NASA TECHNICAL MEMORANDUM

Report No. 53852

DEVELOPMENT OF NONDESTRUCTIVE TEST DEVICE FOR EVALUATION OF 3/4-INCH THICK POLYURETHANE SPRAY-ON FOAM INSULATION (SOFI) ON THE SATURN S-II STAGE

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May 1, 1969

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. NASA TM X-53852

2. GOVERNMENT ACCESSION NO.

3. RECIPIENT'S CATALOG NO.

4. TITLE AND SUBTITLE Development of Nondestructive Test Device for Evaluation of 3/4-Inch Thick Polyurethane Spray-On Foam Insulation (SOFI) on The Saturn S-II Stage

5. REPORT DATE May 1, 1969

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S) John Haymes and H. S. Haralson

8. PERFORMING ORGANIZATION REPORT #

9. PERFORMING ORGANIZATION NAME AND ADDRESS

Spaco, Inc.
3022 University Dr. NW
Huntsville, Alabama 35805

10. WORK UNIT NO.

11. CONTRACT OR GRANT NO. NAS 8-20081

13. TYPE OF REPORT & PERIOD COVERED NASA Technical Memorandum

12. SPONSORING AGENCY NAME AND ADDRESS

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Monitored by the Quality and Reliability Assurance Laboratory

16. ABSTRACT

This report describes the technical survey, research development, and applied engineering effort performed to develop a nondestructive test for evaluation of the cryogenic insulation used on the Saturn S-II stage.

Several methods of testing were studied but the sonic impedance method was determined to be the most favorable.

Since the sonic impedance method was capable of locating defects in the insulation smaller than specifications limitations, it is recommended for inspecting the insulation on the S-II stage liquid hydrogen tanks.

17. KEY WORDS

Nondestructive Testing
Spray-on Foam-Insulation (SOFI)
Acoustical NDT Methods

18. DISTRIBUTION STATEMENT

STAR Announcement

19. SECURITY CLASSIF. (of this report) U

20. SECURITY CLASSIF. (of this page) U

21. NO. OF PAGES 37

22. PRICE

MSFC - Form 3292 (May 1969)

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SUMMARY

Several methods were evaluated to determine the best method for the nondestructive testing of the cryogenic insulation used on the Saturn S-II Stage.

The sonic impedance method was capable of detecting unbonds and voids with minimum dimension of 1.0 inch which is smaller than the specification limits of 2.0 inches minimum defect dimension.

The sonic impedance method is recommended for nondestructive evaluation of cryogenic insulation over the other methods evaluated for the following advantages:

- It can be operated manually or in an automated system.
- The readout or flaw discrimination is made by an electrical system (meter or recorder), instead of complete dependance upon the operator's ability.
- It can detect unbonds and voids in 3/4 inch insulated structure after the polyurethane protective coating has been applied.

SECTION I. INTRODUCTION

This report describes the technical survey, research, development, and applications engineering effort performed within the George C. Marshall Space Flight Center (MSFC) Quality and Reliability Assurance Laboratory to develop a nondestructive test (NDT) for the evaluation of the cryogenic insulation used on the Saturn S-II Stage. This insulation is of the low-density polyurethane foam type and is applied by a spray-on technique to the exterior of the S-II Stage liquid hydrogen tanks of the Saturn V vehicle. The foam has been designated SOFI (Spray-On Foam Insulation) and is referenced as such throughout this report.

The insulation is designed to preclude excessive heat transfer between the atmosphere and cryogenic liquid fuel. Hence, the SOFI must be free of voids in accordance with limits defined by specification requirements and must bond to the aluminum tank skin in a manner adequate to prevent loosening and spalling during stage ground tests or actual flight conditions. In addition, existing unbonds must not be extensive enough to cause spalling as a result of "cryopumping" during the thermal extremes of tanking and detanking operations.

The development effort described herein was undertaken because of apparent limitations in the present NDT technique employed by North American Rockwell (NAR) Seal Beach, California. This NDT system essentially consists of a brush, microphone, and earphones. By moving the brush manually across the SOFI, a broad band of audible frequencies is generated, with resonance conditions over void or unbond areas. This method has several limitations and disadvantages. It is operator dependent; it does not lend itself to automation; it cannot detect unbonds after the polyurethane protective coating has been applied; and no permanent recording is obtained.

The first step in the selection of a NDT technique was an evaluation of the pertinent SOFI properties and the existing quality requirements. From this information a sound basis for consideration or rejection of a test method was formed. A detailed technical survey of various NDT techniques was then performed. Based on strong theoretical evidence, which is presented in this report, a vibrational impedance method was selected and a prototype impedance head was fabricated, improved, and evaluated.

The evaluation was performed on coated and uncoated test panels containing preplaced voids and unbonds at 3/4 inch depths, coated test panels with preplaced unbonds at 2.0 inch depths, uncoated test panels with preplaced voids at 2.0 inch depths, and uncoated 3/4 inch test panels with no known defects. From the conclusions reached as a result of this evaluation, positive recommendations are made concerning the implementation of this technique.

SECTION II. MATERIAL UNDER TEST

A. SOFI DESCRIPTION

The SOFI material is a rigid polyurethane foam, with a density which may vary (by specification) between 2.5 and 3.4 pounds, per cubic foot. The foam is applied to the aluminum skin of the S-II Stage liquid hydrogen tank by spray-on equipment, which allows a free-rise condition. After curing, the foam is machined to the required thickness of 3/4 ± 1/4 inch over 90 percent of the tank skin area. The remaining area, J-ring and other structural interfaces, varies from 2.0 to 4.0 inches in machined thickness. After machining, a protective coating, NARMCO 7343 or equivalent with a titanium dioxide pigment, is applied to the foam. Pertinent physical properties relating to the foam and SOFI/aluminum laminate are as follows:

Property	Specification Requirement
Compression Strength	35 psi at $70^{\circ} \pm 0.5^{\circ}F$
Tensile Strength (Direction of Rise)	40 psi at $70^{\circ} \pm 0.5^{\circ}F$
Bond Strength (to Aluminum)	40 psi
Bond Strength (Foam Interface)	25 psi

B. S-II STAGE SOFI QUALITY REQUIREMENTS

NAA Specification MA0606-045 establishes application, quality, and allowable defect requirements for SOFI. The most stringent allowable defect requirement of this specification is that no detectable voids are allowable within 12.0 inches of a sidewall closeout area. The specification also stipulates that "a detectable void or debond is defined as a void or debond 2.0 inches or greater in the smallest direction." Specification MA0606-045 further requires that the bond and tensile strength of the foam be verified by production quality verification (PQV) tests performed per Specification MQ0501-034. The PQV apparatus referenced by this specification was used to verify that test panels used in the project and discussed in this report met tensile and bond strength requirements established for SOFI.

SECTION III. NDT TECHNIQUES SURVEY

A. GENERAL

Several techniques were considered/evaluated for developmental application to meet NDT requirements of SOFI/aluminum laminate. These included the conventional, established techniques, such as radiography techniques previously evaluated on other nonmetallic materials, and the presently used NAR sonic brush. Previous experience indicated that the two most important SOFI properties (i.e., nonmetallic and very low density) would strongly influence the transfer of energy into the SOFI and would be the determining factor in the technique selection. Of the techniques surveyed, the more prominent are discussed in the following paragraphs.

B. RADIOGRAPHY

X-radiation methods are not feasible for the detection of defects in SOFI/aluminum laminate due to the low density of the SOFI. Neutron radiographic methods, although feasible, are not practical at this time due to applications problems and cost.

C. ULTRASONICS (PULSE ECHO)

Ultrasonic (pulse echo) methods are not feasible due to the high acoustic attenuation of the SOFI and the low impedance mismatch between the SOFI and a defect (air interface).

D. MICROWAVES

Microwave methods were previously evaluated on low density polyurethane foam/aluminum laminate of this type (Saturn S-IC Stage fuel exclusion riser). Although the method exhibited a good ability to detect small density variations and entrapped moisture in the foam, delaminations without air gap would not be detectable, and void detection resolution would require higher frequency equipment of special design which would be cost prohibitive.

E. ELECTROSTATIC FIELD INTENSITY MEASUREMENT

Based on the premise that the level of an electrostatic field will change abruptly around a defect in low density foam, two electrostatic field measuring instruments were evaluated for their ability to detect defects in foam. Defects were detected; however, the successful use of the two instruments evaluated required a close control of the residual charge on the foam. A successful method for residual charge control was not found, so development of this technique was discontinued.

F. LOW FREQUENCY SOUND VELOCITY MEASUREMENT

Low frequency sonic through-transmission methods were evaluated on foam/aluminum laminates. Since it was realized that sonic energy level changes would not locate voids in the foam, the through-transmission methods were limited to the detection of voids through measurements of changes in the sound velocity through the structure. The routinely occurring variations of sound velocity in the foam defeated all attempts to locate voids with this method.

G. SONIC BRUSH

Tests were performed with the NAR brush and microphone device. Four operators were selected and given hearing tests. Two of the operators passed the hearing tests and two failed. The hearing test was an amplitude versus frequency plot from 100 cycles/sec to 6 kc/sec. Test failure was established by a below the medically established normal amplitude detection at any frequency. These four selected operators then performed evaluations of test panels contained simulated defects.

The following conclusions were reached as to the sonic brush capabilities:

1. Operator practice on known defects is essential. Preplaced defects could not be readily detected by operators without considerable experience.

2. Operators who passed the hearing test could not locate defects any better than the operators who failed the test.

3. Defects with a minimum dimension of 1.0 inch can be detected in 3/4-inch thick SOFI test panels.

4. Defects in test panels with the protective coating could not be detected with the sonic brush.

5. The dimensions of simulated unbonds larger than 2.0 inches by 2.0 inches can be determined within $\pm$ 1/2 inch if extreme care is exercised.

6. The dimensions of detectable unbonds smaller than 2.0 inches by 2.0 inches could not be determined.

H. LIGHT REFLECTION METHOD

Based on the porous nature and translucent quality of the SOFI, a method of detecting defects in SOFI/aluminum laminates, by observing the absorption and reflection of a light beam in the foam, was evaluated for defect detection. This method proved capable of detecting voids in 3/4 inch SOFI as small as 1.0 inch by 1/4-inch in area, with a 1/4-inch thickness. However, when the defects were less than 1/4-inch thick, they could not be detected. This method was also subject to false indications, resulting from foam coloration changes and surface scratches. This method also could not detect defects in coated SOFI.

I. VIBRATIONAL IMPEDANCE METHODS

The inertia changes on a diaphragm vibrating in contact with the SOFI, caused by a defect in a SOFI/aluminum laminate, was the theoretical basis for the vibrational impedance technique development and evaluation. This technique demonstrated considerable potential; consequently, the vibrational (sonic) impedance technique was developed to an effective prototype stage. The bases for selection and the developmental effort on this technique is discussed in detail in the subsequent sections of this report.

SECTION IV. SONIC IMPEDANCE TECHNIQUE

A. CONCEPT AND THEORY

The theoretical considerations discussed below formed the basis for the initial selection and subsequent application of the vibrational impedance method. It was known that when a diaphragm vibrates in contact with a medium, the frequency and amplitude of the vibrations would be dependent upon the following parameters:

1. Physical properties of the diaphragm

2. Physical size of the diaphragm

3. Manner in which the diaphragm is supported

4. The density of the contacted medium

The effect of the parameters on the frequency of the diaphragm is defined by the following relationships:

For a circular diaphragm vibrating in a vacuum (no secondary medium contact),

$$f = C \; t/r^2 \left[\frac{E}{\rho \; (1 - \sigma^2)} \right]^{1/2}$$

t - diaphragm thickness

r = diaphragm radius

ρ = diaphragm material density

E = diaphragm material modulus of elasticity

σ = Poissons ratio of the diaphragm material

C = support constant

The support constant varies with the manner in which the diaphragm is supported. For a diaphragm rigidly clamped along its periphery, C is equal to 0.475. At the other extreme (zero support), C is equal to 4.75. In practice the support constant for a diaphragm clamped at its periphery will be between the two values given above.

When the vibrating diaphragm is placed in contact with a medium, the frequency and the amplitude decrease due to an increase in the inertia of the diaphragm. In the case of a diaphragm with only one side in contact with a medium, the inertia of the diaphragm is increased by the loading effect of the contact medium. The frequency is now defined by the following formula.

$$f = C\, t/r^2 \left[\frac{E}{\rho\,(1-\sigma^2)}\right]^{1/2} \bullet \frac{1}{(1+B)}^{1/2}$$

where B is equal to $0.6689\ \frac{\rho_1}{\rho} \bullet \frac{t}{r^2}$ and ρ_1 is the density of the contact medium.

As the fundamental frequency of the diaphragm decreases with an inertia gain, the amplitude also decreases since the added inertia of the contacted medium restricts the deflection of the diaphragm. In order to detect a defective area in a composite structure, such as low density foam bonded to an aluminum plate, the defective area must offer a different inertia load to the vibrating diaphragm than a good area. This is readily understood, since a defective area offers less mass to vibrate than a good area.

B. SPEAKER-DRIVEN IMPEDANCE HEADS

Based on the theory that a vibrating plate in contact with SOFI bonded to an aluminum plate will change in frequency and amplitude in the proximity of a defective area, a prototype vibrational impedance head was produced. The first impedance head was driven by a pressure wave created by a small speaker.

Although the speaker driven system performed well in locating knife-slit type simulated unbonds in 3/4-inch thick SOFI, it had two major didadvantages. The first was the difficulty of matching the optimum drive frequency (as dictated by the resonant cavity length) with the fundamental frequency of the drive plate. The second was the high intensity of the noise level produced by the speaker at the power levels required for good vibration inducement. This high noise level often resulted in operator fatigue and headaches after short periods of operation.

C. COIL-DRIVEN IMPEDANCE HEAD

Since the vibrating plate impedance method was shown to be feasible by tests with the speaker-driven prototype unit, it was decided to continue with this approach. To circumvent the disadvantages of the earlier impedance heads it was determined that both of the major disadvantages could be overcome by the use of a coil in place of the speaker as the drive mechanism. A coil would eliminate the resonant cavity problem since the energy transfer to the drive plate would be electromagnetic (eddy current) instead of a cavity dependant pressure wave, and the noise producing vibrations would be generated only by the drive plate and would be low level in nature.

The fabrication of a prototype eddy current driven (coil) impedance head was aided by the laboratory availability of an Eddy Sonic test system. The Eddy Sonic system, North American Sonic Test System model 203 with Eddy Sonic module model 202, contained all of the microphone driven head components (figure 1), with the exception of a diaphragm which was easily attached to the Eddy Sonic probe holder.

The prototype Eddy Sonic vibrational impedance head is shown in figures 2 and 3. The thickness of the diaphragm was selected as a result of testing performed with 0.010, 0.020, 0.032, 0.060, and 0.090-inch thick diaphragms. The 0.020-inch thick diaphragm exhibited the maximum meter deflection differential between a good area and a simulated unbond and was used for all subsequent evaluations. The Mylar ring was attached to the periphery of the diaphragm to decrease the loading on the diaphragm, (and thus increase its Q) and to decrease the sliding friction. The diaphragm without the stand-off ring was sensitive to SOFI thickness variations.

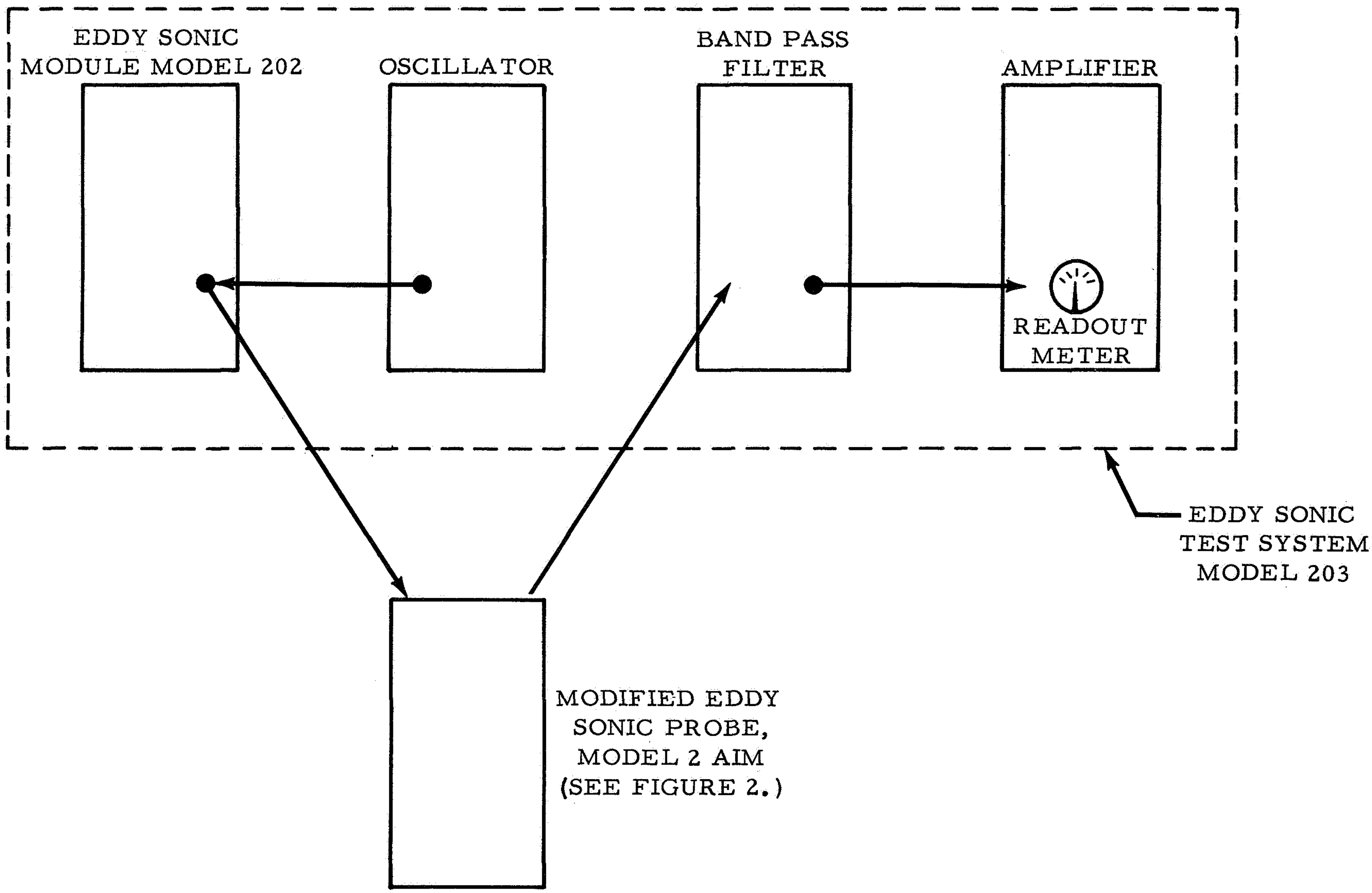


Figure 1. Coil-Driven Sonic Impedance System

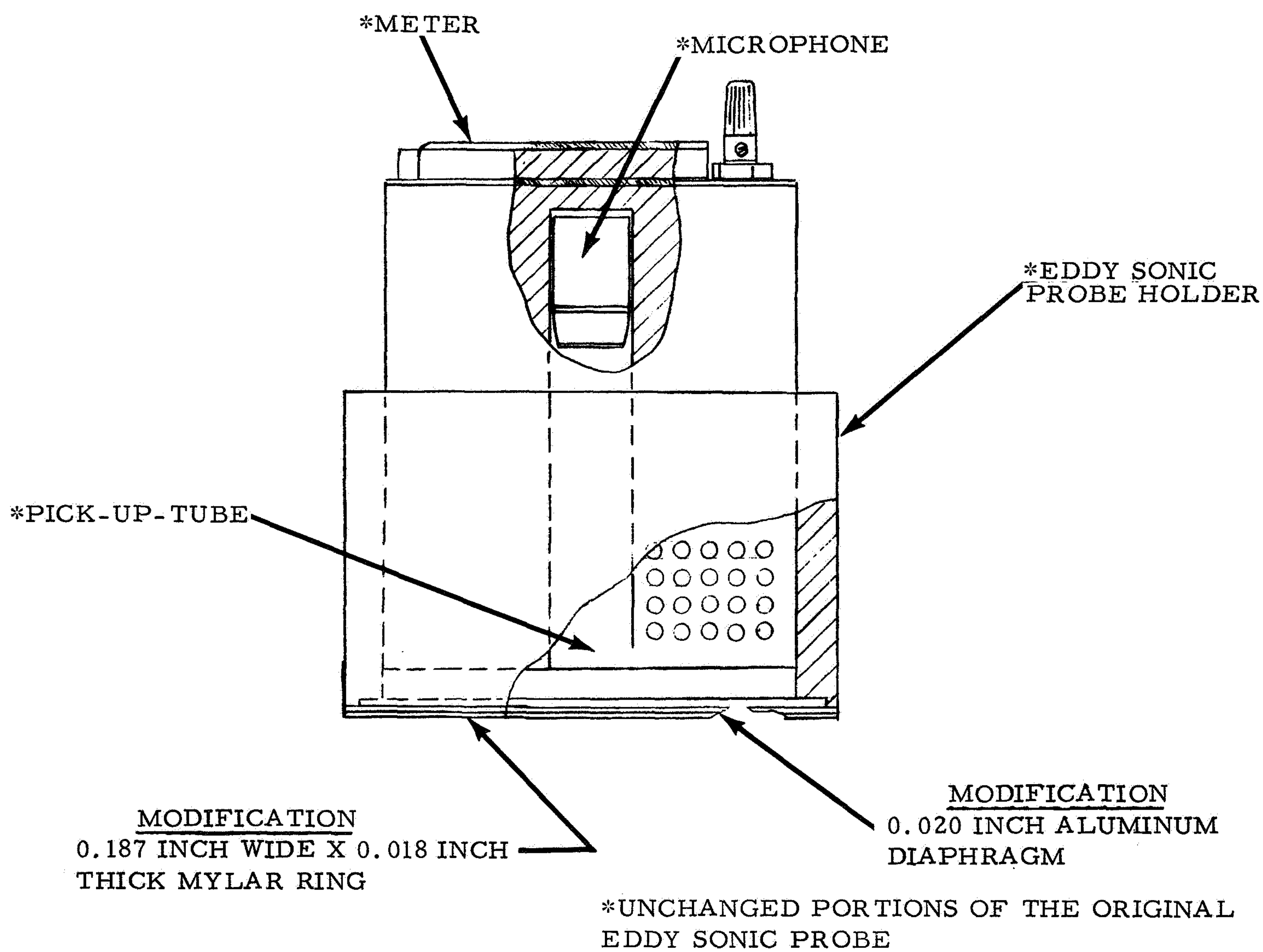


Figure 2. Modified Eddy Sonic Probe, Model 2A1M

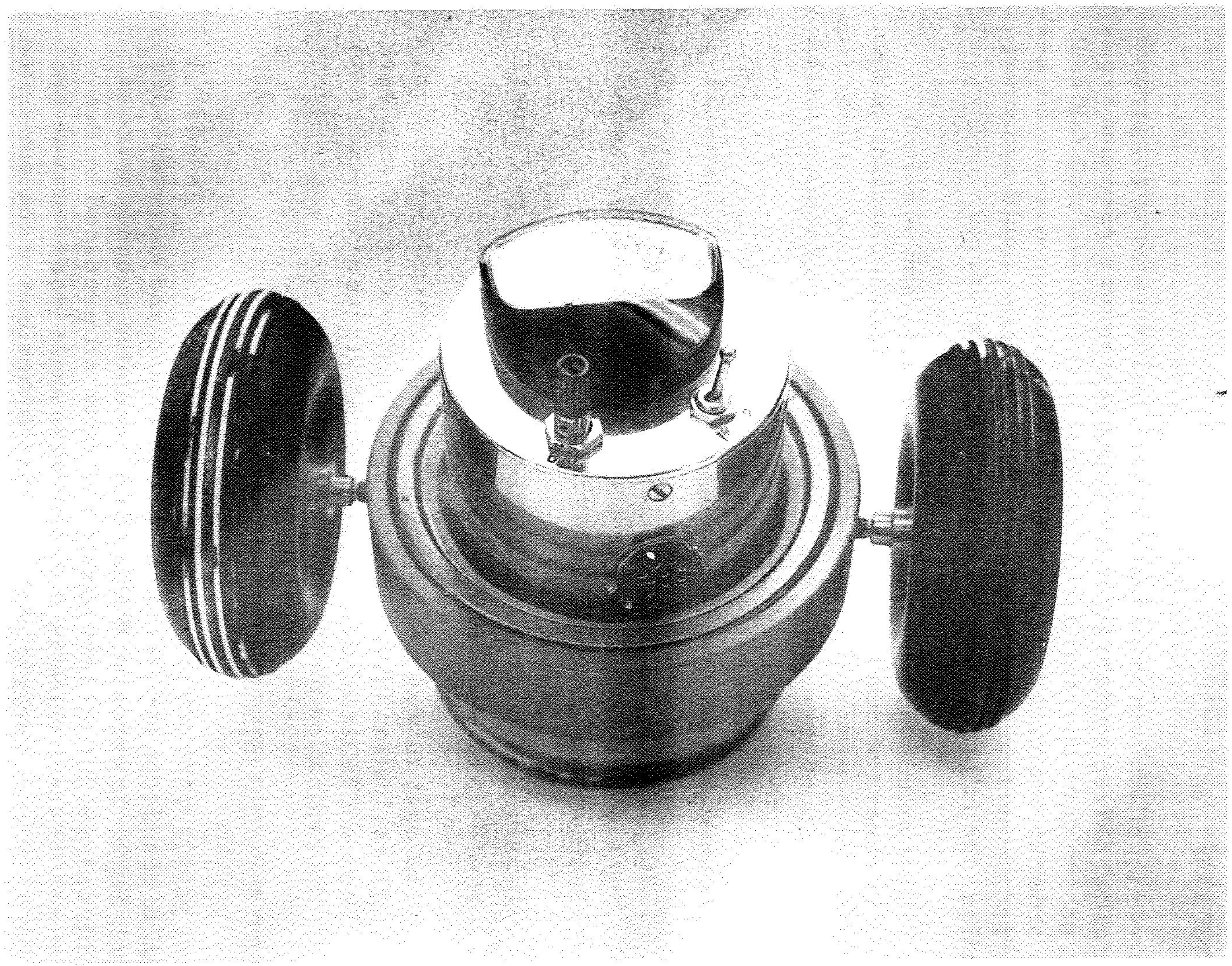


Figure 3. Coil-Driven Impedance Head

SECTION V. TECHNIQUE EVALUATION

A. GENERAL

Since the coil-driven impedance system had two major advantages over the speaker driven system (it is not dependent upon a resonant cavity and it does not produce operator fatiguing noise), it was selected for evaluation. In order to evaluate the capabilities of the system to meet the previously defined inspection requirements of the S-II Stage liquid hydrogen tank insulation, the following test sequence was observed.

1. Test panels were obtained with 3/4, 2.0, and 4.0-inch thickness of SOFI on 1/4-inch thick aluminum backing plates.

2. Defects of known sizes and shapes were preplaced in coated and uncoated test panels.

3. Manual and automated scanning modes were evaluated on test panels containing preplaced defects.

4. Test panels not containing preplaced defects were tested in an attempt to locate naturally occurring defects.

5. Destructive tests (dissection) were performed on all test panels evaluated for naturally occurring defect detection.

6. The system was evaluated on the thinnest test panels first. An evaluation of the system on the next test panel thickness was not initiated unless positive results were obtained from the evaluation on the thinner panels.

B. TEST PANELS (SIMULATED DEFECTS)

Test panels were prepared with simulated voids and unbonds for the evaluation of defects at 3/4-inch depths in coated and uncoated SOFI and 2.0-inch depths in uncoated SOFI. The simulated unbonds were of the same dimensions for all test panels and were all prepared by the insertion of a 0.025-inch thick by 0.5-inch wide knife blade between the SOFI and the aluminum backing plates. The dimensions of the simulated unbonds are shown in Table 1. The void-type defects were prepared by

Table 1. Simulated Unbonds (Knife Slits)

Defect Location	Defect Area (Inch)	Defect Thickness (Inch)
Between SOFI and Backing Plate	6 by 0.5	0.025
Between SOFI and Backing Plate	6 by 0.75	0.025
Between SOFI and Backing Plate	6 by 1.00	0.025
Between SOFI and Backing Plate	6 by 1.25	0.025
Between SOFI and Backing Plate	6 by 1.50	0.025
Between SOFI and Backing Plate	6 by 1.75	0.025
Between SOFI and Backing Plate	6 by 2.0	0.025
Between SOFI and Backing Plate	6 by 2.25	0.025
Between SOFI and Backing Plate	6 by 2.50	0.025
Between SOFI and Backing Plate	6 by 2.0	0.025
Between SOFI and Backing Plate	6 by 4.0 by 1.0 (trapezoid)	0.025

REMARKS:

Two uncoated and one coated 3/4 inch SOFI thickness test panels were prepared with the above defects. One uncoated 2.0 inch SOFI thickness panel was prepared with the above defects.

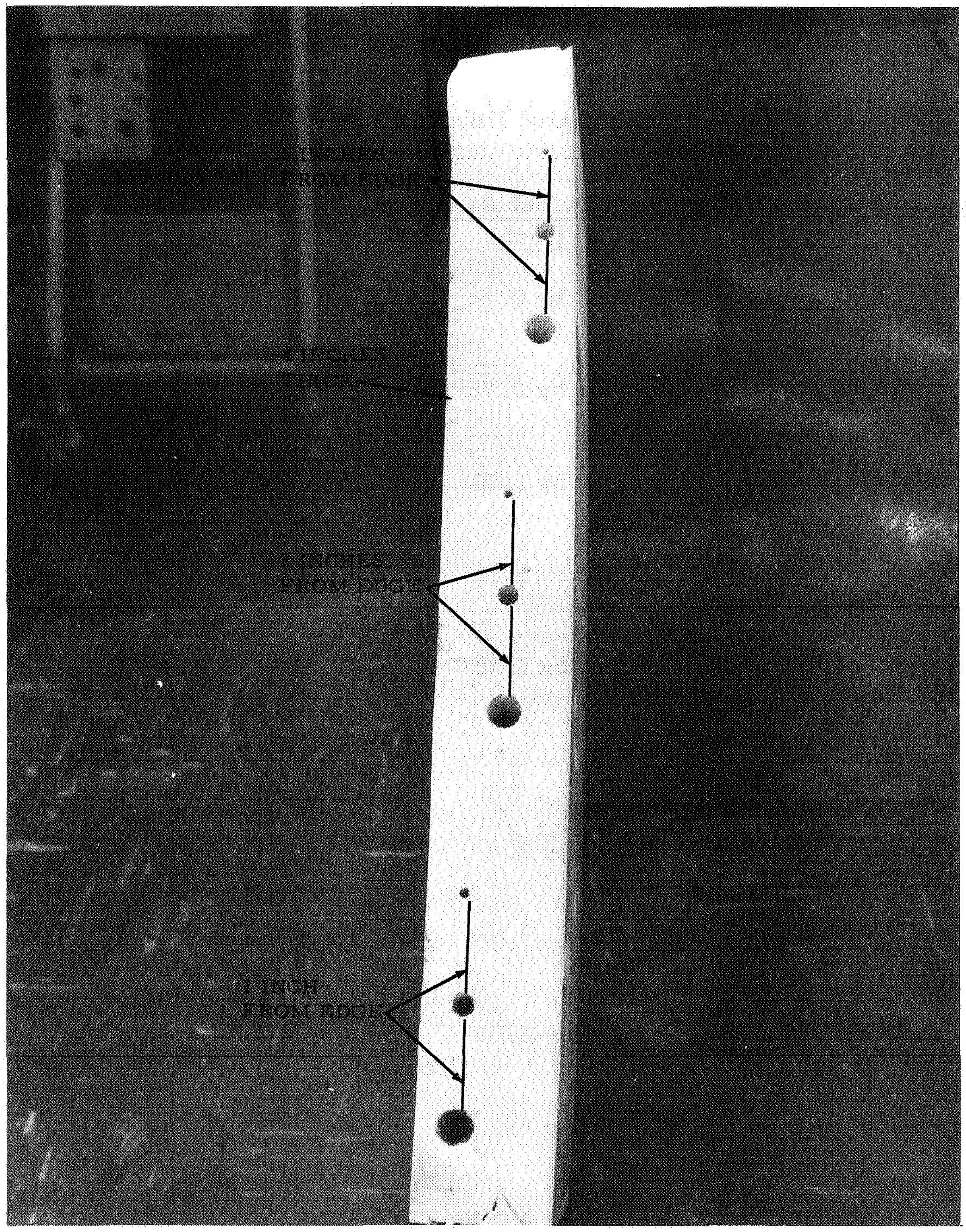


Figure 4. Voids, Drilled Holes, in Test Panel (Typical Example)

drilling holes (figure 4 is a typical example) of various diameters into the foam parallel to the foam surface at 3/4 and 2.0 inches center depths. A tabulation of these defects is given in Table 2. In order to obtain void-type simulated defects of large sizes (1.0 inch diameter maximum for 3/4 inch SOFI and 2.0 inch diameter maximum for 2.0 inch SOFI), it was necessary to use 2.0 inch SOFI thickness panels for the preparation of the 3/4-inch depth defects and 4.0 inch SOFI panels for the preparation of the 2.0-inch depth defects. This was considered legitimate simulation since the purpose of these test panels was the determination of the defect depth detection limitations as well as defect diameter. Because of the Specification NAA MA0606-045 definition of a "void" (a defect with a minimum dimension of 2.0 inches), only one defect dimension was varied. The width of the defect was selected for variation because it was the easiest to control. The width of the simulated unbonds was varied (incrementally increased) from 0.5 inch to 4.0 inch for both 3/4 inch and 2.0 inch test panels. The width of the voids at 3/4-inch center depths was varied from 0.25 inch to 1.0 inch and the voids at 2.0-inch center depths was varied (incrementally increased) from 1.0 inch to 2.0 inches. Coated test panels with SOFI thickness in excess of 2.0 inches and uncoated panels with SOFI in excess of 4.0 inches were not evaluated because of the negative results in defect detection beyond 3/4-inch depth in coated panels and 2.0-inch depth in uncoated panels.

C. TEST PARAMETERS

After the preparation of the simulated unbond test panels, the test frequency was determined by obtaining a frequency vs amplitude (meter reading) curve over a 6.0 by 2.0 by 0.025 and a 6.0 by 1.0 by 0.025 inch simulated unbond. (See figure 5.) Based on this relationship, a test frequency of 585 cycles-per-second was selected and used for all subsequent testing on 3/4 inch SOFI. The two other system variables (current supplied to the coil driver and the receiver amplifier level) were preset (1.5 amps to the driver, 20 meter divisions readout) to a constant level over a selected well-bonded area for all testing on 3/4 inch SOFI. Attempts to obtain the same relationship for thicker test panels were unsuccessful since only small variations in amplitude with drive frequency were noted. This was the first indication that the systems would be limited to the testing for defects at a depth of 3/4 inch in SOFI.

Table 2. Simulated Voids (Drilled Holes)

Defect Location, Inch (From SOFI Surface)	Defect Area (Inch)	Defect Thickness (Hole Diameter, Inch)
3/4 (defect center)	6.0 by 0.25	0.25
3/4 (defect center)	6.0 by 0.50	0.50
3/4 (defect center)	6.0 by 0.75	0.75
3/4 (defect center)	6.0 by 1.00	1.00
2.0 (defect center)	6.0 by 1.00	1.00
2.0 (defect center)	6.0 by 1.50	1.50
2.0 (defect center)	6.0 by 2.00	2.00

REMARKS:

One coated and one uncoated 2.0 inch SOFI thickness test panels were prepared with the 3/4-inch defect center locations. One uncoated 4.0 inch SOFI thickness panel was prepared with the 2.0-inch defect center locations.

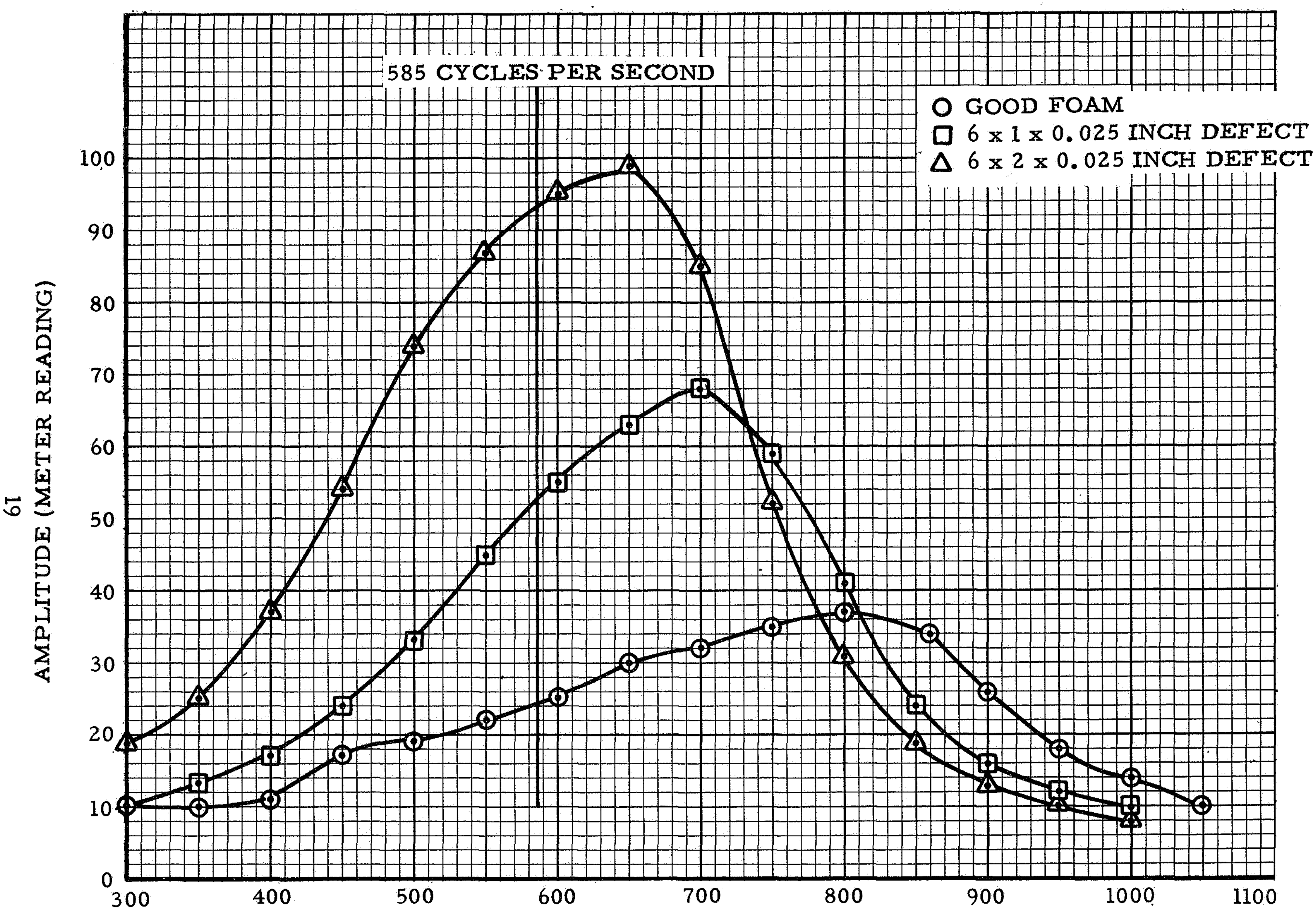


Figure 5. Frequency Amplitude Relationship for a 0.020-Inch Thick, 2.75-Inch Coil-Driven Diaphragm on 3/4-Inch Thick SOFI

D. MANUAL SCAN METHOD

Manual scanning of the test panels was performed by slowly sliding the impedance head across the surface of the SOFI. Care was exercised so that an overlap equal to 1/2 the diameter of the impedance head was obtained for each scan across the test panel. When the meter on the impedance head read 50 scale divisions or more, this point was marked on the SOFI surface with an ink applicator. Upon completion of the scan, the points within a general area were connected to form the boundary of a suspected defective area.

E. AUTOMATED SCAN METHOD

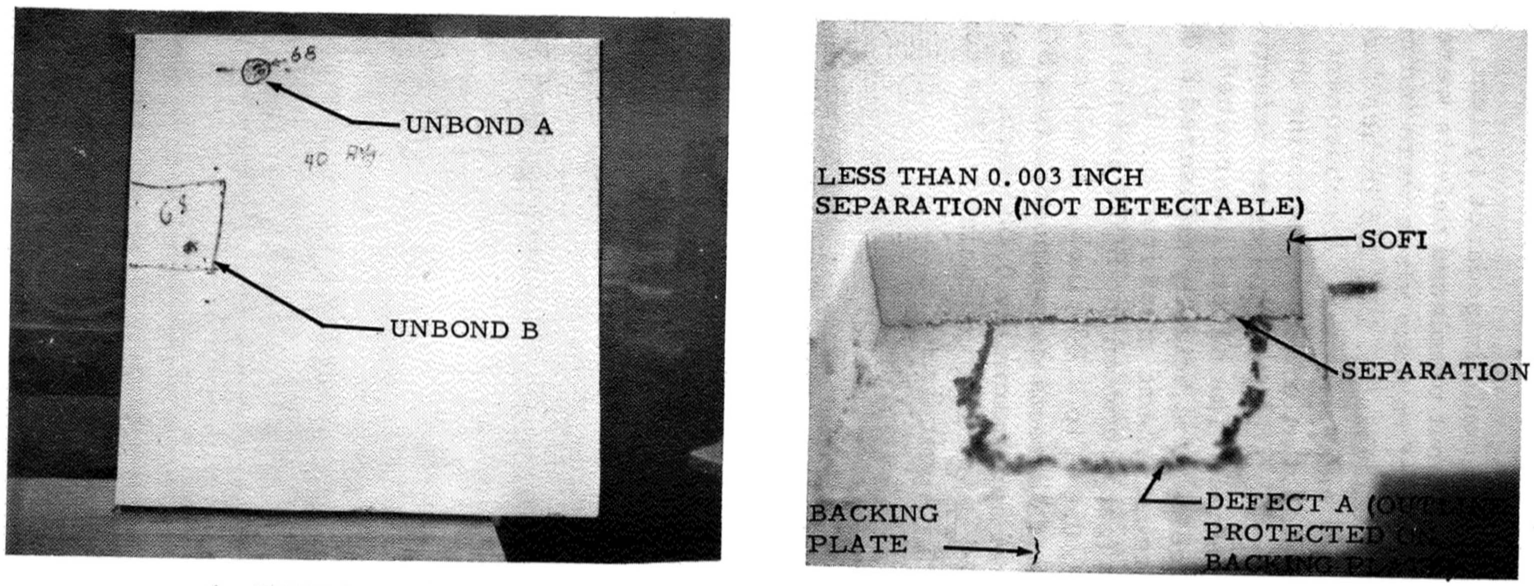
Automated scanning of the test panels was accomplished by attaching the impedance head to an X-Y scan system which contained an Alden facsimile (C-scan) recorder. The recording level was adjusted so that any meter reading of 50 scale division or greater would record. The scanner controls were adjusted to provide a scan speed of approximately 20 feet-per-minute and an index per scan of 0.100 inch. Scan speeds as high as 30 feet-per-minute and index amounts up to 0.250 inch were tried with no loss in recording resolution.

F. TEST RESULTS - SIMULATED DEFECTS

The test panels (coated and uncoated) containing simulated voids and unbonds were both manually and automatically scanned. The only difference noted was a 10 percent increase in the background reading, when operating in the automated mode, because of sliding noise. The smallest simulated unbond detected with either scanning method, in both coated and uncoated 3/4 inch SOFI thickness panels was 6.0 by 1.0 by 0.025 inches. The smallest simulated void detected at a 3/4-inch depth in both coated and uncoated SOFI was 6.0 by 1.0 by 1.0 inches. Simulated voids and unbonds at 2.0-inch depths could not be detected. For a detailed listing of the manual scan data refer to tables A-1 through A-6 in the Appendix A. The automated scan test data on simulated unbonds is shown in figures A-1 through A-3.

G. TEST RESULTS - NATURALLY OCCURRING DEFECTS

To complete the evaluation of the sonic impedance system, ten 3/4 inch SOFI test panels (uncoated) without preplaced defects were manually scanned. A total of six areas of various sizes were indicated as defective with the smallest area measuring 1.5 by 1.5 inches (area) and the largest measuring 8.0 by 6.0 inches (area). A subsequent destructive analysis of the test panels, performed by removing the SOFI one square inch at a time, revealed that all of the indicated defective areas were naturally occurring unbonds. The unbond determined to be 1.5 by 1.5 inches with the impedance system actually measured 2.0 by 2.0 inches (figure 6) and the largest unbond measured 8.0 by 6.5 inches. The maximum separation (gap) between the SOFI and the backing plate for these defects varied from 0.010 to 0.037 inch. In all cases the test-determined boundary of these defects corresponded to a SOFI separation from the backing plate of approximately 0.003 inch. Below 0.003 inch gap no indication of defectiveness was obtained. The complete test data is tabulated in table A-7 in Appendix A.



A. UNBOND LOCATION

B. CROSS SECTION OF UNBOND A

Figure 6. Naturally Occurring Unbonds

SECTION VI. CONCLUSIONS AND RECOMMENDATIONS

The coil-driven sonic impedance method was capable of detecting unbonds and voids with minimum dimension of 1.0 inch in 3/4 inch SOFI. The minimum gap or defect thickness dimension of detectable defects was established to be 0.003 inch on test panels containing natural occurring unbonds. No differences were noted in the systems capabilities on coated and uncoated SOFI or in manual or automated scanning modes. Unbonds and voids in SOFI thickness of 2.0 inches or greater were not detectable.

Since the sonic impedance method demonstrated an ability to locate defects smaller than the specification limit of 2.0 inches (minimum defect dimension), its use in inspecting the SOFI insulation on the S-II Stage liquid hydrogen tanks is recommended. The recommended use is further justified by the following advantages of the impedance method over the presently used brush and microphone technique:

1. It can be operated either manually or in an automated system.

2. The readout or flaw discrimination is made by an electrical system (meter or recorder) rather than a complete dependance upon the operator.

3. It can detect unbonds and voids in 3/4 inch SOFI insulated structures after the polyurethane protective coating has been applied.

APPENDIX A

TEST DATA

Table A-1. Manual Scan Test Results of Uncoated 3/4 Inch SOFI With Simulated Unbonds (Knife Slits)

Defect Dimension (Inches)	Defect Thickness	Meter Reading Over Defect	Meter Reading Range Over Good Areas
6 by 4 by 1 (trapezoid)	0.025	80 to 100	25 to 35
6 by 4 by 1 (trapezoid)	0.025	80 to 95	25 to 35
6 by 0.50	0.025	25 to 35	25 to 35
6 by 0.50	0.025	25 to 35	25 to 35
6 by 0.75	0.025	20 to 30	25 to 35
6 by 0.75	0.025	30 to 35	25 to 35
6 by 1.00	0.025	55 to 70	25 to 35
6 by 1.00	0.025	50 to 65	25 to 35
6 by 1.25	0.025	50 to 65	25 to 35
6 by 1.25	0.025	60 to 70	25 to 35
6 by 1.50	0.025	60 to 70	25 to 35
6 by 1.50	0.025	65 to 80	25 to 35
6 by 1.75	0.025	70 to 80	25 to 35
6 by 1.75	0.025	65 to 80	25 to 35
6 by 2.00	0.025	70 to 90	25 to 35
6 by 2.00	0.025	65 to 90	25 to 35
6 by 2.25	0.025	80 to 100	25 to 35
6 by 2.25	0.025	75 to 90	25 to 35
6 by 2.50	0.025	60 to 100	25 to 35
6 by 2.50	0.025	60 to 100	25 to 35

TEST PARAMETERS

Frequency	Current to Coil	Receiver Amplifier	Filter
585 cycles-per-second	1.5 Amperes	Adjusted until meter reading of 20 divisions obtained on selected area of 3/4 inch SOFI standard	1170 cycles-per-second

Table A-2. Manual Scan Test Results of Coated 3/4 Inch SOFI With Simulated Unbonds (Knife Slits)

Defect Dimension (Inches)	Defect Thickness	Meter Reading Over Defect	Meter Reading Range Over Good Areas
6 by 4 by 1 (trapezoid)	0.025	70 to 100	40 to 45
6 by 0.50	0.025	40 to 45	40 to 45
6 by 0.75	0.025	40 to 45	40 to 45
6 by 1.00	0.025	50 to 60	40 to 45
6 by 1.25	0.025	50 to 60	40 to 45
6 by 1.50	0.025	50 to 70	40 to 45
6 by 1.75	0.025	70 to 80	40 to 45
6 by 2.00	0.025	70 to 90	40 to 45
6 by 2.25	0.025	70 to 90	40 to 45
6 by 2.50	0.025	55 to 95	40 to 45

TEST PARAMETERS

Frequency	Current to Coil	Receiver Amplifier	Filter
585 cycles-per-second	1.5 Amperes	Adjusted until meter reading of 20 divisions obtained on selected area of 3/4 inch SOFI standard	1170 cycles-per-second

Table A-3. Manual Scan Test Results of Uncoated 2.0 Inch SOFI With Simulated Voids (Drilled Holes, 3/4 Inch Center Depths)

Defect Dimension (Inches)	Defect Thickness (Hole Diameter)	Meter Reading Over Defect	Meter Reading Range Over Good Areas
6.0 by 0.25	0.25	35 to 40	35 to 40
6.0 by 0.50	0.50	35 to 40	35 to 40
6.0 by 0.75	0.75	35 to 40	35 to 40
6.0 by 1.00	1.00	50 to 60	35 to 40

TEST PARAMETERS

Frequency	Current to Coil	Receiver Amplifier	Filter
585 cycles-per-second	1.5 Amperes	Adjusted until meter reading of 20 divisions obtained on selected area of 3/4 inch SOFI standard	1170 cycles-per-second

Table A-4. Manual Scan Test Results of Coated 2.0 Inch SOFI With Simulated Voids (Drilled Holes, 3/4 Inch Center Depths)

Defect Dimension (Inches)	Defect Thickness	Meter Reading Over Defect	Meter Reading Range Over Good Areas
6.0 by 0.25	0.25	25 to 35	25 to 35
6.0 by 0.50	0.50	25 to 35	25 to 35
6.0 by 0.75	0.75	25 to 35	25 to 35
6.0 by 1.00	1.00	50 to 60	25 to 35

TEST PARAMETERS

Frequency	Current to Coil	Receiver Amplifier	Filter
585 cycles-per-second	1.5 Amperes	Adjusted until meter reading of 20 divisions obtained on selected area of 3/4 inch SOFI standard	1170 cycles-per-second

Table A-5. Manual Scan Test Results of Uncoated 2.0 Inch SOFI With Simulated Unbonds

Defect Dimension (Inches)	Defect Thickness	Meter Reading Over Defect	Meter Reading Range Over Good Areas
6 by 0.50	0.025	40 to 45	40 to 45
6 by 0.75	0.025	40 to 45	40 to 45
6 by 1.00	0.025	40 to 45	40 to 45
6 by 1.25	0.025	40 to 45	40 to 45
6 by 1.50	0.025	40 to 45	40 to 45
6 by 1.75	0.025	40 to 45	40 to 45
6 by 2.00	0.025	40 to 45	40 to 45
6 by 2.25	0.025	40 to 45	40 to 45
6 by 2.50	0.025	40 to 45	40 to 45
6 by 2.00	0.025	40 to 45	40 to 45
6 by 4.00	0.025	40 to 45	40 to 45

TEST PARAMETERS

Frequency	Current to Coil	Receiver Amplifier	Filter
585 cycles-per-second	1.5 Amperes	Adjusted until meter reading of 20 divisions obtained on selected area of 3/4 inch SOFI standard	1170 cycles-per-second

Table A-6. Manual Scan Test Results of Uncoated 4.0 Inch SOFI With Simulated Voids (Drilled Holes, 2.0 Inch Center Depths)

Defect Dimension (Inches)	Defect Thickness (Hole Diameter)	Meter Reading Over Defect	Meter Reading Range Over Good Areas
6.0 by 1.0	1.0	40 to 45	40 to 45
6.0 by 1.5	1.5	40 to 45	40 to 45
6.0 by 2.0	2.0	40 to 45	40 to 45

TEST PARAMETERS

Frequency	Current to Coil	Receiver Amplifier	Filter
585 cycles-per-second	1.5 Amperes	Adjusted until meter reading of 20 divisions obtained on selected area of 3/4 inch SOFI standard	1170 cycles-per-second

Table A-7. Manual Scan Test Results of Uncoated 3/4 Inch SOFI With Naturally Occurring Unbonds

Defect Dimensions (Actual)(Inches)	Defect Thickness (Maximum)	Test Indicated Area	Meter Reading Over Defect	Meter Reading Range Over Good Areas
2.0 by 2.0	0.010	1.5 by 1.5	50 to 60	20 to 25
5.5 by 4.0	0.035	5.0 by 3.5	50 to 80	20 to 25
6.0 by 3.0	0.030	6.0 by 2.5	50 to 75	20 to 25
6.0 by 5.0	0.035	5.0 by 5.0	50 to 70	20 to 25
7.5 by 6.5	0.025	7.0 by 6.0	50 to 80	20 to 25
8.0 by 6.5	0.037	8.0 by 6.0	50 to 75	20 to 25

TEST PARAMETERS

Frequency	Current to Coil	Receiver Amplifier	Filter
585 cycles-per-second	1.5 Amperes	Adjusted until meter reading of 20 divisions obtained on selected area of 3/4 inch SOFI standard	1170 cycles-per-second

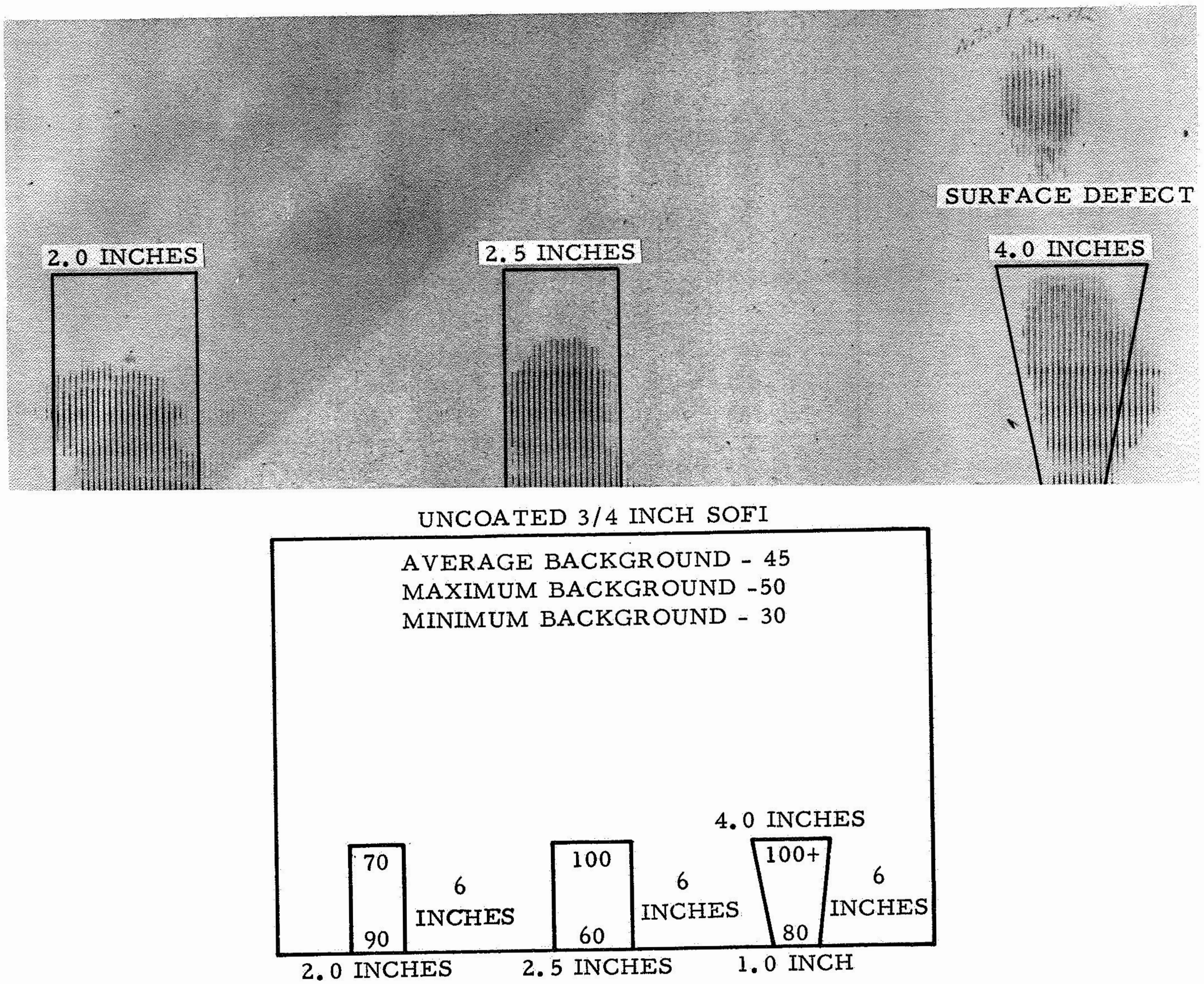


Figure A-1 Unbond Location and C-Scan Recording, 3/4 Inch Uncoated SOFI

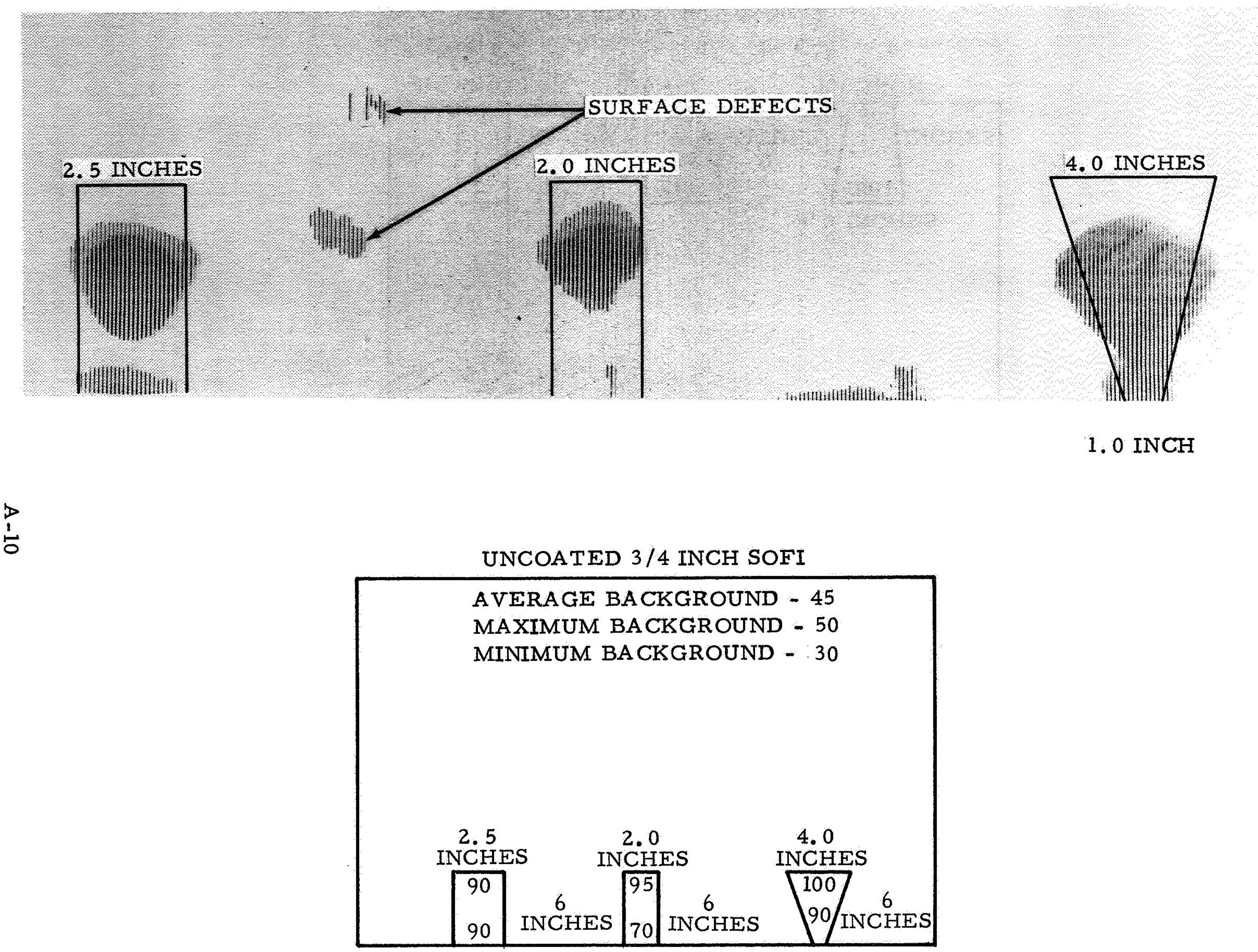
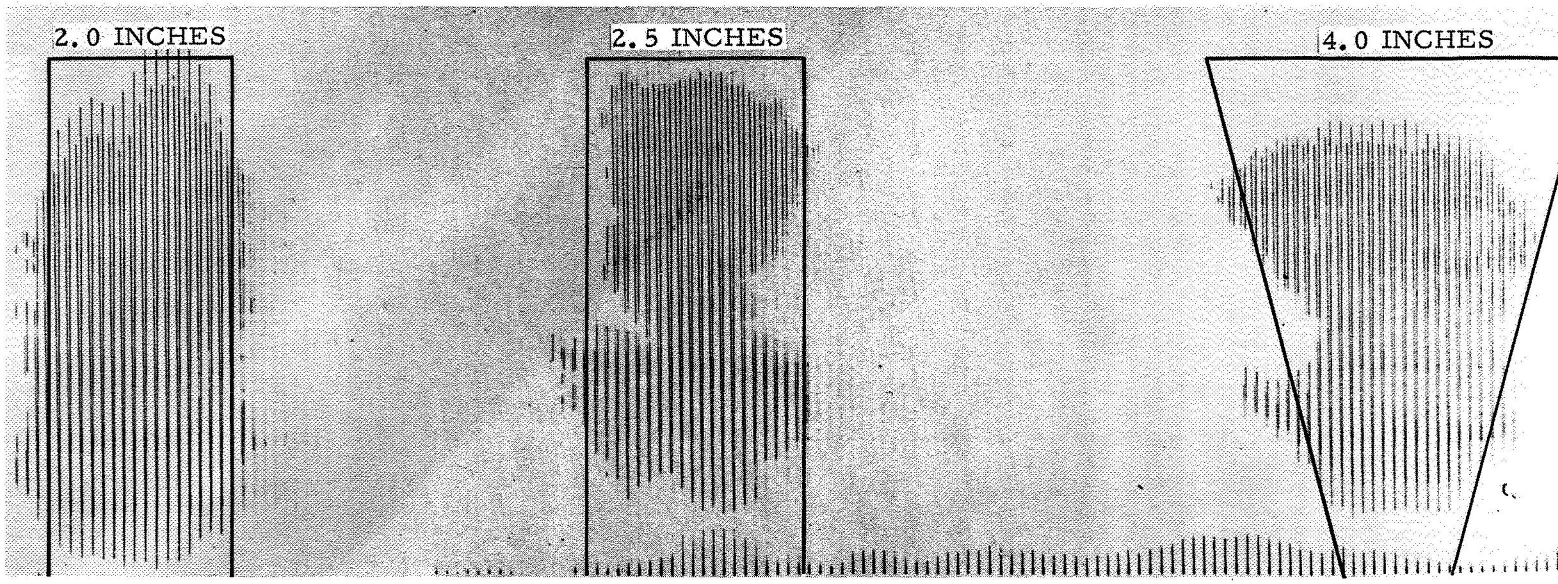


Figure A-2. Unbond Location and C-Scan Recording, 3/4 Inch Uncoated SOFI



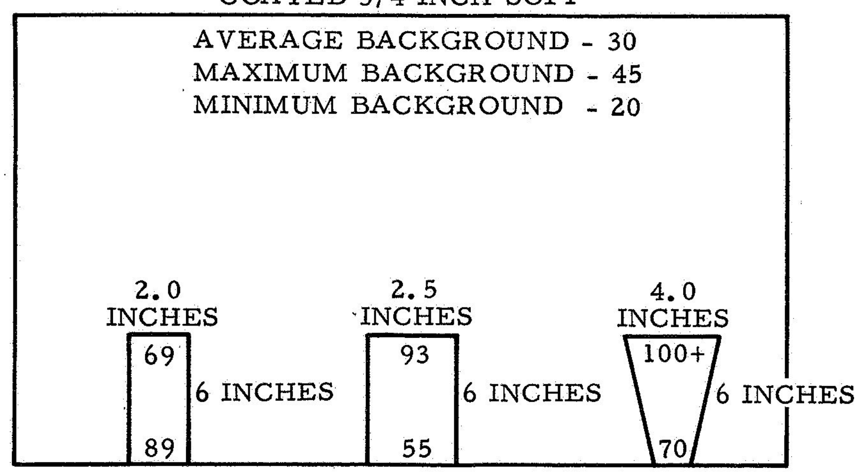


Figure A-3. Unbond Location and C-Scan Recording, 3/4 Inch Coated SOFI

APPENDIX B

REFERENCES

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2. Rayleigh, J. W. S.: The Theory of Sound, Volume II, 1945, Dover Publications.

TECHNICAL MEMORANDUM TM X-53852

APPROVAL

DEVELOPMENT OF NONDESTRUCTIVE TEST DEVICE FOR EVALUATION OF 3/4 INCH THICK POLYURETHANE SPRAY-ON FOAM INSULATION (SOFI) ON THE SATURN S-II STAGE

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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