MINUTES

DEFENSE CONFERENCE ON NONDESTRUCTIVE TESTING

15th ANNUAL MEETING

4, 5, 6 OCTOBER, 1966

U. S. ARMY
MATERIALS RESEARCH AGEI
WATERTOWN, MASSACHUSETTS 02172

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FOREWORD

The following minutes of the fifteenth annual meeting of the Defense Conference on Nondestructive Testing have been compiled for the information and use of the agencies represented at the sessions held on 3, 4 and 5 October 1966.

This meeting convened at the Hotel Bradford in Boston, Massachusetts, under the Host Chairmanship of Mr. E. H. Rodgers of the U. S. Army Materials Research Agency.

The Executive Secretary and Chairman of the Steering Committee, Mr. Harold A. O. Baller of Edgewood Arsenal, was officiating chairman of the 3 day session.

The large amount of personal time and effort devoted to the preparation of the conference and to these minutes by Mr. Charles P. Merhib of the U. S. Army Materials Research Agency is acknowledged.

The Steering Committee wishes to thank all participants for a successful conference and desires that future meetings will see continuing cooperation among the member agencies of the Department of Defense.

ERNEST H. RODGERS (HOST CHAIRMAN)
Chief, Nondestructive Testing Branch
U. S. Army Materials Research Agency

PURPOSE OF DEFENSE CONFERENCES ON NDT

SCOPE

The coordination of the development and the application of nondestructive methods for the testing and inspection of materials and assemblies for the Department of Defense.

OBJECTIVES

1. To provide for an effective dissemination of information pertaining to nondestructive methods and applications among members and their respective establishments in the Department of Defense.

2. To provide for the utilization of the knowledge, skills, and experiences of specialists in the various branches of the Department of Defense for the attack and solution of problems within the Military establishment.

3. To encourage (wherever applicable) uniform practices in the application of nondestructive testing methods.

FUNCTIONS

1. Development of a common report and information distribution list. (Emphasis on individuals rather than on organizations.)

2. Development and distribution of a current bibliography of defense establishment and/or contractors' reports, going back at least to 1946.

3. Development and distribution of abstracts of present and projected programs (Research, Development, and Engineering).

4. Compilation and distribution of useful information such as location, work specialties, staff, and facilities of:

   a. Government laboratories or other installations active in the development or utilization of nondestructive testing methods.

   b. Commercial laboratories or installations active in the field of interest.

c. Consultants and Contractors active in the field of interest.

5. Evaluation of problems and proposed solutions in conference. The steps which are likely to be taken are:

a. Analysis of the problem in terms of design, engineering, production, inspection, and testing history. Such an analysis may be partial before presentation, but should be as complete as possible before specific solutions are detailed.

b. Presentation of problem to conference as a whole or conference panel qualified in nondestructive testing inspection.

c. Liaison between the group in which the problem arises and those qualified, as indicated by conference discussion, to provide assistance in the solution. (Once liaison is effected, the two groups proceed without channeling through the conference).

d. Report to conference (for the record) the degree of success or failure of the approach taken. If a solution has been reached, the formulation of requirements should be presented.

ORGANIZATION

1. Members - Employees of the Defense Establishment concerned with nondestructive testing, inspection, or evaluation, having confidential security clearance.

2. Officers - A secretarial board of not less than three, or not more than seven, who shall be elected yearly by a majority of the conference. This group will serve to receive and transmit information, to act as a steering group, and will elect one of their number as executive secretary.

3. Meetings - The conference shall meet at least once a year at various establishments, as agreed upon between representatives of the establishment and the steering group. The presiding officer at such meetings shall be the conference member whose establishment is acting as host.

THE 1966 STEERING COMMITTEE

H. BALLER (Executive Secretary) - Edgewood Arsenal

E. McELVEY - Wright-Patterson Air Force Base

S. HART - U. S. Naval Research Laboratory

B. BOISVERT - Naval Air Systems Command

W. BENNETT, (Lt. Col.) - Kelly Air Force Base

E. RODGERS - U. S. Army Materials Research Agency

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INTRODUCTORY REMARKS

MR. RODGERS

Good Morning:

As Host Chairman of the Fifteenth Annual meeting of the Defense Conference on Nondestructive Testing, it is a pleasure to see such a large and distinguished group. It is our desire that your stay will be profitable while at this meeting and pleasant "after hours".

If there is anything that we can do for you during your visit please contact me at any time.

At this time I have the pleasure of introducing the Commanding Officer of the U. S. Army Materials Research Agency, Colonel Dimitri A. Kellogg, who will welcome you to this meeting.

COLONEL DIMITRI A. KELLOGG

Good Morning, ladies and gentlemen:

We of the U. S. Army Materials Research Agency are most happy to serve as host activity to this 15th Annual Defense Conference on Nondestructive Testing. The first conference was hosted at our installation back in 1951, and I understand many of the original organizers are present today.

It is gratifying to see the continuing interest evidenced by your presence. There are representatives here from the Army, Navy, Air Force, Defense Supply Agency, and the Defense Contract Administration Service Districts, Regions, and Offices.

Your Steering Committee for this Conference has selected some very interesting and informative problems and papers for discussion and I believe you will find the sessions well worth your attendance.

Both defense and civilian requirements are pushing us all to the limit of strengths of materials - faster than we can create new, stronger ones. This means more exacting specifications - and more exacting nondestructive testing of practically every individual major component.

The theory and practice of nondestructive testing is therefore an increasingly important element in the mission of the Army Materials Research Agency, and this is why we have particular interest in this Conference, from our standpoint - and from yours.

We would like to repeat our welcome, and wish you an interesting and pleasant time.

Thank you.

MR. RODGERS

Thank you, Colonel Kellogg.

Now is the time when I can enjoy being Host Chairman of this important meeting, because at this time I can turn the meeting over to Mr. Harold Baller of Edgewood Arsenal who is the Executive Secretary and Chairman of your Steering Committee. Mr. Baller has worked long and hard to bring to you this fine agenda.

FORMAL PROBLEMS

PROBLEM I - SEPARATION OF BASE ADAPTER FROM 81MM MORTAR SHELL

Mr. John G. Barr
Frankford Arsenal

PROBLEM

During acceptance test firings of 81mm H.E. M374 metal parts assemblies, there have been occurrences where on impact the base adapter has separated from the shell body at the brazed joint. As a functional requirement for metal parts security, this condition of separation is cause for rejection of parts lot represented by the sample fired.

High quality brazed joints on this particular item, and similar munition items, are a necessity. Failure of a brazed joint in the mortar tube could cause a serious premature, while separation during flight will cause a short round affecting the safety of friendly ground troops. While marked success can be accomplished under laboratory type conditions, the operation is difficult to accomplish reliably in mass production due to the inherent nature of the process, the close component dimensional controls, and the cleanliness required of the mating surfaces being brazed.

A more highly reliable non-destructive test method is required to effectively meet the demands of the current production build-up program.

BACKGROUND

The first point to consider is that the brazed joint is basically between dissimilar materials even though they are of the ferrite classification. The shell body material is cast Pearlitic Malleable Iron, while the base adapter material is AISI 1018 Steel. A sectionalized assembly of the shell body and base adapter is shown on Figure 1. A blown-up section of the area under discussion is shown on Figure 2.

There are two brazing methods in production practice at the present time. Figure 3 is a pictorial presentation (not to scale) of the method which has been in production the longest. Since the start of production, several refinements have been incorporated into the procedure and the important controls found to affect the process efficiency are contained in the contractor's

process inspection requirements which read in part -

"Roving Inspection and Maintenance

A. Coil height to be checked by Quality Control twice each shift with a depth micrometer or special step gage.

B. Heating cycle 90 seconds, checked as needed.

C. Dial settings to conform with setting on Tocco Quality Control Report.

D. Acid to be changed every four (4) hours or sooner if dark yellow color appears.

E. Brazing fixture to be cleaned, oiled, and greased twice per shift.

F. Area to be kept clean.

G. Unused stock, (caps, braze material, flux) must be covered.

H. Quality Control to check temperature of each station, temperature range 1250° - 1350° F, at least once per shift or when any significant change in meter readings or procedures occur. Use surface pyrometer."

The second method is shown on Figure 4 and the process technique is the same as the first method except for the location of the brazing ring and the addition of the braze shim.

It is readily recognizable from the above discussion that to assure the adequacy of the braze joint a major emphasis is placed on rigid adherence to the approved brazing process, mainly with respect to cleanliness of the mating parts, induction coil location, temperature of induction coils, and duration of the heating cycle.

The next area to consider, Final Acceptance Inspection, is of pertinent concern to this meeting. The final acceptance procedures, relating to the braze joint, will be discussed in detail but not necessarily in the order in which they are performed.

1. The braze metal shall be visible around the entire area where the base adapter joins the shell body wall inside. This is a 100% visual inspection and any void on the exposed braze surface is cause for rejection.

2. The braze metal shall also be visible for the full 360° around the joint between the rear of the body and the base adapter flange. This is also a 100% visual inspection but the inspection criteria allows for surface discontinuities on the exposed joint periphery of up to 1/4 inch in length but the total accumulation of the discontinuities shall not exceed 1 inch.

3. Each body assembly shall withstand the stresses developed by the application of 5000 pounds per square inch (psi) minimum internal hydrostatic pressure for 5 seconds, without leakage, rupture, or permanent deformation. With respect to the braze joint, this requirement and test is an inspection for the possible occurrence of a "cold" brazed joint and for a gross leakage path through the total joint surface. Each body assembly is subjected to this test and is stamped with the letter "H" when it complies with the requirement.

4. After hydrostatic testing, each accepted body assembly shall withstand an internal air pressure of 150 pounds per square inch (psi) for 15 seconds minimum, without evidence of leakage. Each body assembly which has passed the hydrostatic test is dried by an approved method and is then subjected to the air pressure test. The witnessing for leakage is performed while the body assembly is immersed in clear water and under the specified air pressure. This test is performed to reject any body assembly which shows any evidence of a minute leak. Each body assembly which complies with this requirement is stamped with the letter "A".

5. The requirement for the quality of the total brazed joint is that the aggregate area of inclusions, lack of adhesion or other defects shall not exceed 25% of the faying surfaces of the respective joint; and the maximum extent of a defect shall not exceed 25% of the overlap distance (width) of the joint.

The test technique being used to inspect for this requirement is really the crux of the problem being presented at this meeting, particularly since the existing test technique is a destructive type.

The current test method requires that two (2) samples shall be selected from each submitted lot and shall be inspected in the following manner.

a. The rear portion of the body assembly, one inch forward of the base adapter shall be removed in such a manner that no portion of the brazed joint will be damaged.

b. The rear portion of the body assembly containing the base adapter shall then be cut vertically through the center of the base adapter.

c. Each portion of the body casting shall be peeled from the base adapter section.

d. After peeling, the brazed area of both pieces of the base adapter and both pieces of the body casting shall be visually examined to determine compliance with the above stated requirement for quality of the brazed joint.

It is readily recognizable that the sample size is small and therefore, as previously stated, places a large degree of dependency on rigidly applied

brazing process controls. Furthermore the evaluation of the exposed brazed surfaces is strictly dependent on the human element and is therefore directly related to an experience factor and a judgment factor.

6. As a final test, ten (10) samples from each submitted production lot of body assemblies are ballistically fired to determine metal parts security. Upon recovery after the firing test the recovered shell body assembly shall exhibit no evidence of excessive deformation or breakup of any component, except the obturating band, in the mortar tube or in flight.

SUMMARY

It has become expediently necessary that a reliable nondestructive test technique for inspection of the braze joint quality is required to replace the destructive type peel test presently employed. Such a non-destructive inspection system would materially improve product reliability and reduce inspection costs inherent with the destructive test coupled with the human evaluation element.

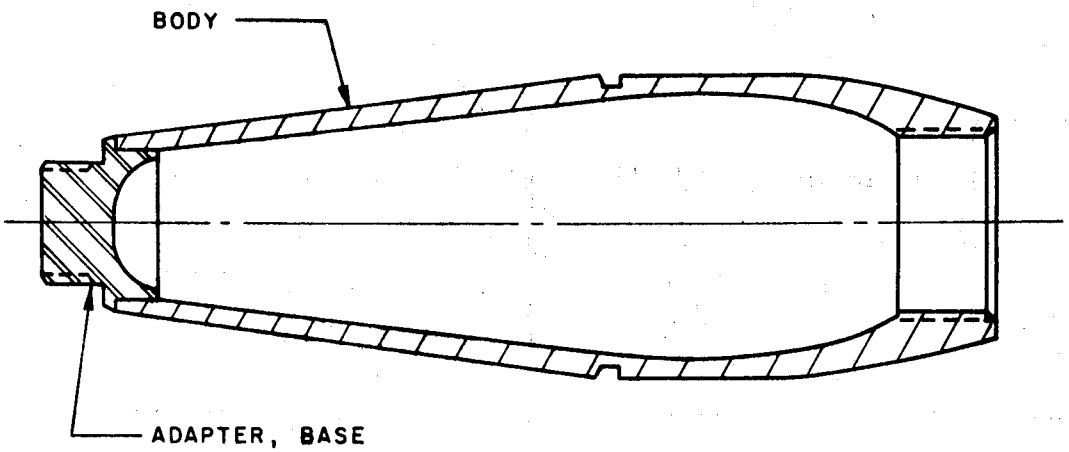

Figure 1.

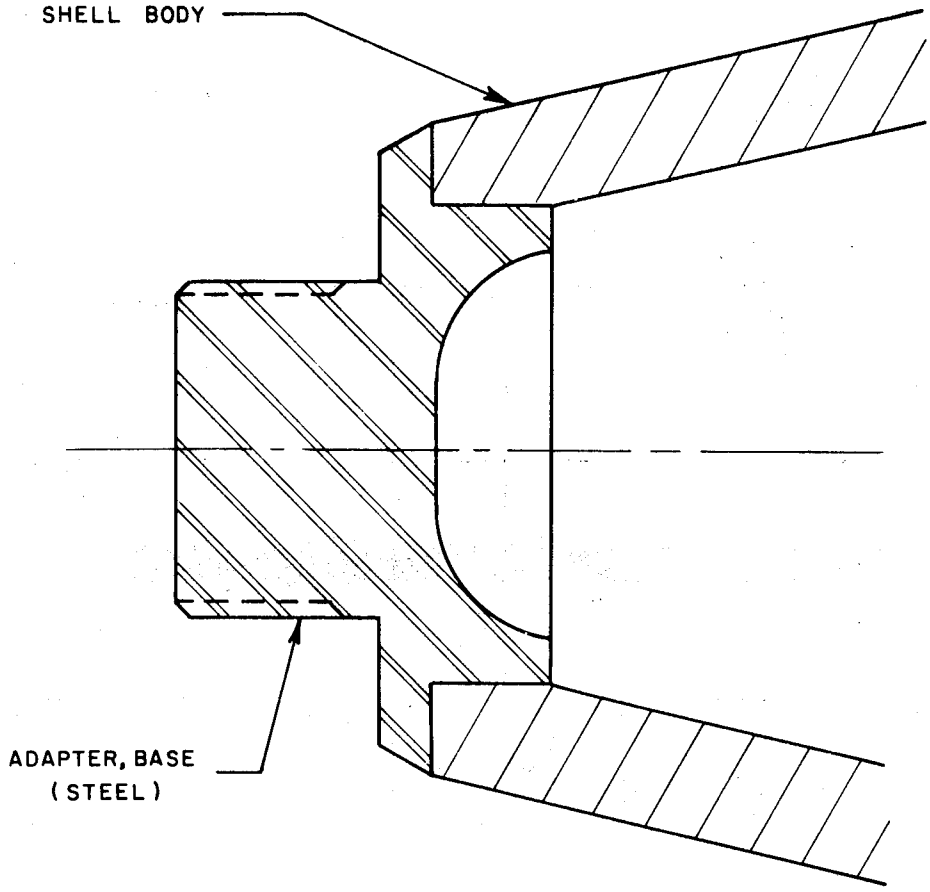

Figure 2.

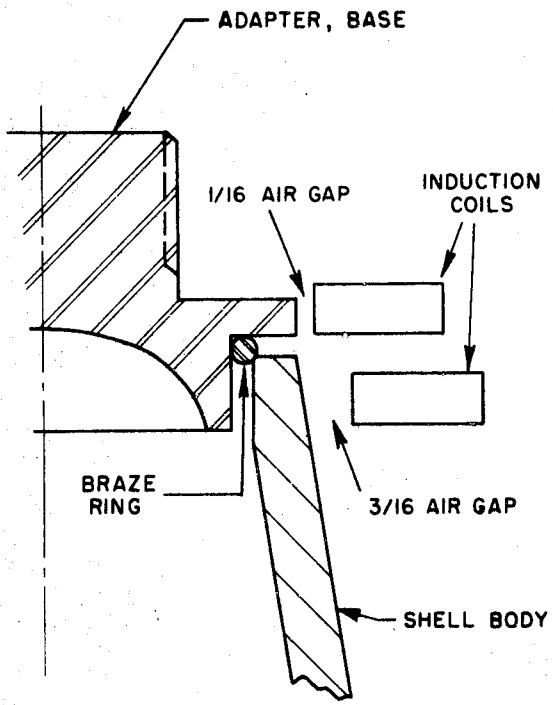

Figure 3.

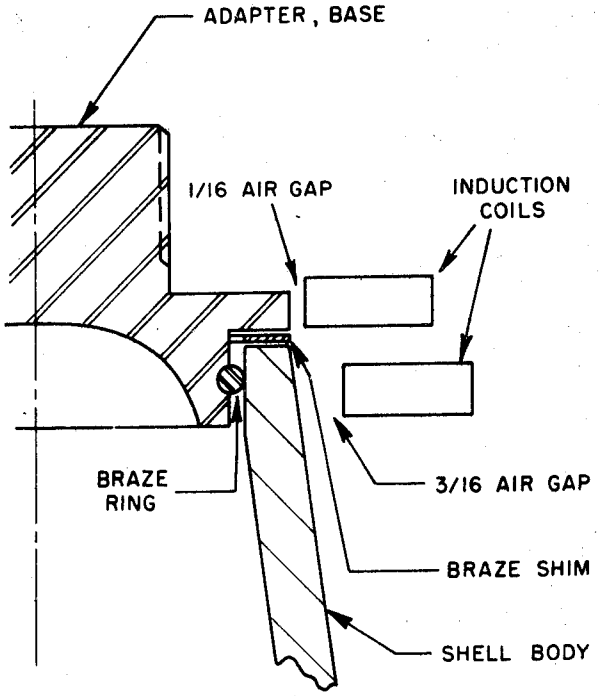

Figure 4.

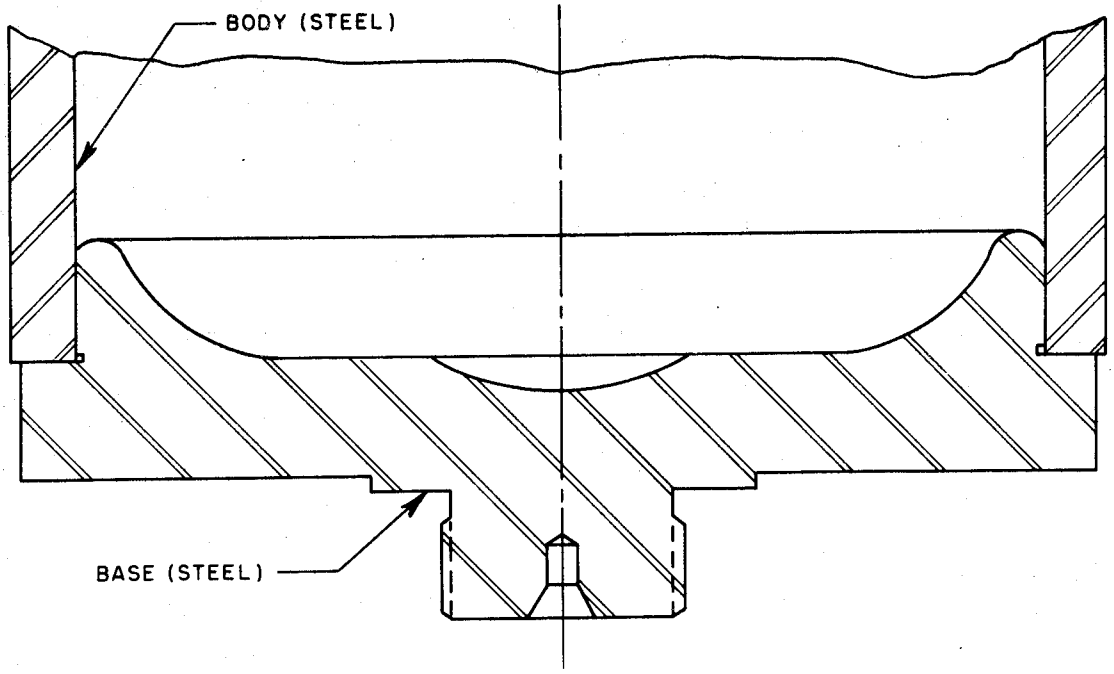

Figure 5.

PROBLEM 2 - A PROBLEM IN THE NONDESTRUCTIVE TESTING OF TORPEDO PARTS

Mr. J. G. Turbitt
Naval Torpedo Station

The U.S. Naval Torpedo Station at Keyport, Washington; is primarily concerned with proofing, testing, and evaluating torpedoes. In addition it manufactures some torpedo parts especially accessories such as exercise heads used during proofing. These parts, of course, must meet quality control standards. As a part of this quality assurance, the drawings for typical parts such as the Warhead Mark 37 and the Exercise Head Mark 64 require X-raying of all welds which penetrate the shell. These welds must meet Class II requirements of MIL-W-22248 except:

1. Scattered porosity shall not exceed Grade 3 of OD 7574.
2. Linear porosity shall not exceed Grade 1 of OD 7574.
3. Incomplete penetration of welds shall not exceed Grade 1 of OD 7574.

The skin is formed from 3/16 inch plate and is welded to the rings and bosses which are machined from rolled bars and forgings. The materials for these parts are 6061 aluminum alloy and 4043 electrodes. The welding process is the consumable electrode, inert gas method. After the parts have been welded together, the bead is ground off the outside but excess metal is not usually removed from the inside.

At present we use X-rays to examine the welds with variations of equipment, set-up, and exposure to fit the geometry of the area. Figure 1 shows the typical areas on a Warhead Mark 37. Similar situations occur in the Exercise Heads such as the Mark 64. For convenience, we will use the Warhead Mark 37 for discussion.

Areas A and B are similar in the difficulty of having the 1-inch stiffening rings between the weld and the film. Area C has the extra thickness and odd configuration of the joint ring in the way. Area D is complicated by the heavy exploder boss behind the weld. Area E has the very thick transducer housing hiding the weld being examined. A more detailed discussion of each of these will demonstrate the problems.

The longitudinal seam weld of the skin, Area A (Figure 2), has only the problem from the greatly increased thickness where the stiffening rings cross the seam. With proper exposure, satisfactory radiographs are obtained, that is, a 2 T hole in a 0.25 penetrameter shows. We use a 3-minute exposure, Type M film, 39-inch source-to-film distance and 70 KV, 10 ma X-rays from a 250 KV Westinghouse Industrial X-ray Unit.

Area B (Figure 3) is part of a circumferential weld which joins the nose to the shell. Since the exploder cavity prevents the insertion of the Baltospot 360° tube, the weld is examined in four 90° segments with the film on the inside. We use a 2-1/2-minute exposure, Type M film, 39-inch source-to-film distance and 110 KV 10 ma X-rays. However, this procedure requires examining a 3/16-inch thick weld through about 1 inch of the ring with the film held about 1-inch away from the weld by the stiffening ring, as in Area A.

Area C (Figure 4) is the circumferential weld which secures the joint ring. For this examination, we use a Baltospot, Model 150B, X-ray unit with a 360° beam, which covers the ring with one exposure. We take advantage of the fact that the X-rays are emitted in a cone with about a 70° angle from the tube axis. By positioning the source as shown, the interference from the lip and the bevel are projected to one side of the weld. However, the radiation must go through about 1-1/2-inches of aluminum to reach the weld, a very undesirable situation. Therefore, we get radiographs showing at best a 4 T hole in a 0.25 inch penetrameter on a 1-inch shim using a 2 minute exposure, Type M film, 9-inch source-to-film distance and 110 KV 3 ma X-rays.

Area D (Figure 5) includes the weld which secures the exploder cavity boss to the skin. We first tried placing the film on the outside of the skin and sending X-rays through the weld from the opposite side of the warhead. This was not satisfactory because the X-ray shadows from the stiffening rings and exploder cavity prevented accurate interpretation of the radiographs. Results are better with the arrangement shown; the film is on the inside of the boss and the X-rays come through from the outside. This arrangement requires specially cut film and fitted cassettes. Four pieces of film are used with a semicircular piece cut out of each to fit around the exploder cavity. Two are put in each cassette (double loading) so four pieces are used for each exposure. The film holders are placed with the cut-away edges overlapping to give coverage all around the boss. Again the weld under examination is 3/16-inch thick and must be examined through about 1-1/4-inches of metal. Also some geometric unsharpness is created by the relatively large 1-1/2-inch distance between the film and the weld. Results are fair using a 5-minute exposure, Type M film, 39-inch source-to-film distance and 86 KV 10 ma X-rays. The best sensitivity is a 2 T hole in a 0.625 penetrameter on a 1-inch shim.

The worst situation occurs in Area E (Figure 6) where the transducer housing is welded to the nose even though this nose piece is examined before it is joined to the rest of the shell. The film is placed next to the

weld and the X-rays came in through the open end of the part, as shown. The extra metal of the transducer housing creates a serious problem in getting adequate sensitivity in the radiograph. Our best results have been obtained with a 15-minute exposure, Type R film, 59-inch source-to-film distance and 150 KV 10 ma X-rays. The sensitivity obtained is a 4 T hole in a 0.25 penetrameter on a 2-inch shim.

We have considered ultrasonic testing of the welds but have not had an opportunity to develop and test these techniques. We have made some use of our Branson Model 30B, Sonoray to check the thickness of the skin after the outer weld bead was ground off.

Recommendations or suggestions for a better method of insuring the quality of these welds would be very much appreciated. It is obvious that the effectiveness of a new procedure would need to be established. We hope that some of the attendees at this conference have had experience with similar problems and can help us to improve our testing with a reduction of time and cost.

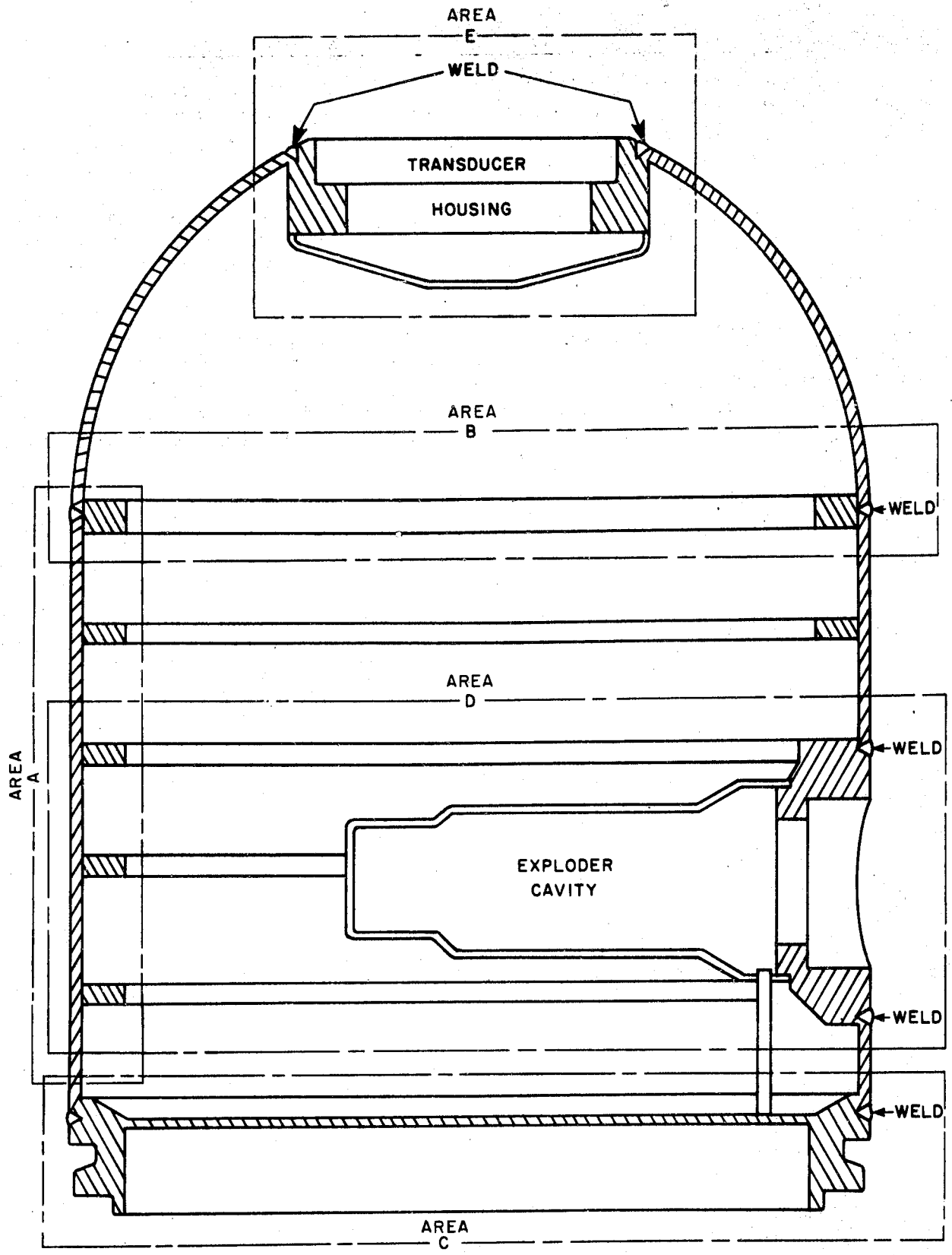

Figure 1. MK 37 Warhead Buord DWG 877240

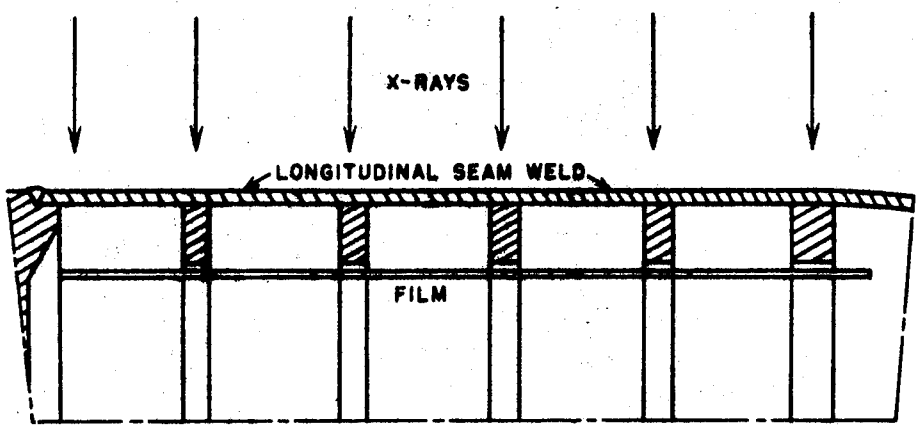

Figure 2. Area A

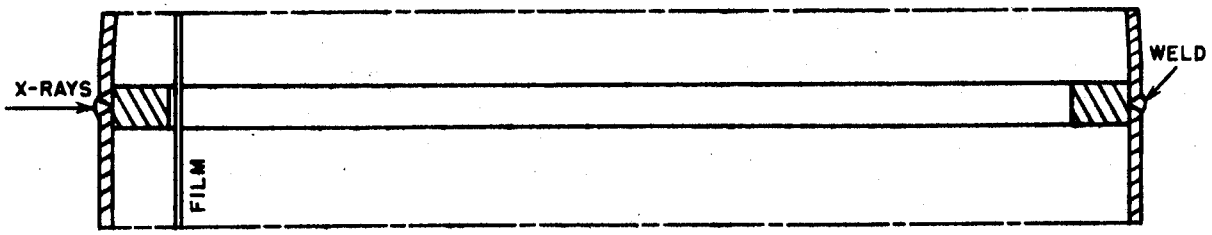

Figure 3. Area B

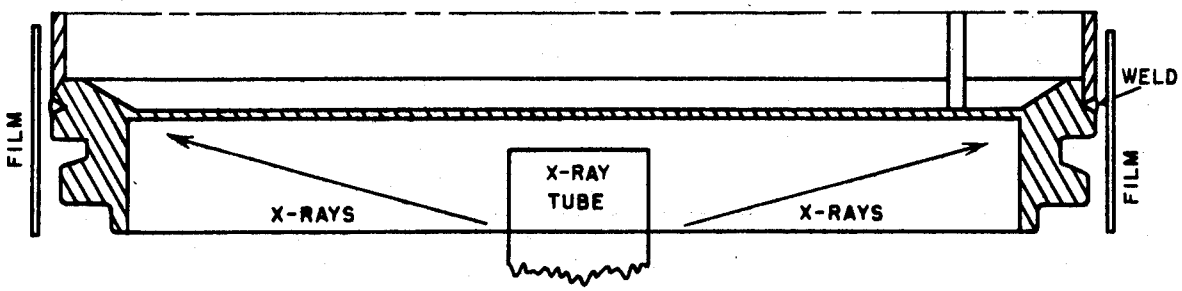

Figure 4. Area C

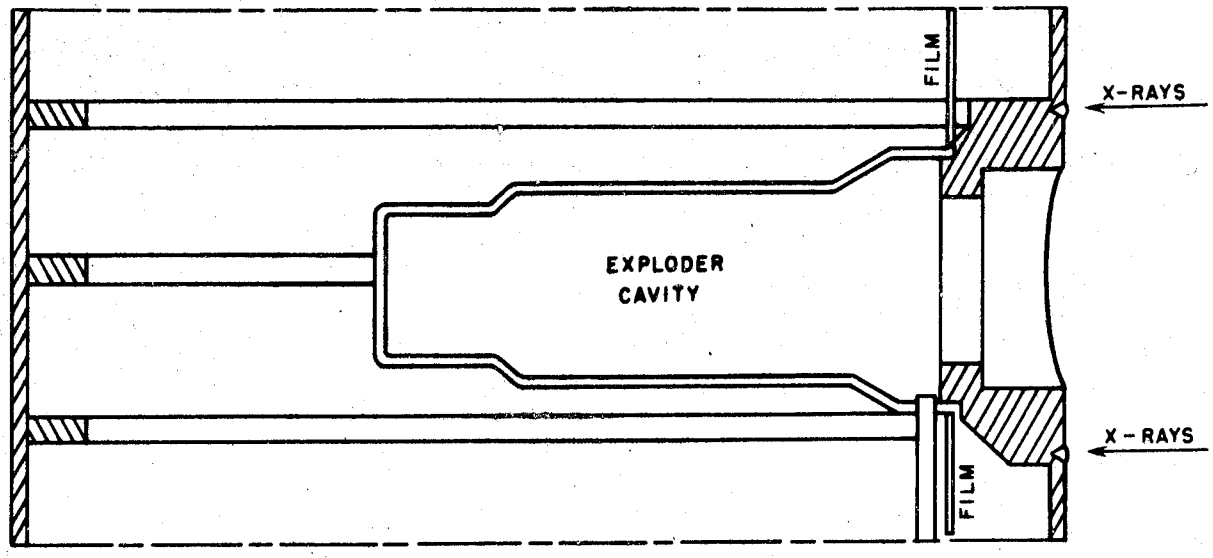

Figure 5. Area D

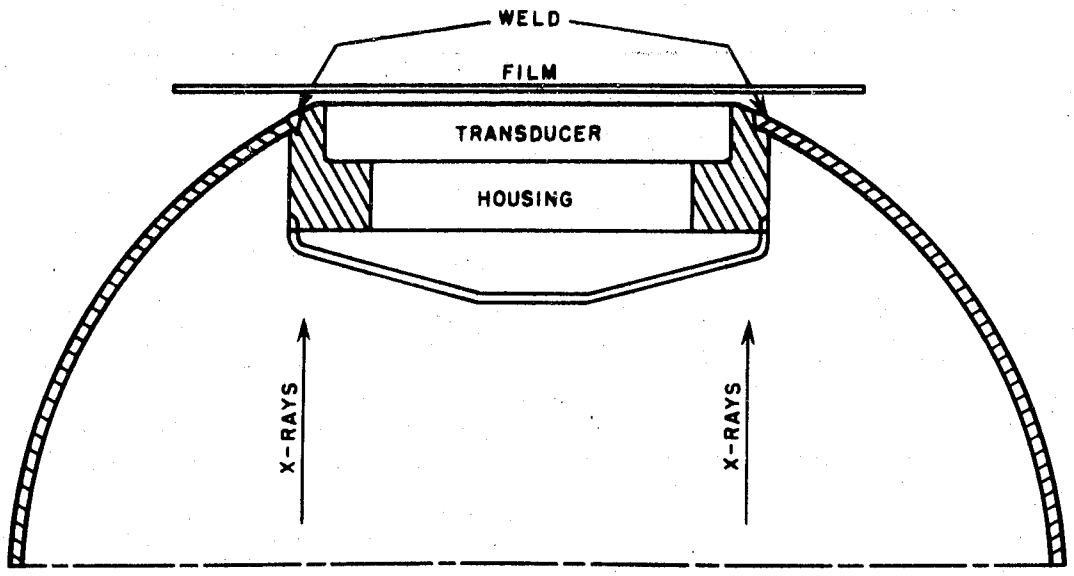

Figure 6. Area E

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PROBLEM 3 - NDT OF M149, 400 GALLON WATER TANK

Mr. David L. Gamache
U.S. Army Tank-Automotive Center,
Warren, Michigan

INTRODUCTION

This presentation is concerned with the nondestructive detection of defects in urethane foam insulation which is bonded to fiber glass panels. The defects include large gas pockets or voids in the foam and lack of adhesion between the foam and panels. The specific application of this NDT method is the Army's M149, 400 Gallon, Water Tank.

Figures 1, 2, and 3 are several views of the M149 water tank, which is used to carry drinking water and other potable liquids to the troops in the field. Normally the tank is filled in a rear support area and towed by a truck to a forward area. The three broad requirements of this tank are: (1) it must be rugged to withstand the stresses of off highway operations, (2) it must not contaminate or alter the flavor of the water it carries, and (3) it must have superior insulating qualities to hold water for long periods without severe temperature change. When properly constructed, this tank meets all these requirements and more, including being easily repaired when damaged by small arms fire.

TANK CONSTRUCTION

The tank is constructed of an inner and outer shell of 3/16 inch thick fiber glass reinforced polyester resin plastic. (Figure 4) Sandwiched and bonded between the inner and outer shells is a rigid closed cell urethane foam approximately 2 inches thick. There is an internal baffle, not shown, to curtail water movement. The baffle is constructed separately and attached to the inner shell. The tank is 7 feet long, 3 feet high, and 4 1/2 feet wide.

The tank shells are currently hand molded in longitudinal half sections and joined together by plying up fiber glass matting at the joints. (Figure 5)

The outer shell is assembled around the inner shell and spaced by several small locks of urethane foam.

After the inner and outer shells are assembled, the tank is placed on end and a small quantity of liquid urethane foaming mixture is metered between the shells through four small openings in the upper end. After approximately 15 to 30 seconds, the liquid begins to foam and fill the space between the shells. Foaming of the tank is accomplished in four separate fills, each operation forming a layer in the tank.

TANK DEFECTS

As stated earlier, the defects we are attempting to locate are hollow voids in the foam and lack of bond between the foam and fiber glass walls. A knowledge of the flow producing mechanism is necessary to have a comprehensive understanding of the water tank problem. We shall, therefore, focus our attention momentarily on the foaming operation.

Foaming in place, a technique used in the water tank, is a delicately balanced operation requiring careful control of temperature, mixture ingredients, and time. Foam cell growth will be too fast or too slow depending upon mixture and wall temperature and result in non-uniform cell size. The urethane mixture must be stoichiometric; that is, the mixture must contain just the correct amount of each ingredient or again the foam will not be correct. Since the chemical reaction takes place within 15 to 30 seconds after mixing, it is important to have all the liquid into place prior to the reaction. If the liquid is poured into soft foam, it will be trapped and cannot properly expand. There is also the problem of correct venting to prevent the air in the walls from being trapped by the foam. It can be seen then, if tight control of process and reactants is not maintained, the results add up to poor quality. One of the earlier tank contractors mixed the urethane in buckets and obtained results that, at best, could be described as frightful. In some cases, the mix foamed too soon and in others, the foam remained sticky for long periods which varied from batch to batch. One present contractor uses an automatic metering pump, but still has some difficulty because of careless workmanship. Therefore, our nondestructive testing efforts are of necessity aimed at process control.

The next question is; what constitutes a defect? In order to be able to evaluate our NDT efforts, we must set limits and define a defect. To do this, let's examine one tank taken from production.

Figure 6 is a half section of a tank which has completed 2,700 miles at the Aberdeen Proving Grounds and several hours of destructive testing at the Detroit Arsenal. In the upper left hand section of the tank along the outer edge, there is a separation between the fiber glass shell and the foam insulation. Since there is no adhesion between the shell and foam, the integral strength of the tank is sharply reduced in this area. These areas of debond occurred throughout the tank.

The second area of interest is the rear bulkhead on the right side of the photograph where there is a long opening between the inner shell and foam. This rupture occurred because there is a reduction in bond area and,

therefore, bond strength caused by long stringers of bubbles at the surface. This appears to be air trapped during the foaming operation.

The third area of concern is in the baffle in the left hand section of the photograph. Here is a void which was a result of improper mixing or a deviation from stoichiometric mixing.

Figure 7 is a close up of the failure in the rear bulkhead. It shows the reduced bonding area due to formation of bubbles and stringers.

Figure 8 is a close up of the void in the baffle foam. This type of flaw is of importance not only because of reduced strength and insulating properties, but also there is a potential contamination of the water. The water could enter the void through a small crack in the inner shell, become contaminated between the shells, and re-enter the tank when the water level is lowered.

Now that the appearance and cause of defects have been established, the next step is to determine what size of void and what area of debond we can tolerate. Unfortunately, we do not have any photographs or detailed description of failures in the field upon which to base our criterion. Therefore, a standard has been tentatively established, based on a measure of level of quality which we can expect a diligent contractor to perform and the level of flaw detection we can expect from past NDT results.

Since we know that the foaming operation depends upon tight process control, we can expect that even under the most favorable conditions, there will be some defects which will not be detrimental to the function of the tank. Figure 9 is a transverse cross section of the tank showing several areas of debond. The area of special interest in this view is the upper right section which is enlarged in Figure 10. According to the DuPont people, who are suppliers of the foam products, these laminar flaws can be expected to occur under normal well controlled operations, and can be regarded as approximately the maximum flaw which should be tolerated. Furthermore, there should be no difficulties encountered with foam bonding to the fiberglass and that extensive debond area should not occur.

The bogey which we have established based on many intangibles, is the detection of a 2 inch diameter spherical void and 2 inch diameter debond area. It is hoped that we can accurately detect flaws even smaller, but this should suffice for our inspection needs.

Figure 11 should clear up one detail. It shows the shape and size of the baffle which for the most part has been omitted from this presentation. The small ellipse outlined in the lower right and left hand sections is the parting line between successive foaming operations.

NDT METHODS

The final question remaining is, "What have we accomplished to date in solving this problem?"

In most respects, this question is a somewhat difficult one to answer, because I have been connected with the Army and the water tank for only five months and the tank problem has been in existance for over 2 1/2 years. Most of the nondestructive test information I will review is second hand. I offer this not as an excuse, but to qualify the lack of completeness of details on some NDT methods.

Any nondestructive test method considered must be: (1) fast - it must be able to inspect a complete tank in approximately 45 minutes; (2) it must be low cost, somewhere less than $5,000.00, if possible, and (3) it must be reliable.

Following is a brief summary of our investigations into NDT methods for the water tank:

Ultrasonics - An attempt was made by the Martin Company using a 500 KC transducer, pulse echo technique, to obtain reflections from a 2 inch diameter by 2 inch deep cylindrical hole. The results were questionable and difficult to interpret. Apparently, the depth of penetration did not exceed 1/4 inch because of back scattering. Through transmission was also attempted with similar results. Sperry Products of Automation Industries also tried ultrasonics with no usable results due to the high attenuation.

It should be noted here that in the last month, we have had some very encouraging results in the 80 KC range. These results will be discussed in detail at the panel report.

Audiosonics - In this field, two methods have been attempted and a third under investigation. The first was tapping on the side of the tank and listening for a hollow sound. Under the most ideal conditions, the results were ambiguous and unreliable. The second method was to place an audio transmitter inside the tank and listen outside with the Sperry Gyroscope Company's Sceptron. No usable results were obtained. North American Aviation has developed a Sonic Resonator which we are investigating. Water tank panels have been sent to them to use in their laboratories.

Microwave - As in high frequency ultrasonics, attenuation prevented the signal from penetrating into the material.

X-Ray - The Picker X-Ray Corporation successfully demonstrated that both radiography and fluoroscopy would detect voids in the foam. The high cost of equipment as well as the cost per tank was considered excessive.

Gamma Back-Scattering - This was ruled out because of the low density differential between the foam and air.

Stress Coat - Stress coating was attempted but apparently is usable on metal surfaces only.

Infrared Scanning - Mr. Dave Wilburn of the Detroit Arsenal conducted a study of infrared techniques on fiber glass panels and has published his results in a technical report. Infrared proved successful in his preliminary study, but was never continued because, at that time, the cost of production inspection equipment was considered excessive. Since then, there has been a continued reduction in the cost of infrared equipment which has convinced us to take another look at infrared.

Finally, a method was devised based on the theory that by using a cooling medium on the inside of the tank and controlling the outside temperature and humidity, a large enough temperature differential would be produced across the insulated wall to induce sweat or frost to appear on the outside surface in areas of faulty insulation. Ice water, dry ice, and liquid nitrogen were used. Ice water at 32° F produced no results after 8 hours duration. Dry ice at (-109°F) revealed only very large voids after 1/2 hour. The liquid nitrogen (- 310° F) indicated the position of small voids but damaged the inside of the tank. The final conclusion was that this method was not sufficiently sensitive.

CONCLUSION

The M149 water tank is a rugged vehicle which possesses the ability to maintain water for long periods without physical or chemical change. The primary inspection problem is the detection of voids in the urethane foam insulation and the lack of adhesion between the insulation and tank walls. Many NDT methods have been investigated to detect these flaws but to date no solution has been found which meets all our requirements.

ADDENDUM - RESULTS OF LOW FREQUENCY ULTRASONIC INVESTIGATION ON THE M149, 400 GALLON WATER TANK

A low frequency ultrasonic technique was investigated using sections of a water tank at the laboratories of the General American Research Division, General American Transportation Corporation near Chicago. The test was a demonstration of the penetration capabilities of low frequency ultrasound, using continuous wave thru - transmission methods.

The system used for the test is shown in block diagram form in Figure 12. The transmitting and receiving transducers were 1 inch diameter piezoelectric ceramic discs designed to operate in the sonic and low ultrasonic region. These tests were performed at approximately 80 KC, using an oil couplant, and an oscilloscope to measure the attenuation of the signal. To facilitate testing, artificial voids and ply separations were introduced into sound tank sections.

Figure 13 shows the location and size of various diameter holes in the urethane foam and the signal attenuation caused by these holes. From this

it can be seen that the minimum detectable hole appears to be somewhere between 3/16 inch and 3/8 inch diameter.

Figure 14 shows the effect of attenuation versus transducer location relative to the centerline of a 3/4 inch diameter hole. The results of this test imply that void detection would not be critically sensitive to transducer location.

Figure 15 shows the location and size of various ply separations between the urethane foam and fiber glass wall. The thickness of these separations is 1/32 inch. The results indicate the minimum detectable ply separation is between 1/4 inch and 1/2 inch wide.

Figure 16 shows the effect of attenuation versus transducer location relative to the centerline of a 1 inch ply separation. Due to the closeness of the transducer to the defect the relative location of the transducer greatly effects attenuation.

These brief tests indicate that a low frequency ultrasonic thru - transmission technique is capable of detecting both voids and debond. The method is simple and inexpensive. However, a thru - transmission technique is not easy to implement when a whole tank is to be inspected.

Pulse echo techniques were not tried since there was no pulse equipment available in the low frequency range. Several methods have been proposed to implement low frequency ultrasonics including pulse echo and a pitch-and-catch method. A contract is currently being written to have General American Research complete this program.

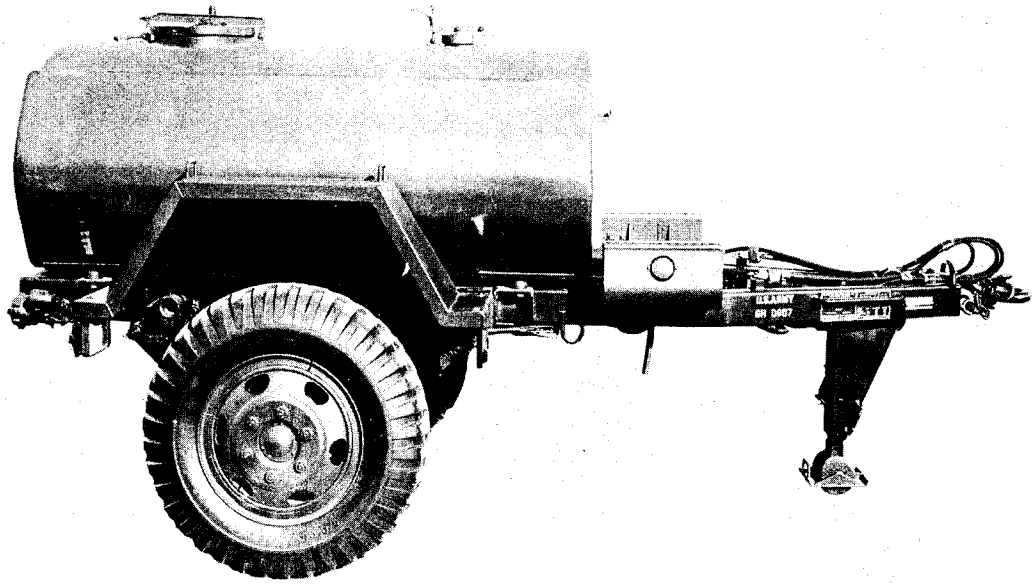


Figure 1.

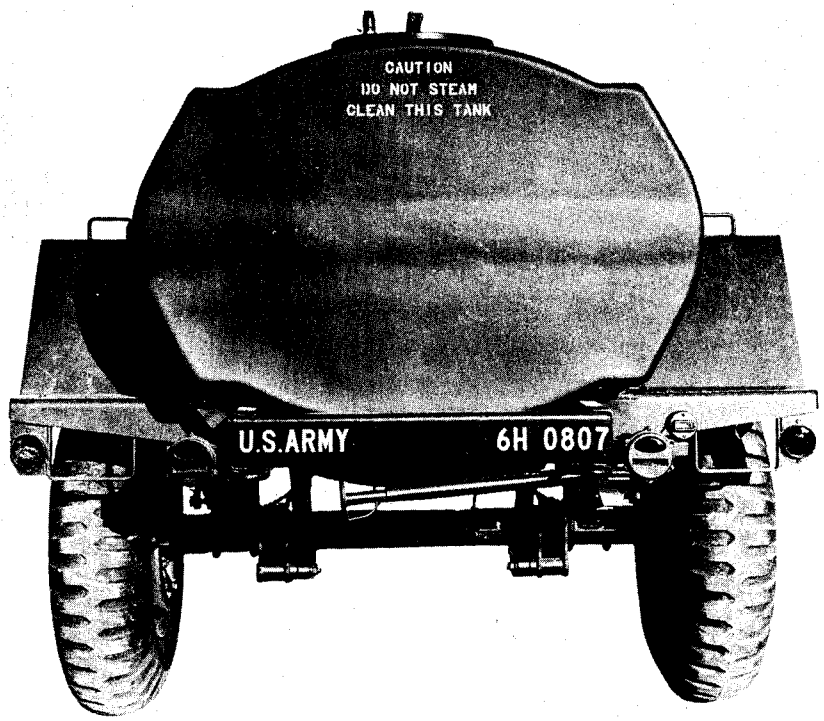


Figure 2.

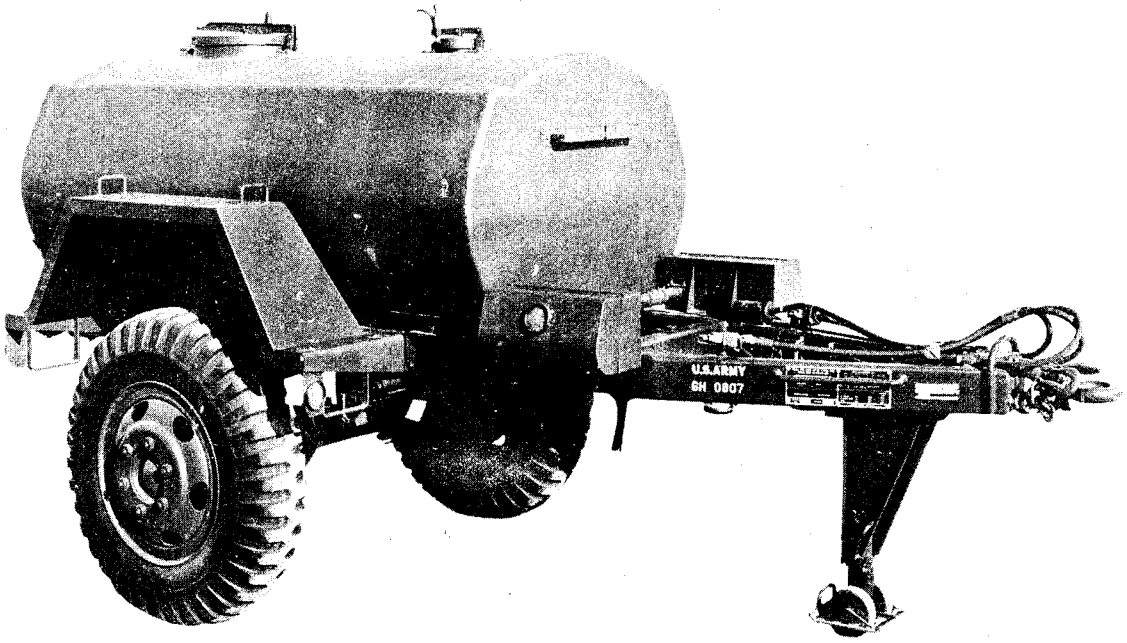


Figure 3.

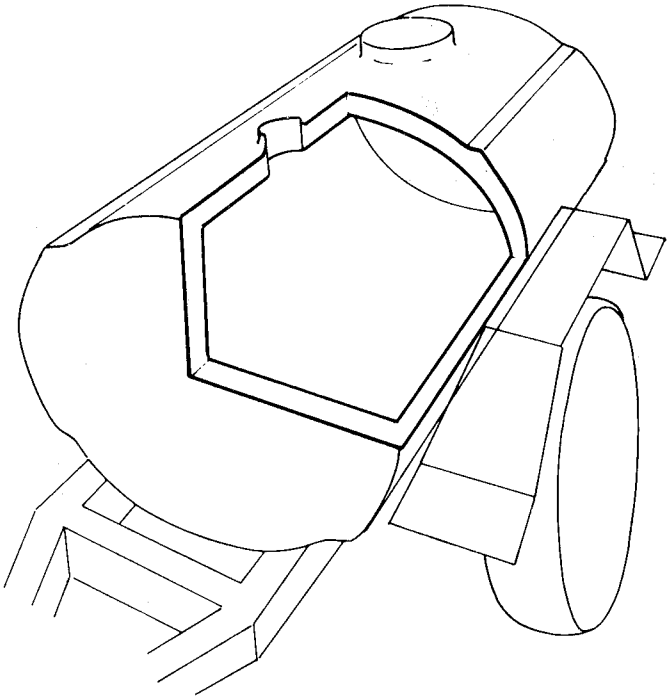


Figure 4. Wall Construction M149 Water Tank

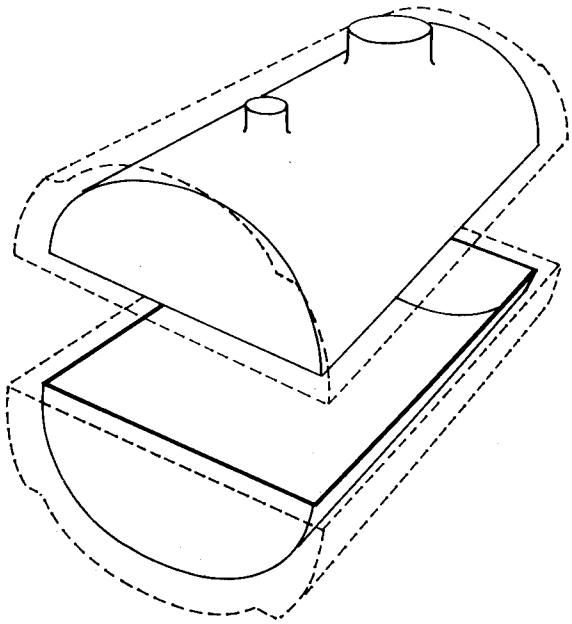


Figure 5. Inner Shell Assembly M149 Water Tank

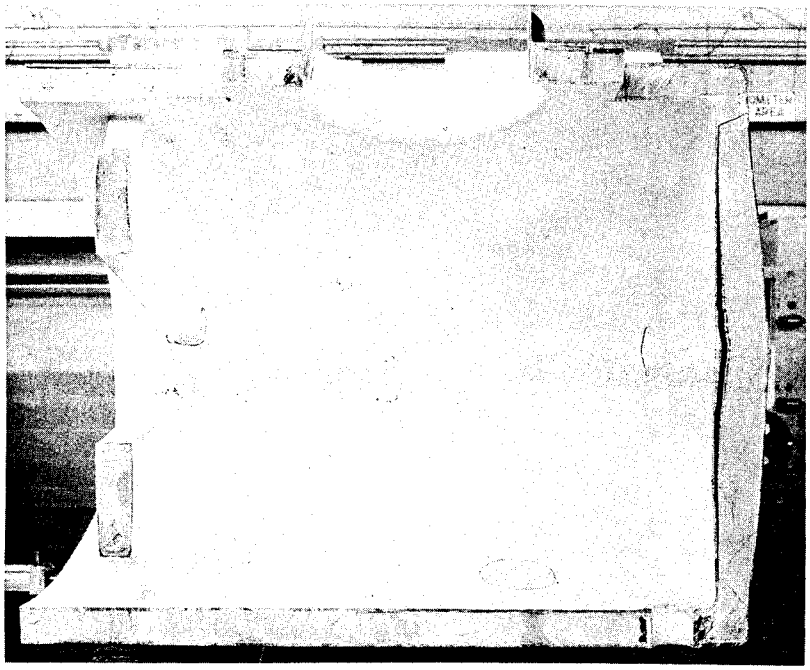


Figure 6.

Figure 7.

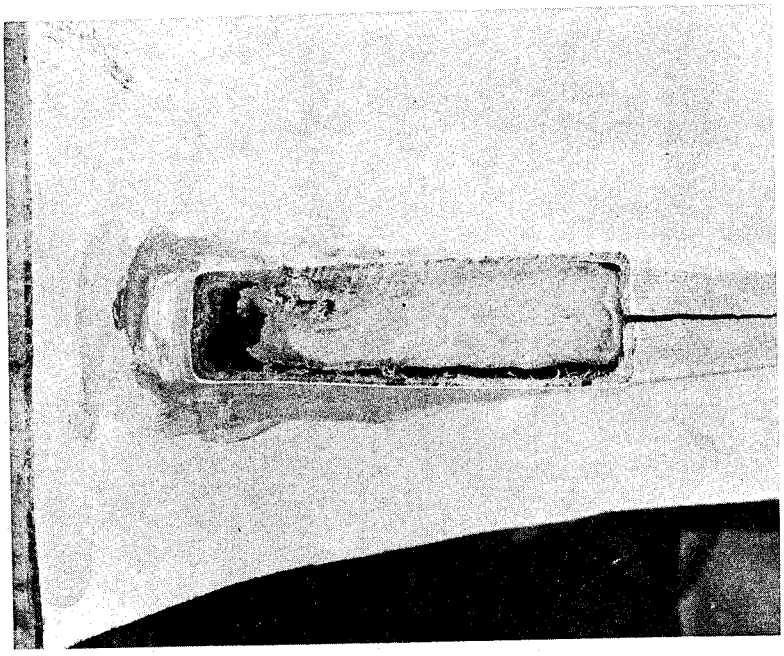


Figure 8.

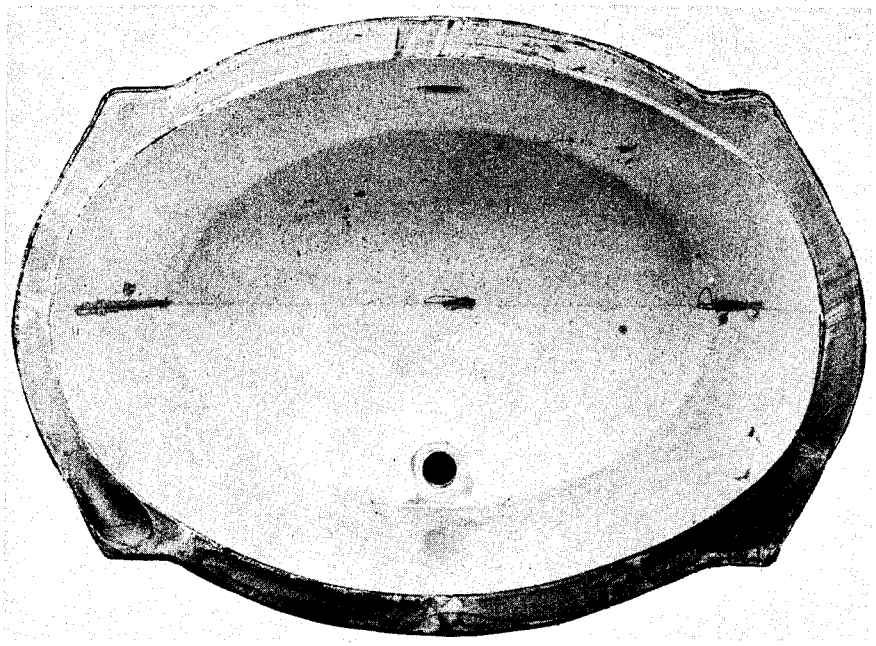


Figure 9.

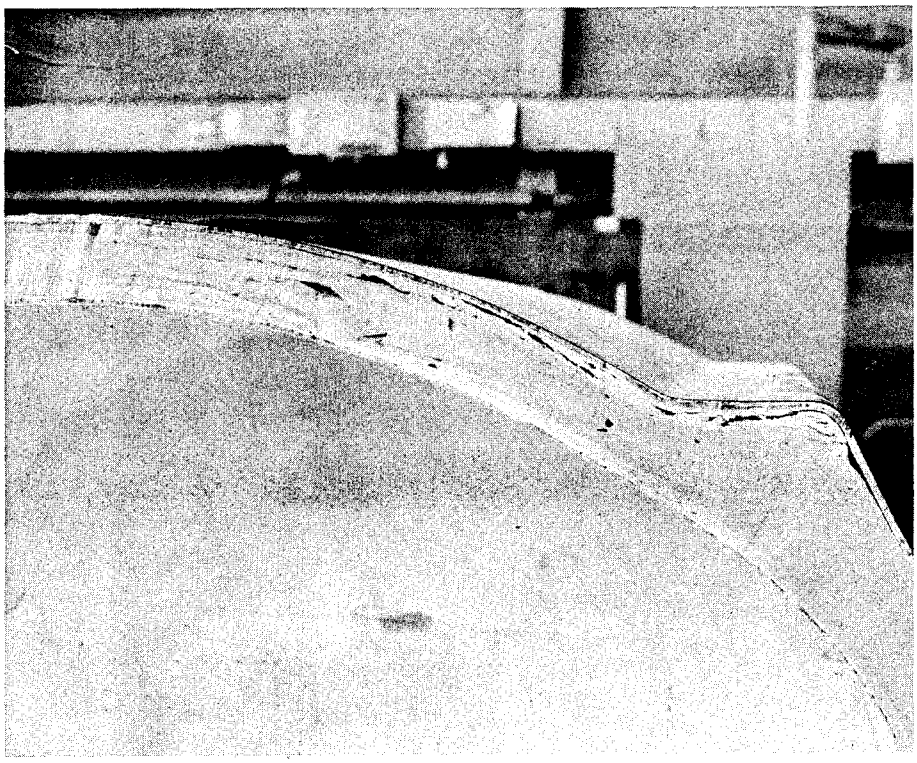


Figure 10.

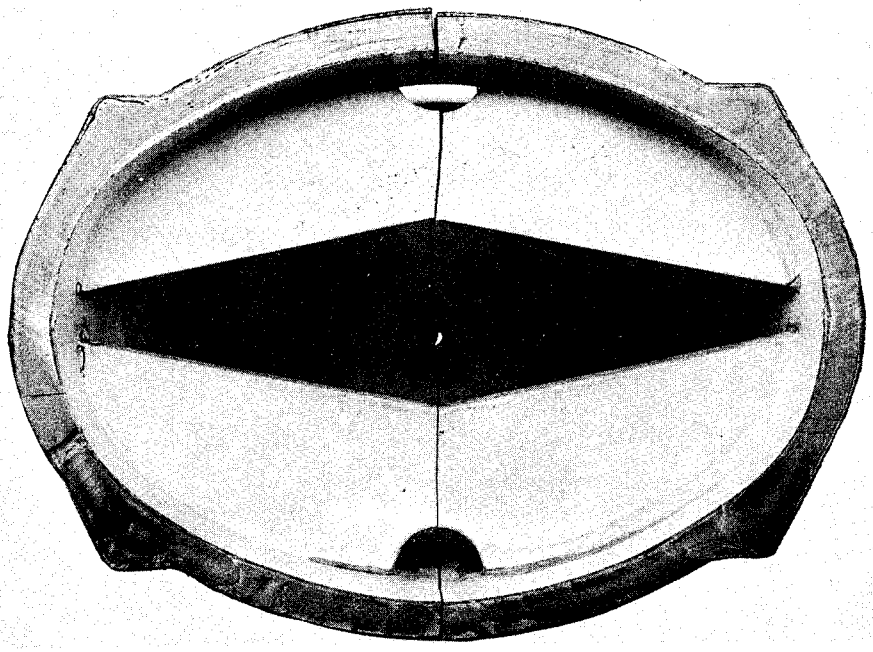


Figure 11.

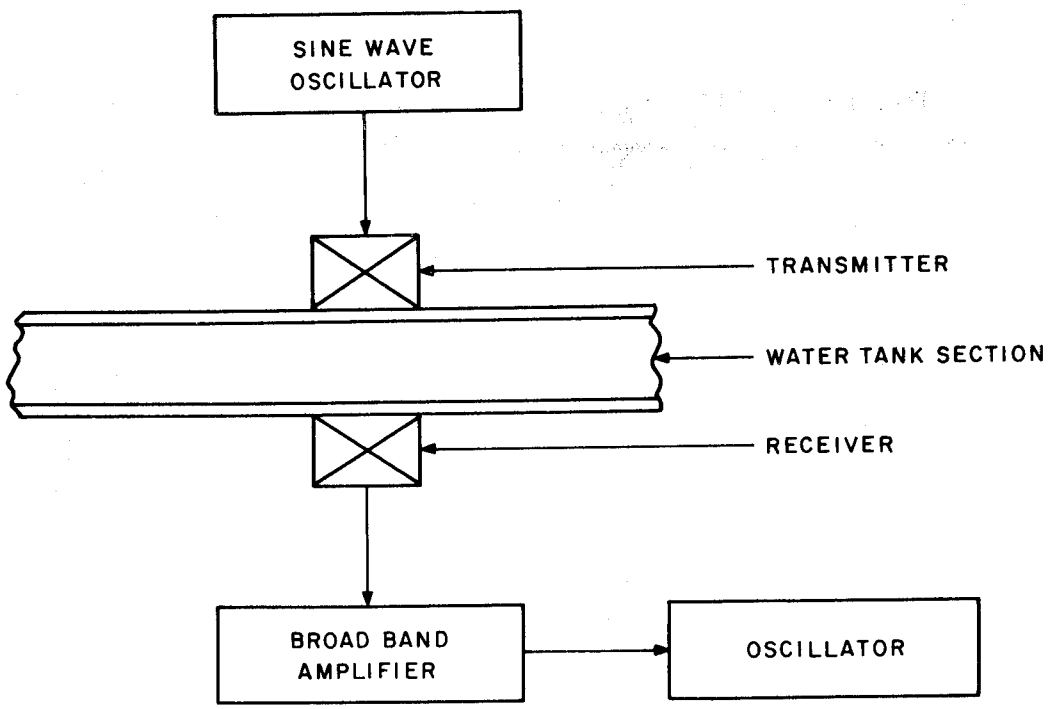


Figure 12. Test, Block Diagram

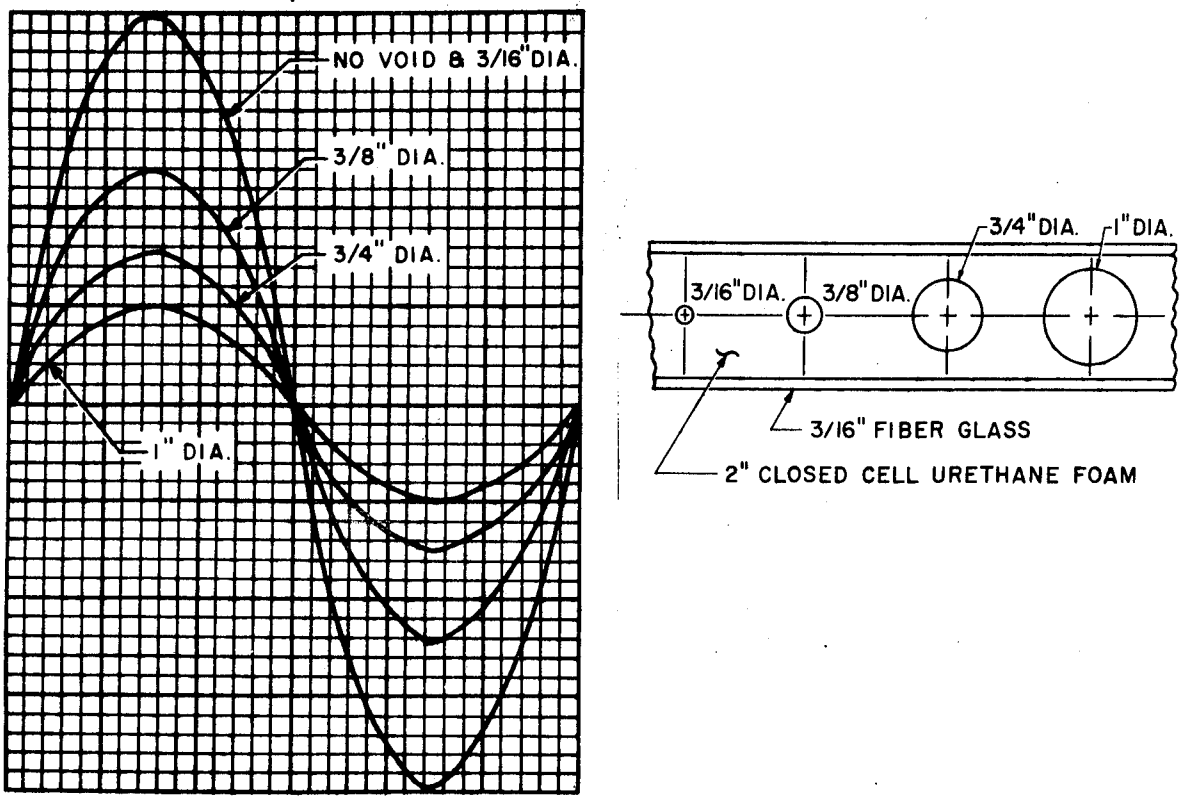


Figure 13. Attenuation Vs. Void Size

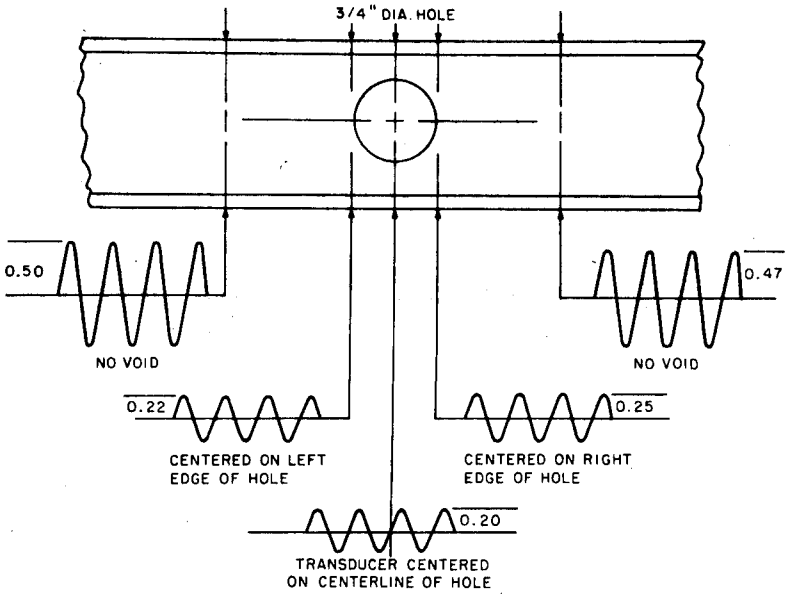


Figure 14. Attenuation Vs. Position of Transducers for 3/4" Hole

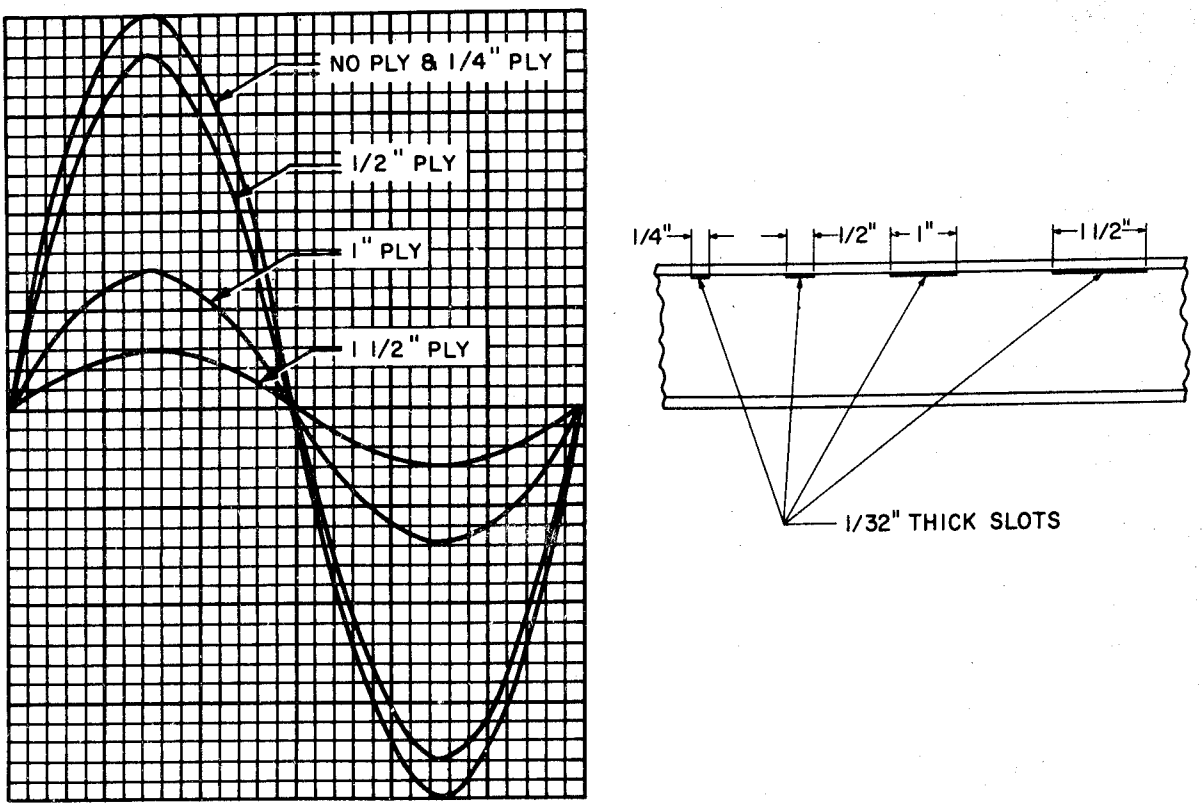


Figure 15. Attenuation Vs. Ply Separation Size

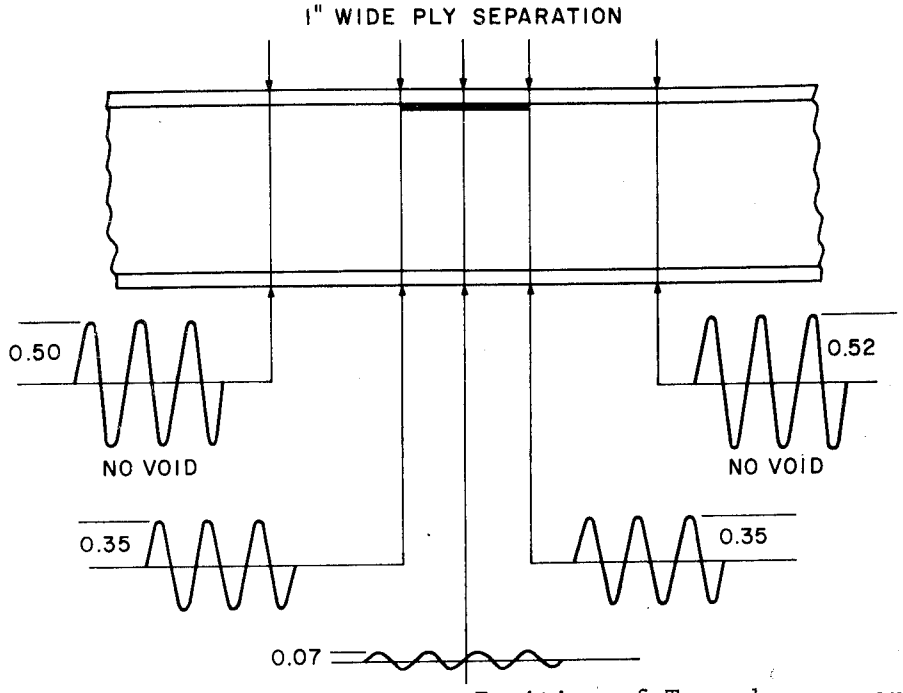


Figure 16. Attenuation Vs. Position of Transducer over 1" Wide Ply Separation

PROBLEM 4 - ULTRASONIC CRACK-DEPTH ESTIMATION IN HIGH STRENGTH STEEL AND TITANIUM STRUCTURAL WELDMENTS

Mr. S. Goldspiel, Mr. G. DiGiacomo and Mr. A. L. Chick
U.S. Naval Applied Science Laboratory
Brooklyn, New York

THE PROBLEM

Nondestructive (NDT), and particularly ultrasonic (UT), crack-depth estimation is of vital importance in fabrications of high yield steel and titanium weldments for submersible hull and pressure vessel structures. A good NDT method would have widespread application to modern technology in general where high strength to weight ratio are emphasized and detection of stress raisers must be positive and easily achieved. Immediately, however, the concern of NASL in the problem arises from its interest in two specimen types:

1. For estimation of retained life (cycles) of tee-welded plate fatigue specimens of high strength alloy weldments; and

2. For exploratory work of crack growth studies in high strength steels.

The following development work conducted by NASL, toward solution of the problem since its original proposal to the 15th DOD Conference on NDT on 22 July 1966, is presented below for constructive criticism.

SPECIMENS

The tee-welded plate fatigue specimen is shown in Figure 1. The test must be carried out without removing the specimen from the machine in which it is subjected to the cyclic loading. Figure 2a is an overall view of the experimental setup. The ultrasonic probe must be manipulated within the limitations imposed by the heavy grid structure of the holding down fixture which is over the specimen proper. A closeup of the specimen within the fatigue machine is shown in Figure 2b. Figure 3 shows a butt-weld plate specimen which is being developed for exploratory crack growth studies for high strength steels. The appearance of the crack at about 4X, on the rough polished specimen edge, is shown in the enlarged portion of Figure 3.

Although the problem for the two specimens appears to be practically identical, several differences between them are important when ultrasonics is used. Apart from the geometry, the most important differences worthy of note are:

1. For the tee-weldment accessibility is from one side only; and the length of the web makes alternate sonic paths impractical for check determinations.

2. For the butt-weldment use of hardfacing deposit for building in a stress raiser introduces a weld within a weld and two markedly different sonic interfaces; and since the groove is not filled with the deposit to the top there may be uneven sound reflectors from the surface downward.

INITIAL ANALYTICAL TREATMENT, BEAM WIDTH ASSUMED NEGLIGIBLE

Analytical expressions for the inclination and depth of the crack for the tee-welded specimen were first derived by the use of a "back-reflection" method and on the simplifying assumption that the ultrasonic beam has no width. Figure 4 shows a sketch used to make the analysis. The vertical component of the crack depth, d, and its inclination to the vertical, ϕ, are functions of two items which are measureable. These are:

S, the transducer motion on a line perpendicular to the weld direction (at a particular "station" on the base metal) between reflections from the skip distance at the surface and the reflection from the bottom of the crack; Δ, is the ultrasonic steel path difference as indicated by the oscilloscope signals from points C and F of Figure 5.

The derived expressions for the crack length (l), inclination (ϕ), and depth (d), in terms of the measured quantities, Δ and S, and the nominal probe angle, θ, are as follows:

$$l = \frac{S \cos \theta}{\sin (\theta + \phi)} \tag{1}$$

$$\phi = \operatorname{arc\,cot} \left[\frac{\frac{\Delta}{S} - \sin \theta}{\cos \theta} \right] - \theta \tag{2}$$

$$d = \frac{S \cot \theta}{1 + \cot \theta \tan \phi} \tag{3}$$

Use of nomographs makes the computation of ϕ and d simple and rapid. Figure 6 shows how ϕ is obtained from a measurement of Δ and S. Figure 7 shows how d is obtained from S for various ϕ's.

Figure 8 summarizes initial results obtained by the approach just described. It will be noted that the agreement for depths of about 1/2 in. and over is fair to good, based on visual observation of cracks at corresponding sections of the weldment. On the other hand for shallower depths the agreement between ultrasonically determined values and actual ones is poor and the former are consistently an overestimate. This difference can be explained by the fact that in actual practice the beam width is not zero.

MODIFIED TREATMENT INVOLVING BEAM WIDTH

Even a cursory consideration suggests that beam width should affect the measurement of cracks of small depth more than those which are of the order of magnitude or larger than the beam width in the plane of measurement. The factors on which beam width depends are: (1) transducer material, size, frequency and angle, (2) path length, and (3) coupling.

When an actual sample is tested the relationship between the crack depth and the beam width is of course not known. Therefore, the first part of the problem involves an initial estimation of the crack depth. The approach described above used "back-reflections" and hence was referred to as the "back-reflection" method. It can be shown that this method is not valid when the beam width is greater than the crack depth and that at any rate its use leads, to weaker signals than a "direct-reflection" method would. For these reasons the initial estimates, especially when the crack depths are expected to be small, utilized the "direct-reflection" method. Some of the advantages of this approach are: (1) reduces effects of beam divergence; (2) reduces effects of attenuation due to path length; (3) reduces effects of back surface back scattering; and (4) improves sensitivity and reliability for small crack depths. The method is explained and discussed in some detail below.

Figure 9 shows the transducer in position for which the extreme ray of the sound beam, having a finite angular width, just reflects from the bottom of the crack. The inclination of the crack can be determined from the equation

$$\phi = \text{arc cot}\left[\frac{\frac{d\,\Delta}{d\,S} - \sin\theta}{\cos\theta}\right] - \theta$$

shown for Figure 4, since d/s is independent of whether it is determined by back or direct-reflection.

Now, if as in Figure 9, d_ϕ = vertical depth of the crack, and γ = half angular beam width, it can be shown that:

$$d_\phi = \frac{S \cos(\theta+\gamma)\cos\phi}{\sin\left[(\theta+\gamma)+\phi\right]} \qquad (4)$$

Equation (4) is derived as follows:

$$d_{\phi} = 1 \cos \phi \tag{4a}$$

$$\frac{1}{\sin(\pi/2-\theta-\gamma)} = \frac{S}{\sin\left[\pi - \left\{\pi/2-\phi-(\pi/2-\theta-\gamma)\right\}\right]}$$

$$1 = \frac{S}{\sin\left[(\theta+\gamma)+\phi\right]} \tag{4b}$$

$$d_{\phi} = \frac{S \cos(\theta+\gamma) \cos\phi}{\sin\left[(\theta+\gamma)+\phi\right]} \tag{4c}$$

For the initial trials of the method on a butt-weld plate specimen, the half beam width angle used in computations was taken from the manufacturer's literature, since the angle depends to a large degree upon the frequency and size. The results obtained vs. actual measurements of ϕ and d are shown in Table 1. In this tabulation several points are worthy of note:

1. When a larger angular probe is used (at the same frequency and size) the half angular beam width, γ, and S are larger. The later fact places a practical limitation on the use of probes with larger angles.

2. The method is capable of handling cases where the inclination, ϕ, is negative (counterclockwise from normal).

3. The measured and ultrasonically determined values of d agree within about 15%, and such agreement is equally good for relatively small crack depths.

Table 1. FIRST RESULTS WITH DIRECT REFLECTION METHOD

					D (inches)	
Sample #	$^{o}\theta$	$^{o}(\theta+\gamma)$	S"	$^{o}\phi$ Approx.	Actual	Expermt'l
1	45	55	0.65	0	0.40	0.46
2	70	83	2.30	0	0.32	0.28
3	45	55	0.70	0	0.45	0.49
4	45	55	0.80	0	0.52	0.56
5	45	55	0.45	0	0.32	0.32
6	45	55	0.50	0	0.29	0.35
7	45	55	0.31	-30	0.22	0.25

Calculations show that for small crack depths and $\phi = \pm 10^{\circ}$, ϕ may be neglected with an error in d of only 10%. For these conditions:

$$d_{\phi} = S \cot (\theta + \gamma) \tag{5}$$

DISCUSSION

For more precise work, the angular beam width should be determined by use of the actual sample material, since (as was previously mentioned) it depends not only on the transducer frequency and size but also on the material path length and coupling (or surface finish of sample). The analytical expressions which can be used for this purpose are derived next.

Determination of Transducer Half-Angular Beam Width (γ) - Previously it was shown that

$$d_{\phi} = \frac{S \cos (\theta + \gamma) \cos \phi}{\sin (\theta + \phi + \gamma)}$$

Since γ does not depend on ϕ, we can choose any ϕ (e.g. the most convenient value being $\phi = 0$) for experimental purposes. For a 45° probe equation (1) becomes

$$d_{\phi} = \frac{\cos \gamma - \sin \gamma}{\cos \gamma + \sin \gamma} S \tag{6}$$

This shows that there is a linear relationship between d and S and that the multiplying factor for s is a constant, say K.

Using calibration blocks with normal slots (to surface) of varying depth, for a given surface condition, we can measure corresponding values of s and obtain a plot of d vs. S. The slope of this plot is K. Therefore:

$$d_{\phi} = \frac{\cos \gamma - \sin \gamma}{\cos \gamma + \sin \gamma} S = KS \tag{7}$$

or

$$\tan \gamma = \frac{1 - K}{1 + K} \tag{8}$$

In effect, it follows that the half angular beam width, γ, can be determined experimentally by plotting d vs. S for known slot depths and inclinations. Since γ is independent of $\emptyset$, the calibration block was made for convenience with vertical slots, as shown in Figure 10. K referred to above is obtained from the slope of plots of d vs. S for the calibration block.

The sketch of Figure 11 shows quite convincingly how the beam width (in the plane of measurement) acts to give an overestimate of the ultrasonic values of depth. The overestimate is by an amount equal to the beam width at the location.

Beam Width and Accuracy of Crack-Depth Estimate - In Figure 11, let l_b = expected length of crack in plane normal to the beam direction; then

$$l_b = l \cos (90^\circ - \theta - \emptyset) = l \sin (\theta + \emptyset) \qquad (9)$$

Values for l_b as determined from the oscilloscope path difference and probe displacement depend on the signal amplitude, and hence are also functions of coupling and plate surface finish. This is clear when one considers that the signal amplitude and width are both greater for conditions of good coupling and plate surface finish; and vice versa.

These considerations are being studied further at this time in an effort to improve the accuracy of crack depth estimation. Fortunately, however, results obtained from actual scaled plates did not need the correction for crack depths over about 1/2-inch. It is evident that under actual test conditions, poor coupling and attenuation lead to an underestimate of "S" by an amount approximately of the order of magnitude of the beam width, b. This will not be the case when the plate finish and coupling change considerably. It would also not apply to crack depths below the value of the beam width at the crack location.

For small crack depths (smaller than the beam width) the use of the direct-reflection method is mandatory. This is accomplished by reflecting the outer ray of the beam bundle (which is away from the central portion), and measuring the probe distance S from the crack at the moment when the peak disappears from the oscilloscope. While for the direct method work reported here the 45° probe was used almost exclusively, the use of a higher angle probe becomes advantageous at times and mandatory when the crack depth is small. This is especially true when accessibility and space limitations are involved in the sample.

Even though the ultrasonic method (here described) or any other NDT method might be improved beyond what has been shown here, the NDT estimate in general can never perfectly agree with the depth determined by destructive means. This becomes clear when we take into consideration the following:

1. The depth determined from polished sections only represents the value at a specific point, whereas the ultrasonic measurement applies to a width which is, at the very least, dependent on the probe dimension.

2. The crack depth as observed from a polished section will differ depending on magnification employed to check it.

3. The ultrasonically determined value may be lower than the actual one if the crack is in part extremely tight (as would be the case if the material were in compression) so that it will not attenuate the ultrasound.

FUTURE WORK

It is also clear that other NDT methods, such as radiography and electrical resistance, may prove better (within limits) for lower crack depths and less effective for greater depths. Various approaches will be tried in order to improve the crack depth estimation to a reasonably good practical agreement with the "true" value.

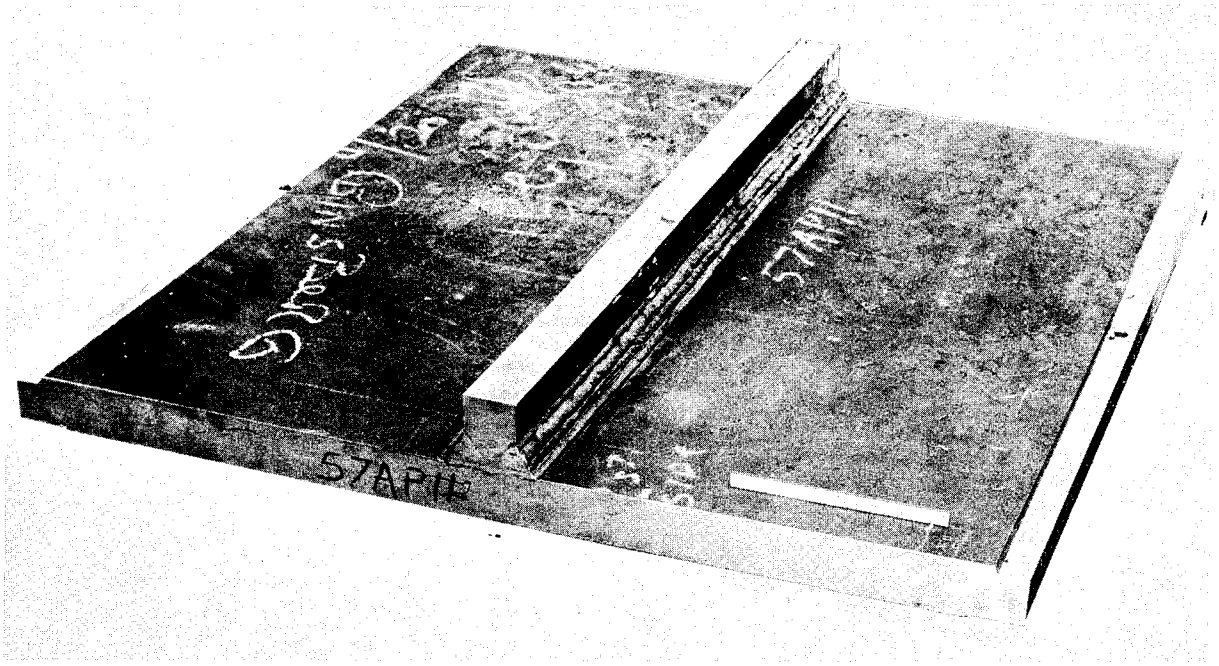
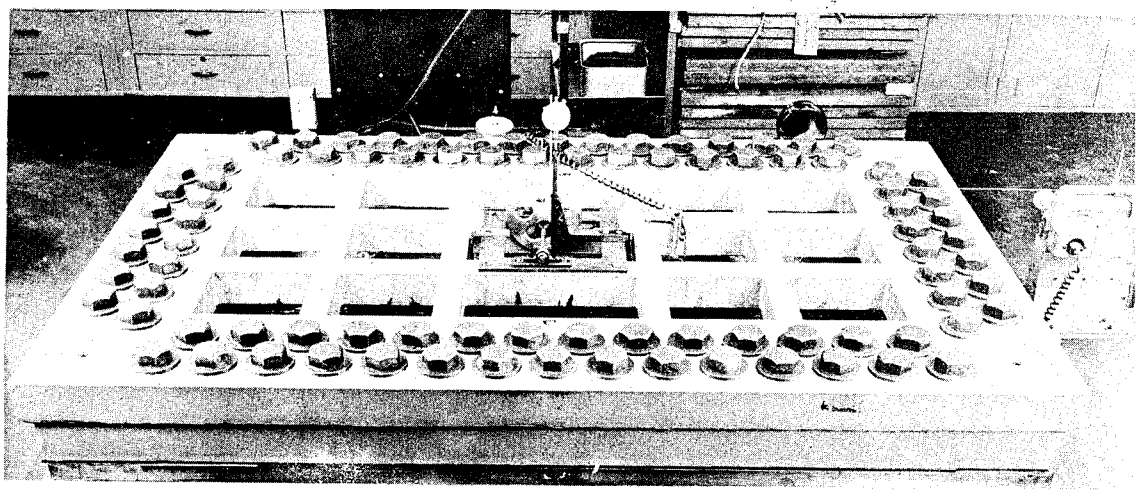
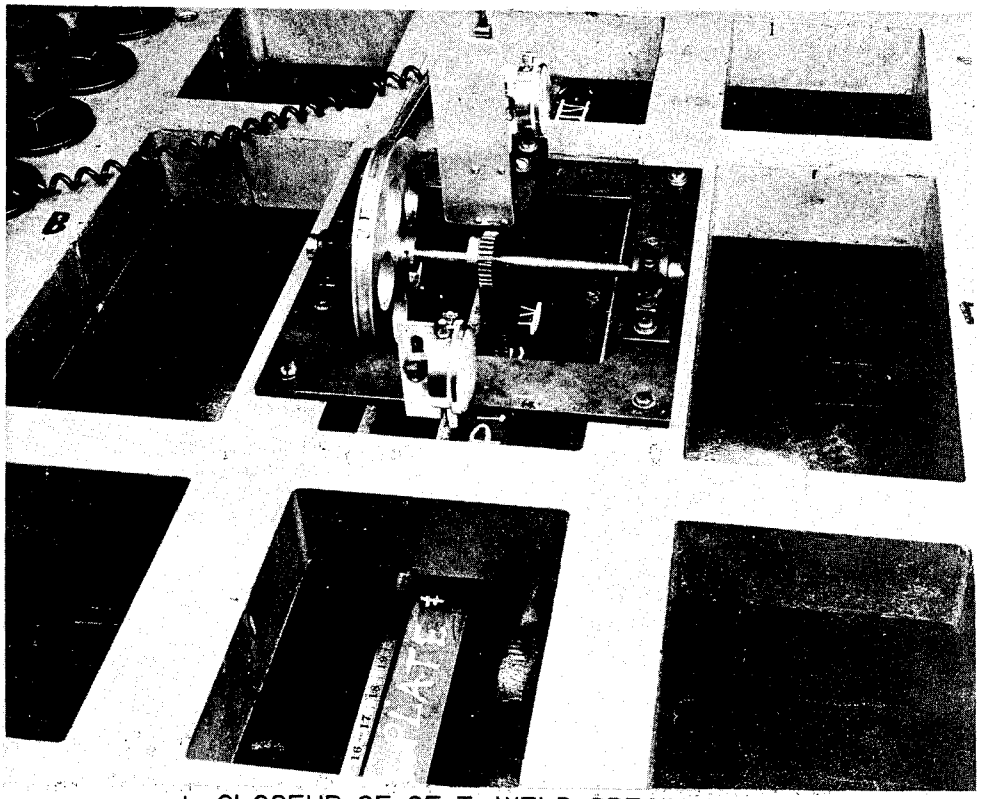


Figure 1. Tee-Welded Fatigue Specimen



a. OVERALL VIEW



b. CLOSEUP OF OF T-WELD SPECIMEN

Figure 2. Fatigue Test Setup

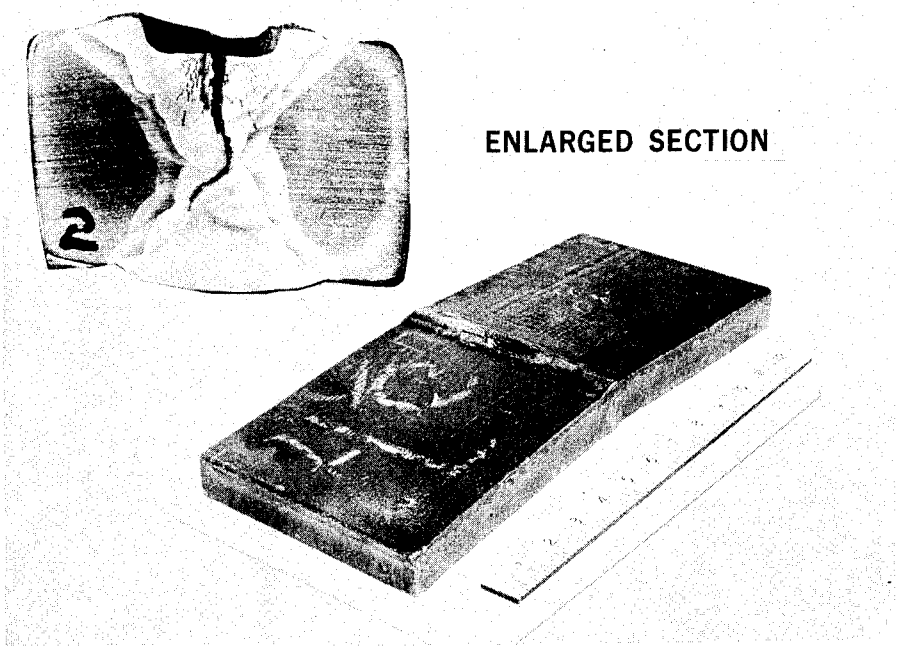
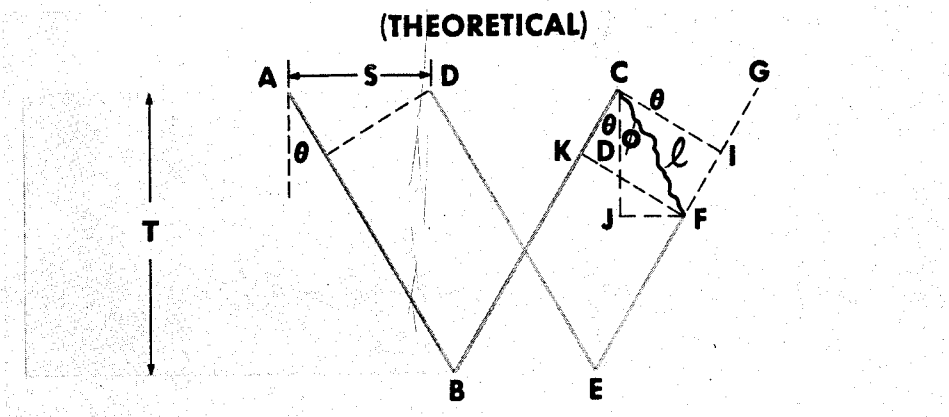


Figure 3. Butt-Weld Specimen for Estimation of Notch-Toughness Overal View and Enlarged View of Section Including Crack



T = Plate Thickness
S = Probe Displacement on Plate Surface
△ = Sound Path Difference
θ = Probe Angle
φ = Inclination of Crack
D = Crack Depth

$$\triangle = FG = FI + IG = \ell \cos(\theta + \phi) + S \sin\theta$$

Figure 4. "Back-Reflection" Method

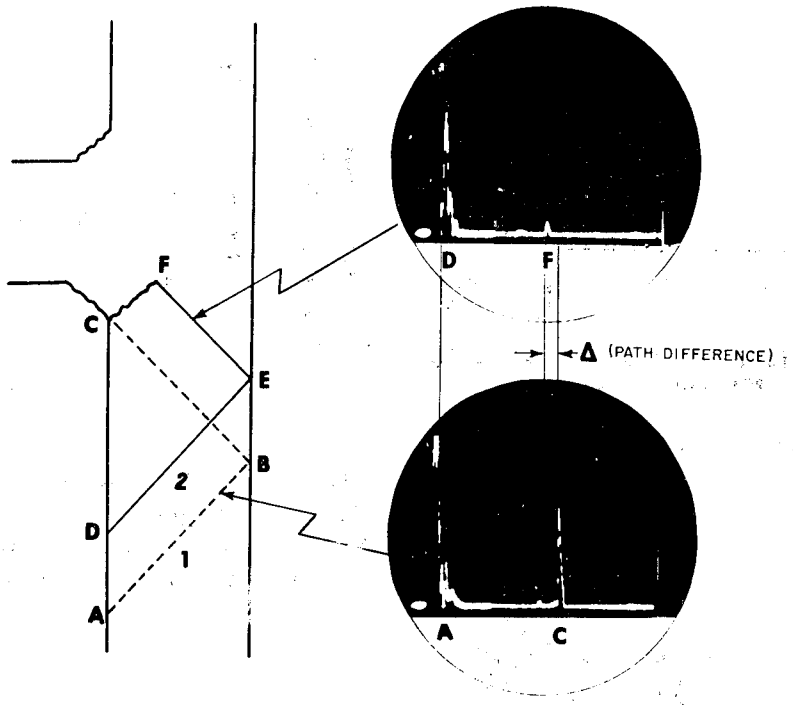


Figure 5. Oscilloscope Signals and Ultrasonic Path Difference

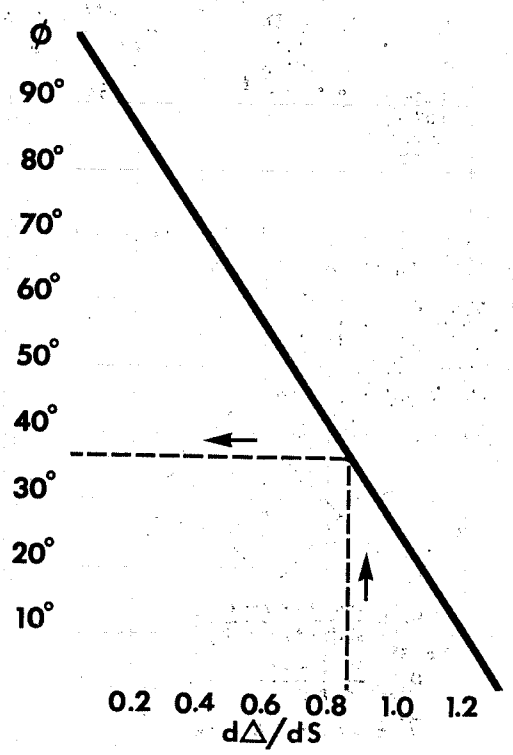


Figure 6. Crack Inclination (Ø) vs. d Δ/dS

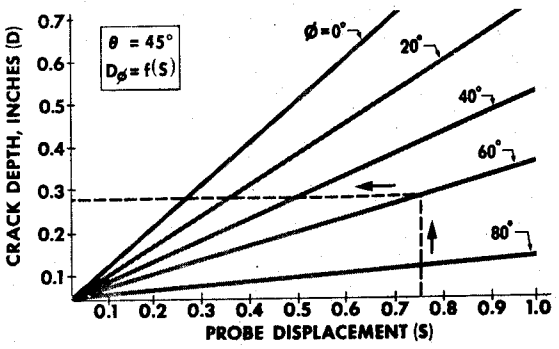


Figure 7. Crack Depth, d, vs. Probe Motion, S.

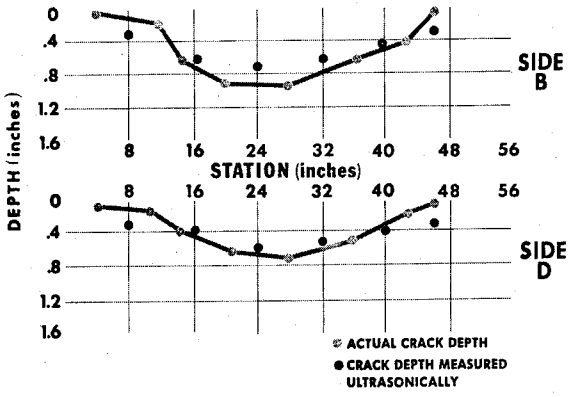


Figure 8. Initial Results for Tee-Welded Fatigue Specimen. Crack Depth for Various Stations, Actual vs. Ultrasonically determined

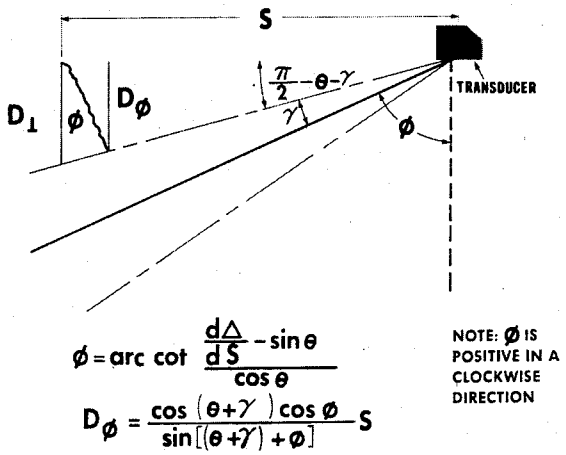


Figure 9. "Direct" Reflection Method

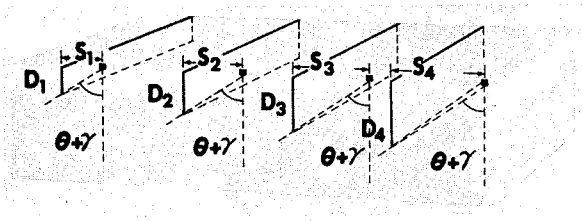


Figure 10. Beam-Width Calibration Block

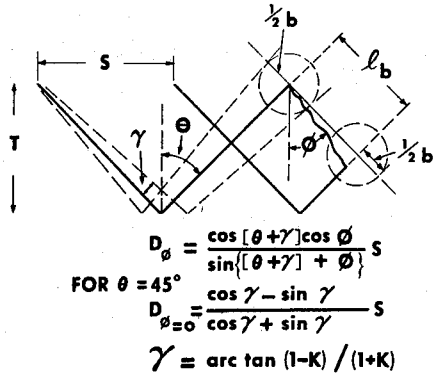


Figure 11. Effect of Beam Width on Crack Depth Estimation

PROBLEM 5 - DUCTILITY OR ELONGATION DETERMINATION OF SINTERED IRON ROTATING BANDS FOR ARTILLERY SHELL

Mr. Domenic J. Molella
Picatinny Arsenal
Dover, New Jersey

The problem is to determine the ductility or elongation of rotating band blanks. These blanks are made from iron powder which is cold compacted, sintered, coined, annealed and then impregnated with wax. Figure 1 shows a photograph of the band blank which is .865 -.005 inch wide, has a .191 + .020 inch wall thickness and an ID of 4.145 +.020 inch. The chemical composition requirements after sintering are shown in Table 1:

TABLE 1 - CHEMICAL COMPOSITION

Composition	Percent
Total Iron, min.	97.90
Combined Carbon, max.	0.15
Total Silicon, max.	0.20
Total Aluminum, max.	0.15
Sulfur, max.	0.05
Phosphorus, max.	0.05
Manganese, max.	0.60
Other Elements, max.	0.90

The density of the band blank after annealing and before wax impregnation should be 5.90 to 6.19 gm/cc. The photomicrograph in Figure 2 is representative of the porosity which is present throughout the blank. After impregnation with a micro-crystalline wax, the wax content should be 2.0 percent minimum by weight. Although not specified, the surface finish of the completed blanks has been found to be not greater than 64 micro-inches, RMS.

Present methods of testing the band blanks consist of visual inspection and destructive tensile and ductility tests. Visual inspection consists of viewing the finished blanks with the naked eye to determine workmanship and to detect detrimental defects such as chipped edges, cracks or excessive oxide film. The tensile test consists of testing the whole blank since there is no correlation between the tensile strength of the blank and that

of a test specimen that is separately compacted from iron powder and sintered. Figure 3 shows the "saddle-type" fixture which is used. The test is performed at a crosshead speed of 0.250 inch per minute and the transverse tensile strength is calculated by dividing the load at fracture by twice the original cross-sectional area of the band blank. The tensile test results for all specimens representing a lot should be 16,000 psi minimum. At least 10 samples are tested from each lot of 10,000 pieces or less and at least 20 samples from each lot of over 10,000 pieces. Since the elongation or ductility of the band blank cannot be determined by the above tensile test method, a separate test method is used for determining the ductility or elongation. It consists of placing the blank on a tapered mandrel having a diametric taper of 0.020 inch per inch (Figure 4) and pushing downward by hand until the blank is firmly wedged on the taper of the mandrel. The diameter of the mandrel in the plane of the leading face of the blank is taken as the ID of the blank at start of test. The initial ID can also be measured on the blank. The blank is then pushed along the mandrel until the ID is expanded a minimum of 5 percent. When expanded the bands should not fracture. At least 5 samples are tested from each blank lot of 10,000 pieces or less and at least 10 samples from each lot of over 10,000 pieces.

The ductility requirement of the band blank is very important in that it must be capable of being properly seated into the shell band seat (Figure 5) without cracking. After seating the density of the band usually increases to 0.25 gm/cc, max. and the hardness also increases proportionately. It must also be ductile enough so that scallops which form at the edge of the rotating band during engraving from the gun barrel (Figure 6) do not break-off. If scallops break off, the debris leads to excessive wear of gun barrel or premature of subsequent shell in the gun. If the band is too brittle, it might crack in gun barrel and break loose outside the gun thus endangering our troops and decreasing accuracy.

It is quite obvious that the above inspection and test methods are expensive and also unreliable. A highly reliable, economical nondestructive test method which will replace the visual, tensile and ductility tests is desirable; however, if this is not feasible, then one which will replace the ductility or elongation test is urgently needed. Since the production rate is in the millions, testing by automation is obviously required. Copper shortage necessitates use of substitute materials. Sintered iron which was extensively used by the Germans during World War II has been found to be best suited. Consequently, the need for a reliable (above 99%) test method is immediate in order to insure safety and satisfactory production and permit 100 percent inspection. There is no restriction as to size, weight or transportability of the test equipment.

Figure 1. Photograph of Rotating Band Blank 9/16X

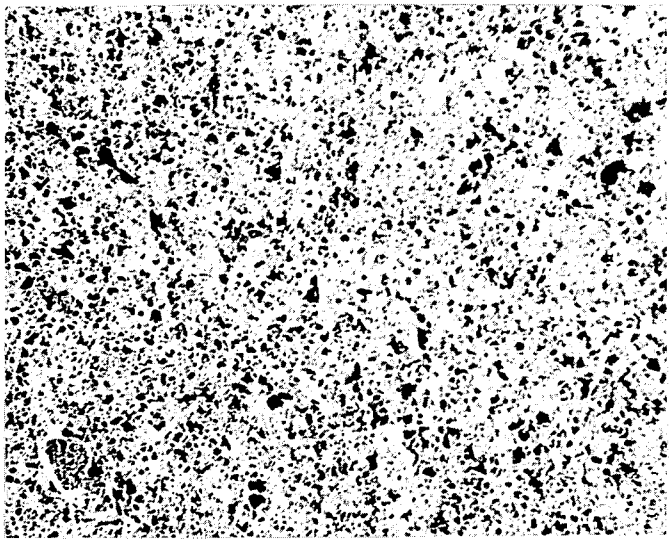
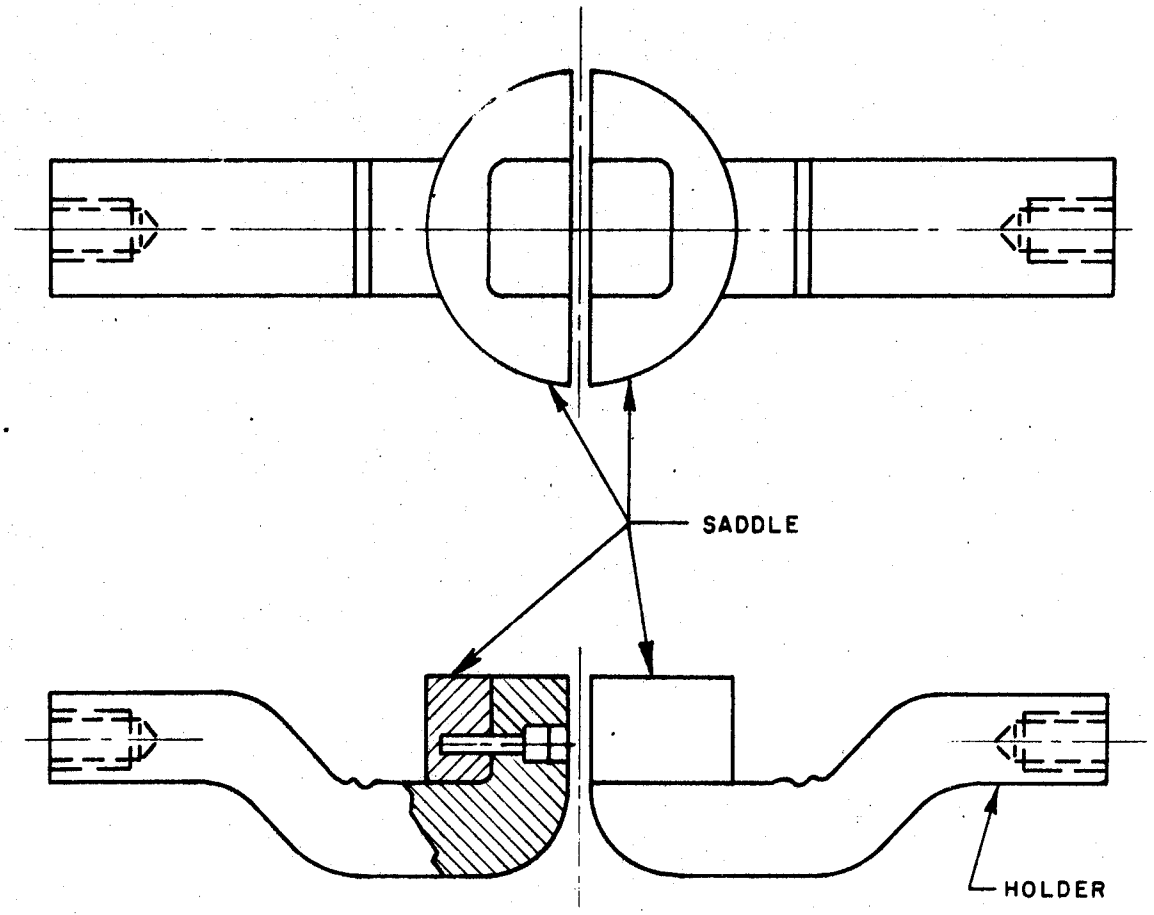


Figure 2. Photomicrograph of Rotating Band Blank Showing Representative Porosity. Unetched 100X



DIAMETER OF THE SADDLE = MINIMUM DIAMETER OF THE ROTATING BAND BLANK MINUS 0.020 INCHES MINUS 0.010 INCHES (MACHINE TOLERANCE)

Figure 3. Tensile Test Fixture Assembly for Rotating Bands

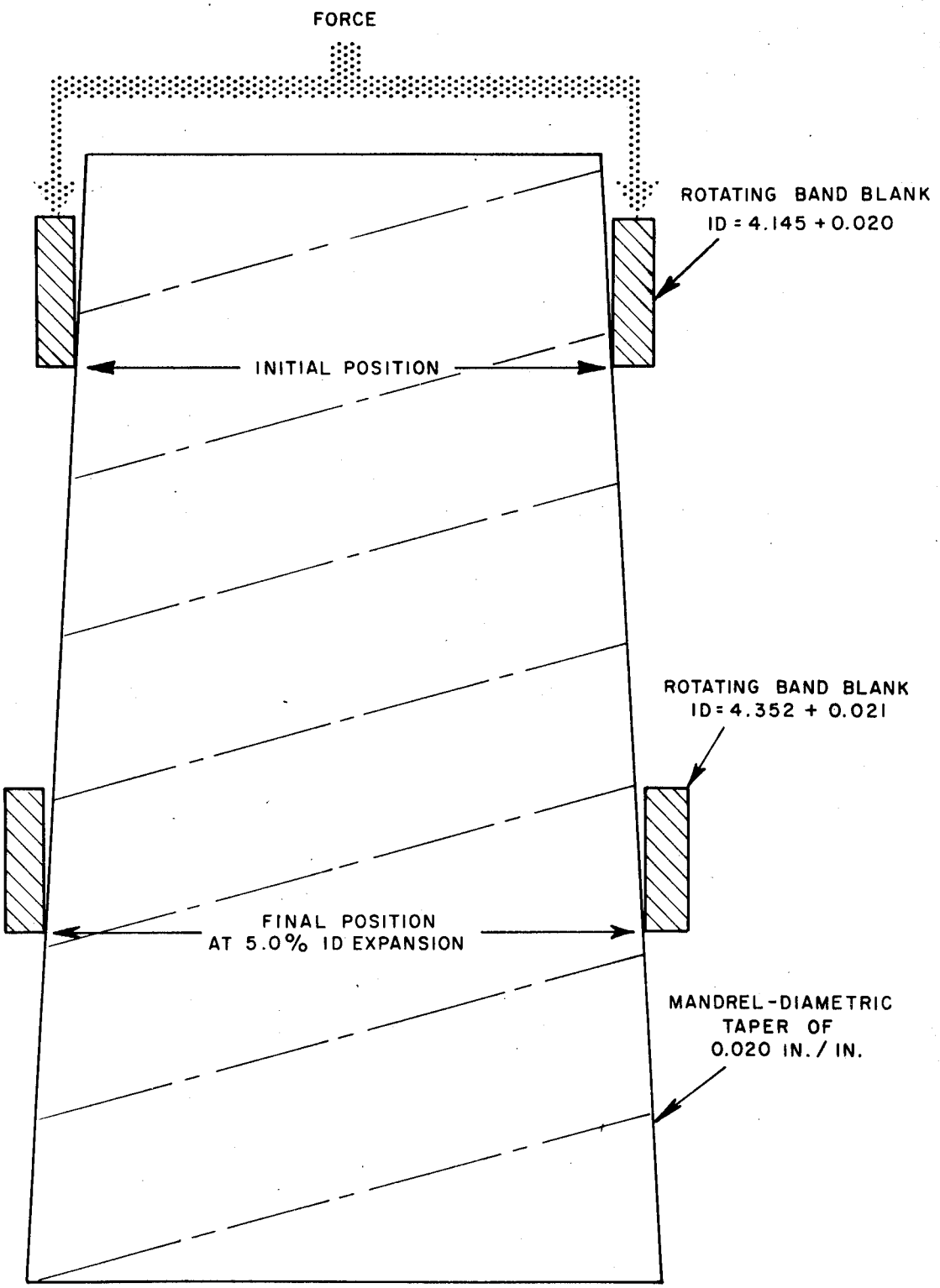


Figure 4. Ductility Test Fixture

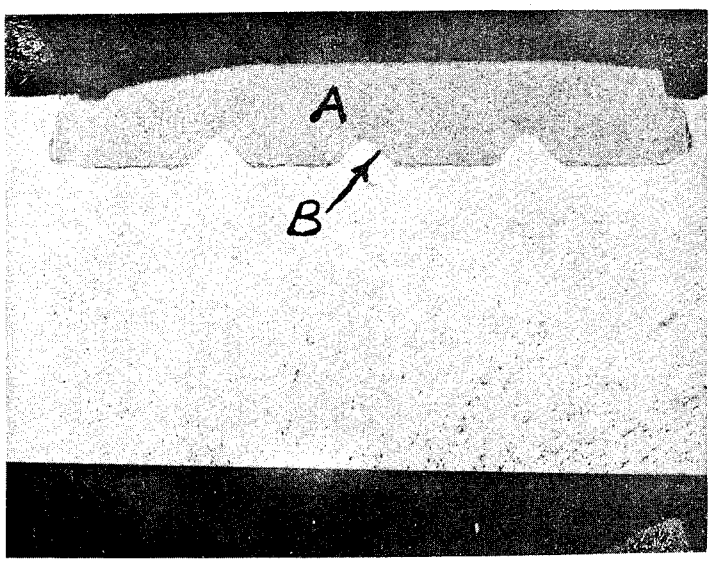


Figure 5. Photomacrograph of Rotating Band Blank (a) After Seating Onto Band Seat (b) of 105MM Shell. Etchant: Nital 4X

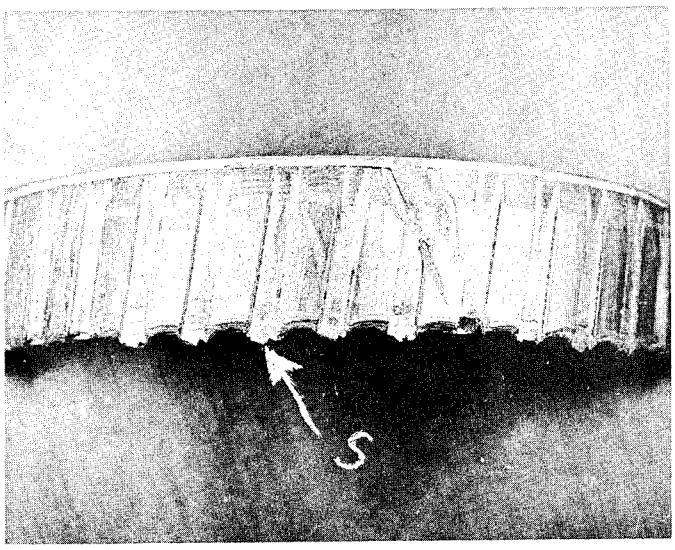


Figure 6. Photograph of Section of Rotating Band Showing Scallops (s) Formed During Engraving in Gun Barrel. 1X

FORMAL PAPERS

PAPER I - EDDY CURRENT INSPECTION OF TURBOJET ENGINE TURBINE DISKS FOR LOSS OF STRENGTH

Mr. Lawrence G. Marler
Oklahoma Air Materiel Area
Tinker Air Force Base, Oklahoma

INTRODUCTION

My paper concerns the use of eddy currents to detect a reduction in a material's strength after it has experienced repeated exposure to temperature and stress. I shall discuss the problem that necessitated this inspection technique, the experimental program that led to this method of inspection, and our present activity in this area.

BACKGROUND

Our desire for a method to determine nondestructively material strength loss was generated by J-47 disks' failures. The B-47 is powered by six of these engines. The engine has an axial flow, twelve stage compressor, single stage turbine, and a fixed exhaust nozzle. During normal operation, the turbine disk's designed temperature range of 400 to 1100°F is maintained by bathing it in cooling air bled from the compressor.

The J-47 turbine disk is extremely sensitive to overtemperature because of its composite structure - a rim of Timken 16-25-6 welded to a webb of AISI 4340. Any interruption of cooling air flow results in an increase of turbine disk temperature. If cooling air flow is not restored, turbine disk strength is reduced until large pieces of the rim are ripped from the webb by centrifugal force and hurled at high velocity into the surrounding engine and aircraft structure.

Less dramatic but equally damaging in the long run are occurrences of cooling air interruptions that do not result in instantaneous disk ruptures. Crystalline structure changes, a disk's metallurgical memory, records and stores various time-temperature-stress events. An accumulation of these changes reduces disk strength until the disk has insufficient strength to withstand even normal operating stresses.

In 1959, we were hit with loss of five (5) B-47 aircraft because of turbine disk rupture. Also seven (7) other disk ruptures occurred, but the aircraft were able to return home. Naturally, various steps were taken to

minimize cooling air flow interruptions, but an equally important task was development of a method to segregate disks according to their time-temperature-stress history.

EXPERIMENTAL PROGRAM

Logically our first action was the examination of specimens from ruptured disks and intact disks with known histories. Several simple but significant facts were learned. They were:

(1) The AISI 4340 portion of the disk was more sensitive to time-temperature-stress events than the Timken 16-25-6 rim.

(2) The AISI 4340 material strength was being reduced without a visible manifestation of this change.

(3) A fair correlation between surface hardness and present tensile strength existed, but a hardness testing process is destructive in nature.

Armed with these conclusions we reviewed the available hardness sensitive nondestructive tools and selected an eddy machine for evaluation.

A review of eddy current technology will show their behavior, when induced in a test piece, is influenced by a number of test piece variables. These include geometry, surface condition and electrical and metallurgical properties. By observing this influence and comparing it with similar observations made during their flow through reference standards of known quality, the test pieces worth may be judged. The success of this type of inspection being limited by the testor's ability to suppress the influence of variables of no interest.

After selecting the eddy current method for inspecting turbine disks, we proceeded to manufacture reference standards having known amounts of strength loss. These standards were made by machining a number of paired specimens from virgin AISI 4340 material. One specimen was a cylinder two (2) inches in diameter and one (1) inch long. Its mate was a standard tensile test specimen having a one (1) inch gage length and a quarter (0.250) inch diameter. Large numbers of these paired specimens were exposed to temperature for varying lengths of time, thus simulating normal and abnormal engine conditions. The hardness was measured on one end of the cylinder and eddy current flow was induced in the other end of the cylinder and compared with the flow through an unexposed cylinder. Hardness of the tensile test specimen was determined and then its tensile and ultimate strengths were obtained by the usual destructive test. To simulate engine conditions, the tensile specimen was subjected to 750^{o}F soaking temperature during the test. The curve shown in Figure 1 was constructed from the data provided by these experiments. This curve illustrates the relationship of hardness, ultimate strength and relative eddy current machine readings.

Having obtained the relationship between relative eddy current machine readings and material strength, we began a pilot disk inspection program. This program taught us of the eddy current machine's need for a stable electrical power supply and the importance of allowing a turbine disk to reach temperature equilibruim with the inspection area's environment.

A major revelation of the pilot program was the necessity of not disturbing the disk's residual magnetism until after the eddy current inspection. By accident we learned that residual magnetism is part of a disk's time-temperature-stress memory complex. Any attempt to inspect a turbine disk after magnetic particle inspection produced erratic and impossible results. Demagnetization of a disk produced similar undesireable results. By inspecting the disks prior to any operation that affects residual magnetism, we were able to achieve the desired results.

Concurrently with the magnetism problem we learned that a satisfactory inspection could not be accomplished on disks damaged to the extent of visible change, such as cracking or severe cross section area reduction, usually referred to as neckdown. We attributed this to the presence of internal voids and discontinuities caused by the disk's deformation. Since our reference specimens did not contain these anomalies, a proper comparison was not being accomplished. Disks containing this degree of damage were obviously defective so no changes were made in our method.

Disks found unsuitable for engine use during the pilot program were destructively tested. In most cases, the destructive tests confirmed the eddy current evaluation. In those cases not confirmed, easy explanations were found such as inspector error. Upon the conclusion of the pilot program, the eddy current technique became a routine requirement for disks undergoing overhaul.

At the beginning of our lab experiments we selected a Budd Corporation RAD AC Model 150 as our eddy current machine. The choice was dictated by supply convenience, but fortunately it has proven to be a versatile, rugged and reliable performer. This type machine was used in the pilot program and is used today at the disk overhaul facility.

Since the pilot program, over 5,000 turbine wheel inspections have been accomplished. The contribution this inspection has made to J-47 engine reliability cannot be separated from the contributions made by various other measures taken at the same time. However, we were able to return to service disks with alleged time-temperature-stress damage having over $1,000,000 in value. This paid the costs of our program many times over.

PRESENT ACTIVITY

Our present activities are concerned with developing eddy current inspection procedures for J-79 turbine disks. Unlike the J-47 disks, these have a monolithic structure of A286. A286 is a corrosion and heat resistant, iron-nickel-chromium, non-magnetic alloy.

The J-79 engine is used in the F-4 and the B-58. To date the engine has not experienced any ruptured disks, but their operating time is limited. The time limit placed on these disks was determined by the manufacturer using theoretical calculations. Disks removed after reaching this time are visibly sound and destructive tests show little strength loss.

Many of the disks removed could continue in service if a nondestructive inspection method was available for ascertaining their strength condition. Using the laboratory methods described earlier, we have developed the relationships shown in Figures 2 and 3. With this information and additional lab testing we are attempting to predict remaining useful disk life. I should have additional results and data to report at the next annual meeting.

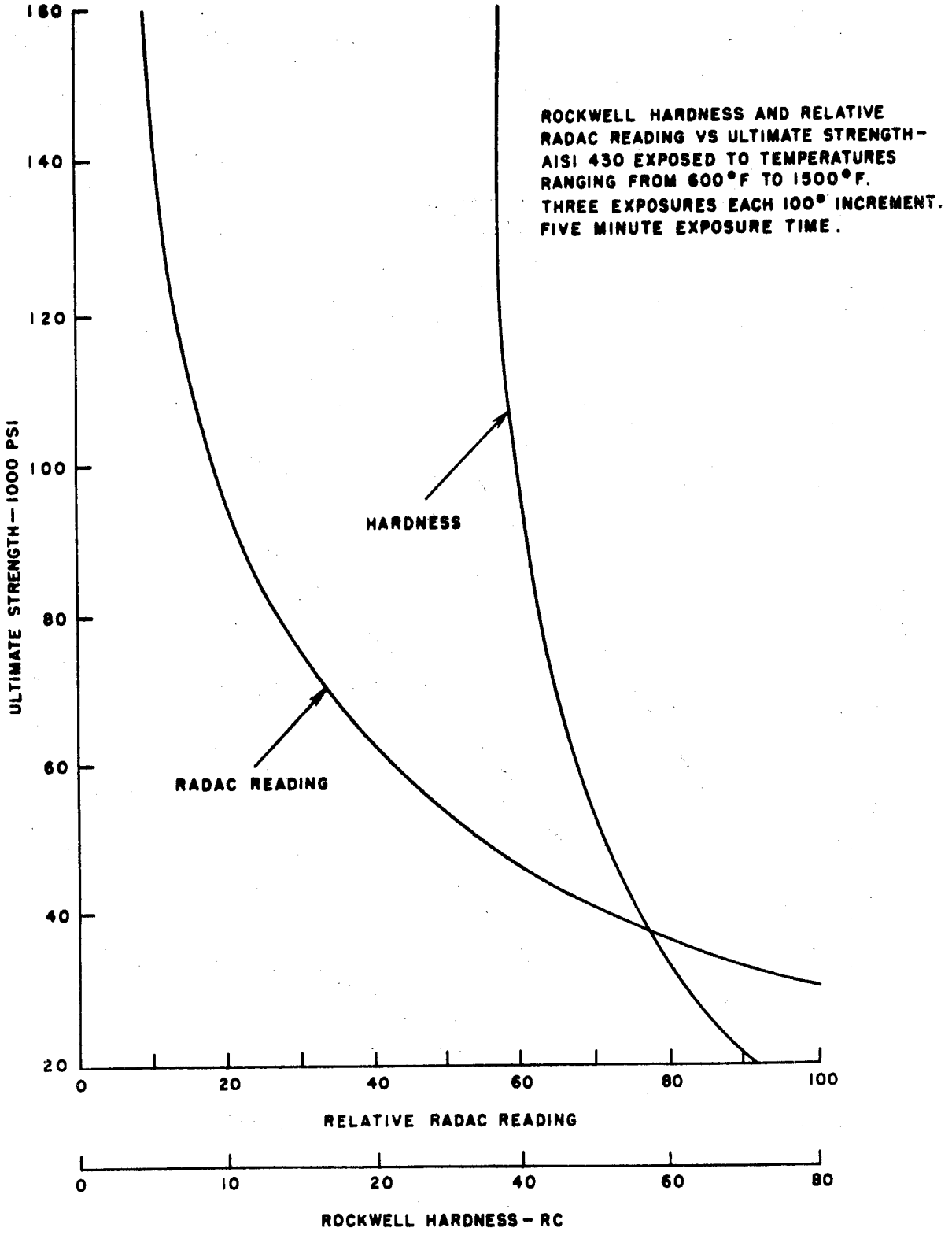


Figure 1. Rockwell Hardness and Relative Radac Reading vs Ultimate Strength

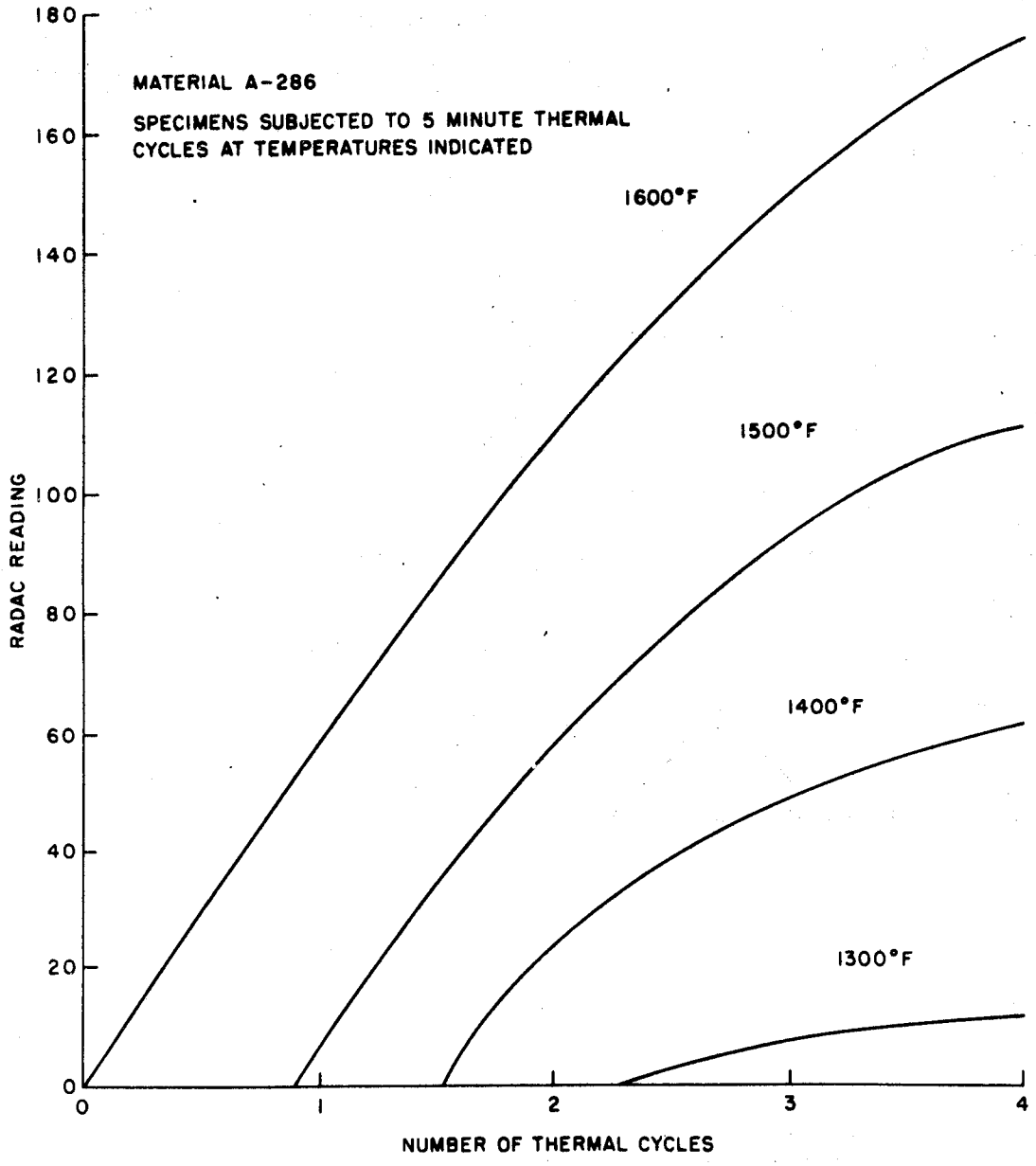


Figure 2. Number of Thermal Cycles vs Relative Radac Reading

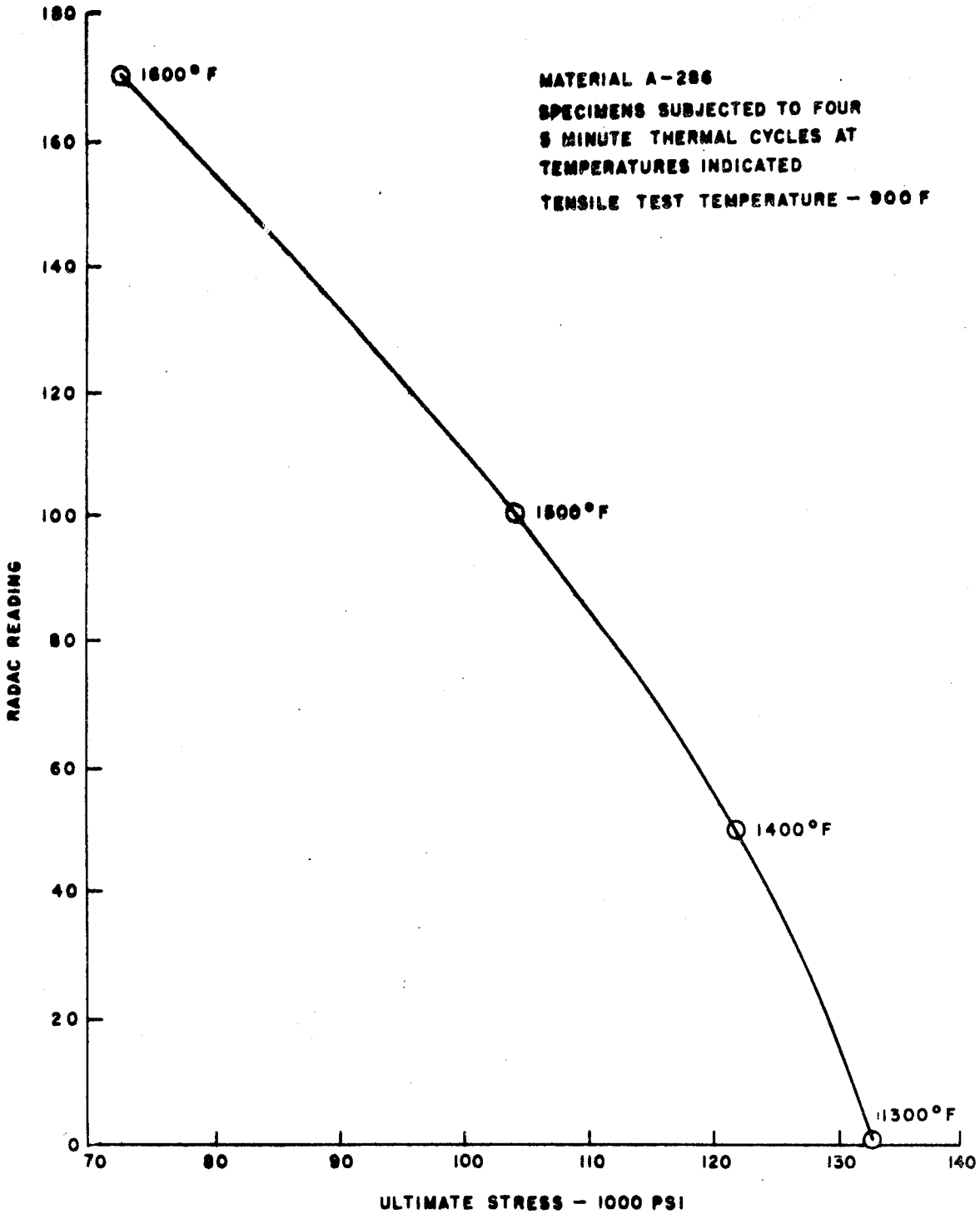


Figure 3. Radac Reading vs Ultimate Stress

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PAPER 2 - MICROWAVE NONDESTRUCTIVE TESTING

Theresa M. Lavelle
Frankford Arsenal
Philadelphia, Pennsylvania

INTRODUCTION

A laboratory test program was initiated at Frankford Arsenal with the prime objective of investigating the possibility of applying microwave techniques to nondestructive testing of dielectric materials. Microwave techniques are feasible because of their basic characteristics of reflection, scattering, absorption, and transmission by any non-metal, as well as interference effects from dielectric slabs. In the test program these characteristics are utilized to measure or detect thickness, flaws, lack of bond, and degree of cure. The main advantage of using microwave energy is that direct contact with the sample is not necessary. The program was conducted at two (2) frequencies 9.6 GHz (X-Band) and 35 GHz (KA Band). The higher test frequency, having an increased resolution was capable of detecting smaller flaws. The results of this test program and possible N.D.T. applications will be discussed in this paper.

LABORATORY TEST SAMPLES

The test samples were prepared with epon 828 and 815 resin with catalyst D. Today most pressure vessels and rocket motor cases are filament-wound glass fiber-resin structures. The epoxy resin used in preparing the test sample is representative of that epoxy used in the filament-wound pressure vessels. The dielectric constant for epon 828 and 815 resin varies between three (3) and four (4) depending upon the test frequency. This is a nominal figure which is characteristic of several plastics. Figure 1 is a picture of the various test samples.

THICKNESS MEASUREMENTS

Thicknesses of epoxy resin slabs were determined by monitoring either the energy transmitted or the energy reflected. This was accomplished by measuring the interaction between the front and back wall reflections. The phase difference between these reflections forms a standing wave pattern as shown in Figure 2. The reflected waves can be either in or out of phase depending

upon the path length through which the waves travel. When the path length, which is twice the thickness of the sample, is equivalent to $1/4\,\lambda$, or any odd multiple of $1/4\,\lambda$, the two (2) reflected waves are 180^{o} out of phase, cancelling each other. When the path length is equivalent to $1/2\,\lambda$, or any odd multiple of $1/2\,\lambda$, they are in phase, reinforcing each other. The waves emerging from the back wall follow the same pattern as the reflected waves from the front wall. The magnitude of the transmitted waves are smaller due to the absorption in the medium and the standing wave pattern is shifted an amount equivalent to the thickness of the sample.

The block diagram shown in Figure 3 is a typical bench experimental setup for thickness measurements at a test frequency of 9.6 GHz. Figure 4 is a picture of the equipment used in the reflection technique. Epoxy resin slabs were irradiated with a constant source of energy. The samples were placed on the open wave guide and the resulting D.C. voltage recorded. From these readings and the dielectric constant a calibration curve can be drawn as shown in Figure 5 in whatever units that are most practical. In practice the number of points plotted can be greatly reduced. However, by using a great number of points in the curve, a small thickness change of 1 mm can be detected using this method. The upper portion of the curve is interpolated to smooth out errors produced by the meter sensitivity. In actual testing the test frequency can be calculated so that the thickness to be inspected will fall along the steep slope portion of the curve. An important point to note is that these measurements are extremely sensitive to shifts in position. Changes in positions shift the entire standing wave pattern. A shift on the order of .005 inch between sample and source can cause as much as 60% error in the readings. It is not necessary to come into direct contact with the sample but the sample has to be mounted in such a fashion that the distance between it and the source remains constant.

DETECTION OF MATERIAL CHANGES

Microwave transmission techniques were used to detect changes in material properties, such as density and degree of cure. A combination of physical and chemical changes occur while the sample is undergoing the cure cycle. These changes manifest themselves in increasing dielectric constant and decreasing density.

The test frequency used in detecting density changes was 35 GHz. The samples tested were epoxy resin blocks 1.0" by 1.5" square. They were machined to a tolerance of .002 inch. The transmitted energy varied from block to block due to different sample density which is inversely proportional to the transmitted energy.

Figure 6 is a typical lab set-up which monitors the cure cycle of a sample. Transmission measurements at a test frequency of 9.6 GHz were used to determine degree of cure. An oven was used to speed up the cure process; otherwise more than 24 hours would be necessary to complete one (1) test.

The samples are epoxy resin blocks which vary in volume from 2.0 cu. inches to 20 cu. inches. They were irradiated with a constant amount of microwave energy. Before the curing process is activated, very little energy is transmitted through the material. Figure 7 is a typical cure cycle of epoxy resin. As the cure process begins, the amount of transmitted energy increases and continues to increase until the cure cycle is completed.

FLAW DETECTION

Thickness changes and material changes can exist in the form of discontinuities within a test specimen, such as voids and inclusions.

A useful way of detecting flaws is by utilizing the microwave scattering technique. Besides being transmitted and reflected, a portion of microwave energy scattered from a flaw is different from that scattered from a flawless portion of the sample.

Figure 8 is a diagram of the scattering set-up. The receiving horn is placed perpendicular to the transmitting horn. Theoretically, scattered energy can be detected at any angle. In addition to the scattered energy, stray energy is also detected which is divergent incident energy and energy bouncing from other surfaces. At an angle of 90^{o} these stray energies are at a minimum. The samples tested were blocks of epoxy resin with a glass sphere located at the center. The sphere diameter varied from 10 mm to 40 mm. Some of these spheres are hollow and some are solid. The hollow spheres simulate flaws due to air bubbles or voids while the solid beads simulate inclusions.

As can be seen in the diagram, the sample is irradiated with a constant source of energy at a test frequency of 9.6 GHz. A transformer was used to couple as much energy as possible into the sample. It acts as an impedance matching device by a gradual tapering of the same epoxy resin material as the test specimen. This cuts down the abrupt change in wavelengths in the guide, and in the test specimen. All four (4) faces of the sample were scanned. The energy scattered from a flawless sample was recorded. The flaws were then detected by comparing the energy scattered from a block containing a sphere with the energy from a sphereless specimen.

This experiment was conducted to determine if a flaw can be detected and what sizes can be detected. Figure 9 is a scan of four (4) faces with and without a flaw. It is easily detectable, but a correlation between flaw size and intensity of the scattered energy could not be determined. Besides scattering from the sphere there was energy scattered due to internal reflections. This can be shown in the variations of scattered energy from face to face. In fact, the sphere can be located such that the internal reflections would set up a destructive interference pattern, preventing the bead from being detected.

In addition to glass spheres, drilled holes were used to simulate cylindrically shaped flaws in the epoxy blocks. The magic tee reflection tech-

nique at 35 GHz which permits a greater resolution than at 9.6 GHz, was used to detect flaws varying in diameter from 5.8 mm down to 1.02 mm.

Figure 10 is a block diagram for the test set up used to detect these cylindrical flaws. The magic tee forms a tuned bridge system. Energy is transmitted through the sample at arm 2. The most striking feature about the "magic tee" is that if energy enters arms 1 and 2, their vector sum will appear at E and their vector difference at H. Therefore, the wave reflected from a sample will be compared with that from a sliding short. If both waves have the same amplitude and phase, a null will occur at the detector.

The samples tested were epoxy resin blocks 1.0 inches by 1.50 inches square and were machined to a tolerance of .002 inches. A cylindrically shaped flaw was simulated by drilling a hole through the center of the one (1) inch face. The system is calibrated by setting a null on a flawless sample. When you scan a sample containing a flaw a null no longer exists. There is a change in the reflected energy and this upsets the tuned condition.

LACK OF BOND

Another problem for which microwaves can be used is the detection of a lack of bond. The samples tested were filament-wound reinforced plastic with a rubber liner. Figure 11 is a picture of a typical sample. The plastic varied from 0.14 inches to 1.91 inches thick. The liner varied from .09 inches to 2.93 inches thick. The unbonded area between the plastic and rubber liner varied from .05 to 1 inch in diameter. The lack of bond was simulated by drilling flat bottom holes with a wide shoulder on which a plexiglass disc was glued. This disc prevented any adhesive from entering the hole during the bonding process.

The method used for detecting the lack of bond was the "magic tee" reflection method, previously described. The test frequency was 35 GHz. The sample was scanned by placing the sample on a table and tripod. This enabled complete freedom for scanning along any axis. Figure 12 is an example of typical scan on a sample containing an unbonded area. A null was established on a good portion of the test specimen. When an area of unbond was detected, an unbalanced condition existed. This can be seen by the change in the recorded reflected energy.

CONCLUSIONS

Some of the defects that affect the strength and reliability of filament-wound structures are improper cure cycle and shrinkage of epoxy resin, inclusions of foreign materials, lack of bond between the glass fiber filament-wound structure and the rubber insulator.

Microwave reflection and transmission techniques have been successful in measuring thickness to a resolution of .0393 inch in six (6) inches of epoxy

resin. Direct contact with the sample is not necessary and the reflection technique has the added advantage of requiring access only to one surface of sample. This technique can be used as a thickness gage for coatings on metal plates. It is recommended that the range of detectable coating thickness be determined.

The degree of cure of epoxy resin was determined by measuring the energy transmitted through the resin. When the samples were fully cured the amount of transmitted energy reached a constant level. The cure cycle was monitored continuously and at selected intervals. In each case the degree of cure could be determined by comparing readings with a calibration curve.

Density changes were detected by measuring the amount of energy transmitted through a sample. As the density increased, the transmission of microwave energy decreased. Density changes of .02 gm/ccm could very easily be detected.

Cylindrical flaws varying in diameter from 1.016 mm to 5.80 mm were detected using a tuned reflection technique.

Spherical glass beads varying in diameter from 20 to 40 mm have been detected by comparing the energy scattered by the spheres with the energy scattered from a sphereless block.

Microwave reflection methods have been shown to be useful in detecting lack of bond between filament-wound reinforced plastic and rubber liner. The lack of bond varied from .05 to 1 inch in diameter.

Based on the test results, it appears recommendable that microwave techniques be further investigated for the detection of even smaller flaws and areas of unbond than previously tested by using higher test frequencies (70 or 90 GHz) and perhaps by using sweep frequency techniques.

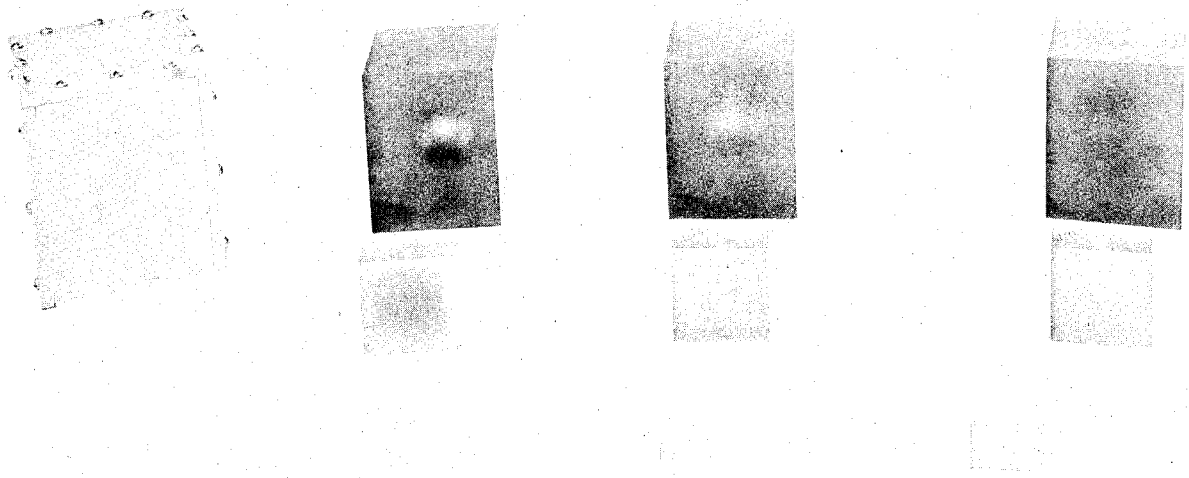

Figure 1. Laboratory Test Specimens with Test Mold

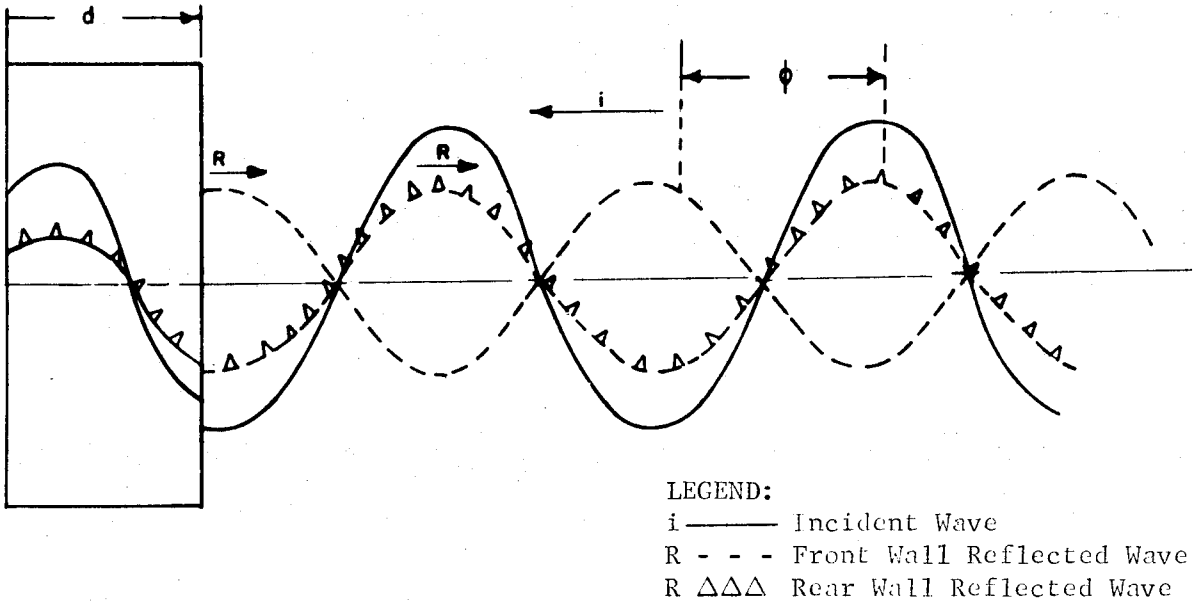

Figure 2. Standing Wave in Front of a Plane Dielectric Sheet

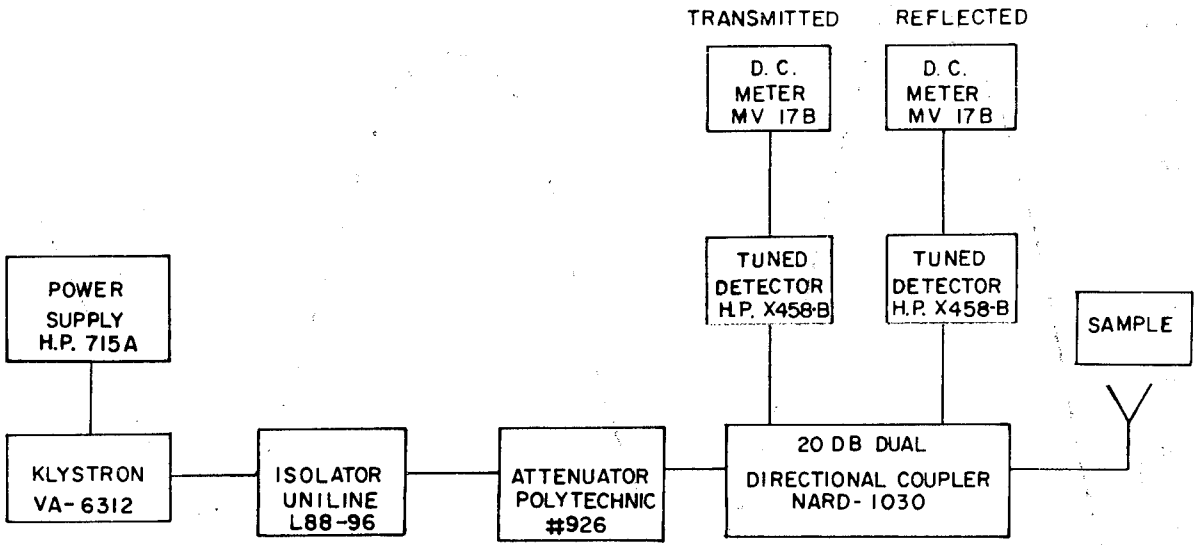

Figure 3. Reflection Method

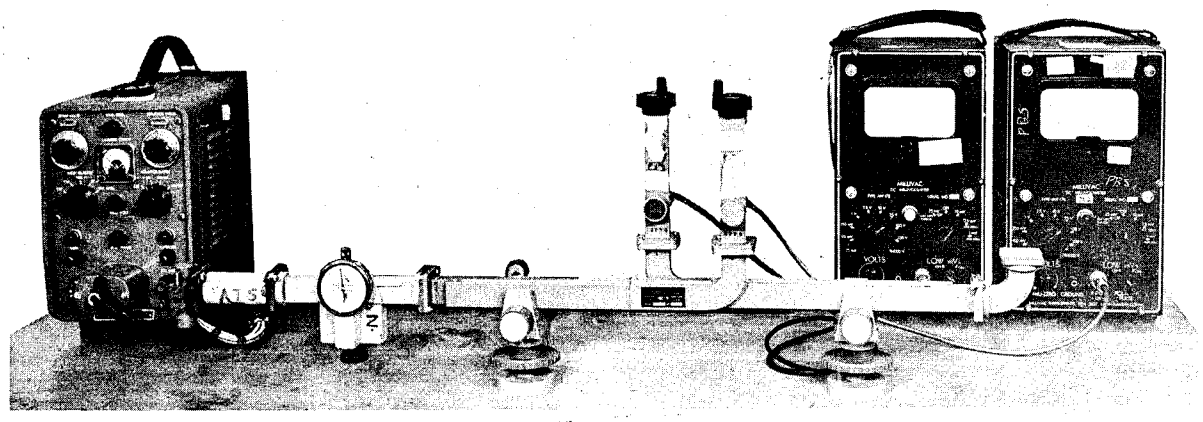

Figure 4. Arrangement for Reflection Method

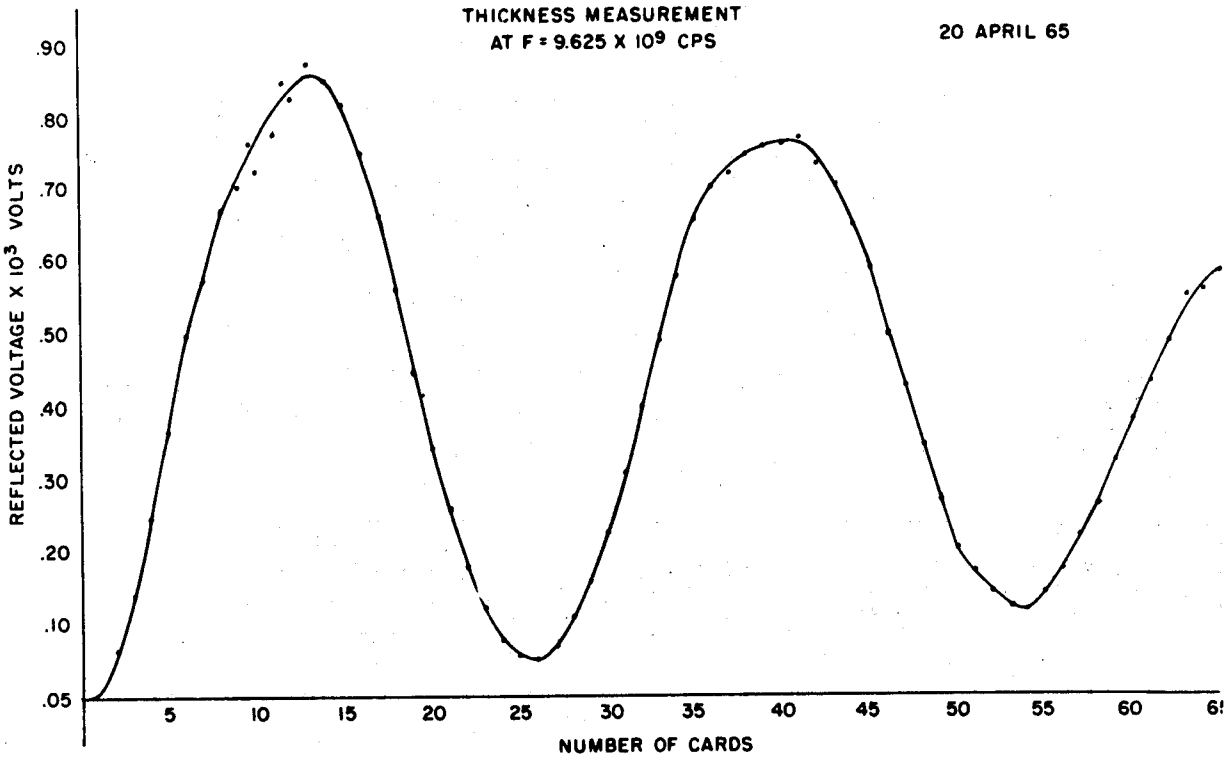

Figure 5.

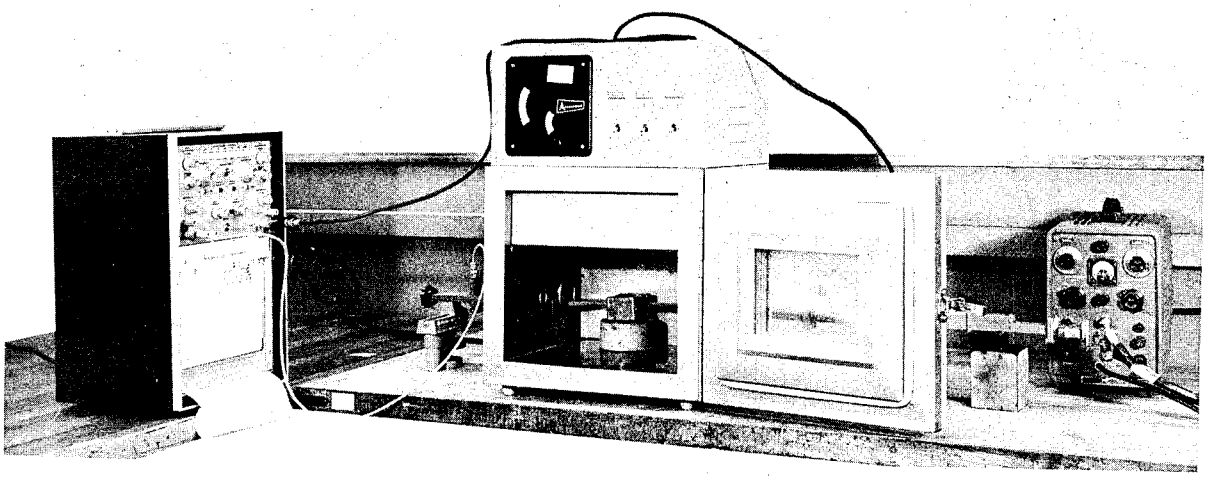

Figure 6. Arrangement for Degree of Cure

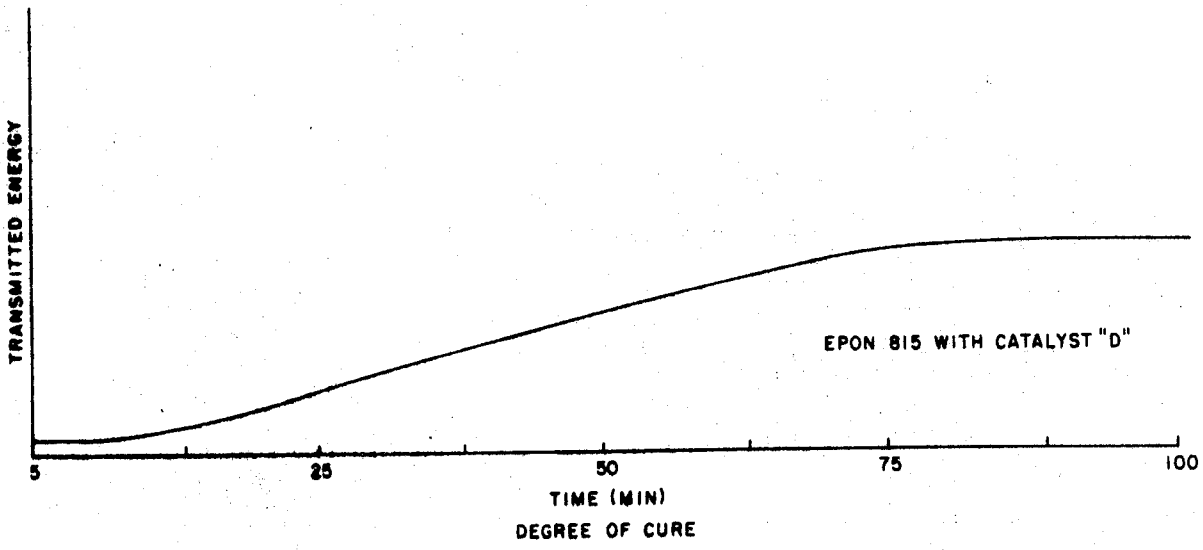

Figure 7.

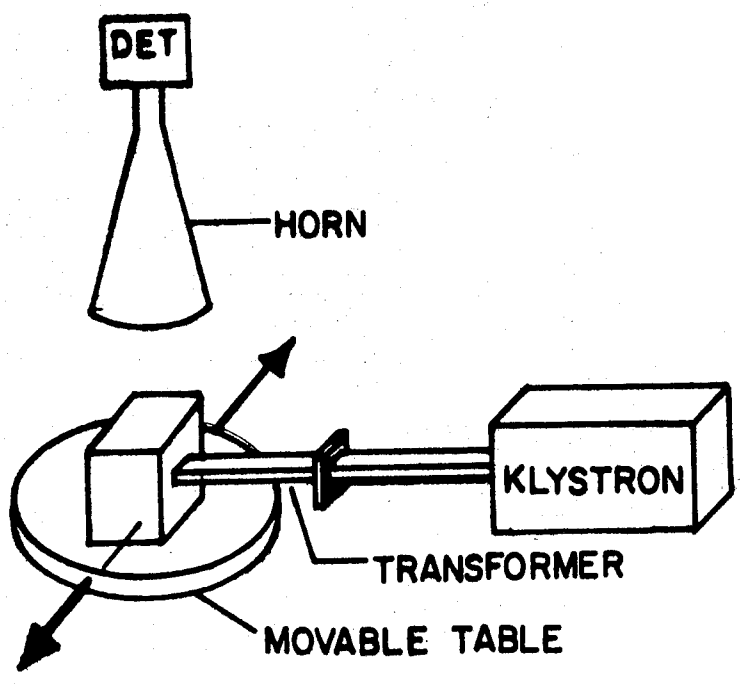

Figure 8. Scattering Arrangement

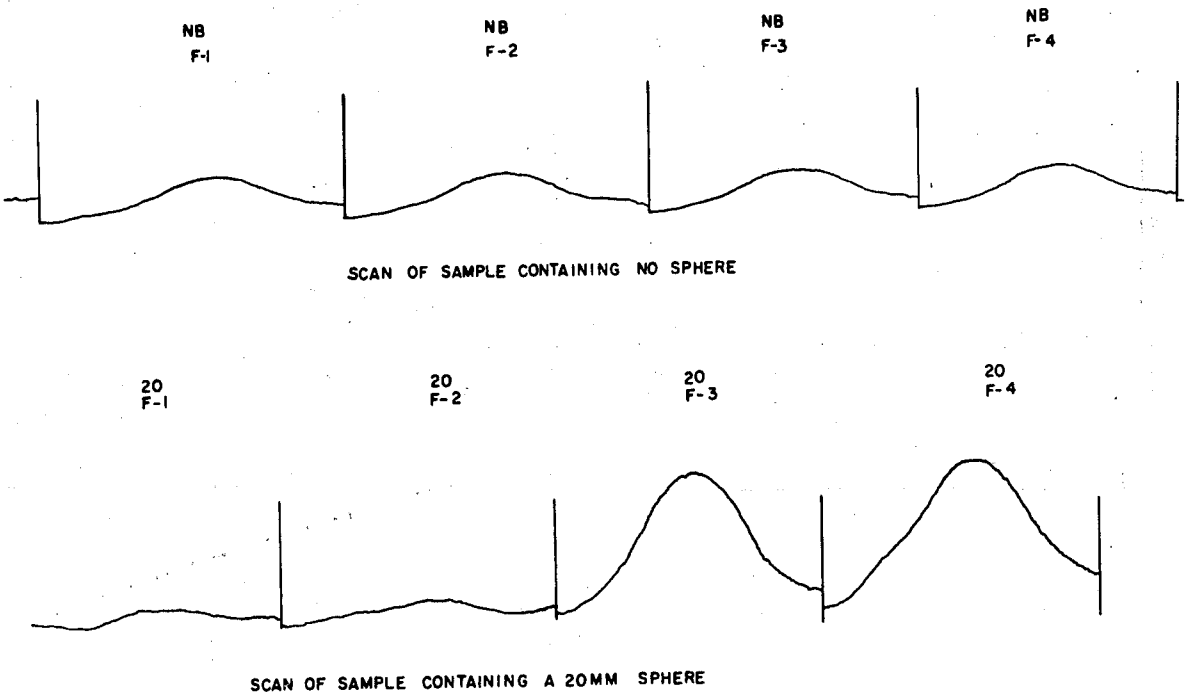

Figure 9.

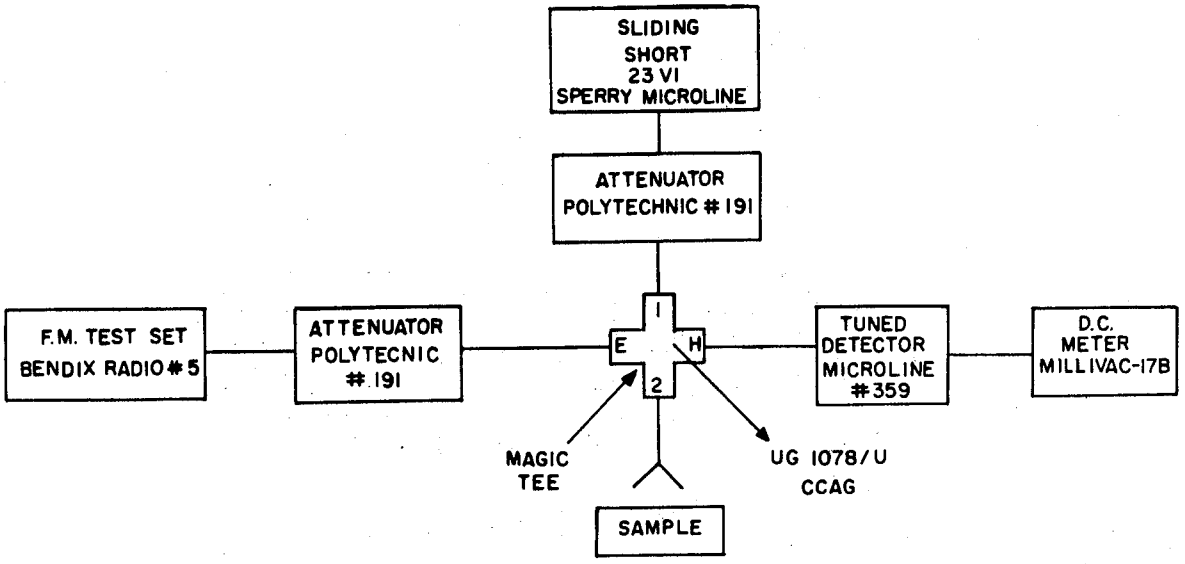

Figure 10. Magic Tee Reflection Method

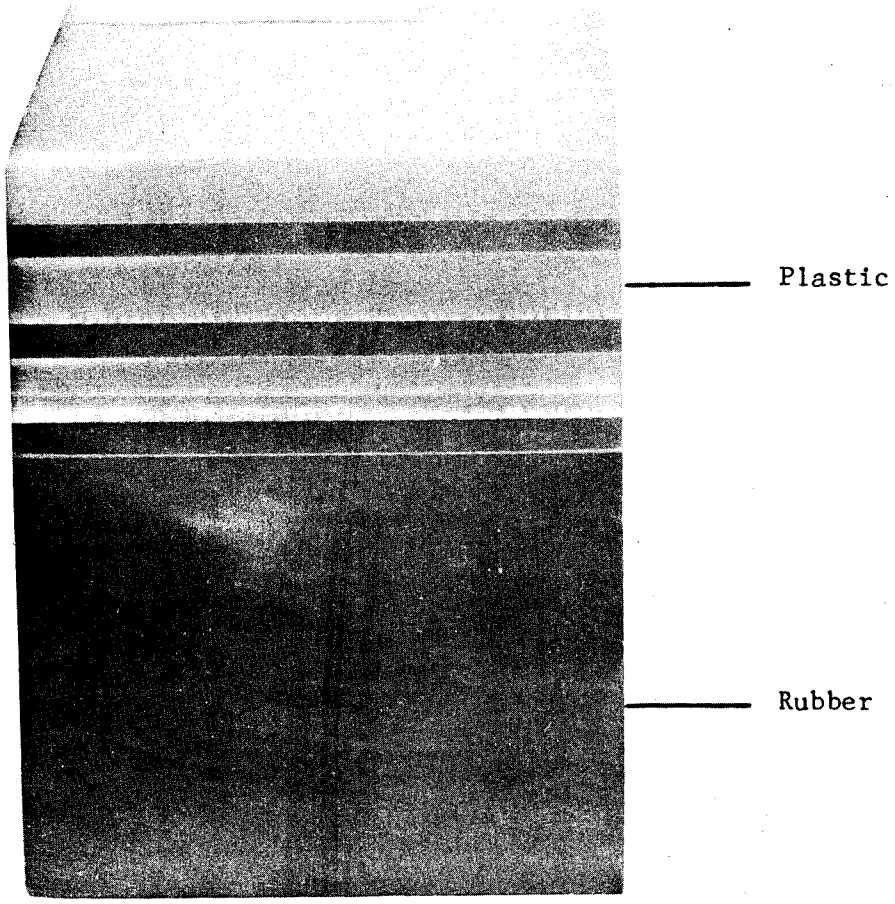

Figure 11. Filament-Wound Plastic with Rubber Liner

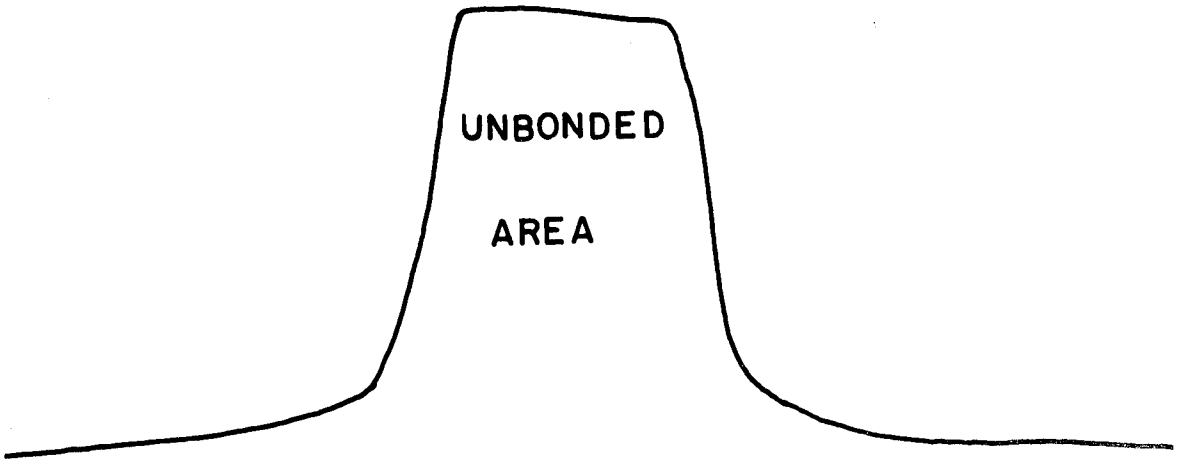

Figure 12. Scan of Filament-Wound Plastic Sample

PAPER 3 - INFRARED MULTIPLE-SCAN BOND INSPECTION SYSTEM

Mr. Paul E. J. Vogel
U. S. Army Materials Research Agency

ABSTRACT

This report describes the experimental development of an infrared multiple-scan system for inspecting bond integrity or other material characteristics that influence infrared radiation. It includes a description of the detector head, chopper, amplifier, switcher and related instrumentation.

INTRODUCTION

An experimental investigation conducted by the U. S. Army Materials Research Agency aiming at an effective one-sided infrared test system has been reported previously.* On the basis of that work, it appeared feasible to consider the use of a larger number of detectors in order to provide faster inspection of larger specimens.

The development of a multiple-scan prototype was conducted by the Applied Physics Branch of the U. S. Army Materials Research Agency, aiming at a device that would be sensitive, light-weight and portable, and which would include a display system that would allow immediate comparison of the infrared emission of adjacent areas.

EQUIPMENT

The experimental development resulted in a system shown schematically in Figure 1. The system employs no optics other than a fused quartz filter. As it is intended for rapid identification of gross flaws, the target area of each detector is a 1/4" diameter circle with the detector head 1/4" from the specimen. Each field of view overlaps the adjacent detectors at a range of 1-inch. Although the detector response changes because of heat-up over an extended period, no temperature control is incorporated in this

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* AMRA TR 63-14, Infrared Bond Defect Detection System, Gericke-Vogel, September 1963.

prototype because all cells elevate fairly uniformly and the comparative output characteristic of the system continues. Cooling the detectors by discharging R-12 refrigerant across them to atmosphere was tried roughly and this method appears feasible. It will be incorporated using a 2-lb cylinder, flexible hose, and an adjustable restrictor to keep the detector head portable.

DETECTOR HEAD

The detector head, Figures 2 and 3, consists of an aluminum body having ten parallel 1/4-inch holes bored on 1/2-inch centers from the face to the back. A 1/2-inch shaft, slotted longitudinally and blackened, penetrates the body perpendicular to the holes to provide simultaneous chopping of the entering radiation, and to provide a common reference. The chopper is directly driven by an 8,000 rpm series motor with the speed controlled by a variable transformer to give a maximum a-c signal of 266 cps. At the back of the detector head, ten lead sulfide photoconductors are embedded one at each boring in a silicone rubber adhesive which provides a secure mounting medium, some measure of protection from shock and vibration, and strain relief for the detector leads. Above each detector is a shielded compartment containing the load resistor, power supply terminals, and output connector to the amplifier. To assure a uniform voltage to all cells and to maintain system warm-up, one 90-volt battery continuously supplies the bias voltage. The detector head and chopper motor are rigidly connected and the assembly can be handheld to scan. The head is connected to the amplifier package by shielded cables. This cable bundle would be bulky for use in a production item, and would be replaced by a more compact loom. No thermal noise is evident from these carriers when they are flexed. The chopper shaft concept is sound and the frequency is ample for prototype purposes, however, the particular design gives a very brief period of exposure to the impinging radiation. The period is being equalized to the reference exposure in another shaft configuration that will provide square-wave modulation and a higher chopper rate. A fused quartz filter having high transmittance in 0.8-2.3 micron range is mounted on the face of the detector head.

AMPLIFIER

The amplifier package is presently in bread-board form and consists of ten individual transistorized audio-frequency amplifiers each having separate input and output cables, batteries, and on-off and volume controls. This arrangement of the amplifiers provides compensation for minor variations in the operating characteristics of the detectors and other components and allows balancing of the ten sub-systems to a common radiation reference. With the outputs balanced to the weakest signal, the amplification is sufficient to give an optimum trace on the Techtronic Type 564 oscilloscope at a mid-range setting of 0.1-volt/division. Plug-in accessories being used with the oscilloscope are a 3A72 amplifier and a 3B4 time base.

SIGNAL SWITCHER AND TRIGGER

A relatively simple mechanical rotary switcher, Figure 4, was designed to sample each signal every two seconds, and the make-before-break contact arm dwells on each input for 0.2 seconds. The switcher is direct-driven by a 30 rpm gearhead motor. A normally-open cam operated microswitch is mounted on the rotary switch to trigger the sweep at the start of the input from the first detector.

DISPLAY

The display was made on the oscilloscope mentioned which has a storage feature useful in verifying the reproducibility of the signals. The sweep was delayed to about two seconds with a vernier adjustment made to compensate for a slight switcher motor drift.

The principal feature of this multiple scan is the ability to compare ten signals almost simultaneously, or to be more precise, in two seconds. Triggering and sweeping as stated before, each of the 10 signals sequentially occupies one of the ten grids of the CRT face, i.e., the No. 1 detector repetitively displays in the first grid square, the No. 2 detector in the second square, and so on through the entire display. The storage scope holds an image which is somewhat fainter than the beam trace so that changes in amplitude in successive scans can be recognized.

At this sweep rate, an interesting effect can be obtained, providing fine adjustments are made in the focus and astigmatism, by slowing the chopper motor speed so as to display anything from a solid signal down to four or five individual cycle traces for each detector. Any slower cyclic rate becomes erratic because the chopper motor begins to overload at about 500 rpm.

EXPERIMENTS

One experiment is shown here to portray the response of this system. The specimen is the one reported in the referenced paper, and it consists of a 6-inch OD steel cylinder with 1/8-inch wall thickness with a 1/8-inch liner and a 2-inch simulated propellant with hollow core and a first and a second interface longitudinal bond flaw.

The detector head was held tangent to the cylinder and at an angle of approximately 30° so that moving at 0.9 in./second the flaw remained under the detector head for the two seconds required for the switcher to display each signal. In this attitude, and with the center detectors about 1/8-inch off the specimen, the end detectors were 1/2-inch off the specimen and had overlapping fields of view. The specimen was rotated under a heat source until the surface temperature reached about 70°C. The defect indications were obtained as shown in Figure 5. The equal traces of detectors #1, #2 and #9, #10 result from their overlapping views and lower amplitudes by being more distant from the flaw. Detectors #3, #4 and #7, #8 indicate

rising and falling amplitude respectively in accordance with their proximity which was of an order to preclude overlap. The peak amplitude of #5 and #6 shows these to be the nearest to the specimen.

This experiment shows the relationship between proximity and amplitude in this system, the zeroing of all detectors, and the sequential display of the individual detectors in one trace. The visualized use of the system, however, would have all detectors equidistant from the specimen which would be swept with the head to provide a comparative display. The flat face of the head could be shaped to conform to various symmetrical contours and with appropriate detector spacing would give the same type display.

CONCLUSIONS

The results of this experimental investigation indicate that the multiple scan system, in a more refined package, would offer a simple, inexpensive, and effective nondestructive testing tool that can furnish a meaningful display to a semi-skilled user.

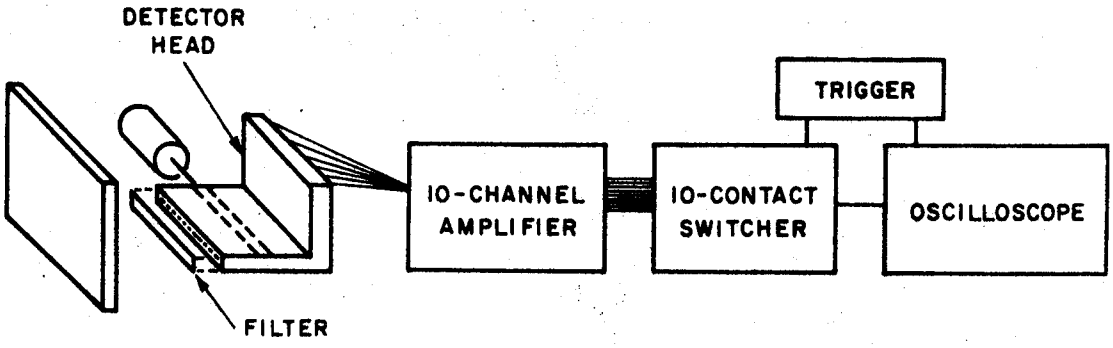


Figure 1. Multiple Scan System

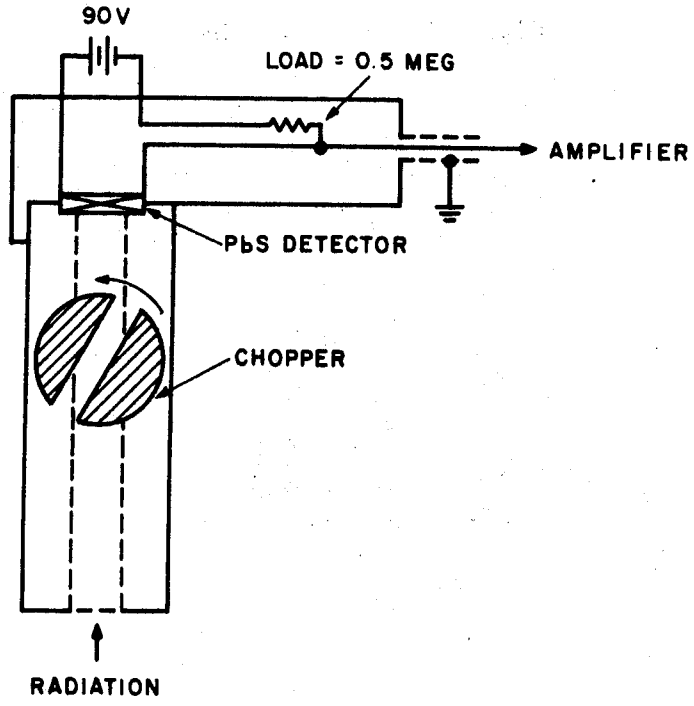


Figure 2. Detector Head Section

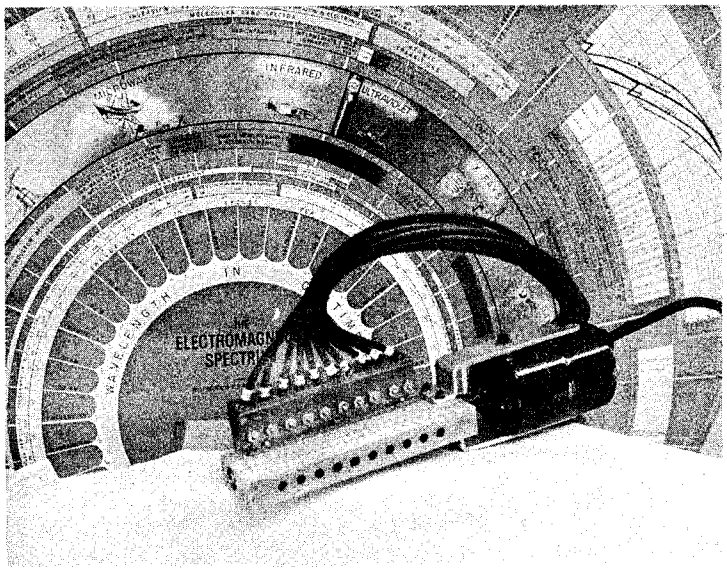


Figure 3. Detector Head

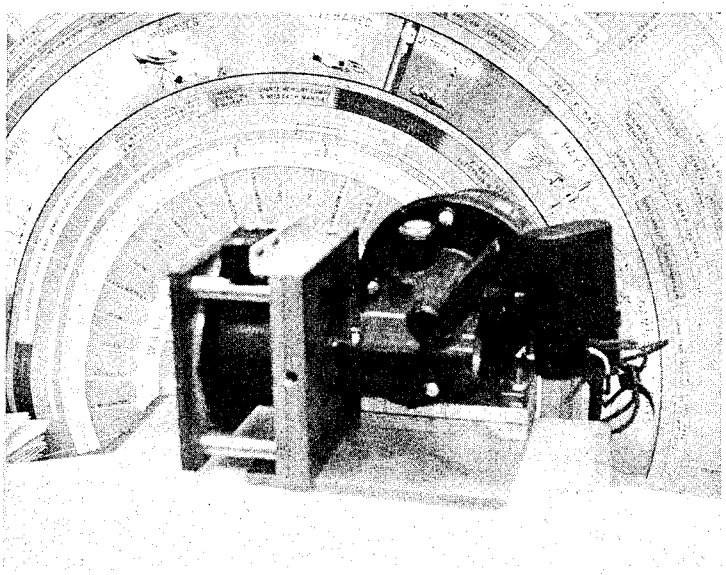
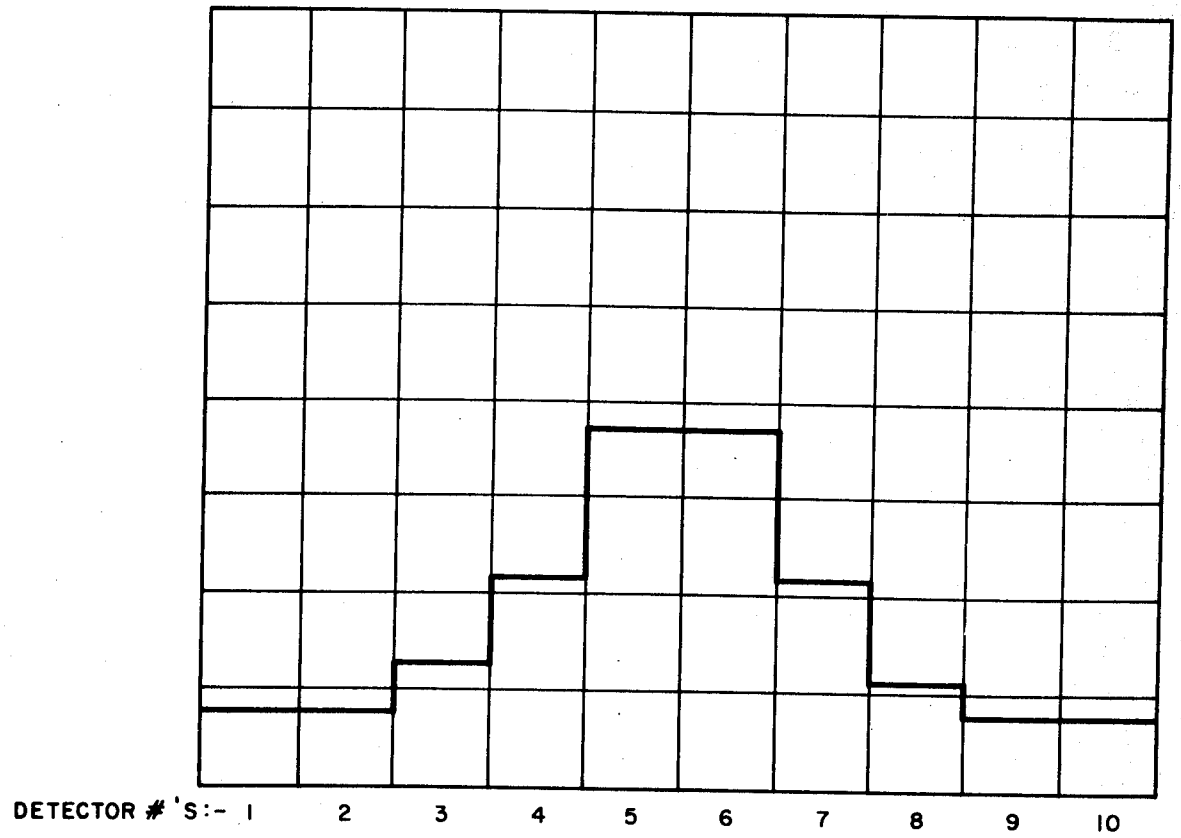


Figure 4. Switcher



10 - DETECTOR DISPLAY
(2-SECOND SWEEP)

Figure 5.

PAPER 4 - AN IMPROVED METHOD FOR INSPECTING SOLDER CONNECTIONS

Mr. Shelton Washington
Picatinny Arsenal
Dover, New Jersey

SUMMARY

During the past year, Picatinny Arsenal has been attempting to develop a nondestructive technique for inspecting solder connections which may have considerable merit in military applications. It is the aim of this program to examine the feasibility of applying a nondestructive testing technique to solder connections which will indicate whether or not heat was properly applied and therefore the instant and future condition of the joint. The nondestructive test involves use of a soft solder composition with a suitable phosphor having the desired thermal-luminescence qualities to make ultraviolet examination of the solder joint a useful indication of its mechanical and electrical performance at the time of inspection and at future times. A particular phosphor is introduced into the flux of a suitable soft solder composition used for soldering of connections. This phosphor will have to have, among other qualities, the character of possessing luminescent properties which are quenched if the joint is raised to a certain optimum temperature. In use the joint would be soldered, using such a composition, and then examined under ultraviolet light to see if the quench temperature had been reached. If the flux residue around the joint fluoresces, this is a positive indication of insufficient heating. If the flux residue does not fluoresce, then adequate heat was supplied. Use of this technique in production will allow the inspection of assemblies rather than individual soldered connections, reducing inspection man-hours substantially.

INTRODUCTION

The importance of soldering in our everyday life can scarcely be overstressed. It is one metallurgical operation that is probably known better and practiced, more or less aptly, by more people than any other. Perhaps of greatest interest to us now, among the many applications of solder, is the use of solder in making electrical connections in circuits and instruments. With the tremendous present and potential growth in automation and instrument-controlled devices in our defense systems, the need for

billions of tight, dependable connections is apparent. Moreover, the performance of any given military system and these many controls is literally at the mercy of any one of its many connections. Soldering can easily be the weak link in a chain of complicated equipment if it is not done properly. With the continuing trend toward mass soldering operations additional emphasis has been put on developing more efficient and more fool-proof methods of inspecting solder joints.

THE COLD JOINT PROBLEM

There is evidence that a good number of equipment failures in critical and costly military systems may be attributable to an improper type solder connection commonly called a "cold solder joint". Improper joints of this type can cause changes in circuit impedances which could have a deleterious effect on system performance. Some connections may actually open, causing catastrophic failure of the system. One of the principal causes of such faulty connections is improper application of heat to the surfaces to be connected. In proper hand-soldering technique, the soldering iron tip must be applied to the surfaces being joined in such a manner that maximum heat will be transferred through the joint to the solder while still protecting the wire insulation and neighboring components that might be adversely affected by excessive heat. Good soldering technique demands that the joint forming the connection be heated, and the heat from the joint melt the solder. Since the flux in solder has a lower flow temperature than the solder has, it will flow across the joint with a cleaning action which removes any dirt, oxidation, or other foreign deposit which may hinder proper wetting. As the solder itself melts, it melts a thin portion of the parts being connected, and this melted portion blends with the solder alloy to form a new alloy made up of the solder alloy and the small liquidus amount of the parts being joined. The resultant connection possesses excellent electrical and mechanical properties. When, however, poor heating techniques are used, joints with poor electrical and mechanical qualities result.

Present methods of detecting faulty solder joints that can have drastic consequences in system operation consist of visual and probing type inspection. A visual inspection of a cold joint might reveal poor heating techniques by the chalky appearance or the rough piled-up surface of the solder fillet. The usual probing technique is to pry the joint with an ordinary orange stick or other mechanical probe to detect mechanical looseness. Besides being ineffectual, probing can result in too much force being applied so that the act of inspecting can actually cause damage. Another problem is that the wires or components may be displaced so that they rest against adjacent terminals or sharp edges which might damage the insulation. It should also be noted that neither the visual or probe technique will reveal incipient flaws due to poor heating techniques which may worsen during use when vibration is encountered, to the point where actual faulty operation results.

THE PROPOSED SOLUTION

During the past year, the Quality Assurance Directorate of Picatinny Arsenal has been attempting to solve the cold joint problem by developing a new nondestructive technique for inspecting solder connections. The nondestructive test involves use of a soft solder composition with a suitable phosphor having the desired thermal-luminescence qualities to make ultraviolet examination of the solder joint a useful indication of its mechanical and electrical performance at the time of inspection and at future times. The basic idea of this technique is to introduce a particular phosphor into the flux of a suitable soft solder composition used for soldering of connections. This phosphor will have to have, among other qualities, the character of possessing luminescent properties which are quenched if the joint is raised to a certain optimum temperature (the most favorable temperature for good soldering, for example). In actual use the joint would be soldered, using such a composition, and then examined under ultraviolet light to see if the quench temperature had been reached. If the excess flux residue around the solder joint fluoresces, this is a positive indication of insufficient heating. If the flux residue does not fluoresce, then adequate heat was supplied. The flux then, when used in soldering electrical connections would provide a means, by its fluorescence or lack of fluorescence, of determining that the proper soldering temperature had been reached.

This program came about as a result of an invention by Mr. Peter L. Krohn of Mohawk Industries, Inc., of Easton, Pennsylvania. Mr. Krohn developed a soft solder composition which includes a soft solder having a solidus temperature of 361°F, a suitable flux for said soft solder, and a sufficient amount of a phosphor which will cause the composition to luminesce when the composition is exposed to ultraviolet light prior to being heated to a temperature of above about 361°F, but which will decompose upon the composition being heated to a temperature of above about 361°F. Utilizing this basic concept, Picatinny Arsenal has embarked on an extensive research and development program, through a contract with Mohawk Industries, to perfect a suitable composition and a testing technique which can be put to practical use on military systems.

Use of a solder composition of this type in production would allow the inspection of entire assemblies rather than individual soldered connections, thus reducing inspection man-hours substantially. The successful outcome of this program might provide a method that will take less than 10 percent of the time taken by present methods of inspecting electrical connections for defects of cold soldering.

Soldering and luminescence are very diverse fields. Each process is quite complex, and entire volumes may be written on each. Before discussing the progress made on our program, a brief discussion should be made on the basic principals involved in both soldering and luminescence; in order that the reader may get a better appreciation of the goals of the program and of the problems encountered while attempting to reach those goals.

SOLDER, SOLDERING AND FLUXES

Solder is an alloy of two or more metals (or, less frequently, it may be a pure metal), which when melted, is used to join metallic surfaces through the phenomena of wetting. Wetting is the ability of a liquid to form a continuous film on a solid surface.

Pure metals transform from liquid to solid to liquid at one temperature; alloys, however, may melt over a temperature range. Soldering with alloys or metals that melt below 800°F is termed soft soldering, and it is with soft solders that we are concerned. Any series of alloys can best be observed by showing the relationship of chemical composition to melting characteristics, and, this information may be presented in the form of a phase diagram.

The most commonly used solders are alloys of tin (Sn) and lead (Pb). The tin-lead phase diagram, Figure 1, then, may well be used to illustrate both general properties of solders, and specific properties of this alloy series.

Figure 1 shows graphically the phase changes of all alloys of the tin-lead series. The diagram can be divided into three sections: (1) the area below the line ABEC, which represents the alloys of tin and lead in solid solution; (2) the area inclosed by ABECDE where solid and liquid exist together in a semiliquid, or plastic, state; and (3) the area above AED where the alloys are in a liquid state. The temperature at which a change in phase (solid, plastic, or liquid) begins is indicated at the right side, and the alloy composition is indicated at the top of the diagram.

The phase diagram, then, provides the following information:

1. The highest temperature at which any given alloy, in the series being observed, is completely solid; this is the solidus temperature, and is sometimes referred to as the melting point.

2. The lowest temperature at which any given alloy, in the series being observed, is completely liquid; this is the liquidus temperature, and may be referred to as the flow point. Soldering temperatures are normally about 100°F above the liquidus temperature.

The tin-lead phase diagram shows that:

1. Any alloy of tin and lead which contains over 19.2 percent tin begins to melt (enters the plastic range) at 361°F. As the percentage of lead rich or tin rich alloys increase, from point E in Figure 1, the temperature range over which the alloy is plastic also increases.

2. The alloy containing 63 percent tin and 37 percent lead (E, Figure 1) does not have a plastic range, but changes sharply from liquid to solid on cooling (or solid to liquid on heating) at 361°F. Any alloy which changes

from solid to liquid (and vice versa) without going through a plastic phase is called an eutectic alloy. In the tin-lead series this 63 percent tin--37 percent lead alloy also has the lowest liquidus (flow) point of all the tin-lead alloys.

There are many types of solder and each has its specific use. The type normally used, for hand soldering, in electrical and electronic equipment is a mixture of tin and lead known as "type 60/40". The first number indicates the percentage of tin and the second number the percentage of lead.

All common metals are covered with a nonmetallic microscopic film known as an oxide, which forms an effective insulating barrier that prevents metals from touching each other. As long as this nonmetallic barrier is present on the surface of the metals, the metals themselves cannot make actual metal to metal contact, and as a result, intermetallic solvent action (soldering) cannot take place. It is the function of the soldering flux to remove the nonmetallic oxide film from the surface of the metals and keep it removed during the soldering operation, in order that the clean free metals may make mutual metallic contact.

The flux must be thermally stable at the soldering temperature. While the temperature of activation should be below the melting point of the solder, the temperature of inactivation must be well above the solder melting point. The fluxing action should, at the temperature of soldering, lift the oxides from the base metals and flow these oxides away from the joint while at the same time protecting the exposed surface from further oxidation until the surfaces are wetted by the molten solder. As the solder flows around the joint, the dihedral angle of thermo-dynamic equalibrium in wetting should be as near zero as practical to obtain. An angle of 180^{o} indicates nonwetting while an angle less than 75^{o} is considered satisfactory (see Figure 2).

Flux does not constitute a part of the soldered joint; after soldering; the flux residue, still retaining its captured oxides, lies inert on the surface of the soldered joint. The flux for use on electronic equipment must not have a corrosive effect upon the metals.

On this program we have been concerned chiefly with nonactivated water white rosin and mildly activated water white rosin. These fluxes meet the requirements of Specification QQ-S-571d and MIL-F-14256C.

CONCERNING LUMINESCENCE

Luminescence is most conveniently defined as the radiation emitted by a molecule, or an atom, after it has absorbed energy to go to an excited state. The duration of emission is greatly dependent upon processes by which energy can be stored over long periods of time. This storage phenomenon is responsible for the persistence of emission in certain

materials long after excitation is removed, an effect called phosphorescence - as opposed to fluorescence, which authorities like to define as light emitted only while energy is being applied.

Fundamentally, luminescence is a simple process. Consider a hydrogen atom. At regular temperatures, its single electron will be in a state of lowest energy - a statement one can take to mean the electron is traveling in its smallest orbit around the nucleus. If the atom is excited - say by absorbing a photon of light, then the electron will be driven up to a higher energy state representable as an orbit further removed from the nucleus. The excited atom is unstable in this state, and after a short time the electron - without any external stimulus - will ultimately drop back to its original energy level, giving off a photon of reduced energy and, hence, of lower frequency, resulting in visible light.

There are relatively few natural objects in nature that luminesce. The reason for this is simply that the world is not composed of atoms so isolated from one another than the absorbed energy can only be dissipated as photons. As soon as we depart from low-pressure monatomic gases and consider the polyatomic molecules in liquids and the atoms in solids we are confronted with a competing way in which the absorbed energy can be used - namely, to increase the rate and amplitude of the atomic vibrations. Increasing the vibrational energy of the system raises the temperature and cuts down the amount of energy available for light emission.

Over many years it has become clear that luminescence can only occur efficiently in materials where there are special atomic or molecular sites in which the absorbed energy can be emitted by means of optical electron transitions rather than be dissipated as increased atomic vibrational energy. In solids these so-called luminescence centers may be impurities, such as the copper ions that replace a fraction of a percent of the zinc ions to give zinc-sulfide (ZnS) its familiar green emission.

One generally accepted theory of fluorescence that here suits our purpose follows closely the concepts of semiconductor physics. The light emitted from phosphor crystals may be attributed to the return of an electron to a luminescence center. As an example, consider zinc-sulfide, with the addition of copper, as a phosphor. (Pure ZnS crystals will not emit visible light when exposed to ultraviolet excitation.) The luminescence center of the ZnS crystal is in the immediate vicinity of a copper ion within the crystal. Ordinarily, these centers have electrons associated with them in a normal (unexcited) state. When exposed to ultraviolet light of the proper wave length (about 3350 Å), the electrons become excited (due to energy absorbed from the light) and leave the center. In place of the electron, we now have an electron hole (see Figure 3).

When the electron returns and recombines with the hole, energy is given up in the form of light at a visible frequency (a longer wave length). This is because the conversion is not 100 percent efficient and the loss of energy results in the lower frequency.

Note at this point that, if the impurity ion of copper had not been added, the frequency shift upon recombination would not be great enough to be useful to our purpose. The jump of an electron to the conduction band from the valence band in a pure ZnS crystal and back again would not give up enough energy to cause the frequency shift required.

The impurities added are sometimes referred to as activators. Most metals are satisfactory activators and all else being equal, the frequency of the emitted light will depend on the metal or metals used.

Prevailing theory holds that the activator (copper in this case) forms localized energy levels within the natural forbidden energy levels of the ZnS crystal. These new levels are the levels of the luminescence centers of the phosphor. When copper atoms contained in these centers absorb ultraviolet light, their electrons are also excited to the conduction band. The electrons lie above the original ZnS valence band and ultraviolet radiation of longer wave length will raise the center electrons to the conduction band.

Actually, this is an oversimplification of the luminescence process. A little thought at this point reveals that no visible light is any more likely to be emitted by the return of these electrons than by electrons in pure ZnS. This flaw in the whole theory has been neatly overcome by some experts in this field by assuming the presence of "traps" just below the conduction bank which capture the electrons (see Figure 4). It then is the electron transition from trap to center level that causes the light emission.

For a more detailed treatise on the quantum mechanics of luminescence, References 1, 2 and 3 are recommended.

PROGRAM PROGRESS

If any nondestructive test is to be valid, there must first be established the quantitative relationship between the test parameter being measured and the fault which this indirect measurement indicates. In other words, preliminary specifications must be set up to relate the fact of luminescence or no luminescence to a bad solder joint. This is a double-barreled requirement. First the relationship of heat to fault must be established and then the relationship of luminescence to heat. The former can be obtained by controlled experimentation, while the latter has been established by Mr. Krohn's invention (which has been patented).

Prior to our research program, the invention (adding a phosphor, that would lose its luminescence when heated, to a soft solder) was merely a laboratory curiosity. The intent of the program was to perform a sufficient amount of basic research into the fields of luminescence and soldering in order to develop a practical nondestructive testing technique for the examination of solder joints.

At the very outset of the program, it was realized that several barriers would have to be met and overcome in order to develop a useful nondestructive test. Following are some of these problems and questions that presented themselves:

1. What is the relationship of heat to fault in soldering?

2. What is the exact relationship of luminescence to heat?

3. Of the tens of thousands of luminescent chemicals available, which ones would suit our purposes?

4. The proper heat quench temperature would have to be established.

5. The phosphor additive must not alter the mechanical or electrical condition of the connection.

6. Any residue left by the process must not have deleterious effects on the wire, insulation, or surrounding area.

7. The process itself must not be a fungus nutrient and it should not in itself be toxic.

8. Under oxidation, which might occur during heating, the process must not give off toxic gases in concentration or amounts which would be injurious to workers.

9. The phosphor chosen should be relatively inexpensive and amenable to chemical production techniques.

10. The overall testing process must be simple and straightforward enough for average inspectors to handle.

One of the first activities to be carried out on the program was the determination of the type of fault created by improper heating techniques. Initially, a short literature search was made and consultations with some leading government and industry reliability engineers were held. It was determined from these that there is a direct relationship of heat and heat dwell time of a solder joint to the subsequent mechanical properties of the joint. This is shown dramatically in test results carried out under an Army contract (Reference 7). Referring to Figures 5 through 8, you will note that the solder temperature of 450°F almost always yielded a poorer solder joint than did a temperature of 600°F.

There were additional findings resulting from the search of technical literature applying to the question of inadequate heating of solder joints. Some of these findings are listed below:

1. It is estimated that 80 percent or more of the missile failures can be traced to faulty solder joints.

2. The proper temperature of the leads being joined should be between 370°F and 625°F - depending on the job at hand and the solder composition.

3. There are several reasons for poor solder joints - contamination of the joint by foreign objects, film, etc., poor solder flow, improper amounts of flux, poor mechanical arrangement of the joint before soldering and probably of most importance, insufficient heat of the junction.

In general, the first few weeks of the program were spent gathering as much information as possible on the phenomena of fluorescence and the theory of soldering. Numerous books and publications were reviewed and several consultations were made, both in person and via telephone, with experts in these fields.

After determining that work similar to that which we were planning on doing had not been done in the past, the laboratory equipment necessary to the program was ordered. Several chemical suppliers were contacted and sample quantities of fluorescent compounds were obtained.

During the month of July 1965, actual laboratory testing of chemicals began. Twenty (20) different chemicals were checked, by themselves and in compounds, for their fluorescent properties before and after deposition on tinned copper substrates - also before and after heating to soldering temperatures. Sixty-eight (68) different combinations were tested and a few showed promise. Appendix 1 contains a partial list of the chemicals and test results of this period. (Because of the large volume of data involved, it was decided to include only a representative list of the test results. This practice is followed in each appendix.)

The testing continued through the remainder of the summer and into the fall of the year. Hundreds of fluorescent chemicals were reviewed and/or tested. By September 30th, over 600 chemical compounds were thoroughly investigated for possible application. Of these, nineteen (19) were chosen and purchased for experimental work.

It became evident early in the program that the number of chemicals requiring investigation would be quite large. Therefore, it was necessary to develop a set of guide lines to apply to the chemicals. These guide lines were designed to narrow our field of endeavor to the actual requirements for compatibility with the tin-lead soldering flux systems. These guide lines are shown below:

1. Melting point or permanent heat quenching of fluoreseent properties should be a nominal 500°F. Range of 475°F (245°C) to 525°F (275°C).

2. Chemical, in amounts normally used in the flux system, must be nonhazardous in any form to humans.

3. Must glow brightly under ultraviolet excitation at frequencies from 3660 Å to 2537 Å, preferably at 3660 Å. Should be dull colored or colorless or of different color under normal interior illumination.

4. The chemicals constituting the fluorescent substance shall not be corrosive in the quantities normally used - either in short term or long term application.

5. The fluorescent chemicals must not become a part of the tin-lead solder alloy or shall not alter the tin-lead alloy characteristics.

6. The chemical must dissolve or disperse in alcohol normally used in flux.

7. Will be used on a tin-lead alloy substrate.

8. Should be organic, without traces of any metal (particularly; aluminum, zinc, copper, arsenic, iron, bismuth, silver, antimony, nickel).

Within the framework of these guide lines, the investigation of chemicals continued. Approximately 1600 fluorescent chemicals had been reviewed and/or tested by October 30th.

In October, an ultraviolet optical system was constructed to cover the heat source used to determine heat quenching temperatures, with the ultraviolet source mounted so that samples could be observed while undergoing test.

Without going into great detail, it was noted during this period that many fluorescent chemicals demonstrate different degrees of fluorescence in flux and alcohol. It was determined that the degree of fluorescence, under ultraviolet excitation, depends, in many cases, on the fluorescent chemical concentration in the flux. Work was started in this area to determine the optimum concentration for the results desired. Appendix 2 is a chart showing some of the results obtained in the heat quench test.

The original test method employed for observing heat quench was to drop the compounded flux mixtures on the cold surface of a hot plate and bring the temperature up slowly, noting the temperature at which the fluorescent properties were destroyed. As it turned out, this method was the wrong method because time, as well as temperature, played a large part in determining the fluorescent properties of the flux; that is, a flux mixture on the hot plate might extinguish at 200°F after 10 minutes but might also retain its fluorescent properties at 500°F if exposed for only 10 or 20 seconds. At this point the test method was changed. The hot plate was now brought to a temperature of 500°F and the flux, with the fluorescent chemicals compounded therein, was dropped on the hot surface while continuously exposed to ultraviolet radiation, and the quenching effect of the heat was noted.

A great number of flux mixtures were tested in this manner and a very disturbing property or characteristic presented itself. Upon cooling, the flux would again regain its ability to fluoresce under ultraviolet radiation. Further investigation demonstrated that it was the inherent property of the rosin itself that was causing the trouble. In other words, the fluorescent chemical added to the flux may or may not have quenched at our combinations of time and temperature.

It was known that 500°F ± was probably the optimum temperature for soldering. Therefore, it was essential to develop a method that would not only quench the fluorescence of the chemicals added to the flux, but one that would also quench the inherent fluorescent property of the flux. This was a very formidable problem which resulted in several weeks of research and testing.

It seemed at the time that the most logical thing to do would be to get rid of either the fluorescent property of the basic flux or find a way to destroy the secondary emission. Noting that the light was emitted from the blue region, it was decided to incorporate a yellow dye, picric acid. The results were promising; that is, the yellow dye did absorb most of the inherent radiation of the flux. After noting these results, a program was instituted whereby yellow dyes were thoroughly researched.

During the early months of 1966, several hundred chemicals and dyes were reviewed and tested. Also, during this period it was decided to perform some experiments with solid rosin flux. Heretofore, only a liquid type flux had been used.

PRESENT STATUS

Judging from the results of the experiments completed to date, it appears that a prototype of a workable product has been developed. Mohawk Industries has produced the first flux, in what seems to be a family of fluxes, that quenches in the desired manner. The flux was developed using appropriate fluorescent compounds in a solid rosin flux (solid at room temperature) of the type incorporated in the core of tin-lead alloy solder. The flux itself (without additives) possesses inherent fluorescent properties that preclude its use without treatment of special additives. Furthermore, the optimal amount of additives and the best method of combining them with the flux have not as yet been determined.

The details of the latest experiments will not be given in this report, but will be published at the end of the program.

We are now in the third, and last, phase of the program. During this phase it is hoped that a flux combination will be perfected.

The solderability of solder joints will be tested using the most promising compounds developed in this phase, and those found acceptable will be labeled for use in manufacturing quantities of core solder for test and evaluation.

The flux developed will be used to solder joints that shall be subjected to tensile tests in which the strength of a bond connecting two bare copper wires shall be measured. Flux samples effecting acceptable solder joints shall be incorporated into the core of 60/40 solder. Sufficient quantities of the core samples shall be produced for field testing, probably at Government installations.

Should the results of field tests prove encouraging, environmental tests shall be conducted. Temperature, humidity and accelerated aging tests will be made on a sufficient number of sample joints. Chemical analysis of the flux residue shall be made in order to determine its properties and the products (vapors and gases) resulting from the soldering process.

If this program is successful, the resulting test procedure could save hundreds of thousands of dollars per year in inspection time, and more important, could result in improved reliability. Millions of dollars have been wisely spent on component reliability via inspections, quality control procedures, accelerated life testing, examination of the physics of failure, and statistical examination of Mean Time Between Failures, etc. The weak link in this reliability chain might very well be a weak solder "link". It is hoped that this program will result in the improvement of the reliability of soldered connections.

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APPENDIX I

Partial Results of Tests Performed in July 1965

Tests were run in order to determine the feasibility of using fluorescent materials as an indicator of temperature attained during soldering process.

Flux mixtures were prepared by saturating a solution of alcohol at room temperature, then adding the solution to white rosin flux.

No.	Chemical	Co.	On Tin/Lead Substrate When Mixed w/Flux
1	S-Amino-2, 3-dihydro-1, 4-phthalazinedione Residue	Kodak	Blue
2	Eosin Y Residue	Kodak	Weak Orange
3.	Acridine No Residue	Kodak	
* 13	Chrysene Does not appear to dissolve or disperse	Baker	
* 16	Eosine YB High Conc. Lumps up - Leaves Residue	GAF	Weak Orange
* 21 to 40	Nos. 1 to 20 mixed with flux #196 (Kester)	The items showing promise when examined are further developed in subsequent compounds	
41 to 60	Nos. 1 to 20 mixed with flux #135 (Kester)		
61	#135 Flux and phenanthrene - heated (No extra alcohol) Great improvement over 30 and 50 in brightness		Whitish
* 65	15, 61 and 64 mixed (Off-white color - very bright heat quenched - comes back as faint orange) (Looks promising)		Yellowish Very bright

No.	Chemical	Co.	On Tin/Lead Substrate When Mixed w/Flux
68	67 diluted in #135 flux - works quite well (Additional phenanthrene added to increase brightness) Quenches completely at 400°F (permanently)		Yellowish Very bright

NOTES:
1. For those items without comment, the fluorescent properties were too weak to note.
2. The type of flux seems to have no effect on fluorescent properties.
3. The fused polycyclic hydrocarbons such as phenanthrene appear to have the brightest fluorescence in proper concentration.
4. Number 61 appears to improve other fluorescent materials.

NOTE: * These chemicals intentionally omitted. Chemicals that are listed are representative of the entire quantity.

APPENDIX 2

Partial Results of Heat Quench Test

Chemical and Flux Room Temp. Observation	250°F	300°F	350°F	400°F	450°F	500°F
Experimental Luminescer L29, PL-65-62 (Cyanamid) in Alpha 100 WW Rosin Flux, M.P. 302°C #127 Blue Fluorescence	Some slight dimming	Very dim. Recovers slightly on cooling	No fluor. Very slight recovery on cooling	No fluor. Very slight recovery on cooling	Complete quench. No recovery on cooling	
Saturn Yellow T-17 (Switzer) in Alpha 100 WW Rosin Flux #128 Green Fluorescence	Some slight dimming	Dimmer - went out after 1/2 hr. Recovers somewhat on cooling	No fluor. No recovery on cooling			
Aurora Pink A-11 (Switzer) in Alpha 100 WW Rosin Flux #129 Red Fluorescence	Some slight dimming	No fluor. No recovery on cooling				
Rose Pink (Pylam) in Alpha 100 WW Rosin Flux #135 Slight Pink Fluorescence	No fluor. No recovery on cooling					

Chemical and Flux Room Temp. Observation	250°F	300°F	350°F	400°F	450°F	500°F
Orange Red R103G114 (Radiant) in 2-Propanol #114 Bright Red Fluorescence	Bright red fluor.	Bright red fluor.	Bright red fluor.	Decreased red fluor.	Dim red fluor. Recovers to brighter orange red on cooling	Very faint red fluor. Recovers to brighter red on cooling. 550°F. Extremely faint indication of fluorescence. Some slight recovery on cooling
Tinopal PCR (Geigy) in Alpha 100 WW Rosin Flux #139 Pale Blue Fluorescence	Dim blue fluor.	Very little fluor. Some recovery on cooling	no fluor. very little recovery on cooling	No fluor. No recovery on cooling		
Tinopal RBS 200% (Geigy) in Alpha 100 WW Rosin Flux	Blue fluor.	Reduced blue fluor. Some recovery on cooling	Extremely faint fluor. Some recovery on cooling	No fluor. Very little recovery on cooling	No fluor. No recovery on cooling	
Tinopal 4BM Conc. (Geigy) in Alpha 100 WW Rosin Flux #143 Blue-Green Fluorescence	Blue-green fluor.	Reduced blue-green fluor. Some recovery on cooling	No fluor. Faint recovery on cooling	No fluor. No recovery on cooling		
Flural 7GA (G.A.F.) in Alpha 100 WW Rosin Flux #146 Pale Yellow Fluorescence	Very dim yellow fluor.	Extremely dim fluor. fluor. Very slight recovery on cooling	No fluor. Very slight recovery on cooling	No fluor. No recovery on cooling		

APPENDIX 3

Partial Test Results of Compounds

Tested With Solid Rosin Flux

Sample A-2. Experimental Luminescer, L-29, manufactured by American Cyanamid mixed with solid flux. (The solid flux has been labeled as sample No. 914 and will be referred to as simply "914" henceforth.) A bright blue-white glow radiates from the fluxed substrate but does not quench completely with heat.

Sample A-3. 7-Diethylamino-4-Methylcoumarin mixed with 914 displays a bright blue-white fluorescence, but does not quench without abnormal heat and time.

Sample A-4. Tinopal ANA, mixed with 914, does not exhibit a bright enough glow and hence was discarded without heating.

Sample A-5. Phenanthrene mixed with 914 glows bright blue, - does not quench properly.

Sample A-6 Eosin Y mixed with 914 exhibits a dull rust color glow. Discarded without further testing.

Sample A-7. Eosin Y and Tinopal, equal parts, mixed with 914. A bright rust color glow results but does not quench in a satisfactory manner.

Sample A-21. Uvitex SIA Conc. mixed with 914 results in no fluorescent glow at all.

Sample A-22. Rhodanine mixed with 914 results in a fire orange glow. When subjected to soldering operation, a partial to full quench is achieved.

Sample A-23. Eosine YB Hi Concentrate mixed with 914 results in a full orange glow that does not quench when subjected to soldering heat.

NOTES: 1. Flux was melted at temperature at 250^{o}F and then mixed with fluorescent chemicals.

2. After solidifying, the flux compound was smeared on a tinned copper surface and observed under ultraviolet radiation at a wave length of 3360 Å.

3. Copper strip was then heated to soldering temperatures, allowed to cool, and then once again observed under ultraviolet source.

4. Samples A-1 and A-8 through A-20 intentionally omitted.

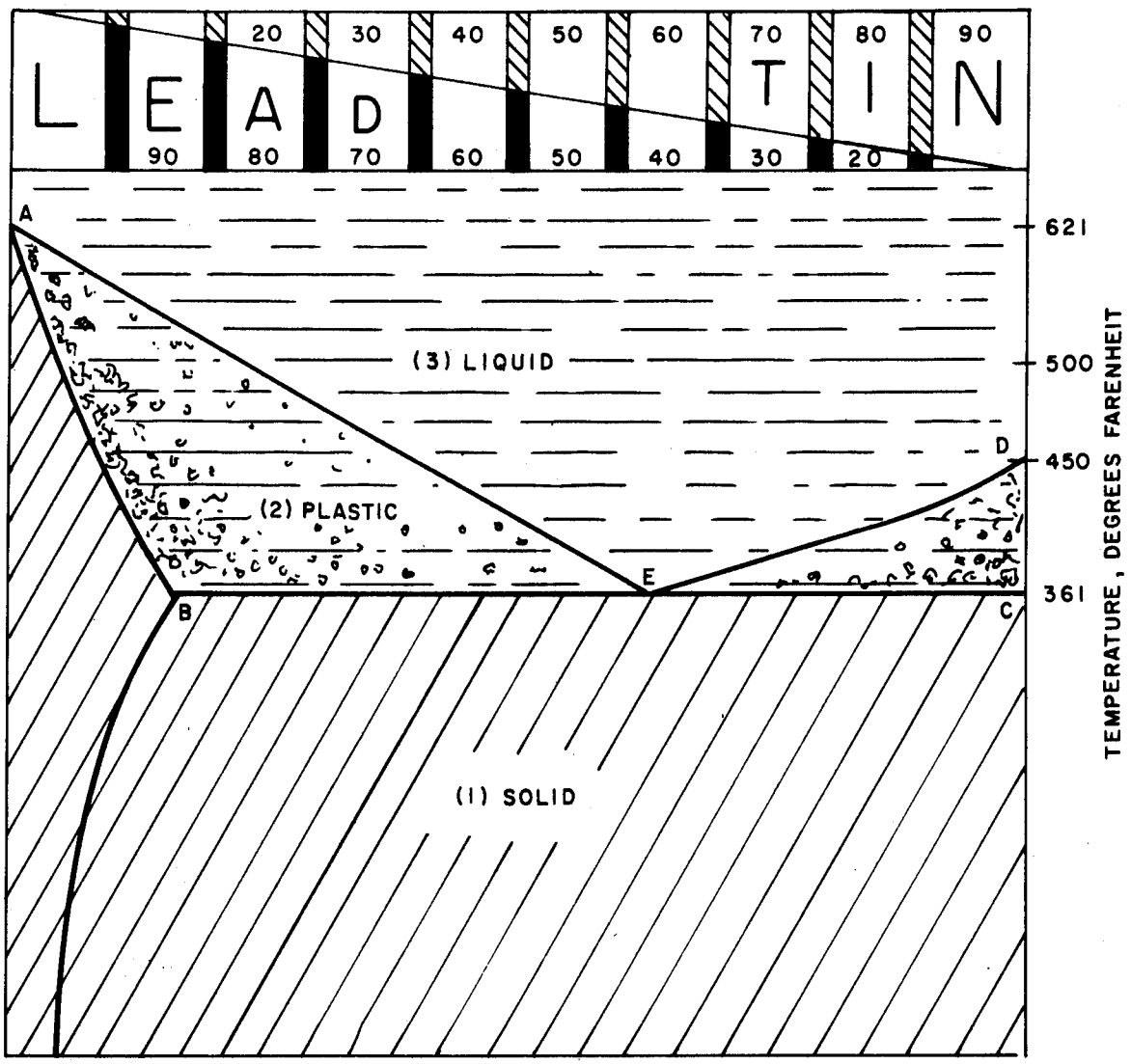


Figure 1. Tin-Lead Phase Diagram

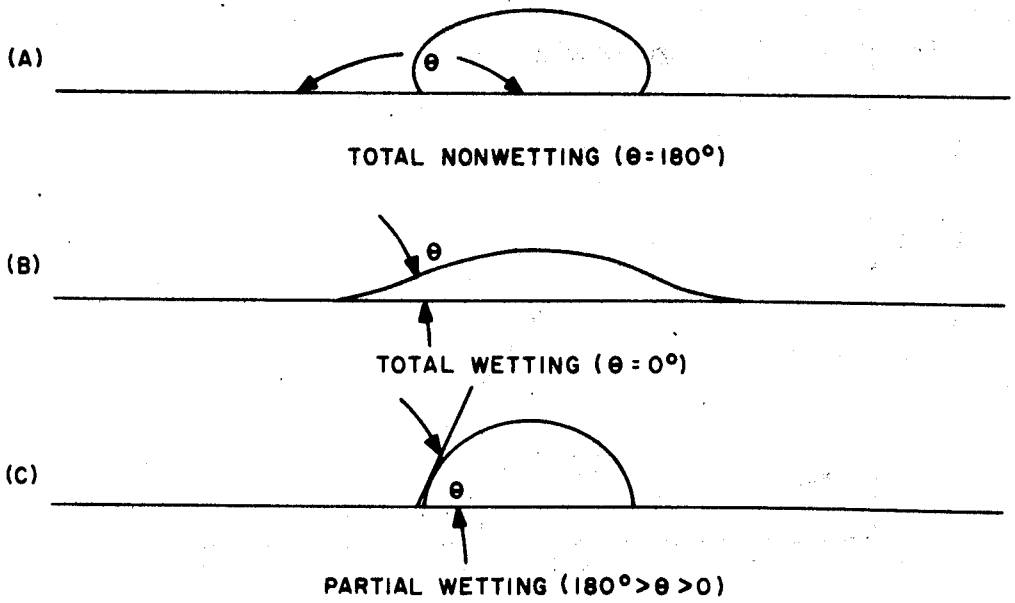
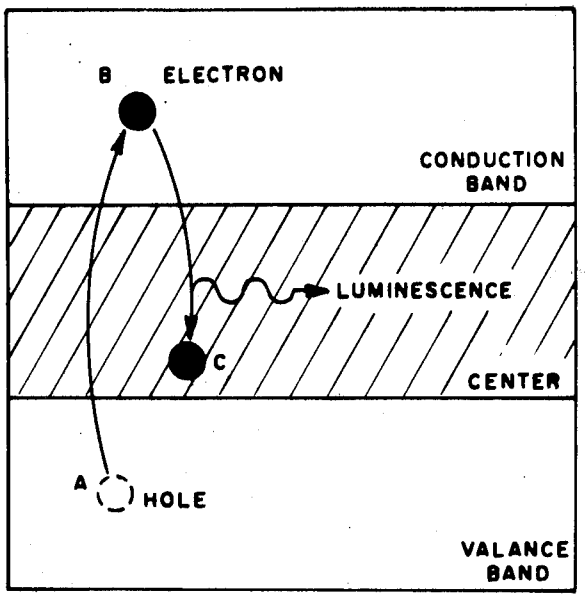


Figure 2. Relation Between Dihedral Angle θ and Degree of Wetting.



1. Electron becomes excited by ultraviolet light and is kicked from valence band to conduction band, A to B.

2. Electron returning to hole, giving up visible light (luminescence) in the process, C.

Figure 3. Luminescence Process in Zinc Sulfide

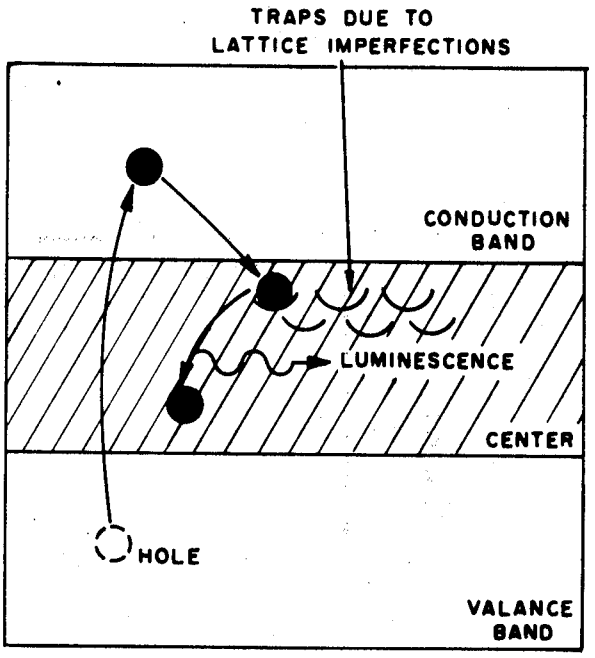


Figure 4. Luminescence Process in Zinc Sulfide (Showing Trap Action)

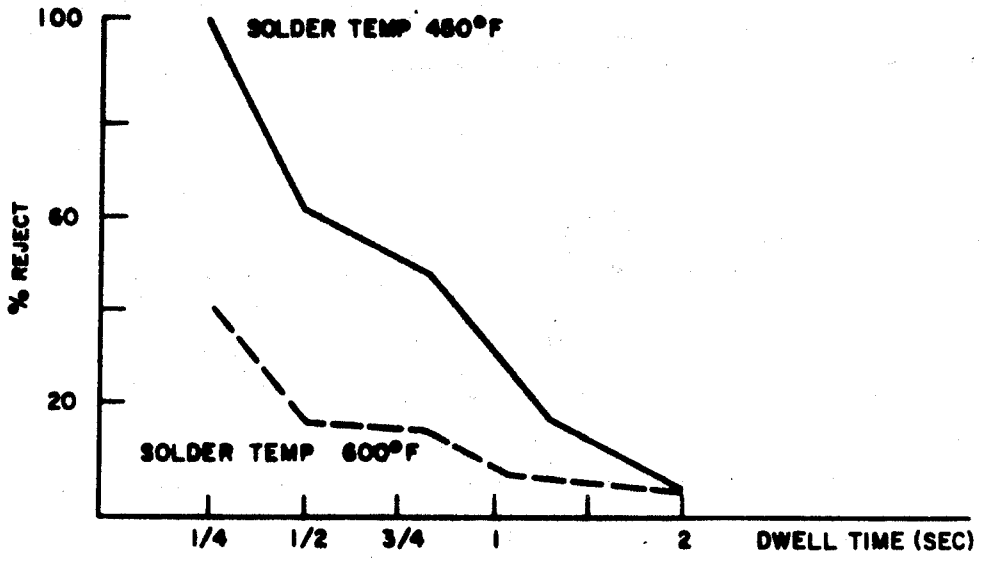


Figure 5. All Elements Clean

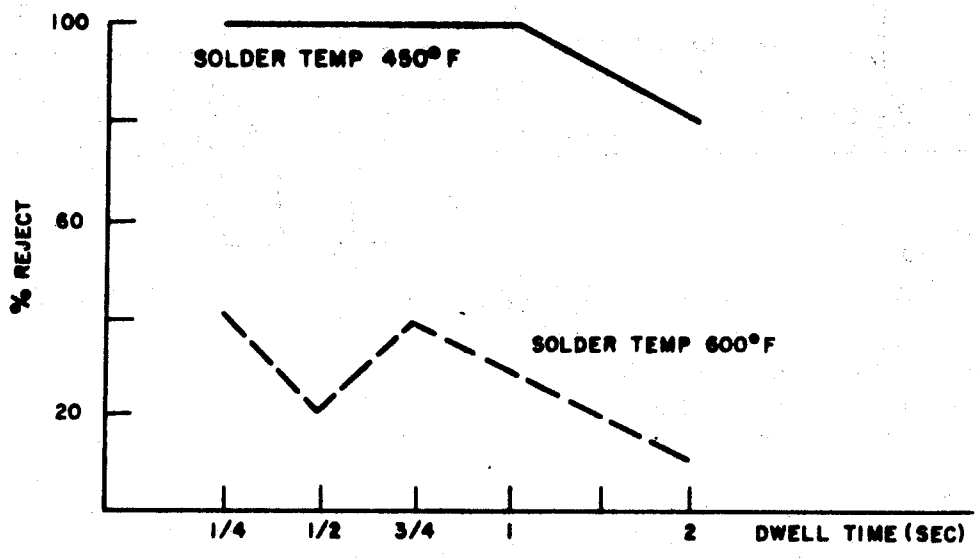


Figure 6. Wire Clean - Board Contaminated

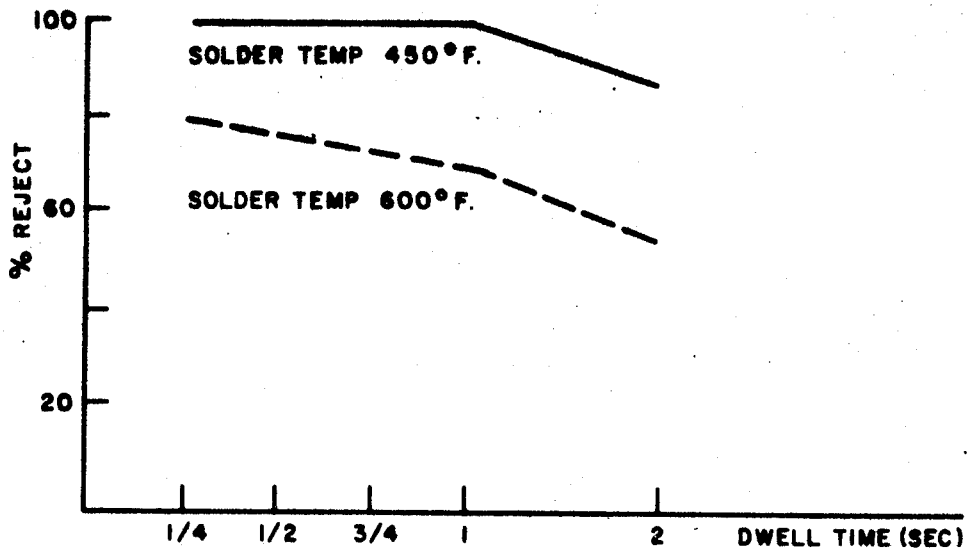


Figure 7. Board Clean - Wire Contaminated

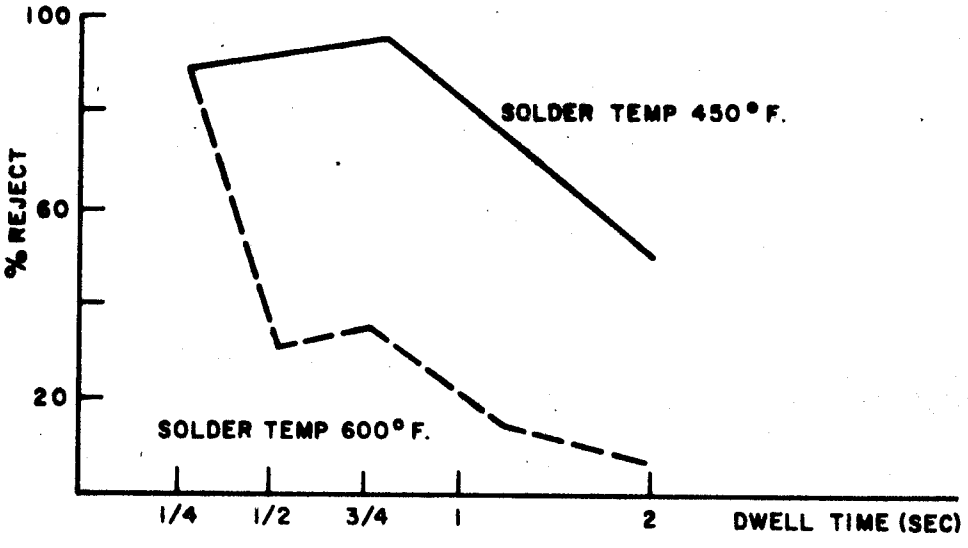


Figure 8. Wire Clean - Board Oxidized

PAPER 5 - NEUTRON RADIOGRAPHY TO DETERMINE THE CONDITION OF THE CHARGE IN EXPLOSIVE DEVICES

Mr. Howard Heffan
U. S. Naval Weapons Station
Concord, California

ABSTRACT

Along with the increasing application of explosive loaded devices and assemblies in missiles and space components, where one-shot reliability is of paramount importance, has developed the requirement for nondestructive examination of the low density explosive materials sealed in metal cases. In recent studies of the applicability of nondestructive test methods for the POLARIS Missile EBW Detonator, containing powdered Pentaerythrite Tetrenitrate (PETN), neutron radiography demonstrated the ability to show slight separations, density changes, recrystallization, and moisture in the charge. The technique used neutrons from the 30 KW Nuclear Test Reactor of the General Electric Vallecitos Atomic Power Laboratory, commercial X-ray film, and a back gadolinium screen. Further application of neutron radiography to explosive cord assemblies, conventional ammunition primers, detonators, and other loaded items in which the steel, brass, or lead case prevents application of any other nondestructive test method, shows that neutron radiography can satisfy the need for a sensitive examination. Work is continuing with the development of optimum screens, a practical neutron source, other imaging methods, and further perfection of the technique.

INTRODUCTION

Small explosive charges contained in steel, brass, and lead jackets are used extensively in missiles, rockets, and space systems. In bombs, shells, and rockets, the train of explosives between the fuze and warhead may contain a number of individual charges of varying size; in a complex missile system, small explosive devices are used for system activation, staging, and other uses, and may include small detonators, explosive cords, and similar sealed explosive items. In most cases, each small detonator or explosive charge in the train is critical and the reliability of the devices must be assured.

Assurance of soundness of both new and stored devices relies heavily on destructive testing of samples. In the Navy's surveillance programs of

explosive detonators, primers, and other fuze components, for example, thousands of sample rounds may be fired periodically. Acceptance levels for the firing tests vary and depend on the critical nature of the device, the inherent quality of the material, the complexity of the assembly, the quality of the test, and sometimes on the urgency of the need for the material.

The recurring problem of unexpected test and service failures of these explosive components is a cause of serious concern. The overall question of explosives reliability can be stated in terms of three basic problems:

1. The presence of true defects in the manufactured component.

2. The "normal" deterioration of stored components with age, and the possibility that some items will age faster than average.

3. Faster deterioration of initially serviceable devices by an accident to the charge during test or storage.

Except for an occasional application of X-ray radiography, nondestructive examination of the explosive in these components is not performed. Most NDT methods are inapplicable or unreliable. Furthermore, the correlation of the quality of the material which makes it unserviceable to the information indicated in a nondestructive test is lacking. Of the many nondestructive test methods available for use, neutron radiography alone may have the ability to supply information relative to the soundness and deterioration of explosives within a device.

Following an inquiry from the Special Projects (POLARIS) Office, Sunnyvale, the Naval Weapons Station, Concord, began an intensive study of the applicability of neutron radiography in determining the soundness of the explosive PETN charge in loaded detonators and explosive cord assemblies. One specific problem of concern in the detonator is the accidental recrystallization of the powdered PETN that may result from the seal welding of the end closure after loading or from other causes. A problem of interest in the explosive cord assembly is the presence of contact at the junction of the charge in the cord with the explosive attached to the cord ends.

POLARIS EBW DETONATOR

This detonator is loaded with 0.5 grams of powdered Pentaerythrite Tetranitrate (PETN) in a steel chamber that also contains the exploding bridgewire. The explosive is about 6mm in diameter and 17mm long. The steel wall of the chamber is 4mm thick. Loading is done by pressing the powder after which a plastic disc is placed over the exposed surface of the PETN, and a steel disc is seal welded over the end of the chamber. Tests of the produced device include a leak test, X-ray radiography, bridgewire continuity, and other electrical tests. Satisfactory performance of this device requires retention of compressed PETN powder in intimate contact with the bridgewire.

In order to obtain a range of interesting conditions, selected detonators were treated as follows:

1. Oven heating to produce incipient melting of the PETN with detonators oriented with the closure end down, closure end up, and horizontal.

2. Oven heating to produce bulk melting and recrystallization.

3. Removal of the charge and replacement with remelted PETN to occupy part of the chamber, with powdered PETN occupying the remainder.

4. Introduction of fractional milligram quantities of moisture into the PETN.

EXPLOSIVE STRAND

Explosive strands, or cords are made in several sizes, lengths, and configurations. In the sample examined, the explosive charge is slightly less than 1 mm in diameter, and is contained in a lead sheath. A plastic tube and woven fiberglas encase the lead. After loading and assembly of the cord, the ends are cut and fitted with other explosive devices to form the assembly. Performance of these systems requires that the strand of explosive be continuous without gaps, voids, or separations, and that intimate contact be made between the strand ends and the attached explosive.

NEUTRON RADIOGRAPHY

From theoretical considerations, it can be shown that optimum radiography can be achieved if the 6 mm thick explosive PETN (density = 1.1) in the EBW Detonator is radiographed with (x-ray or neutron) radiation in which the linear attenuation coefficient equals about 4 cm^{-1}. This would be obtained with X-rays from a generator operated at about 10 KV, but the steel case thickness prevents the use of X-rays below about 75 KV. Therefore, radiography of the device with X-rays can not approach optimum. For thermal neutrons, the powdered PETN has a linear attenuation coefficient of 0.6 cm^{-1}, and the steel, 1.15 cm^{-1}. Thus, the thermal neutrons have the ability to penetrate the steel case and produce adequate radiological contrast for inspection of the explosive load. Similar values apply for the case of explosive strands encased in lead and brass. Table 1 summarizes the expected attenuation of thermal neutrons by steel (iron), powdered and crystalline PETN explosive, and water.

Neutron radiography as reported by others indicates that practical and direct inspections can be achieved with X-ray film by the use of proper metal intensifying screens. 0.01-inch rhodium front foil and gadolinium back foil appears in the literature as the best choice. Exposures of the order of 10^7 to 10^8 n/cm^2 are necessary with the very fine grained film. The physical size of the source and the geometry of the radiography arrangement controls the resolution of detail that can be obtained, and the work of the other investigators indicate that detail as small as 0.003-inch can be demonstrated.

Thus, for this problem, obtaining sensitive neutron radiographs required:

1. An intense beam of thermal neutrons from a nuclear reactor emanating from as small a spot as practicable.

2. Assembly of a near optimum film-screen assembly.

3. Control of geometry, scatter, and film processing similar to that required for high quality X-ray radiography.

Neutron radiographs were made of the treated and untreated detonators and explosive cord samples at the Nuclear Test Reactor Facility of the General Electric Company Vallecitos Atomic Power Laboratory in Pleasanton. This reactor is arranged to perform experimental work with neutron radiation, and contains a horizontal beam that passes out of a 4-inch hole in the core and into the exposure room. The reactor is operated at 30 kilowatts, and the intensity of the neutron beam, as determined by the gold foil technique is approximately 10^8 n/cm^2-minute, with a very high percentage of thermal energy neutrons. A column containing helium gas was placed between the wall opening and the radiography stand about 8 feet away.

Gamma-radiation was present in the beam with an intensity of over 1,000 roentgens per hour. This could be reduced to the exposure room background intensity by adding about 4 inches of lead in the beam; the lead also reduces the neutron beam intensity by 30 percent. Experimental exposures with and without the lead showed that the gamma-radiation did not degrade the image on film sufficiently to warrant the use of the lead, and all subsequent exposures were made without lead in the beam. Attempts at improving the resolution by beam collimation showed only a slight effect with the procedure used, and was discontinued after the initial use. The beaming effect is evident on the early radiographs.

Some preliminary work was done with the G.E. special film technique. This involves acetate film and a boron screen. Conversion of the neutrons into image forming particles creates a latent image on the acetate film, which appears when the film is immersed in appropriate etchants. These required a 5-minute exposure in the neutron beam. After the 0.006-inch thick gadolinium foil, neutron radiographs with X-ray film were made of all samples. In this procedure, the film was loaded in a cardboard film holder in the darkroom, with the gadolinium foil placed behind the film. Prior exposures of the gadolinium left to residual radioactivity, and these screens could be reused immediately as in ordinary X-ray radiography with lead screens. Exposures on medium grained X-ray film (Kodak Type AA) required a 2-minute exposure in the neutron beam; fine grained Type M film required a 10-minute exposure; and Type R required a 20-minute exposure. It was found that with two film in the cassette in front of the screen, proper exposure resulted to the film directly in front of the gadolinium foil only. Apparently, the soft (beta?) radiation from the gadolinium is absorbed by a thickness of X-ray film.

Table 2 lists the results of the EBW Detonator examinations. Figure 1 is a representative radiograph of the detonators; Figure 2 is the neutron radiograph of the sample explosive strand--it shows no defects, and intimate contact with the charge at the ends.

INDUCED RADIOACTIVITY

As expected, the material that was placed in the neutron beam became radioactive, and after 1 exposure, the detonator showed activity at the rate of about 10,000 counts per minute (less than the level of intensity in the reactor control room). This activity decayed rapidly and overnight decreased to less than 50 counts per minute. The principal active nuclide is probably manganese-56 (2.4 hour half-life), which is present in the steel in small percentages. Considerable activity was found in the aluminum alloy supports for the detonators, which received up to 20 exposures per day. This activity did not interfere with the radiography, and decayed to the level of background after one day. No activity was found in the film, screens, or film holders.

DISCUSSION OF RESULTS

The work reported here should be considered as preliminary. Although adequate to make a judgment as to the confirmation of theory, and even to decide on the acceptability of examined explosive devices, the radiography technique could be improved to a marked degree. Optimum screens are being assembled and will result in the use of finer grained film with relatively fast exposures. Improvements in the beam collimation will result in achievement of optimum resolution, and coverage of a larger area than the 5-inch diameter beam used in this work. The work done indicates that this examination can be accomplished in a practical and routine manner with a nuclear reactor at a cost of under $5.00 per detonator. On a lot basis, with the improvements in beam and radiography techniques indicated, the cost of inspection by neutron radiography may be reduced to 50% of the above figure.

CONCLUSIONS

The neutron radiographs of the detonators and explosive strands were found to be sensitive and highly informative about the condition of the PETN load, and is a useful technique for the examination of explosives that are sealed within metal containers. The gaps that were introduced into the treated detonators were shown to exist not only in the center of the cavity, but also at the critical bridgewire location. Recrystallized PETN was shown to attenuate neutrons sufficiently to make it visible in contrast to the powdered material. Through good exposure and film processing control, it may be possible to obtain quantitative densitometric information regarding the density of the explosive load, and relate this to the occurrence of recrystallization and deterioration. The presence of moisture is readily demonstrated by neutron radiography, and it is probable that other contaminates would be shown if present. Although this work with thermal neutrons covers thickness of material up to 2 cm, the use of more energetic neutrons makes possible similar inspections of thicker material.

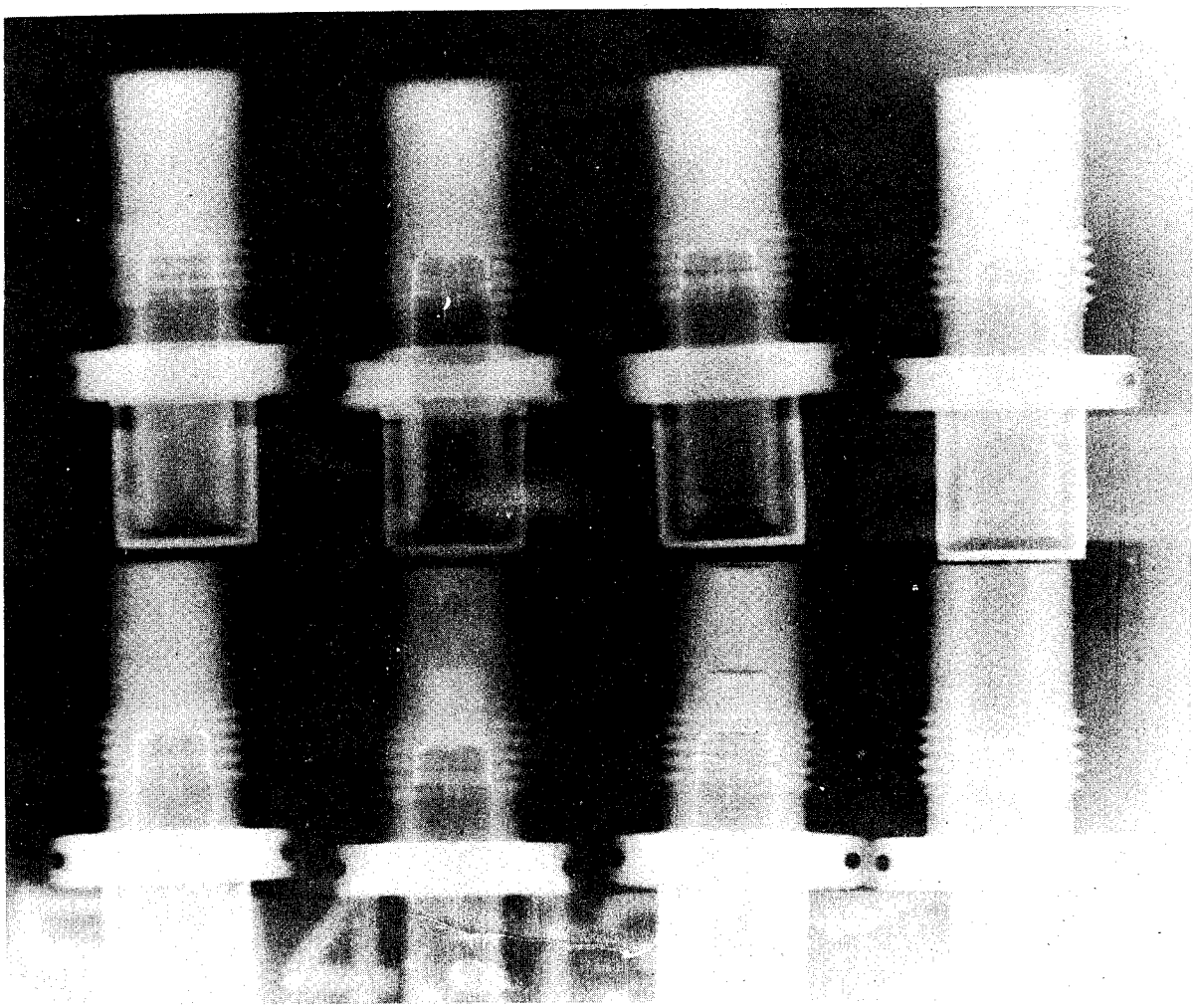
TABLE 1
THERMAL NEUTRON TRANSMISSION ($1/1_o$)

Thickness (mm)	Iron $\mu = 1.15\ cm^{-1}$	PETN ($C_5 H_8 N_4 O_{12}$) Powder Density = 1.1 $\mu = 0.6\ cm^{-1}$ (1)	PETN ($C_5 H_8 N_4 O_{12}$) Crystal Density = 1.7 $\mu = 1.0\ cm^{-1}$ (1)	Water $\mu = 2.53\ cm^{-1}$ (1)
1	89%	94%	90%	78%
2	79	88	81	60
3	71 (2)	83	75	47
4	63	77	68	37
5	56	73	61	28
6	50	68 (3)	55	22
7	45	64	50	17
8	40	60	46	13
9	36	56	41	10
10	32	53	38	8
12	25			
14	20			
16	16			
18	13			
20	10			

Notes:
(1) Attenuation due to scatter by Hydrogen
(2) EBW wall thickness
(3) EBW PETN Diameter

TABLE 2
INDICATIONS ON NEUTRON RADIOGRAPHS OF TREATED DETONATORS

Sample	
2	Mid-cavity gap in PETN, and gap between PETN and mica disc.
6	Slight gap between PETN and mica disc; slight radial shrinkage of PETN.
7	Charge completely melted out of cavity with end closure intact.
9	Gaps at mica disc, in center of cavity, and at the bridgewire; radial shrinkage of PETN.
13	Gaps at mica disc, in center of cavity, and at the bridgewire; radial shrinkage of PETN.
14	Cast and powdered loads visible, no defects.
16	Charge completely melted out of cavity, lucite insert is visible.
17	Dispersed crystalline PETN visible.
18	Charge completely melted out of cavity.
19	Gaps at mica disc, in center of charge, and at bridgewire; slight radial shrinkage of PETN.
20	Water in PETN visible near top of cavity.



Upper row and lower left detonators show no discontinuities;

14 - bottom row - contains remelted PETN in lower half and low density powder in upper half

13 - bottom row - shows gaps at bridgewire, in center, and at top, and shows radial shrinkage caused by the incipient melting of the PETN

lower right - empty

Figure 1. Neutron Radiograph of POLARIS EBW Detonators

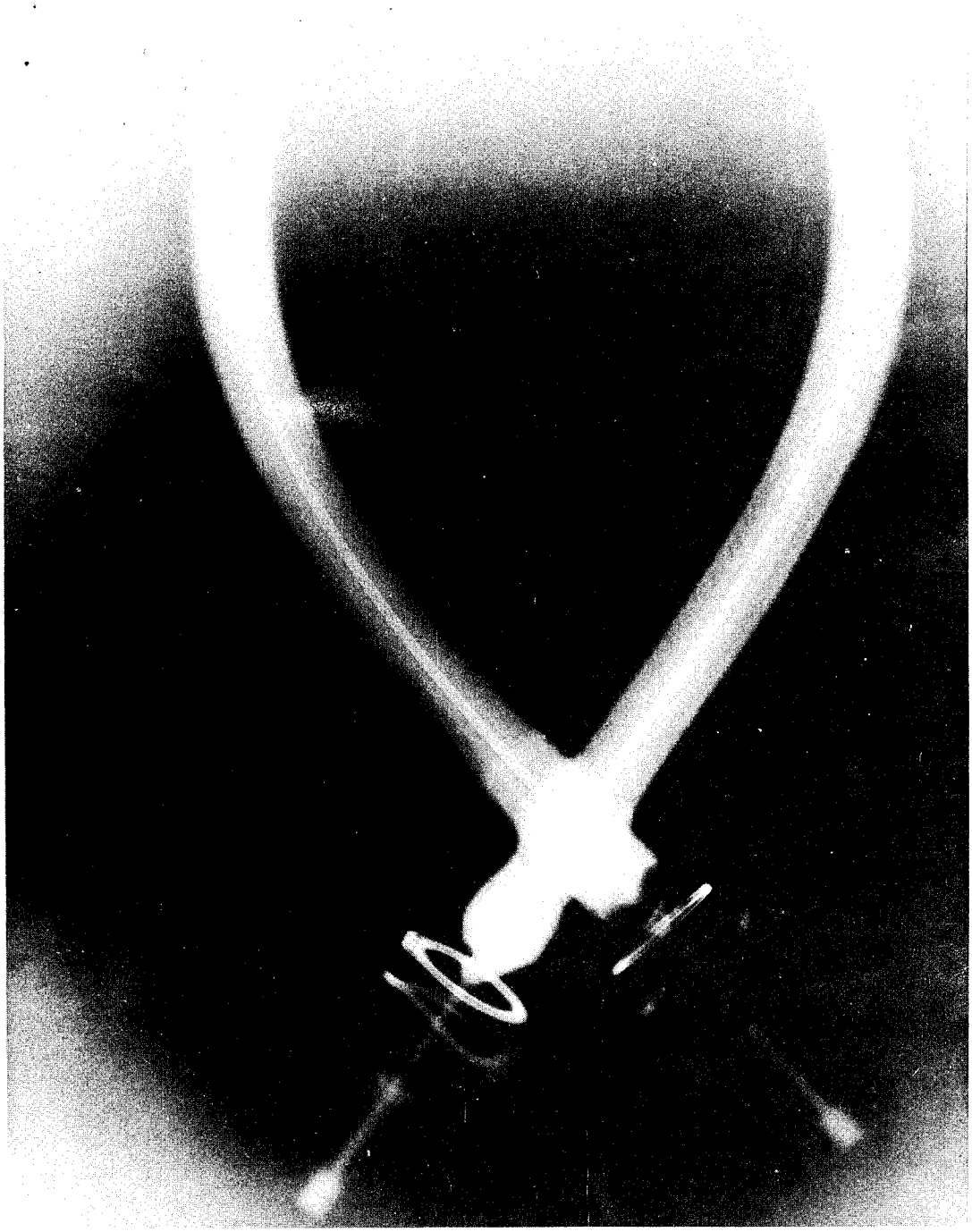


Figure 2. Neutron Radiograph of Explosive Strand Assembled to explosive detonators at the ends

10970-03

PAPER 6 - NONDESTRUCTIVE INSPECTION OF ADHESIVE BONDED METAL HELICOPTER ROTOR BLADES

Mr. Richard T. Lennon
Mr. Clifford R. Warg
Defense Contract Administration Services
Boston Region
Rochester District

ABSTRACT

The helicopter blade assemblies manufactured by Textron's Bell Aerosystems Company for the UH-1 helicopter are adhesive bonded units. All elements of the blade are bonded together into one homogeneous unit free from rivets, bolts or other external protrusions. When finished, however, these blades do not lend themselves to typical inspection methods to determine the adequacy of the bonding process relative to complete bonding.

Bell selected two nondestructive inspection methods which have proven to be reliable, namely, Ultrasonic Immersion Testing, and Manual Tapping. Details of these two inspection methods are presented together with a description of the equipment used. Blade materials, manufacturing methods, quality characteristics, acceptance criteria and test techniques and related problems are described.

HISTORICAL BACKGROUND OF BLADE DESIGN

The first use of a honeycomb at Bell in a rotor blade was during 1958 when a UH-1 tail rotor blade was produced with honeycomb filling the entire length and almost the complete width of the blade. All models in the UH-1 Series in current production also have honeycomb tail rotors.

Beginning in 1959, the first main rotor blade was produced with honeycomb. Called the UH-1B main rotor blade, honeycomb filled about 90% of its interior. All models in the UH-1 Series have had honeycomb main rotor blades since initial production.

Bell's new Model 540 or "door-hinge" rotor has a 27-inch chord and is wider than any previous Bell blade produced with a honeycomb interior. The Model 540 rotor system features simplicity of design, lower aerodynamic drag, improved performance and maneuverability and greatly reduced vibration.

The Model 540 rotor has been standard on all production Army UH-1B's and Marine Corps UH-1E's beginning in June 1965. On ships equipped with the Model 540 rotor system, more extensive use of honeycomb has been made in the construction of the vertical fin.

Since 1960, all tail rotor blades on both the Model 47G and 47J helicopters have contained a small honeycomb structure near the root of the blade.

The application of honeycomb in rotor blades at Bell has remained essentially unchanged, with one notable exception. Originally, the "honeycomb" used contained a perforated core for weight reduction. Within the past two years, Bell has changed to non-perforated honeycomb to preclude the entrance of moisture into the blade with a resultant spread throughout its inner surfaces.

The helicopter blade assemblies manufactured by Textron's Bell Aerosystems Company for the UH-1 helicopter as described in the proceding paragraphs are adhesive bonded units. All elements of the blade are bonded together into one homogenous unit free from rivets, bolts or other external protrusions. However, when finished, these blades do not lend themselves to ordinary inspection methods to determine the adequacy of the bonding process relative to complete bonding.

Bell selected two nondestructive inspection methods which have proven to be reliable, namely, Ultrasonic Immersion Testing and Manual Tapping. Details of these two inspection methods are presented herein together with a description of the equipment used. Blade materials, manufacturing methods, quality characteristics, acceptance criteria, and test techniques and problems are also described.

MATERIALS OF BLADE CONSTRUCTION

Figure 1 depicts a typical cross section of the 540 type blade. The following list and description indicate the variety of materials involved:

1. Leading Edge Spar - An extruded section of 2024 T4 aluminum alloy. After the spar is given a longitudinal taper, a closure strip is applied to form a box beam during layup as shown in Figure 2.

2. Top and Bottom Skins - 0.016 in. thick anodized al. alloy sheet.

3. Honeycomb - 0.001 in. foil thickness 5056 aluminum alloy sheet, adhesive bonded and procured to contour.

4. Doublers - 2024T3 0.032 in. thick aluminum alloy sheet stock anodized.

5. Grip Plates - 4130 forged steel, machined and cut to proper dimensions following bonding.

6. Drag Plates - 2024T4 anodized aluminum alloy cut to length and machined to final blade dimensions after being bonded to the blade.

7. Leading Edge Cover - 18-8 stainless 0.025 in. thick sheet steel and bonded to the leading edge of aluminum main spar to provide abrasion resistance in the root and mid span sections.

8. Tip Leading Edge Cover - Cobalt Steel alloy-Haynes 68 0.025 in. thick sheet to provide abrasion resistance in the most critical area.

9. Adhesives - 3 M type AF 126 Epoxy resin is used to bond all parts of the UH-1 blade together. Adhesives are purchased in rolls of 72 ft. length and 0.010 inches thick. It is kept at a storage temperature of $0^{o}F$ until used. Shelf life is 3 months.

10. Primers - Liquid EC 2320 (3 M Co.) is used to prepare metal surfaces to be bonded.

11. Mid Span Weight - QQ-L-201 Grade "B" lead is used in this application. Lead is received in sheet stock and formed to fit the internal surface of the leading edge where it is bonded in place.

12. Inertia Weight - Naval brass. The weight is cast to the shape of the internal portion of the spar and fits into the end of same where it is bolted in place.

13. Trailing Edge Spar - 2024T4 anodized aluminum alloy cut to shape prior to bonding.

Examination of the above list, reveals the variety of materials used in helicopter blade construction. To provide good bonds between these materials extreme care must be exercised in cleaning prior to assembly, preparation of the metal surfaces and in the handling of the materials during layup. Laxity in cleanliness is conducive to poor bonding. Bell has overcome a majority of these problems by maintaining rigid surveillance of all processes involved, such as degreasing, etching, anodizing, rinsing, vapor blasting, etc. Once the metal surfaces are cleaned and prepared for final assembly layup, personnel use white gloves in handling the parts. The layup itself is in a semi-clean room environment. Such precautions have reduced the number of rejections due to poor bonding.

MANUFACTURING METHODS

The primary process involved in blade assembly is adhesive bonding of the components. After the blade elements are cleaned and treated, sections are laid up on a special table with sheet adhesive between the surfaces to be bonded. The table is actually a blade contour mold into which the laid up parts fit to form a blade with the necessary degree of twist. Once the elements are laid up in the mold, mechanical pressure and heat are applied

along the leading and trailing edges. This softens the adhesive and provides sufficient bonding between parts to permit subsequent handling prior to final curing.

The whole blade assembly is then placed in a rubber bag equipped with vacuum hose connectors. After it has been determined that the bag is pressure tight, the bagged blade is placed on a molded contour table and the bag is evacuated. It is then placed in an autoclave and cured for 65 minutes at 260°F and 50 psig. Temperature at a selected point within the blade under the grip plate area, is monitored by means of thermocouples bonded between the metal surfaces. When the desired temperature is attained, the curing period is begun.

BLADE DESIGN

The blade (Type 540) consists of extruded aluminum leading and trailing edge spars. These spars are the main structural members of the blade and provide the greater portion of the beam strength. Aluminum honeycomb covered with an aluminum skin top and bottom, forms the airfoil section between the two spars. The honeycomb provides necessary rigidity between the aluminum cover sheets and maintains airfoil contour. The finished blade has a 27 in. chord and when installed on the helicopter provides a 44 ft. diameter blade assembly. Leading edge abrasive resistance is provided by a sheet of stainless steel formed to fit and bonded to the extruded leading edge main spar from the root to the 83% point. The remaining 17% of the leading edge is covered with a sheet of cobalt steel to provide even greater abrasion resistance in this more critical area. The root section contains a series of aluminum sheet doublers bonded to the external skin and main spars to provide stress distribution, plus grip plate and drag link plates for attaching points to the rotor yoke.

QUALITY CHARACTERISTICS

The quality characteristics desired involves the detection and determination of the size and location of voids in bonded assemblies. (Voids are defined as unbonded areas where bonding is required.)

The bonding acceptance criteria established by Design Engineering is designated for each area of the blade, (i.e. edge voids are not allowed in the outboard 7 inches of each finger of the doublers while some void area, depending on size is allowable outboard of station 100.) Station numbers represent distances in inches from the centerline of the helicopter rotor shaft. A detailed description as to the allowable void size and location is given for each section of the blade in the Design Process Specification.

Where repairs of unbonded areas are permitted, localized heat is applied to soften the adhesive. The bond line in the void area is then opened up and the loose adhesive is removed. The inner surfaces are then cleaned with denatured alcohol and reprimed. A piece of AF126 adhesive cut to fit the void is then inserted between the surfaces. Mechanical

pressure and heat is applied to the two pieces to be rebonded and the adhesive is allowed to cure for the required time.

Each blade is fabricated with additional length at both tip and root ends. Subsequent to nondestructive testing for voids, these ends are cut off as shown in Figure 3 and subjected to destructive testing to verify the bond strength, (i.e. pull tests, shear, peel, core slippage, and bond filleting.)

METHOD OF TEST

Detection of voids is accomplished by two methods - Manual Tapping on blade surfaces and Ultrasonic Immersion Inspection.

MANUAL TAPPING INSPECTION

Figure 4 shows a typical blade set up used to detect voids by the tapping methods. Two hammers are employed; an aluminum hammer of 10 oz. for aluminum surfaces and a steel hammer of 27 oz. for the steel and cobalt leading edges (see Figure 5). The weight of each hammer and the number of taps per minute are such as to produce a continuous sound so that any difference in sound tone can readily be detected. The rate of tapping will vary depending on surface material and construction of assemblies and will cover the range from 100 to 200 taps per minute.

Tapping is employed from station 82 to the tip of the blade. The usual method used is to tap the entire length of the leading edge including the bond line between the stainless steel and cobalt sections and the leading edge spar. During the tapping of the skin to detect voids between skin and core, the tapping operation is extended to the skin and spar joint along the entire length of the blade. By this means, skin to spar and core slippage voids can be detected. A similar operation is employed for the detection of voids between the skin and trailing edge spar.

The success of the tapping operation depends upon the ability of the operator to detect differences in sound between good and bad areas. Depending on the thickness of materials used and the size of the void, this may become very difficult and only the operator with considerable experience and skill may be able to detect it. Naturally as the void area becomes smaller in area, the less difference there will be in the sound change, thus increasing the difficulty for detection. The working area used for the tapping of course should be relatively quiet to permit personnel to sense the minute changes in sound tone as the blade is tapped.

Finally, the operator of the tapping hammer requires sufficient skill such that he can produce the required tapping rate without denting or dimpling the surface. This is a matter of tactile experience for the operator. He is advised of the cost of the blade involved and is told of the consequences should he damage a blade during the tapping process. It

is interesting to note that musical percussionists and/or those with an innate sense of rhythm make excellent "tappers".

ULTRASONIC INSPECTION

Theory and Principles

Ultrasonic inspection utilizes high-frequency mechanical vibrations for nondestructive testings of material. These vibration frequencies cover the range between 0.2 and 25 megacycles per second and are similar to sound waves but far beyond the audible range and are waves of particle vibration. Their mode of vibration is in the form of longitudinal waves with particle vibration in the direction of travel. They are rapidly attenuated in air or gases and travel best in most liquids and solids. Important characteristics of these ultrasonic vibrations are:

(1) They may travel long distances through materials.

(2) They travel in well-defined beams.

(3) The velocity of the vibrational wave is a constant through a given material.

(4) Temperature variation over wide limits has little effect on the velocity of the vibrational wave.

(5) Vibrational waves will be reflected at discontinuities or boundaries of different elastic and physical properties.

(6) They will change their mode of vibration under certain conditions, as at interfaces of materials having different elastic and physical properties or when reflected from boundaries.

The heart of an ultrasonic testing system is the method of transforming electrical pulses into mechanical vibrations, and transforming the mechanical vibrations back into electrical pulses. This transformation may be accomplished by a number of substances possessing the piezoelectric characteristics; most common substances used for this purpose are quartz, lithium sulphate, barium titanate and lead zirconate. The Bell equipment contains barium titanate and lithium sulphate crystals.

If an electrical pressure or voltage is applied across such crystal, its thickness will vary as the frequency of the applied voltage. Conversely, if mechanical pressure is exerted on the face of the crystal, it will generate a small voltage of the same frequency as the applied mechanical vibration.

As stated above, the ultrasonic vibrations used in this type inspection are of a "pulse" type and are not continuous. The pulses are generated as

a result of a radio frequency pulse of the desired frequency being applied to the piezoelectric crystal which then emits an ultrasonic vibration pulse.

The crystal is actuated for a controllable period of time (about 2 millionths of a second or less) resulting in a short burst of sound waves. The pulse travels through the material to the opposite boundary where it is picked up by the receiving search unit. After the crystal has given off this short burst of vibrations, it stops vibrating for a period long enough for the receiving unit to accept it. This cycle of transmitting and receiving is repeated at a rate of 60 times per second.

The assembly holding the crystal is referred to as a "Search Unit".

In immersion testing, the search unit and the part to be tested are immersed in water or oil (almost any liquid is suitable for this purpose). The crystal in a waterproof housing is supported by a simple arrangement for projecting a horizontal beam and is mounted such that it can be rotated in any direction, raised and lowered, or moved back and forth through the tank in order to search over the desired areas. Two units are used; one acts as transmitter and the second as receiver. The transmitting search unit projects a beam of vibrations into the test material; these vibrations travel through the material to the opposite surface where they are picked up by the receiving search unit. Any discontinuities in the path of the beam will cause a reduction in the amount of energy passing through to the receiving search unit.

Equipment Description

The equipment utilized to perform this type of inspection was designed by the Budd Company of Phoenixville, Pa., with some units purchased from Sperry Products. The system consists of a tank, recorder, reflectoscope, transducers and a bridge (see Figure 6).

(1) Tank-Measures forty feet long, four feet wide and forty-two inches deep. For testing, the tank is filled approximately 3/4 full with a solution of deionized water and 1/2% by weight of sodium chromate. The use of deionized water helps eliminate air entrapment which would result in erroneous readings. Water temperature is ambient. The tank has a continuous water filtering system with a recirculating capacity of 30 gallons per minute through a 10 micron filter. The bottom of the tank is cleaned by vacuuming as necessary. A lily-pad skimmer is used to clean the surface of the water.

(2) Alden Recorder-Model 319A - A direct writing device which produces the record as the part is being inspected. The record is immediately visible to the operator and is a permanent recording that needs no further processing or fixing, see Figure 7. The unit is capable of recording defects as small as 0.300 in. dia. The recording paper width is 16 inches which allows the scanner to inspect longitudinally 96 inches of blade with a 6:1 ratio between the scanner and the recorder.

The total vertical scanning height is limited by the design of the tank and bridge assemblies. The recorder is coupled to the bridge scanning mechanism through a gear box providing ratios of 1:1, 3:1, and 6:1 between recording and actual blade coverage.

(3) UM-721 Reflectoscope with a UM-710 Special Function Cabinet - For each of the two receiving transducers, one Pulse-Receiver and one E550 Transigate is required. The above equipment provides instantaneous visual indication of the scanning results (see Figure 8) in addition to supplying the signal inputs to the Alden recorder for making the permanent record.

(4) Transmitting Transducer-Special 360° Ring Type, 400 KC 5/8 in. diameter, Barium Titanate transducer attached to the end of a horizontal search tube.

(5) Receiving Transducer - 5.0 Megacycle, 3/4 in. diameter, lithium sulphate transducer.

(6) The transmitting and receiving transducers are spaced 7 in. apart as shown in Figure 9.

(7) Bridge - A structural frame work divided into two sections (main and trailer) spanning the tank. Both sections are equipped with guide rollers. Its purpose is to support and position the transducers for thru transmission inspection of one or two blade assemblies.

Detent assemblies permit the carriage with manipulators to be rapidly positioned transversely for a setup of the desired inspection operating mode. The variable longitudinal scanning speed can be varied from zero to twenty inches per second and the vertical indexing can be varied from 0.010 in. to 1.00 inches. With the present transducers, the area of coverage is about 3/8 in. wide. The main bridge supports the ultrasonic test equipment and positions the receiving transducers as required for inspecting a single blade or simultaneous inspection of two blades. The trailer bridge supports and positions the transmit transducer and search tube assembly as required for a single or double blade inspection. A blade guide assembly attaches to the main bridge to hold the blade trailing edge in position with respect to the transducer assemblies.

The blade must be thoroughly cleaned prior to test. In order to accomplish this and subsequent testing the exposed honeycomb at each end must be blanked off with fitted plates having edges sealed with REN 1220 plastic sealer. The end plates are equipped with air pressure hose fittings to which is attached an air supply to pressurize the internal honeycomb to 4 to 5 psi. This prevents water from entering the blade when submerged during testing.

The next operation is to clean the blade external surfaces and the internal surfaces of the leading edge spar. This prevents false indications

during ultrasonic testing. Cleaning is accomplished by scrubbing the surfaces with Scotch-Brite pads and tapwater. Clean surfaces are indicated by "waterbreak" test. Figure 10 shows blade being positioned on cleaning table.

Station markers are then applied to station 25, 82 and 108 to define the scanning boundaries. The markers are 3/4 in. thick plexiglass having a 2-1/4 in. equilateral triangle shape. They are applied by means of double backed adhesive tape 4 in. forward of the trailing edge.

The blade is then submerged in the tank so that it is supported on the leading edge at the root and tip end with the chord vertical, (trailing edge closest to the water surface). The butt end of the blade is placed so that the transmitting crystal may enter the spar cavity at this end.

The machine is warmed up and a check of its penetrating capabilities is made using a known impedance block, see Figure 11. It must be capable of 100% saturation through the block.

The search tube with the transmitter is then positioned in the leading edge spar cavity such that contact is not made with any internal surfaces. Using a scanning ratio of 3:1 and a 0.050 in. indexing, with a bridge speed of 5 inches per second a scan of the lead weight area is made. The sensitivity of the scan is set at 50% saturation thru the bonded area. The transigate setting is such that penetration below 30% will indicate a discontinuity. This will initiate an audible or visual signal in addition to making a permanent record. If a defective area is indicated the scan ratio can be reduced to 1:1 and the defective area is traced out in full size.

While the search tube is still positioned in the main spar cavity, the area through the top and bottom grip plate is scanned at a 3:1 ratio with a 50% sensitivity. See Figure 7.

The next scan is performed with the transmitter and receiver on opposite sides of the blade 4 in. down from the trailing edge. In this position 50% sensitivity is maintained through the drag plates at a 6:1 scan ratio. The remainder of the blade is scanned also at a 6:1 ratio maintaining 60% sensitivity with the transmitter and receiver on opposite sides of the blade. In any case where suspected voids are indicated, the area is scanned at a ratio of 1:1 or 2:1. Figure 7 illustrates a typical scan without voids.

Interpretation of the test results is based upon tests made on blade sections having intentionally induced bond discontinuities of known sizes in different laminates. Acceptance standards are based on laboratory tests evaluated in terms of bond quality requirement. Figures 12 and 13 are typical inspection records showing a blade with voids between leading edge spar and core and between skin and core. These voids were first detected by tapping and subsequently verified by ultrasonic testing and X-ray.

PROBLEMS

The most predominant problem in ultrasonic testing of the blade is the presence of foreign material on the blade surfaces. Not only must the blade surfaces be thoroughly cleaned but subsequent handling to install it in the tank must be done with gloves to prevent finger prints. Finger prints not only give false indication themselves but are conducive to the attachment of air bubbles on the blade surfaces during immersion. Air bubbles also give false indications.

Squeeze out of adhesive will also give false indication and only experienced operators can interpret the results correctly.

Another problem is scatter produced by sound being reflected from other surfaces to produce hash on the reflectoscope trace. This has been partially resolved by masking off those portions of the transmitting crystal not directed toward the blade. This masking has materially reduced the scatter and produces a cleaner trace on the reflectoscope.

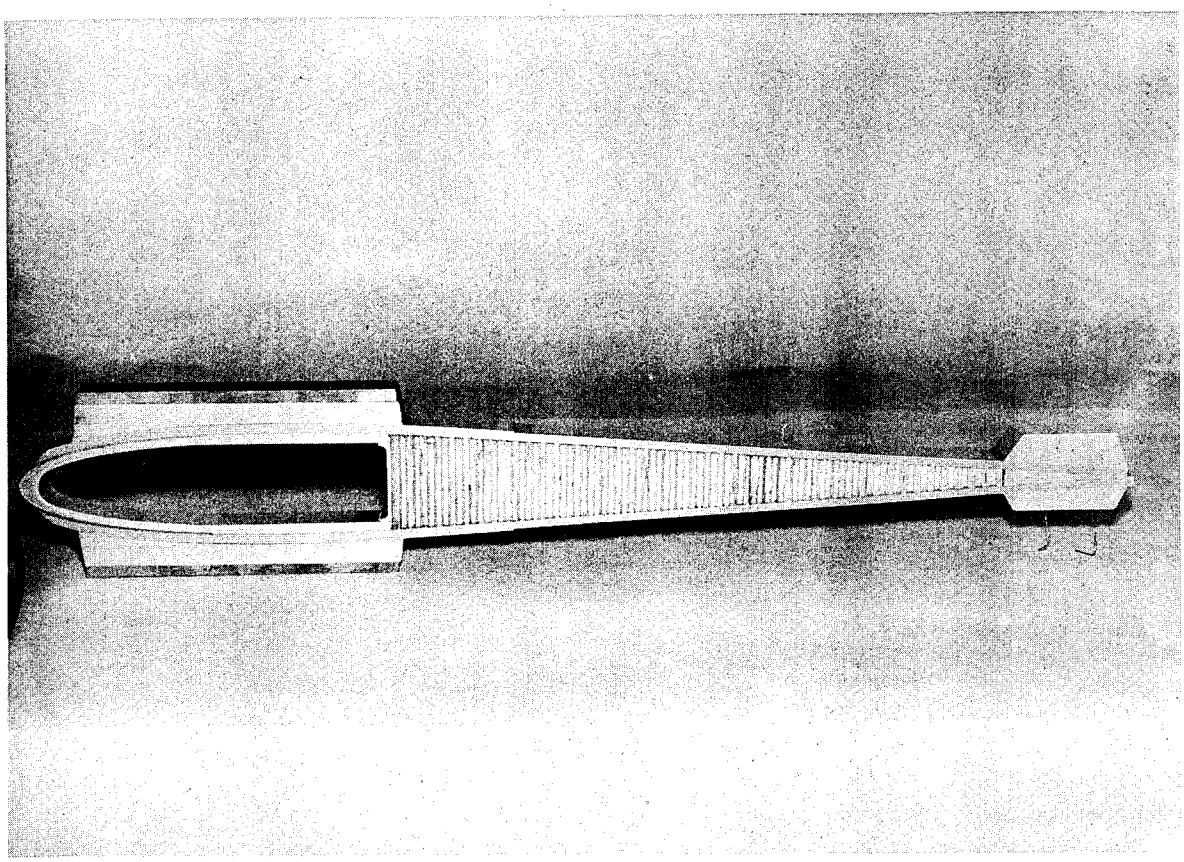


Figure 1.

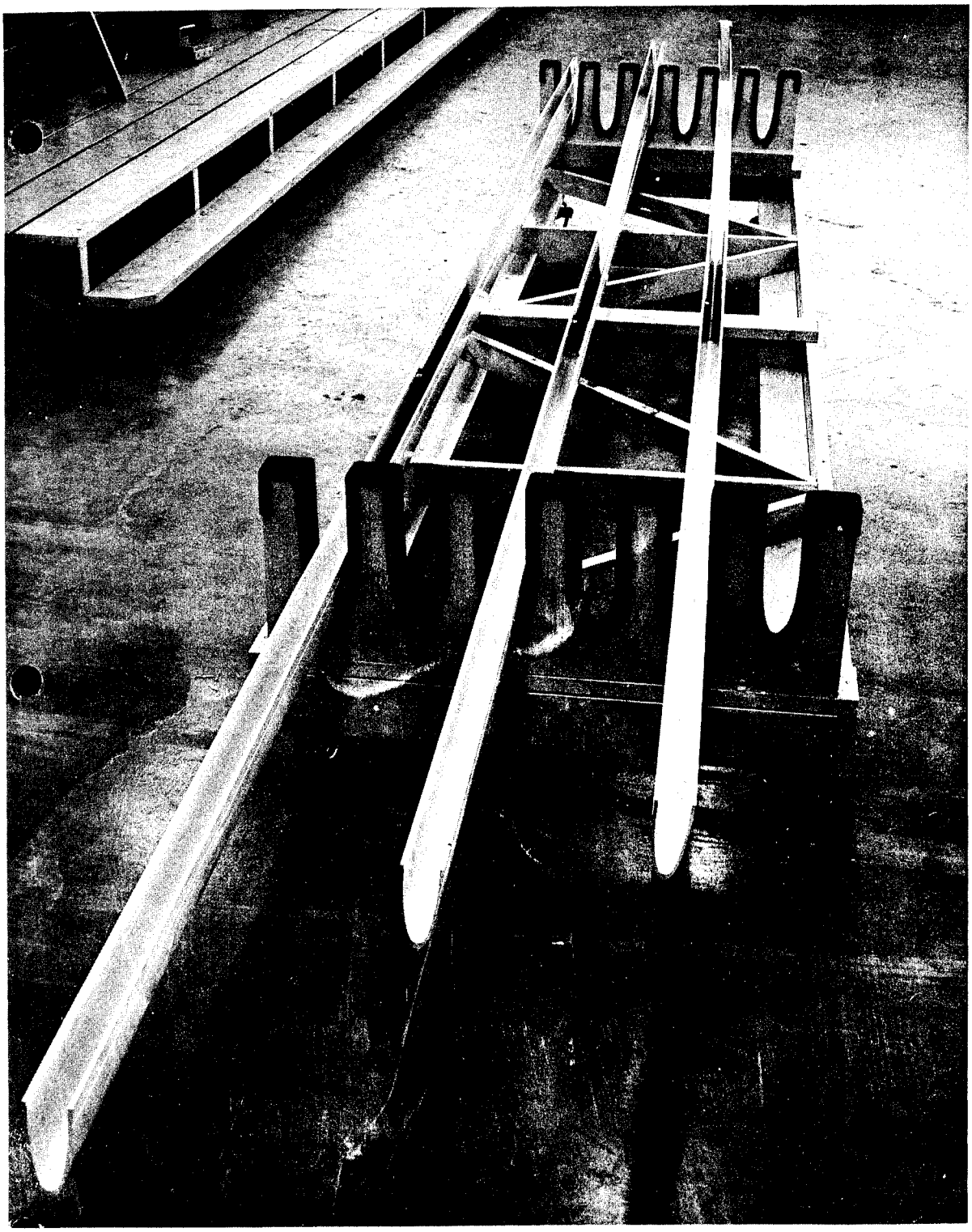


Figure 2.

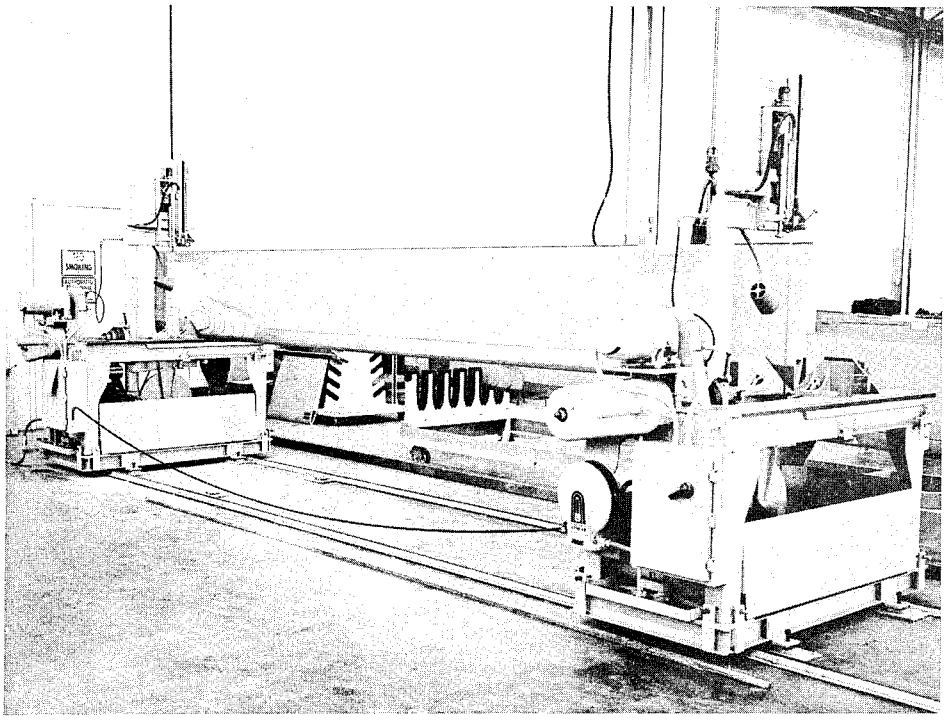


Figure 3.

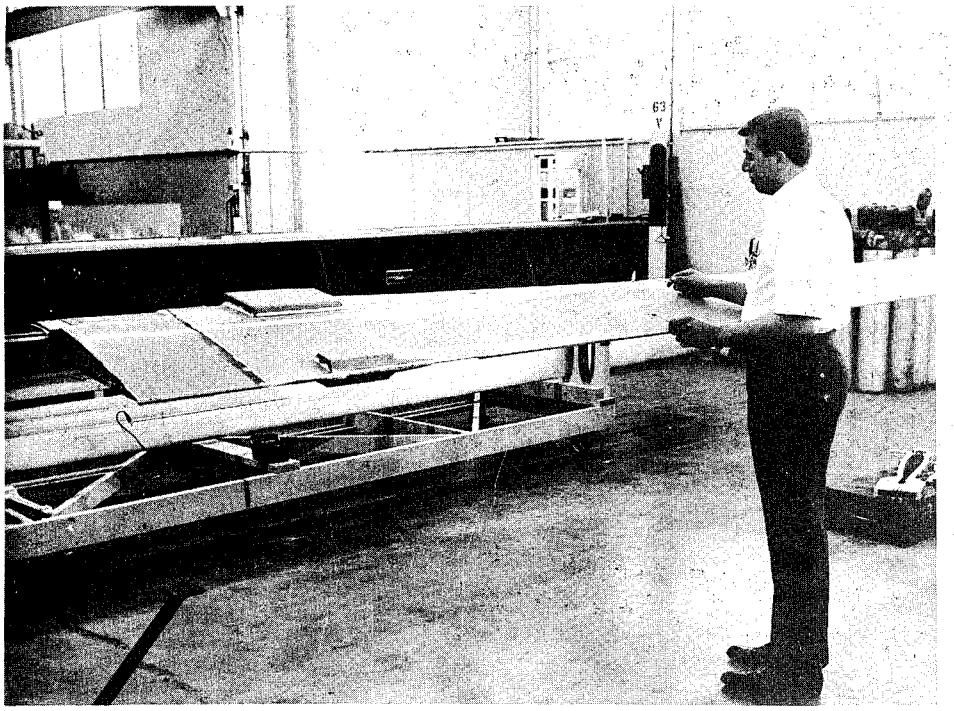


Figure 4.

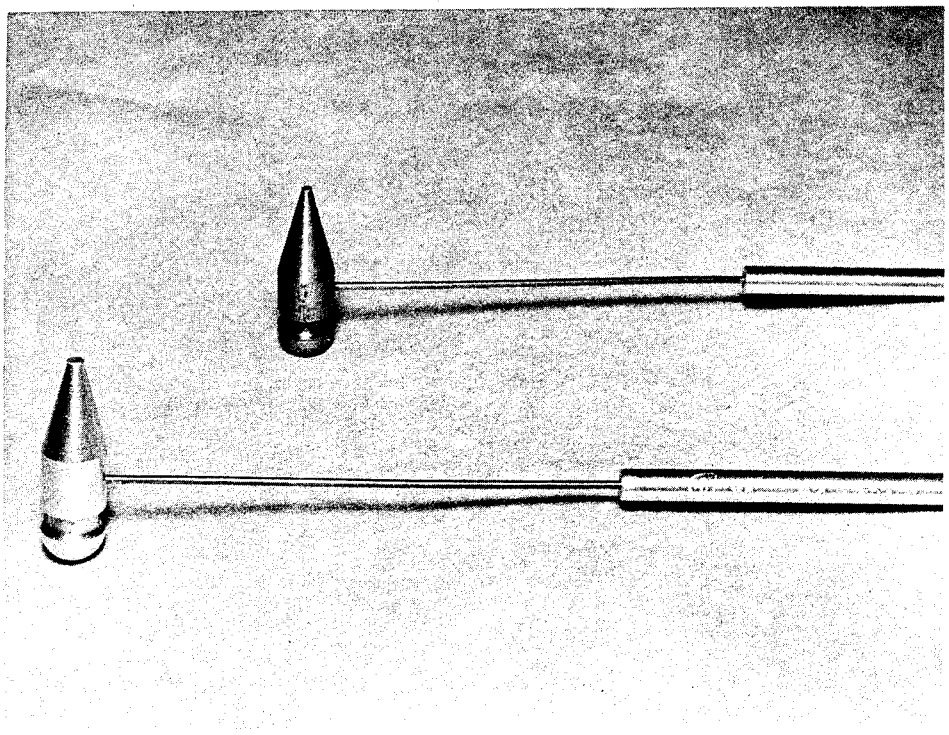


Figure 5.

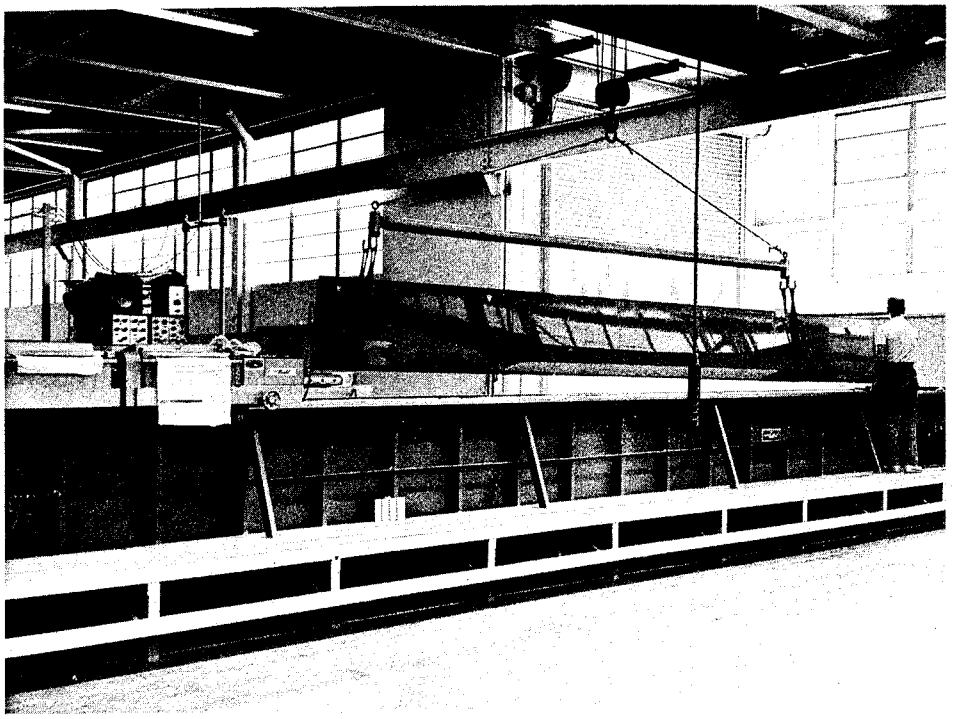


Figure 6.

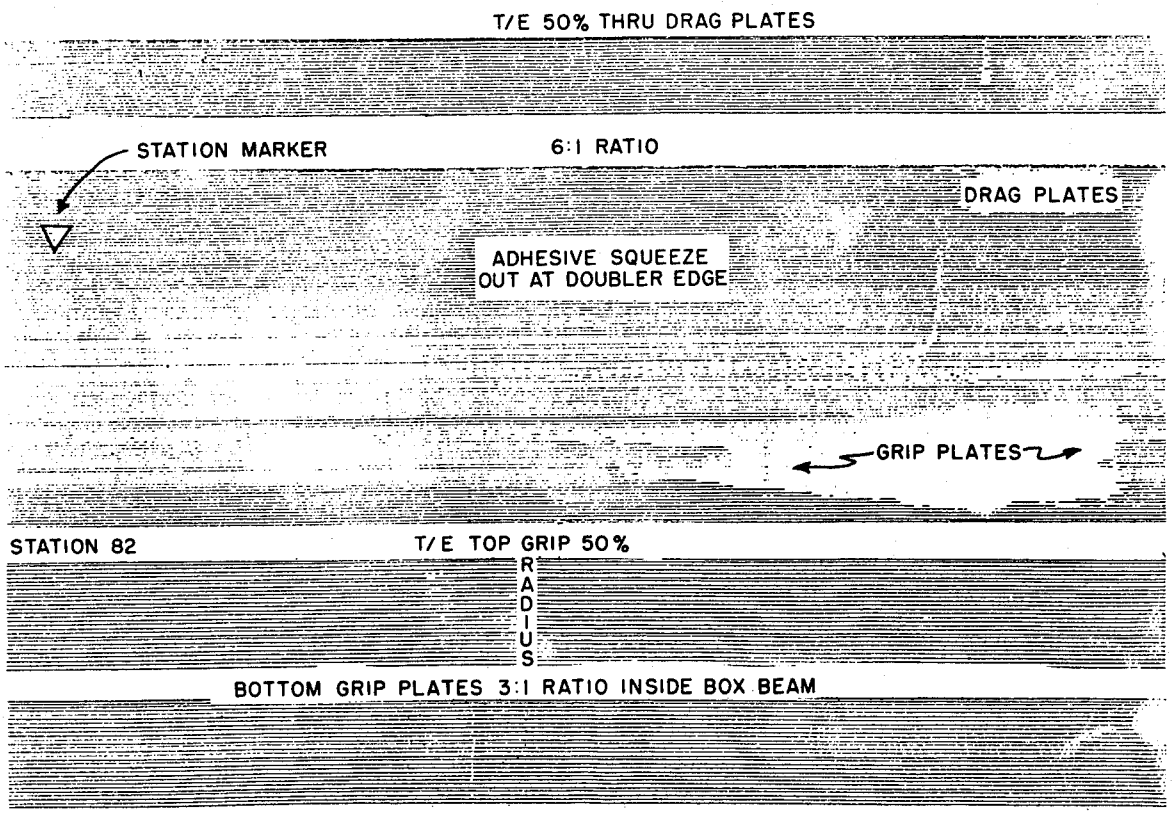


Figure 7. Ultrasonic Record of Blade Inspection

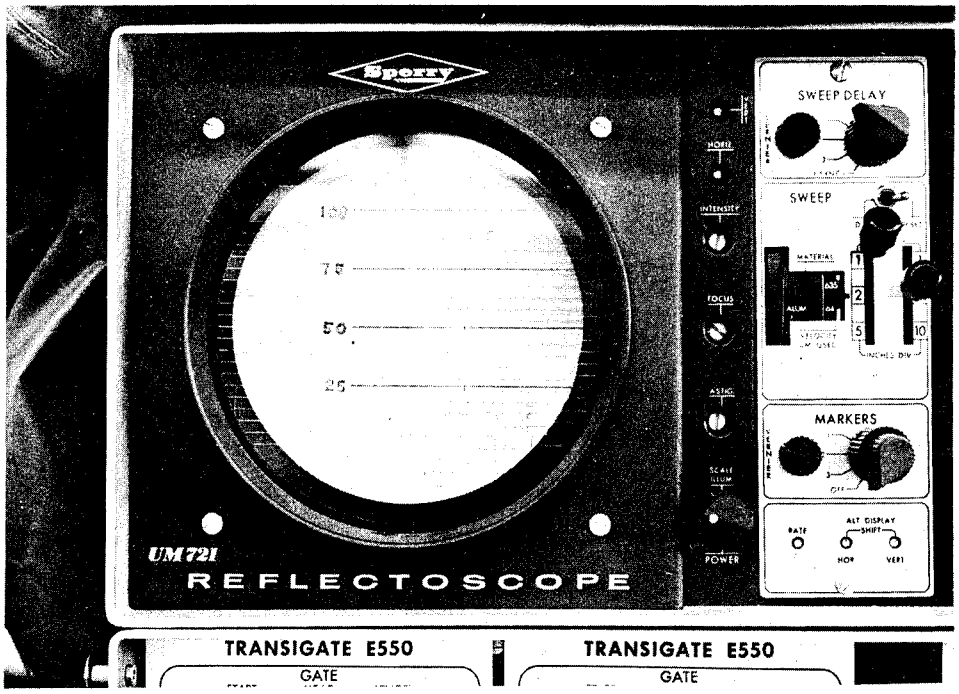


Figure 8.

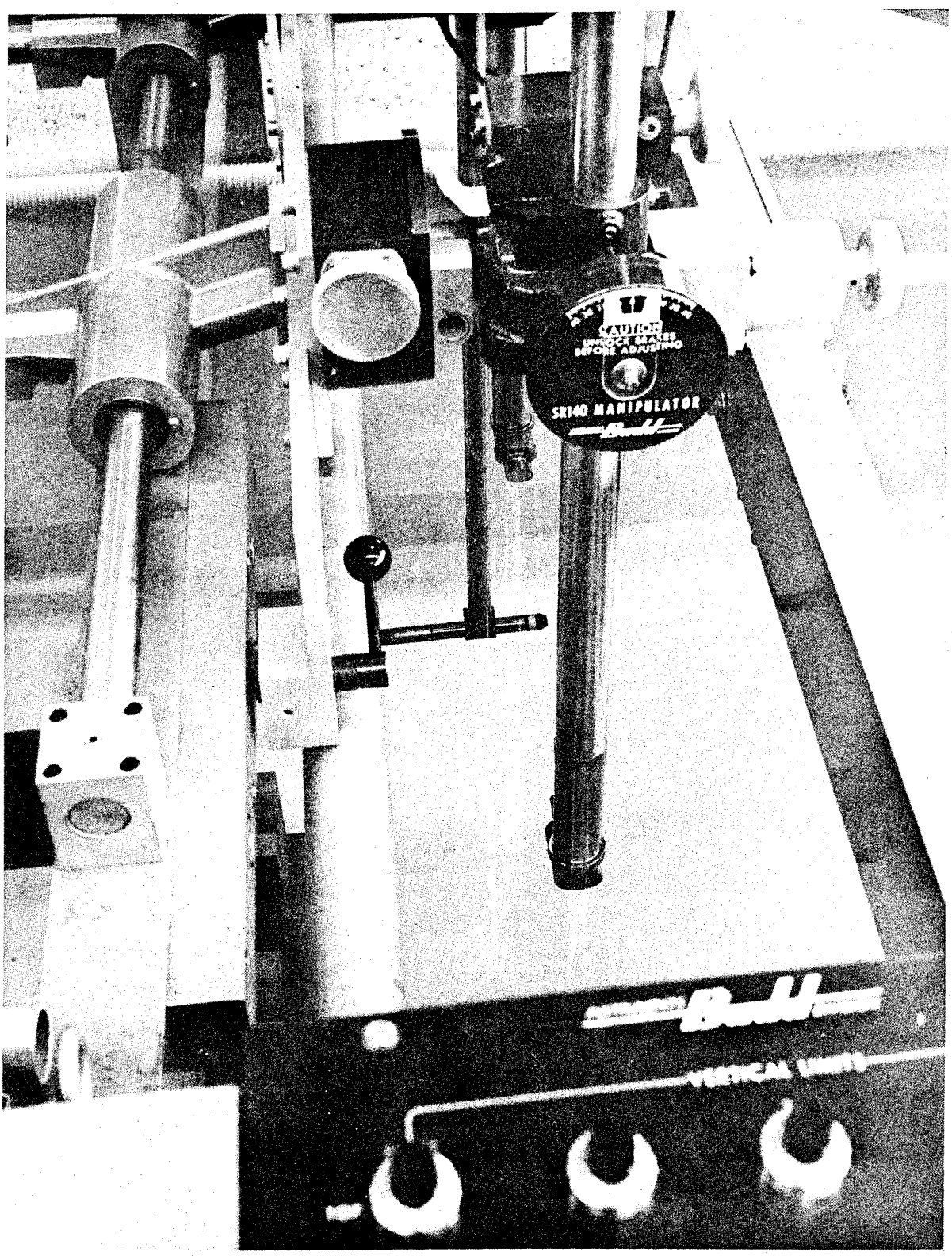

CAUTION
UNLOCK BASE
BEFORE ADJUSTING
SR140 MANIPULATOR
Bell

Figure 9.

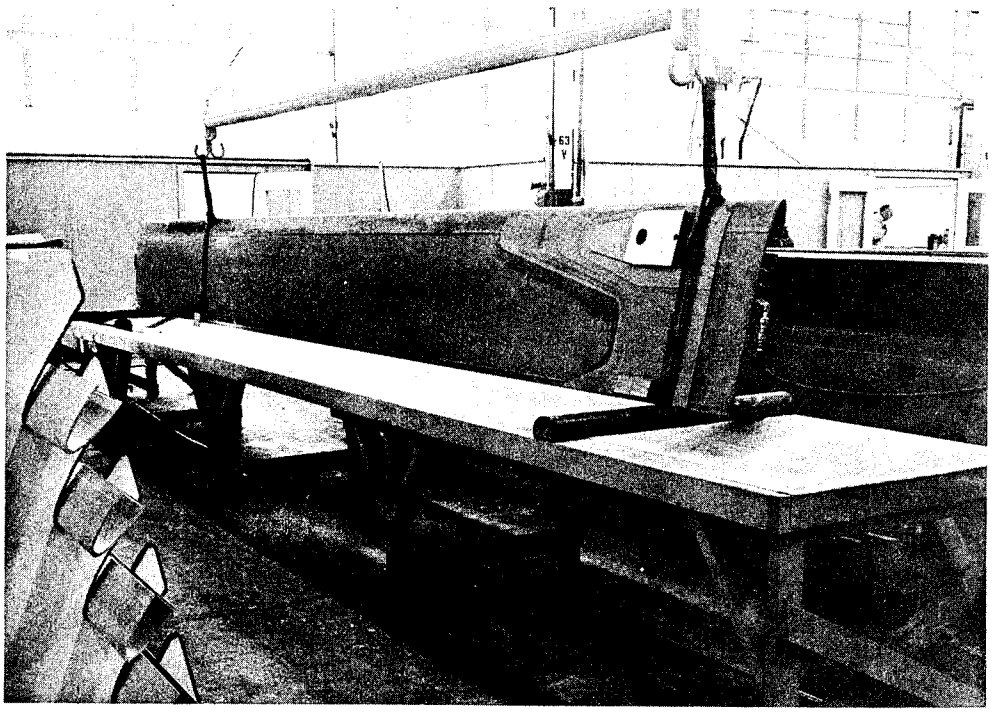


Figure 10.

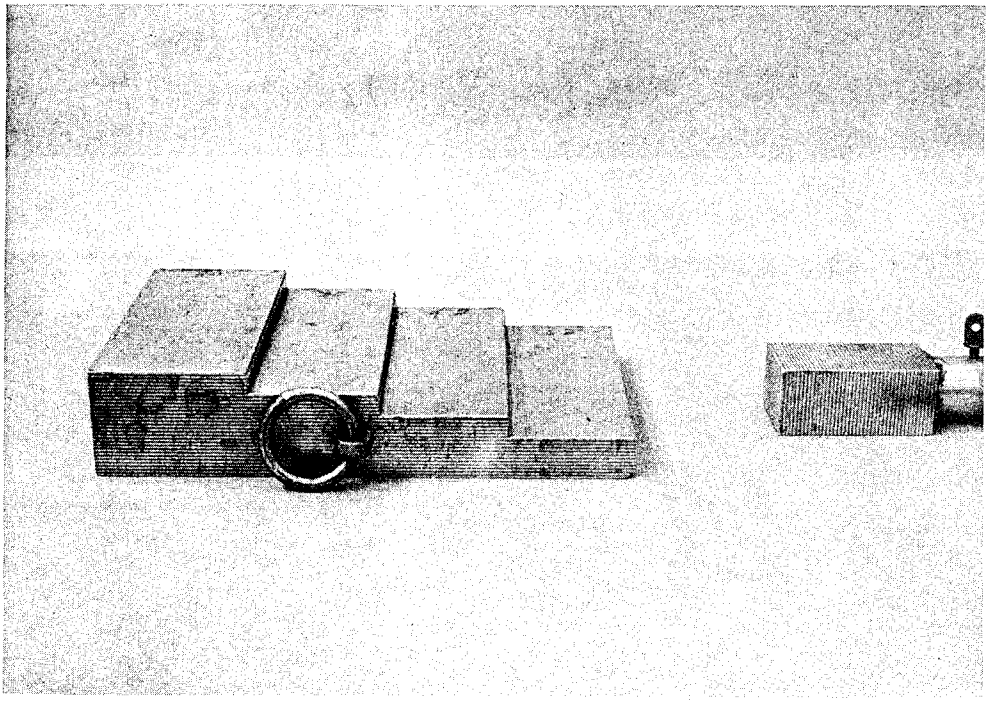


Figure 11.

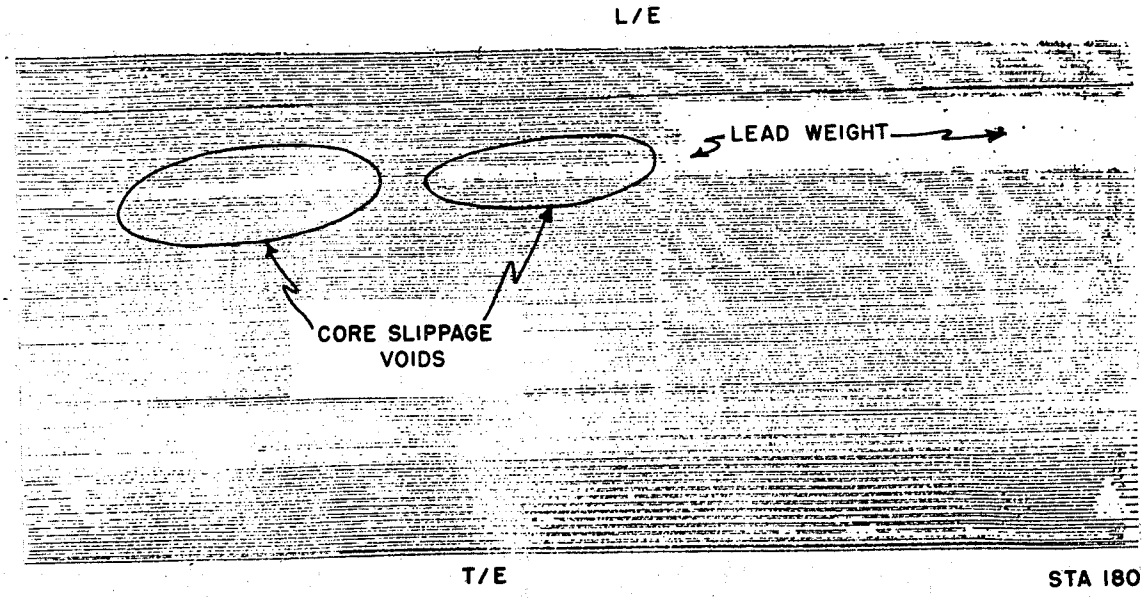


Figure 12.

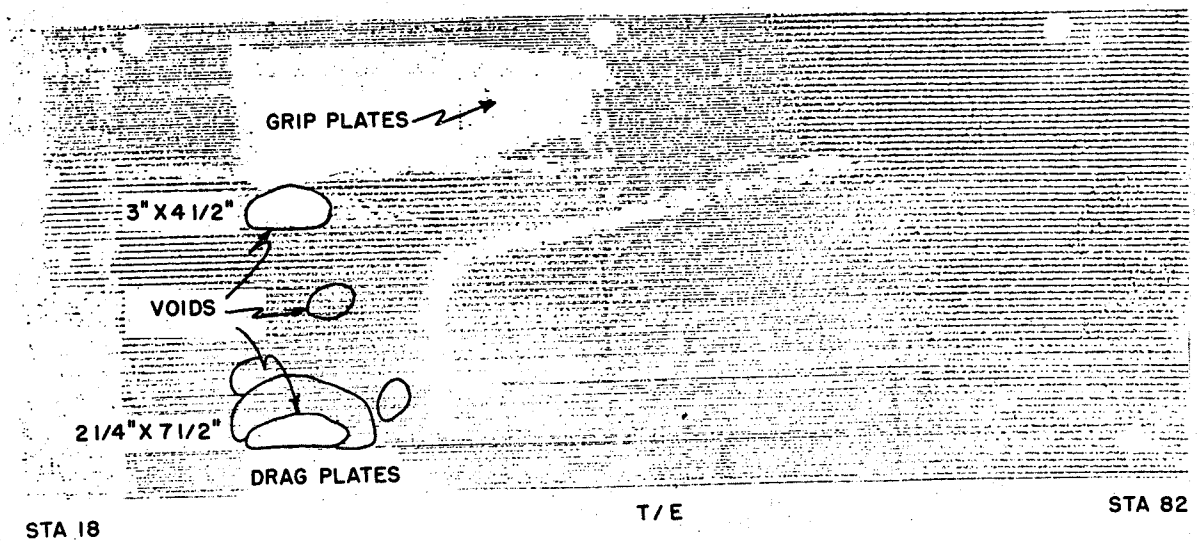


Figure 13.

PAPER 7 - THE USE OF INDUSTRY DOCUMENTS BY THE GOVERNMENT

Mr. T.E. Dunn Jr.
U.S. Army Materials Research Agency

The subject of my talk today would appear not to be in phase with the general theme of this three day meeting. But from past experience, my field of interest, standardization, appears to be interjected into other areas. Hence, the developing use of industry or technical society standardization documents in place of Government documents may be of interest to you.

The use of industry documents by the Government has always been permissive in accordance with the Armed Services Procurement Regulators. However, they could be used only when there were no similar Federal or Military documents. Such permissive use would appear to afford a rather wide latitude. Such was not the case however for there was bilinear coverage in specifications and standard test methods. Coverage of a commodity or test method by an industrial society specification or standard was to a great extent duplicated by the Government or vice versa.

Originally then the same commodity or method was similarly covered under a different designation or nomenclature. Confusing to say the least and one step away from standardization. Time phasing of changes to either system immediately destroys the similarity that was present in the first instance and soon we have the same basic commodity or method bearing two differing descriptions.

Different methods were tried wherein an effort was made to weld these two lines into one and still stay within the guidelines of the A.S.P.R. In Federal Test Method Standard No. 791, Lubricants, Test Methods, ASTM test methods were given a Method number in that standard and cross referenced. In some material specifications, such as QQ-S-741 for structural steels and MIL-S-12505 for high strength low alloy plate, sheet and strip, the requirements of the specification were called out by reference to the applicable ASTM document. This was a step in the right direction, but still left a double designation system.

The D.O.D. Manual M200 which is the bible of standardizations for D.O.D. has always stated that industry documents should be used in the preparation of Government documents. However, the D.O.D. Directive No. 4120.8 titled Use of Industry Documents, for the first time promoted the use of industry documents in lieu of preparation of similar Government ones. Because of various interpretations of this document, action to carry out its intent lay fallow for some time.

Because of our Agency's involvement in standardization in materials and test methods for the Department of the Army, we had been for some time extremely interested in carrying out the intent of the D.O.D. Directive. In the interest of national standardization, we were convinced that there should be one document to describe a commodity or method rather than many. We requested projects in two areas to conduct technical analysis studies to determine if substitution of industry documents for Government documents could be made. One area covered test methods, Federal Test Method Std. No. 175 covering Adhesives, the other covered procurement specifications in the general commodity area of steel wrought products.

The first project was completed and 26 ASTM methods were recommended for inclusion in Federal Test Method Standard No. 175. About half of these would supersede methods in the document, the others were newer methods which had not been included in the document but had been transcribed in adhesive product specifications.

The test method standard has been revised and is now being submitted to GSA for approval. The individual ASTM test methods will be accepted for DOD use and will be included in the DODISS and copies will be available for the Military Agencies at the Central Stocking Point for standardization documents, the Naval Supply Depot.

The second project presented a rather large task and therefore was broken down into three phases. Phase 1 which covered the large tonnage steel product forms has been completed and general concurrence in the replacement of Government documents by industry documents was received. As a result seven ASTM specifications for steel products have been accepted for use by DOD and will also be shown in the DODISS and be available for distribution.

The industry societies with which we have been working in these studies have been most cooperative. They have been most willing to bring their documents in line with the requirements as to format and coverage as presented by the Government. Many changes are being made at present to the industry documents in the steel area and that explains why only seven have been accepted. When the changes mentioned above are completed by the societies, it is anticipated that this number will grow very quickly.

To go on from here, we have a project now for the revision of Fed. Test Method Std. No. 151, Metals; Test Methods. We plan in this revision to substitute industry standards for the present test methods where they are similar and to introduce new industry methods which presently have no

coverage in the document. Of interest to you is the fact that probably 95% of these new methods will cover nondestructive testing. We do hope that in doing this we will be headed in the direction of a single recognized test method for the various nondestructive tests.

One problem area which commands great interest in the field of nondestructive testing, concerns the "qualification" or "certification" of personnel operating nondestructive testing inspection equipment. This Agency has been aware of this problem for some time now. In fact, back in 1959-1960 we made an extensive survey of documentation in the nondestructive testing area. At that time, we studied this problem and recommended that corrective actions be taken; however, it was not possible to implement all of these recommendations and the problem that existed in 1959-1960 has mushroomed.

Industry has of late shown a deep concern with this problem and within the last two months I have had several contacts from industry bemoaning the present state and seeking a solution. For example, in the ultrasonic field; there are at least three documents with another forthcoming covering personnel qualifications. For the three specifications, qualification is performed at Buffalo, Philadelphia, and San Francisco. It can readily be seen that this situation creates a problem to the manufacturer. In fact rather than go through such procedure, ultrasonic testing is subcontracted to testing companies who have qualified personnel. Such a practice results in a sharp increase in material costs which could be avoided by having a single qualification standard.

Because of the recently awakened industry interest, we plan to pursue the idea of development of documentation to cover personnel by the industry societies. We also plan to request a project to study again the documentation in the nondestructive area with the hope that an orderly standardization approach can be recommended and implemented.

SPECIAL REPORT

NONDESTRUCTIVE TESTING IN THE AIR FORCE

Lt. Col. William F. Bennett
Hq SAAMA (SANETP)
Kelly AFB, Texas

Nondestructive testing within the Air Force has two major facets. The first is developmental and is conducted by the Air Force Materials Laboratory at Wright-Patterson AFB. There, the Systems Project Officers (the people who ride herd on new weapons systems) are supported in their dealings with the manufacturers of new systems and supporting equipment. Further, the Materials Lab supports and evaluates new advances in the state of the art for possible application to Air Force inspection requirements.

The second area of Air Force NDT activity deals with service inspection as an integral part of the field maintenance of weapons systems. It is here that our major emphasis is presently being placed. The reason for this is purely economic. The maintenance function is a major cost factor in the operation of a weapons system and any avenue toward a more effective, a less costly, and a more timely detection of material defects is money in the bank. The unavoidable benefits in the area of mission effectiveness and flight safety are too obvious to belabor. With this as a background, let me take a few minutes to explain where we are now and how we got here.

In the early fifties, most of our depot maintenance activities were involved to some extent in rudimentary NDT. These efforts were pretty well limited to the use of penetrant and magnetic particle methods.

In 1958, MATS followed the lead of the airline industry and began a program to use industrial X-ray to improve their maintenance inspections. The depots quickly followed suit. Equipment was purchased, personnel were trained, and after the usual growing pains, the Air Force NDI effort advanced another step.

Note that I said "NDI", not "NDT". This patently heretical break with tradition brings up a major point. We are embarked on the development of a major program to adapt the benefits of nondestructive testing methods to the field maintenance of Air Force systems by operating commands. In this program we are not in the least concerned with process control, product quality assurance, raw material testing, or the like. I don't mean to imply that these functions are not important but I emphasize that they're the

province of the manufacturer's and the DOD's Quality Assurance activities. In the operating Air Force we are not involved with testing, per se. But we have always been highly involved in inspection. We rely on the manufacturer and DOD QA to provide us with a sound initial product. We then inspect constantly for service-generated defects. We are interested in a maximum avoidance of remove/replace operations. We are almost paranoic about scheduled, pre-mission discovery of defects because modern aircraft and missile systems have made the old procedure of recovery, discovery, and repair unacceptable to say the least. We plan to leave no technological stone unturned in obtaining the best in inspection methods. Thus, the Air Force chooses to call this a nondestructive inspection program.

The NDI program, as it exists today, began to take form about 1962. An equipment list had been published to include not only equipment for magnetic particle, penetrant, and X-ray methods; but for optical, eddy current, and ultrasonic methods as well.

Like so many programs, whether industrial or governmental, this one started at the grass roots. In 1964 it was still there. Progress was being made, but it was painful and slow. In no weapons system was extensive and effective use being made of NDI. In most cases, the whole problem was solved by simple avoidance. What I mean is that, in spite of much laborious and painstaking groundwork, there really wasn't a program, as such. Webster defines a program as "a brief outline of the order to be pursued in a public exercise." We had lots of exercise, but not much order.

The break came in 1964 with the establishment of Project "TIME" - Technologically Improved Maintenance Engineering. It includes such programs as corrosion control, spectrometric oil analysis, and NDI.

Under this program the purchase of NDI equipment for 50 bases was authorized; a few in each major command. The philosophy behind this cautious approach was that we could thus begin to develop a nucleus of trained and experienced NDI technicians. We could at the same time move out slowly in the equipment area to see that each item purchased would be suitable for our needs before being bought in quantity. Further, we would have a capability to test NDI applications as they were being developed.

This brings us to today. The list of NDI equipped bases has grown slightly to 58. The equipment list has been updated and includes equipment for a fairly complete range of NDI work using optical, penetrant, magnetic particle, eddy current, ultrasonic, and radiographic methods - at a cost of about $75,000 per base.

Here is a brief list of the major items of equipment you will find in an NDI laboratory at a typical Air Force Base:

Optical Method:
- Borescopes
- Magnifiers

Penetrant Method:
- Fixed penetrant unit (MA-2)
- Portable penetrant kit and black light

Eddy Current Method:
- General purpose unit (ED-500)
- Conductivity meter (FM-120)

Magnetic Particle Method:
- 144", wet horizontal unit (6000a, ac/dc) (MB-3)
- Mobile unit (6000a) (KRQS-6)
- Portable unit (750a, ac/dc) (KH-07)

Ultrasonic Method:
- Pulse-echo inspection unit (UM-715)
- Pulse-echo thickness gage (UT-Gage)
- Resonance thickness gage (SO-300 & Vidigage 14B)
- Ultrasonic translator (Delcon 118)

Radiographic Method:
- 160 KVP, 5 ma portable X-ray machine (SPX 160)
- 275 KVP, 10 ma mobile X-ray machine (SPX 275)
- Automatic or hand film processer

Recording Equipment:
- Oscilloscope recording camera (HP 196)
- Still camera (Polaroid 110B)

Here are some examples of what we've been doing with the limited capability we've had up to now.

A year ago last spring, we lost a C-124 with all aboard shortly after takeoff from Dover AFB, Del. The loss was attributed to the failure of the wing at station 498. See Figure 1. It occurred because of fatigue cracks which started at bolt holes in the lower forward spar cap.

Figure 2 is a shot of the spar cap itself. A rather gross crack is marked by the pencil line.

Figure 3 shows the same area during fluorescent penetrant inspection. The large crack shows in places.

Figure 4 is a look at the under side of the same area which shows not only the crack we saw before but another running from the bolt hole which has not yet propagated to the top surface. What we needed was an inspection which would detect these cracks at an early stage without having to pull

the leading edges. The initial setup for eddy current inspection was made here and was applied fleet-wide.

Our problems are not by any means restricted to the older aircraft. Figure 5 is a radiograph of a C-141 Starlifter control surface. This is a positive, and the darker areas are water. How do we get water in such a random pattern? We found that it is entering at the leading edge where the fibers of the scrim cloth have become exposed by abrasion and is wicked in and deposited in this random fashion.

Figure 6 is a shot of another adhesive bonded honeycomb control surface from the C-141. This is a different type of structure which allows the water to travel freely fore and aft. You can see the deformation that has occurred because of freezing.

To show you just a few of the other uses we've had for radiography, a 275 KVP X-ray machine was set up for a routine oil cooler shot.

And Figure 7 is the resulting radiograph. Needless to say this newly overhauled cooler was returned to the contractor for a little more work.

Figure 8 shows another job that's becoming rather commonplace - checking souvenirs such as these Vietnamese dolls for hidden explosives.

A continuing problem has been the erosion thinning of exhaust systems. We can't wait for them to fail because some rather spectacular fires can result. Here Figure 9 shows a resonance thickness unit being used on an R-4360 exhaust section.

Figure 10 shows the preliminary setup for pulse-echo inspection of the C-141 MLG pivot pin. The area of interest is the inboard section of each bearing area where cracks have been occurring. All these C-141 applications are not shown to imply that it is falling apart, it is just that the illustrations came out well.

Figure 11 shows the inspection in progress on the flight line.

The eddy current inspection of wheel bead seat areas for cracks and corrosion pitting could almost be called time-honored. But as in Figure 12 that we're hard at it too - at every tire change on many aircraft. This is a C-130 wheel.

Even though we're still trying to get our feet on the ground in the NDI business, we are moving out with some of the newer applications. An application study (Figure 13) has just been completed to apply gamma radiography to both the J-57 and J-75 engines. Figure 14 is one of the resulting radiographs showing a crack near the flame tube and some deformation of the burner can.

A preliminary study shows that for each engine we can save about 13 manhours and 8 hours of aircraft downtime over a manual teardown for hot section inspection.

We have been using ultrasonic C-scan equipment for some time to check for both intergranular corrosion around fasteners and pitting corrosion inside fuel tank areas. Here in Figure 15 is the latest in the family of such scanners set up on a C-124.

The scanning bridge weighs about 60 pounds and its vacuum pads will hold it in almost any position on the aircraft.

Figure 16 shows the scanning bridge being used on the lower wing surface.

Figure 17 shows the associated electronics recording and control modules, which will record an area 10 1/2" by 18". Each module can be handled easily by one man and the whole system, weighing about 500 pounds, fits nicely in the family station wagon.

In support of the program, several publications have recently been issued. A general technical order (T.O. 33B-1-1) has been published covering the theory and applications of each method. Those of you who have seen it have noticed that it draws heavily on industry sources for which we are most grateful. Those of you who have read it in any detail have noticed that it is easily criticized both from the technical and from the rhetorical standpoints. A revision is in progress and your comments, suggestions and gripes will be most welcome.

Air Force Regulation 66-38 formally announced the NDI program in March of this year. Its objectives are (a) to obtain a more accurate and timely judgment of equipment condition, (b) to emphasize before the fact inspection vs recovery, discovery, and repair, (c) to minimize weapon system downtime, (d) minimize maintenance manpower cost, and (e) increase weapon system reliability and safety. It established these basic policies:

1. NDI methods will be specified and used in weapon maintenance inspection wherever they will enhance safety or reduce maintenance costs, inspection manhours, or weapon downtime.

2. Procurement contracts will require manufacturers, suppliers, service contractors, and repair contractors to utilize NDI techniques to the optimum degree to insure a quality product.

3. Government quality assurance representatives will use NDI methods in evaluating and approving both products and repair services offered to the Air Force.

This brings us to the question of people. From recent articles in Materials Evaluation and from papers delivered at other meetings, I see that the personnel problem is not peculiar to the Air Force. Our approach to the matter has been through our NDI School at Chanute AFB. This school has grown with the program. (Perhaps I should say it has grown ahead of the program.) It presently provides 360 hours of classroom instruction and lab work in all NDI methods for which we're equipped. We feel that it is one of the finest such schools available anywhere.

But good training is not enough. We have to identify the graduates. It takes considerable experience before we have a really qualified technician. And if we can't hang on to the man, we can't develop this experience. While I agree that this sort of problem is not unknown to industry, ours is a second order problem. Those few of you who are my age will recall the common gripe back in the "big war" that everything was "by the numbers". Things have changed since then. We have more numbers now and what's even more important, our personnel people have discovered electronic data processing. A moment ago I talked of our great strides in training. Who are we training? We're training aircraft mechanics, metalworkers, welders, engine mechanics, and people from many other technical areas. Thus, the problem. We had no way to tell the personnel computer that these people had new skills. As a result, a requirement for welders in Southeast Asia was almost certain to take some highly trained and experienced NDI technicians. For the lack of a number (a specialty code) with which to identify these people, we were losing them almost as fast as the school could turn them out. Fortunately, the problem has finally been solved. A specialty for NDI technicians has been published, which allows us to identify our people and insure their proper utilization.

The key actions needed now to advance the Air Force NDI program are these:

Air Force Systems Command must insist that NDI provisions be automatically considered in the design and acquisition phases of each new weapon or weapon support system. The optimum degree of NDI must be included in the system inspection handbook before the operational phase begins. The operating commands must receive an up-to-date inspection program along with the bird.

Air Force Logistics Command, having the logistics and engineering responsibility for operational systems, must see that the NDI applications are updated constantly to treat new inspection problems as they arise and to take advantage of improvements in NDI equipment as they occur. And, even more important because of its immediacy, is the task of applying NDI methods to the present operational systems. In case our austerity program has escaped your notice, I should remind you that these systems go back to the ubiquitous DC-3 and work their way up through the present generation of first line aircraft. This is going to be a large task but an essential one. Every inspection handbook must be updated to include the optimum use of NDI as a matter of routine maintenance.

At the moment we find ourselves ill-equipped for this job. Our engineers, technicians, and managers don't have the familiarity with the NDI field which is required. Our approach to this problem includes the establishment of two special courses. One of these is designed for the working engineer and covers the engineering applications of NDI in a concentrated two week course at Chanute AFB. This course has been running since early July and has been rather well received. The other is being conducted at the depots by a traveling team of instructors. It is a short course to familiarize weapons system managers and technicians with the capabilities and limitations of each inspection method. We feel that these courses will put us in a far better position to manage the handbook updating program.

Air Training Command, as they have with every new program, will have to expand their present NDI course. It must expand in size to meet the larger training load that our growing capability will require. And it must expand in scope to keep in step with the advancing state-of-the-art.

In summary, the tools we need right now in the Air Force NDI program are included in these three basic documents: the tech order, the table of allowance and the regulation. The only essential ingredient remaining is a lot of good, hard work. This, I think we can provide.

This brings us to the subject of this exercise--What are the Air Force requirements? Since this is the important part, it won't take long.

Let me address this question to you in two parts: first, what do we require of the aerospace manufacturers?

As far as they are concerned, the requirements can be simply stated. Every new system that comes down the pike must come with a near state-of-the-art maintenance inspection program. Air Force Systems Command must insist that they utilize our NDI capability in the day-to-day maintenance of their system. This means that the inspection and structural repair handbooks that they provide must take every economical advantage of NDI methods. At this point you might ask, "Suppose you allow your inspection equipment to become outdated to the extent that they can't provide a suitable inspection?" Here's one of the fringe benefits as far as we're concerned. If the manufacturer finds the better mousetrap, he need but prove it to the System Program Officer and us and we'll do our best to get some. This is one way that we can take advantage of industry's expertise in maintaining an effective and up-to-date program.

Another point I would like to make concerns inspection standards for equipment calibration and acceptance/rejection criteria. Our situation requires a departure from current practice in this area. Consider the Air Force program as compared to that of an airline operator. A Boeing Service Bulletin which requires, for example, an ultrasonic inspection, will give the specifications from which the operator can manufacture a suitable setup standard. How many such standards will, say TWA or Eastern require? Perhaps one or two. But what about a similar field inspection on the C-130

fleet? Now we are talking in terms of ten or twenty standards; one for each C-130 field maintenance activity. Thus, we have a two-headed dilemma. The first is economic. We can't afford to manufacture large numbers of standards for each and every application. The second is that, without very close manufacturing control, they won't really be "standards" at all and our inspections will suffer accordingly. We propose as a solution that each inspection requiring a setup standard specify the use of a universal standard such as an ASTM block or other appropriate reference insofar as possible. We hope, before too long, to adopt a suitable grouping of standards for Air Force use. Initially this will include longitudinal, shear, and surface wave ultrasonic standards and appropriate eddy current standards. We have a lot of homework to do on this one and any suggestions will be welcomed.

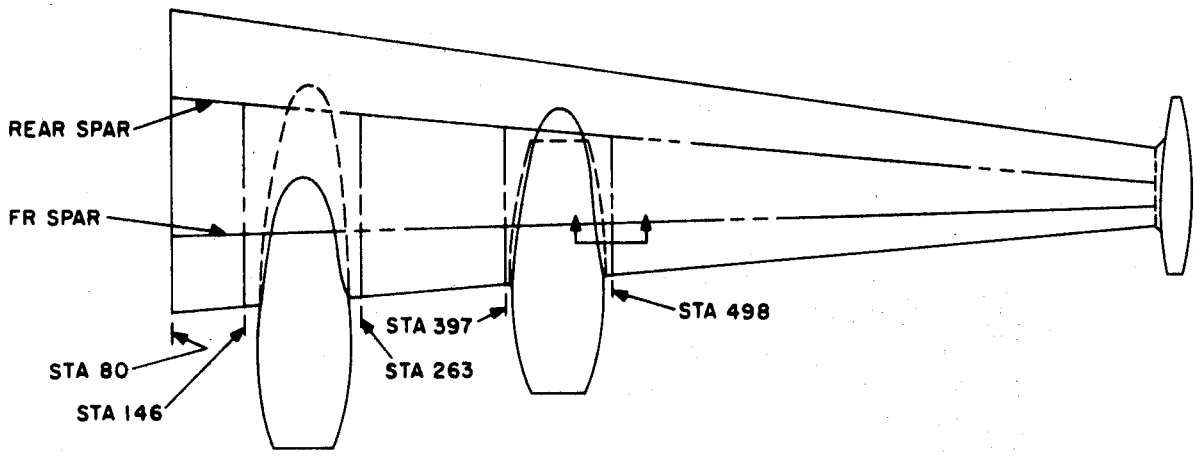
On the other side of the coin, what do we require of the NDI equipment manufacturers?

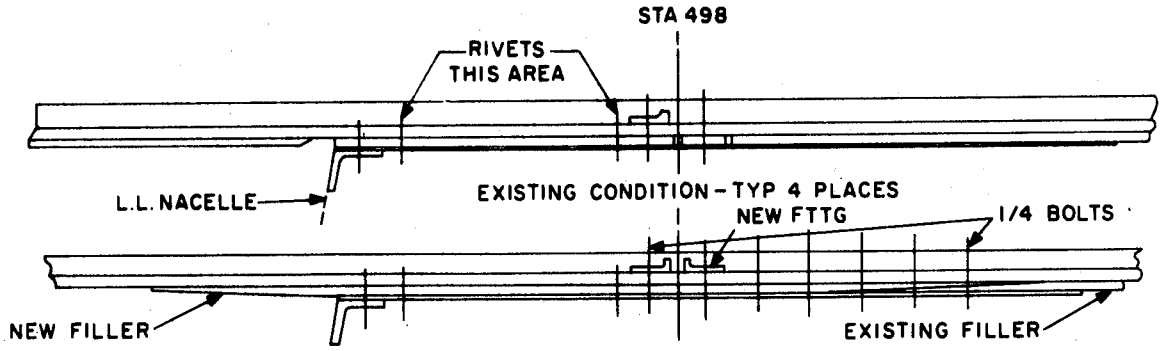
Notice that most of the NDI equipment that we have chosen has one feature in common - portability. We get two benefits this way. The first is mobility. We must be prepared to maintain our aircraft at any point in the world and at a moment's notice. The second has to do with a continuing effort to reduce aircraft movement during maintenance work. We would prefer to bring the inspection equipment to the aircraft rather than vice versa. Portable, or at least mobile, equipment takes care of both of these requirements for us. But portability itself is not enough. What we really need are units with self-contained power supplies. Eddy current equipment is a good example. A need exists for a battery operated, light, and rugged eddy current unit for both crack detection and conductivity measurement. We are evaluating several proposals for such a unit now.

I gave you our long, sad tale about people. With all due respect to their considerable ability, there are few post-doctoral physicists and metallurgists in their ranks. We've got to keep it simple! We need instruments that are light, portable, accurate, direct-reading, Murphy-proof, rugged, self-powered, and INEXPENSIVE! (Notice, I didn't say "cheap".) We need advanced instruments and methods; instruments which will improve our inspections, methods which will do with one instrument what we are now doing with three, and methods which will avoid operator-induced variables. Remember that our interest is in maintenance inspection rather than in production work. We need solutions to the many inspection problems being generated by material and fabrication innovations. And last but not least, we need help.

Gentlemen, it all boils down to a few basic facts:

> The Air Force is going to use NDI methods to save lives, to save time, and to save money. And, along with these savings, we are going to provide, through the careful use of NDI, to the people of the United States a better deterrent in a more reliable weapon.



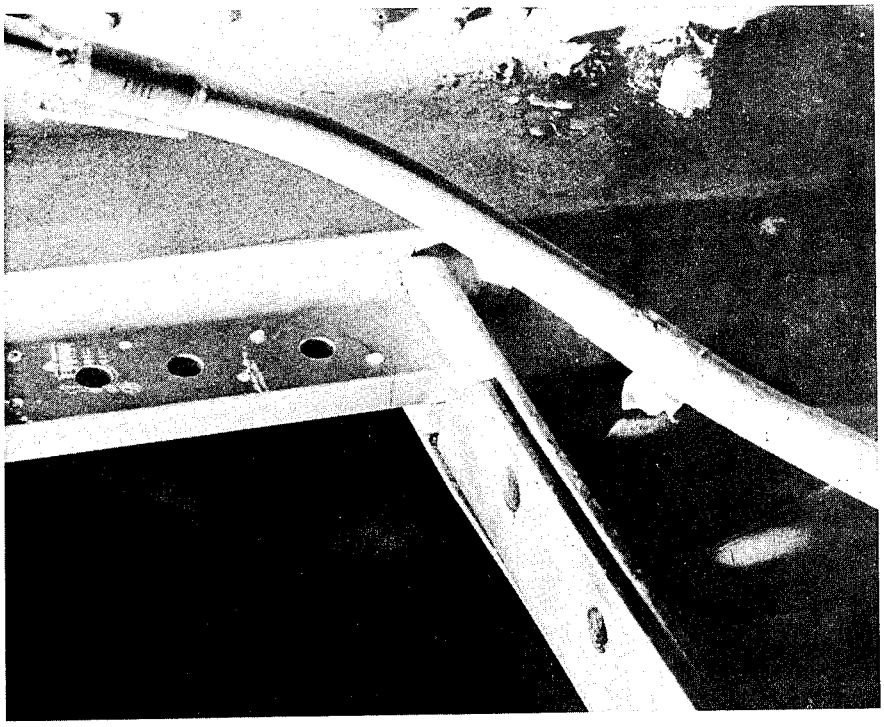


PREVENTATIVE FIX - SIMILAR 4 PLACES

REPAIR PROCEDURE PER DWG 5458547

1. REMOVE LEADING EDGE
2. REAM 1/4 BOLT HOLES TO .032 OVERSIZE
3. ADD FILLER & TAPER SPLICE TO EXISTING FILLER
4. REPLACE (1) FTTG WITH NEW FTTG TO NEST INSIDE FLANGE
5. REPLACE EXISTING RIVETS WITH 3/16 OVERSIZE SCREWS

Figure 1.



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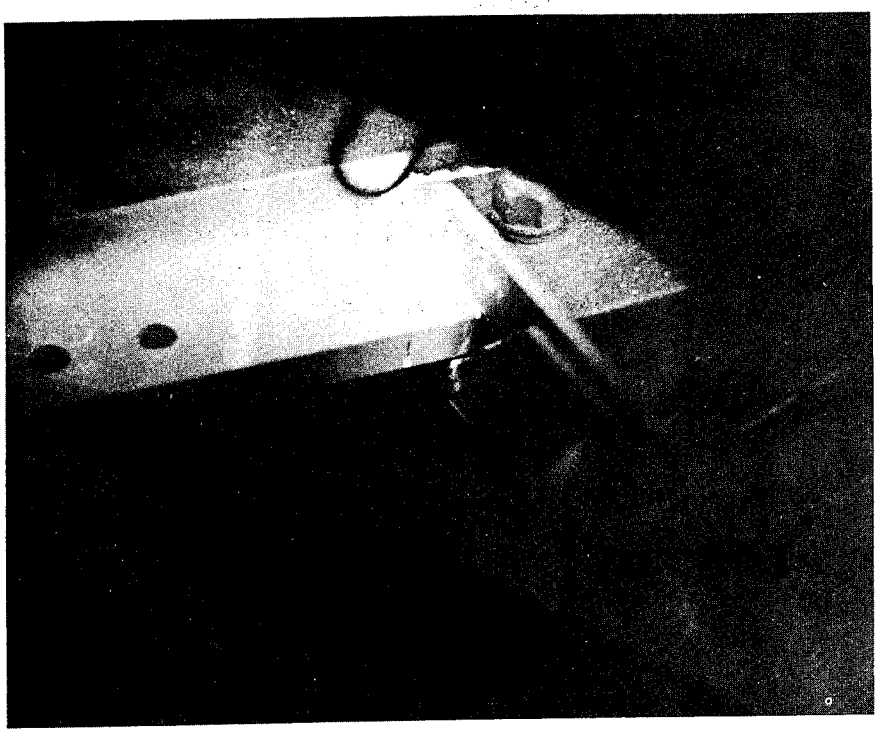

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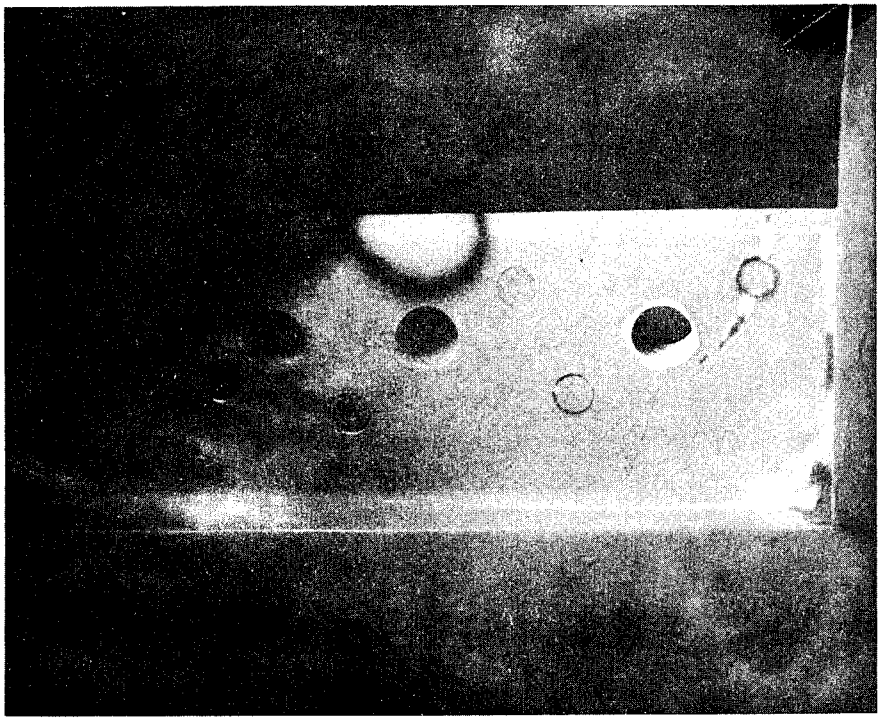

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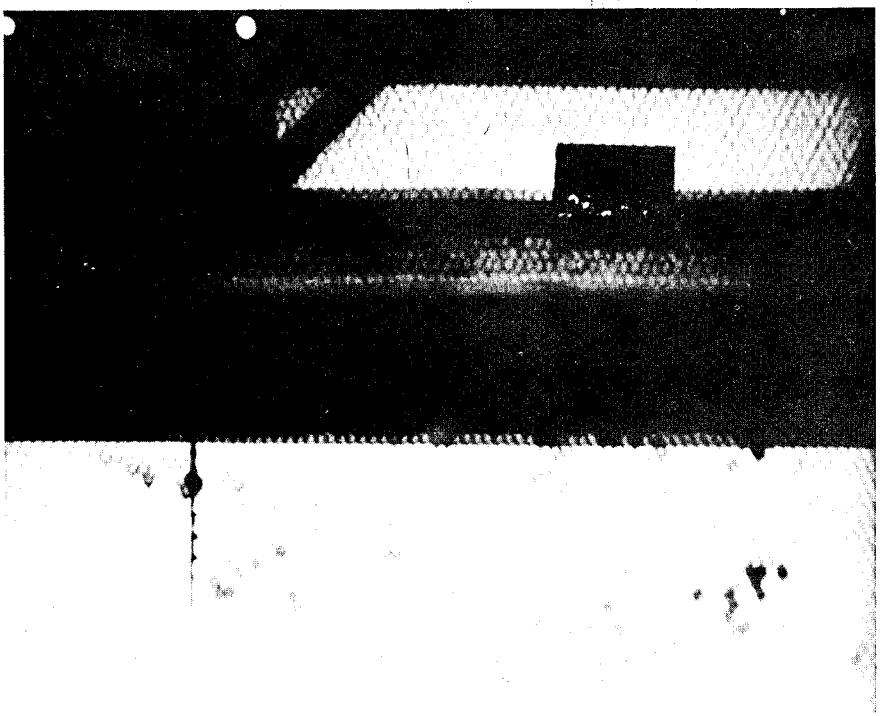

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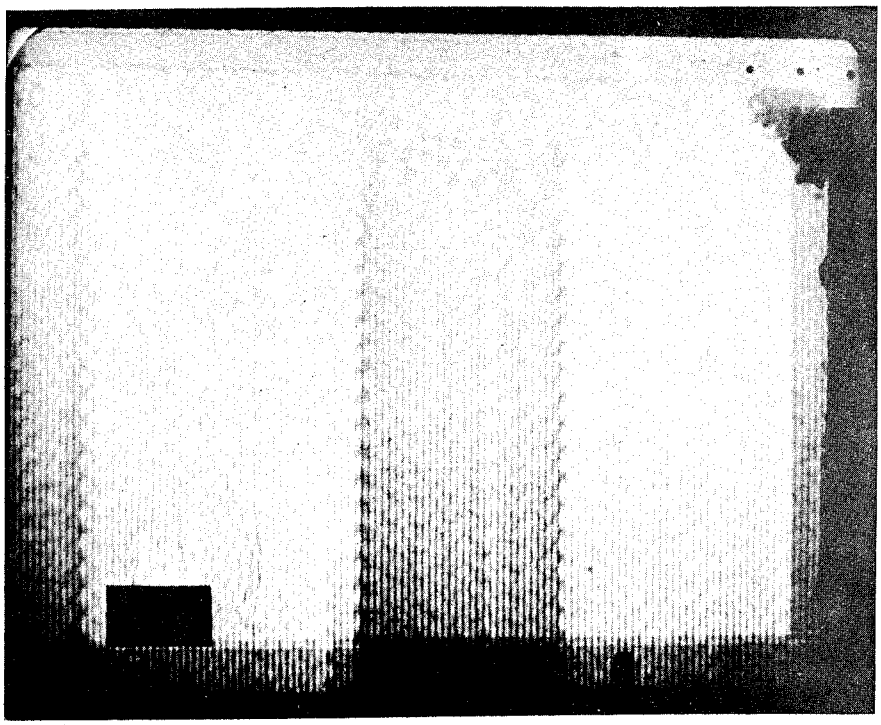

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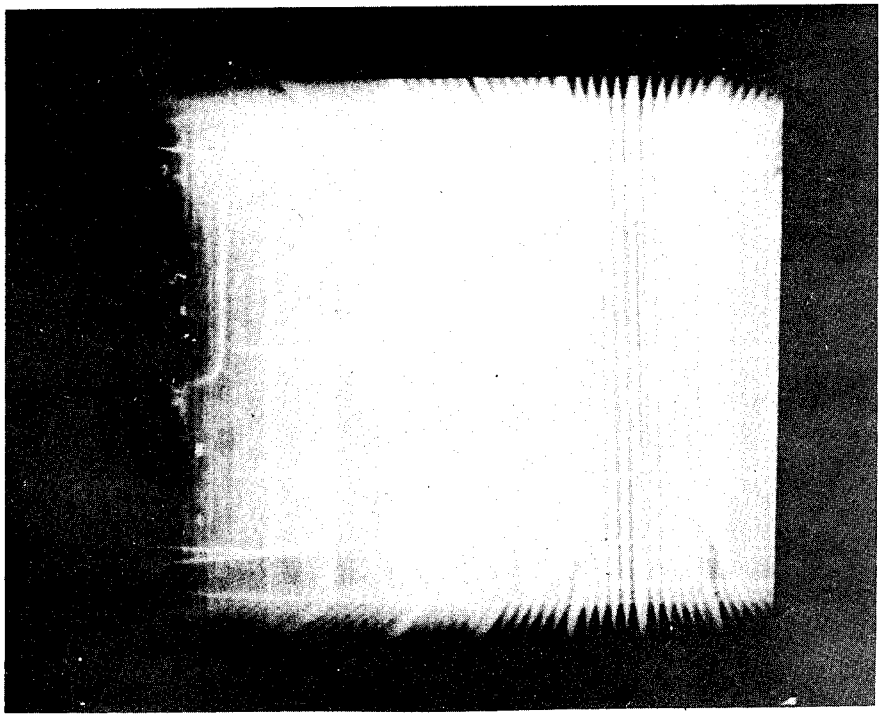

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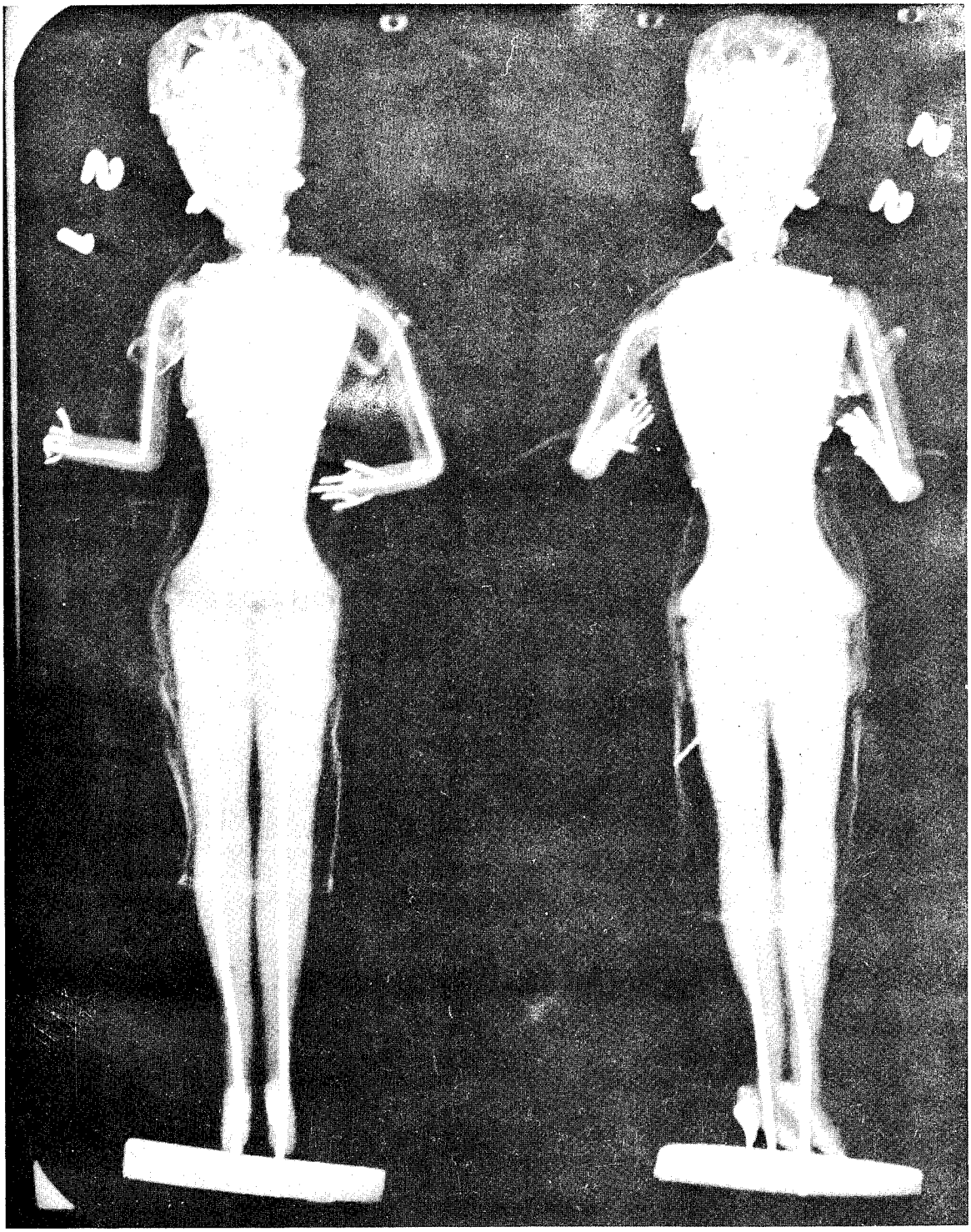

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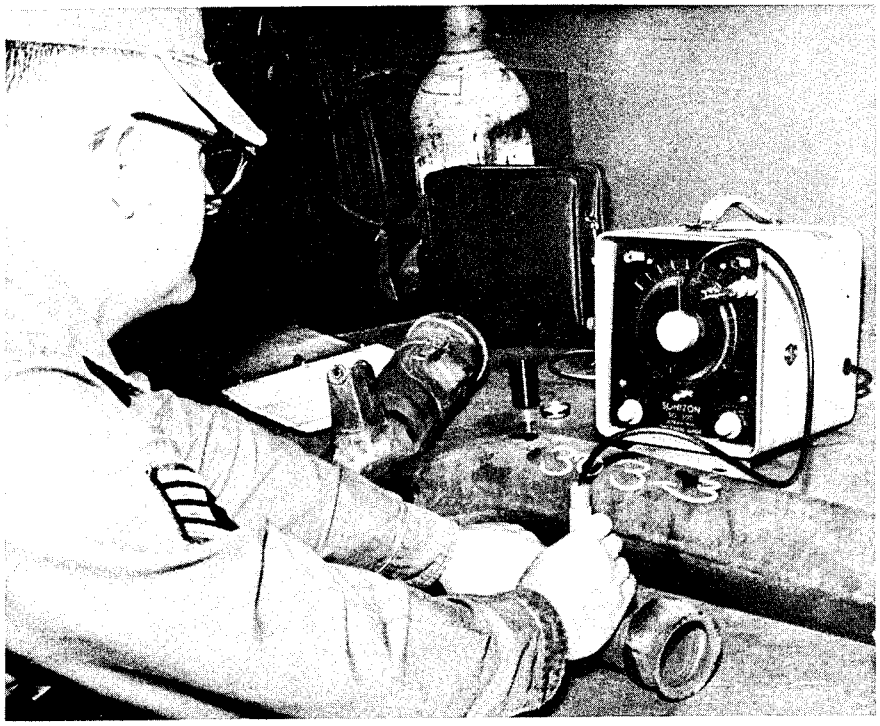


Figure 9.

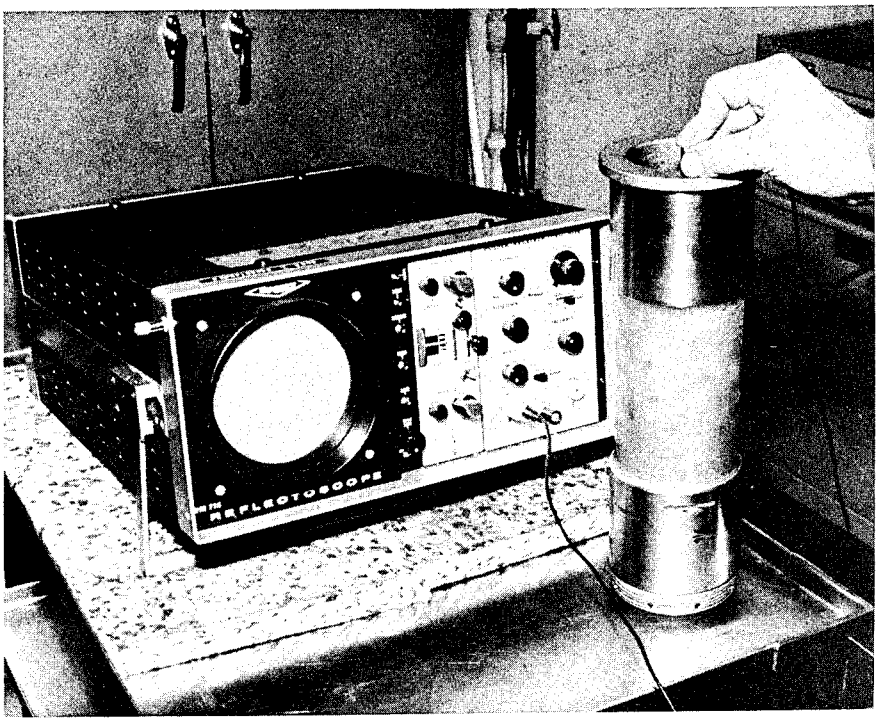
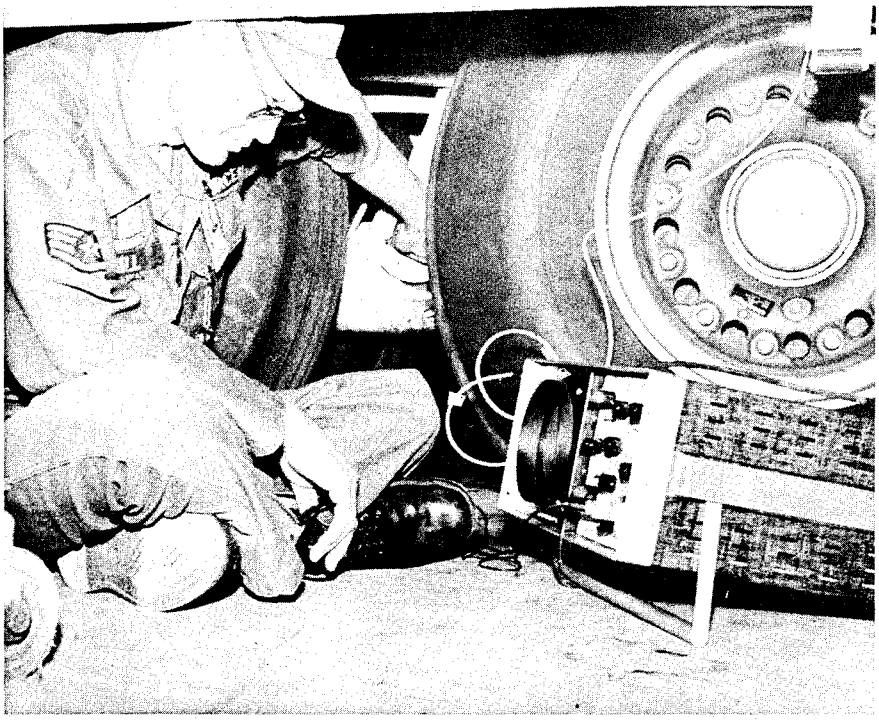


Figure 10.



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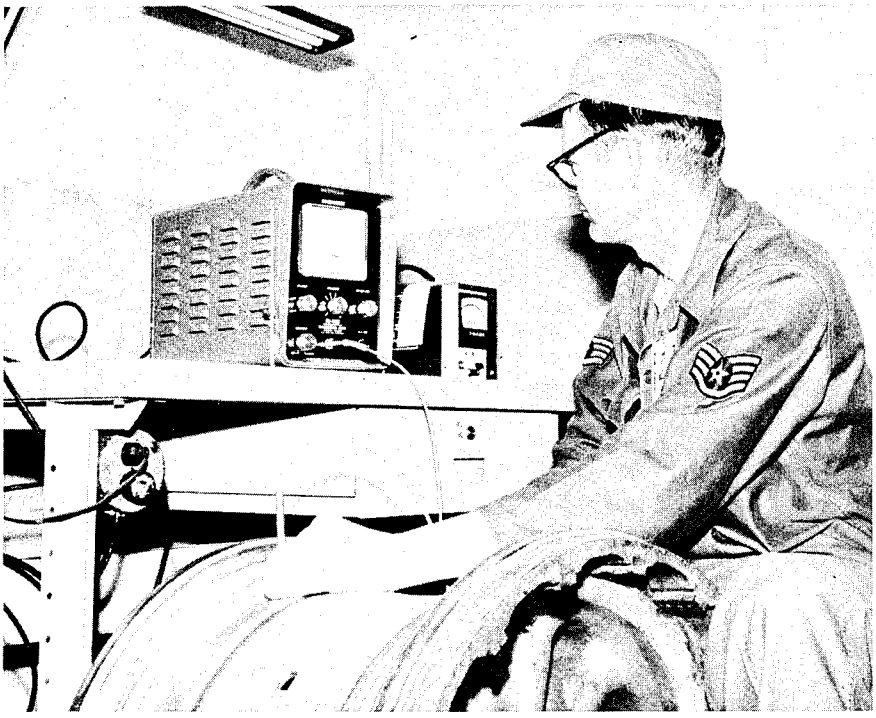

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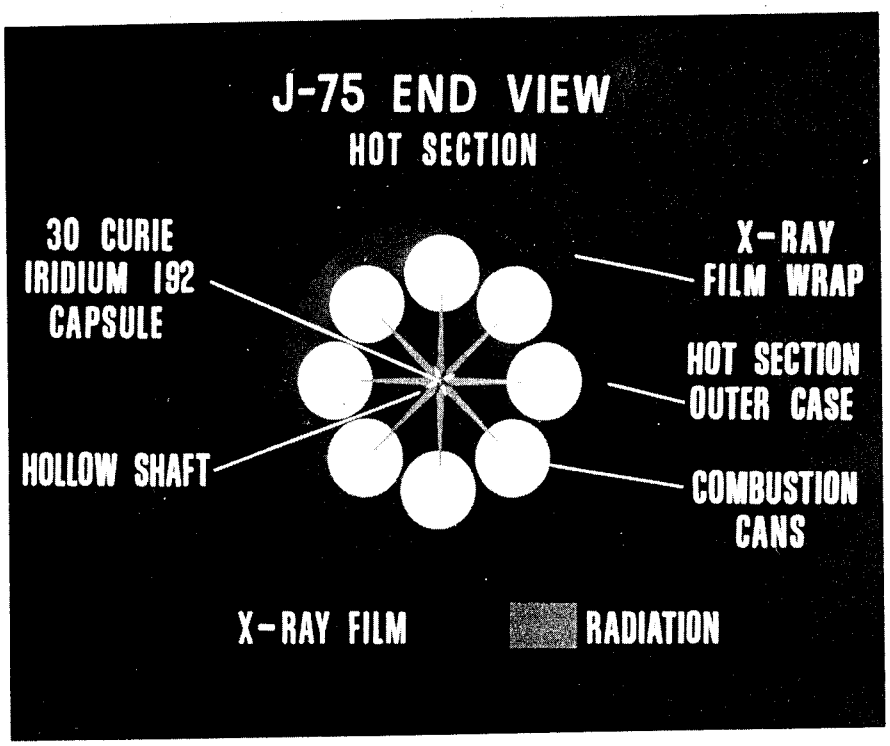

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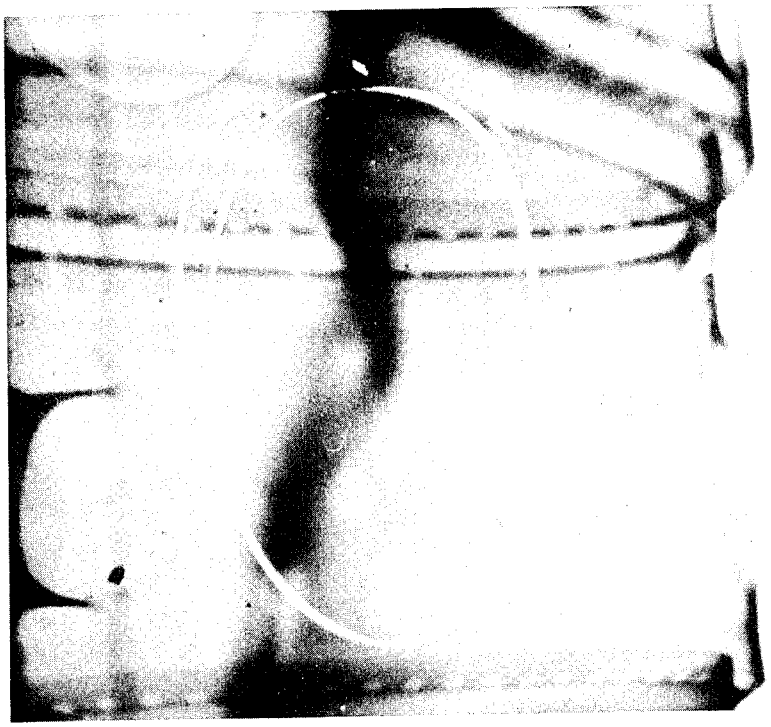

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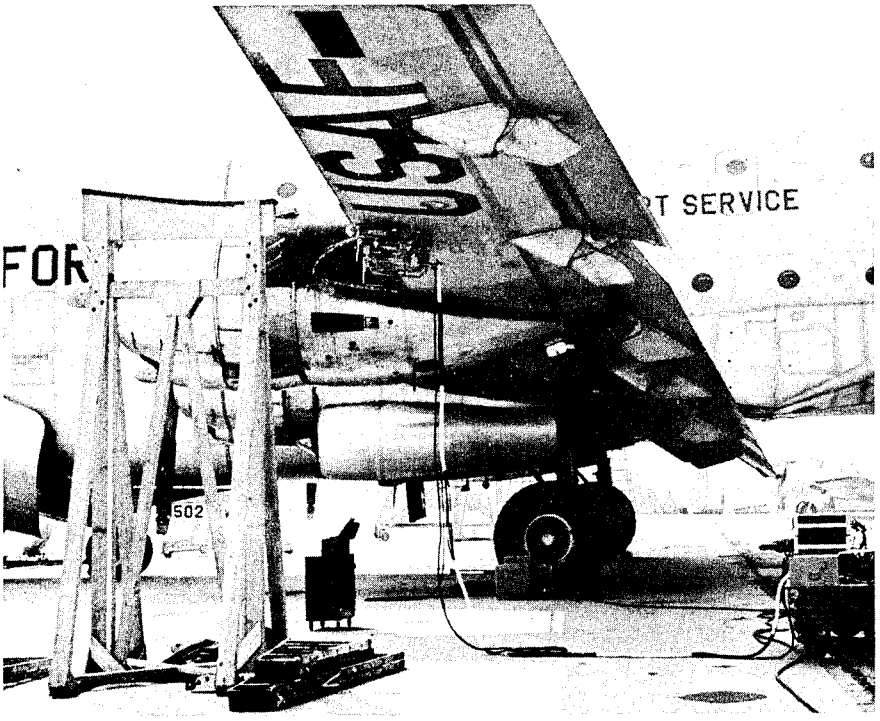

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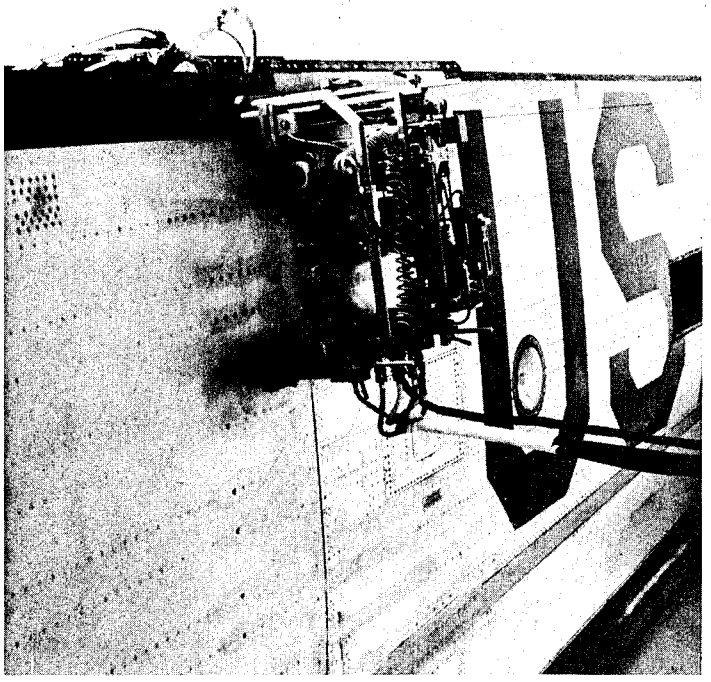

Figure 16.

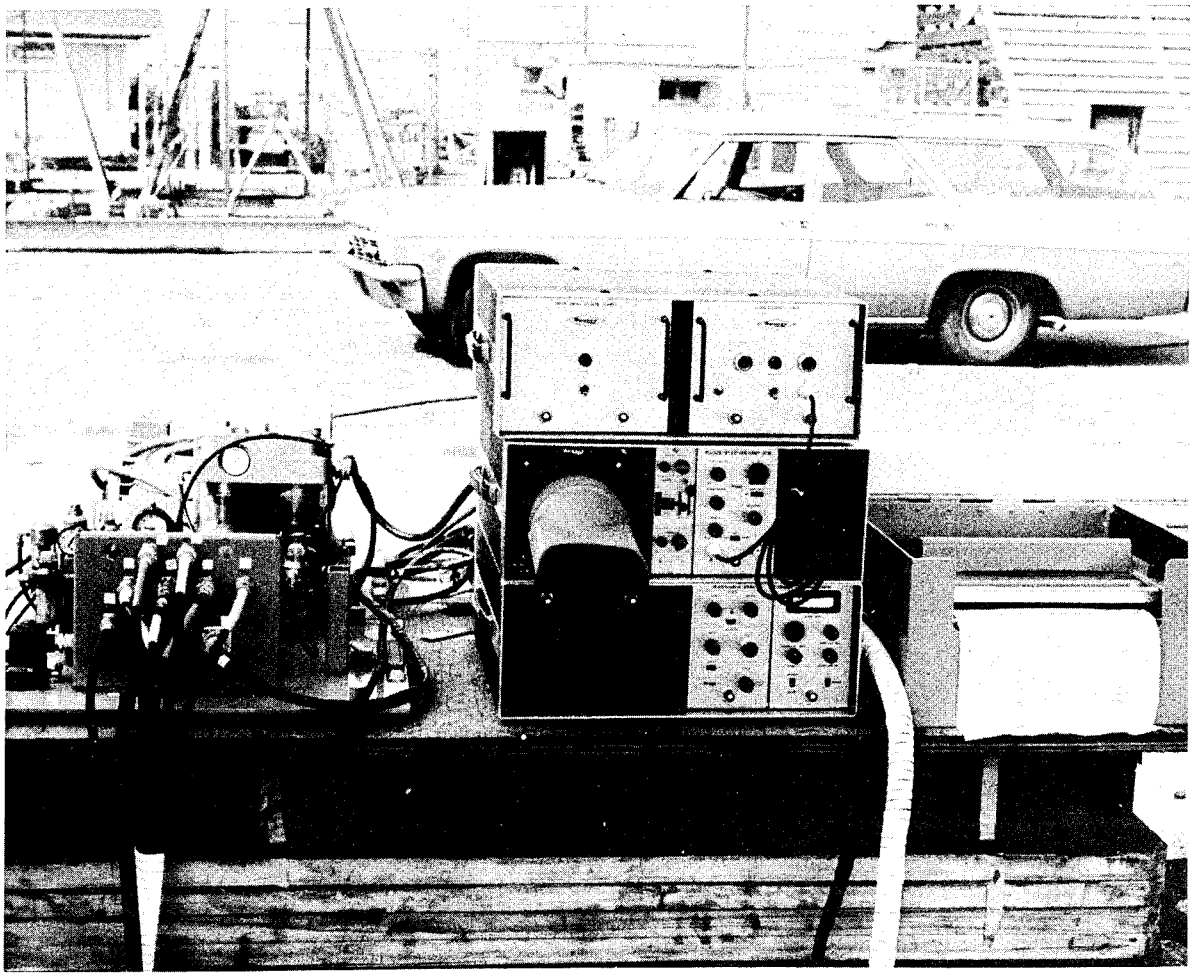

Figure 17.

SPECIAL HANDOUT REPORTS

10970-04

REPORT I - QUALITY ASSURANCE TESTING OF METAL TO METAL BONDING FOR AIRCRAFT STRUCTURES

Mr. Edmond Lemaster
Air Force Quality Assurance
Policies, Procedures and
Engineering Branch
AF Plant 13, Wichita, Kansas

The use of adhesives has existed for as long as thirty-three hundred years. Formulas, several centuries old, are in existence for making adhesives from fish, eggs, stag horns and numerous other strange ingredients. Unfortunately, there was very little advance in adhesive technology until the 20th Century and most of the developments have been concentrated within the past twenty years. It is worth noting that in spite of this historical background, adhesive bonding is, or has been, rarely used for primary loaded structures. Bonding techniques have been relegated to the joining or bonding of secondary, noncritical assemblies. The reasons underlying this philosophy are more mental than they are physical. Certainly, the reason is not due to the lack of strength of the bonded surface or joint. You are probably familiar with the much publicized demonstration where a truck is lifted by a bonded surface only one square inch. Perhaps some of you have seen examples of broken castings that have been bonded and subsequently tested to failure with the bonded joint remaining completely intact. Strength, at the bonded area, is present. What is lacking is reliability. For bonding to be effectively used in critical aircraft structures, there must be a high degree of confidence and reliability. The probability of a single, random failure which can mean the loss of the weapon system, cannot be tolerated.

Briefly, you are reminded of the processes used to provide a bonded structure in today's military aircraft. When an assembly is selected for metalbonding, parts are preformed, cleaned and placed in a tool or jig. Heat is applied to cure the adhesive. During the cure cycle, some means of maintaining positive pressure is used. Three important factors must be emphasized for the control of quality in the finished product.

1. Absolute cleanliness must be controlled during the lay-up operation.

2. Curing time and temperature must meet the requirements of the adhesives used.

3. An acceptable method of applying the required pressure, uniformly over the entire part, during the cure process is essential.

Failure to comply with these requirements can produce an unacceptable assembly.

Inspection procedures for determining the adequacy of the bonding process also presents difficulties. One method, and perhaps the earliest, was the tear-up process. A selected quantity of the first production assemblies was destructively tested to determine that the process and tools were adequate and that the time-temperature-pressure cure cycle was satisfactory. The economics associated with this quality control procedure were recognized early. It is not uncommon for a weapon system bonded assembly to represent a value in excess of 20 or 30 thousand dollars. It is quite self evident that a manufacturer of bonded assemblies cannot tolerate this type of scrap cost for an extended period of time.

To eliminate the need for destructively testing, the practice of preparing test specimens was initiated. These test specimens were prepared at the same time, under the same conditions, using the same methods as the production assembly. The specimens are placed adjacent to the assembly so that they experience the same temperature-time-pressure cycle as the end product. The test specimens are then destructively inspected and the results used as accept-reject criteria for the assembly. Criticism has been directed toward this approach in that it verifies the process and quality of the specimen only with secondary information provided regarding the quality and integrity of the bonded assembly. Production assemblies have been known to fail even though the test samples provided satisfactory results. The cause of failure can usually be traced to loss of control of one of the three fundamentals mentioned earlier, lack of cleanliness, lack of adequate pressure or deviations from the time-temperature cure cycle.

To assure additional data regarding the quality, integrity, reliability of the finished product, various nondestructive testing methods have been explored and implemented. Those receiving the widest acceptance have been X-ray, ultrasonic and sonic tests.

X-ray examination will give reliable information as to the condition of the assembly after processing. Of particular interest is the structure of the honeycomb core and a determination of the integrity of the honeycomb cell, has it been crushed, is it in the proper position or location, that is, has it or has it not shifted. Also, if foam fill is used in small cavity areas, X-ray can be used to determine if these cavities are adequately filled. X-ray examination however, provides minimal information regarding the quality or strength of the bond existing between the various elements within the assembly.

Sonic and ultrasonic test methods currently available provide some information regarding bond strength. The word "some" is emphasized and must not be disregarded. Not one of the inspection techniques available at this time will answer all of the questions regarding the quality of the bonding application. The pulse echo ultrasonic techniques have been generally successful in detecting the presence of porosity in a bond line for the case of

metal-to-metal bonds. When through-techniques are used, it is possible to evaluate the strength of a section containing honeycomb. Ultrasonic methods function on the basis of determining the ability of a part to transmit sound. If a metal-to-metal lap joint is inspected by pulse echo techniques and exhibits good sound transmission characteristics, the bond is assumed to be free of voids and porosity. The acceptance of this fact as true accounts for the success and general application of this method. One disadvantage is that it is possible to have sound transmission through a weak joint. This can result from contamination during fabrication. Contamination can seriously degrade bonding strength and yet permit sound to pass across it. Awareness of this limitation, the ultrasonic inspection technique for detecting porosity in a bond line, should alert the technician to determine the adequacy and accuracy of the pressure used in the cure cycle.

To a lesser degree, sound transmission characteristics can be used to evaluate the bond in terms of its time-temperature cycle. It should be mentioned that the correlation here is not as good as the correlation to porosity. The presence of an oily contaminate in a bond line can totally destroy bond strength while permitting sound transmission thereby indicating an acceptable bond.

The Fokker Bond Tester functions with high frequency sound. The principle of operation differ from those of pulse echo techniques. In the Fokker, a transducer is used to measure the amount of ultrasonic acoustical loading that a part will exert on the test crystal. Should a void or porous bond line be present under the transducer, a substantially different instrument response will be obtained when compared to the response of an acceptable bond. Under certain circumstances, it has been possible to correlate the response of the Fokker Bond Tester to the ultimate strength of a lap shear joint. The disadvantage indicated for the pulse echo technique also apply to the Fokker evaluation. The instrument functions on a basis of sound transmission in and through the part. Conditions which can degrade the bond, yet transmit sound, are not reliably detected with this instrument.

Finally, for a sonic test, one invariably reverts to the famous Half Dollar Test. It is said that an experienced inspector can tap a bonded structure with a half dollar and make an acceptable evaluation of the quality of the bonding process. The fact that this statement is, and can be made, is an indication of the inadequacy of the test generally availabe for bonded structure.

The costs associated with destructive testing have been previously indicated. They are excessive. Costs associated with nondestructive ultrasonic tests are substantially reduced but are considered to be expensive. For the pulse echo and the through-transmission techniques, only a small area of the bond can be evaluated at a given time. The search transducer must be scanned over the entire surface of the part being inspected. This normally requires expensive and elaborate automatic scanning and recording equipment. Inspection time is necessarily time consuming. When the Fokker Bond Tester is used, expensive equipment is not normally required. However, a large

amount of inspection is necessary for the technician to hand scan the surface of the part. In the Half Dollar Test, equipment is readily available and inexpensive. Training and experience are the priceless ingredients. The time honored adage seems to apply: You get what you pay for.

Against this background, it is appropriate to suggest some of the advantages associated with the newer techniques in thermal and infrared bond testing. The principles supporting these methods are relatively simple. A heat source is applied to the part to be tested. The surface temperature will be determined by the ability of the part to transfer the heat away from the area being inspected. If the temperature over the surface is measured and recorded, it will result in a thermal pattern representative of the bond beneath the surface. A hot spot will result over a poor bond. A cold spot will result over a defective bond. What is needed to make this a useful test technique is an adequate means of observing and recording these temperature patterns.

Two methods have recently become available for recording the variation of surface temperatures on the test object. They are infrared radiation systems and liquid crystals.

Infrared radiation, or heat radiation, can be detected by special sensitive TV vidicon tubes. When these tubes are a part of a closed circuit TV system it is impossible to see the "glow" of a mildly heated object and to see variations in the surface temperature of that object. During the last few years the sensitivity of infrared detectors has been lowered to the point that this kind of detection can be accomplished at or slightly above ambient temperature. When this technique is applied to the evaluation of a bonded structure, the part is heated and the nonuniformity in surface temperature can be associated with poor thermoconductivity of the bond, which, in turn, can be related to total void or general porosity in the bond line.

The liquid crystal method is employed in a similar manner, by applying the liquid to the surface, application of mild heat and observing the rather prominent color changes that occur as the certain point goes through the critical temperature. Hot spots, associated with poor bonding, can be readily seen by a vivid color against a black or dark background.

Your first question about these new methods might well be, do they detect all of the unbonded conditions? The answer is NO! Any defect type which will permit uniform heat glow through the bond joint and still result in a loss of strength cannot be detected by these systems. Your next question might be, what advantage do these two systems offer over the older methods? The answer is primarily one of economics. These thermal techniques make it impossible to inspect the entire surface of the part at one time. When compared with the need of detail scanning under the ultrasonic techniques, the savings in manhours and production flow time can be rapidly translated into dollar savings for the manufacturer and the customer.

Methods used in the fabrication and inspection of bonded structures have been presented. Assurance of specified reliability have been considered.

Test method, currently in use or coming into focus, have been presented. The most recent systems now under consideration have known disadvantages even before they have been put into extensive use. However, the newer methods do represent a substantial improvement over those used previously. Prior to extending the full measure of confidence necessary for the use of bonded structures in primary load carrying applications, there must be additional assurance of the adequacy of quality control and the satisfactory compliance with required reliability. These assurances are not yet available.

There will surely be a large number of additional methods proposed and abandoned before an acceptable inspection technique is firmly established. For as long as the principles applied to bonding and bond testing are in the area somewhere between the art and the science, reliance will rest heavily on the ability of the artist to do his best work.

10970-05

REPORT 2 - AN ULTRASONIC METHOD FOR MEASURING THE THICKNESS OF NOSE CONE ANNULI

Mr. Louis C. Cardinal
U.S. Naval Research Laboratory
Washington, D. C. 20390

INTRODUCTION

Personnel of the Harry Diamond Laboratories approached us with a problem concerning the need of a method to measure the thickness of proximity fuse nose cone annuli to within $\pm$ 0.005 inches. The nose cones were made of molded polyethylene. Figure 1 shows construction at the end. Section F-F of Figure 1 is a cross-sectional view of the nose and annulus of the cone. The specified thickness of the annulus was 0.050 + 0.008 inches. Since there were already approximately one thousand of these proximity fuse nose cones assembled, thickness measurements could only be made from the outside of the annulus.

INSPECTION TECHNIQUE

The use of any contact ultrasonic technique was immediately ruled out because the inspection surfaces were irregular and the total transit time of the ultrasonic energy through the material was so short. Transit times ranging from 0.6 to 1.2 usecs were encountered. This corresponds to polyethylene thickness ranging from 0.025 to 0.050 inches.

A water column technique was established which eliminated the problems encountered when using standard contact methods. A special jig to hold the transducer and cone was fabricated. The technique is shown in Figure 2. The axis of the cone was purposely moved off center from the transducer axis so that the thickness of the area in question could be measured. The jig was filled with water and the cone rotated on its axis. The transducer was tied into the ultrasonic test equipment which in this particular case was an Immerscope. Since there is only a limited amount of horizontal sweep expansion available on all ultrasonic test instruments, use of an auxiliary oscilloscope was necessary to obtain the necessary sweep expansion for the short time durations being observed. The video output of the Immerscope was fed to a Tektronix Type 585A oscilloscope for this reason.

Figure 2 shows a Branson 10 mc 0.5 inch diameter Type Z transducer. This size transducer produces a beam which is large enough to give only an average

thickness measurement because the beam covers such a large area -- approximately equivalent to a circle 0.375 inches in diameter. To concentrate the sound beam to only a small area one must use a "beam restrictor". This can be accomplished by either collimation or by placing a disc of sound absorbing material with a small central orifice over the transducer face.

There are now available from several manufacturers small transducers such as the one shown in Figure 3. This particular unit is a 5 mc, 0.010 inch diameter Type PZT transducer mounted in a hypodermic needle. It was manufactured by NORTEC Inc., of Richland, Washington. This is the unit which was used to measure the thickness of the cones.

EQUIPMENT CALIBRATION

Calibration of the Type 585A oscilloscope sweep was not necessary, but in order to select the proper sweep length to cover the polyethylene thickness range of 0.020 inches to 0.60 inches, three individual thicknesses of polyethylene sheet material were used. Figures 4, 5, and 6 are oscillograms obtained with these thicknesses. The oscilloscope sweep represents 0.2 usecs/cm. Since such a short sweep time was used, the pulses became spread out and the start of the rise of the pulse is a little uncertain. Therefore times between peaks were used. Note the change in spacing between the 0.0615 inch thick sheet and the 0.028 inch thick sheet.

The first peak (left) is the echo received from the water to polyethylene interface; the second peak (right) is the echo reflected from the opposite side of the polyethylene sheet. In each case the opposite side was air-backed.

TEST PROCEDURE AND RESULTS

Several nose cones were furnished for the test. One which was submitted as a good cone was marked "OK". This cone was used as a standard.

Each cone was placed in the jig, as shown in Figures 2 and 3 and slowly rotated on its axis through 360^{o}. The minimum thickness point was noted and recorded. Minimum thickness is the point where minimum spacing between the two peaks is observed on the oscilloscope screen.

Figure 7 is an oscillogram of the cone marked "OK". There was very little thickness variation noted when this cone was rotated. Comparing Figure 7 with Figure 5 shows the accuracy obtainable. This accuracy is approximately $\pm$ 0.002 inches.

Figures 8, 9, 10, and 11 are oscillograms taken every 90^{o} of a cone marked "2-E", which was considered the worst thickness variation encountered in any of the cones tested. This also shows the need to rotate through 360^{o} for each cone using a restricted beam, because if by chance only one measurement had been made at, for example, the 180^{o} position (Figure 10), the cone would have been considered good.

Table 1 lists the ten cones tested and the minimum thickness measured in each case.

CONCLUSIONS

It is feasible to use ultrasonics to measure the thickness of the annulus of a polyethylene nose cone to an accuracy of $\pm$ 0.005 inches provided the proper techniques are observed. The measurements can be accomplished using standard equipment and a "jig" as shown in Figures 2 and 3. The average time to check a nose cone is approximately one minute.

Table 1

H.D. Lab Designation	Min. Thickness in inches
OK	0.050
1-A	0.041
1-B	0.032
1-G	0.041
2-E	0.026
2-F	0.028
2-H	0.021
3-F	0.028
4-E	0.032
4-F	0.032

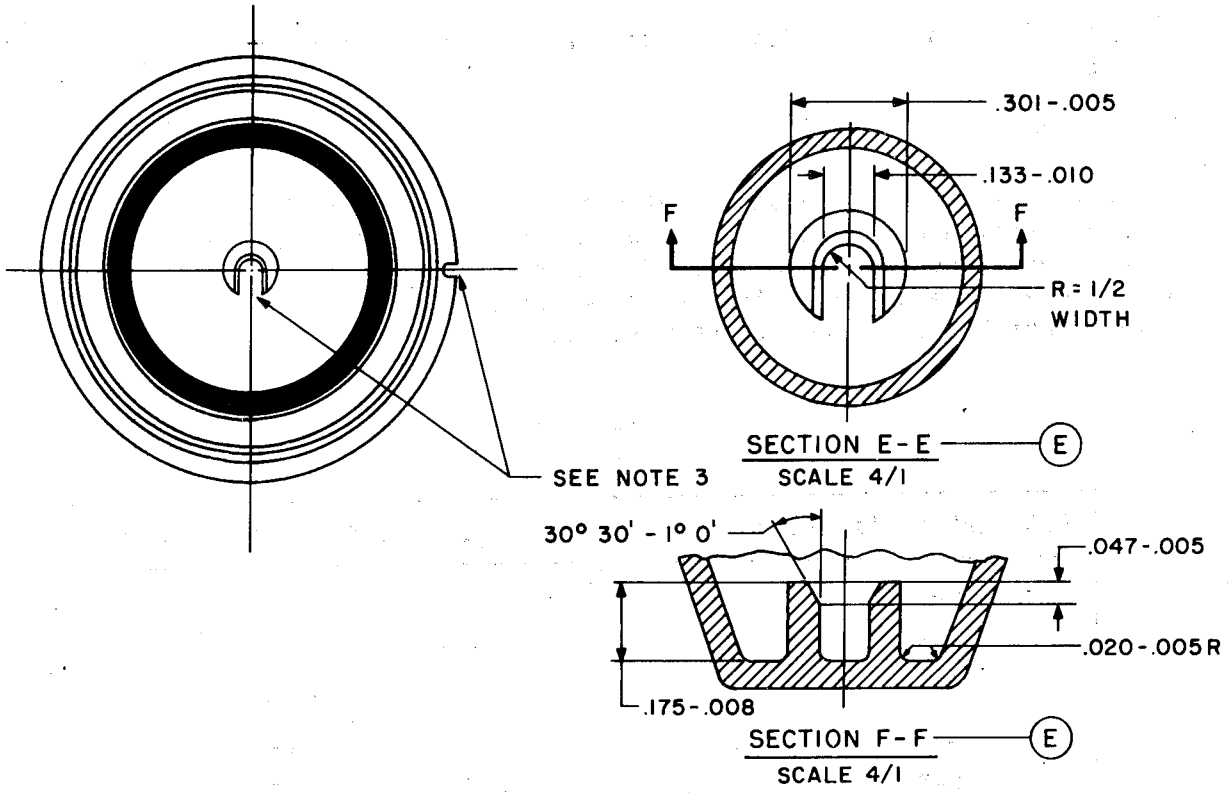

Figure 1.

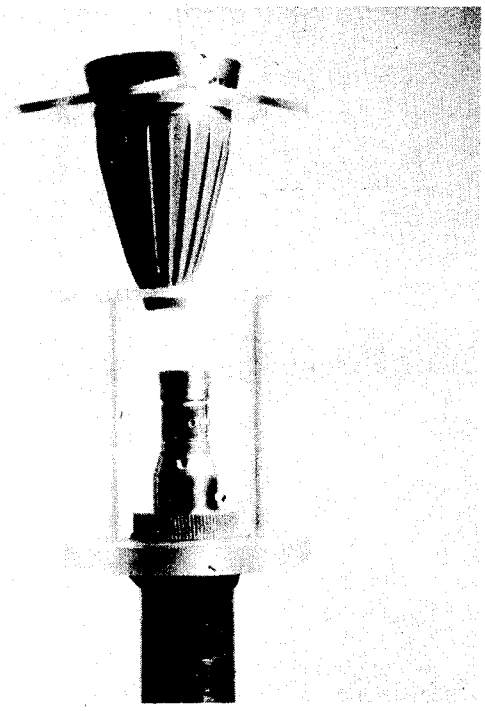

Figure 2.

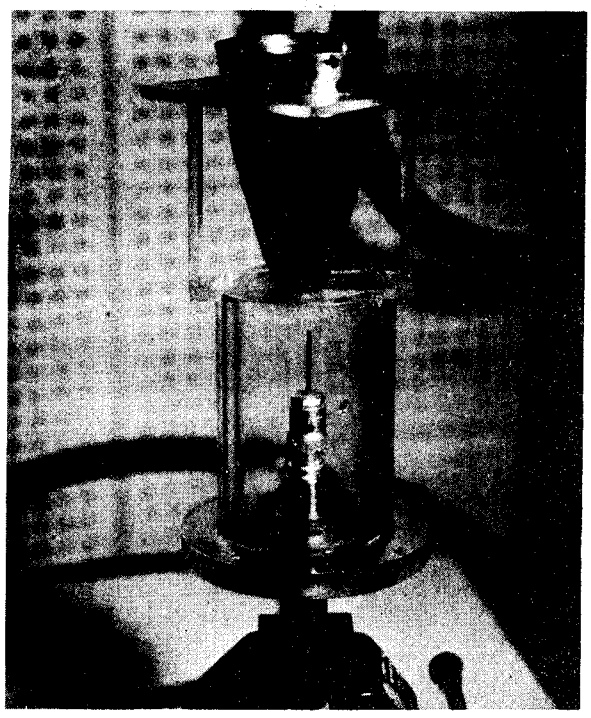

Figure 3.

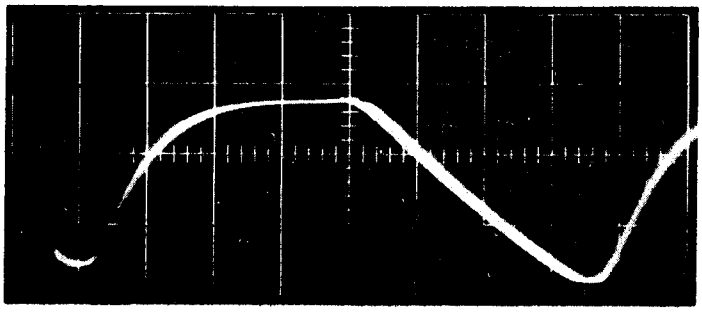

Figure 4. Polyethylene 0.0615"

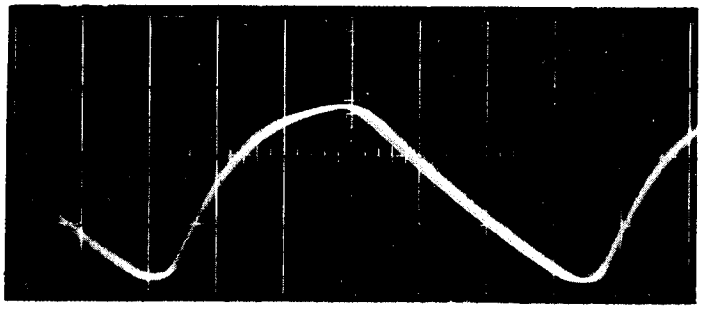

Figure 5. Polyethylene 0.051"

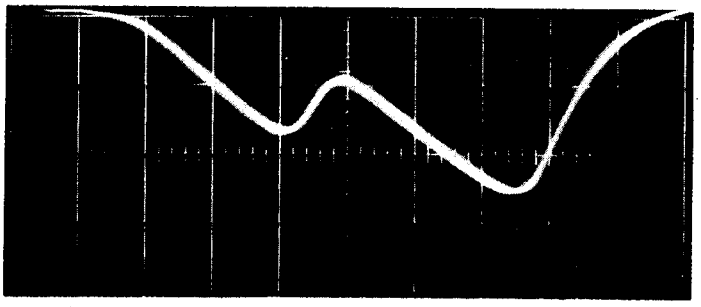

Figure 6. Polyethylene 0.028"

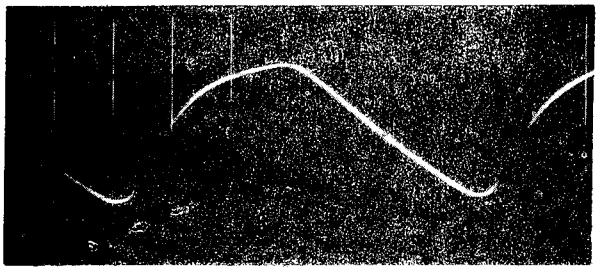

Figure 7. Standard (Marked "OK") 0.050"

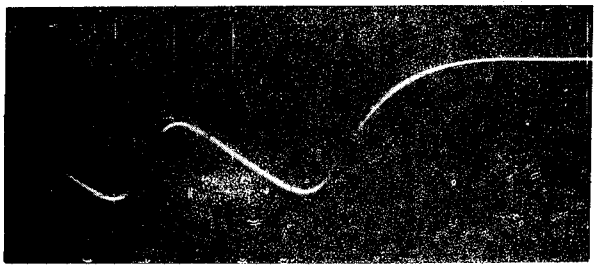

Figure 8. 2-E 0^{O}-0.026"

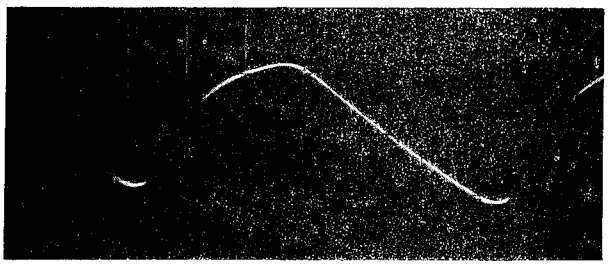

Figure 9. 2-E 90^{O}-0.039"

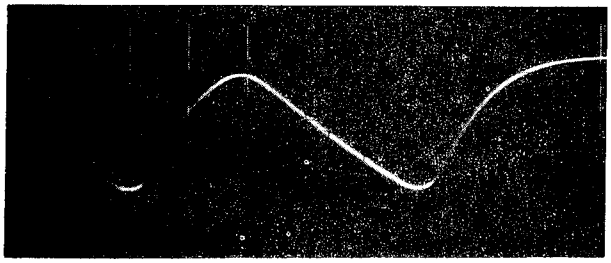

Figure 10. 2-E 180^{O}-0.049"

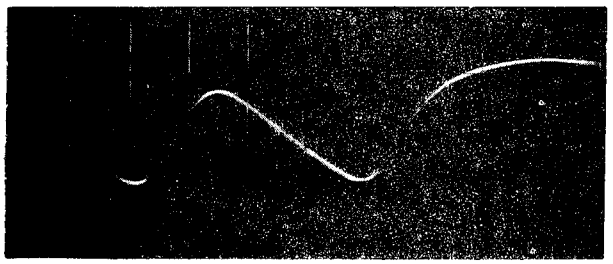

Figure 11. 2-E 270^{O}-0.032"

REPORTS OF PANELS

SUMMARY REPORT OF PROBLEM NO. I

SEPARATION OF THE BASE ADAPTER FROM THE 81MM MORTAR SHELL

Mr. Richard R. Rowand
Problem Coordinator

The problem as outlined on page 7 of the program and given in the published text of the conference essentially concerns the integrity of the brazed joint of the base adapter in the 81 mm mortar shell.

The subject was excellently presented by Mr. Barr. The essential information was provided for the consideration and recommendations of the panel and conference members.

In addition to the definition of the major problem area, the brazing techniques used and the quality control measures pursued were discussed in detail and are considered to be adequate. A suggestion was made that ultrasonic cleaning should be considered and/or evaluated for assuring cleanliness of the mating surfaces in lieu of or in addition to present methods.

Mr. Barr also listed the current steps of final production acceptance which include both internal and external visual inspection, hydrostatic testing, immersed air testing, statistically sampled destructive evaluation and finally, sample firing and recovery analysis.

The two major goals and the reasons for presenting this problem are:

1. To improve shell reliability.

2. To use NDT to reduce destructive test requirements.

In summarizing both the floor and panel discussions, it was determined that a method which would permit 100 percent inspection would be desirable and sufficient time would be available during production for such an inspection providing an automated system could be developed for in-line use.

It was also determined that only in a qualitative sense is the relationship between strength and per cent bond actually known. Of the many techniques suggested, the panel has chosen ultrasonic methods as perhaps most likely to provide a timely solution. All radiographic techniques which were considered were not sufficiently advanced or were considered to be too

time consuming. Electrical resistance testing was also suggested but would involve considerable development effort. Torque testing of the base adapter was also suggested; but again, this would require a major developmental effort to perfect adequate techniques.

During the panel discussion, it was learned that Picatinny Arsenal is currently developing a "push test" to evaluate the integrity of the base adapter-shell body braze joint which will be able to exceed the current limitations of the hydrostatic test. This development should permit the accumulation of strength data and in turn the possibility of correlation with ultrasonically observable quality factors.

It is, therefore, the panel's recommendation that both pulse echo and through transmission ultrasonic techniques be considered, keeping in mind the need ultimately for an automated system to inspect total joint integrity.

Concepts such as those being developed for the Air Force Materials Laboratory and the Army Materials Research Agency (AMRA) under contract with the International Harvester Company for measuring material cleanliness may ultimately be of assistance in problem areas such as this one.

Mr. Otto Gericke, AMRA, has graciously consented to assist in an initial evaluation of ultrasonic techniques applied to this problem.

As problem coordinator, I wish to thank both Mr. Barr for the excellent manner in which he covered this problem and also Mr. Scollins for his contributions during the discussion period. I also wish to express my appreciation for the excellent response of both conferees and panel members.

SUMMARY REPORT OF PROBLEM NO. 2

NDT OF TORPEDO WELDS - U.S. NAVAL TORPEDO STATION

Mr. D. Stein
Problem Coordinator

For discussion purposes, the Warhead Mark 37 was selected by the presenter to typify a general problem of determining quality of weld in torpedo parts. The quality of the several welds is defined by various specifications in terms of radiographic requirements. Although radiography of the five weld areas is being done, the problem reduced to the following:

HOW COULD THE RADIOGRAPHIC TECHNIQUES CURRENTLY IN USE BE IMPROVED TO ACHIEVE THE DESIRED SENSITIVITY?

Factors contributing to the problem are:

1. Excessive distance of film from the weld.

2. Inclusion of extraneous metallic mass in the radiography.

It is important to recognize that if another NDT method is used, the user must embark on a program to establish acceptance standards for this method which equate to the radiographic standards. This is not considered to be a minor effort in terms of time and money.

Several probing questions tried to bypass the radiographic method, and were aimed at strength tests for the welds. However, we must presume that certain correlative testing was performed to relate radiographic weld quality with the integrity of the welds. If this is not the case, then we are in the realm of a completely new problem, and its resolution must take precedence over the problem presented by Mr. Turbitt. Thus we return to the basic consideration of how to achieve an improved radiographic sensitivity for the torpedo welds.

Several suggestions involved relocation of the X-ray beam for coverage of the welds. Mr. Turbitt has detailed notes on these.

Additionally, suggestions considered worthy of further exploration are:

1. Use a radioactive pellet, or ring (or ring sector to facilitate locating and removing) containing a radioisotope, such as thulium, or other low energy radioactive sources.

2. Use a scatterer material (Cu or Al), and make use of secondary radiation.

Mr. Turbitt has detailed notes on the above.

Finally, should it be necessary, it was considered that Image Intensifying Fluoroscopy with Magnification was worthy of investigation.

Mr. Turbitt has asked me to express his gratitude for the assistance he received from this Conference.

SUMMARY REPORT OF PROBLEM NO. 3

NDT OF 400 GALLON WATER TANK - U.S. ARMY TANK AUTOMOTIVE CENTER

Mr. E. Iverson
Problem Coordinator

The problem coordinators and technical consultants carefully considered the two basic characteristics requiring evaluation. They were:

1. Voids in the foam.

2. Lack of bond between the foam and fiberglass outer and inner shell.

During the discussion of NDT techniques, several methods were discussed that may have merit, however, in many of these methods no research was available to substantiate recommendations. For example:

1. Microwave NDT has possibility for performing this inspection and Miss Lavelle, Frankford Arsenal, has volunteered to experiment with sections of the tank to investigate microwave possibilities.

2. Radiographic methods were discussed, however, it was believed that bond separation would be difficult to show, and secondly, radiographic inspections could prove expensive and time consuming.

3. Audiosonic methods have potential, however, at present, no proven technique was known to the group for implementation.

4. Ultrasonic methods appear to have the greatest potential. As stated by Mr. Gamache during his presentation, the U.S. Army Tank Automotive Center has experimented with low frequency ultrasonics, using continuous wave thru-transmission.

The technical consultants appeared to be in agreement that ultrasonics could be used to detect both voids in the foam and lack of bond to the outer and inner shell. Experiments have proven that voids can be detected of much smaller size than that considered important in this project. Also, other experiments proved that separations of materials can also be detected.

The personnel from the U.S. Army Tank-Automotive Center reported that their project is proving to be equally reliable through the use of ultra-

sonics. They still have problems to be resolved however. It appears that they can now continue their research with the knowledge that the NDT specialists within DOD confirm ultrasonics as being the most feasible approach to the problem.

SUMMARY REPORT OF PROBLEM NO. 4

CRACK DEPTH MEASUREMENT IN TEE-WELDED PLATE FATIGUE SPECIMENS - U.S. NAVAL APPLIED SCIENCE LABORATORY

Mr. B. Mondress
Problem Coordination

You will recall that this problem refers to the measurement of crack depth in welded plates. Specifically, it concerns both tee welds and butt welds in plates used as fatigue specimens. Thus, it is not a production problem at the moment, but a search for an accurate method of correlating crack propagation as a function of the number of test cycles.

The problem was presented by Mr. Goldspiel of the U.S. Naval Applied Science Laboratory in Brooklyn, N.Y. First, he explained the conventional "back reflection" ultrasonic method that was in use at the time the problem was first submitted. He stated that the agreement between the ultrasonic readings and the measurements made after sectioning the specimens was, at best, only fair. The reason for this was the oversimplification in the computed value of depth caused by ignoring the finite beam width of the energy source.

The presenter then explained the work done since the original submission of the problem. This concerns the more promising "Direct Reflection" method. The derived expressions, in this case, do consider beam width and can account for positive and negative angles of inclination of the crack. The correlation between the ultrasonic readings and physical measurements, with this method, was greatly improved.

Mr. Goldspiel requested criticism of his technique, and methods by which it could be supplemented or improved. He stated that many points needed clarification, for example:

1. How do we define the true depth of the crack?

2. How do we account for changes in direction or angle?

3. How do we treat cracks too tight for proper energy penetration?

At a later meeting with the technical consultants and other interested persons, the problem was discussed in more detail. After certain aspects

of the instrumentation were explained, it was generally agreed that the approach was a sound one and that the "direct reflection" technique should be pursued further.

It was suggested that the available equipment be applied to a current test program at the Taylor Model Basin. This program concerns fatigue testing of very large diameter pressure vessels, on which all types of welds are applied. This would get the work "out of the lab" and provide an excellent chance for evaluation.

It was also suggested that the presenters consider the use of focus transducers to supplement the results obtained with their equipment. These transducers attempt to achieve a constant diameter beam and may be of value in this case.

The possible application of radiography was considered briefly. However, it was stated that although it might be useful for shallow cracks, the inherent wandering of deeper cracks would make it unsuitable for their measurement.

Finally, a comment was made after the meeting that work on magnetic field changes as a measure of crack depth, had been done. Studies are now being made at AMRA to effect the proper D.C. field penetration to obtain a useful correlation with crack depth.

Thanks are due to Mr. Goldspiel for an excellent presentation of the problem and to the people that contributed to the later discussion.

SUMMARY REPORT OF PROBLEM NO. 5

DUCTILITY ON ELONGATION DETERMINATION OF SINTERED IRON ROTATING BANDS FOR ARTILLERY SHELLS - PICATINNY ARSENAL

Mr. L. Cardinal
Problem Coordinator

This problem concerns the need for a more economical and reliable means of determining the ductility and tensile strength of sintered iron rotating bands for artillery shells. A nondestructive test method is desired, but if none is feasible, an improvement of the existing destructive methods will be of value.

At present, only a batch sampling method is used. Process control and failure analysis data are nonexistent since only a small percentage of the total number of rotating bands manufactured have been subjected to destructive tests and analysis.

Solutions suggested were as follows:

1. An improved mandrel design which will not only simplify the ductility test but can, with proper design, increase the reliability of such a test. [1]

2. Electromagnetic methods can only be used if the manufacturing variables are very closely controlled. [2]

3. Both the ductility and the tensile strength can be determined by measuring the sonic and ultrasonic velocity, provided the band material is of uniform density. [3]

4. Density variations can be detected by either radiography or ultrasonics. Radiography would be very useful for this purpose because of its simplicity.

5. The Naval Research Laboratory has offered to make preliminary sonic and ultrasonic velocity measurements.

6. The Naval Ordnance Laboratory has offered to make the preliminary radiographic density analysis.

REFERENCES

1. Suggestion submitted by Mr. Dunn, DCASR, New York.

2. Electromagnetic Studies of Sintered Components, Research Reports by Julian Rossinick of Frankford Arsenal.

3. Springfield Armory report #SA-TR19-1516 dated 6 March 1966 by K.A. Fowler and H.P. Hatch, Titled "Resonant Frequency Method For Evaluation of Sintered Powder Metal and Investment Cast Products."

STEERING COMMITTEE ELECTION RESULTS

The New Steering Committee For 1967 Is As Follows:

Stephen D. Hart (Executive Secretary)
Code 6254
Naval Research Laboratory
Washington, D.C. 20390

Lt. Col. W.F. Bennett
Hq. SAAMA (SANETP)
Kelly Air Force Base
Texas

David M. Moses
Defense Contract Administration Services Hq's
DSAH-FQES
Cameron Station
Alexandria, Virginia 22304

D.L. Gamache
U.S. Army Tank Automotive Center
Attn: SMOTA-QED
Warren, Michigan

John G. Turbitt
Naval Torpedo Station
Attn: Code 3345
Keyport, Washington

James E. Peale
Attn: WRNEAI
Robins Air Force Base
Georgia 31093

Ernest H. Rodgers
U.S. Army Materials Research Agency
Attn: AMXMR-TMT
Watertown, Mass. 02172

Address all correspondence pertaining to the 16th Conference (fall of 1967) to the Executive Secretary.

APPENDICES

APPENDIX I

LOCATIONS AND DATES OF PREVIOUS CONFERENCES

Organizational Meeting, Watertown Arsenal, Watertown, Massachusetts
3 - 4 Oct. 51

2nd Conference, Frankford Arsenal, Philadelphia, Pennsylvania
23 - 24 Jan. 52

3rd Conference, U.S. Naval Gun Factory, Washington, D.C.
19 - 20 Nov. 52

4th Conference, Research and Development Laboratories, Fort Belvoir, Virginia
17 - 18 Mar. 54

5th Conference, Naval Ordnance Plant, Indianapolis, Indiana
16 - 17 Mar. 55

6th Conference, Detroit Arsenal, Centerline, Michigan
9 - 10 Apr. 56

7th Conference, U.S. Naval Ordnance Test Station, China Lake, California
19 - 20 Feb. 57

8th Conference, San Antonio Air Materiel Area, Kelly Air Force Base, Texas
4 - 5 Dec. 57

9th Conference, Army Ballistic Missile Agency, Redstone Arsenal, Alabama
15 - 16 Oct. 58

10th Conference, Naval Air Material Center, Philadelphia, Pennsylvania
6 - 7 Oct. 59

11th Conference, Oklahoma City Air Materiel Area, Tinker Air Force Base, Oklahoma
13 - 15 Sep. 60

12th Conference, Natick Laboratories, Natick, Massachusetts
28 - 30 Aug. 61

13th Conference, Naval Ammunition Depot, Concord, California
25 - 27 Sep. 62

14th Conference, Robins Air Force Base, Georgia
25 - 27 Aug. 64

APPENDIX 2

LIST OF ATTENDEES AT FIFTEENTH ANNUAL DEFENSE CONFERENCE ON NONDESTRUCTIVE TESTING

Eddie S. Aguilar
Ch. Metal Processing
ATTN: MDMMF. 23
Hollomon A.F.B.
New Mexico

William H. Baer
Materials Research Laboratory
Engineer Research & Development Lab.
Fort Belvoir, Va. 22060

T/Sgt Floyd W. Baker
Hq ADC (ADMME-B/NDI)
Colorado Springs, Colo.

Nicholas T. Baldanza
Plastec, Bldg. 3401
Picatinny Arsenal
Dover, N.J.

Harold A. Baller
U.S. Army, Edgewood Arsenal
ATTN: SMUEA-QADE
Edgewood Arsenal
Maryland 21010

CW04 Stanley J. Baron
AFSWC (SWMM)
ATTN: Nondestructive Insp. Proj. Officer
Kirtland Air Force Base
New Mexico 87117

Commanding Officer
U.S. Army, Frankford Arsenal
ATTN: John G. Barr-Q3210
Bldg 220-1
Philadelphia, Pa. 19137

Arthur D. Beatrice
USAF, L.G. Hanscom Fld.
Section ESBMH-4-4, 3245th C.A.M. Sq.
Bedford, Mass.

Hq. SAAMA
(SANETP/ Lt. Col. W.F. Bennett)
Kelly Air Force Base
Texas

George F. Berg
Fld Eval Div, SMUEA-TSFE
Dir/Tech Supp. Bldg. 1570
Edgewood Arsenal, Maryland 21010

Edward J. Beth
DCASR, O'Hare
Quality Assurance Eng. Div. Q.E.E.
Chicago, Ill.

Carlo Blasetti
Code PQT-NMEF
Naval Weapons Station
Yorktown, Virginia

Defense Contract Administration Serv. Reg.
ATTN: Doyle L. Braun - QES
11099 S. Lacienega Blvd.
Los Angeles, Calif. 90045

John F. Britt (DCRB-QES)
DCASR
666 Summer St.
Boston, Mass. 02210

Robert H. Brockelman
Army Materials Research Agency
Applied Physics Branch
Watertown, Mass. 02172

4500 Air Base Wing
4500 Cams (Fmd)
ATTN: M/Sgt Claude L. Brown Jr.
Nondestructive Inspection Lab.
Langley Air Force Base, Va. 23365

Jack C. Browning, T/Sgt
4522 Field Maint. Sq.
ATTN: NDI Lab
Nellis Air Force Base
Nevada 89110

T/Sgt John E. Bruegger
3913-G Falcon Cts. N.
McGuire Air Force Base
New Jersey

William P. Byrd
Chemical and Materials Lab.
WRMQQCM
Robins Air Force Base
Georgia

M/Sgt Samuel O. Callihan
NCOIC Fabrication Branch
313th FMS
Forbes Air Force Base
Kansas

H.F. Campbell
U.S. Army Materials Research Agency
Materials Stnd. Office
Watertown, Mass. 02172

Louis C. Cardinal
Naval Research Laboratory
Code 6254
Washington, D.C. 20390

Albert L. Chick
Code 934
U.S. Naval Applied Science Lab.
Flushing & Washington Aves.
Brooklyn, N.Y. 11251

J.A. Conway
U.S. Army Materials Research Agency
Materials Stnd. Office
Watertown, Mass. 02172

Willard L. Cookerly
DCASR
ATTN: DCRB-QES
666 Summer St.
Boston, Mass. 02210

Richard J. Cotton
DCASD-Newark
ATTN: DCRN-DNQEA
240 Route 22
Springfield, N.J.

438 FMS (MAC)
Fabrication Br. Ch.
ATTN: CM Sgt. William M. Daniels
AF 33276288
McGuire Air Force Base
New Jersey 08641

S. Der Boghosian
U.S. Army Materials Research Agency
ATTN: AMXMR-TMT
Watertown, Mass. 02172

J.A. Desjardins
DCASR Boston
ATTN: DCRB-QES
666 Summer Street
Boston, Mass.

Field Maint. Officer
6486 Fld. Maint. Sq.
ATTN: George W. Dial, T/Sgt
APO San Francisco, Calif. 96553

Arthur H. Drumlevitch
Air Force Plant Repr. Office
c/o Lockheed Missiles & Space Co.
Sunnyvale, Calif.

Joseph C. Dunn
DCASR - New York
ATTN: DCRN-QES
Quality Assurance Eng.
770 Broadway
New York, N.Y. 10003

T. Dunn
Ch. Materials Stnd. Office
U.S. Army Materials Research Agency
Watertown, Mass. 02172

Charles H. Dyer
Bldg. 70
U.S. Naval Ordnance Lab.
Silver Spring, Md. 20910

Charles A. Edgar
ATTN: AMXNC-Q
New Cumberland Army Depot
New Cumberland, Pa. 17070

Paul Edmiston
U.S. Army Egewood Arsenal
ATTN: SMUEA-QAIP
Edgewood Arsenal
Maryland 21010

K.A. Fowler
Applied Physics Branch
U.S. Army Materials Research Agency
Watertown, Mass. 02172

Richard A. Gaites
U.S. Naval Applied Science Lab.
Code 931
Flushing & Washington Aves.
Brooklyn, N.Y. 11251

William E. Gallimore
Code PQT
U.S. Naval Mine Engineering Facility
U.S. Naval Weapons Station
Yorktown, Va. 23491

D.L. Gamache
U.S. ATAC, SMOTA-QED
Warren, Michigan

Otto R. Gericke
Applied Physics Branch
U.S. Army Materials Research Agency
Watertown, Mass. 02172

S. Goldspiel
Metallurgy Br, Code 932
Naval Applied Science Laboratory
Flushing & Washington Aves.
Brooklyn, N.Y. 11251

S/Sgt. Wilfred Goyne
1370th Photo Mapping Wing (PMM)
Turner Air Force Base
Georgia 31703

Henry B. Gratton
Hqs. AFLC-MCME
Wright-Patterson Air Force Base
Ohio

Robert Grubinskas
Applied Physics Branch
U.S. Army Materials Research Agency
Watertown, Mass. 02172

Charles E. Haire
DCASR, Atlanta
ATTN: DCRA-QES
3100 Maple Dr.
Atlanta, Ga.

Walter Hand
U.S. Naval Applied Science Lab.
Code 935
Flushing & Washington Aves.
Brooklyn, New York 11251

Stephen D. Hart
Code 6254
Naval Research Laboratory
Washington, D.C. 20390

Harold Hatch
U.S. Army Materials Research Agency
ATTN: AMXMR-TMT
Watertown, Mass. 02172

Howard Heffan
Quality Evaluation Laboratory
Code QEPN
U.S. Naval Weapons Station
Concord, California 94520

Everett C. Iverson
3345th Tech. School
Dept. of Weapons Systems Support Training
ATTN: TSDT
Chanute Air Force Base
Illinois

Harry P. John
Defense Contract Adm. Services Region
ATTN: QES-3
2800 S. 20th St.
Philadelphia, Pa.

James E. Johnson
O & R Dept. Code 344, Bldg. 341
North Island, Naval Air Station
San Diego, Calif. 92135

Sacramento Air Material Area
SMMQQL-D (S.E. Johnson)
McClellan Air Force Base
California

Gerald J. Kenaley
Quality Assurance Office
Army Weapons Command
Rock Island Arsenal
Rock Island, Illinois

Alfred S. Kress
U.S. Army Tank Automotive Command
ATTN: SMOTA-QE
Warren, Michigan

Commanding Officer
Frankford Arsenal
ATTN: Theresa M. Lavelle, N5100-201-3
Bridge & Tacony Sts.
Phila, Pa. 19137

Richard T. Lennon
DCASD Rochester
317 Childs St.
Rochester, N.Y.

Officer in Charge
Polaris Missile Facility Pacific
ATTN: Jerry L. Lyman, SPB-232
Bremerton, Washington 98314

Lawrence G. Marler
OCAMA (OCNEPA)
Tinker Air Force Base
Oklahoma

Vern T. Marooney
Major, Colo. Air National Guard
Buckley ANG Base - DMM
Aurora, Colorado 80010

Commanding Officer
U.S. Army Aeronautical Depot Maint. Center
ATTN: AMXAC-MEM, Charles E. Martens
Corpus Christi, Texas

William C. Mayfield Jr.
A.F. Logistics Command Maint. Tech. Office
ATTN: OCRE
Hdq's Oklahoma City Air Material Area
Tinker Air Force Base
Oklahoma

Electronics System Division
3245th CAM Sq.
ESBMH-4-2
ATTN: Charles M. McArthur
Hanscom Field, Bedford, Mass.

P.C. McEleney
Applied Physics Branch
U.S. Army Materials Research Agency
Watertown, Mass. 02172

Air Force Materials Laboratory
Applications Division
MAAS/ E.W. McKelvey
Wright-Patterson Air Force Base
Ohio 45433

Commanding Officer
Aberdeen Proving Ground
ATTN: STEAP-DS-EP (J.M. McKinley)
Aberdeen Proving Ground, Md. 21005

Luke K. McSherry E.E.
Solid State & Freq. Control Div.
ECL ECOM, AMSEL-KL-S
Ft. Monmouth, N.J.

Angelo M. Mello, Jr.
DCASR, c/o General Electric Co.
1000 Western Ave.
Lynn, Mass.

Emilio Mendoza
MQQC, Bldg. 321
Kelly AFB, Texas

Richard E. Meoli
AFCMD (CMQE)
AF Unit Post Office
Los Angeles, Calif. 90045

Charles P. Merhib
U.S. Army Materials Research Agency
ATTN: AMXMR-TMT
Watertown, Mass. 02172

T/Sgt Glen E. Miller
4756 Field Maintenance Sqdn. (NDI)
Tyndall Air Force Base
Florida

Domenic J. Molella
Metals Eng. Sect. Bldg. 352
ATTN: SMUPA-DT3
Picatinny Arsenal
Dover, N.J. 07801

Commanding Officer
Frankford Arsenal
ATTN: M. Mondress, SMUFA - N3200
Bridge & Tacony Sts.
Philadelphia, Pa. 19137

317th TAC (Wing)
317th F.M.S.
ATTN: M/Sgt. James R. Moore
Non-Destructive Lab.
Lockbourne Air Force Base
Columbus, Ohio

Lawrence E. Moore
62nd MAW - FMS/FAB/NDI
McChord Air Force Base
Washington 98438

Louis J. Moore
Director of Technical Services
USA General Equip. Test Activity
Fort Lee, Virginia 23801

David M. Moses
Defense Contract Adm. Services Hqs.
DSAH FQES
Cameron Station
Alexandria, Virginia 22314

F.J. Mozzi
DCASD Hartford
ATTN: DCRB-DHQE
557 Asylum Street
Hartford, Conn.

Thomas Muckle
Process Eng. Sect.
Benet R & E Labs.
Watervliet Arsenal
Watervliet, N.Y.

R.T. Muse
U.S. Army
General Equipment Test Activity
Fort Lee, Va.

T/Sgt Wilbur L. Nichols
551st Field Maint. Sqdn.
Otis Air Force Base
Mass. (NDI Lab)

Sal. Norod
Bldg. #6, Q.C.D.
Picatinny Arsenal
Dover, N.J. 07801

DMMFM/NDI
1001st F.M.S.
ATTN: Lt. Ognibene
Andrews Air Force Base
Washington, D.C. 20331

M/Sgt Leo F. Osweiler
313 Trp. Carr. Wg.
DM/NDI Project Office
Forbes Air Force Base
Kansas 66620

John Paul DCCS
Service School Command Annex
Box 6 NDT
Naval Station
San Diego, Calif 92136

James E. Peale
WRNEAI
Robins Air Force Base
Georgia 31093

John F. Plexico
AMSMI-RTQ
Redstone Arsenal, Alabama

Walter C. Reffelt
c/o Lake City Army Ammunition Plant
ATTN: SMULC-IE-Q
Independence, Missouri

Don J. Reinert
Nondestructive Insp. Supv.
108th Tac. Ftr. Gp. N.J.A.N.G.
McGuire Air Force Base
New Jersey

U.S. Navy Marine Engineering Lab.
ATTN: H.L. Rekate
Code 729
Annapolis, Maryland

Chief of Maintenance
325th Fighter Wing
ATTN: NDI Lab, 325 MME-F (NDI)
(Sgt. Richardson)
McChord Air Force Base
Washington, 98438

E.H. Rodgers
U.S. Army Materials Research Agency
ATTN: AMXMR-TMT
Watertown, Mass. 02172

B.H. Roffee
Spec. Asst. Science & Technology
Bldg. 2100, Yuma Proving Ground
Yuma, Arizona

Commanding Officer
Frankford Arsenal
ATTN: Eugene Roffman
N3100 202-1
Philadelphia, Pa.

Bernard B. Rosenbaum
Dept. of the Navy
Naval Ship Systems Command
Code 03422
Washington, D.C. 20360

Charles M. Rothery
DCASR - St. Louis
ATTN: DCRS-QES
1136 Washington Ave.
St. Louis, Mo. 63101

Richard R. Rowand
Air Force Materials Lab.
ATTN: MAMD
Wright-Patterson Air Force Base
Ohio

C/M/Sgt. Rosella P. Saker
McConnell A.F. B.
23 Tac. Ftr. Wing
2837 Vanderburg Court
Wichita, Kansas

Laurence J. Sauter
Hq. DSA (DSAH-PRQ)
Cameron Station
Alexandria, Va.

Paul Schindler
Picatinny Arsenal
Ammo Engr. Lab, AED
ATTN: SMUPA-DC5
Bldg. 240
Dover, New Jersey

Commanding Officer
Picatinny Arsenal
ATTN: J. Scollins, SMUPA-DC1,
Bldg. 351
Dover, N. J.

Lt. James H. Scott
Service School Command Annex
Naval Station Box 6 NT
San Diego, Calif. 92136

Major John Skidmore
Hq. AFSC (SCKAQ)
Andrews Air Force Base
Washington, D.C.

Commanding Officer
U.S. Army Combat Developments
Command
Maintenance Agency
ATTN: CDCMA-E (Mr. Slusarksi)
Aberdeen Proving Ground, Md. 21005

Richard W. Spencer
Quality Control Supt.
108 Tfg. N.J.A.N.G.
McGuire Air Force Base
New Jersey

David Stein
Quality Assurance Directorate
ATTN: SMUPA-NDI, Bldg. 3409
Picatinny Arsenal
Dover, New Jersey 07801

M. Stellabotte
U.S. Naval Air Engineering Center
Philadelphia, Pa.

James L. Studdard
U.S. Army Missile Command
ATTN: AMCPM-LCC
Redstone Arsenal, Ala. 35809

Henry A. Tisch
AED, Bldg. 351
Picatinny Arsenal
Dover, N.J.

Commanding Officer
Naval Torpedo Station
ATTN: John G. Turbitt, Code 3345
Naval Torpedo Station
Keyport, Wash.

Major Robert C. Vadnais
Hq AFLC (MCMCA)
Wright-Patterson AFB
Ohio 45433

T.E. Valvoda
DCASR
Cleveland, Ohio

Paul E. Vogel
Applied Physics Branch
U.S. Army Materials Research Agency
Watertown, Mass. 02172

317th Field Maint. Squadron
Non-Destructive Insp. Lab.
ATTN: M/Sgt. Joe T. Walker,
AF16209873
Lockbourne Air Force Base
Ohio 43217

Clifford R. Warg
DCASO-Buffalo
1021 Main Street
Buffalo, N.Y.

Shelton Washington
Quality Assurance Directorate
ATTN: SMUPA-NR1, Bldg. 65
Picatinny Arsenal,
Dover, N.J.

M/Sgt Ira S. Watts Jr.
ABGL (PGMM)
ATTN: NDI Project Officer
Eglin Air Force Base
Florida 32542

Hart Webber
USA ECOM
P & P Directorate
Engrg. Support Div.
Ft. Monmouth, N.J.

T/Sgt. George B. Wing
5578B Hunter Ave.
Otis Air Force Base
Mass. 02542

Frank Wojciechowski
DCASD - Hartford
557 Asylum Avenue
DCRB-DHQE
Hartford, Conn.

Commanding Officer
U.S. Army Tank Automotive Center
SMOTA-RCMG, (W. Wulf)
Warren, Mich. 48090

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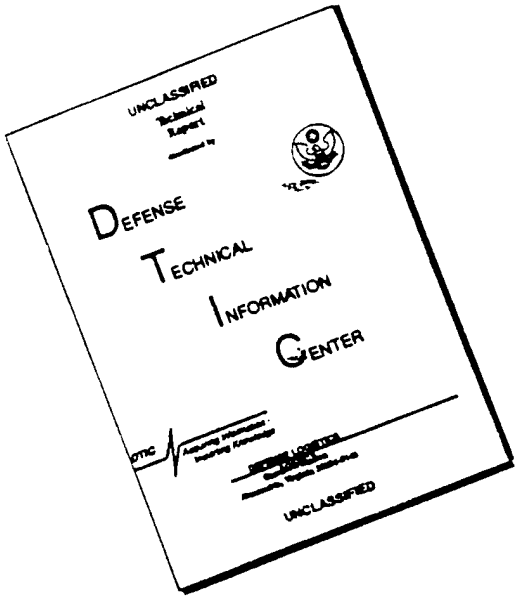

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