NBSIR 75-776

Investigation of Two Techniques for Application in Test Methods for Detecting Defects in Spacecraft Thermal-Protection Material

Seymour Edelman, Steven C. Roth, and J. Franklin Mayo-Wells

Electronic Technology Division
Institute for Applied Technology
National Bureau of Standards
Washington, D. C. 20234

September 26, 1975

Final Report Covering Period
July 1, 1972 to June 30, 1973
Contract T-2979B

Prepared for

NASA Lyndon B. Johnson Space Center
Houston, Texas 77058

NBSIR 75–776

INVESTIGATION OF TWO TECHNIQUES FOR APPLICATION IN TEST METHODS FOR DETECTING DEFECTS IN SPACECRAFT THERMAL-PROTECTION MATERIAL

Seymour Edelman, Steven C. Roth, and J. Franklin Mayo-Wells

Electronic Technology Division
Institute for Applied Technology
National Bureau of Standards
Washington, D. C. 20234

September 26, 1975

Final Report Covering Period
July 1, 1972 to June 30, 1973
Contract T-2979B

This report constitutes an account for the record of exploratory work undertaken to provide input for technical decisions regarding the utilization of the techniques in question for proposed test methods. The results indicated that the techniques were not suitable for further development for the proposed tests, and no refinements of the pre liminary experiments were carried out.

Prepared for
NASA Lyndon B. Johnson Space Center
Houston, Texas 77058

ABSTRACT

The feasibility of utilizing either of two nondestructive techniques as a basis for the development of methods for detecting and locating defects in a spacecraft thermal shield was investigated. One technique consisted of scanning the surface of a heated specimen with a polymeric pyroelectric detector. Success with this technique required that an unflawed specimen be homogeneous with respect to the transfer of thermal energy along the surface of the material. In the other technique, conducted at room temperature, two polymeric piezoelectric elements were bonded on opposite sides of a known defect. Analysis of the amplitude and phase differences between the signal supplied to the exciting element and that received by the sensing element over a swept range of frequencies was intended to provide information to locate the defect. Success with this technique required that in an unflawed specimen the speed of sound along a known direction be constant or vary in the same manner along two known directions.

Experiments showed that neither technique was unambiguously capable of detecting previously identified flaws in the specimen thermal-shield material supplied by the sponsor. The utilization of these techniques as a basis for further development is not recommended.

Key Words: acoustic transmission; nondestructive test; piezoelectric; polymeric piezoelectric transducer; polymeric pyroelectric sensor; pyroelectric; spacecraft; thermal scanning; thermal shield.

INVESTIGATION OF TWO TECHNIQUES FOR APPLICATION IN TEST METHODS FOR DETECTING DEFECTS IN SPACECRAFT THERMAL-PROTECTION MATERIAL

S. Edelman, S.C. Roth, and J.F. Mayo-Wells

1. INTRODUCTION AND SUMMARY

This is the final report of work done under NASA Request Number T-2979, issued by the L.B. Johnson Manned Spacecraft Center, Houston, Texas. The objective of the work was to examine two approaches to nondestructive evaluation of the shuttle [spacecraft] thermal protection system. The effort was to be exploratory in nature to investigate if utilization of either of the given approaches would likely result in a useful, reliable method for detecting and locating defects in thermal-shield material.

This material, which in its intended use is bonded to the spacecraft structure, is described as a fibrous, ceramic material. It is coated with a glaze said to provide thermal control, waterproofing, and abrasion resistance. Types of defects of interest to NASA include water absorption sites, voids or local density variations, sites in which a degradation of thermal conductivity has occurred, and discontinuities in the glaze coating, including cracks, delaminations, and sites where the glaze has separated from its substrate. Defects in the bond between the thermal-protective material and the shuttle structure are also of interest.

The sponsor supplied a specimen of the glazed material which had several cracks in the coating, for which the approximate position was known and identified by a mask. The exploratory work was to be limited to an evaluation of the capability of the selected approaches to detect these surface cracks.

The two approaches were based on techniques using polymeric sensors developed at the National Bureau of Standards [1,2,3,4]*. One technique consisted of scanning the surface of a heated specimen with a polymeric pyroelectric detector. Success with this technique required that an unflawed specimen be homogenous with respect to the transfer of thermal energy along the surface of the material. In the other technique, conducted at room temperature, two polymeric piezoelectric elements were bonded on opposite sides of a known defect. Analysis of the amplitude-and-phase differences between the signal supplied to the exciting element and that received by the sensing element over a swept range of frequencies was intended to provide information to locate the defect. Success with this technique required that in an unflawed specimen the speed of sound along a known direction be constant or vary in the same manner along two known directions.

Experiments showed that neither technique was unambiguously capable of detecting previously identified flaws in the specimen thermal-shield material supplied by the sponsor. The utilization of these techniques as a basis for further development is not recommended.

---

*Figures in brackets identify references, section 5.

2. THERMAL-SCANNING EXPERIMENTS

2.1 Apparatus and Procedure

An existing rotating thermal-detector system [5] was modified for the thermal-scanning feasibility investigation. This detector was originally designed to provide a thermal signature from the scanned area (such as the walls of a room) and to detect and locate in azimuth the presence of thermal events causing a specified change in the signature from scan to scan. The modifications included (1) removal of the optical collection and radiation sensor assembly from the rotating mount; (2) modification of the optical system to reduce the field of view to a circle 5 mm in diameter for an optical path length of approximately 30 cm; and (3) construction of new sensors with an electrode geometry providing a reduced shunt capacitance and hence improved signal-to-noise ratio. These modifications were intended to permit the detection of a thermal discontinuity as narrow as 0.02 mm and a few celsius degrees in magnitude. This estimated performance was based on that of the unmodified system* and was considered adequate for the purpose of detecting thermal anomalies associated with surface cracks in the sponsor's specimen.

The detector system, as modified, consisted of a concave spherical mirror of 5-cm focal length, with the pyroelectric polymer film detector located near the center of curvature and sufficiently off axis to avoid obstruction of the incoming radiation. The sensitive area of the detector film was approximately 3 mm in diameter and was positioned to receive radiation from a 5-mm-diameter area of the scanned surface. The optical system was mounted in an aluminum tube. The receiving end of this tube was closed by a thin film of infrared-transmitting polymeric material to shield the detector from air currents; the opposite end was closed by the mirror mount. Attenuation of radiation by the film was approximately 30%, broadband. An FET operational differential amplifier operated at unity gain was used to match the extremely high impedance of the detector film (on the order of 10^{13} Ω) to the input impedance of an oscilloscope or other instrument used to display and record observations. A storage oscilloscope was the principal instrument used to observe the sensor output during the scanning experiments.

The signal from the preamplifier was fed into the storage oscilloscope and the trace was photographed. Usually, a series of scans was made as rapidly as possible, each trace displaced vertically from the preceding on the oscilloscope screen, and the series photographed together. The time between scans was about one minute.

---

*The following description of a simple demonstration conducted many times is presented as a somewhat dramatic indication of the system's capability. An unmounted automobile tire was supported in the laboratory in a frame that permitted rotation of the tire. The demonstrator placed his thumb on the tire tread for approximately 10 s. The "heated" area was rotated out of view of the scanning detector, which was about 30 cm distant, and a baseline scan was developed by the detector and displayed on a storage oscilloscope screen. After 10 min, the demonstrator rotated the tire to bring the heated area into view of the scanner. The "thermal thumbprint" was then clearly identifiable on the oscilloscope screen in successive scans.

Several methods for scanning the specimen smoothly were tried. In the method found most suitable, the aluminum tube was mounted on the frame of xy recorder, and the specimen was mounted on the mechanism for traversing the pen so that the region scanned included at least one known crack.

The specimen on which the tests were made was a rectangular parallelepiped, approximately 13 x 9 x 6 cm, of the shuttle thermal-protection system material and was stamped LMSC LI-1542. The sponsor also furnished a mask locating several defects. In particular, one 13 x 9-cm face was described as having a crack nearly parallel to the 9-cm edges and another nearly parallel to the 13-cm edges.

A number of scans were performed with the specimen at room temperature and at several elevated temperatures. The elevated temperatures were produced by heating the face of the specimen with a heat lamp (to about 90°C), a Meeker burner (to about 150°C), or a gas-oxygen flame (to about 300°C).

In addition to scanning the specimen face after raising the specimen temperature, the specimen was scanned a number of times after the face had been heated and then sprayed or sponged with water or with a solution of water and detergent. In some cases, the hot face of the specimen was sprayed or sponged with isopropyl alcohol. These procedures had been used by the sponsor in other methods for detecting cracks.

2.2 Results

Typical records are shown in figure 1, experiments A through E. Three scans are shown for each experiment, covering a duration of approximately five minutes. The top scan was recorded with the specimen at the highest temperature of that experiment; the specimen was in each case successively cooler for the middle and bottom scans. Each scan was started with the sensor viewing one face of the specimen near one end; the large deflections at the extreme right were generated as the scanned area passed off the opposite end of the specimen. Thus the horizontal axis corresponds to distance along the selected face. A vertical deflection of 1 cm typically represented an output change of 0.5 V from the detector preamplifier; in the figure, deflection downward corresponds to increasing temperature. Planned calibration of the detector was not carried out after the nature of the results became evident.

In the scan sets shown and in the others from which these were selected, it was usually possible to identify the deflection due to the known crack except when the sample had cooled nearly to room temperature. In almost every case, other deflections were present which were as large as or larger than the deflection due to the known crack. Also, it was noted that the shape of the deflection due to the known crack varied from one record to another in an unpredictable manner. On the basis of these observations, it was concluded that thermal scanning with a pyroelectric detector is not promising as the basis for a reliable method for detecting defects in the surface glaze of thermal-protection material.

3. ACOUSTIC-TRANSMISSION EXPERIMENTS

3.1 Apparatus and Procedure

Two polymeric piezoelectric transducers that had been developed for other work [6] were mounted on the same surface on either side of a known crack in the specimen described in 2.1*. Each transducer served in turn as an exciting element and as a sensor of acoustic waves over a swept-frequency range of 20 Hz to 600 kHz. The exciting waveform was typically sinusoidal, although half-sine and ramp (sawtooth) pulses with the same range of repetition rates were also used. The output signals from each transducer were amplified and displayed on the screen of a double-beam storage oscilloscope.

These output signals were found not to exhibit frequency correlation with the exciting signals. Investigation by means of a commercial accelerometer revealed that the acoustic signal transmitted to the specimen by a single polymeric transducer serving as driver was not strong enough for a reasonable detection signal-to-noise ratio. Accordingly, a lead-zirconate-titanate driver was constructed with a pair of active-element discs connected mechanically in series and electrically in parallel. The acoustic signal transmitted to the specimen by these drivers was found adequate for the experiments, and the polymeric transducers were found suitable for sensing the signal.

Two polymeric transducers were mounted on the specimen approximately equidistant from the acoustic source. One transducer was on the same side of a known crack as the source and the other was on the opposite side of the crack. The general procedure was to look for differences in the phase and amplitude of the signals received by the two transducers. Frequencies and waveshapes were as before.

The transducer signals were amplified and displayed on the storage oscilloscope or fed to a wave analyzer with a range of 20 Hz to 20 kHz, the output of the analyzer being displayed on the oscilloscope screen.

3.2 Results

Visual comparison of the displayed transducer output waveforms did not reveal the presence of trace deflections (or differences between the traces for the two transducers) that could be unambiguously related to the crack. That is, there were deflections that could be attributed to the crack, but these were found amid a large number of unattributable deflections. The analyzer output exhibited a similar multiplicity of possible signals. As in the case of the thermal scanning experiments, the indications of the presence of the crack varied from one test to another and were often smaller than other indications which had no relationship to the crack. It was concluded that no reliable indication of the crack could be found with the equipment available.

---

*A number of methods for bonding the polymeric transducers to the specimen were tried. It proved impossible to achieve good mechanical coupling between transducer and specimen surface with bonding agents that permitted the transducer to be removed without damage for re-use. A silver-filled rubber formulation was found to provide an acceptable bond and also electrical shielding of signal leads and transducer. This bonding agent was used in the experiments.

3.3 Experiment with Bricks

A piezoceramic driver was cemented (with alundum cement) to one end of a commercial red building brick with dimensions of approximately 20 x 9 x 5 cm. The brick had a groove about 1 mm wide sawn across the middle of a narrow face for a depth of 2 cm. The brick was arranged to stand on the driver, and either a commercial piezoelectric accelerometer or a polymeric piezoelectric transducer was bonded to the opposite end. The output from the sensing transducer was fed to a wave analyzer, and the output from the analyzer fed to a strip-chart recorder. The driver was excited with sine waves swept very slowly from about 20 Hz to 20 kHz. The sweep time was on the order of 20 min; chart speeds varied from 0.5 to 5.0 mm/s. The intent was to provide the best possible frequency discrimination within the equipment limits. The recorder trace showed a very large number of deflections over almost the entire frequency range, including several that corresponded closely in frequency to the predicted "resonance" frequency based on the speed of sound in brick and the dimensions. However, these deflections were no larger than many others. Further experiments with half-length, three-quarter length, and whole-length bricks with no obvious surface cracks resulted in similar traces, with no deflections unambiguously related to brick dimensions. The results of these experiments suggested that voids and other inhomogeneities present in the brick produced a pattern of acoustic waves that could not be interpreted by simple means.

4. CONCLUSIONS AND RECOMMENDATIONS

The results of the experiments with bricks provided a possible explanation of the poor results achieved in the thermal-scanning and acoustic-transmission experiments. Examination of the specimen supplied by the sponsor showed that a small amount of exfoliation of the glaze surface had occurred along some of the edges (as received, the specimen was glazed over all surfaces). A small cut was made into the specimen near one of these exfoliation sites to permit examination of specimen construction. It could be seen that the block was covered with an uneven layer about 0.8-mm thick, that the surface of the main portion of the block was quite irregular, and that the degree of adhesion of the covering layer to the main portion of the block varied from place to place. As a working hypothesis, it is assumed that the erratic results from tests with both techniques were caused by random and accidental combinations of thermal-energy or acoustic-energy waves. Wave transmission may have been affected by local inhomogeneities in the transmission path arising from the unevenness in the two layers of material and their inhomogeneous coupling.

The results of the work described in this report show that defects in the specimen thermal-shield material cannot be detected reliably and unambiguously with the techniques and apparatus used.

There appears to be little promise of using thermal scanning techniques with pyroelectric sensors as the basis for developing a viable method for detecting such defects, and further development is not recommended.

Theoretical considerations suggest that polymeric piezoelectric transducers might so be used at frequencies corresponding to wavelengths smaller than the thickness of the glaze coating. The production of even a few such transducers for feasibility test would itself constitute a development effort, and there is no guarantee that the thermal shield used in flight vehicles will be free from inhomogeneities that do not constitute defects from the point of view of the application, but which would make interpretation of transducer output signals very difficult. The geometry of the shielding material as applied to a flight vehicle is also likely to complicate the analysis task. For these reasons, the acoustic transmission technique as evaluated using polymeric piezoelectric transducers is considered not promising as a basis for a defect-detection method for the given application and further development is not recommended. Modified techniques using higher frequencies and pulses were not evaluated but may offer promise.

5. REFERENCES

[1] Edelman, S., Roth, S.C., and Grisham, L., Electrical Generation of Motion in Elastomers, *Shock & Vibration Bull.* 39 part 2, pp. 7-9 (1969).

[2] Edelman, S., Grisham, L., Roth, S.C., and Cohen, J., Improved Piezoelectric Effect in Polymers, *J. Acous. Soc. Amer.* 48, pp. 1040-1043 (November 1970).

[3] Cohen, J., Edelman, S., and Vezzetti, C.F., Pyroelectricity and Piezoelectricity in Oriented Films of Polyvinylfluoride and Polyvinylidene Fluoride, Book, Electrets, Charge Storage and Transport in Dielectrics, Ed. M.M. Perlman, pp. 505-516 (The Electrochemical Society, Inc., Princeton, NJ, 1973).

[4] Cohen, J., and Edelman, S., Polymeric Pyroelectric Sensors for Fire Protection, AFAPL-TR-74-16 and NBSIR 75-728 (July 1975).

[5] Scanning Thermal Detector Developed, *Nat. Bur. Stand. Tech. News Bull.*, NBSTAR 56 (12), p. 277 (December 1972).

[6] Edelman, S., Piezoelectric Polymer Stress Gages, Proc. Symposium on Advancement in Instrumentation for Civil Engineering Applications, Technical Report No. AFWL-TR-73-186, Air Force Weapons Laboratory, Kirtland Air Force Base, NM, pp. 221 *et seq.* (1973).

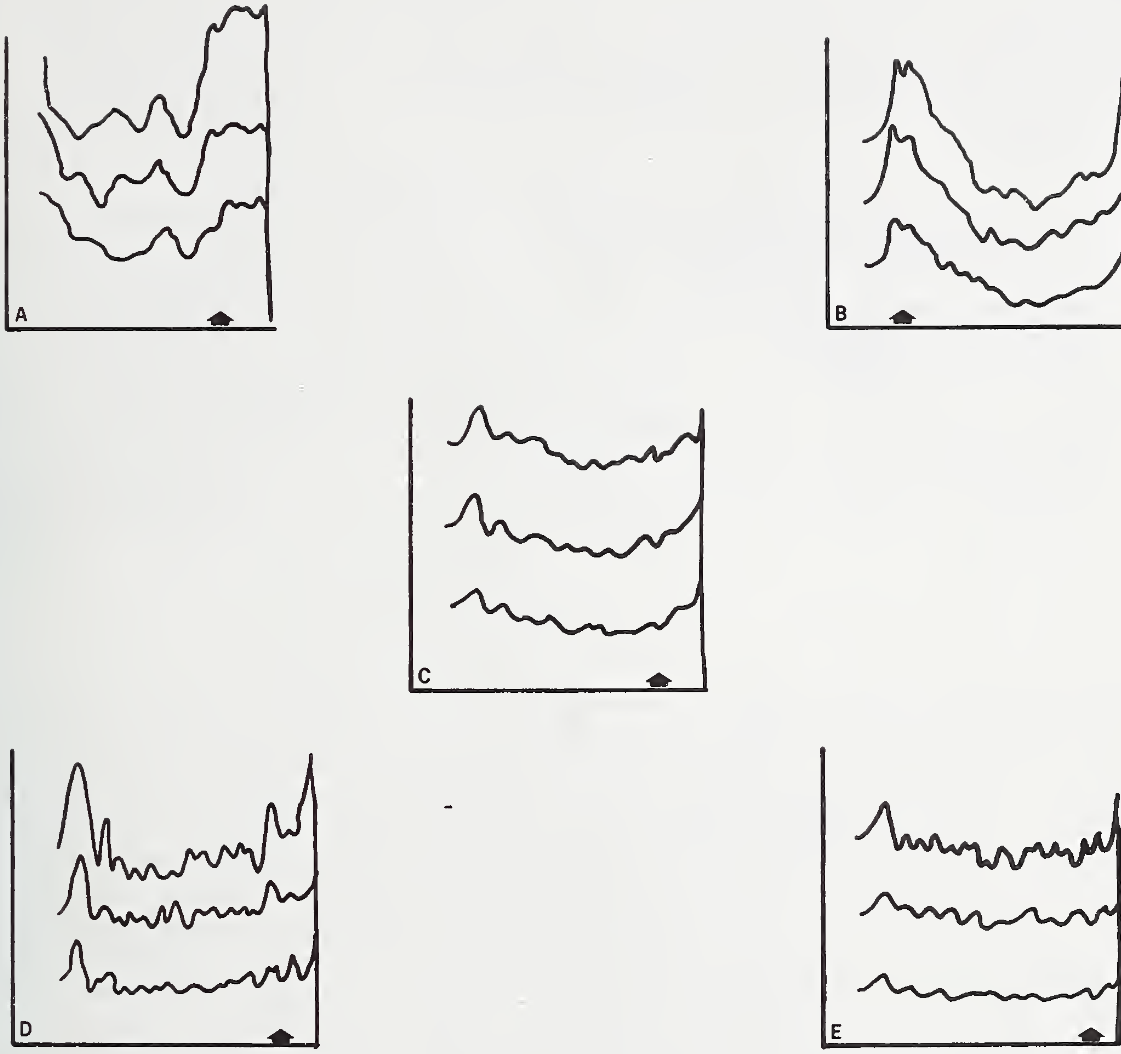

Figure 1: Drawings made from photographs of oscilloscope screen showing traces for three scans of pyroelectric sensor across one face of specimen thermal-shield material, for five experiments. The horizontal axis corresponds to distance along the selected face; trace deflection downwards corresponds to increasing temperature. In each case, the crack location is indicated by the arrowhead. Each scan was started with the sensor viewing one end of the specimen; the large vertical trace deflection at the right represents the other end of the specimen. Over the time of the scans shown for each experiment (about 5 min), the specimen was at its highest temperature when the top trace was recorded and successively cooler for the middle and bottom traces.
Experiment A: crack parallel to specimen 13-cm edges; specimen heated to about 150°C, wiped with detergent solution, and reheated briefly.
Experiment B: crack parallel to specimen 9-cm edges; specimen heated to about 150°C, wiped with detergent solution, and reheated briefly.
Experiment C: crack parallel to specimen 13-cm edges; specimen heated to about 150°C, wiped with water, and reheated briefly.
Experiment D: crack parallel to specimen 13-cm edges; specimen heated to about 150°C.
Experiment E: crack parallel to specimen 9-cm edges; specimen heated to about 300°C, wiped with detergent solution, and reheated briefly.

NBS-114A (REV. 7-73)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBSIR 75-776	2. Gov't Accession No.	3. Recipient's Accession No.

4. TITLE AND SUBTITLE
Investigation of Two Techniques for Application in Test Methods for Detecting Defects in Spacecraft Thermal-Protection Material

5. Publication Date
September 26, 1975

6. Performing Organization Code

7. AUTHOR(S)
Edelman, S., Roth, S.C., and Mayo-Wells, J.F.

8. Performing Organ. Report No.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

10. Project/Task/Work Unit No.
4253552

11. Contract/Grant No.
T-2979B

12. Sponsoring Organization Name and Complete Address *(Street, City, State, ZIP)*
Lyndon B. Johnson Space Center
National Aeronautics and Space Administration
Houston, TX 77058

13. Type of Report & Period Covered
Final 7/1/72-6/30/73

14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The feasibility of utilizing either of two nondestructive techniques as a basis for the development of methods for detecting and locating defects in a spacecraft thermal shield was investigated. One technique consisted of scanning the surface of a heated specimen with a polymeric pyroelectric detector. Success with this technique required that an unflawed specimen be homogeneous with respect to the transfer of thermal energy along the surface of the material. In the other technique, conducted at room temperature, two polymeric piezoelectric elements were bonded on opposite sides of a known defect. Analysis of the amplitude and phase differences between the signal supplied to the exciting element and that received by the sensing element over a swept range of frequencies was intended to provide information to locate the defect. Success with this technique required that in an unflawed specimen the speed of sound along a known direction be constant or vary in the same manner along two known directions.

Experiments showed that neither technique was unambiguously capable of detecting previously identified flaws in the specimen thermal-shield material supplied by the sponsor. The utilization of these techniques as a basis for further development is not recommended.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Acoustic transmission; nondestructive test; piezoelectric; polymer piezoelectric transducer; polymeric pyroelectric sensor; pyroelectric; spacecraft; thermal scanning; thermal shield.

18. AVAILABILITY [X] Unlimited

[ ] For Official Distribution. Do Not Release to NTIS

[ ] Order From Sup. of Doc., U.S. Government Printing Office Washington, D.C. 20402, SD Cat. No. C13

[X] Order From National Technical Information Service (NTIS) Springfield, Virginia 22151

19. SECURITY CLASS (THIS REPORT)	21. NO. OF PAGES
UNCLASSIFIED	10
20. SECURITY CLASS (THIS PAGE)	22. Price
UNCLASSIFIED	$ 3.25