Center
PATT Case Number: 49702
TEF Number: 382
Date of Latest Information Used: July 12, 1971

SOLID STATE IMAGING DEVICE
TECHNOLOGY TRANSFER EXAMPLE SUMMARY

The Electron Tube Division of Westinghouse Electric Corporation was conducting research for the development of light amplification panels when it was awarded a contract (NAS 8-21206) from Marshall Space Flight Center in July 1967. The contract redirected this research toward radiographic amplification panels and supported the development of working prototypes from the basic principles involved. One of these panels, together with a portable power pack and radio isotope source, can provide a briefcase-sized X-ray unit. The image may be preserved by photographing the panel display.

The new panel consists of a relatively simple, thin layered construction. It provides images of higher contrast sensitivity and better resolution over longer storage periods than are attainable with previous image amplifiers of this general type. The device also combines very high radiation sensitivity (10 milliroentgens, or less, of penetrating radiation required for optimum display, compared to 350 milliroentgens for a "Thorne" image amplifier) with fast image buildup and erasure capabilities. When excited by X-ray or gamma ray radiation directed through a test specimen, the image amplifier produces a daylight-visual image of the radiographic structural details in its field of view. These characteristics are achieved by the addition of two layers to a basic image amplifier and cascading this assembly with a modified "Thorne" panel. The two new layers are connected electrically in series. Radiation applied to the photoconductive layer reduces its resistance, which decreases the voltage drop across it; this increases the voltage across the electroluminescent layer causing a light pattern of the input energy to be produced. A Tech Brief was issued in 1968, which described the current state of the panel's development. The basic configuration has not changed since then, although considerable refinement has taken place.

The Westinghouse division, which is located in Elmira, New York (58901), has developed a potential new product as a result of the NASA contract. The company has sold approximately 20 laboratory built panels, worth a total of $20,000, for evaluation in medical, welding and other NDT applications. The invention appears to provide a significant advance in radiography, and the company is conducting a promotional campaign for commercial applications. If the panels are mass produced, the quality will be improved, and the cost will be reduced by a factor as great as 100.

Marshall has awarded two no-cost contracts for the development and evaluation of medical applications for a portable X-ray unit which uses the panel. Tulane University Medical School in New Orleans, Louisiana and Southeastern State College in Durant, Oklahoma have each received one of the $400 units. The Tulane project, initiated by NASA's Biomedical Application Team (BATeam) at the Research Triangle Institute in Research Triangle Park, North Carolina, will utilize the panel to monitor cancer growth. The natural growth rate will be minimally affected by the low radiation requirements of the panel. The Southeastern State College project, initiated by NASA's Technology Use Studies Center, will develop the unit's applications for veterinarians. The quick response and portability of the unit will be used to X-ray large animals in the field.

A major photographic company (20501) has used the TSP to invent a new electroluminescent device with potential medical and industrial applications. The NASA information was described as "quite valuable" in developing the unusual device. Prototypes have been successfully tested, and a patent is pending. It will be marketed after the patent is issued.

Atomics International, a division of North American Rockwell Corporation in Canoga Park, California (21588), evaluated prototypes of the panel for use in its quality control testing of one product: nuclear reactor fuel elements. Although the panel was satisfactory for this application and would have reduced costs, the company no longer makes this product.

Control Numbers

Tech Brief Number:	68-10363
NASA Center:	Marshall Space Flight Center
PATT Case Numbers:	20501, 21588, 58901
TEF Number:	117

Date of Latest Information Used: October 22, 1971

NDT SPOT TEST FOR METAL IDENTIFICATION

TECHNOLOGY TRANSFER EXAMPLE SUMMARY

M. L. Wilson of Langley Research Center has compiled a flowchart indicating an ordered test sequence to permit rapid identification of metals and alloys. Even complex alloys can be identified within 30 minutes by personnel with very little training. The test requires only the application of standard chemical reagents to metal surfaces, spot-plate depressions or on filter paper. Colors or specific reactions produced by the reagents allow identification to be made. Only a minute amount of metal is destroyed, so the test is reasonably called nondestructive. All commonly used metals are covered by the procedures, which specify required amounts of reagents, reaction time and possible results. The flowchart also lists separate procedures for confirming the presence of individual elements in an alloy and an enumeration of nominal compositions of one hundred common alloys. In 1970, NASA announced the availability of the spot test TSP in Tech Brief 70-10520.

This TSP has been requested by more than 1,063 individuals throughout the country. Many requesters have found immediate applications for the procedure to the verification of alloys during manufacturing and scrap metal separation. One example of the interest shown in the technology is the Institute of Scrap Iron and Steel, Incorporated, which has distributed 350 copies of the Tech Brief to its member companies. The following examples are typical of the applications which have been made of the spot test.

Goodyear Atomic Corporation in Piketon, Ohio (44768) saved up to $15,000 between August 1971 and March 1972 by using the spot test on aluminum alloy compressor blades. Goodyear metallurgists anticipate similar savings of time and money in the future.

The Portland, Maine division of E. W. Bliss Company (44636) is using the spot test to identify metal alloys from which it produces parts for jet engines and fire fighting equipment. The primary application is in verifying stock material which may become mixed in the stockroom. The company has developed its own set of known comparison samples and estimates that the spot test procedure has eliminated the need to purchase more than $9,500 worth of spectrographic equipment and reference samples.

Chicago Vitreous Corporation (47012) uses the spot test to solve customer problems. The company sells porcelain enamel frit which is applied to products by the customer. About 75 percent of customers' application problems involve incorrect identification of substrate metals. The firm has saved up to $1,000 in commercial laboratory fees on several occasions.

The Houston Branch of Rockwell Manufacturing Company (48880), a producer of offshore oil rig equipment, uses the spot test as a standard procedure in processing customer complaints on malfunctioning equipment. Malfunctions often result from having used incorrect alloys in a given component, and the spot test quickly and conveniently provides a check.

Sanford Ink Company in Bellwood, Illinois (45010) is investigating the potential market for a new product based on the TSP. The proposed product would consist of a set of Sanford's magic marker type pens containing the reagents for conducting the spot test. This set would be sold with a copy of the flowchart from the TSP.

An industrial hygiene chemist with the New York State Department of Labor in Tonawanda (44538) is using the spot test to help identify health hazards associated with metal fabrication. He is particularly interested in alloy components such as beryllium and cadmium. The test provides quick results with sufficient accuracy for his work; he will continue to use it frequently.

The chairman of mechanical and engineering technology at The Pennsylvania State University in Middletown (66874) presently uses part of the spot test sequence in his course on materials and processes, and is planning to include the technology in his automotive design course. His primary interest in the method is testing for lead in brass alloys.

Material engineers with New Hampshire Ball Bearings, Incorporated in Petersborough, New Hampshire (47074) are using the spot test to verify alloy identification for incoming rough stock during fabrication and for finished bearings when there is a reason to suspect that the alloy is mislabeled. The spot test has replaced, in part, the in-house use of spectrographic analysis and saves at least two hours of time over this more expensive method each month.

The Research and Development Division of Kraftco Corporation in Glenview, Illinois (47744) has decreased the time required to analyze food processing problems which arise from the reaction of a food and atmosphere combination with the stainless steel equipment. By using the spot test, the steel alloy is quickly identified so that the reaction may be analyzed and prevented. The spot test has led to the selection of an alternative stainless alloy for a given application and to the diagnosis of incorrect alloys provided by a supplier.

Control Numbers

Tech Brief Number:	70-10520
NASA Center:	Langley Research Center
PATT Case Numbers:	44538, 44636, 44768, 45010, 47012, 47074, 47744, 48880, 66874
TEF Number:	378

Date of Latest Information Used: March 17, 1972

NDT MEASUREMENT OF RESIDUAL STRESS
TECHNOLOGY TRANSFER EXAMPLE SUMMARY

C. D. Schwebel of the Boeing Company, under contract to Kennedy Space Center, originated a conceptual model for indirect and nondestructive measurement of residual stresses in metals. His suggestion is based on the fact that the electrochemical solution potential of a metal depends on the metal's condition of stress. The necessary apparatus for this residual stress measurement technique consists of two electrolytic cells, a differential galvanometer, and a reference specimen holder. One cell is placed on the metal surface to be tested and the other on the reference specimen. The operator loads the reference specimen until the galvanometer indicates the same potential from both electrolytic cells. At this point he measures the deflection in the reference specimen and uses its known modulus of elasticity to calculate its stress. Its calculated stress is the same as the residual stress in the test specimen.

Design engineers with the Magnavox Company in Fort Wayne, Indiana (54932) are attempting to develop an operational methodology for the concept. Their application concerns corrosion rate prediction for the structures produced by the company for ocean site installations. The prediction would be based on an existing large quantity of data relating the corrosion rate and the residual stresses in metallic components of the structures and a nondestructive measurement of residual stresses in a new component.

Engineers with Metal Improvement Company in Carlstadt, New Jersey (27106) are investigating the NASA method for possible adoption to measure the compressive residual stresses introduced in metal components by shot peening. The company does shot peening as a commercial service to improve surface fatigue life of the component. If the engineering evaluation provides satisfactory results and the method is adopted, the company will have greatly improved the service and its saleability since the information is usually required by customers.

The Associated Spring Corporation in Bristol, Connecticut (26855) investigated the method and rejected it as requiring too much sophistication for testing springs. Arcoa, Incorporated, a consulting engineering firm in Phoenix, Arizona (26854), has tested a prototype and found the method to be satisfactory. The evaluation data and the prototype are available for future consulting work.

Control Numbers

Tech Brief Number: 68-10378
NASA Center: Kennedy Space Center
PATT Case Numbers: 26854, 26855, 27106, 54932
TEF Number: 379
Date of Latest Information Used: June 10, 1971

1966 NONDESTRUCTIVE TESTING SYMPOSIUM TECHNOLOGY TRANSFER EXAMPLE SUMMARY

A number of NASA-developed nondestructive testing (NDT) methods and related equipment were described to government, industrial, and academic representatives attending the Second Technology Status and Trends Symposium on October 26-27, 1966 at the Marshall Space Flight Center. The symposium was an activity of the NASA Technology Utilization Program. The proceedings were published in 1967 as SP-5082, Nondestructive Testing: Trends and Techniques.

Several ultrasonic techniques were described and analyzed for testing adhesion and strength in composite materials, residual stresses in aluminum, and welds in aluminum. An X-ray method, axial transverse laminography, was presented which allows imaging of thin cross sections of multilayer printed circuits without sectioning the test sample. Two major pieces of equipment which were designed under contract to Marshall Space Flight Center, the X-ray television system and the fast scan infrared microscope, were described and compared to conventional systems of the same type. The symposium was completed with a discussion of the studies at Marshall related to the prediction of future trends in NDT based on anticipated requirements. The major goals for NDT were the achievement of complete assurance of hardware interrogation to the desired quality levels and the development of faster testing methods. A number of investigations related to these general goals were briefly described: ultrasonic imaging systems, solid-state radiographic imaging systems, neutron radiography, liquid crystal applications and smaller, more portable equipment. In each of the examples cited below, the transfer was initiated by the symposium; the transfer activity is now based on the published proceedings.

The Boulder, Colorado division of Automation Industries (57803) has used the SP since 1967 as a basis for judgement and a guide in testing and product development. This division does corporate and contractual research on NDT equipment and techniques. It also produces thermal and ultrasonic NDT devices. A manager in the division reported that in some areas of NDT, NASA accomplishments described at the symposium are still the state-of-the-art.

An engineer with the Tennessee Valley Authority in Chattanooga, Tennessee (56301) has adapted information on liquid crystals from the SP to develop techniques for measuring temperature differences in power generating machinery such as turbines. The liquid crystals are used in places on the generators where thermocouples do not provide satisfactory results. The data provided by these techniques are used to monitor the machinery and to develop design modifications.

A professor in the metallurgical engineering department of the University of Missouri at Rolla (56302) has included technology from the SP and symposium in his course on nondestructive testing for seniors and first year graduate students. Approximately 200 students have taken the course since it was initiated in September 1967. The NASA material has provided almost ten percent of the course input.

The R & D laboratories of the Aluminum Company of America in New Kensington, Pennsylvania (57802) are using the SP as a reference book to develop new procedures for quality assurance inspection of aluminum alloy wrought products in the company's plants. These procedures involve the use of ultrasonics for testing residual stresses and welds, and for identifying defects produced by other forming processes. A spokesman reported that several of the company's standard testing methods were directly traceable to the SP, which provided from 10 to 30 percent of the input in developing the methodology.

Control Numbers

Special Publication Number:	SP-5082
NASA Center:	Marshall Space Flight Center
PATT Case Numbers:	56301, 56302, 57802, 57803
TEF Number:	381
Date of Latest Information Used:	July 19, 1971

FIBER OPTICS DETECT SURFACE IRREGULARITIES
TECHNOLOGY TRANSFER EXAMPLE SUMMARY

In order to acquire a capability for detecting surface irregularities in a specific tube flare, Marshall Space Flight Center contracted with Metro Physics, Incorporated in Santa Barbara, California (30502) to develop a new sensing device. The invention, described in Tech Brief 69-10152, permits taking a large number of discrete dimensional measurements on very small areas with a single setting and an accuracy on the order of micro inches. The fiber optics sensor portion of the instrument consists of bundles of optically transmitting fibers with their ends arranged on the gauge in a pattern of measuring points. Each measuring point is composed of transmitting and receiving fibers. The transmitting fibers are joined to a common light source, and the receiving fibers have an independent light sensor. Light emitted from transmitting fibers reflects from the inspected surface to the receiving fibers. The amount of light reflected is a measure of the distance between the measured surface and the end of the bundle. The rest of the unit consists of electronics for activating the fiber optics, for activating the scanning functions, for receiving, amplifying, and displaying the scanned data on a cathode ray tube, and for determining the distance being sensed and the deviation from standard.

As a result of its work in developing the device, Metro Physics has been able to further develop a commercial product. Great interest in the instrument has been shown by machine tool manufacturers, since it can check contours, measure critical part dimensions, measure surface flatness and finish, measure holes and measure deflection. To date only custom-built units have been sold, but Metro will soon begin mass production of the device as a result of the response to a recent advertising campaign. This will significantly reduce the present price of $1,200 and greatly increase its marketability.

In an unusual application attempt, the firm is working with NASA's Technology Application Team at the Illinois Institute of Technology Research Institute in Chicago to modify the instrument for use in detecting indented writing (i.e., impressions made on backing sheets or pages of a pad under the sheet upon which someone has written).

The Law Enforcement Assistance Administration and several police departments are active in this adaptation of space program technology.

Control Numbers

Tech Brief Number: 69-10152
NASA Center: Marshall Space Flight Center
PATT Case Number: 30502
TEF Number: 331
Date of Latest Information Used: July 29, 1971

OPTICAL STRAIN MEASURING DEVICE

TECHNOLOGY TRANSFER EXAMPLE SUMMARY

A noncontacting-strain-measuring gauge and extensometer for remotely measuring the mechanical displacement along the entire length of a test specimen was developed at the Jet Propulsion Laboratory under contract to the NASA Pasadena Office. It consists of an optical system which continuously senses and records the displacement of reflective bench marks on a test specimen when the specimen is subjected to stress. This displacement is directly related to the strain in the specimen. The sensing is done by means of a light source, a photocell, and a combination of lens and mirror. The photocell signals are electrically amplified and reproduced on a cathode ray tube and a strip chart recorder.

Engineers at the Bell Telephone Laboratories in Holmdel, New Jersey (53850) have developed several minor design modifications of this strain measuring device, and a prototype is planned. If the prototype tests are satisfactory, the device will be used for in-house automated testing of microelectronic components. According to a Bell engineer, the NASA invention appears to be very well suited to this application, and its use will allow a substantial savings in quality control inspection costs.

Control Numbers

Tech Brief Number:	70-10292
NASA Center:	NASA Pasadena Office
PATT Case Number:	53850
TEF Number:	383

Date of Latest Information Used: March 27, 1972

SONIC IMPEDANCE NDT

TECHNOLOGY TRANSFER EXAMPLE SUMMARY

The problem of detecting voids in polyurethane foam insulation layers has resisted solution by many attempted NDT methods, including microwave, X-ray, neutron radiography, ultrasonics, electrostatic field intensity, low-frequency sound velocity, sonic-brush noise generation and microphone pickup, and optical absorptance/reflectance. These methods are either very costly or insufficiently sensitive.

SPACO, Incorporated, under contract to Marshall Space Flight Center, developed a sonic impedance method to detect voids and unbonded regions in the layers as small as one inch in diameter and 0.03-inch thick. Sonic impedance occurs when an acoustical signal is damped by solid, well-bonded foam; the absence of this damping indicates a flaw. The NASA technique may be performed manually or automatically with a transducer even through a protective coating on the test object. The readout can be made directly by meter or recorder, which eliminates subjective evaluation by the operator. The discovery was announced in a 1970 Tech Brief.

The product development division of a major corporation (48782) was planning to include the sonic impedance technique in production line quality control specifications for a potential new product if the market studies related to it were favorable. The planned product was a sandwich panel of two plastic forms separated by polyurethane foam to be used in boats and campers. If the foam and plastic are not properly bonded, lengthy exposure to sunlight will produce blisters in the plastic. Prior to receiving this NASA technology, the lack of a production quality control method for the panels presented a serious problem to its marketability. In December 1971, the corporation closed down the facility that was developing the panel product. There are no further plans to use the NASA technology.

<u>Control Numbers</u>

Tech Brief Number:	70-10012
NASA Center:	Marshall Space Flight Center
PATT Case Number:	48782
TEF Number:	376

Date of Latest Information Used: March 27, 1972

INFRARED SCANNER FOR NONDESTRUCTIVE TESTING

TECHNOLOGY TRANSFER EXAMPLE SUMMARY

In the mid-1960's, Raytheon Company developed an operational infrared scanning microscope system for automated nondestructive testing of electronic components, under contract to NASA's Marshall Space Flight Center. The unit, which Raytheon called the Compare System, included the results of previous research funded in-house and by the Defense Department. The Compare System incorporated computer processing and storage capabilities with high sensitivity, fast detector response, and good resolution on the real-time cathode ray tube display. Thermal infrared profiles for semi-conductor chips, transistors, and integrated circuits can be measured and plotted with the Compare System. An analysis of each profile yields valuable information on electrical and physical properties for design improvement and quality control of the electronic component tested.

Several Raytheon engineers who had helped develop the technology founded Dynarad, Incorporated in Norwood, Massachusetts (70001) in 1968. Dynarad then purchased all of Raytheon's rights related to infrared nondestructive testing, together with Raytheon's prototype model of the Compare System. With in-house funds, Dynarad miniaturized the system to make it portable, redesigned the scanning device, incorporated a variety of detectors to provide different infrared channels for different applications, and made several other refinements on the Compare System design. As a result of these developments, Dynarad introduced two products on the commercial market in 1971: the Fast Scan Infrared Camera and the Fast Scan Infrared Microscope. In the first year, 33 Fast Scan Infrared Cameras were sold at prices ranging from $18,900 to $26,700. The cameras are being used for nondestructive testing of electronic circuits, void detection in honeycomb construction, gas laser research, and automobile tire design testing. They are being evaluated by potential customers for computer-automated, assembly line quality control for automobile radiators and tires.

The NASA development contract with Raytheon included a test program to study the potentially destructive phenomenon of second breakdown in bipolar power transistors. In 1971, NASA published Tech Brief 71-10022 which described the fast scan infrared detection and measurement instrument and Tech Brief 71-10021 which described the test program results from using the instrument.

Perkin-Elmer Corporation in Pomona, California (57574) used the TSP for Tech Brief 71-10021 to establish test procedures for a power transistor component used in several of the company's mass spectrometer products. As a result of the tests, the transistor was found to be prone to second breakdown and was subsequently replaced in the products. By eliminating this cause for equipment failure, Perkin-Elmer is saving time, money and reputation. The need and technique for testing power transistors for second breakdown is now a part of the company's engineering expertise and will probably be used in the future.

Control Numbers

Tech Brief Numbers: 71-10021, 71-10022
NASA Center: Marshall Space Flight Center
PATT Case Numbers: 57574, 70001
TEF Number: 398
Date of Latest Information Used: January 18, 1972

NONDESTRUCTIVE TESTING MANUALS

TECHNOLOGY TRANSFER EXAMPLE SUMMARY

Quality control in large volume production is usually conducted by statistically sampling the output, with acceptance contingent upon finding a predetermined minimum number of defects. For space applications, however, defects are not permissible; and statistical sampling is not a feasible method of quality control. Every item must be assured reliable, with maximum confidence in its integrity. In addition, when using conventional strength tests, a material is subjected to stresses and loads to the point of failure, following which the tested item is no longer usable. Nondestructive testing permits evaluation of every item of output without damage to the material. NDT is thus a necessary procedure for accepting materials for space use.

Applications of available NDT technology have been limited due to the scarcity of information and instructional materials for training technicians. NASA acted to solve this problem by contracting with the Convair Division of General Dynamics to develop a set of training handbooks. The finished product includes three volumes on eddy current testing (TB 67-10374), two volumes on magnetic particle testing (TB 68-10391), four volumes on ultrasonics (TB 69-10108), two volumes on liquid penetrant testing (TB 69-10278), and six volumes on radiographic testing (TB 71-10156). For each type of NDT, at least one volume is in a programmed instruction format through which a student progresses by making selective path choices concerning the validity of each of a series of statements arranged in a sequence of increasing difficulty and comprehensiveness. The other volumes are in standard text format; they contain a comprehensive comparison of NDT methods with specific details on the capabilities and limitations of each method for particular defects.

Convair (53871) is now publishing and selling a set of manuals which are almost identical to the NASA TSP's. The company has also developed a training course based on the material. The American Society for Nondestructive Testing (ASNT) has sold more than $230,000 worth of the manuals published by Convair to buyers in 42 countries. Convair's $600, three-week NDT course was begun in July 1967. Since then, more than 600 supervisory engineering personnel have attended. Convair has invested $250,000 in its teaching facility for the short course.

Eddy current testing is based on the interaction between magnetic fields and electrical currents. An inductance coil is placed near the surface of a test object which must be fabricated from an electrically conducting material. The coil's alternating current produces a magnetic field and associated electrical eddy currents inside the object. Internal flaws affect the magnetic field which, in turn, affects the coil's current; this last effect is registered on an indicator. Dover Corporation in Memphis, Tennessee (5170) used the NASA handbooks to train two NDT technicians who test the quality of purchased materials. Use of the books saved the firm about $2, 000 per man trained. Frank D. Weaver & Associates, engineering consultants in Houston, Texas (6706), uses eddy current testing for pipeline materials. The NASA handbooks provided the company's capability in eddy current testing; a literature search capable of yielding equivalent information would have cost about $2, 000 and probably would not have been undertaken.

Magnetic particle tests can be performed on finished components, billets, hot rolled bars, and forgings by magnetizing the test specimen, applying the magnetic particles, and interpreting the pattern formed by the particles. National Castings in Cleveland, Ohio (27624) used the manuals to convince a customer of the effectiveness of this kind of NDT, which resulted in lower manufacturing costs. The company also trains its NDT inspectors with the manuals. A Midwestern tool company's (27634) chief metallurgist and his staff studied the handbooks to ascertain the firm's equipment needs and to justify the capital outlays for the equipment necessary to perform magnetic particle NDT. Manufacturing costs have since been decreased because defective parts are now identified early in the production process through magnetic particle NDT. Kaufman Fabricators, Incorporated in Kaufman, Texas (27642) trained a foreman to perform magnetic particle NDT by using the NASA documents. The company was thus enabled to complete with confidence two unusual jobs requiring three-inch plate welding and fabrication of certain contours by cutting and welding in lieu of bending the material. Allied Structural Steel Company in Hammond, Indiana (27744) saved $1, 500 in training costs with the manuals. Prior to establishing its internal NDT expertise, the firm had hired outside technicians to perform NDT on large structural welds, and encountered severe problems of coordinating the availability of the technicians with its own production schedule. The major benefit of using the NASA manuals is the increased efficiency possible with having their own employees qualified and available to perform the tests. The General Electric Company's Large

Generator and Motor Department in Schenectady, New York (31534) established a training program for NDT engineers. The instructor drew more than half the material from the magnetic particle handbooks. He estimated that a savings of 25 hours of his time could be attributed to use of the manuals in preparing the first course for 21 engineers.

Liquid penetrant testing is the oldest and most widely used NDT method. It can be used to detect surface discontinuities in nonporous metallic and nonmetallic products, such as welds, forgings, castings, and plastics and ceramics. Capillary action, which elevates or depresses the surface of a liquid in contact with a small discontinuity in a solid, constitutes the basic physical principle for liquid penetrant testing. A liquid with low tension and high capillarity is applied to a test specimen and allowed to penetrate discontinuities. Subsequent removal of the liquid from the surface leaves liquid in the discontinuities, and a blotting action "developer" is applied to indicate the location of the discontinuity. Visibility of the indication is enhanced by adding dyes to the liquid before application. Beech Aircraft Corporation in Wichita, Kansas (40622) has trained eighty quality control inspectors in liquid penetrant testing by using the manuals as both course texts and reference sources.

Ultrasonic testing is a rapid and economical method for detecting flaws by measuring echoes and converting the measurement to an indicator of flaws. Radiography is an old and well known method, encompassing X-ray, gamma-ray, neutron radiography, radiation backscatter and fluoroscopy. Most companies use several NDT methods in receiving inspection, assembly line quality control and equipment monitoring. In such cases the complete collection of training handbooks is usually purchased. The senior NDT consultant for Mobil Oil Company's Research and Development Branch in Paulsborough, New Jersey (53789) reviewed the complete set of NASA manuals and recommended their use in an article prepared for Mobil's monthly newsletter. As a result, NDT instructors at Mobil's refineries are using the manuals to train new employees for NDT they will perform on refinery production equipment. Use of the manuals saves time and makes possible a more thorough introductory course. A large Eastern firm is using the NASA documents and other information on the various NDT methods to aid in its equipment design and materials purchasing. A proper method for each problem is selected, and the required tests are performed to aid the firm in securing high quality equipment at minimum cost. The major benefit achieved, as is the case for most large companies which use the entire set of manuals, is the ability to use safely materials at a high proportion of their ultimate strength and thereby reduce costs. A yearly savings of $1,000,000 is attributed to use of the NASA information by this proprietary company.

The ASNT carries an advertisement for the Convair manuals in the Society's monthly publication, which states that they are "the most complete and comprehensive set of training manuals ever offered for NDT personnel." Most of the volumes sold by ASNT are in one of two sets: programmed instruction volumes for all five methods or reference volumes for all five methods. To date, the Society has sold more than 1,400 of the former sets at $125.50 per set and more than 1,800 of the latter sets at $30.50 per set.

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NONDESTRUCTIVE TESTING OF BRAZED COMPONENTS

TECHNOLOGY TRANSFER EXAMPLE SUMMARY

Welded and brazed joints on space vehicles must withstand severe operational stresses, including vibration, large mechanical loading and extremes of temperature. A variety of nondestructive tests are used to verify the integrity of brazed joints, some of which are specifically useful for certain materials, geometries and joint accessibility. A study of radiographic, ultrasonic, thermographic, and leak tests was conducted by North American Rockwell Corporation under a Marshall Space Flight Center contract. The illustrated report, available as TSP 68-10394, gives the results of the study, descriptions of some unique methods and equipment, and summary tables of the advantages and limitations of the various NDT methods for brazed components.

The Tenneco Hydrocarbon Chemicals Division of Tenneco Chemicals, Incorporated in Pasadena, Texas (27305) reviewed the TSP to verify the feasibility of joining techniques that may enable the firm to reclaim blocks used in acetylene production. Blocks damaged during the combustion-manufacturing process may be reclaimed by bonding a three-inch plate to the damaged surface; such reclamation of the blocks may save the firm $70,000 per year.

Homelite Division of Textron, Incorporated in Port Chester, New York (24342) is attempting to develop a nondestructive test from technology presented in the TSP for the brazed joint in one of its products. A preliminary investigation indicated that the techniques described in the document could probably be used to solve a quality assurance problem in the company's chain saws. The brazed joint, which connects the clutch drum and the chain sprocket, separates during use in an undesirable percentage of the saws and must be replaced under warranty. A company spokesman reported that the development of a good quality assurance method on this particular joint will solve a nuisance problem for the company. Homelite's metallurgical and quality assurance personnel have the NASA document now and will soon proceed to adapt technology from it.

The National Business Aircraft Association, Incorporated (NBAA) in Washington, D.C. (24833) is an association of companies which operate aircraft as an adjunct to their normal business. The association staff provides state-of-the-art information and technical assistance to member companies for the purposes of increasing efficiency and reducing costs. As part of this function, the staff has sent the TSP to the NBAA technical committee and to aircraft maintenance personnel at the two airports in the country with the largest number of business aircraft.

Control Numbers

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NONDESTRUCTIVE TESTING OF HONEYCOMB STRUCTURES

TECHNOLOGY TRANSFER EXAMPLE SUMMARY

A research program was conducted at North American Aviation, under contract to Marshall Space Flight Center, to discover a means of detecting disbonds in composite structures. From theoretical and test data, a relationship was established between bond strength and the vibratory response of face sheets of honeycomb composite panels. Valid parameters were determined for the ultrasonic measurements of the bond strength of organic adhesives. From this information, various methods of bond strength determination were proposed, of which the automatic DOT (Driver-Displacement Oriented Transducer) method appears most applicable to both the lap shear type application and the honeycomb sandwich structures. The system has the distinct advantage of providing noncontact bond strength measurements. Four types of honeycomb composite structures were fabricated to provide reference standards for evaluating both the ultrasonic techniques and the scanning/recording system. Deliberate disbonds, in the shape of triangles or squares, were located at predetermined interfaces on the honeycomb panels. Based on the results of a comprehensive literature survey, five basic ultrasonic techniques were chosen as potential solutions for the honeycomb composite inspection problem. To evaluate these techniques, five breadboard systems were developed and tested: pulse-echo interference, impedance, decrement, spectrum analysis, and intermodulation. The impedance system showed the most promise, and further development resulted in the successful detection and recording of disbonds in the specimens. A number of semiautomated scanning/recording systems were developed to supplement the ultrasonic technique evaluation. An advanced, fully automated system was integrated with the ultrasonic detection system. This combined system (the DOT method) was characterized for transducer and circuit specifications, and operating instructions were prepared. The results of this research program were announced in Tech Brief 67-10574.

Southwest Research Institute in San Antonio, Texas (4303) is using the TSP to reduce costs on a research project involving hydrostatic pressure tests of deep ocean pressure vessels to evaluate different vessel designs. The vessels are made with a honeycomb structure. If the vessel ruptures during tests as a result of poor bonding, a production flaw, the vessel has been wasted since this provides no information for design evaluation. To prevent this waste, the NASA technology is used to scan ultrasonically and to analyze areas of poor bonding which are then repaired before pressure testing.

Control Numbers

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PATT Case Number: 4303
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STRAIN GAGE INSTALLATION MANUAL

TECHNOLOGY TRANSFER EXAMPLE SUMMARY

Detailed specifications for installing laboratory strain gages have been compiled into a handy reference manual, TSP 70-10715, by North American Rockwell Corporation under contract to Marshall Space Flight Center. The manual provides laboratory technicians with a ready source of instructions on the techniques and procedures for cementing a wide variety of strain gages onto most of the commonly encountered engineering materials. Materials covered include various steels, aluminum, titanium, beryllium, magnesium, copper, ceramics, plastics and graphite. The manual is presented in two major sections. The first gives detailed instructions for preparing surfaces of the various materials for strain gage installation. Specific note is made of any health or safety hazards presented by the materials. The second section gives detailed procedures for installing various types of strain gages using a variety of conventional bonding agents.

Technicians at Continental Testing Laboratories, Incorporated in Fern Park, Florida (51950) are trained to install strain gages on test objects with the NASA manual. Continental performs a variety of tests, including several for strain, on electronic components and electromechanical systems as a contract service. The manual is also used as a reference for solving particular problems which arise in the course of installing strain gages.

Motorola, Incorporated in Scottsdale, Arizona (52304) has used information from the manual on a contract job in which they installed strain gages on the jet engine compressor blades produced by another company. Tests were then conducted on the blades by their producer. The manual is also used for strain gage installation on Motorola's products. The information on particular techniques, cleaning procedures, and maintenance of the cleaned surface are particularly important to Motorola testing personnel.

Medical researchers at Temple University in Philadelphia, Pennsylvania (51572) have used a procedure from the manual to construct a device for heart research on test animals. The device consisted of a metal sheet with strain gages attached to it, which was then wrapped around the animal's heart. Without interfering with the heart's function, it provided data on the heart's relative stroke volume output.

Control Numbers

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TEF Number: 384
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