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Report developed under SBIR contract for topic A01-166 'Embedded Sensor Technology for Solid Rocket Motor Health Monitoring'. This final report presents the significant progress achieved during this Phase I period. Results from constant load tests indicate that the current build standard of sensor is stable and does not creep when under 90% full-scale tensile load for over eight months. The tests are continuing and the current plan is to continue the trial for at least another four months. Sensors and loggers have been manufactured and delivered and the full specification and calibration sheets are attached to the report. Six laboratory analog samples have been cast and successfully tested and the manufacturing and testing procedures are given in the report. The recorded data was good and has been analyzed and the preliminary results are discussed. This data and results from future tests will be analyzed to establish prognostic parameters for use in future phases of the work. A review of this analysis and the initial conclusions drawn are also included in the report.

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PHASE I FINAL REPORT

PERIOD 1/31/2002 TO 7/31/2002

EMBEDDED SENSOR TECHNOLOGY FOR SOLID ROCKET MOTOR HEALTH MONITORING

MICRON REPORT NO: 02-221A

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SECTION 1 - Program Milestones and Deliverables

The SBIR Phase I kickoff meeting took place at the Propulsion and Structures Directorate of the U.S. Army Aviation and Missile Command (AMCOM) on the 14th March 2002. Representatives from MICRON, DASCOR, and AMCOM Propulsion and Structures and Engineering Directorates were in attendance. MICRON Instruments personnel presented their planned approach to achieving the goals set forth in the Department of Defense FY 2001 Program Solicitation 2001.2. The Phase I Objectives listed in the solicitation were as follows:

Phase I Objectives:

- Perform literature review, development, and investigation to select one or two most promising sensor technologies to be used as an embedded sensor for monitoring stress and/or strain in solid rocket motor bondlines.
- Fabrication of 12 selected sensors and 3 loggers with associated calibration sheets.
- Design and manufacture of equipment to precision match the semiconductor stress sensing elements for future production of improved sensors.
- Establish temperature and pressure sensitivity, long-term measurement stability and chemical compatibility, and in the field sensor calibration procedures.
- Develop associated prognostics (i.e. what does the sensor reading mean w/r/t solid rocket motor structural and ballistic integrity).
- Consider the requirements to establish integration into RRAPDS system (provide capability for continual or intermittent monitoring of sensor readings through RRAPDS or a data acquisition scheme compatible with RRAPDS).

Through the results of literature review (discussed in section 2) and past sensor development (funded largely by Micron Instruments and other NATO countries), it was shown that an imbedded stress transducer would meet the majority of the desired features and would provide data addressing the most critical, and yet most difficult parameter for evaluation in a solid rocket motor health monitoring system – transient bondline stress. Sensor features such as operational temperature range, accuracy, sensitivity, non-intrusiveness, long term measurement stability, versatility, robustness for installation, safety, low power requirements, ease of calibration, material compatibility, low corrosion sensitivity, and cost were all given consideration. A cooperative laboratory study was conceived with AMCOM personnel, to obtain valuable data focused upon achieving the Phase I objectives.

The first batch of six sensors and two data loggers were delivered for installation into laboratory analogs and the required training session to use the associated data logger software has been successfully completed.

The following sensors were delivered in batch one: Model No. #150584 (as shown in Figure 1) and the calibration sheets are given in Appendix A for reference.

Serial No	Sensitivity (mV)	Static Error Band (%FS)
60716	18.83	0.176
60717	21.48	0.236
60718	21.86	0.093
60719	19.30	0.078
60720	20.46	0.225
60721	21.06	0.081

The following data loggers were also delivered: Model No Ml 1008-1 (shown in Figure 2) and the calibration sheets are given in Appendix B for reference.

Serial No.	**V_{offset} (V)**	**Gain**
9823-0006	2.04/1.02	158.5/19.81
0107-0004	2.04/1.32	153.3/19.43

The given values are the average of the four stress channels/average of the four temperature channels.

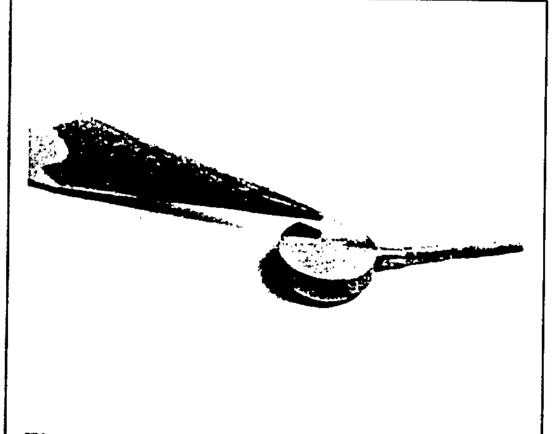


Figure 1. Model No. 150584 Sensor

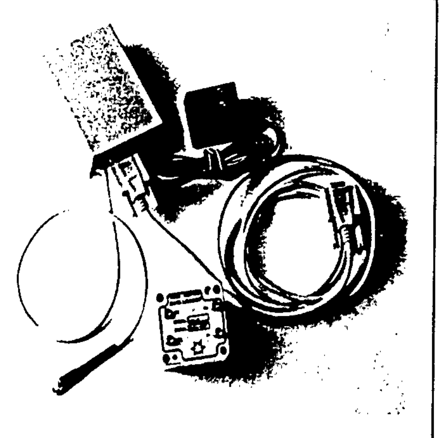


Figure 2. Model No. Ml 1008-1 Logger

A second batch of sensors and a high frequency logger have been delivered for further testing. The calibration sheets are given in Appendix A for reference.

Serial No.	**Sensitivity (mV)**	**Static Error Band (%FS)**
62176	20.88	0.1754
62177	22.26	0.3244
62178	21.51	0.3602
62179	35.29	0.2358
62180	18.16	0.0874
62181	24.29	0.1782

A High Frequency logger Model No ML1001-8-1HF was also delivered and the calibration sheet is also given in Appendix B for reference.

Serial No.	**V_{offset} (mV)**	**Gain**
0207-0001	2496.46	5.011/74.326

SECTION 2 - Review of Sensor Technology

A critical review of published papers (a list is given in Appendix C) has been undertaken. The reported results from trials using Micron embedded sensors have been assessed to establish the achieved performance of the technology. The results can be characterized into two separate areas: Sensor Performance and Installation Effects.

2.1 Sensor Performance

The majority of sensors performed as calibrated with properties as reported on the associated calibration sheets. A reliability problem with the robustness of the plug/socket used to attach the sensor cable to the bridge completion unit and to the logger was responsible for intermittent continuity. This problem has been addressed and more robust electrical connectors will be used for Phase II sensors.

A requirement to seal the sensor to ambient pressure was also established when high-pressure calibration trials were undertaken on 'bare' sensors and a number of the units leaked and equilibrated to zero load. To overcome this problem it has been recommended that a scheme be developed to hermetically seal the sensor as part of the Phase II submission. This would also improve the sensor stability and long term accuracy. Work will been performed at AMCOM using the supplied sensors to establish temperature and pressure sensitivity over the temperature range -50°F to +150°F and pressures up to 100 psi. The pressure sensitivity results will be discussed later in this report.

2.2 Installation Effects

It is essential that the sensor be correctly mounted in the test sample. To make the most accurate stress measurement, the mounting should be as non-compliant as possible (i.e. rigid with respect to the propellant grain). However, the optimal method of installation will depend upon the particular design and manufacturing sequence of the solid rocket motor, its own structural and thermal requirements, and the location in the motor for which the stress is to be measured. One objective of the design of the laboratory analog was to address whether the effect of installation into a semi-rigid insulation could be tolerated and whether the effect of insulation compliance could be compensated for within the sensor calibration. In this way, more options may be provided to the motor manufacturer to achieve compromise between the needs of the motor, the required manufacturing operations, and proper sensor installation.

A second requirement for accurate stress measurement is that the propellant must be well bonded to the sensor or through its various interfaces. Cleanliness is essential to facilitate good bonding. Long term chemical compatibility of all the components must also be assured for both safety and structural integrity. In the laboratory analog design chosen for Phase I, the sensor has been installed at the interface between the liner and insulation. The liner material is approximately 0.020 inches thick, and is composed of the same polymeric base material as the propellant (hydroxyl terminated polybutadiene). Pathfinder analogs were cast and liner peel testing was completed to ensure that liner formulation and cure were adequate to achieve a good bond to the surface of the sensor. Each rocket motor/laboratory analog sample geometry can be different with unique problems for egress and cable management with respect to installation. Past experience and recommended practice has been documented. Methods of cable management and egress from a tactical motor will be developed and tested as part of the Phase II work items.

SECTION 3 –Precision Semiconductor Strain Gage Matching System (PMS)

3.1 Typical Thermal Gage Matching Systems and Limitations

Manufacturers of semiconductor gages sell their gages in thermally matched sets of two or four. Unlike foil or wire gages, the semiconductor gage has a very large change in resistance with temperature. If not thermally matched for slope and intercept, temperature compensation for balance would be difficult and over all performance would be compromised.

Gages are normally installed (soldered) free standing so that induced stress is minimized. The circuit board is designed to go into a temperature chamber. Air that is heated or cooled enters the chamber from one side and exits at the opposite side. Small temperature chambers are used to minimize the thermal differential across the chamber, which determines the resistance tolerance in the gage matching. Approximately fifty gages are installed onto a circuit board and four boards are inserted and form a three dimensional array in the center of the chamber. The object is to minimize the thermal differential across the chamber and the new system has been designed to eliminate these uncertainties.

To read the gage resistance, power is applied from a constant current supply and the circuit compensates for any line change. A computer measures the gage resistance taking multiple readings over a finite period of time and averages them. This is done to reduce noise error and increase the accuracy. Resistive readings are taken at –50, 0, 78 and 278 °F. The gage sets are matched within plus or minus two ohms. Due to the thermal differentials across the three dimensional array of circuit boards, thermal resistive errors of up to +/- four percent of the ambient resistance is possible. These resistive errors increase the thermal non-linearity and decrease the long-term stability when used in bridges for sensor application.

3.2 PMS Description and Hardware

A new test panel has been designed to support the Precision Semiconductor Strain Gage Matching System (PMS) program. Two have been produced to support testing of up to four gage boards in the temperature chamber. Each test panel contains four relay select boards and an interconnect board. Test current is programmable by using the Sentinel's analog output capability. The test arrangement is shown in Figure 3.

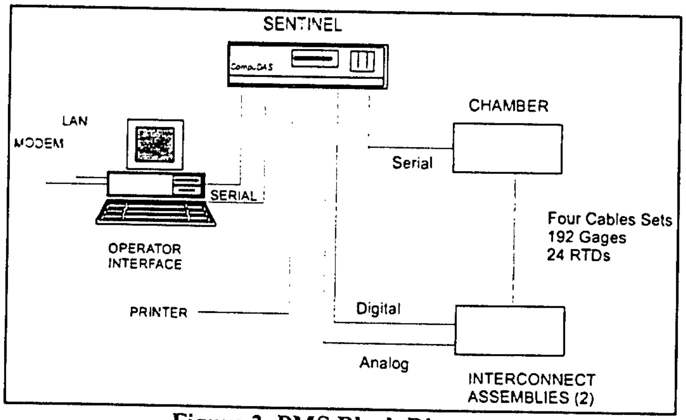


Figure 3 PMS Block Diagram

A new gage test board has also been developed. This gage board arranges gages in a series arrangement in groups of 12. Four sections on the board provide for 48 gages. Four boards are loaded into a temperature chamber of size and operation used in the presently used standard matching system. A populated board is shown in Figure 4. The gages resistance is measured by exciting the gage with constant current to cancel any line resistance changes and measuring the voltage drop across the gage with is proportional to resistance. The PMS measures the actual temperature across the three dimensional array of gages on the circuit boards.

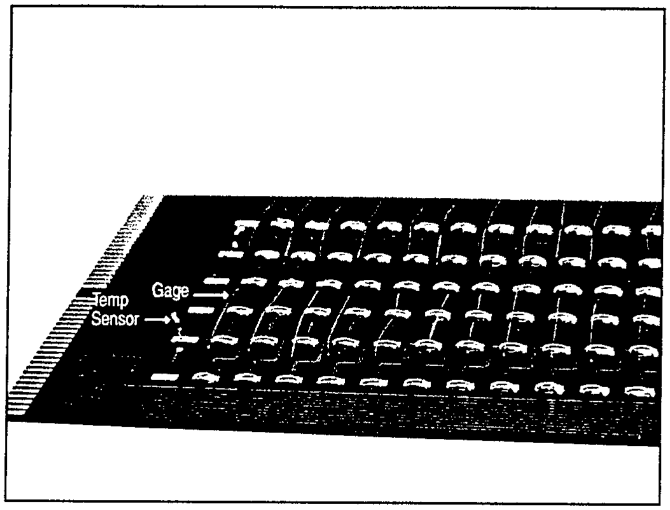


Figure 4. PMS Populated Gage Board

3.3 PMS Operation

One "Quad", or group of 12 gages, is selected. A test current is passed through the string plus three additional series elements. Two elements are platinum RTDs, which are mounted on the gage test board, one at each end of the 12 gages. The third element is a precision shunt mounted in the test panel. All 15 devices (12 gages, 1 shunt, and 2 RTDs) have the identical current flowing through them. The Sentinel measuring and control system reads the 15 voltages in a high-speed mode. Each device is read 17 times over a 60 cycle time period so that a 60 Hz digital filter can be applied. The 15 devices are read in a total elapsed time of 180 milliseconds. The RTDs are used to map the temperature of each gage. Using this data it calculates the true temperature at the gage location being measured. With this data, the system calculates the temperature coefficient of resistance (thermal sensitivity) of the gage. The computer also calculates the difference in temperature at the gage location and the specified true test temperature. The resistance of the gage, if it was at the test temperature, is calculated and used to match the gages. Accuracy of measurement more than ten fold better than the standard system will be possible.

3.4 Accuracy of system

The Sentinel system uses a 16 bit ADC and is calibrated to 0.01%. Application software has been created that features an auto zero correction for each of the 15 analog input channels. Test current is measured and known for each Quad test. The end result of this design is measurement accuracy and repeatability of 0.1 ohms with nominal 500 ohms gages. Test data taken from a reference test board is shown in Appendix D. Precision known resisters were used for this board to eliminate the effects of temperature or time variations for the measurement of system stability and accuracy. Channels 0 and 13 are the locations for the RTDs. Channel 14 is the system shunt. Channels 1 through 12 are the gage assignments. The elements on this board were measured with a 6 digit HP ohmmeter using the four wire measurement technique. Three sets of actual readings are presented to demonstrate repeatability. Actual sample values are presented with the first group of readings and as can be seen the difference is less than 0.015%. The measurement accuracy is better than 0.2 ohms which is a twenty fold improvement. This precision gage matching is expected to permit production of sensors with minimum long-term drift.

Well designed motors using established propellants with well know characteristics and which are not pushing the technology are expected to last 15 years or more. The error due to long term drift of health monitoring sensors must be within the allowable error band, which could be as low as one psi for such motors. If the drift is low and predictable, the data can be corrected and the accuracy required achieved.

SECTION 4 – Long Term Measurement Stability

Calibration checks of the sensor after casting of the propellant grain is not possible, therefore it is essential that the units used for long term health monitoring are accurate and stable. Any creep or zero shift in the sensor output would be indistinguishable from changes in the measured bond stress. Long term changes in balance with no sensor stress have also been run and were found to be acceptable. To test the stress stability of the current system a cantilever constant load test consisting of a static load applied to the sensor diaphragm was initiated and has been running for 28 weeks. The loading fixture is shown in Figure 5 and a local view of the sensor under tension load shown in Figure 6. The stress was applied to the sensor via a hard rubber interface and hanging weights. Extra care was used to ensure that the bonded surface area was limited to be that of the active surface area of the sensor diaphragm. The test rig was exposed to the ambient temperature variations and the data downloaded at regular intervals. An outline of the results for the test is given below with the start and end values for each download period.

Date	Start(V)	Finish (V)
31st December	2.410/1.593	2.395/1.598
31st Dec to 22nd Jan	2.395/1.616	2.416/1.703
22nd Jan to 19th Feb	2.417/1.721	2.415/1.720
20th Feb to 24th April	2.411/1.717	2.435/1.725
2nd May to 16th July	2.437/1.735	2.445/1.833

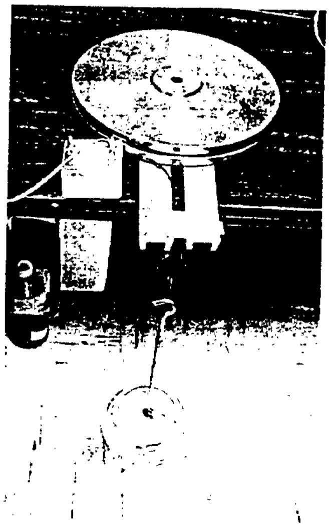


Figure 5. Test Rig

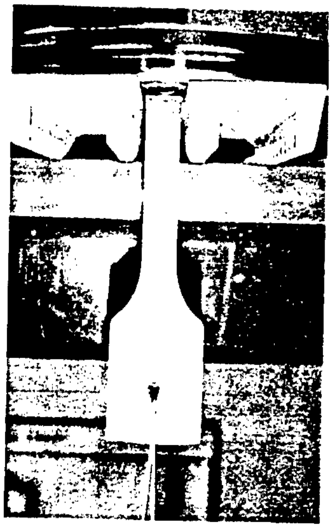


Figure 6. Sensor under Test

The plot of the results are given in Figure 7 which shows that the variation of output is 2.42 ± 0.025 V for the load which is limited by the accuracy of the logger, and the ambient temperature variations. The trend of the load follows the average increase in the ambient temperature. There is no significant indication of sensor creep, i.e. a reduction in the recorded load, in the results for the test period of 28 weeks and the test will continue until the end of the year.

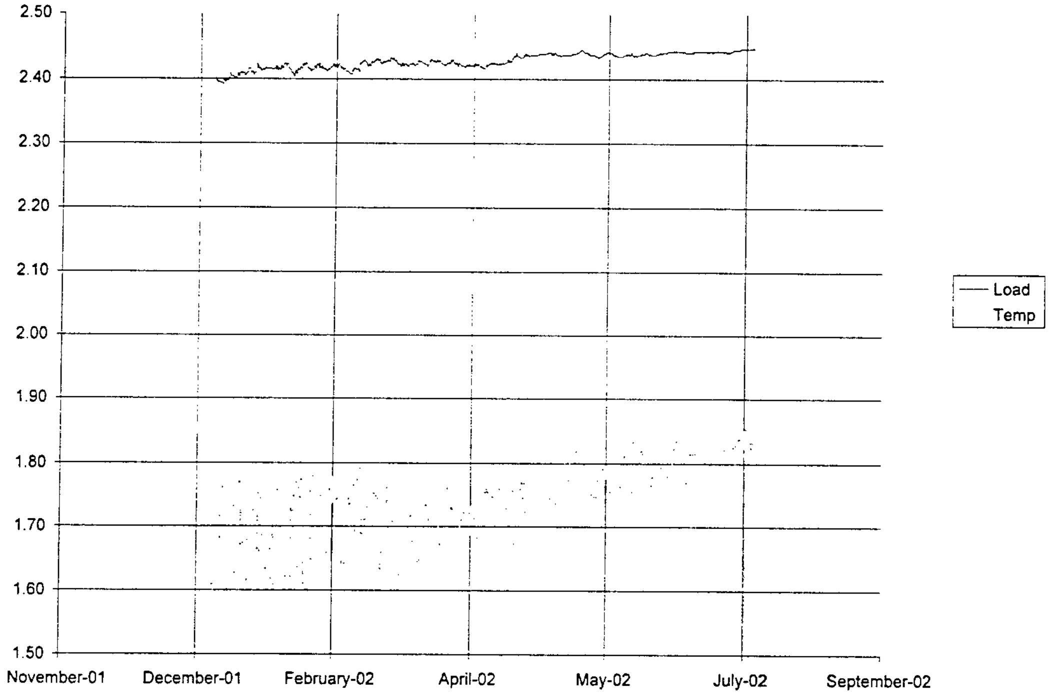


Figure 7. Long Term Stability Test Results

SECTION 5 - Evaluation of Chemical Compatibility

One of the concerns which must be addressed for any embedded sensor in a solid rocket motor is whether the sensor itself is compatible with the chemistry of the propellant, the liner, and the insulation in the bondline. Of these, the propellant will contain the most caustic constituents.

In typical solid rocket motor applications, there will be one of two common families of materials which must be considered; and these are associated with the type of propellant system used in the rocket motor. The two types of systems can be generally described as either composite or double base propellants. In the former, the propellant is composed of rigid oxidizer and fuel particles embedded in an inert polymeric matrix (approximately 84-91% solids by weight). In the latter, the propellant is composed of nearly all polymeric material, some of which may be energetic, and may also contain some level of solids loading. Composite propellants normally use ammonium perchlorate or ammonium nitrate as their oxidizing agents; both are materials which can go into solution and produce corrosive by-products in the presence of significant moisture. Double base propellants, by comparison, can contain many types of chemical explosives, such as nitroglycerin. Both families can contain trace elements such as plasticizing agents, ballistic modifiers, and stabilizers; which are subject to diffusion processes, and which may in fact have long term effects on sensors installed in motors.

An exhaustive evaluation of this issue could not be addressed within the scope of a Phase I effort. Fortunately the double base propellant motors, due to the high strain capability of their formulations, are much less susceptible to bondline stress failures (their aging mechanism is more governed by loss of chemical stabilizer through depletion reactions). For this reason, a composite propellant formulation was chosen to be used in the laboratory studies (HTPB/AP/AL).

An evaluation of sensor construction and materials can be used to infer the inherent chemical compatibility and resistance to corrosion. The sensor main cavity is composed of either 6Al-4V titanium or 17-4 precipitation hardened stainless steel. Both materials are relatively impervious to attack from hydrochloric or nitric acids; one by-product of ammonium perchlorate or ammonium nitrates in solution. The lead wire exiting the sensor is covered with a 0.010 inch thick, Teflon insulation, which is also not expected to be in any measurable way affected by propellant constituents. While this version of the sensor is not hermetically sealed, any significant moisture penetration into the sensor cavity is not expected; and would result in far worse damage to the motor itself, than to the embedded sensor.

SECTION 6 - Sensor Calibration Procedure

As discussed in previous sections, a particular laboratory analog geometry, propellant material, and construction approach was selected, to be consistent with the objectives of the Phase I study, and to provide laboratory test articles for use by AMCOM. Despite the fact that the most accurate installation of the sensor would be placement directly onto the metal substrate (motor case or bond tab), it was of equal importance that other installation methods be assessed. Previous investigations, described in the literature, had not fully characterized the tolerance to and the effects of, insulation compliance. For these reasons, and to achieve simplicity in casting tooling design, AMCOM personnel chose to install sensors into the insulation substrate which made up the structure of the bondline. The insulation material was Kevlar-filled PolyIsoprene; for which cure, stiffness, and adherence properties were assessed in separate studies. The analog casting tooling and sensor installation are shown in Figures 8 and 9, respectively. The insulation was machined to contain a small cavity and slot in which the sensor could be embedded and bonded in place with epoxy (FUSOR 305, Lord Chemical). This installation method ensured that the sensing diaphragm would be located precisely at the insulation-to-liner interface.

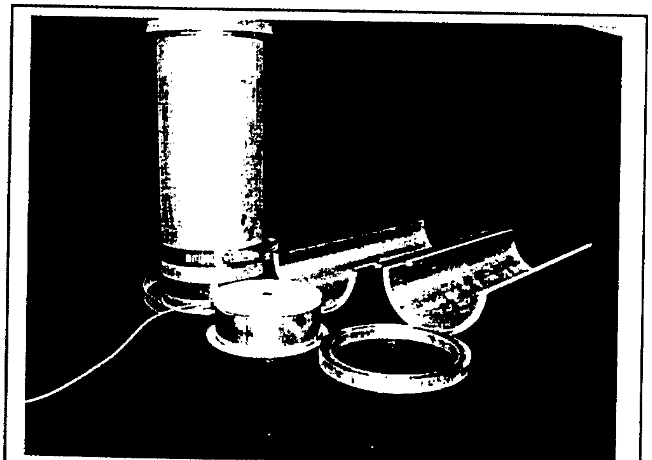


Figure 8. SBIR Analog Casting Tooling

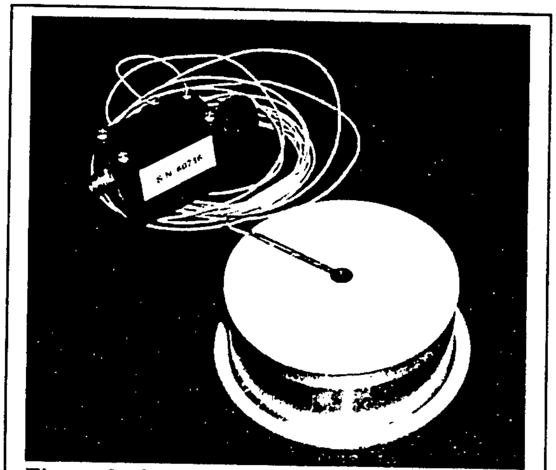


Figure 9. Sensor Installed in Insulation

Selecting this method of installation, while most convenient for analog casting, also meant that considerable effort must be expended to perform calibrations of the sensors which accounted for insulation compliance. To achieve this, a series of tools were fabricated. MICRON sent to AMCOM a factory calibration fixture, to calibrate the sensors using dry nitrogen gas pressure (0 to 100 psi). An additional calibration chamber was fabricated, so that the same sensors could be re-calibrated after being installed into the insulation on the end tab. In this way, the effect of insulation compliance could be measured and accounted for in data reduction for combined loads testing of the analogs. Shown in Figure 10 are the calibration station and test fixtures.

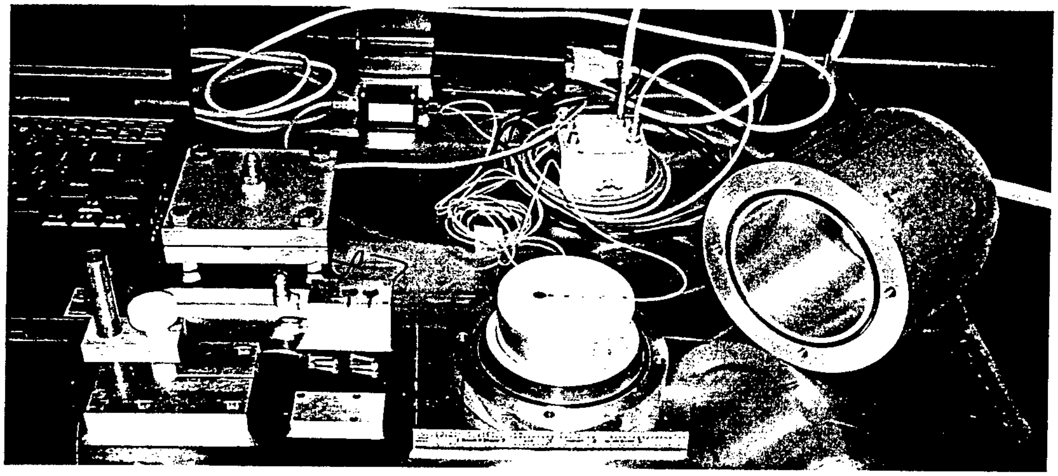


Figure 10. Sensor Calibration for Insulation Compliance

Shown in Figures 11a and 11b is a comparison of calibration curves for sensors #60718 and #60719, which show that the factory calibration fixture and AMCOM calibration fixture both provide similar data, and that when embedded in the insulation, the effects of compliance may either increase or diminish with pressure. The reason for this phenomenon is not clearly understood and more evaluation of this issue is needed. Nonetheless, the results thus far give good confidence that the effect of insulation compliance may be accounted for on a case-by-case basis, prior to propellant casting.

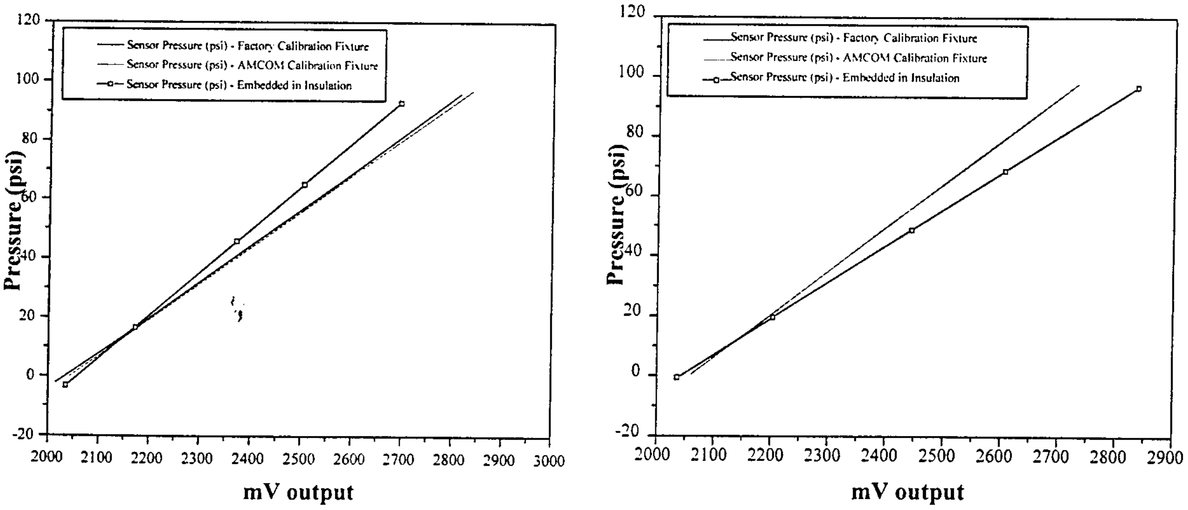


Figure 11a. and 11b. Respective Calibration Curves, Accounting for Insulation Compliance

SECTION 7 – Development of Associated Prognostics

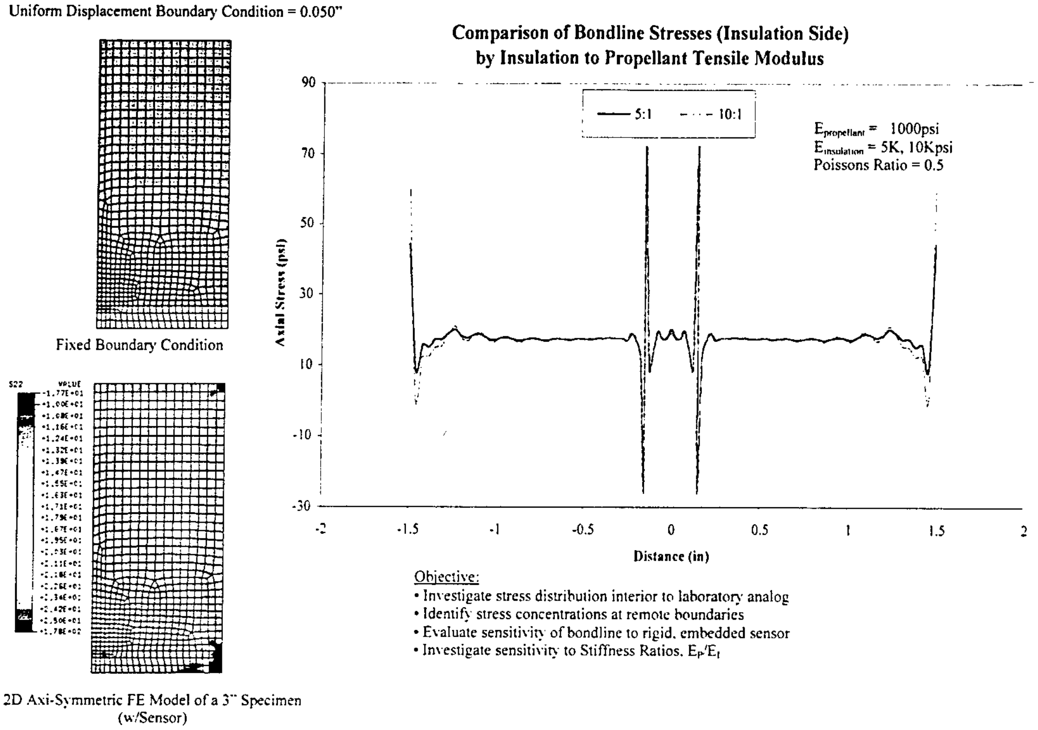
AMCOM personnel conceived and implemented a series of tests using the cast laboratory analogs. The first six tests of the series have recently been successfully completed, and are reported herein. The concept for the testing was to devise a laboratory test article, which would be subjected to combined loads and cyclic testing, with known and controlled boundary conditions, while simultaneously measuring global loads and displacements. In this way, the articles might be subjected to realistic and complex loading scenarios and the embedded sensors might be rigorously challenged for accuracy and sensitivity. The testing took place with specimens oriented at angles ranging from 0° (pure tension) to 90° (simple shear). Through finite element analysis of the analog geometry when subject to asymmetric loads, the stress distribution and its expected magnitude at the bondline are known. The combination of measurement of global loads and displacements, along with stress analysis provides means to validate sensor performance.

7.1 Laboratory Analog Stress Analysis

Prior to installation of sensors into the analogs, a series of two and three dimensional finite element analyses were performed. The viscoelastic materials were treated as linear elastic, nearly incompressible.
The objectives of these analyses were:

To size the laboratory analog specimen
To investigate its interior stress distribution
To identify and mitigate stress concentrations at remote boundaries
To evaluate the sensitivity of the bondline arising from a rigid embedded sensor
To investigate sensitivity of the geometry to various ratios of propellant to insulation stiffness; $\mathbf{E_P/E_I}$.

Shown in Figure 12 is one such finite element model, and a plot of the stress at the interface. A discontinuity exists due to the sensor on the insulation side which is not mirrored on the propellant side. The discontinuity was independent of propellant and insulation stiffness within the range selected ($1 \leq \mathbf{E_P/E_I} \leq 10$). The 2D model also allowed investigators to optimize overall aspect ratio (height-to-diameter). Once the two-dimensional axisymmetric analyses were completed a three-dimensional model was developed, and used to assess the stress distribution in the analog when subject to asymmetric loading (tensile, combined tensile-shear, simple shear). Shown in Figure 13 are the deformed geometry for each configuration and a concurrent plot of the stress distribution along the bondline interface. A stress relief groove cut into the insulation was determined to be needed to reduce (but not eliminate) the stress concentration around the perimeter of the specimen. The finite element analysis also showed that the maximum stresses for each loading condition did not occur in the geometric center of the specimen. For this reason, some of the analogs were fabricated with the sensor offset by one third of the bonded diameter, and combined loads testing completed for comparison to those with sensors in the center. Overall the finite element analysis showed that the analog was suitable to meet the objectives for which it was designed.



Objective:
- Investigate stress distribution interior to laboratory analog
- Identify stress concentrations at remote boundaries
- Evaluate sensitivity of bondline to rigid, embedded sensor
- Investigate sensitivity to Stiffness Ratios, E_P/E_I

Figure 12. Two Dimensional Finite Element Model of Laboratory Analog

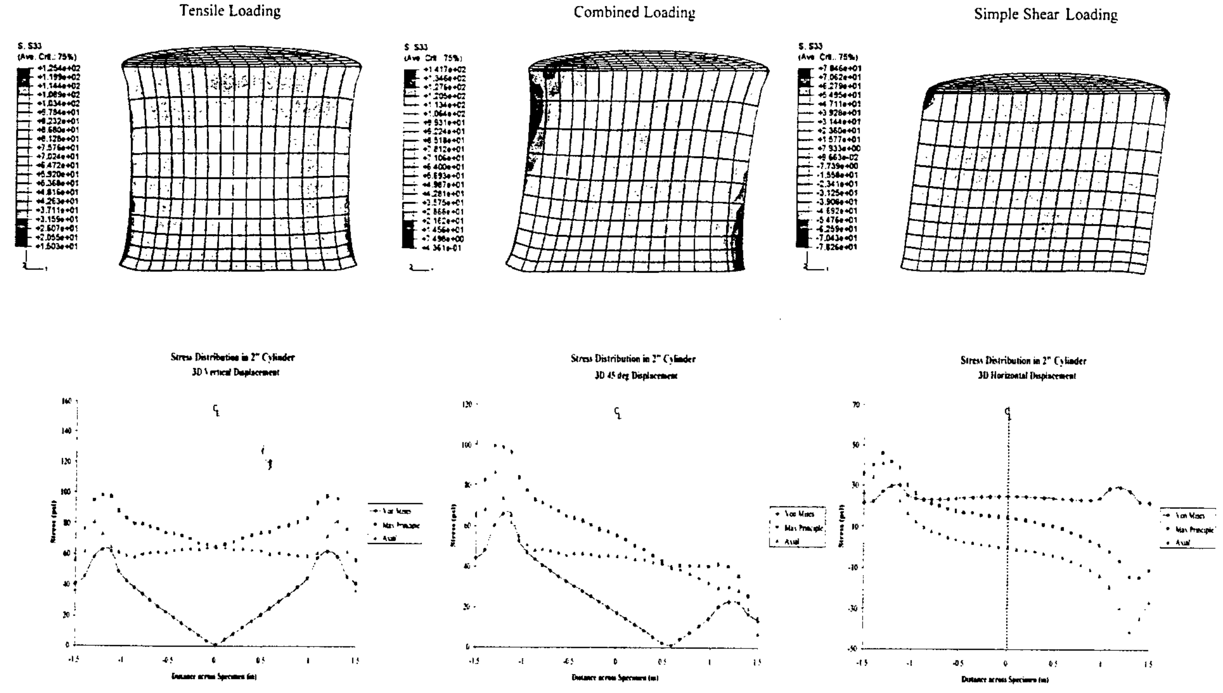


Figure 13. Three Dimensional Finite Element Models of Laboratory Analog

7.2 Analog Fabrication

Analogs were cast and cured by AMCOM personnel. After bonding the insulation in place onto an end tab, the insulation is machined, the sensor bonded, and a 24-hour cure cycle (+140°F) imposed to dry out the insulation and fully cure the epoxy. Liner is mixed, manually applied by brush, and pre-cured for 24 hours. Prior to assembly into the casting tooling, a thin "wet coat" of liner was applied, to ensure the best propellant-to-liner bond. Propellant is mixed and vacuum cast, and the analogs are cured for six (6) days at +140°F. Following removal from the curing oven and a 24-hour cool down period, the analogs are de-tooled and prepared for testing by machining the upper surface and bonding an endtab.

The configuration of the analog is shown schematically in Figure 14. It may be seen that the test geometry is a right circular cylinder, with a height to diameter ratio of approximately 1. This design, when tested in combined loads or cyclic tension, produces a stress state at the bondline, which is highly constrained and multi-axial; similar to that in a rocket motor. However, one advantage is that unlike a rocket motor, stresses may be induced mechanically (in a tensile test machine), rather than thermally; thus negating the complexity of specifically treating the thermo-viscoelastic material behavior. One modification was made to the specimen that is not shown in the schematic. After stress analysis, it was determined that large stress concentrations existed at the exterior circumference of the specimen, at the bondline interface. To reduce the magnitude of these, a circumferential stress relief slot (0.30 inch depth) was cut into the insulation, as will be illustrated in later figures.

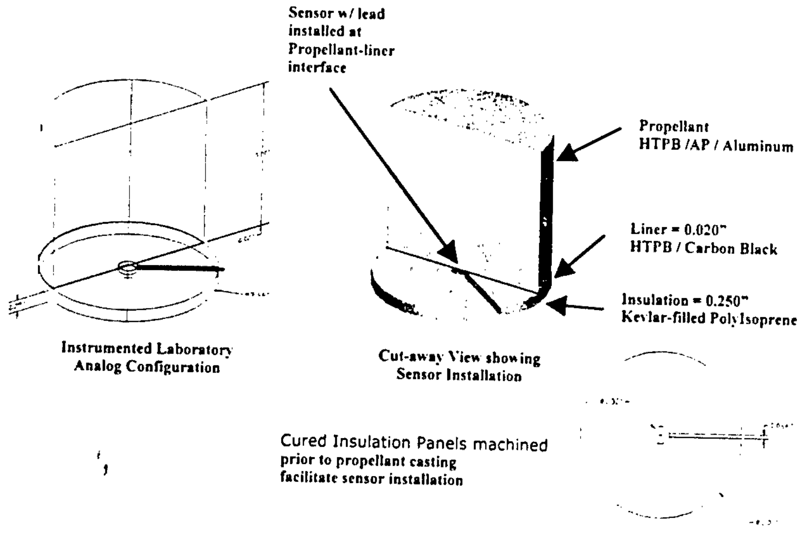


Figure 14. SBIR Analog Configuration Drawing (sans Stress Relief Groove)

The sequence of fabrication steps for an analog are illustrated in Figure 15, which also demonstrates that much of the process requires tactile contact and could lead to some variation in final product. In order to assess any potential for this, a certain amount of the propellant from each casting was cured separately for quality assurance testing of mechanical properties. Also, liner "peel boat" witness samples were cast and tested to verify liner cure and bond quality. This data is shown in Table I.

Table I. Analog Propellant Properties Summary

Mix #	**Max Strength (psi)**	**ε @ Max Load (%)**	**Initial Modulus (psi)**	**Break ε (%)**	**Peel Strength (lbs/in)**
GM02-05	119.3	37.7	1053	39.81	Wet = 9.8 No Wet = 7.5
GM02-11	117.2	39.5	1035	41.97	Wet = 17.7 No Wet = 11.1
GM02-21	110.0	38.9	962	42.28	Wet = 13.9
GM02-30	117.1	40.5	809	42.50	Wet=17.4

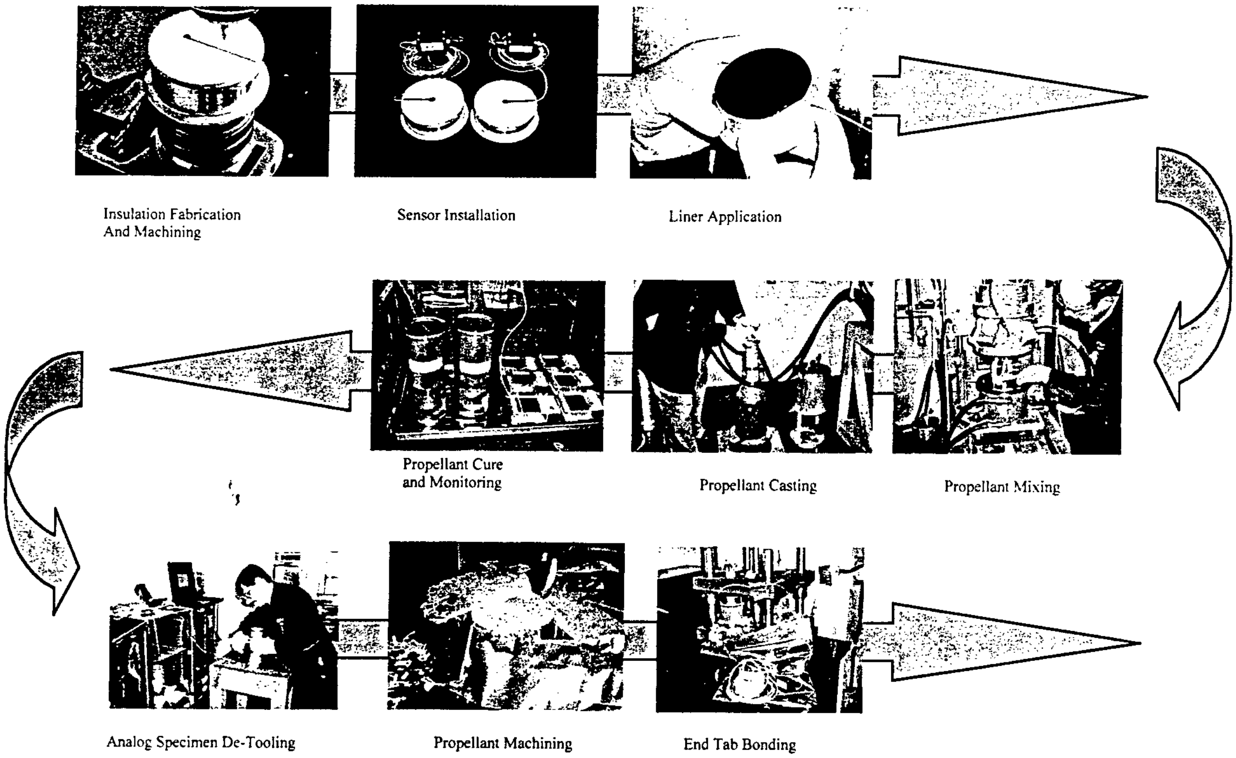


Figure 15. Fabrication Steps for Analog Specimens

During the cure process, post-cure cool down, and de-tooling, embedded sensors were logged to record the build-up of cure stress and any stress induced by de-tooling.

7.3 Preliminary Test Results

The first two analogs, designated as #1 and #2, were fabricated with sensor serial numbers #60716 and #60717, respectively. A complex load sequence was implemented, in which each analog was subjected to a series of 5 load cycles, followed by constant strain for 10 minutes (stress relaxation), followed by 5 cycles, followed by constant strain, ... etc. The sequence was repeated in such a way that the strain magnitude in each step was increased 1%, 2%, 3%, etc.; up to failure. The global load and displacement were monitored through computer data acquisition, such that the sensor readings and global measurements could be compared after the test. Analog #1 was subjected to pure tension (0° orientation) and Analog #2 was subjected to a combined tension-shear load sequence (45° orientation). A rigid linear bearing test fixture was fabricated and installed in the INSTRON tensile test machine, to ensure that the boundary conditions would be controlled throughout each test; consistent with those imposed in the finite element stress analysis. The test fixture and Analog #2 are shown in Figure 16 for illustration.

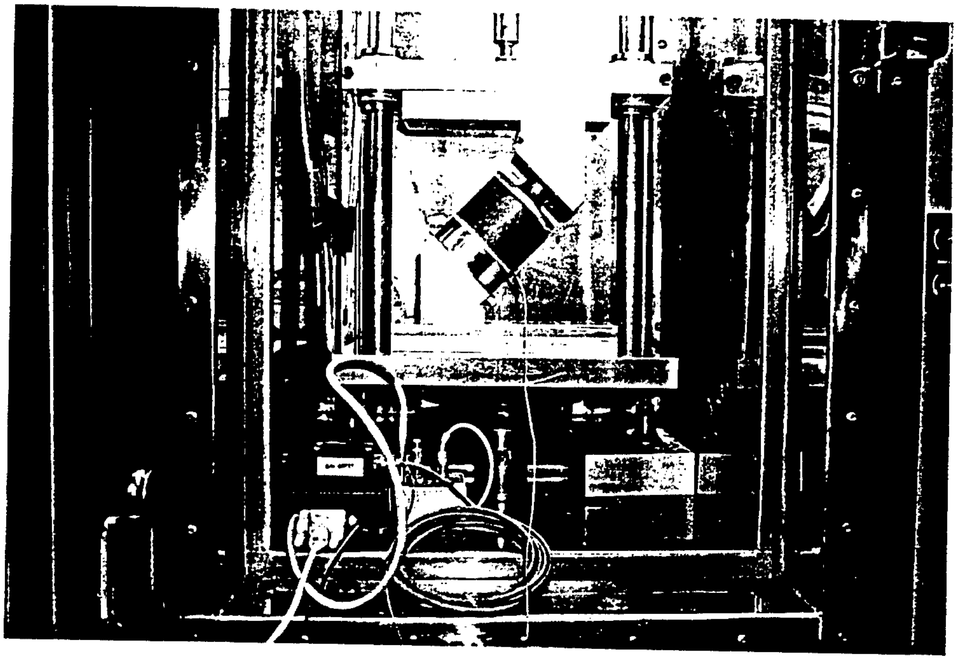


Figure 16. Analog #2 Installed in Rigid Linear Bearing Test Fixture

Test results for Analog #1 and #2 are shown, respectively, in Figures 17 and 18, which also illustrate the complex load sequence. In Figure 17, it is seen that the sensor output follows the nominal stress sequence, defined as the remote load normalized by effective cross-sectional area. More importantly, the sensor captured both the failure event and its location. While the global load still indicates some residual strength capability in the analog, the sensor indicates near-zero stress. Post –test dissection of the article showed that failure had initiated cohesively in the propellant and in close proximity to the bondline.

Similar results are illustrated by Figure 18 for the tension-shear test. Good correlation results between the sensor and global load measurement, up until the initiation of failure. Unfortunately, the analog was installed into the test fixture with the cable exiting the bondline on the tension side. This lead to a premature failure of the sample, remote from the sensor. As can be seen in Figure 19, the failure occurs at the external perimeter rather than interior to the bondline. Figure 19 also illustrates the insulation flap (stress relief) described in previous sections. Still, the sensor correctly records the fact that there is residual capability internal to the analog. This test sequence was repeated with Analog #3, with the cable exiting the sample on the compression side. An additional improvement to the test was that the sensor was offset from center, closer to the region of maximum shear stress. Comparison of results between tests demonstrates this, as shown in Figure 20.

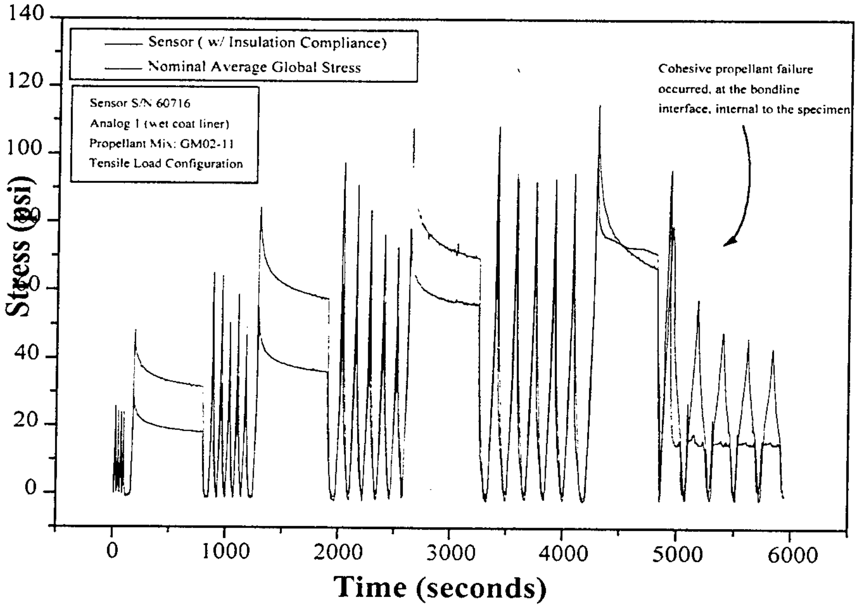


Figure 17. Test Results for Analog #1 (Pure Tension)

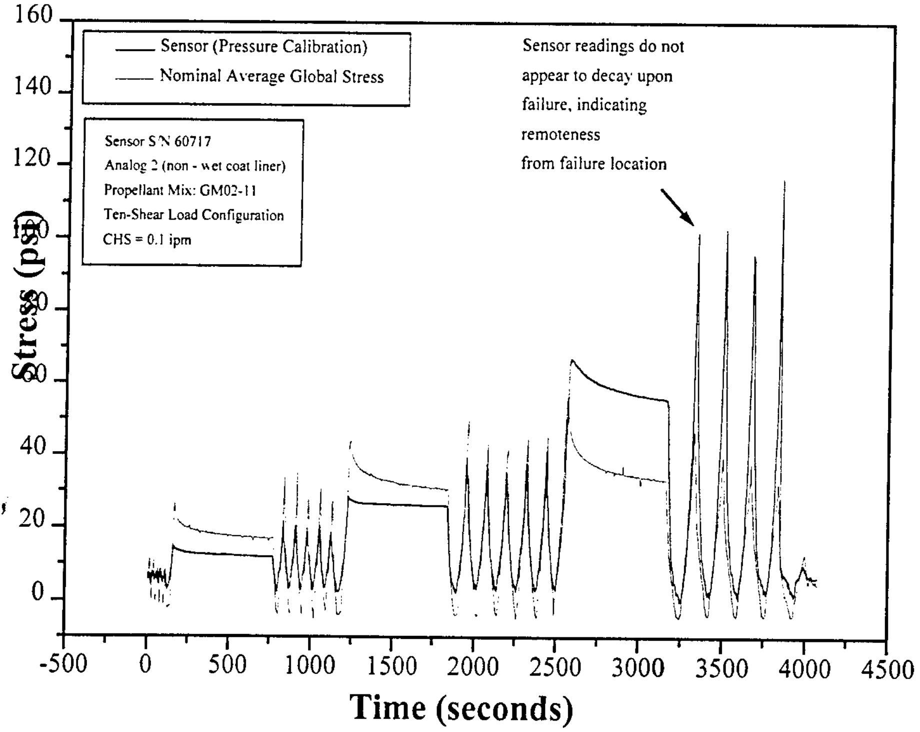


Figure 18. Test Results for Analog #2 (Tension-Shear)

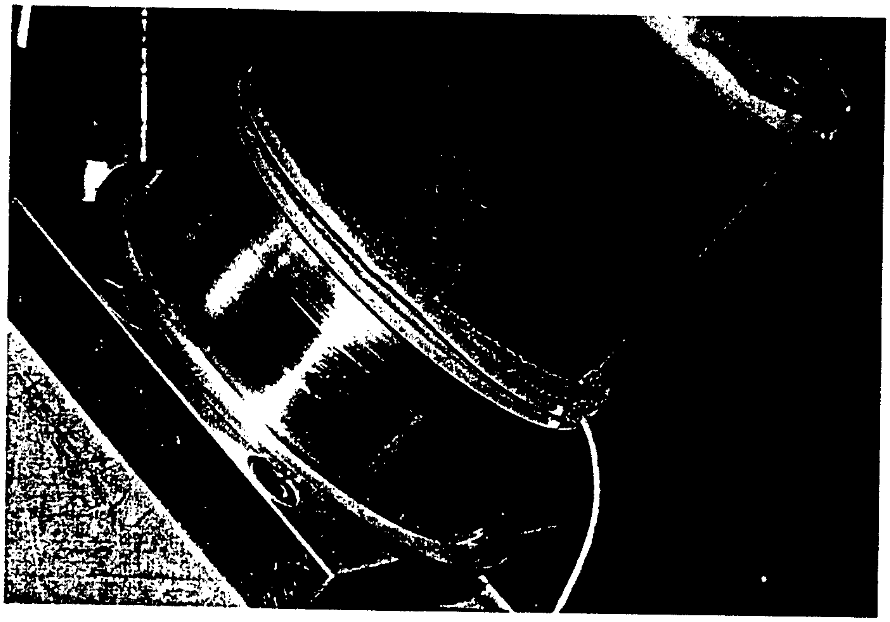
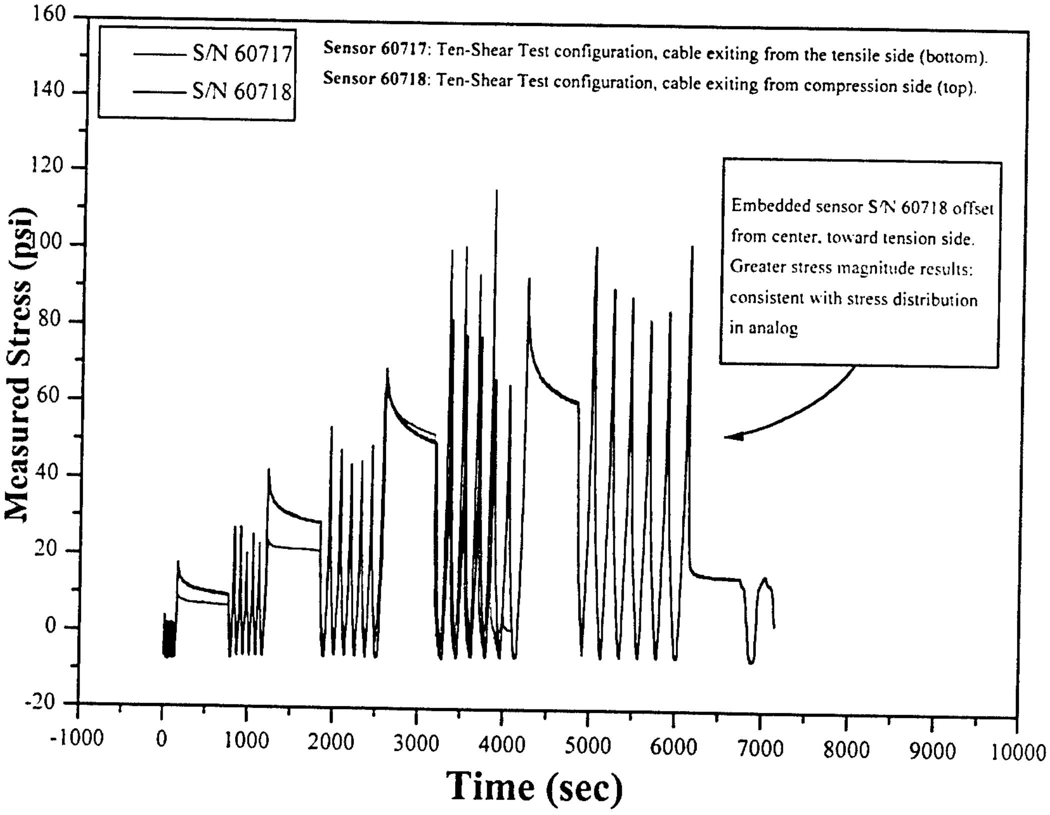


Figure 19. Detailed View of Analog #2 in Tension-Shear



Sensor 60717: Ten-Shear Test configuration, cable exiting from the tensile side (bottom).

Sensor 60718: Ten-Shear Test configuration, cable exiting from compression side (top).

Embedded sensor S/N 60718 offset from center, toward tension side. Greater stress magnitude results: consistent with stress distribution in analog

Figure 20. Comparison of Tension-Shear Test Results

Other testing performed with the sensors installed into analogs included cure monitoring and a long-term creep test. Shown in Figure 21 is a plot of the stress history during cure at +140°F. Data from the two sensors exhibits a slight offset (one shows a tensile stress throughout while the other shows tensile stresses only after cooling from cure temperature). Figure 22, shows the apparatus in which Analog #6 was subjected to a constant load creep test, of approximately 100 lbs. (22.5 psi), for greater than 28, 000 minutes. The test results given in Figure 23 shows that the stress begins to rise late in the profile; although data transfer to archive was not consistently achieved. Considerable noise in the signal was induced by the remote power source used for both the data logger and LVDT. These results are indicative of variance of response due to manufacturing and highlight the need for further training, testing, calibration, and analysis.

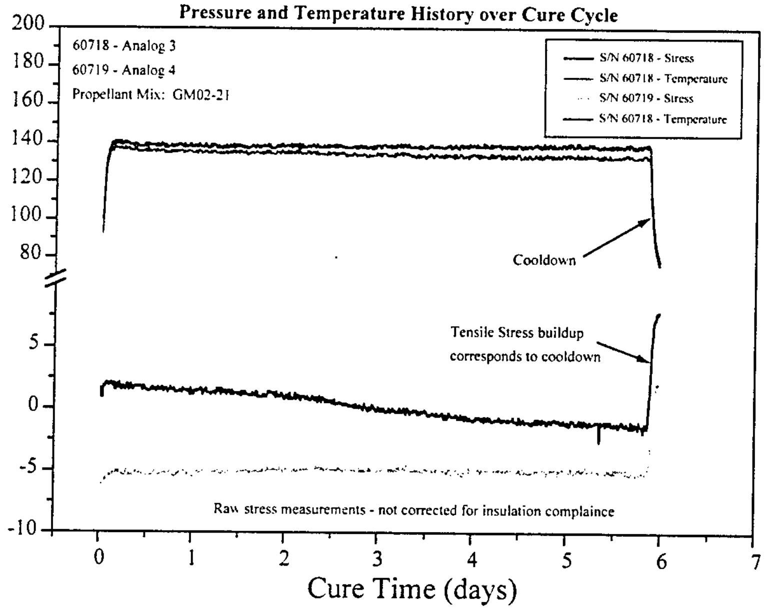


Figure 21. Cure Monitoring of Analogs #3 and #4.

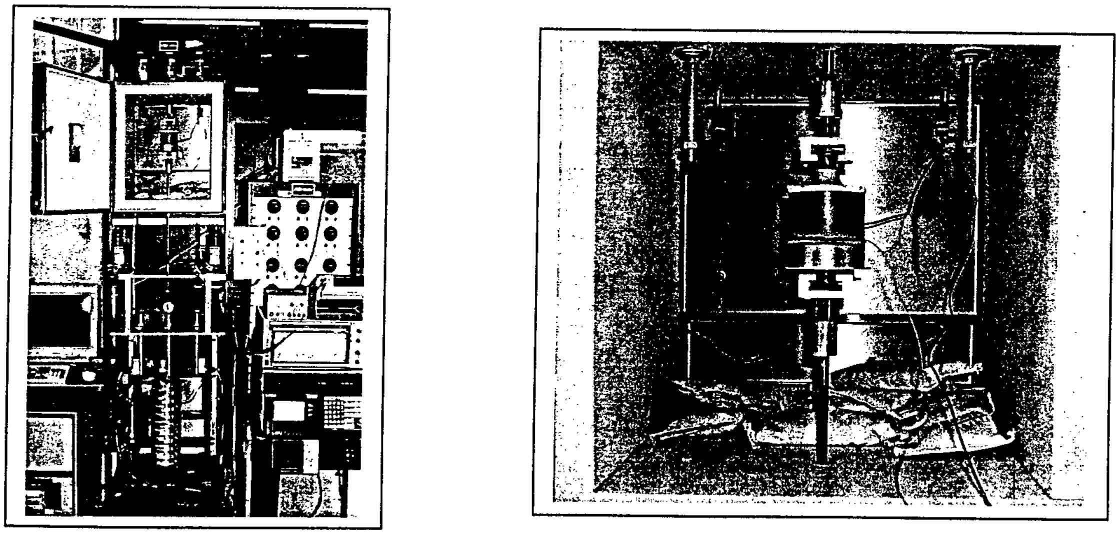


Figure 22. Creep Test Apparatus

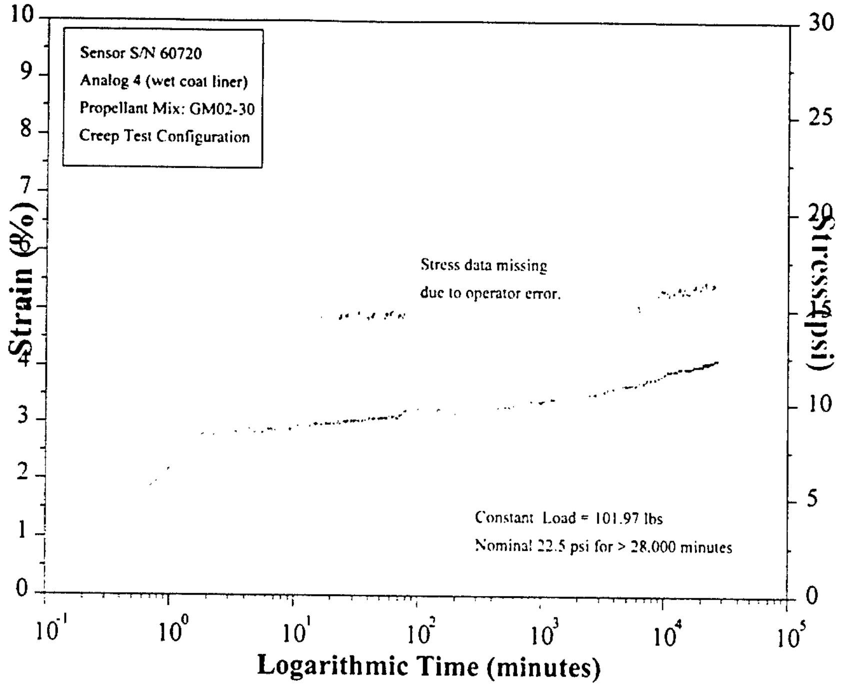


Figure 23. Long Term Creep Test of Analog #6

SECTION 8 -Conclusions and Recommendations

Bondline stress data, continuously monitored, may be directly input into cumulative damage–based failure predictive models or may be used as an instantaneous detector of propellant grain cracks and/or debonds. Optimized placement of stress transducers may even allow triangulation to locate an induced flaw. These features have great benefit and great potential to achieve the ultimate goal of health monitoring in solid rocket motors.

The results of design, calibration studies and functional testing under SBIR contracts provide the Army with confidence that embedded sensors which accurately interrogate and validate structural integrity for rocket motors can be developed and employed with good precision. SBIR Phase II program objectives have been conceived and are being pursued. Of particular interest is to establish installation procedures and combustion chamber egress designs which can be implemented in a rocket motor production environment, to demonstrate these on a production Army motor design, and support data interface and download with prototype RRAPDS hardware.

APPENDIX A

SENSOR CALIBRATION SHEETS

PRESSURE TRANSDUCER CALIBRATION DATA

Model Number 150584	*Serial Number* 60716	*Pressure Range* 100PSI	*Date* 12 Mar 2002
Diaphragm Materials Steel	*Customer* HUNTSVILLE	*Excitation* 4.0mA	*Type Unit* Gage
			Excitation Type Constant Current

Pressure Calibration Data

Date of Pressure Calibration
6 Jul 01

Pressure	Increase (1)	Decrease	Increase(2)	Straight Line through Endpoints	Linearity (%FS)	Hysteresis (%FS)	Repeatability (%FS)
0PSI G	1.08mV	1.08mV	1.08mV	1.08mV		0.0000%	0.0000%
20PSI G	4.83mV	4.82mV	4.84mV	4.85mV	0.0804%	0.0502%	0.0502%
40PSI G	8.61mV	8.57mV	8.63mV	8.61mV	0.0100%	0.2009%	0.1005%
60PSI G	12.38mV	12.32mV	12.40mV	12.38mV	0.0100%	0.3014%	0.1005%
80PSI G	16.18mV	16.15mV	16.14mV	16.14mV	0.1808%	0.1507%	0.2009%
100PSI G	19.91mV		19.98mV	19.91mV			0.3516%
SENSITIVITY	18.83mV						

STATIC ERROR BAND
± 0.1758%FS

Thermal Calibration Data

Date of Thermal Calibration
2 Jun 99

	Low Temp.	Ambient	High Temp	Temperature Range	Thermal Balance Shift	Thermal Sensitivity Shift
Temperature	-50°F	75°F	150°F			
0 PSI	-0.06mV	-0.76mV	1.11mV	-50°F to 75°F	-3.6665%FS	9.1411%FS
100PSI	18.43mV	19.55mV	19.57mV	75°F to 150°F	9.3923%FS	-9.2918%FS
Sensitivity	18.49mV	20.31mV	18.46mV	AVERAGE	± 0.0235%FS	± 0.0232%FS

Pressure and Thermal Hysteresis

TEMPERATURE (°F)	-50	-30	-10	10	30	50	70	90	110	130	150
TEMPERATURE (°C)	-46	-34	-23	-12	-1	10	21	32	43	54	66
TEMP. SENSOR OUTPUT (mV)	-166.8	-140.2	-113.5	-86.4	-59.9	-33.6	-8.2	18.1	42.0	66.2	89.9
PRESSURE SENSOR OUTPUT (mV)	-0.31	-0.15	0.00	0.15	0.27	0.41	0.55	0.74	0.85	0.85	0.88

MICRON INSTRUMENTS
4509 Runway Streeet, Simi Valley, CA 93063 (805) 522-4676

PRESSURE TRANSDUCER CALIBRATION DATA

Model Number 150584	*Serial Number* 60717	*Pressure Range* 100PSI	*Date* 12 Mar 2002
Diaphragm Materials Steel	*Customer* HUNTSVILLE	*Excitation* 4.0mA	*Type Unit* Gage
			Excitation Type Constant Current

Pressure Calibration Data

Date of Pressure Calibration
6 Oct 99

Pressure	Increase (1)	Decrease	Increase(2)	Straight Line through Endpoints	Linearity (%FS)	Hysteresis (%FS)	Repeatability (%FS)
0 PSI G	-0.26mV	-0.31mV	-0.31mV	-0.26mV		0.2356%	0.2356%
20PSI G	4.02mV	3.98mV	4.00mV	4.04mV	0.0754%	0.1885%	0.0943%
40PSI G	8.32mV	8.28mV	8.27mV	8.33mV	0.0566%	0.1885%	0.2356%
60PSI G	12.56mV	12.59mV	12.55mV	12.63mV	0.3205%	0.1414%	0.0471%
80PSI G	16.92mV	16.82mV	16.92mV	16.92mV	0.0189%	0.4713%	0.0000%
100PSI G	21.22mV		21.22mV	21.22mV			0.0000%
SENSITIVITY	21.48mV						

STATIC ERROR BAND
± 0.2356%FS

Thermal Calibration Data

Date of Thermal Calibration
6 Oct 99

	Low Temp.	Ambient	High Temp	Temperature Range	Thermal Balance Shift	Thermal Sensitivity Shift
Temperature	-50°F	50°F	150°F			
0 PSI	-0.14mV	0.20mV	-0.38mV	-50°F to 50°F	1.6023%FS	-1.8850%FS
100PSI	21.36mV	21.30mV	20.90mV	50°F to 150°F	-2.7333%FS	0.8483%FS
Sensitivity	21.50mV	21.10mV	21.28mV	AVERAGE	±0.0068%FS	±0.0047%FS

Pressure and Thermal Hysteresis

TEMPERATURE (°F)	-50	-30	-10	10	30	50	70	90	110	130	150
TEMPERATURE (°C)	-46	-34	-23	-12	-1	10	21	32	43	54	66
TEMP. SENSOR OUTPUT (mV)	-218.9	-175.1	-131.2	-86.5	-44.6	0.2	43.5	84.5	125.5	172.5	216.0
PRESSURE SENSOR OUTPUT (mV)	-0.08	-0.08	-0.09	-0.11	-0.15	-0.18	-0.16	-0.12	-0.31	-0.45	-0.69

MICRON INSTRUMENTS
4509 Runway Streeet, Simi Valley, CA 93063 (805) 522-4676

PRESSURE TRANSDUCER CALIBRATION DATA			*Date* 12 Mar 2002
Model Number 150584	*Serial Number* 60718	*Pressure Range* 100PSI	*Type Unit* Gage
Diaphragm Materials Steel	*Customer* HUNTSVILLE	*Excitation* 4.0mA	*Excitation Type* Constant Current

Pressure Calibration Data					*Date of Pressure Calibration* 29 Sep 99		
Pressure	**Increase (1)**	**Decrease**	**Increase(2)**	**Straight Line through Endpoints**	**Linearity (%FS)**	**Hysteresis (%FS)**	**Repeatability (%FS)**
0PSI G	-0.30mV	-0.32mV	-0.32mV	-0.30mV		0.0928%	0.0928%
20PSI G	4.07mV	4.07mV	4.05mV	4.07mV	0.0093%	0.0000%	0.0928%
40PSI G	8.45mV	8.44mV	8.43mV	8.44mV	0.0278%	0.0464%	0.0928%
60PSI G	12.81mV	12.82mV	12.80mV	12.82mV	0.0278%	0.0464%	0.0464%
80PSI G	17.20mV	17.20mV	17.16mV	17.19mV	0.0557%	0.0000%	0.1855%
100PSI G	21.56mV		21.52mV	21.56mV			0.1855%
SENSITIVITY	21.86mV						

STATIC ERROR BAND

± 0.0928%FS

Thermal Calibration Data					*Date of Thermal Calibration* 29 Sep 99	
	Low Temp.	**Ambient**	**High Temp**	**Temperature Range**	**Thermal Balance Shift**	**Thermal Sensitivity Shift**
Temperature	-50°F	50°F	150°F			
0 PSI	0.22mV	-0.11mV	-0.12mV	-50°F to 50°F	-1.5306%FS	1.1596%FS
100PSI	21.00mV	20.92mV	20.60mV	50°F to 150°F	-0.0464%FS	-1.3915%FS
Sensitivity	20.78mV	21.03mV	20.73mV	**AVERAGE**	±0.0039%FS	±0.0035%FS

Pressure and Thermal Hysteresis

TEMPERATURE (°F)	-50	-30	-10	10	30	50	70	90	110	130	150
TEMPERATURE (°C)	-46	-34	-23	-12	-1	10	21	32	43	54	66
TEMP. SENSOR OUTPUT (mV)	-201.2	-150.2	-99.3	-48.5	2.0	52.2	101.7	155.1	203.6	251.1	297.4
PRESSURE SENSOR OUTPUT (mV)	0.31	0.16	0.04	-0.05	-0.10	-0.13	-0.10	-0.04	0.03	0.11	0.23

MICRON INSTRUMENTS

4509 Runway Streeet, Simi Valley, CA 93063 (805) 522-4676

PRESSURE TRANSDUCER CALIBRATION DATA

Model Number 150584	*Serial Number* 60719	*Pressure Range* 100PSI	*Date* 12 Mar 2002
Diaphragm Materials Steel	*Customer* HUNTSVILLE	*Excitation* 4.0mA	*Type Unit* Gage
			Excitation Type Constant Current

Pressure Calibration Data

Date of Pressure Calibration
25 Sep 99

Pressure	Increase (1)	Decrease	Increase(2)	Straight Line through Endpoints	Linearity (%FS)	Hysteresis (%FS)	Repeatability (%FS)
0PSI G	0.03mV	0.03mV	0.03mV	0.03mV		0.0000%	0.0000%
20PSI G	3.89mV	3.89mV	3.88mV	3.89mV	0.0000%	0.0000%	0.0517%
40PSI G	7.74mV	7.74mV	7.75mV	7.75mV	0.0517%	0.0000%	0.0517%
60PSI G	11.59mV	11.59mV	11.57mV	11.61mV	0.1035%	0.0000%	0.1035%
80PSI G	15.46mV	15.45mV	15.44mV	15.47mV	0.0517%	0.0517%	0.1035%
100PSI G	19.33mV		19.30mV	19.33mV			0.1552%
SENSITIVITY	19.30mV						

STATIC ERROR BAND
± 0.0776%FS

Thermal Calibration Data

Date of Thermal Calibration
25 Sep 99

	Low Temp.	Ambient	High Temp	Temperature Range	Thermal Balance Shift	Thermal Sensitivity Shift
Temperature	-50°F	50°F	150°F			
0 PSI	0.40mV	0.31mV	-0.25mV	-50°F to 50°F	-0.4656%FS	-0.0517%FS
100PSI	18.00mV	17.90mV	16.73mV	50°F to 150°F	-2.8971%FS	-3.1557%FS
Sensitivity	17.60mV	17.59mV	16.98mV	AVERAGE	± 0.0084%FS	± 0.0080%FS

Pressure and Thermal Hysteresis

TEMPERATURE (°F)	-50	-30	-10	10	30	50	70	90	110	130	150
TEMPERATURE (°C)	-46	-34	-23	-12	-1	10	21	32	43	54	66
TEMP. SENSOR OUTPUT (mV)	-260.5	-199.6	-137.5	-75.2	-12.4	50.7	116.7	184.2	247.4	309.5	369.8
PRESSURE SENSOR OUTPUT (mV)	0.28	0.04	-0.16	-0.32	-0.45	-0.53	-0.55	-0.57	-0.56	-0.51	-0.46

MICRON INSTRUMENTS
4509 Runway Streeet, Simi Valley, CA 93063 (805) 522-4676

PRESSURE TRANSDUCER CALIBRATION DATA

Model Number 150584	*Serial Number* 60720	*Pressure Range* 100PSI	*Date* 12 Mar 2002
Diaphragm Materials Steel	*Customer* HUNTSVILLE	*Excitation* 4.0mA	*Type Unit* Gage
			Excitation Type Constant Current

Pressure Calibration Data

Date of Pressure Calibration
25 Sep 99

Pressure	Increase (1)	Decrease	Increase(2)	Straight Line through Endpoints	Linearity (%FS)	Hysteresis (%FS)	Repeatability (%FS)
0PSI G	-0.04mV	-0.04mV	-0.04mV	-0.04mV		0.0000%	0.0000%
20PSI G	4.07mV	4.06mV	4.06mV	4.05mV	0.0881%	0.0490%	0.0490%
40PSI G	8.17mV	8.17mV	8.16mV	8.14mV	0.1273%	0.0000%	0.0490%
60PSI G	12.29mV	12.28mV	12.28mV	12.24mV	0.2644%	0.0490%	0.0490%
80PSI G	16.42mV	16.42mV	16.40mV	16.33mV	0.4505%	0.0000%	0.0979%
100PSI G	20.42mV		20.49mV	20.42mV			0.3428%
SENSITIVITY	20.46mV						

STATIC ERROR BAND
± 0.2253%FS

Thermal Calibration Data

Date of Thermal Calibration
25 Sep 99

	Low Temp.	Ambient	High Temp	Temperature Range	Thermal Balance Shift	Thermal Sensitivity Shift
Temperature	-50°F	50°F	150°F			
0 PSI	-0.43mV	-0.11mV	-0.09mV	-50°F to 50°F	1.5671%FS	1.1263%FS
100PSI	18.53mV	19.08mV	18.75mV	50°F to 150°F	0.0979%FS	-1.7140%FS
Sensitivity	18.96mV	19.18mV	18.84mV	AVERAGE	±0.0042%FS	±0.0043%FS

Pressure and Thermal Hysteresis

TEMPERATURE (°F)	-50	-30	-10	10	30	50	70	90	110	130	150
TEMPERATURE (°C)	-46	-34	-23	-12	-1	10	21	32	43	54	66
TEMP. SENSOR OUTPUT (mV)	-257.9	-197.2	-134.9	-72.1	-8.6	55.6	122.5	190.9	255.1	319.0	382.6
PRESSURE SENSOR OUTPUT (mV)	-1.10	-0.97	-0.84	-0.72	-0.62	-0.55	-0.42	-0.41	-0.44	-0.44	-0.52

PRESSURE TRANSDUCER CALIBRATION DATA

Model Number 150584	*Serial Number* 60721	*Pressure Range* 100PSI	*Date* 12 Mar 2002
Diaphragm Materials Steel	*Customer* HUNTSVILLE	*Excitation* 4.0mA	*Type Unit* Gage
			Excitation Type Constant Current

Pressure Calibration Data

Date of Pressure Calibration
25 Sep 99

Pressure	Increase (1)	Decrease	Increase(2)	Straight Line through Endpoints	Linearity (%FS)	Hysteresis (%FS)	Repeatability (%FS)
0 PSI G	-0.06mV	-0.05mV	-0.05mV	-0.06mV		0.0476%	0.0476%
20PSI G	4.16mV	4.16mV	4.16mV	4.15mV	0.0381%	0.0000%	0.0000%
40PSI G	8.38mV	8.37mV	8.36mV	8.36mV	0.0762%	0.0476%	0.0952%
60PSI G	12.61mV	12.60mV	12.58mV	12.58mV	0.1619%	0.0476%	0.1429%
80PSI G	16.80mV	16.82mV	16.80mV	16.79mV	0.0571%	0.0476%	0.0000%
100PSI G	21.00mV		21.01mV	21.00mV			
SENSITIVITY	21.06mV						0.0476%

STATIC ERROR BAND
± 0.0810%FS

Thermal Calibration Data

Date of Thermal Calibration
25 Sep 99

	Low Temp.	Ambient	High Temp	Temperature Range	Thermal Balance Shift	Thermal Sensitivity Shift
Temperature	-50°F	50°F	150°F			
0 PSI	-0.26mV	-0.15mV	0.01mV	-50°F to 50°F	0.5238%FS	0.5714%FS
100PSI	19.11mV	19.34mV	19.28mV	50°F to 150°F	0.7619%FS	-1.0476%FS
Sensitivity	19.35mV	19.45mV	19.25mV	AVERAGE	± 0.0032%FS	± 0.0026%FS

Pressure and Thermal Hysteresis

TEMPERATURE (°F)	-50	-30	-10	10	30	50	70	90	110	130	150
TEMPERATURE (°C)	-46	-34	-23	-12	-1	10	21	32	43	54	66
TEMP. SENSOR OUTPUT (mV)	-264.0	-205.0	-144.2	-83.0	-20.7	42.2	108.5	176.1	239.9	303.0	365.1
PRESSURE SENSOR OUTPUT (mV)	-0.76	0.74	-0.72	-0.70	-0.67	-0.66	-0.61	-0.62	-0.64	-0.65	-0.66

MICRON INSTRUMENTS

4509 Runway Streeet, Simi Valley, CA 93063 (805) 522-4676

PRESSURE TRANSDUCER CALIBRATION DATA

Model Number 150584	*Serial Number* 62180	*Pressure Range* 100PSI	*Date* 23 Jul 2002
Diaphragm Materials Steel	*Customer* HUNTSVILLE	*Excitation* 4.0mA	*Type Unit* Gage
			Excitation Type Constant Current

Pressure Calibration Data

Date of Pressure Calibration
5 Jul 01

Pressure	Increase (1)	Decrease	Increase(2)	Straight Line through Endpoints	Linearity (%FS)	Hysteresis (%FS)	Repeatability (%FS)
0PSI G	1.30mV	1.29mV	1.29mV	1.30mV		0.0514%	0.0514%
20PSI G	4.90mV	4.90mV	4.89mV	4.93mV	0.1644%	0.0000%	0.0514%
40PSI G	8.53mV	8.53mV	8.52mV	8.56mV	0.1747%	0.0000%	0.0514%
60PSI G	12.19mV	12.17mV	12.16mV	12.20mV	0.0308%	0.1028%	0.1542%
80PSI G	15.80mV	15.81mV	15.78mV	15.83mV	0.1439%	0.0514%	0.1028%
100PSI G	19.46mV		19.47mV	19.46mV			0.0514%
SENSITIVITY	18.16mV						

STATIC ERROR BAND
± 0.0874%FS

Thermal Calibration Data

Date of Thermal Calibration
11 Aug 99

	Low Temp.	Ambient	High Temp	Temperature Range	Thermal Balance Shift	Thermal Sensitivity Shift
Temperature	-50°F	50°F	150°F			
0 PSI	2.24mV	0.62mV	-2.29mV	-50°F to 50°F	-8.3248%FS	0.1028%FS
100PSI	20.41mV	18.81mV	15.25mV	50°F to 150°F	-14.9538%FS	-3.3402%FS
Sensitivity	18.17mV	18.19mV	17.54mV	AVERAGE	± 0.0582%FS	± 0.0084%FS

Pressure and Thermal Hysteresis

TEMPERATURE (°F)	-50	-30	-10	10	30	50	70	90	110	130	150
TEMPERATURE (°C)	-46	-34	-23	-12	-1	10	21	32	43	54	66
TEMP. SENSOR OUTPUT (mV)	-182.9	-136.3	-88.1	-40.0	7.7	51.9	103.8	158.7	204.2	251.3	302.6
PRESSURE SENSOR OUTPUT (mV)	3.98	3.44	2.93	2.49	2.10	1.71	1.34	1.30	0.84	-0.73	-1.38

MICRON INSTRUMENTS
4509 Runway Streeet, Simi Valley, CA 93063 (805) 522-4676

PRESSURE TRANSDUCER CALIBRATION DATA

Model Number 150584	*Serial Number* 62181	*Pressure Range* 100PSI	*Type Unit* Gage
Diaphragm Materials Steel	*Customer* HUNTSVILLE	*Excitation* 4.0mA	*Excitation Type* Constant Current

Date

23 Jul 2002

Pressure Calibration Data

Date of Pressure Calibration

5 Jul 01

Pressure	Increase (1)	Decrease	Increase (2)	Straight Line through Endpoints	Linearity (%FS)	Hysteresis (%FS)	Repeatability (%FS)
0PSI G	0.96mV	0.95mV	0.95mV	0.96mV		0.0396%	0.0396%
20PSI G	5.78mV	5.77mV	5.78mV	5.82mV	0.1505%	0.0396%	0.0000%
40PSI G	10.66mV	10.61mV	10.64mV	10.68mV	0.0634%	0.1980%	0.0792%
60PSI G	15.48mV	15.45mV	15.50mV	15.53mV	0.2139%	0.1188%	0.0792%
80PSI G	20.36mV	20.27mV	20.35mV	20.39mV	0.1267%	0.3564%	0.0396%
100PSI G	25.25mV		25.21mV	25.25mV			0.1584%
SENSITIVITY	24.29mV						

STATIC ERROR BAND

± 0.1782%FS

Thermal Calibration Data

Date of Thermal Calibration

8 Oct 99

	Low Temp.	Ambient	High Temp	Temperature Range	Thermal Balance Shift	Thermal Sensitivity Shift
Temperature	-50°F	50°F	150°F			
0 PSI	-0.76mV	-0.23mV	0.81mV	-50°F to 50°F	2.0990%FS	-1.7426%FS
100PSI	23.81mV	23.96mV	23.19mV	50°F to 150°F	4.3564%FS	-7.4059%FS
Sensitivity	24.63mV	24.19mV	22.32mV	AVERAGE	± 0.0161%FS	± 0.0229%FS

Pressure and Thermal Hysteresis

TEMPERATURE (°F)	-50	-30	-10	10	30	50	70	90	110	130	150
TEMPERATURE (°C)	-46	-34	-23	-12	-1	10	21	32	43	54	66
TEMP. SENSOR OUTPUT (mV)	-102.6	-76.3	-49.1	-21.9	6.1	33.9	62.4	95.1	122.7	151.3	179.7
PRESSURE SENSOR OUTPUT (mV)	-0.99	-0.92	-0.83	-0.70	-0.58	-0.41	-0.18	0.14	0.28	-0.27	0.38

PRESSURE TRANSDUCER CALIBRATION DATA

Model Number 150584	*Serial Number* 62176	*Pressure Range* 100PSI	*Date* 23 Jul 2002
Diaphragm Materials Steel	*Customer* HUNTSVILLE	*Excitation* 4.0mA	*Type Unit* Gage
			Excitation Type Constant Current

Pressure Calibration Data

Date of Pressure Calibration
5 Jul 01

Pressure	Increase (1)	Decrease	Increase(2)	Straight Line through Endpoints	Linearity (%FS)	Hysteresis (%FS)	Repeatability (%FS)
0 PSI G	0.22mV	0.22mV	0.22mV	0.22mV		0.0000%	0.0000%
20 PSI G	4.37mV	4.36mV	4.37mV	4.40mV	0.1232%	0.0474%	0.0000%
40 PSI G	8.53mV	8.51mV	8.52mV	8.57mV	0.1991%	0.0948%	0.0474%
60 PSI G	12.70mV	12.70mV	12.70mV	12.75mV	0.2275%	0.0000%	0.0000%
80 PSI G	16.85mV	16.82mV	16.89mV	16.92mV	0.3507%	0.1422%	0.1896%
100 PSI G	21.10mV		21.07mV	21.10mV			0.1422%
SENSITIVITY	20.88mV						

STATIC ERROR BAND
± 0.1754%FS

Thermal Calibration Data

Date of Thermal Calibration
8 Oct 99

	Low Temp.	Ambient	High Temp	Temperature Range	Thermal Balance Shift	Thermal Sensitivity Shift
Temperature	-50°F	50°F	150°F			
0 PSI	1.93mV	0.40mV	0.30mV	-50°F to 50°F	-7.2512%FS	0.2844%FS
100PSI	22.78mV	21.30mV	21.40mV	50°F to 150°F	-0.4739%FS	1.0427%FS
Sensitivity	20.85mV	20.90mV	21.10mV	AVERAGE	± 0.0193%FS	± 0.0033%FS

Pressure and Thermal Hysteresis

TEMPERATURE (°F)	-50	-30	-10	10	30	50	70	90	110	130	150
TEMPERATURE (°C)	-46	-34	-23	-12	-1	10	21	32	43	54	66
TEMP. SENSOR OUTPUT (mV)	-81.2	-61.6	-41.2	-20.5	0.8	21.7	43.3	69.0	91.0	113.8	138.1
PRESSURE SENSOR OUTPUT (mV)	2.02	1.65	1.30	1.02	0.75	0.56	0.43	0.51	0.52	0.19	0.19

MICRON INSTRUMENTS
4509 Runway Streeet, Simi Valley, CA 93063 (805) 522-4676

PRESSURE TRANSDUCER CALIBRATION DATA

			Date 23 Jul 2002
Model Number 150584	*Serial Number* 62177	*Pressure Range* 100PSI	*Type Unit* Gage
Diaphragm Materials Steel	*Customer* HUNTSVILLE	*Excitation* 4.0mA	*Excitation Type* Constant Current

Pressure Calibration Data

Date of Pressure Calibration
27 Sep 99

Pressure	Increase (1)	Decrease	Increase(2)	Straight Line through Endpoints	Linearity (%FS)	Hysteresis (%FS)	Repeatability (%FS)
0PSI G	0.24mV	0.21mV	0.21mV	0.24mV		0.1333%	0.1333%
20PSI G	4.64mV	4.65mV	4.64mV	4.69mV	0.2311%	0.0444%	0.0000%
40PSI G	9.07mV	9.04mV	9.07mV	9.14mV	0.3289%	0.1333%	0.0000%
60PSI G	13.45mV	13.48mV	13.52mV	13.60mV	0.6489%	0.1333%	0.3111%
80PSI G	18.00mV	17.88mV	18.00mV	18.05mV	0.2133%	0.5333%	0.0000%
100PSI G	22.50mV		22.41mV	22.50mV			0.4000%
SENSITIVITY	22.26mV						

STATIC ERROR BAND
± 0.3244%FS

Thermal Calibration Data

Date of Thermal Calibration
27 Sep 99

	Low Temp.	Ambient	High Temp	Temperature Range	Thermal Balance Shift	Thermal Sensitivity Shift
Temperature	-50°F	50°F	150°F			
0 PSI	0.10mV	0.11mV	-0.36mV	-50°F to 50°F	0.0444%FS	-2.9778%FS
100PSI	23.00mV	22.38mV	21.58mV	50°F to 150°F	-2.0889%FS	-1.3333%FS
Sensitivity	22.91mV	22.24mV	21.94mV	AVERAGE	±0.0052%FS	±0.0108%FS

Pressure and Thermal Hysteresis

TEMPERATURE (°F)	-50	-30	-10	10	30	50	70	90	110	130	150
TEMPERATURE (°C)	-46	-34	-23	-12	-1	10	21	32	43	54	66
TEMP. SENSOR OUTPUT (mV)	-136.8	-104.0	-70.8	-37.9	-4.7	27.8	60.9	98.1	130.9	164.1	196.7
PRESSURE SENSOR OUTPUT (mV)	0.82	0.56	0.33	0.17	0.01	-0.07	-0.11	-0.05	-0.02	-0.13	-0.05

MICRON INSTRUMENTS

4509 Runway Streeet, Simi Valley, CA 93063 (805) 522-4676

PRESSURE TRANSDUCER CALIBRATION DATA			*Date* 23 Jul 2002
Model Number 150584	*Serial Number* 62178	*Pressure Range* 100PSI	*Type Unit* Gage
Diaphragm Materials Steel	*Customer* HUNTSVILLE	*Excitation* 4.0mA	*Excitation Type* Constant Current

Pressure Calibration Data

Date of Pressure Calibration
27 Sep 99

Pressure	Increase (1)	Decrease	Increase(2)	Straight Line through Endpoints	Linearity (%FS)	Hysteresis (%FS)	Repeatability (%FS)
0PSI G	-0.69mV	-0.69mV	-0.69mV	-0.69mV		0.0000%	0.0000%
20PSI G	3.61mV	3.61mV	3.60mV	3.61mV	0.0096%	0.0000%	0.0480%
40PSI G	7.91mV	7.91mV	7.93mV	7.91mV	0.0192%	0.0000%	0.0961%
60PSI G	12.22mV	12.20mV	12.29mV	12.22mV	0.0192%	0.0961%	0.3362%
80PSI G	16.60mV	16.47mV	16.55mV	16.52mV	0.3939%	0.6244%	0.2402%
100PSI G	20.82mV		20.97mV	20.82mv			0.7205%
SENSITIVITY	21.51mV						

STATIC ERROR BAND
± 0.3602%FS

Thermal Calibration Data

Date of Thermal Calibration
27 Sep 99

	Low Temp.	Ambient	High Temp	Temperature Range	Thermal Balance Shift	Thermal Sensitivity Shift
Temperature	-50°F	50°F	150°F			
0 PSI	-7.85mV	-1.20mV	-1.32mV	-50°F to 50°F	31.7963%FS	-27.8098%FS
100PSI	19.41mV	20.30mV	20.01mV	50°F to 150°F	-0.4323%FS	-0.6724%FS
Sensitivity	27.32mV	21.53mV	21.39mV	AVERAGE	± 0.0795%FS	± 0.0712%FS

Pressure and Thermal Hysteresis

TEMPERATURE (°F)	-50	-30	-10	10	30	50	70	90	110	130	150
TEMPERATURE (°C)	-46	-34	-23	-12	-1	10	21	32	43	54	66
TEMP. SENSOR OUTPUT (mV)	-73.5	-55.2	-36.6	-18.2	0.5	18.8	37.3	58.1	76.5	95.0	113.0
PRESSURE SENSOR OUTPUT (mV)	-1.85	-1.80	-1.71	-1.61	-1.48	-1.35	-1.12	-0.82	-0.76	-0.74	-0.55

MICRON INSTRUMENTS

4509 Runway Streeet, Simi Valley, CA 93063 (805) 522-4676

PRESSURE TRANSDUCER CALIBRATION DATA

Model Number 150583	*Serial Number* 62179	*Pressure Range* 100PSI	*Date* 23 Jul 2002
			Type Unit Gage
Diaphragm Materials Titanium	*Customer* HUNTSVILLE	*Excitation* 4.0mA	*Excitation Type* Constant Current

Pressure Calibration Data

Date of Pressure Calibration

6 Jul 01

Pressure	Increase (1)	Decrease	Increase(2)	Straight Line through Endpoints	Linearity (%FS)	Hysteresis (%FS)	Repeatability (%FS)
0PSI G	0.75mV	0.64mV	0.64mV	0.75mV		0.3052%	0.3052%
20PSI G	7.76mV	7.63mV	7.63mV	7.81mV	0.1332%	0.3607%	0.3607%
40PSI G	14.80mV	14.74mV	14.72mV	14.87mV	0.1831%	0.2497%	0.2220%
60PSI G	21.87mV	21.78mV	21.72mV	21.92mV	0.1498%	0.2497%	0.4162%
80PSI G	28.98mV	28.88mV	28.81mV	28.98mV	0.0055%	0.2775%	0.4717%
100PSI G	36.04mV		35.98mV	36.04mV			0.1665%
SENSITIVITY	35.29mV						

STATIC ERROR BAND

± 0.2358%FS

Thermal Calibration Data

Date of Thermal Calibration

6 Jul 01

	Low Temp.	Ambient	High Temp	Temperature Range	Thermal Balance Shift	Thermal Sensitivity Shift
Temperature	-50°F	50°F	150°F			
0 PSI	0.50mV	-0.06mV	-0.90mV	-50°F to 50°F	-1.5538%FS	0.2497%FS
100PSI	35.70mV	35.23mV	34.60mV	50°F to 150°F	-2.3307%FS	0.5827%FS
Sensitivity	35.20mV	35.29mV	35.56mV	AVERAGE	± 0.0097%FS	± 0.0021%FS

Pressure and Thermal Hysteresis

TEMPERATURE (°F)	-50	-30	-10	10	30	50	70	90	110	130	150
TEMPERATURE (°C)	-46	-34	-23	-12	-1	10	21	32	43	54	66
TEMP. SENSOR OUTPUT (mV)	-420.9	-355.7	-288.6	-221.8	-153.8	-87.5	-20.7	58.3	123.3	184.0	250.9
PRESSURE SENSOR OUTPUT (mV)	0.50	0.40	0.29	0.18	0.06	-0.06	-0.16	-0.22	-0.30	-0.51	-0.90

APPENDIX B

LOGGER CALIBRATION SHEETS

Data Logger Calibration Report
Serial # 9823-0006

Model No.	**ML-1001-8**	Quiescent Power:	**>=75**	Remote Start	OK
Serial No.	**9823-0006**	Header Memory:	OK		
SGC S/N:	**9823-0006**	Data Memory:	OK		
Date:	**4/2/02**	Download:	OK		
Temp (C)	**25**	Low Battery:	OK		

ChNo.	**Iexc-uA** MicroAmps	**Voffset** Milli-Volts	**Max Dev** Counts	**3-Sigma** Counts	**Vin** MilliVolts	**Vout** Milli-Volts	**MaxDev** Counts	**3-Sigma** Counts	**Gain** Vout/Vin	**Gain Error** Percent
1	**1023.44**	**2,033.48**			11.1852	3,821.43		1.5	**159.850**	-0.09%
2	1023.44	**1,296.02**			63.2284	2,558.32		0.39	**19.964**	-0.18%
3	**784.69**	**2,041.04**			10.8631	3,757.71		0.58	**158.028**	-1.23%
4	784.69	**1,020.00**			61.4031	2,232.17		0	**19.741**	-1.29%
5	**781.53**	**2,041.37**			10.8555	3,756.76		1.44	**158.020**	-1.24%
6	781.53	**1,020.31**			61.3602	2,233.41		1.38	**19.770**	-1.15%
7	**783.75**	**2,043.01**			10.8787	3,762.41		0.29	**158.052**	-1.22%
8	783.75	**1,020.59**			61.493	2,235.49		1.49	**19.757**	-1.22%

NOTES: Data in **BOLD** face is to be entered in the DataLogger software Calibration window.

Measurements taken from the data logger are based on 100 or more sequential readings at 1/2 second intervals.

Iexc and **Vin** measurements were taken with an HP 34970A Data Acquisition Unit. Readings were integrated over 100 line cycles.

April 02,2002: changed fixed gain on temperature channels to 20 nominal.

Data Logger Calibration Report
Serial # 0107-0004

Model No. **ML-1008-1**
Serial No. **0107-0004**
SGC S/N: **9821-0033**
Date: **4/4/02**
Temp (C) **23**

Quiescent Power: **>=73**
Header Memory: OK
Data Memory: OK
Download: OK
Low Battery: OK

Remote Start OK

ChNo.	**Iexc-uA** MicroAmps	**Voffset** Milli-Volts	**Max Dev** Counts	**3-Sigma** Counts	**Vin** MilliVolts	**Vout** Milli-Volts	**MaxDev** Counts	**3-Sigma** Counts	**Gain** Vout/Vin	**Gain Error** Percent
1	**1017.75**	**2,044.00**	0	0.00	11.1111	3,747.78	4	2.41	**153.340**	-4.16%
2	1017.75	**1,322.00**	0	0.00	62.8007	2,541.69	7	4.36	**19.422**	-2.89%
3	**1017.93**	**2,037.00**	0	0.00	11.1135	3,739.54	2	1.6	**153.196**	-4.25%
4	1017.93	**1,320.00**	1	1.00	62.8144	2,541.52	8	5.96	**19.446**	-2.77%
5	**1017.7**	**2,041.23**	1	1.00	11.1109	3,743.63	7	6.64	**153.219**	-4.24%
6	1017.7	**1,321.70**	1	1.00	62.7983	2,539.91	17	16.46	**19.399**	-3.01%
7	**1017.5**	**2,044.00**	0	0.00	11.109	3,747.24	2	1.77	**153.321**	-4.17%
8	1017.5	**1,321.00**	0	0.00	62.7891	2,541.57	7	6.18	**19.439**	-2.80%

NOTES: Data in **BOLD** face is to be entered in the DataLogger software Calibration window.
Measurements taken from the data logger are based on 100 or more sequential readings at 1/2 second intervals.
Iexc and **Vin** measurements were taken with an HP 34970A Data Acquisition Unit. Readings were integrated over 100 line cycles.

New board set with SN 9821-0033 installed into case 0107-0004 on April 04, 2002

By:

Data Logger Calibration Report
Serial #: 0207-001

Model No.	**ML1008-1HF**				Quiescent Power:	N/A					
Serial No.	**0207-0001**				Header Memory:	OK		**mV Per Count Correction**		**Nominal Gains**	
SGC S/N:	**see below**				Data Memory:	OK		**mV**	5000	**Temperature**	5.032
Date:	**7/15/02**				Download:	OK		**Count**	4096	**Pressure**	73.866
Temp (C)	**25**				Low Battery:	N/A		**Ratio**	1.220703		
					Remote Start	OK					

	Iexc-uA	**Voffset**		**Max Dev**	**3-Sigma**	**Vin**	**Vout**	**MaxDev**	**3-Sigma**	**Gain**	**Gain Error**
ChNo./ Serial No.	MicroAmps	Counts	mV	Counts	Counts	MilliVolts	Counts	Counts	Counts	Vout/Vin	Percent
1 sn 0207-001a	**4098.25**	2,043.21	**2494.15**	13	7.90	321.506	3,364.58	316	57.9	**5.017**	-0.30%
2 sn 0207-001b	**4098.25**	2,044.95	**2496.28**	11	7.30	21.438	3,345.98	43	11.4	**74.082**	0.29%
3 sn 0207-002a	**4098.73**	2,045.99	**2497.55**	13	6.80	321.456	3,364.78	288	53.3	**5.008**	-0.48%
4 sn 0207-002b	**4098.73**	2,043.72	**2494.77**	13	8.20	21.428	3,343.50	49	11.5	**74.045**	0.24%
5 sn 0207-003a	**4096.34**	2,046.74	**2498.46**	14	10.20	321.424	3,365.68	324	55.4	**5.009**	-0.46%
6 sn 0207-003b	**4096.34**	2,046.14	**2497.73**	12	10.40	21.433	3,344.31	41	12.9	**73.936**	0.10%
7 sn 0207-004a	**4098.80**	2,046.41	**2498.06**	14	8.50	321.645	3,366.20	313	55.4	**5.009**	-0.46%
8 sn 0207-004b	**4098.80**	2,043.63	**2494.67**	12	8.10	21.448	3,348.03	46	13.8	**74.239**	0.51%

NOTES: Data in **BOLD** face is to be entered in the DataLogger software Calibration window. Data in Yellow is calculated.

Please note that for this version of the HF logger, Voffset is given in both Counts and mV.

Measurements taken from the data logger are based on 100 or more sequential readings at approximately 1/10 second intervals.

Iexc and **Vin** measurements were taken with an HP 34970A Data Acquisition Unit. Readings were integrated over 100 line cycles.

By:

WKBorsum

APPENDIX C

Sensor Related Papers:

a) Improvements in rocket motor life instrumentation.
E C Francis et al, JANNF S&MB Meeting (Dec 1995)

b) Stress Measurement in Solid Rocket Motors.
H J Buswell, 18th Transducer Workshop, RCC (June 1995)

c) Service Life Prediction Methodologies.
Final Reports TTCP KTA 4-14 (1996)

d) Miniature sensor for measuring solid grain rocket motor case bond stress.
H Chelner et al, Paper 25 AGARD Conference Proceedings 586 (May 1997)

c) Service Life Prediction Using Stress Gage Technology and Nonlinear viscoelastic analysis.
F C Wong, Paper 26 AGARD Conference Proceedings 586 (May 1997)

e) Instrumented Service Life Programme for the Pictor Rocket Motor.
S Y Ho, Paper 28 AGARD Conference Proceedings 586 (May 1997)

f) Bond Line Stress Transducers Effectiveness in Measuring Crack Formation in Solid Propellant Analog Motors.
R W Pritchard, JANNAF JPM (1998)

g) Failure Analysis of Rocket Motors on Pressurization
Final Reports TTCP KTA 4-23 (1999)

h) Characterisation and Use of Bond Stress Sensors in Tactical Rocket Motors.
H J Buswell, AIAA Paper #2000-3139 JPC (2000)

APPENDIX D

Gage Matching Test Data

ch	R Plus Current	R Neg Current	R Average	ACTUAL
0	105.65651037453	105.6578340101	105.65717219232	105.59
1	498.56448697249	498.56491770044	498.56470233646	498.54
2	496.342754157	496.31695266045	496.32985340873	496.34
3	499.64495437767	499.61848832243	499.63172135005	499.62
4	498.13890093668	498.10245930861	498.12068012265	498.19
5	498.80941607881	498.74398993487	498.77670300684	498.82
6	497.58824471893	497.56176547455	497.57500509674	497.67
7	496.48693228342	496.45429932569	496.47061580456	496.57
8	497.51702419865	497.48353003232	497.50027711549	497.63
9	498.13542676496	498.09376648169	498.11459662333	498.25
10	498.22054397212	498.17721762007	498.1988807961	498.33
11	498.20317311352	498.15461627009	498.17889469181	498.30
12	496.94899712229	496.91328058676	496.93113885453	497.06
13	105.48934926596	105.51219572534	105.50077249565	105.51
14	100.09088727773	100.09094765431	100.09091746602	100.09

AVERAGE 497.92

AVERAGE DIFFERENCE 0.07

ch	R Plus Current	R Neg Current	R Average
0	105.66326270054	105.64035066234	105.65180668144
1	498.55064410212	498.53712782043	498.54388596128
2	496.32030332771	496.29963306528	496.30996819649
3	499.62412587672	499.59589573488	499.6100108058
4	498.14418012922	498.09901695928	498.12159854425
5	498.80946090539	498.73010522356	498.76978306447
6	497.57790980799	497.54790131252	497.56290556025
7	496.46621347183	496.44393148383	496.45507247783
8	497.51885094013	497.46966723017	497.49425908515
9	498.11465069529	498.0885857483	498.1016182218
10	498.20323899708	498.17029690098	498.18676794903
11	498.1771836142	498.15291154935	498.16504758177
12	496.96126574653	496.90812037243	496.93469305948
13	105.49704271951	105.50594852087	105.50149562019
14	100.09088481556	100.09094642111	100.09091561833

0	105.65408834299	105.6272062786	105.6406473108
1	498.52472550649	498.4557024775	498.490213992
2	496.28763088565	496.23076420448	496.25919754507
3	499.59637719986	499.51950108929	499.55793914457
4	498.08529620597	498.01940598803	498.052351097
5	498.75746671704	498.63821694521	498.69784183113
6	497.53470692428	497.48055375003	497.50763033716
7	496.42137023798	496.36113168142	496.3912509597
8	497.46523193606	497.38147446756	497.42335320181
9	498.0644537095	498.00897658987	498.03671514969
10	498.14782369537	498.09067354209	498.11924861873
11	498.13392869772	498.05938534762	498.09665702267
12	496.89901078203	496.8182869672	496.85864887461
13	105.48146971841	105.4888161877	105.48514295305
14	100.09087866089	100.09093409143	100.09090637616

SENSOR AND LOGGER DATA SHEETS

Dual Temperature and Normal Bond Stress Transducer

P/N 140583 6AL4V Titanium P/N 140584 17-4 CRES

140583

This dual output miniature semiconductor pressure sensor has been optimized for normal bond stress and temperature measurements in solid grain rocket motors. A silicon high response stress insensitive temperature sensor has been bonded to the diaphragm.

The sensor can be left in place in order to measure chamber pressure.

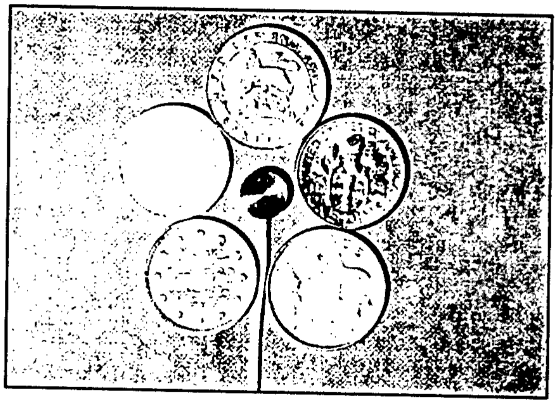
The cable can be removed from the remote bridge completion box. Water seals and individual screw terminal blocks permit easy removal of the Teflon® covered cable, which is circular and has a diameter of 0.055" max.

The sensor is recalibrated to provide positive signal for compressive forces. Excitation to the sensor is 4.0 mA constant current which corrects for line resistance changes due to temperature effects or poor connections. Other current levels or constant voltage excitation are available; consult the factory for these options.

Thermal hysteresis data is an option. Data is presented every 20°F between -50°F and +150°F for three cycles. The stress sensor balance output and temperature sensor outputs are depicted graphically over these temperatures.

Applications

- SOLID GRAIN ROCKET MOTORS
- BOND STRESS MEASUREMENTS
- HIGH FREQUENCY CHAMBER PRESSURES
- PRODUCTION EQUIPMENT AND CONTROLS
- ROBOTICS



Mechanical

Standard Stress Range	±100 psig ($7.03\ kg/cm^2$)
Non Standard Pressure Ranges	Consult Factory
Over Pressure (No change in performance)	2.0x Range
Usable Pressure (Small change in balance)	10.0x Range
Maximum Over Range with 50% Zero Shift	20x Range (140583 [6AL4V Titanium]) 30x Range (140584 [17-4 PH CRES Steel])

Performance (Stress)

Balance (Zero) Output	0.0 ± 1.0 mV
Full Scale Sensitivity	45 ± 10 mV (140583 [6AL4V Titanium] 25 ± 10 mV (140584 [17-4 PH CRES])
Static Error Band	± 0.25% FS Max.
Thermal Hysteresis	< ± 1.0 psi, -45° C to 66° C (-50° F to 150° F)
Long Term Stability	< 2.0% FS/year

Performance (Temperature)

Output0 ± 10 mV at 0°C	(32°F); 325 ± 50 mV at 66°C (150°F)
Temperature Repeatability	±1°C

MICRON
INSTRUMENTS

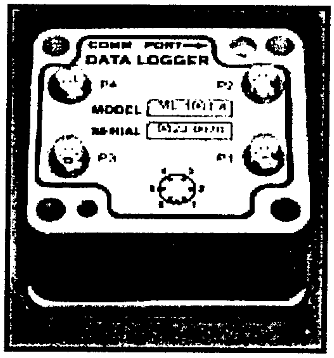
Micron Series Data Logger

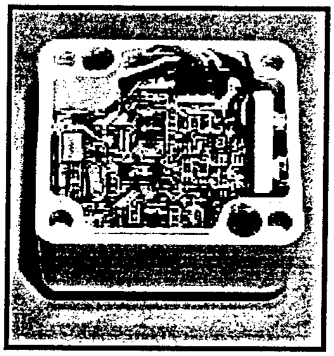
GENERAL

Micron's Data Logger is designed to provide a versatile instrument for conditioning and storing signals under a wide variety of conditions. It uses a building-block architecture that allows the logger to be configured to meet the exact needs of high volume users, as well as providing a variety of off-the-shelf configurations.

The Data Logger is contained in an aluminum or plastic NEMA-4 container. A Serial Interface Adapter (SIA) provides the interface between the Data Logger and the host computer.

The Data Logger records from one to eight channels of information from connected sensors. Sampling rate, start and stop times are user definable from once per second to once every 18.2 hours. The Data Logger operates from a self contained 9 volt battery and is totally autonomous once the Data Logger setup information has been uploaded to memory.





FEATURES

- 1 to 8 active channels, 12-bit resolution, minimal data skew.
- Non-volatile memory will survive complete power loss without losing data.
- Typical power consumption is 350 mAH per year of operation.
- Logging intervals from 1 second to 18 hours.
- Delayed start option to 194 days with 1 second increments.
- Local battery (9V transistor radio style) or external power inputs (7-15 VDC).
- 8 channels total, configured in four pairs.
- Constant voltage or constant current Excitation supplies for each pair of channels.
- Fixed gains and offset voltages correctable in software.
- Windows 95 (NT and CE available soon).
- Complete setup and download functions. Data is stored as a memory image, and in standard "Comma Separated Variable" format compatible with all spread-sheets and data bases.
- All calibration and test identification is stored in non-volatile logger memory.
- Multiple level access via passwords.
- "Real time" utility for displaying current measurements—used for checking logger operations for calibration of sensors.

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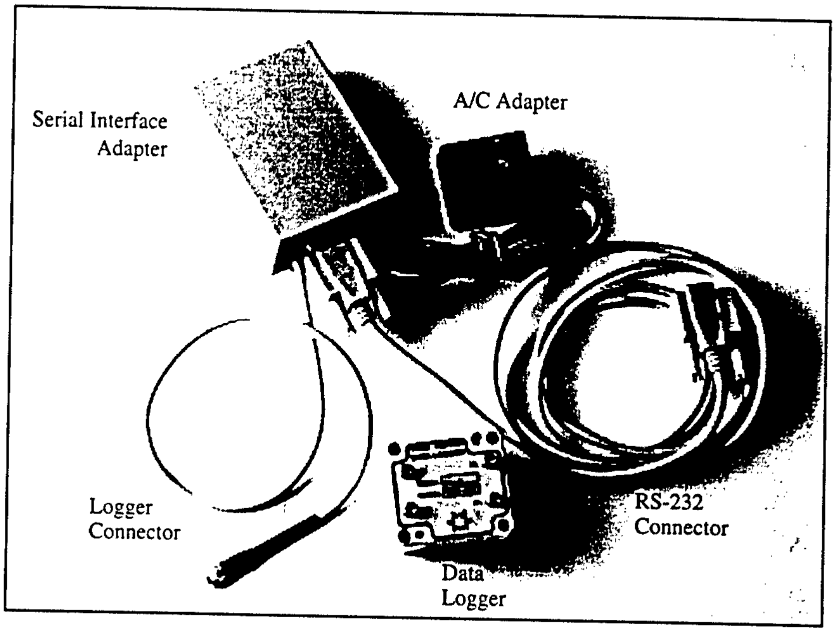
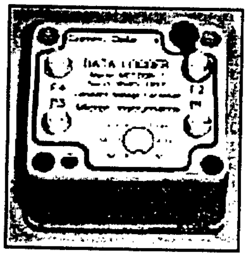
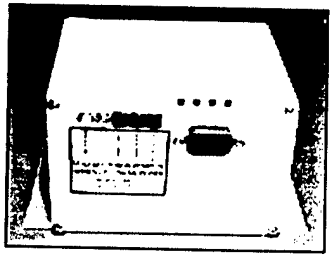


MC1008-1



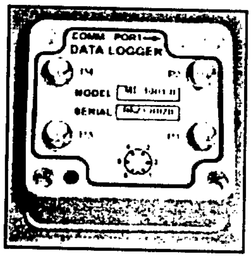
Constsnt Voltage Excitation
8 channels at 12 bits, memory to 81,920 samples, 1 sec to 18 hrs. pgrscan. It is a dedicated data logger set up internally for specific sensors. Although it can be adapted for most sensor types. Very low power consumption, up to 1 year off of 1 internal battery.

ML1008-2



Passive Backplane Logger
Designed for flexibility and will accept a wide variety of plugh-in signal conditioners and logger engines. It has 8 channels at 12 bit resolution, memory to 114,688 samples, 1 scan/sec to 1 scan/18 hrs.

ML1008-1



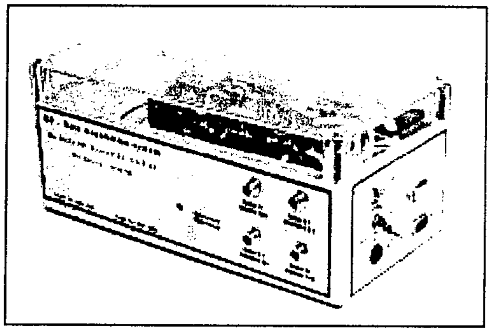
Constsnt Current Excitation
8 channels at 12 bits, memory to 81,920 samples, 1 sec to 18 hrs. pgrscan. It is a dedicated data logger set up internally for specific sensors. Although it can be adapted for most sensor types. Very low power consumption, up to 1 year off of 1 internal battery.

High Frequency Data Logger

Micron's HF1 logger is a microprocessor based, self contained data logger that can be customized for a wide variety of applications. Included in a typical configuration are multiple signal conditioners, high speed and non-volatile memory, a precision high-speed Analog to Digital converter, and a microprocessor controller. Although intended for high volume OEM applications, the unit is versatile enough to serve as a general purpose data logger, and can be set up to accept virtually any type of sensor. The logger and resident signal conditioners store all setup information, including sensor calibration factors on board in non-volatile memory. Calibration information travels with the sensor/signal conditioner, allowing plug-and-play changing of sensors.

Applications

- Health Monitoring
- Seismic Monitoring
- Crash Testing
- Environmental Monitoring
- Flight Testing
- Transportation Shock recording



Features

High sample rates, from 20 to 500 000 samples per second on 8 or 16 channels
High Accuracy, 12 or 16-bit resolution
1 or 2 million samples of event data in high speed mode
Pre- and Post-trigger data acquisition
Programmable exceedance level event triggers on each channel
Multiple trigger sources including exceedance, real time clock, or external switch closure
Highly configurable signal conditioners with non-volatile memory for calibration information
Standard flash cards for nonvolatile data storage to several hundred megabytes
Powered from internal batteries, external power sources, or both

Mechanical

The printed circuit boards comprising the typical logger stack can be configured to fit within a wide variety of housings, ranging from tubular (approx 3.5" diameter by 5" long) capable of withstanding high-G shock and vibration, through simple polycarbonate NEMA-4 plastic enclosures for bench-top testing. The board stack is modular and can be rapidly reconfigured to meeting changing requirements.

Performance

Very high speed storage of data to a ring buffer at rates up to 500,000 samples per second
12 or 16 bit resolution
Precision voltage references and excitation supplies
Precision instrumentation amplifiers
Real Time Clock with crystal temperature compensated to approximately 5 min./yr. over the range of 0-50 degC

Environmental

As an option the ML-100x-HF may be adapted to most operating environments. It may be water proofed, shock resistant to over 1000Gs, explosion proof, and random frequency up to 1G²/Hz to 1000Hz

Electrical

External power required is a source of relatively clean power at 6 to 24 volts DC.
Active current: <200 mA plus excitation supply and signal conditioning requirements
Sleep mode power: <50 uA
Capable of providing constant voltage or constant current excitation, and variants can also support 4-20 mA current loop sensors at 12, 18, or 24 volts loop compliance voltage
Communication: RS232 or RS485 multi-drop. Other protocols available.

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