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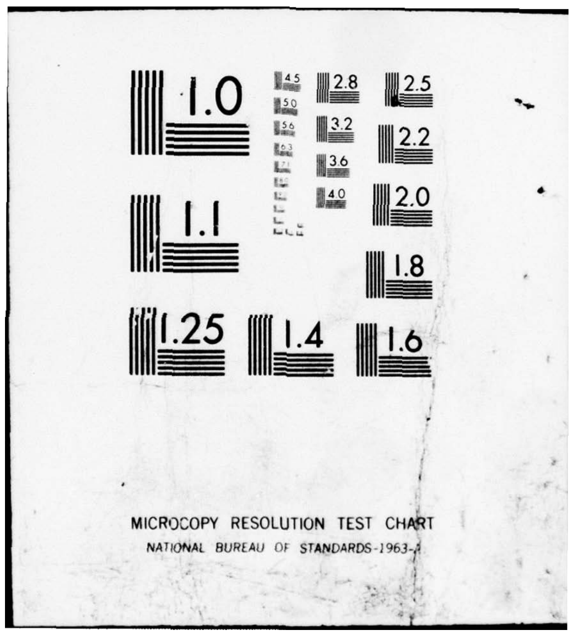
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REPORT NAEC-92-127

POTENTIAL APPLICATIONS OF ACOUSTIC EMISSION TECHNOLOGY AS A NONDESTRUCTIVE EVALUATION METHOD FOR NAVAL AVIATION MAINTENANCE ENVIRONMENT

Handling & Servicing/Armament Division
Ground Support Equipment Department
Naval Air Engineering Center
Lakehurst, New Jersey 08733

5 JULY 1978

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POTENTIAL APPLICATIONS OF ACOUSTIC EMISSION TECHNOLOGY AS A NONDESTRUCTIVE EVALUATION METHOD FOR NAVAL AVIATION MAINTENANCE ENVIRONMENT

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Presents results of a survey for potential use of acoustic emission technology for specific inspection problems within the Naval Aviation Maintenance Environment. Recommended are implementation possibilities, feasibility studies and long term research and development studies.

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SUMMARY

This report presents the results of a survey of the potential use of acoustic emission monitoring for specific inspection and maintenance tasks in performance of ground support of Naval aircraft. One potential application, detecting corrosion in composites, is identified as worthy of an implementation study, since the U.S. Air Force has already proven feasibility. Feasibility studies are recommended for AE detection of defects in landing gear, cockpit canopies, fuel tanks, helicopter rotor blades, retreaded tires and fan blades. Research and development programs are suggested for bearing noise analysis, weld inspection, and damage assessment in composites.

PREFACE

A survey of the potential use of Acoustic Emission Technology as a nondestructive evaluation (NDE) method for Naval Aviation Ground Support has been performed under contract N68335-77-M-5735. This survey was accomplished through visits and communications with various government and industrial facilities. The objectives of this project were to identify potential applications and to prepare feasibility studies for those applications so that the Navy could pursue implementation of this new technology.

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I. INTRODUCTION

The use of acoustic emission (AE) techniques as nondestructive evaluation (NDE) methods is growing worldwide. One indication of this growth is the activity in standards formulation. Official documents on terminology, acceptance criteria, test procedures, calibration, and personnel qualification are being prepared by the American Society for Testing and Materials, the American Society of Mechanical Engineers, the American Society for Nondestructive Testing, the U.S. National Bureau of Standards, and the U.S. Acoustic Emission Working Group, reference (a). Applications of AE techniques are found in many industries, including those of aerospace and aircraft.

Although there are still few routine uses of AE methods, it's clear that eventually AE NDE techniques will become as popular as ultrasonics or eddy current.

Now is an appropriate time to pursue the potential use of AE technology for specific inspection and maintenance problems in aircraft ground support. This can lead to formulation of requirements for AE instrumentation and auxiliary test equipment, which are capable of performing several diagnostic functions. The Navy could then design and develop one or more simple multi-purpose AE instruments, which can be easily and reliably adapted to various AE test procedures.

This report presents the results of a survey of the potential use of AE technology for specific inspection and maintenance problems in ground support of Naval aircraft. The author has performed the survey through visits and telecommunications with various individuals at the following organizations:

Office of Naval Research, Pasadena, CA and Washington, DC
Naval Research Laboratory, Washington, DC
Naval Air Engineering Center, Lakehurst, NJ
Naval Ship Research and Development Center, Annapolis, MD
Naval Air Development Center, Warminster, PA
Naval Air Rework Facility, North Island, CA
Naval Air Rework Facility, Alameda, CA
Naval Air Rework Facility, Jacksonville, FL
USAF Materials Laboratory, Dayton, OH
USAF Air Logistics Center, Sacramento, CA
USAF Air Logistics Center, Oklahoma City, OK
Corpus Christi Army Depot, Corpus Christi, TX
Vought Corporation, Dallas, TX
Southwest Research Institute, San Antonio, TX

As a result of the multiple inputs, several general areas of potential application were classified as having popular appeal. Several specific potential applications were identified and subsequently studied. In this report, those

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Ref: (a) Hartman, William F., "Towards Standards for Acoustic Emission Technology," Nondestructive Testing Standards - A review, ASTM STP 624, Harold Berger, Ed., American Society for Testing and Materials, 1977, pp. 138-145.

applications are discussed with respect to the current state of implementation, additional appropriate research and development, feasibility studies, probable degree of success and the estimated required efforts for some recommended programs. Before continuing on these topics, the basic principles of AE monitoring are reviewed.

A. BASIC PRINCIPLES OF AE MONITORING. Many structural materials, when sufficiently stimulated, will emit packets of ultrasonic acoustic energy; that is, transient sound waves having frequencies greater than audio frequencies. This acoustic emission is caused by microscopic changes within the material as it deforms. The AE can be related to the physical integrity of the material or structure. In fact, by monitoring acoustic emissions in structures, it is possible to detect and locate flaws and to predict impending failure.

Normally, a piezoelectric sensor is used to detect the high frequency acoustic emissions. When mechanically stimulated, a piezoelectric material produces an electrical signal. Such materials are used as transducers of the acoustic emissions into electrical voltages. Thus detected, the signals can be electronically amplified, processed and interpreted. In order to efficiently couple the transducer to the structure, an intermediate liquid substance or couplant is normally used. In this way, extremely faint acoustic events may be detected. The pressures associated with these weak ultrasonic waves are often less than a millionth of atmospheric pressure. As a result, the transduced signal may need to be amplified almost 100,000 times in order to properly process it. At such levels of signal gain, ambient background noises, especially audible ones, would dominate the processed signals. These unwanted noises can be substantially reduced by the use of filters and special discrimination techniques.

Although AE sensors are excited by surface disturbances, acoustic emission monitoring can be used to detect subsurface flaws. If a crack, delamination or inclusion acts as an internal AE source, the stress waves emanating from it will encounter the surface, resulting in wave mode conversions, including surface waves, which relay information about the source to the AE sensors. Thus, as a method of nondestructive testing, AE features the remote detection and location of both surface and subsurface flaws; it has a high sensitivity to sharp cracks; and it is capable of inspecting large areas of structures in one test or during continuous monitoring. A special feature of this NDT technique is that it is essentially passive; the flaw, under stress, supplies its own signal.

In a strict sense, according to current ASTM definition, reference (b), an acoustic emission is taken to be a transient elastic wave, generated by the rapid release of energy from a localized source within a material. More generally, AE may be considered as any radiation of acoustic energy from structural discontinuities or operating mechanisms. This latter definition includes noise generated by leaks and rotating machinery. These are sustained or at least, regularly occurring noises, while the AE associated with crack

Ref: (b) "Standard Definitions of Terms Relating to Acoustic Emission," ANSI/ ASTM E610-77, 1977 Annual Book of ASTM Standards, Part II, American Society for Testing and Materials, 1977, pp. 676-678.

growth consists of discrete randomly occurring events. The ability to measure and interpret both kinds of AE signals requires instrumentation having event counting features together with, typically, an rms measure of continuous signals.

When more than one AE sensor is used, the source of the AE can be located by time-difference-of-arrival method. For sources on a line, this requires a minimum of two sensors. Source location on a surface requires a minimum of three sensors, arranged in a triangular pattern. Sources within the triangle can be located with good accuracy. Outside the triangle, the accuracy degenerates as a function of both position and distance from the triangle. For this reason, several triangular patterns or sensor arrays are often used when performing source location on a large surface.

The interpretation of AE source location data normally results in a tabulation of source locations and classification of each source with respect to its acoustic activity and intensity. Guidelines for AE examination of structures, such as pressure vessels, pipes or other structures that can be stressed by mechanical or thermal means, can be found in an ASTM document, reference (c).

B. NAVAIRENGCEN OBJECTIVES OF AE FOR NDE OF AIRCRAFT. The inspection and repair of aircraft at Rework Facilities require the use of standard NDE techniques. Many types of inspection problems could possibly be resolved by using methods of AE monitoring, reference (d). If simple instrumentation can be designed in order to meet several inspection requirements, then regular use by the NARF can be anticipated, provided the procedures of application are proven and reliable. It is also reasonable to project that limited implementation of AE testing could become routine within the Fleet. As an example, consider the following scenario: a particular model of deck-launched jet aircraft has been experiencing stress corrosion cracking of landing gear. The cracking begins at a location which is not easily visually examined. A feasibility study shows that, using a specific AE sensor and signal processing unit, clear indications of the presence of such cracks can be obtained during a simple loading of the gear. Using a battery operated AE detection unit, landing gears are then regularly checked on deck.

The above type of application is appropriate for initiating the use of AE methods for NDE of Naval aircraft. It required only a simple one-channel system. With a well defined testing procedure and proven results, considerable confidence in the practical use of AE monitoring methods could result. Such success, if obtained in several kinds of applications, would encourage additional studies of the more advanced techniques, such as those which use multiple-channel, computer-based systems. The identification of the potential applications having the highest degree of probable success is the major objective of this study.

Ref: (c) "Standard Recommended Practice for Acoustic Emission Monitoring of Structures During Controlled Stimulation," ANSI/ASTM E569-76, 1977 Annual Book of ASTM Standards, Part II, American Society for Testing and Materials, 1977, pp. 624-627.

(d) Bailey, C.D., "Acoustic Emission for In-Flight Monitoring on Aircraft Structures," Materials Evaluation, 34, 1976, pp. 165-171.

II. ANALYSIS

A. IMPLEMENTATION STUDY OF A PROVEN APPLICATION. Sacramento Air Logistics Center has developed a technique of detecting active corrosion in aluminum-skinned honeycomb panels using acoustic emission monitoring. Thermal stimulation is used to elicit emissions from active corrosion sources and to create breaking forces of degraded adhesive bonds. In these applications, acoustic emission is replacing conventional NDE procedures, and a 75% reduction of the time and costs of inspection has been realized, reference (e). In one successful procedure, an AE sensor is methodically moved from place to place on the surface of the F-111 horizontal stabilizer, which is kept hot (about 160° F) in order to maintain rapid corrosion. An AE reading takes about 15 seconds at each location. This hand-scanning technique results in a mapping out of active-corrosion areas. Moisture-degraded bond areas give acoustic emission during both heating and cooling, the former corresponding to enhanced corrosion and the latter to disbonding activities.

Navy aircraft contain many components which are similar to those being inspected by AE on the F-111. Specific examples of corrosion detection problems are the center splice joint of the C-2 stabilator and the A-6 flap assembly. The latter is checked by the "coin-tap" test; and if corrosion is suspected, an invasive visual inspection is performed. This takes about six hours. It is highly probable that AE scanning can be more reliable and economical. Implementation of the AE technique can be progressive, beginning as a curiosity which should complement routine inspection. A-6 flaps could be independently inspected for corrosion using the AE method. The results could then be compared with the routine visual inspections. If the anticipated benefit is obtained, then AE could become the standard technique.

Several tasks constitute a proposed implementation study:

1. Design and fabricate a simple AE instrument, or use a commercially available unit.

2. Develop a sensitivity calibration procedure.

3. Develop thermal stimulation technique using heat gun.

4. Following trial use, refine steps 1, 2, and 3.

An estimated effort for such an implementation study is 2 to 4 man-months.

B. POTENTIAL APPLICATIONS REQUIRING SIMPLE TO MODERATE FEASIBILITY STUDIES. A simple feasibility study is taken as one that requires only basic single-channel instrumentation, and a small number of specimens. It does not require development of special test gear. It can be performed with less than four man-months' effort. If feasibility is proven, then an implementation study can be

Ref: (e) Rodgers, John and Steven Moore, "The Use of Acoustic Emission for Detection of Active Corrosion and Degraded Adhesive Bonding in Aircraft Structure," Proceedings of DOD NDI Meeting, San Diego, California, November 1975.

performed. The results of such a study can be compared with those of other implementation studies so that common features may be recognized and explored. Then, multipurpose instrumentation can be developed. Some potential applications of AE NDE are: detection of cracks in landing gear and cockpit canopies and leaks in fuel tanks.

1. LANDING GEAR. There are many components on Naval aircraft that are known to be susceptible to stress corrosion cracking (SCC). Various grades of aluminum 7075 alloy have experienced SCC on carrier-based aircraft. Since this problem seems to be generally regarded as a major challenge for NDE methods, it is appropriate that due consideration be given to the potential AE detection of SCC.

Stress corrosion cracking can be detected in two ways by AE monitoring. AE is generated as the crack grows and therefore detection is feasible by using surveillance-type monitoring. (This has been confirmed by the work of a task group of the Acoustic Emission Working Group (AEWG).) The second method is based upon the fact that if the crack closes during unloading, then the subsequent fracturing of entrapped corrodent particles generates AE, thus signaling their presence. Only the second method is considered here because it suggests a simple feasibility study for at least one component, the landing gear.

Aircraft known to have landing gears regularly experiencing SCC are used as a base for this feasibility study. With the aircraft parked on deck, the gear is loaded such that corrodents can easily form in the cracks. If the craft is undisturbed for, say, several days, then it is plausible that reducing the load on the landing gear will cause emissions from those gears which are cracked. This could be done by using a hydraulic jack to relieve some of the load on the gear while an AE sensor picks up any resulting emissions. If this could be done on several carriers and the data correlated with other subsequent examinations of each tested gear, then the extent of feasibility could be stated.

Estimated Effort - 3 man-months.

2. CANOPIES. The Plexiglas canopies used on most Naval jet aircraft are susceptible to cracking which originates in the fiberglass-Plexiglas interface along the base of the canopy. Early detection of cracks is not probable visually and AE detection of cracks in canopies is good because the cockpit can be pressurized above the normal cabin pressure of 15 psi. A feasibility study can be quick and definitive, depending on the availability of cracked canopies.

An AE sensor can be held against a canopy using a suction cup-spring mechanism. As the pressure is increased beyond the normal 15 psi, the AE produced should be related to the extent of cracking which is activated. This assumes that the pressure is such that the stresses in the canopy exceed the maximum stresses generated during flight maneuvers. Determination of the reasonably achievable maximum stresses is the first task of feasibility study. If the results of this task are encouraging, then the next task is to locate some cracked canopies or to artificially crack a canopy. If AE is detected during pressurization, then it can be compared to whatever amount of AE occurs during pressurization of an uncracked canopy. If the cracked canopy gives substantially more AE, then basic feasibility will be established and additional tests can be performed on other canopies in order to confirm repeatability. Since the level of effort for this study is dependent upon sequential successes in each task, the total estimated effort ranges from 1 man-month to 3 man-months.

3. FUEL TANKS. The fuel tanks on certain aircraft are inspected for leaks by using the liquid-application technique of bubble emission. This method consists of creating a 3-psi air-pressure differential across the wall of the tank and observing for bubbles in a liquid medium located on the outside wall of the tank. It is a time-consuming task to scan an entire fuel tank. (Actually, only certain portions of the outer tank wall are easily accessible.) Some leaks make noise. The Navy has studied the use of acoustic leak detection for submarine valves, reference (f). Although that study showed a 3-psi pressure differential to be marginal, the trial use of such a technique for leak detection in fuel tanks should be easy.

A feasibility study should be performed the following way: a portable AE instrument (5kHz-50kHz) should be made available to a NARF which has responsibility for routine inspection of fuel tanks. The AE unit should first be used on a known leaker, following the normal bubble emission inspection. If the leak can be detected and located using an AE scanning method, then other fuel tanks should be first-inspected by AE, followed by bubble emission. If the AE method consistently locates all of the leaks which are found by bubble emission, then it should be implemented as the primary method of locating leaks in fuel tanks. It is estimated that use of a proven AE method of leak detection will reduce inspection time by 50%.

Estimated Effort: 1/2 to 2 man-months (1/2 man-month is the minimum effort required if the study is terminated after the first test; this includes equipment procurement, test procedures, test and reporting).

C. POTENTIAL APPLICATIONS REQUIRING MAJOR FEASIBILITY STUDIES. Potential applications which require major feasibility studies include helicopter blades, retreaded tires and fan blades. All of these require a significant number of specimens and/or appreciable man-hours. The first one also requires multichannel instrumentation. Following discussion of each potential application, a summary of the requirements are given.

1. HELICOPTER BLADES. Some helicopter rotor blades are fitted with pressure-sensitive blade integrity monitors (BIM). These devices operate on the principle of detecting changes in the internal pressure of hollow blades due to the presence of a thru-wall crack(s).

When rotor blades are removed from service because of BIM indications, the location and severity of the discontinuity is often unknown. It is probable that acoustic emission testing of the blade could locate the crack and possibly other local stress discontinuities.

Ref: (f) Dickey, J.W., J.G. Dimmick, and P.M. Moore, "Feasibility of Acoustic Analysis of Submarine Valve Leakage," David W. Taylor Naval Ship Research and Development Center, Report 78/007, January 1978.

A feasibility study could begin with the determination of the preferred method of stimulating the blade. One possibility is flexing before removing the blade from the helicopter. This could be achieved by using the blade tie-down loops as the point of application of the flexing force. However, it is more likely that better stimulation of cracks would result from bending the blades upwards. This is hypothesized because the blades are actually bent upwards in flight while the cracks are growing; and therefore, crack opening and growth is enhanced if the upwards flexure is increased beyond that amount experienced during flight. Hydraulic lift mechanisms could be applied to the tip of each blade; but it is probable that all blades would have to be simultaneously loaded in order to avoid damaging skew forces. For simplicity, the first step in a feasibility study should be laboratory testing of an aluminum blade which is known to have a crack.

A single blade can be tested under laboratory conditions using either "upwards" or "downwards" flexing. Preliminary work should include documentation of the crack's location by another examination technique, determination of the optimum sensor configuration and calculation of allowable applied stresses. This last item is necessary in order to preserve the possibility of eventually using AE inspection methods for testing rotor blades. The sensor configuration would depend on the degree of sensitivity achieved in the method of attachment and on the attenuation properties of the blade. A fair feasibility study would require the testing of at least two cracked blades and two unflawed blades. If feasibility is established at this stage, then it would be a natural extension of the study to determine the feasibility of detecting developing cracks; i.e., cracks which would not result in a BIM indication.

Other types of stimulation could be investigated. Internal pressurization, appreciably above that normally experienced by the blade, is one type of stimulus; forced vibration is another. The possibility of using thermal activation of AE from flaws should be considered. This technique would allow segments of the blade to be separately inspected. Such a procedure would appreciably reduce the instrument requirements for the AE test. Whereas flexing or pressurization would require the entire test region to be simultaneously monitored, local stimulation by heat would allow a simple two-channel flaw locator to be used. The significant accompanying reduction in the complexity of performing the test certainly provides incentives for investigating this possibility. Since there has not yet been any major study of thermal stimulation of cracks in metal alloys, this particular potential application of such a technique could await results from a basic program designed to provide guidelines for thermal stimulation of AE. Summary of recommended feasibility study is as follows:

a. At the minimum, two cracked blades and two unflawed blades.

b. Develop "upwards" loading technique or internal pressure or thermal stimulation.

c. Perform stress analysis for all types of loads used.

d. Use a multichannel AE system or develop unique thermal technique.

Estimated Technical Effort:	Planning, Design & Fabrication of Fixtures	- 2 Man-Months
	Testing & Analysis	- 6-1/2 Man-Months
	Reporting	- 1-1/2 Man-Months
	Total	10 Man-Months

2. RETREADED TIRES. Prediction of impending disbonding of retreaded tires is a goal for NDE techniques. An AE method is an attractive possibility because of the low cost and simplicity associated with its probable utilization. An initial feasibility study should call for a significant statistical sample of tires to be mechanically tested to failure, in modes simulating normal use. AE monitoring could be periodically performed by attaching a sensor to the rim of the tire and stimulating the tire by increasing the internal pressure, followed by return to rated pressure. As damage develops in the tire, the AE during overpressurization should increase. It seems likely that the frequency bandwidth for this potential application may be centered at a lower frequency than is normally used for most other applications.

Another type of study would test the feasibility of the general application and a special procedure. This study would require the use of retreaded tires which are known to be of poor quality or which have a high probability of being defective. It is hypothesized that a disbonded, laminated tire will generate low-frequency AE as it rolls. This seems probable because of the relative motion that occurs at the discontinuity. The AE sensor could be easily coupled to the tire by using either a water jet or a water trough. In the former case, a hand-held instrument is walked along by the wheel as the aircraft is towed. The water jet provides a uniform acoustical contact with the side wall of the tire. The use of a water trough provides more sensitivity and allows the sensor(s) to remain stationary. The sensor(s) would be installed in the sides of the trough. The aircraft is pulled through the trough, the tires being immersed about 1/3 of their diameter. If this latter technique is shown to work well, then it could be refined for field implementation. Summary of recommended feasibility study is as follows:

a. Two types of approaches requiring normal retreaded tires and known defective tires.

b. Develop low-frequency testing technique.

c. Study sensor coupling methods, water jet or trough.

Estimated Technical Effort:	Planning, Design, etc.	- 4 Man-Months
	Testing & Analysis	- 4 Man-Months
	Reporting	- 1 Man-Month
	Total	9 Man-Months

3. FAN BLADES. The use of AE techniques for inspecting TF-30 jet engine first-stage fan blades has been studied by the Materials Engineering Laboratory, NAVAIREWORKFAC, North Island. Although an in-situ AE testing procedure has

been developed, it is the opinion of this author that substantial work remains before feasibility of this possible application is proven. It needs to be shown that natural cracks, which are located anywhere on the blade, will generate AE when the blade is stressed within tolerable limits. This can only be done if the presence and absence of cracks is substantiated by an independent inspection method.

According to Fricker, reference (g), the current, routine nondestructive method of detecting cracks in blades is a tactile test; i.e., a thumbnail is rubbed over the blade's edge. Eddy-current inspection may subsequently be used. In order to establish the feasibility of using AE, many blades should be tested using AE and other methods. Eddy-current inspection could be supplemented with dye-penetrant inspection. If a positive correlation can be obtained between AE data and the other results, then feasibility will be established. Summary of recommended feasibility study is as follows:

a. Many blades need to be tested by AE and other NDE methods.

b. Correlation of results.

Estimated Technical Effort: 5 man-months.

D. POTENTIAL APPLICATIONS REQUIRING R&D APPROACH. Some potential applications of AE technology cannot be adequately tested in a simply defined feasibility study. This is because they encompass a broad range of situations. Therefore, a more general R&D approach needs to be considered. Examples are bearing noise analysis, damage assessment in composites and weld inspections.

1. BEARING NOISE ANALYSIS. Traditional acoustic analysis of rotating machinery is often nowadays referred to as the "low-frequency technique." It is based on the fact that defects in parts such as bearing balls and retainers cause variations in the relative energies of the fundamental and lower harmonic frequencies of the vibration of those and other components. Generally, the upper frequency limit of such analysis is about 50 kHz. However, there are many higher frequencies always present and especially when defects are present. Therefore, in recent years, detection and analysis of signals of higher frequency, 50-300 kHz, has become routine in some applications. This technique can be called "Bearing Fault Detection and Identification by Acoustic Emission Analysis."

A potential area of application for this type of NDE method is "Health Analysis" of bearings in Navy helicopters. The Army has been using a version of this technique in its Bearing Refurbishing Facility in Corpus Christi, Texas. Boeing Vertol has also studied this specialty. However, both of the above organizations have utilized an acoustic analysis system that uses spectral analysis techniques for bearing testing under "test stand" conditions.

Ref: (g) Fricker, Richard T., "The Use of Acoustic Emission Technique for the Inspection of TF-30 Jet Engine First Stage Fan Blades," Materials Engineering Laboratory, Naval Air Rework Facility, North Island, unpublished.

In the spirit of this present study, we seek the potential for using simple, portable AE instruments for in-situ "bearing fault identification."

The use of some portable AE monitors for detecting bearing degradation in pumps has been briefly reported by Bloch, reference (h). Although he enthusiastically claims high reliability in detecting incipient bearing damage, few technical details are given. The procedures for selecting sensors, filters, gains, etc., have not been discussed in the literature. Also, there is a clear need for general guidelines for interpreting the measurements. The potential for this type of application is not yet matched by the current performance of R&D, although general interest by various Navy personnel is typical. (Almost everyone interviewed suggested or strongly supported the development of this technique.) A good approach to this type of R&D would be to select two types of specific applications, say a particular engine bearing and a transmission bearing that have histories of problems; and initiate independent R&D programs to attempt to produce a portable AE instrument capable of performing bearing analysis for each component. The results should provide clear indications of the potential of developing one instrument capable of doing both jobs.

2. WELD INSPECTION DURING WELDING. Certain aircraft engine parts, such as burner cans and tail pipes, are repaired by TIG welding. Both hot and cold cracking can occur to the repairs and therefore AE monitoring is a potential indicator of weld quality. Conceptual techniques are discussed in the ASM Metals Handbook, reference (i). Practical procedures are still being debated within the welding industry.

Since 1973, the ASTM Subcommittee on Acoustic Emission (E7.04) has included among its tasks the formulation of guidelines for AE monitoring during welding. A document, entitled "Recommended Practice for Acoustic Emission Monitoring During Continuous Welding," will provide guidelines for the detection and location of AE sources in weldments and in their heat-affected zones during fabrication, especially in those cases where the time duration of welding is still in progress. This document is still being revised, for it is difficult to formulate general "examination procedures" and "interpretation of results," such that the various methods of continuous welding of various materials are adequately covered.

The Navy should have strong interests in following these developments because of the potential application to fabrication inspection of submarine hull welds. R&D for applications to Naval Air NDE could possibly piggyback the work for ships. On the other hand, it is more likely that a separate study for miscellaneous manual welding tasks could establish some procedural guidelines and instrumentation specifications, which could quickly lead to simple feasibility studies for specific weld-inspection requirements.

Ref: (h) Bloch, Heinz P., "Improve Safety and Reliability of Pumps and Drivers," Hydrocarbon Processing, May 1977, pp. 213-215.
(i) "Nondestructive Inspection & Quality Control," Metals Handbook, Volume 11, American Society for Metals, 1976, pp. 239-242 and pp. 352-354.

3. <u>ASSESSMENT OF DAMAGE IN COMPOSITES</u>. Some composite aircraft components are particularly susceptible to damage. Particles impacting radomes, propellers, spoilers, etc., cause a broad range of damage. Sometime visual indications of recent damage are fairly indicative of its extent; however, small superficial damage can be only a clue to ever-increasing interior degradation resulting from the stress concentrations originating at the small discontinuity. Also, damage to certain composites can result from impact or vibration, even though the cosmetic appearance is unchanged. In the former cases, a means of easily assessing the extent of damage would aid in deciding whether immediate repair was necessary or if increased surveillance of the damage could be used as a temporary safeguard. In the latter case, routine detection and assessment of the degree of damage is desired. Damage can be of many types: abrasion, dent, gouge, scratch, penetration, debond, delamination, patch failure. Identification of the type of damage could be a formidable task for AE alone. Again, the potential for using an AE method is good, but a feasibility study should await results of a more general R&D effort on this topic. There is work under way at NADC on AE testing of composites.

III. RECOMMENDATIONS

This report has defined one implementation study and six specific feasibility studies, which, if separately performed, would require a total effort of approximately 3 man-years. A major commitment to pursuing the use of AE technology as an aid for Naval Aviation Ground Support should permit some of the feasibility studies to be performed as one program, thereby optimizing the overall manpower requirements. An example of this would be the formulation of a program based on the three proposed "simple feasibility studies". The three proposed research and development programs can also be treated with some preferences. Because the proposed program on "damage assessment in composites" would both complement and supplement the proposed implementation study on AE detection of corrosion and disbonding in composites, it is recommended that it be given priority over the other two R&D topics. The proposed R&D programs for "bearing noise analysis" should take preference over the welding studies for two reasons: first, many people encouraged consideration of bearing fault identification by AE methods, while weld monitoring was a less discussed topic; second, programs on weld monitoring are under way at several institutions and their anticipated eventual success could be a springboard for a Navy program on this topic.

The potential applications of corrosion detection in composites, crack detection in landing gear and canopies, and leak location in fuel tanks can be performed with the same basic instrumentation. Assuming that two of those would be proven feasible, development of special instrumentation could then be reasonably justified. A program for performing these feasibility studies is recommended as the minimum immediate commitment by the Navy. All tests should be performed in cooperation with a Naval Air Rework Facility (NARF). Preliminary preparations and initial testing can be accomplished with NARF personnel observing, with subsequent testing handled completely by NARF personnel. All results could be reported in a single document which would address the appropriate continuing efforts.

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