

RESEARCH PRESSURE INSTRUMENTATION

FOR

NASA SPACE SHUTTLE MAIN ENGINE

NASA CONTRACT NO. NAS8-34769

MODIFICATION NO. 7

MONTHLY REPORT

GEORGE C. MARSHALL SPACE FLIGHT CENTER

MARSHALL SPACE FLIGHT CENTER, ALABAMA 35812

June 1985

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HONEYWELL INC.
SOLID STATE ELECTRONICS DIVISION
CONTRACT NO. NAS8-34769

RESEARCH OF PRESSURE INSTRUMENTATION FOR NASA SPACE SHUTTLE MAIN ENGINE

Monthly R & D Progress June 1985 Report No. 21

A. Technical Progress and Plans

- See attachment 'A'

B. Schedule

- See attachment 'B'

C. Status of Funds

	<u>LBM</u>
Total Baseline Plan	\$407,350
Total Funded	\$407,350
Cost Incurred to 6/2/85	\$312,119
Inception to Date Plan	\$323,555*
Estimate at Completion	\$1,062,518**

D. Estimated percent of physical completion: 29% ***

E. At the present time the comparison of the cumulative costs to the percent of physical completion does reveal a significant variance requiring explanation.

* Per replan baseline strategy.

** Per 2/7/85 cost-to-complete proposal

o Total funding to-date:	\$407,350
o Cost-To-Complete Recommendation:	\$655,168
	\$1,062,518

*** % of estimate at complete

ATTACHMENT 'A'

RESEARCH PRESSURE INSTRUMENTATION FOR NASA SPACE SHUTTLE MAIN ENGINE HONEYWELL, INC.

1.0 Introduction and Objective

The first phase of this contract (Tasks A and B) resulted in a highly successful demonstration in April 1983 at the MSFC of Honeywell's bread-board feasibility model of a silicon Piezoresistive Pressure Transducer suitable for SSME applications.

The purpose of Modification No. 5 of this contract is to expand the scope of work (Task C) of this research study effort to develop pressure instrumentation for the SSME. The objective of this contract (Task C) is to direct Honeywell's Solid State Electronics Division's (SSED) extensive experience and expertise in solid state sensor technology to develop prototype pressure transducers which are targeted to meet the SSME performance design goals and to fabricate, test and deliver a total of 10 prototype units.

SSED's basic approach is to effectively utilize the many advantages of silicon piezoresistive strain sensing technology to achieve the objectives of advanced state-of-the-art pressure sensors in terms of reliability, accuracy and ease of manufacture. More specifically, integration of multiple functions on a single chip is the key attribute of this technology which will be exploited during this research study.

The objectives of this research study will be accomplished by completing the following major tasks:

1. Transducer Package Concept and Materials Study

Three transducer design concepts will be generated and analyzed for the SSME application and materials/processes will be defined for the research prototype transducer design.

2. Silicon Resistor Characterization at Cryogenic Temperatures

The temperature and stress properties of a matrix of ion implanted piezoresistors will be characterized over the temperature range of -320°F to +250°F.

3. Experimental Chip Mounting Characterization

The mechanical integrity of chip mounting concepts will be evaluated over temperature, pressure and vibration.

4. Frequency Response Optimization

This task is a paper study which will specify and analyze an acoustic environment for which transducer frequency response can be determined and optimized.

5. Prototype Transducer Design, Fabrication, and Test

This major task will use the results generated in Tasks 1 through 4 above to design and develop a research prototype pressure transducer for the SSME application and will culminate in the delivery of 10 transducers, 5 each for the ranges of 0 to 600 psia, and 0 to 3500 psia. This task is subdivided into the following five areas:

- Feasibility Evaluation of Transducer Concept
- Prototype Transducer Design
- Prototype Transducer Fabrication and Test
- Prototype Qualification
- Prototype Delivery.

6. Reports

Honeywell will submit monthly progress reports during the period of the contract; a final report will be provided at the completion of the contract.

The format of this report will be to discuss the work performed for this reporting period and the plans for the next reporting period for each of the major tasks outlined above.

2.0 Work Performed and Plans

2.1 Transducer Package Concept and Materials Study.

This task was completed per plan during January 1984.

2.2 Silicon Resistor Characterization at Cryogenic Temperatures.

This task was completed in May 1984.

2.3 Experimental Chip Mounting Characterization

A. Work Performed in June

Revisions were made to the Task 3000 and V-ring stress modeling reports (These reports are attached to the NASA copy of this monthly. Attachment C.). The final conclusions to the V-ring stress modeling are as stated in the April Monthly report. These are that stresses in the silicon sensor due to the V-ring compression seal are cause for concern with respect to the capability to calibrate and the effect of moving the sensor capsule from a calibration housing to a final housing. Consequently, close attention will be paid to an experiment planned for the upcoming feasibility sensor build under which capsules will be moved between housings and the impact on the (null) reading observed. If this experiment indicates that large, nonrepeatable stresses cause major null shifts when the capsules are moved, then the alternative approach of calibrating in a subassembly of the deliverable housing will be pursued further.

B. Plans for July

The plans are as follows:

- Close this task.

2.4 Frequency Response Optimization

This task was completed per plan in February 1984.

2.5 Temperature Sensor Network Concept Study

This task was deleted when the contract was negotiated.

2.6 Deliverable Transducer Design, Fabrication, and Test.

2.6.1 Feasibility Evaluation of Transducer Concepts

2.6.1.1 Lead Length Reduction

Based on the results reported in January, we do not expect that we will have to implement this task.

2.6.1.2 Seal Ring Development Phase I

A. Work Performed In June

Twenty X-750 vented O-rings have been ordered from Fluorcarbon. Our literature search and NASA Report 202, "Marshall Material Search and Display System" indicates that A-286 would be less susceptible to hydrogen embrittlement than X-750. A quote is being obtained for A-286 V-rings.

B. Plans for July

Order A-286 V-rings.

2.6.1.3 Seal Ring Development Pass II

This task will not be opened until test results indicate there is an issue with the current V-Ring design/finish which is expected to be resolved by using one of the designs noted in Section 2.6.1.2.

2.6.1.4 Hermetic Feedthrough Development Pass I

A. Work Performed In June

The first phase of this task is complete. The approach followed to process hermetic electrical feedthroughs yielded hermetic joints. However, electrical leakage between feedthrough pins was experienced. The following soldering fixturing and process methodologies are complete.

1. Cleaning procedures
2. Metallizing procedures
3. Soldering procedures
4. Alignment procedures

Further refinements to the process are planned for the second phase of the Hermetic Feedthrough Development. (See Paragraph 2.6.1.5)

2.6.1.5 Hermetic Feedthrough Development Pass II

A. Work performed in June

Failure analysis of assemblies exhibiting unacceptable current leakage between adjacent terminal was completed. Cross-sectioning methods were used. These results indicated the electrical leakage was due to solder bridging between pins and not just flux entrapment. It was also determined that there was very good wetting of the terminal board metallization by the solder with filleting at both the top and bottom of the chamfer. There were also some round voids in the solder joints that were probably caused by flux entrapment. These findings indicate that better alignment of the terminal boards, more space between the metallized pads, and fluxless soldering should all be evaluated in Pass II. Attachment D shows the new metallization pattern that will increase the space between pads by approximately 10 mils.

B. Plans for July

Complete Pass II for evaluating the following:

- o Improve Alignment Fixturing
- o Increase Space Between Feedthrough Metallization
- o Evaluate Fluxless Soldering Using Both Pb-Ag-Sn and Au-Ge solder.
- o Evaluate Thicker Metallization

2.6.1.6 Additional Cryogenic Data

A. Current Status

Test runs on both moderately-doped PN diodes and 500 Ω / \square chrome silicon thin film resistors have been completed. The chrome silicon resistors show predictable performance over the range of -253 $^{\circ}$ C (LN₂) to +125 $^{\circ}$ C and will be satisfactory for utilization in a compensation circuit covering this temperature range.

The PN diodes showed an unexpected, nonlinear increase in resistivity below -196 $^{\circ}$ C (LN₂). A determination is being made of the impact of this change on the output error of the sensors at temperatures between -253 $^{\circ}$ C and -196 $^{\circ}$ C should this type of diode be used in a compensation circuit.

Schottky diodes (metal-semiconductor) were also evaluated as a possible alternative to the PN diodes. However, these diodes also showed a nonlinear resistivity increase at temperatures below -196°C . Attachment E shows plots of the characteristic curve over temperature for circuit compensation resistors and Diodes.

B. Plans For July

The sensor compensation circuit design will be started. Analysis of the output error caused by the nonlinear resistivity change of standard PN diodes will also be started, computer aided tools will be used for this analysis.

A literature search of diode performance at cryogenic temperatures will be completed. Pending the results of the diode literature search, circuit modeling, and further discussions with NASA relative to the scope of the contract, evaluation of other IC circuit components to replace the diodes may be initiated.

2.6.1.7 Error Source Analysis

A. Work Performed in June:

Test samples have been tested over the pressure range of 0 to 5000 psi and a temperature range of -70 to 100°C . The SSME feasibility sensor chips mounted in conventional pressure sensor packages are performing as expected over these ranges of temperature and pressure with respect to zero shift, linearity, and mechanical and thermal hysteresis. Testing has been completed over the cryogenic temperature range (-250 to 100°C). Some zero shifts and sensitivity shifts were observed after low temperature (-250°C) testing. Closer evaluation of these characteristics will be completed during the Feasibility Transducer Fabrication and Test Task (See Paragraph 2.6.1.10). Sensitivity is approximately 1.5x higher than expected. Preliminary findings suggest the additional sensitivity is due to a thinner actual diaphragm and additional piezoresistive contribution due to the implanted leadouts used to access the sensing resistors.

B. Plans For July

Complete data analysis and compile the results.

This data base above will be used as a resource during the Feasibility Transducer Fabrication and Testing Task to analyze output errors in the Feasibility Transducers relative to standard packaging techniques. The data will also be used for preliminary circuit design work (see Paragraph 2.6.3.1)

2.6.1.8 Reference Pressure Process Development Pass I

A. Work Performed in June

All the required piece parts for the process development have been ordered. The vacuum system is nearly complete and the machining of the holding/heating fixture has begun. Attachment F shows the sketch of the vacuum pumping station.

B. Plans For July

Complete the build of the vacuum pumping station and the soldering fixture and begin the reference pressure process development.

2.6.1.9 Reference Pressure Process Development Pass II

This task will not be opened until such time as the results of "Pass I" indicate a second pass is required to achieve the desired reference vacuum conditions.

2.6.1.10 Feasibility Transducer Fabrication and Test

A. Work performed in June

Approximately 20 sets of silicon nitride terminal boards have been polished and are being metallized.

The low temperature and high pressure test fixtures have been prepared for the feasibility test sequence

B. Plans For July

Continue the assembly of the feasibility test capsules and begin temperature/pressure testing of the first feasibility pressure sensors.

2.6.2.1 Preliminary Design Review

This task is scheduled to begin later in the Program, i.e., November 1985.

2.6.2.2 Critical Design Review

This task is scheduled to begin later in the Program, i.e., December 1985.

The "Final Design Review" (F.D.R.) was downscoped during a discussion with T. Marshall (MSFC Contract Monitor). (Re: Telecon, P.J. Anderson, T. Marshall and P. Nussbaum, 6/25/85) The conclusion of that Telecon was that real scope of this task is better described as "Final Design Approval" rather than another review because NASA technical inputs will be provided at the "Critical Design Review". Furthermore, we agreed that this approval could be accomplished by an advanced submittal of the design package that is followed by a Telecon and/or a meeting between T. Marshall, P.J. Anderson and P. Nussbaum. This agreement allows about \$17K of the budget to be reallocated to cover the currently planned scope of the second pass of the Hermetic Feedthrough Development. (Re: Paragraph 2.6.1.5)

2.6.3.1 Circuit/Chip Design and Processing

A. Work performed in June.

Using the test results from the Additional Cryogenic Data and Error Source Analysis Tasks, work was started to set up models for the computer modeling of the compensation circuit design.

B. Plans for July.

Evaluation of the output error expected due to the nonlinear resistivity change of the standard PN diodes will be started. The evaluation of alternative sensor compensation schemes over the full temperature and pressure range will also be started.

2.6.3.2 Transducer Fabrication Parts and Tooling

A. Work Performed in June.

Several phone conversations were held in June with Deutsch Electronic Components Division, G & H Technology, and Tom Marshall (MSFC Contract Monitor) concerning the electrical connectors for the deliverable build.

Since the beginning of this program, we have been advised by NASA that we should use Rocketdyne connector RES1231-EO05N for our deliverable transducers and that Deutsch was the vendor of this connector. Deutsch said that they do make this connector and said it was their part number 77014-10-5PN. However, their print references Rocketdyne connector "RES1231-A1005* (1)". Because of this discrepancy in print numbers we have asked Deutsch to confirm which connector they are currently supplying to Rocketdyne. We have not yet received a reply from Deutsch to date. Deutsch also said that this connector could not withstand 20,000 psi and was only good to - 65°C and not -423°F.

All this information was sent to NASA (% Tom Marshall) in the form of a letter. (See Attachment G) Using this information, Tom has gone back to his connector people and learned that what he needs is a 10,000 psi cryogenic connector Rocketdyne part number RES1232-C1005N made by G & H Technology.

G & H advised us they do make this connector but that it will take them 6 to 8 weeks to make a cost and schedule estimate on our needs of 46 male and 8 female connectors. They did give us a verbal engineering estimate of \$400 to \$500 for the male and \$900 to \$1000 for the female connectors, respectively, with delivery in approximately 30 weeks. They said that they agreed to send us prints immediately of these two parts. Upon receipt of these drawings, we will send them to Tom Marshall for confirmation that they are the ones required for our transducer.

The impact of this situation is that we will incur unplanned cost and schedule variances.

Using cost estimates we previously received from Deutsch, we have budgeted only \$12.1 K for 46

male and 8 female connectors. The estimate from G & H for the same number of connectors is \$28.3K. This represents a cost impact of \$16.2K.

These schedule impact of procuring the G & H connector is estimated to be about 16 weeks.

At this time, the indications are that NASA wants us to procure the G & H connector. Honeywell recommends that the G & H connector be procured in view of the reported moisture problems with the Deutsch connector after exposure to cryogenic temperatures.

B. Plans for July

- o Obtain prints from both G&H and Deutsch for male and female connectors
- o Obtain cost and schedule quotes from both G & H and Deutsch for male and female connectors.
- o Determine if we can accelerate the delivery schedule or if we can obtain these connectors elsewhere (Honeywell SSAVD, etc.).

2.7 Miscellaneous

2.7.1 Vibration Requirements

- Re: 1. NASA Contract No. NAS8 34769, 8/26/82
Exhibit 'A', Section B.1
2. Honeywell's Technical Proposal, 7/12/83,
Sections 2.3 (Pages 2-5 to 2-7), 2.6.1.2 (Pages
2-15 to 2-18), 2.6.1.4 (Page 2-36 and 2-37).

3. Working session at NASA/MSFC, 9/26/84
Attendees:

P.J. Anderson Honeywell Inc.
P. Golley NASA/MSFC
H. Burke NASA/MSFC
B. White NASA/MSFC
C. Kirby NASA/MSFC

4. September Monthly Report, Section 2.7.1.

5. Working Session at NASA/MSFC, 11/20/84

Attendees: P.J. Anderson, Honeywell Inc.
T. Marshall, NASA/MSFC
C. Kirby, NASA/MSFC
B. White, NASA/MSFC

During a November working session (Reference 5), Honeywell proposed a "half-sine pulse" shock test method to satisfy NASA's TSRS requirement as described in Reference 4. The details of Honeywell's proposal were outlined in Attachment 'F' of our November monthly report. T. Marshall, et al accepted the Honeywell proposal for the shock testing and evaluation of the Experimental Transducer.

2.7.2 Test Plans: Experimental Transducer

- Re: 1. Attachment 'F', August Monthly Report

Working Session at NASA/MSFC 11/20/84

Attendees: P.J. Anderson, Honeywell, Inc.
T. Marshall, NASA/MSFC
B. White, NASA/MSFC

With the shock testing issue resolved as noted in Section 2.7.1, T. Marshall, et al accepted Honeywell's test plan as detailed in Reference 1 except the sinusoidal vibration portions of that plan are to be replaced with the "half sine-pulse" test detailed in attachment 'F' of our November monthly report. Honeywell's test plans have been rewritten to reflect these agreements. See Attachment 'C' of our January monthly report.

2.7.3 Replan Effort

We have completed a replan of this program using the current design approach to achieve the original contract scope of work. A Cost-to-Complete proposal was completed and delivered to NASA's Procurement Office in February 1985. (The cover letter date was 2/7/85.)

Our Cost-to-Complete proposal was reviewed with Mr. R.J. Richmond (Designate for Mr. S.J. Morea, Program Manager, Advanced High Pressure Oxygen-Hydrogen Propulsion Program), Mr. A.L. Worlund (Program Manager, Test Bed Engine Program) and our contract monitor, Mr. T. Marshall, et al. Handouts of our presentation were left with the NASA attendees and are therefore not included in this report. Copies are available upon request.

3.0 Schedule -See Attachment 'B'

This schedule reflects the results our replan effort and was included in our Cost-to-Complete Proposal (Folder 1: Technical Proposal).

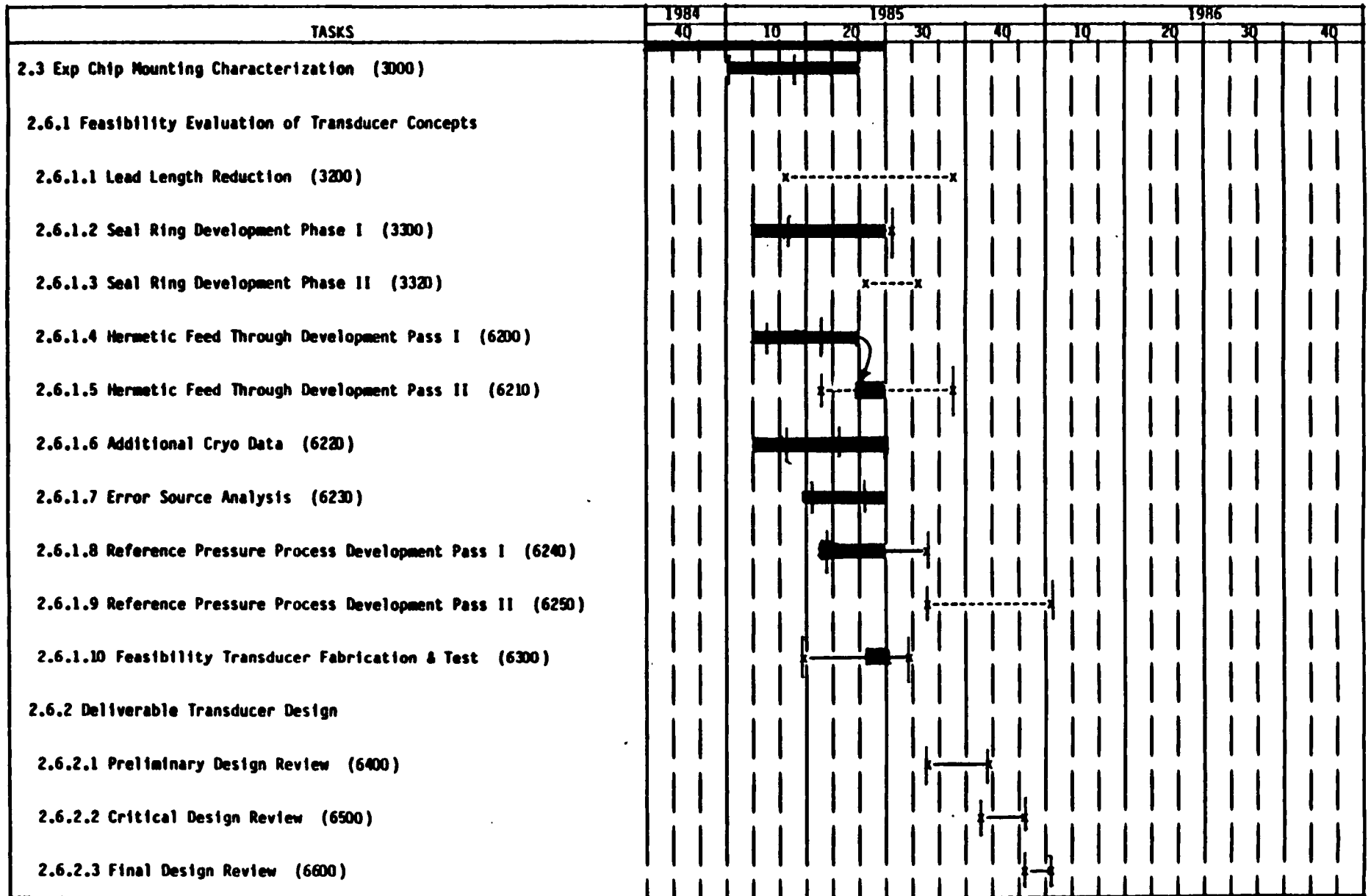
Our current status to this schedule is that we have incurred about a 4-6 week schedule slip. The primary contributors to this slip are slower than planned progress on the Hermetic Feedthrough Task and the need to execute a second pass to achieve the desired results with an acceptable confidence level.

As discussed in paragraph 2.6.3.2, the pending decision to the G & H connectors will impact the completion of the Feasibility Transducer build by about 16 weeks.

It is not clear at this time to what extent these schedule slips can be recovered. We however, will be exploring what can be done to minimize this impact of these schedule slips.

**RESEARCH PRESSURE INSTRUMENTATION FOR NASA SPACE SHUTTLE MAIN ENGINE
SCHEDULE**

Date: 2/85
 Rev: 1
 Page: 1 of 2

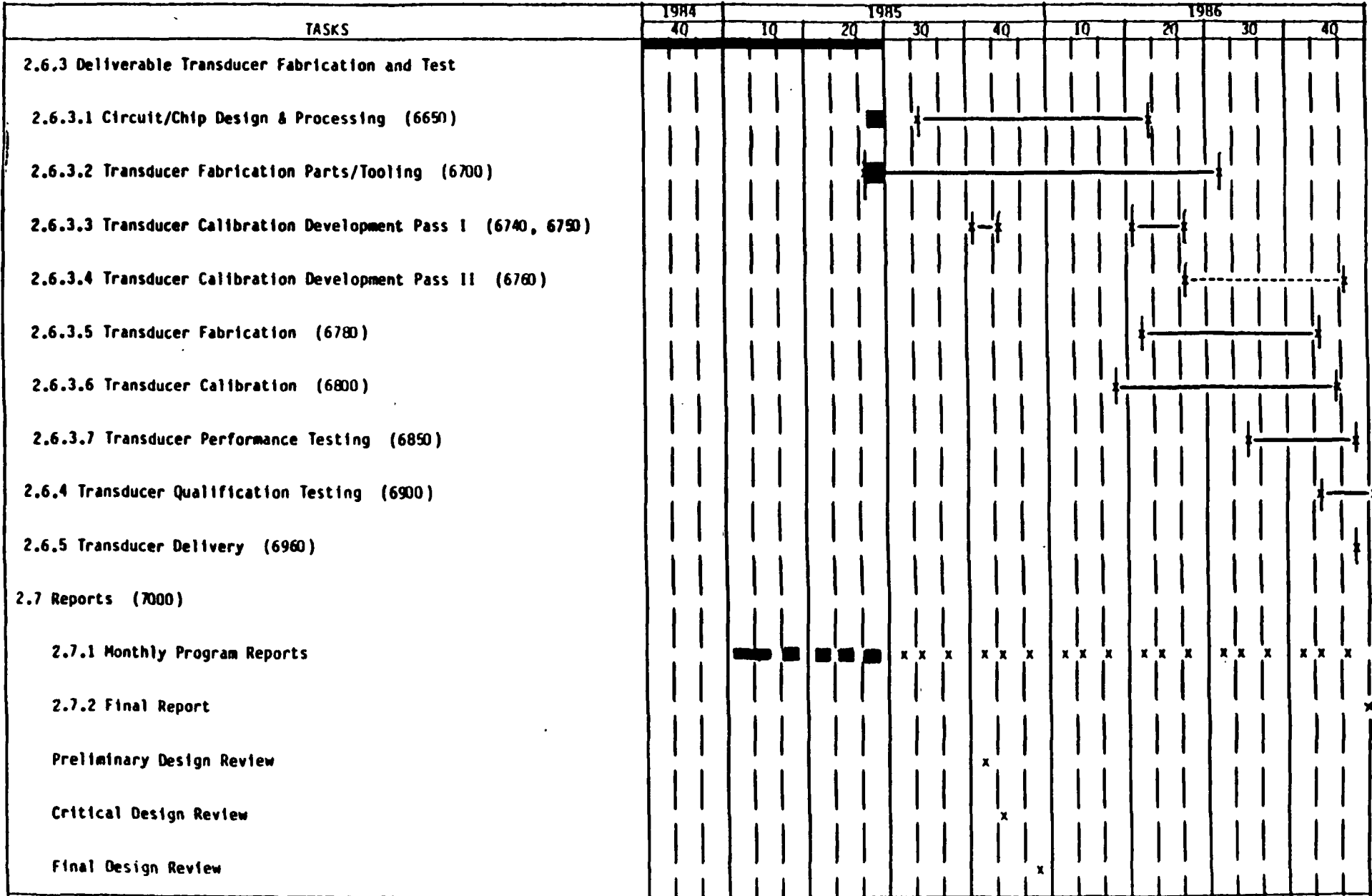


New Baseline Program Schedule per 2/85 Cost-to-Complete Proposal

ATTACHMENT 'B'

RESEARCH PRESSURE INSTRUMENTATION FOR NASA SPACE SHUTTLE MAIN ENGINE
SCHEDULE

Date: 2/85
Rev: 1
Page: 2 of 2



ATTACHMENT 'B'

New Baseline Program Schedule per 2/85 Cost-to-Complete Proposal

ATTACHMENT C

FINAL REPORT: EXPERIMENTAL CHIP MOUNTING
CHARACTERIZATION

TASK DESCRIPTION: The following sub-tasks supporting the overall task objective

were completed:

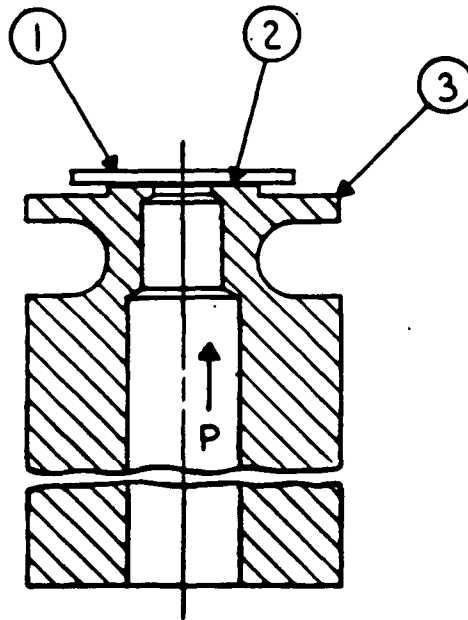
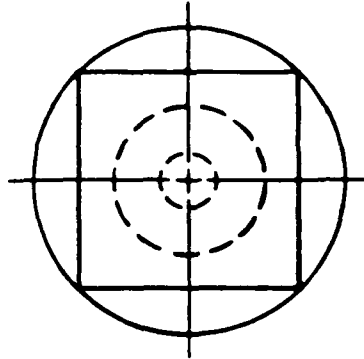
- o 2.3.1 - Define Experimental Processing and Evaluation Testing
- o 2.3.2 - Design Experimental Hardware
- o 2.3.3 - Design and Build Test Hardware
- o 2.3.4 - Develop Assembly Processes
- o 2.3.5 - Prepare Mechanical Silicon Test Chips
- o 2.3.6 - Build Experimental Hardware
- o 2.3.7 - Assemble Experimental Hardware
- o 2.3.8 - Low Temperature Shock Testing
- o 2.3.9 - Room Temperature Pressure and Vibration Testing

2.3.1 SUB-TASK SUMMARY - Define Experimental Processing and Evaluation Testing

The pressure transducer silicon chip mount design is extremely important. Sensor performance, in terms of accuracy, repeatability and stability, is dependent on its interface with the transducer package and pressure media. To determine the pressure capability and the extent that sensor performance is dependent on this interface, two experimental concepts were built, tested and evaluated. The experimental processing and evaluation testing were of the two concepts instrumental in the concept selection for Task 2.1. These were Concept 1, "Steel Tube Direct Chip Mount (Low Expansion Nickel Iron)" and Concept 5, "Silicon to Silicon Nitride Matched Compression Seals" and are shown in Figures 1, 2, 3 and 4.

FIGURE 1

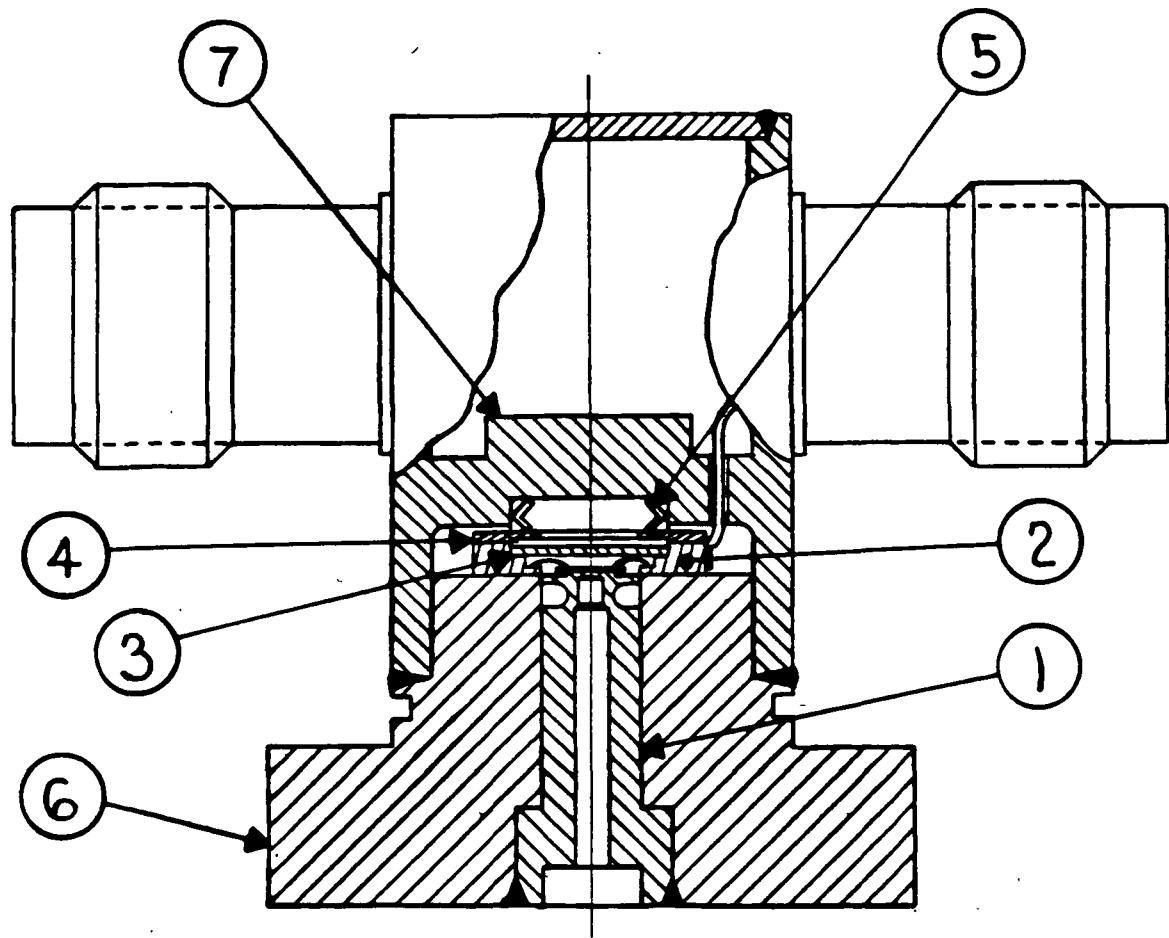
CONCEPT 1: STEEL TUBE DIRECT CHIP MOUNT
(LOW EXPANSION NICKEL IRON)



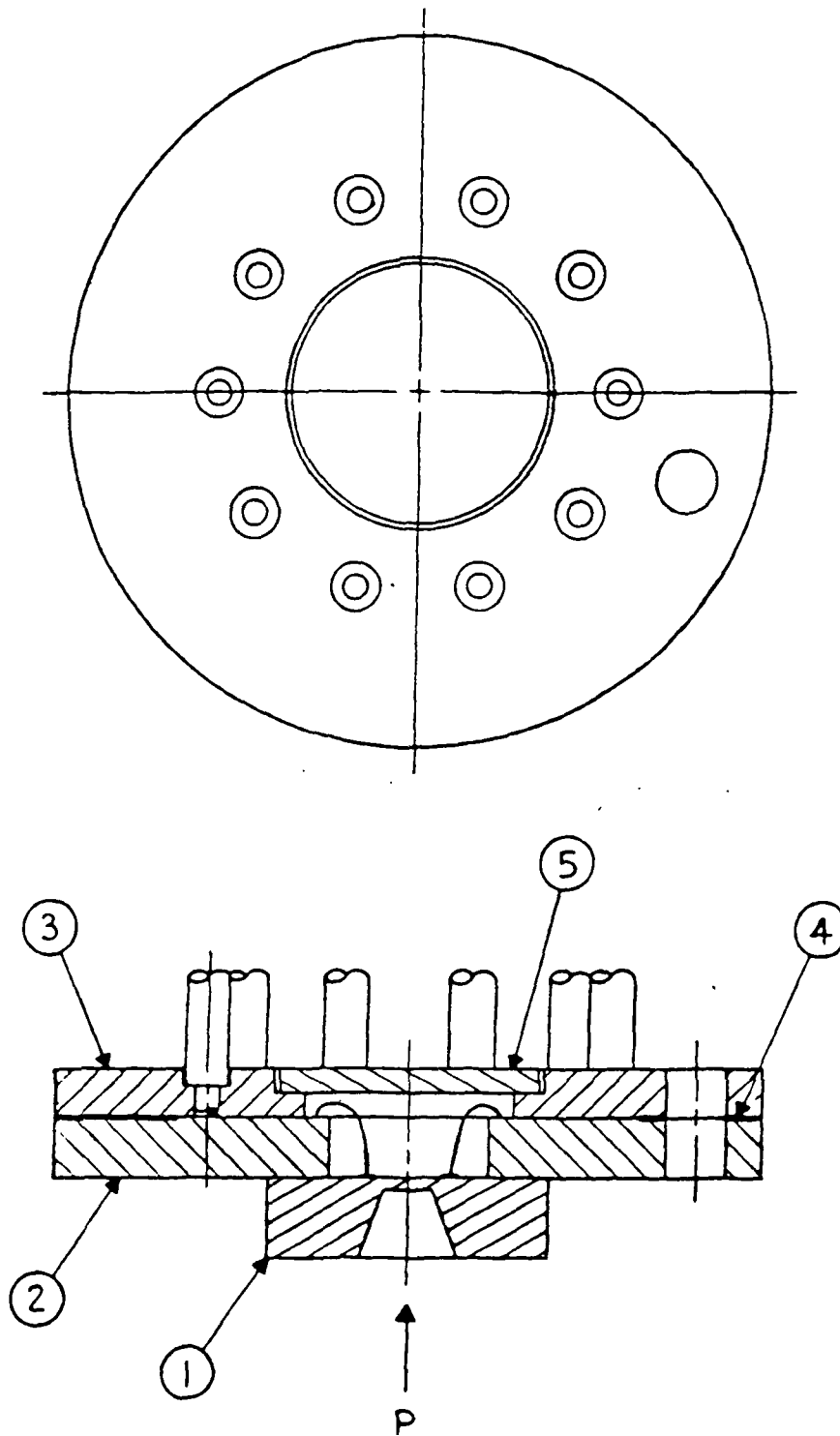
1. SILICON SENSOR CHIP WITH BONDING AREA METALIZED (METALIZATION-SPUTTERED TITANIUM-PLATINUM-GOLD OR OTHER METALIZATION)
2. HIGH STRENGTH SOLDER PREFORM (GOLD-TIN, GOLD-GERMANIUM OR OTHER HIGH STRENGTH MATERIAL)
3. LOW EXPANSION NICKEL IRON-ALLOY 36 OR SIMILAR MATERIAL (METALIZATION-SPUTTERED TITANIUM-PLATINUM-GOLD OR OTHER METALIZATION)

FIGURE 2

CONCEPT 1: SSME PRESSURE SENSOR PACKAGE - STEEL
TUBE DIRECT CHIP MOUNT (LOW EXPANSION
NICKEL IRON)



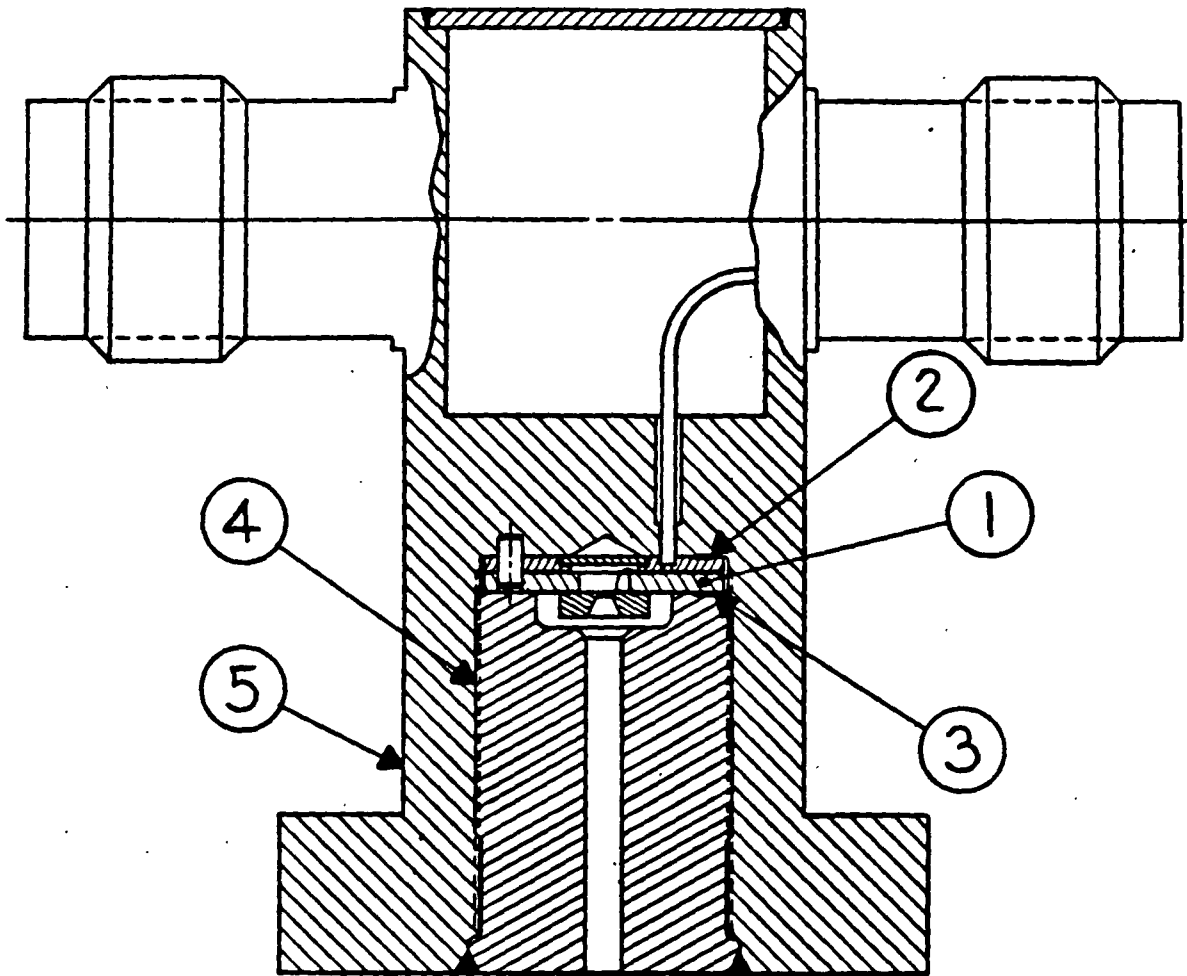
1. STEEL TUBE DIRECT CHIP MOUNT (LOW EXPANSION NICKEL IRON)
2. HEADER - CERAMIC TO PROVIDE ELECTRICAL LEADOUTS AND BONDING AREA FOR COVER GLASS AND STAINLESS STEEL BASE.
3. COVER - GLASS--TO ALLOW LASER TRIMMING OF THE SILICON SENSOR CHIP COMPENSATING NETWORK AND PROVIDE A HERMETIC SEAL BETWEEN THE COVER GLASS AND CERAMIC.
4. STAINLESS STEEL LOAD BEARING PLATE
5. STEEL SEAL TO PROVIDE SILICON DIE PRESSURE RUPTURE PROTECTION
6. STAINLESS STEEL BASE
7. STAINLESS STEEL COVER



1. SILICON SENSOR CHIP WITH BONDING AREA ON CIRCUIT SIDE.
2. SILICON NITRIDE MATERIAL TO PROVIDE HERMETICALLY SEALED ELECTRICAL CONDUCTOR PADS FROM SILICON SENSOR CHIP TO LEAD WIRES.
3. SILICON NITRIDE MATERIAL TO PROVIDE HERMETICALLY SEALED ELECTRICAL CONDUCTOR PADS WITH ELECTRICAL ISOLATION AREAS.
4. SOLDER BOND TO PROVIDE HERMETIC SEAL BETWEEN THE TWO (2) SILICON NITRIDE PARTS.
5. COVER - GLASS--TO ALLOW LASER TRIMMING OF THE SILICON SENSOR CHIP COMPENSATING NETWORK AND PROVIDE A HERMETIC SEAL BETWEEN THE COVER GLASS AND SILICON NITRIDE.

FIGURE 4

CONCEPT 5: SSME PRESSURE SENSOR PACKAGE - SILICON-TO-SILICON
NITRIDE MATCHED COMPRESSION SEALS



- SILICON-TO-SILICON NITRIDE MATCHED COMPRESSION SEALS - CONCEPT
- ALUMINUM WIRE COMPRESSION HERMETIC SEAL
- ALUMINUM WIRE COMPRESSION HERMETIC SEAL
- STAINLESS STEEL BASE
- STAINLESS STEEL HOUSING

1. Concept 1 Evaluation, "Steel Tube Direct Chip Mount (Low Expansion Nickel Iron)"

- Evaluation Test Sample: The chip tube mount configuration is shown in Figure 1 and consisted of the following:
 - o Silicon Sensor Chip
 - Backside (Cavity side) metallized with sputtered Ti/Pt/Au
 - o Solder Preform
 - Au/Ge
 - Preform: ANNULUS .050 ID
.100 O.D.
.001" Thick
 - o Low Expansion Nickel/Iron Tube
 - Alloy 36 (36% Ni - Fe Alloy)
 - Tube ends metallized with sputtered Ti/Pt/Au
 - Bond Area: ANNULUS .045: ID
.125" O.D.
- Evaluation Testing Results: Limited overpressure of the chip mounting Concept 1 was completed. The testing consisted of overpressuring the assembly, with the pressure applied to the backside of the die through the Invar tube pressure port. Pressure was applied up to 10,000 psi in increments of 1000 psi for 10 minutes at each pressure. The device failed at 10000 psi after the pressure was applied for approximately 5 minutes. Further development of the bond between silicon die and the low expansion Nickel/Iron tube would be required to insure concept feasibility.

Failure Analysis results based on the small area bonded, support the conclusion that a 20,000 psi burst pressure can be obtained. Despite this performance, there is a concern relative to this concept, namely, the silicon-steel joint is under tension rather than compression. Clearly, this situation would require an extremely strong joint in order to meet the high pressure/low temperature requirements for this application.

2. Concept 5 evaluation, "Silicon to Silicon Nitride Matched Compression Seals" - The impact of compressive loading on the sensor null (offset) for a structure similar to Concept 5 was experimentally evaluated. This testing simulated the application of a compressive load applied to the outer edge of the silicon nitride terminal boards, and demonstrated its effect on sensor performance for pressure loading up to 20,000 psi. Based on the results of this testing, along with a two-dimensional finite element stress analysis, instrumental in redesign of the original Concept 5 to minimize mounting stress transmission was performed. This design change involved adding an Invar interface, with controlled surface flatness, between the silicon nitride and stainless steel, adding a surface flatness

requirement to the silicon nitride parts and adding a metal compressive C-Ring between the silicon nitride and stainless steel (see Figure 5). This change will uniformly distribute the structural compressive load over the required transducer pressure and temperature range.

The pressure transducer silicon chip mount design utilizes materials with closely matched coefficients of expansion; silicon, silicon nitride, pyrex and Invar. This match will minimize the thermal stresses over the large temperature differential of 682 degrees F required for the SSME application. To insure package survivability at high pressure and cryogenic temperatures the design maintains the transducer seals in compression.

- Evaluation Test Sample: The impact of compressive loading on the sensor null was experimentally evaluated using an in-house developed sensor device. This sensor chip was mounted to a thin glass washer which is in turn mounted to a ceramic "chip carrier" type package. The effect of compressive loads up to 20,000 psi and over temperature were measured.

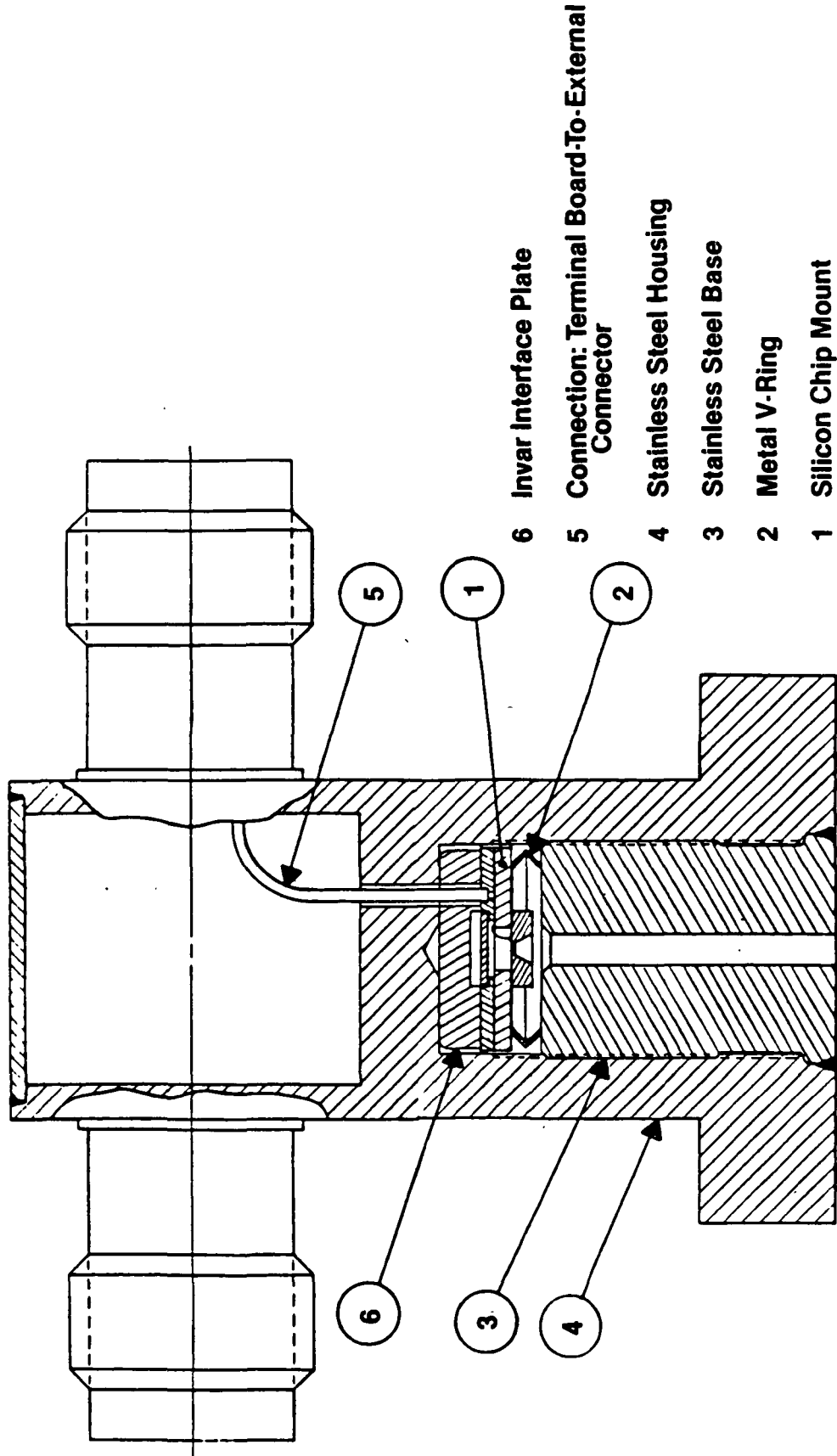
Force was applied to the sensor by a piston and weight arrangement. The force was converted to correspond to a pressure reading through a fulcrum. Weights from the dead weight tester were utilized.

- Evaluation Testing Results: Testing was completed to simulate the compressive pressure loading impact on transducer performance. The purpose of this testing was to determine the strain transmitted to the silicon chip by the impact of compressive loads applied to the outer edge of the silicon nitride. The key findings of this testing are:
 - Compressive loading can result in substantial stress transmission to the sensor chip
 - The stresses transmitted to the sensor are strongly dependent on the method of clamping in the test fixture.
 - The stress transmitted to the sensor is strongly dependent upon the condition (flatness) of the mating surfaces between the test samples and the test fixture.
 - Changes in the piezoresistors ranged between 0-2% when close attention was paid to the aforementioned conditions.

Based on the results of this experimental testing, the original transducer package design concept was changed to minimize stress transmission to the sensor chip by either pressure or temperature. This design change will uniformly distribute the structural compressive load over the required transducer pressure and temperature range. (see Figure 5)

FIGURE 5

SSME PRESSURE TRANSDUCER PACKAGE CONCEPT



Two dimensional, finite element stress analysis was completed for the test sensor used for compressive loading experiments and for Concept 5. The key findings were:

- Both the test sensor and Concept 5 respond similarly under compressive loading. The stress level differences agreed within a range of 1.0 - 1.6.
- The agreement between the experimental and predicted, 2-D, behavior of the test sample are quite different. A 3-D stress model is required to account for the mounting effects noted earlier. It is not planned to do a 3-D analysis of the IPT test sample because of the cost involved. However, a 3-D analysis of the final configuration of Concept 5 will be made.

2.3.2 SUB-TASK SUMMARY - Design Experimental Hardware

- o Experimental Transducer Package Design - The SSME Transducer Package Design is documented in Figure 3 and Figure 4. This encompasses an absolute silicon pressure sensor chip with laser trimmable circuit electronics mounted to a silicon nitride backplate and terminal board. The chip mount vacuum reference of the absolute transducer is established through the hermetic seals of the silicon, silicon nitride and the pyrex cover glass. The sensor chip mount is housed in a common package with electrical interface and pressure port provision.
- o Experimental Transducer Silicon Chip Mount Design - The pressure transducer silicon chip mount design is extremely important. Sensor performance, in terms of accuracy, repeatability and stability, is dependent on its interface with the transducer package and pressure media. There are four basic SSME requirements which dictate the pressure sensor chip mount design. These are:
 1. Pressure Media Interface - The high pressure (9.5K psi), cryogenic temperature (-320 degrees F) and pressure media (LOX, LH2, gaseous helium, nitrogen, oxygen, hydrogen, air and water vapor) require the active circuit side of the pressure sensor chip be separated from the pressure media. This is accomplished by applying the pressure to the backside of the pressure sensor chip.
 2. High Pressure/Low Temperature - The combined high pressure and low cryogenic temperature requirements dictate that the pressure media be applied directly to the chip.
 3. Active Laser Trimming - Active laser trimming of on-chip thin film resistor networks to calibrate sensor performance is normally completed after sensor packaging. This is done to eliminate the packaging and assembly process effects on transducer calibration. This dictates that the trimmable network be visible after packaging and further impacts the pressure sensor chip mounting.

4. Absolute Sensor - The absolute sensor requirement provides an additional challenge. The materials and processes utilized in the construction of the pressure transducer influence the sensor vacuum integrity. Materials were selected based on their diffusion and outgasing characteristics, high hermeticity capability and temperature pressure compatibility.

o Transducer Hardware Design - The design was completed for the following transducer piece parts:

- Stainless Steel Housing
- Stainless Steel Base
- Silicon Nitride Terminal Boards 1 and 2
- Pyrex Cover Glass for laser trimming
- Invar Mounting Plate
- "V" - Ring Seal
- Pyrex Washer for bond between silicon and silicon nitride

2.3.3 SUB-TASK SUMMARY - Design and Build Test Hardware

The design and build of test hardware was completed for the following:

- o Compressive Load Testing - Test fixturing was designed and fabricated to test the impact of compressive loading on the sensor null when force was applied through a special package to the sensor chip.
- o Vibration Testing - This fixture was completed and provided for transient shock testing.
- o High Pressure Testing and Leak Testing - The design and build of this fixture provided both functions of high pressure testing and hermetic leak testing in a single fixture. This fixture utilized a metal V-Ring to provide the high pressure and hermetic interface between the sensor housing and the fixture.

2.3.4 SUB-TASK SUMMARY - Develop Assembly Processes

The SSME Pressure Transducer Design goals, due to the combined effects of cryogenic temperature, high pressure, vibration and absolute pressure sensing are extremely challenging, This impacts the design, materials section and assembly processing. The basic SSME design goals are summarized in Table 1.

Table 1 Summary of SSME Pressure Transducer Design Goals

<u>CONDITION</u>	<u>DESIGN GOALS</u>
Transducer Configuration	- Same external configuration as RC7001
Pressure Changes	- 0 to 600 psia - 0 to 3500 psia - 0 to 9500 psia
Pressure Rating	- 1.5 x F.S. (No permanent null or calibration change) - 2.5 x F.S. or 20K psi Maximum (No permanent damage)
Pressure Media	- Liquid/Gaseous Hydrogen - Liquid/Gaseous Oxygen - Helium - Nitrogen
Temperature Range	- -200°C to + 120°C (Goal of - 253°C)
Vibration	- 0 to 2000 Hz; 400 g's (With superimposed random and steady-state vibration)
Acoustic Frequency Response	- Dynamic Design Goal of 300 Hz Minimum
Full Scale Output	- 30 ± 0.3 mV at 10 VDC Excitation
Thermal Zero Shift	- $\pm 0.005\%$ F.S./Degree
Electrical - To - Pressure Calibration	- $\pm 0.1\%$ F.S. at 80% F.S. Correlation points at Ambient Temperature

The transducer design approach implements the NASA requirement for direct mounting of the pressure transducer to the SSME. This requires the pressure sensing element to be in direct contact with the high pressure cryogenic pressure media. It also requires, based on the state of the hydrogen/oxygen/nitrogen pressure media, that the silicon integrated circuits not be in direct contact with the pressure media. The assembly process development is summarized as follows:

- Process Development for Joining the Silicon Die to the Silicon Nitride Terminal Board: Three approaches were tried.
 1. TE bond of the silicon chip directly to the silicon nitride terminal board - Tried but not successful (see below).
 - 2, TE Bond of the silicon chip to a glass layer deposited on the silicon nitride - Approximately 4000Å of glass was sputtered on to the silicon nitride. Tried but not successful (see below).
 3. TE Bond to Join the Sensor Chip to a Pyrex Washer - Of the three, only this one has a reasonable probability of being successful. This approach uses TE bonding to join the sensor chip to a pyrex washer and a solder bond to join the sensor/pyrex assembly to the silicon nitride. The solder bond is at the pyrex-silicon nitride interface. Some of the key features of these joints are as follows: (see figure 6)
 - o TE bond (silicon to pyrex): Requires optically flat surfaces
 - o Interface metallization (pyrex-silicon nitride: Ti/Pt/Au or Ti-W/Ni/Au both surfaces
 - o Solder: Au/Ge or Lead/Tin/Silver

The integrity of these joints was evaluated using the following temperature shock testing profile:

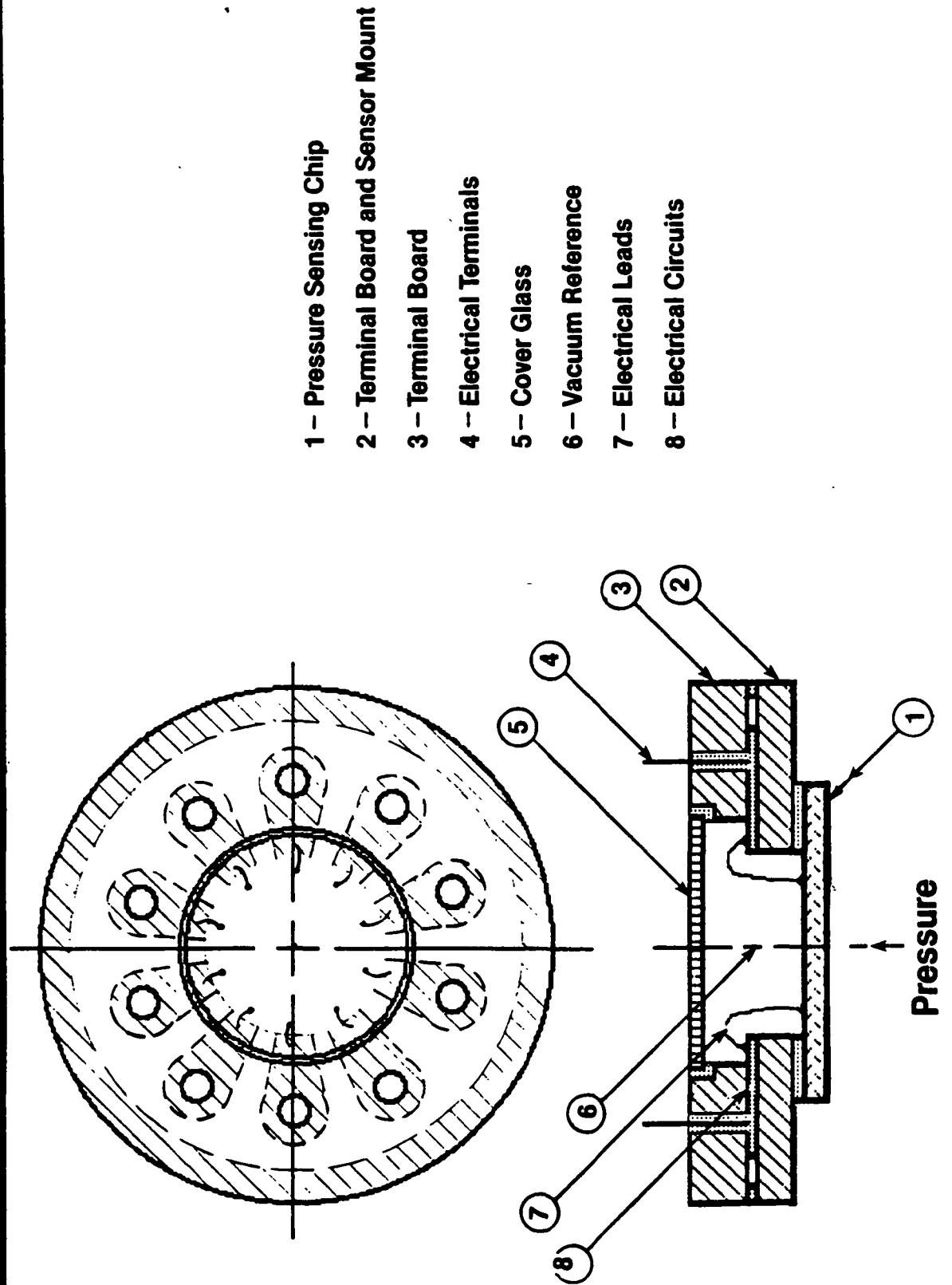
- o Liquid Nitrogen - (-200°C) to 100°C: Five times
- o Liquid Helium - (-255°C) to 25°C: Three times

The test evaluations showed no damage to the joints and after temperature shock the joints were hermetic.

The silicon/pyrex washer/silicon nitride structure was modeled using finite element methods to determine the impact of solder creep on sensor performance. This analysis shows that changes in stress due to solder creep can be transmitted to the sensor chip. However, this effect can be minimized by using a solder that has a high resistance to creep. Because of the high strength properties of the Au/Ge solder, it is expected it will have a high resistance to creep. This may, however, require some critical experiments to verify the magnitude of this effect.

FIGURE 6

SSME PRESSURE TRANSDUCER SILICON CHIP MOUNTING CONCEPT



The difficulty with the other two approaches for joining silicon to silicon nitride was that with or without a sputter-deposited pyrex film on the silicon nitride, the required optical flatness could not be achieved. The next result was that TE bond could not be made.

- Process Development for Joining the Silicon Nitride Terminal Boards Together - Considerable difficulty was encountered in developing the hermetic seals between the two silicon nitride terminal boards and the pyrex washer. New process development was required for the following:
 - o Silicon nitride metalization
 - o Delineation of the metal pattern
 - o Defining and obtaining the required silicon nitride surface finish
 - o Development fixtures for soldering and leak checking
 - o Process variable determination (fluxless hermetic joint)
 - o Failure analysis techniques

In successfully achieving the high degree of hermeticity required for an absolute sensor numerous process and material factors were isolated which effect hermiticity of the silicon nitride joint. The leak rate requirement of 1×10^{-12} cc per second helium equivalent maximum is extremely stringent. The following is a summary of the process development.

- o Silicon nitride metalization - One of the key factors required to achieve the hermetic seals between the silicon nitride terminal boards and the pyrex washer was to change the metalization from Ti-Pt-Au to Ti/W-Ni-Au. This change also permits the metalization pattern required for the hermetic seal area and electrical feed-throughs to be delineated by standard photoresist methods and etching.
- o Delineation of the metal pattern - Two basic processes and the required tooling were developed for delineating the metal pattern; abrasive blast and shadow-masking during metalization sputtering. Delineating the pattern by standard photoresist methods and etching will be utilized in the follow-on tasks.
- o Silicon nitride surface finish - an essential key factor in achieving the silicon nitride hermetic seals was the determination that leaks in the seal area were caused by minute scratches and machining marks. A lapping process was developed to remove the scratches.

2.3.5 SUB TASK SUMMARY - Prepare Mechanical Silicon Test Chips

The fabrication of nonfunctional "sensor" chips (Silicon chips without piezoresistor circuits) was completed in support of the assembly process development activity. The chips were made from three 3.0 inch diameter by 0.100 inch thick wafers. These were lapped to 0.035 inch thick and then cut into 0.225 inch square silicon chips.

2.3.6 SUBTASK - Design and Build Test Hardware

The fabrication of the transducer piece part hardware was completed and itemized as follows:

- Stainless Steel Housing and Base: Parts were machined from 304L stainless steel
- Silicon Nitride Terminal Boards:
 - o Parts were fabricated by Ceradyne Santa Ana, California
 - o Parts were metalized by sputtering with two different metalization systems; Titanium/Platinum/Gold and Titanium-Tungsten/Nickel/Gold
- Invar Mounting Plate: Parts were machined from Invar (Alloy 36)
- Pyrex Cover Glass and Pyrex Washer: Parts were fabricated by Rogers Custom Optics, Minneapolis, Minnesota
- Metal "V and C" Rings: Parts were purchased from Advanced Products, North Haven, Connecticut

2.3.7 SUB TASK SUMMARY - Assemble Experimental Hardware

The procedure used in the assembly of the experimental hardware was as follows:

A. Capsule Assemble

1. The pyrex washer was TE bonded to the top side of the sensor chip.
2. The chip/washer subassembly was sputter metallized on the pyrex side with Ti/W-Ni-Au.
3. The silicon nitride terminal boards were sputter metallized with Ti/W-Ni-Au.
4. The terminal boards and the chip/washer subassembly were soldered together using Au-Ge solder.
5. This capsule assembly was He leak checked and determined to be hermetic.
6. Both one and two mil diameter gold wires were ball-bonded between the sensor chip pads and the metallized pads on the terminal board.

B. Wiring and Potting of Housing

1. Thirty gauge Teflon insulated copper wire was used to make electrical connection between the eight connector pins and the housing.
2. These wires were soldered to the connector pins and silver epoxy bonded to the housing.
3. Four of the eight wires were coated at each end with Dow Corning RTV prior to potting.
4. The housings were potted with Emerson & Cuming epoxy.

C. Housing Assembly

1. The Invar back-up plate was placed into the housing sensor cavity.
2. The sensor capsule was placed on top of the back-up plate.
3. A metal V-ring seal was placed on top of the sensor capsule.
4. The stainless steel base was then screwed into the housing.

2.3.8 LOW TEMPERATURE SHOCK TESTING

One of the methods used to determine the mechanical strength of the chip mounting concept was a thermal shock test. This test was performed on both the capsule subassembly immediately after solder sealing and on completed mechanical transducer models. The procedure for testing the capsule subassembly was as follows:

1. Helium Leak Check
2. Immerse in Liquid Nitrogen (60 sec.)
3. Place in 110°C oven (5 min.)
4. Helium Leak Check

All capsules that were hermetic after solder sealing remained hermetic after this single shock test.

The completed transducers were also thermal shock tested. This test was performed on the device following high pressure and mechanical shock testing. (The complete test plan for the pressure, mechanical shock and thermal shock testing is described in Appendix I.) The temperature shock testing was performed as follows:

I. Test

- A. Immerse complete transducer in liquid nitrogen (10 minutes)
- B. Immediately place in an oven at 110°C (20 minutes)
- C. Repeat steps A and B two more times

II. Evaluation

- A. Helium leak check
- B. Disassemble
- C. Helium leak check capsule subassembly
- E. Electrical continually check

Three capsules that passed the high pressure and mechanical shock testing were thermal shock tested according to this plan. The first unit remained hermetic after thermal shock. The capsule in this device was made with Au-Ge solder and had a small crack in the pyrex washer after mechanical shock testing. This crack did not get any worse during thermal shock and the capsule remained hermetic. This device had no wire bonds. One of the potted wires in the upper portion of the housing had a large increase in resistance after thermal shocking. This was one of the wires that was coated with RTV prior to potting. The exact cause of this resistance increase should become apparent when the potting is removed from the housing during Feasibility Fabrication and Test portion of this program.

The next unit to be tested was made with Pb-Ag-Sn solder and it remained hermetic after thermal shocking. This unit had four wire bonds and none were affected by the shock testing. The seven good potted wires all passed the continuity test. (One potted wire failed the continuity test before temperature shock.)

The final unit to be tested was made with Au-Ge solder, had eleven wire bonds, and had a cracked pyrex washer that had to be sealed with epoxy to make it hermetic prior to pressure and mechanical shock testing. This device was hermetic prior to thermal shock testing but leaked following the test. When visually examined, several small cracks could be seen in the epoxy. There were no wire bond failures and again there was no change in resistivity of the potted wires.

2.3.9 ROOM TEMPERATURE PRESSURE AND VIBRATION TESTING

As the design concept evolved, there was considerable concern that the long lead lengths of the wire connections from the chip to the terminal board would be a cause of failure when the transducers were vibrated. To determine if this was a problem, two sensor capsules were assembled using both one and two mil diameter gold wire and were vibration tested on our VTS 100-C vibration table. Both devices were tested in two axes (parallel and perpendicular to the plane of the die). The vibration conditions were:

- o 40g's: 1000Hz to 2500Hz: 1 octave/min.: 30 min. total
- o 40g's: 2500Hz to 3500Hz: 1 octave/min.: 30 min. total
- o 40g's: 3500Hz to 4800Hz: 1 octave/min.: 30 min. total

No wires failed but the wires were too small to see if there was any resonant frequency. This test indicates that there should be no problems with these wires passing the NASA SSME vibration requirements since 4800 Hz is significantly above the spec maximum of 2000 Hz.

The original plan was to do some limited vibration testing on fully assembled transducers to determine mechanical integrity. The amplitudes of the sinusoidal sweeps were to be as follows:

<u>Frequency</u>	<u>Amplitude</u>
150 to 200 Hz	130g peak
200 to 3000 Hz	150g peak
170 Hz	120g peak
2000 Hz	400g peak

However, before the testing began, it was determined that this testing was more severe than required and that a Transient Shock Response Spectrum (TSRS) test was a more appropriate test procedure. It was then determined that Honeywell had only a limited capability to perform the required testing and analysis to assess the performance of our pressure transducer to the TSRS requirement. It was concluded that we could use a "Half-Sine Pulse" shock test to match very closely with the TSRS requirement. Our experience from previous TSRS work has shown that the actual TSRS results obtained with the half-sine pulse test match the predicted response to within about +3 db to +6 db.

The half-sine pulse test method used to evaluate the pressure transducer was as follows:

- o One axis; two directions where the axis is that which is orthogonal to the surface (i.e., diaphragm) of the sensor chips
- o One axis; one direction where this axis is orthogonal to the one described above
- o One axis; one direction where this axis is orthogonal to both described above
- o Parameters of the Half-Sine Pulse
 - 250 g's
 - 1.0 millisecond
- o Output data: Oscilloscope photograph of acceleration vs. time

This test was performed on the device following high pressure testing. (The complete test plan for the pressure, mechanical shock and thermal shock testing is described in Appendix I.)

Three transducer assemblies were mechanically shock tested (three capsules in two different housings). All three devices passed the test. They were hermetic before and after testing and the wire bonds and potted wires did not fail. One of the capsules had a small crack in the pyrex washer along one edge of the chip, extending to the outside diameter of the washer. Despite this crack the capsule remained hermetic.

Prior to the mechanical shock testing all three assemblies were high pressure tested using the following procedure:

- I. Helium Leak Check
 - A. At atmospheric pressure
 - B. At 1500 psi pressure
- II. Pressure Test (Helium Gas)
 - A. Apply 3500 psi
 - B. Helium leak check at atmospheric pressure
 - C. Apply 6000 psi
 - D. Helium leak check at atmospheric pressure
 - E. Apply 10,000 psi
 - F. Helium leak check at atmospheric pressure
- III. Evaluation
 - A. Continuity test
 - B. Dissassemble
 - C. Visual inspection
 - D. Helium leak check capsule

All three devices passed this high pressure test without any failures.

ATTACHMENT I.

EXPERIMENTAL PRESSURE TRANSDUCER TEST PLAN

- I. Objective: To determine the mechanical integrity of the sensor mounting assembled within the transducer package over temperature, pressure and mechanical shock.
- II. Test Device: An electrically non-functional version of Honeywell's current design approach
- III. Evaluation Methods:
 - A. Physical Condition — Visual
 - B. Hermeticity of Joints and Seals — Helium Leak Check
 - C. Continuity of "Dummy" Electrical Leads — Visual and Continuity Check
- IV. Test Plan:
 - A. Sample Sized = 2 Units (Three capsules in two housings were tested)
 - B. Baseline Continuity Check
 - C. Baseline Leak Check
 - 1. At Atmospheric Pressure
 - 2. At 1500 psi of Helium Pressure
 - D. Baseline Pressure Test
 - 1. Test Gas: Helium
 - 2. Apply 3500 psi
 - 3. Leak Check At Atmospheric Pressure
 - 4. Apply 6000 psi
 - 5. Leak Check At Atmospheric Pressure
 - 6. Apply 10,000 psi
 - 7. Leak Check At Atmospheric Pressure
 - E. Evaluation
 - 1. Disassemble First Unit
 - 2. Continuity Check
 - 3. Visually Inspect And Note Results
 - 4. Leak Check Atmospheric Pressure
 - F. Decision
 - 1. Pending Results From E. Above, Repeat Steps B-E

ATTACHMENT I (CONTINUED)

- G. Sample Preparation For Next Test
 - 1. Reassemble Test Device(s)
 - 2. Leak Check At 1500 psi Of Helium

- H. Mechanical Shock Testing — Part I
 - 1. Sample Size: 2 Units
 - 2. Transient Shock Spectrum
 - a. One Axis; two directions where the axis is that which is orthogonal to the surface (i.e., diaphragm) of the sensor chips
 - b. One axis; one direction where this axis is orthogonal to the one described above
 - c. One axis; one direction where this axis is orthogonal to the two described above
 - d. Parameters of the Half-Sine Pulse
 - 250 g's
 - 1.0 millisecond
 - e. Output data: Oscilloscope photograph of acceleration vs. time

- I. Evaluation
 - 1. Leak Check At 1500 psi Helium
 - 2. Disassemble
 - 3. Continuity Check
 - 4. Visual Inspection And Note Results

- J. Sample Preparation For Next Test
 - 1. Reassemble
 - 2. Leak Check (Hermeticity Not Required, Just Note Leak Rate)

- K. Mechanical Shock — Part II
 - 1. Sample Size - 2 Units
 - 2. Transient Shock Spectrum
 - a. One axis; two directions where the axis is that which is orthogonal to the surface (i.e., diaphragm) of the sensor chips
 - b. One axis; one direction where this axis is orthogonal to the one described above
 - c. One axis; one direction where this axis is orthogonal to the two described above
 - d. Parameters of the Half-Sine Pulse
 - 250 g's
 - 1.0 millisecond
 - e. Output data; oscilloscope photograph of acceleration vs. time

ATTACHMENT I (CONCLUDED)

L. Evaluation

1. Leak Check At Atmospheric Pressure
2. Disassemble
3. Continuity Check
4. Visual Inspection And Note Results

M. Sample Preparation For Next Test

1. Leak Check Sensor Mount Subassembly
2. Reassemble
3. Continuity Check

N. Temperature Shock Testing

1. Immerse In LN₂ For 10 Minutes
2. Immediately Place In An Oven At 110°C For 20 Minutes
3. Repeat A and B Sequence Two More Times In Succession

O. Evaluation

1. Leak Check At Atmospheric Pressure
2. Disassemble
3. Visual Inspection And Note Results
4. Leak Check Sensor Mount Subassembly
5. Continuity Check

P. End Of Testing/Evaluation Of Experimental Transducer Model

ADDENDUM

V-RING STRESS MODELING

G.E.G
6/17/85

Introduction

This report documents the results of "V-ring Stress Modeling" a subtask of the Research of Pressure Instrumentation Program Task 3000 "Experimental Chip Mounting Characterization". The objective of this task was to evaluate the effect of the v-ring compression seal on the sensor chip performance using a computer (finite element) modeling software called ANSYS. The v-ring causes stress to the sensor chip when compressed between the silicon nitride sensor capsule and the stainless steel plug (see Figure 1). The force applied to the sensor capsule by the v-ring is ≈ 250 lb/in. This force is required in order to obtain the hermetic pressure seal.

The stresses in the sensor capsule created by the v-ring compression seal must be nearly symmetric so that the offset or null value is not shifted over a range that would be very difficult to trim out during calibration.

One example of an asymmetric loading of the v-ring would be if the silicon nitride capsule and the stainless steel plug are not co-coplanar; the force due to the v-ring compression seal would be greater on one side than the other. Analysis of this condition will help to determine the calibration procedure and packaging configuration required to successfully complete the laser trim calibration. Capsule orientation may significantly affect the sensor null (or offset) voltage. If so, the concept of calibrating the capsule in one housing, then removing it and completing the packaging in a different final housing may not be feasible.

Summary

Stresses at the high end of the ranges measured are cause for concern with respect to the capability to calibrate and the effect of moving the capsule from a calibration housing to a final housing. Nullshifts ranging from 0.2 to 2.9 millivolts and 0.04 to 0.5 millivolts are expected for the 600 and 3500 psi ranges respectively. Consequently, close attention will be paid to an experiment planned for the upcoming feasibility sensor build under which capsules will be moved between housings and the impact on the null reading observed. If this experiment indicates that large, nonrepeatable stresses

will cause major null shifts when the capsules are moved, then the alternative approach of calibrating in a subassembly of the deliverable housing will be seriously pursued. Calibrating a null shift range of ± 0.5 mV is feasible but calibrating a range as high as ± 2.9 mV may be difficult. Further analysis of this issue will continue in the deliverable circuit design. Nullshift values will also be measured during the feasibility sensor build. If sufficient asymmetric loading exists in the feasibility units then calibration in a subassembly of the final package will probably be the best approach.

Data Summary

Stresses in the silicon sensor due to the v-ring compression seal are expected to cause a nullshift in the range of 0.13 to 0.3 mV. An extreme maximum nullshift may be as high as 1.65mV. These results are based on a 12 mil thick diaphragm. The pressure ranges for the deliverable transducers are 600 and 3500 psi and the current design requires 9 mil and 22 mil diaphragm thicknesses respectively. Stresses in the silicon sensor due to the v-ring compression seal are expected to cause a nullshift of 0.2 to 0.5 milivolts with an extreme maximum of 2.9 milivolts and 0.04 to 0.1 milivolts with an extreme maximum of 0.5 milivolts for the 600 and 3500 psi ranges respectively. Computer-simulation calculations were completed with the following assumptions.

- Model Assumptions :
- 12 mil thick diaphragm with 65 mil radius
 - Sensitivity Factor Π_{44} is $4.794 \text{ E-}6 \text{ in}^2/\text{lb}$
 - V-ring load of 250lbs/in with a superposition asymmetric load of up to $[125 * \text{Cos}(\theta)]$
 - Bridge supply voltage 2.5 Volts.
 - Extreme maximum nullshift is due to the difference between radial and tangential stress components equal to half their individual value (275 lbs/in).
 - Evaluate other diaphragm thicknesses with the following formula: $(t/r)^2 * V_{\text{signal}} = \text{Constant}$

Diaphragm thickness	t	
Diaphragm radius	r	
Sensor nullshift mV	V_{signal}	

ANSYS Finite Element Computer Modeling

Two modeling runs were completed evaluating a 12 mil thick diaphragm. The first simulated a symmetric load and the second an asymmetric load caused by the V-Ring compression seal. The layout of the packaging model is shown in Figure 2. One half of a cross section of the package is drawn and an axisymmetric rotation is assumed by the model. Each of the various materials in the package are identified and the material properties are input to the model. The force applied by the v-ring is specified and an exaggerated view of the deformation caused is shown in Figure 3. The stress values calculated for the circuit side of the sensor chip are analyzed and plotted as a function of diaphragm radius (see Plots 1-5). The stress is computed in psi relative to tangential and radial components of the stress field on the diaphragm. These values of stress are used to calculate the signal output as a function of device sensitivity, supply voltage, and radial and tangential stress values.

$$V_{\text{signal}} = \Pi_{44}/2 * (\sigma_r - \sigma_t) * V_{\text{supply}}$$

- Π_{44} Sensitivity factor for the Feasibility Sensor Chip.
 $\approx 4.794 \text{ E-6 in}^2/\text{lb}$
- σ_r Radial stress component at sensing resistors.
- σ_t Tangential stress component at sensing resistors.
- V_{supply} Supply voltage to sensing bridge. (2.5 Volts is assumed)

Symmetric Load Case

Evaluating the 12 mil thick diaphragm model, the stress values for the symmetric load case of 250 lb/in yields about 550 psi stress for both radial and tangential components at a 50 mil radius of the sensor diaphragm, the radius at which the sensing resistors are located (see Plots 1 & 2). The difference ($\sigma_r - \sigma_t$) is about -22 psi. This small difference is due to the symmetric nature of the model. The null shift expected is about:

$$\begin{aligned} V_{\text{signal}} &= (4.794 \text{ E-6 in}^2/\text{lb}) / 2 * (-22 \text{ lb/in}^2) * 2.5 \text{ Volts} \\ &= -0.13 \text{ mV} \end{aligned}$$

The stress levels of the radial and tangential components are much higher than their difference. Higher actual deltas are to be expected since the stresses are evaluated from a symmetric mathematical model. In reality the packaging induced stresses will not be as symmetric. An extreme worst case would be to assume the difference in $\sigma_r - \sigma_t$ to be 275 psi (50% of the individual stress). In this case the null shift may be as high as 1.65mV.

Asymmetric Load Case

Using a 12 mil thick diaphragm model, the stress values for the asymmetric load case have been evaluated as a superposition force function on the symmetric case of 250 lb/in. The model allows the force to be applied as an $F \cdot \cos(\theta)$ function; where the force on the sensor capsule is a maximum (F) at 0° and a minimum (-F) at 180° . The values of F evaluated are 250, 125, and 50 lb. The stress values are calculated by the model at $0^\circ, 45^\circ, 90^\circ, 135^\circ, 180^\circ, 225^\circ, 270^\circ, 315^\circ,$ and 360° . Stress values at each angle and force F are plotted as a function of sensor chip radius (see Plots 3, 4, & 5). The worst case $\sigma_r - \sigma_t$ values found at 0° were used to evaluate nullshift. Depending on resistor orientation, nullshift may be less. The resulting null shift expected due to each force $F \cdot \cos(\theta)$ superimposed on the symmetric load case is tabulated below.

$F \cdot \cos(\theta)$	Worst case of $(\sigma_r - \sigma_t)^*$	Model values V_{signal}^{**} 12 mil thick	600 psi Units V_{signal}^{**} 9 mil thick	3500 psi Units V_{signal}^{**} 22 mil thick
50 lbs	34 lb/ in ² .	0.2 mV	<u>0.36 mV</u>	<u>0.06 mV</u>
125 lbs	52 lb/ in ²	0.3 mV	<u>0.53 mV</u>	<u>0.09 mV</u>
250 lbs	83 lb/ in ²	0.5mV	<u>0.9 mV</u>	<u>0.15 mV</u>

* Sensing resistors are located at a 50 mil radius on the diaphragm.

** Supply voltage across the bridge is assumed to be 2.5 Volts.

Underlined values are calculated based on the 12mil thick diaphragm 65mil radius model :

$$(t/r)^2 * V_{\text{signal}} = \text{Constant}$$

Diaphragm thickness t

Diaphragm radius r

Sensor nullshift mV V_{signal}

SSME Pressure Transducer Package Concept

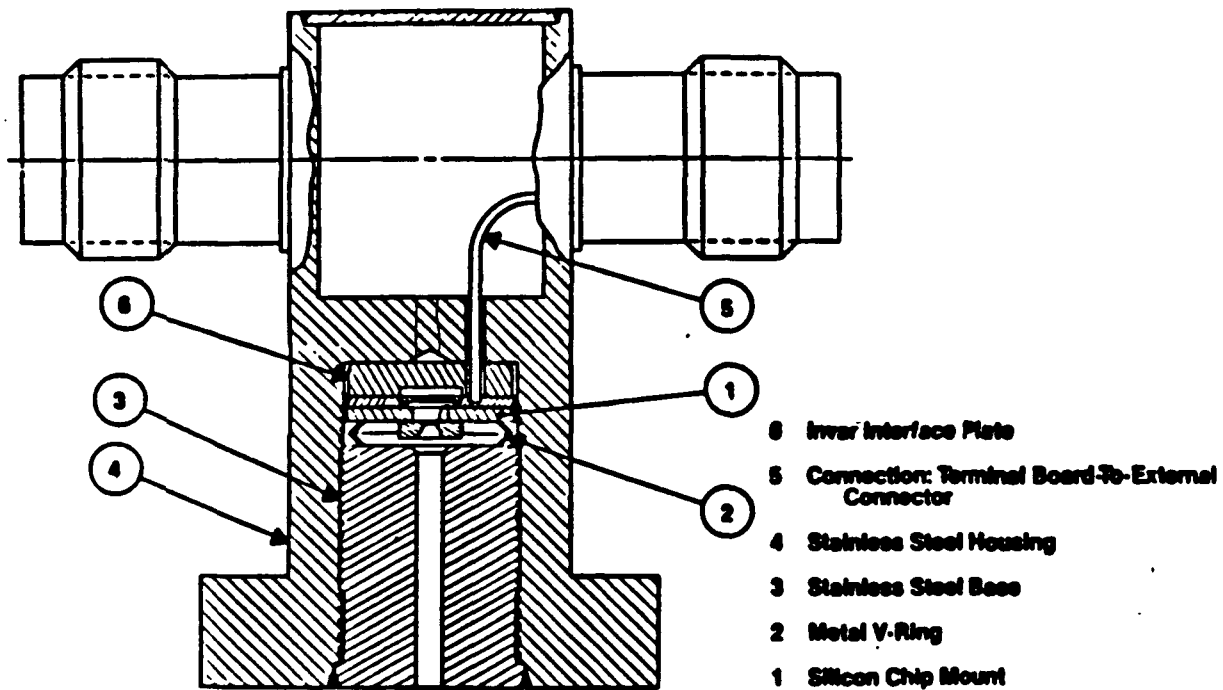


Figure 1

Drawing of ANSYS Model

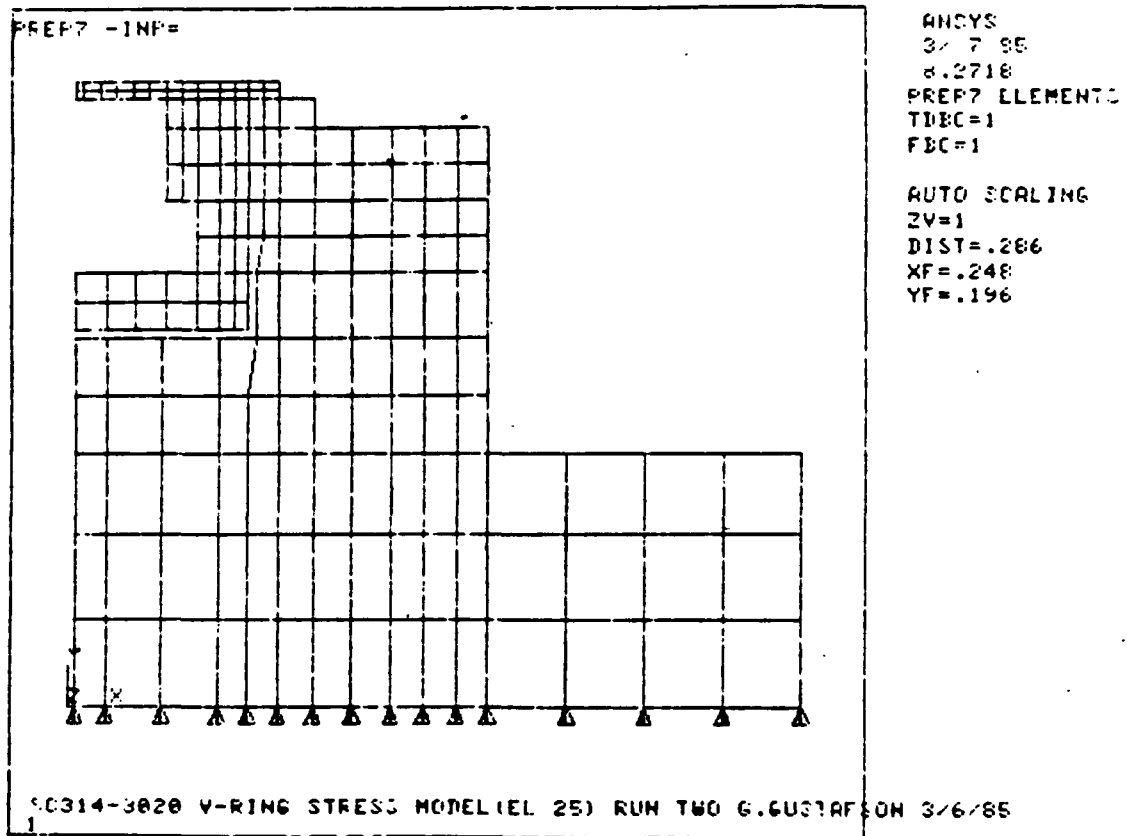


Figure 2

Exaggerated View of the Deformation Caused by the V-Ring Seal

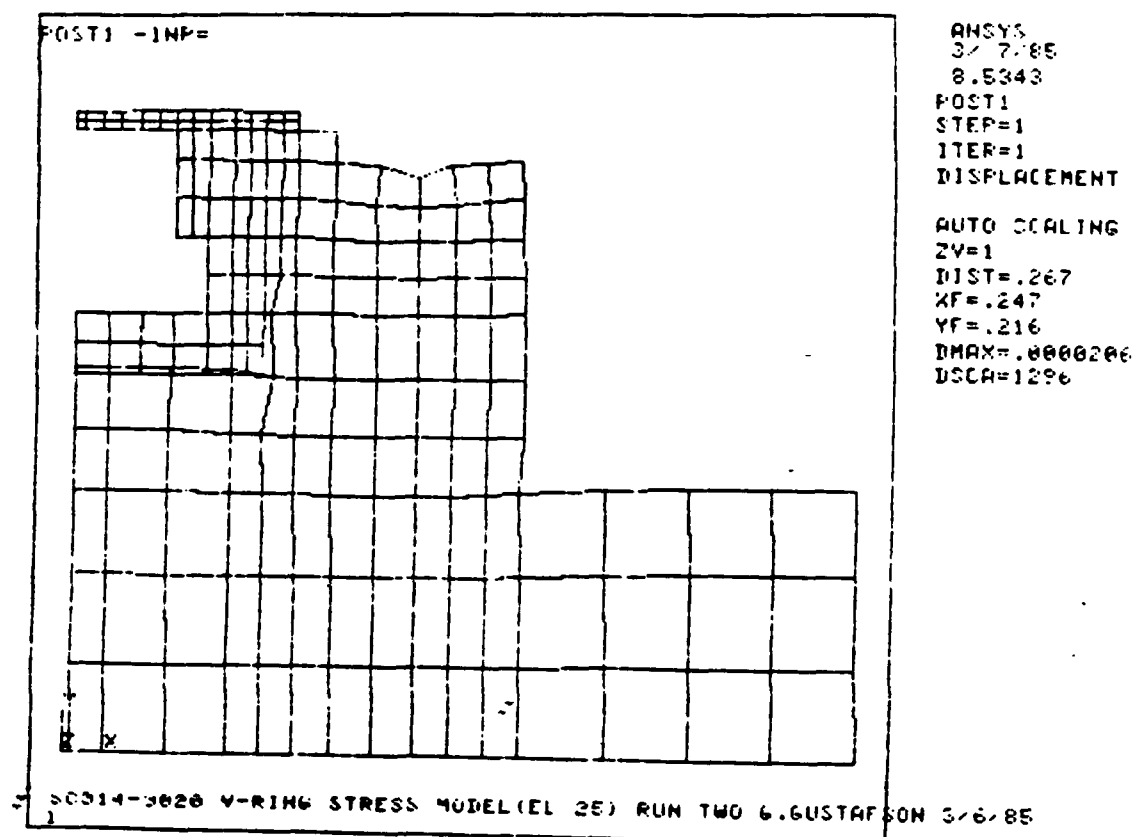
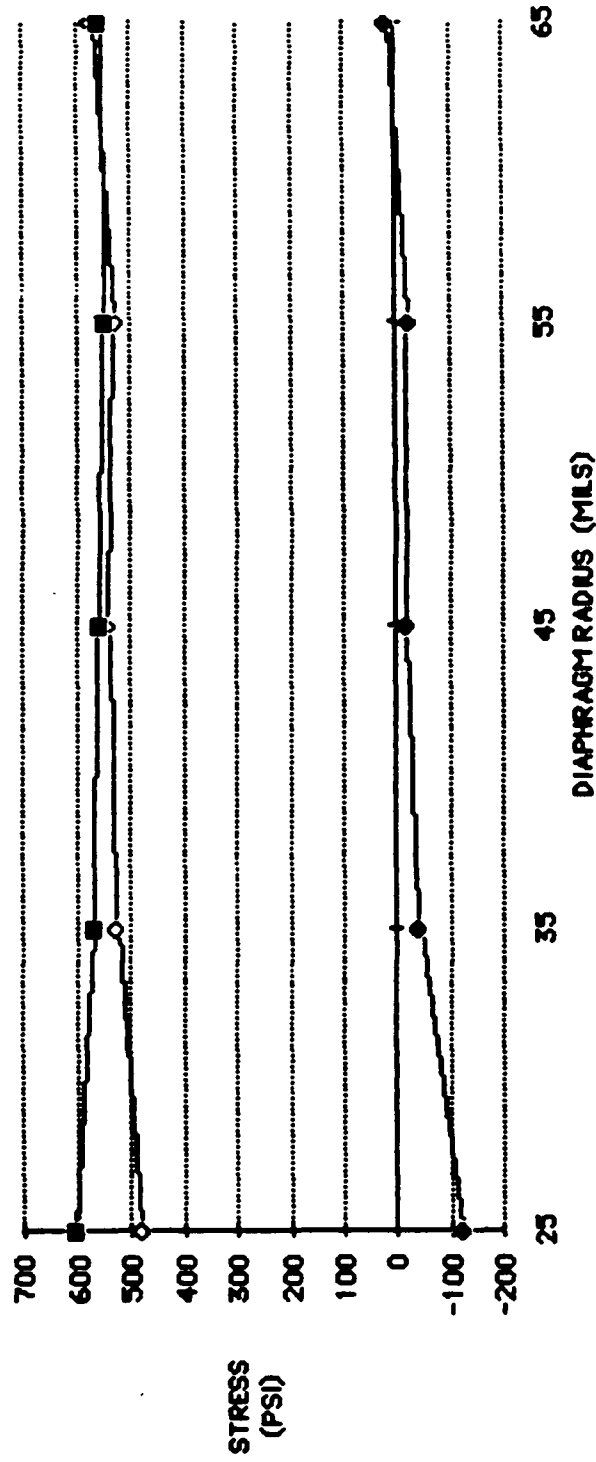


Figure 3

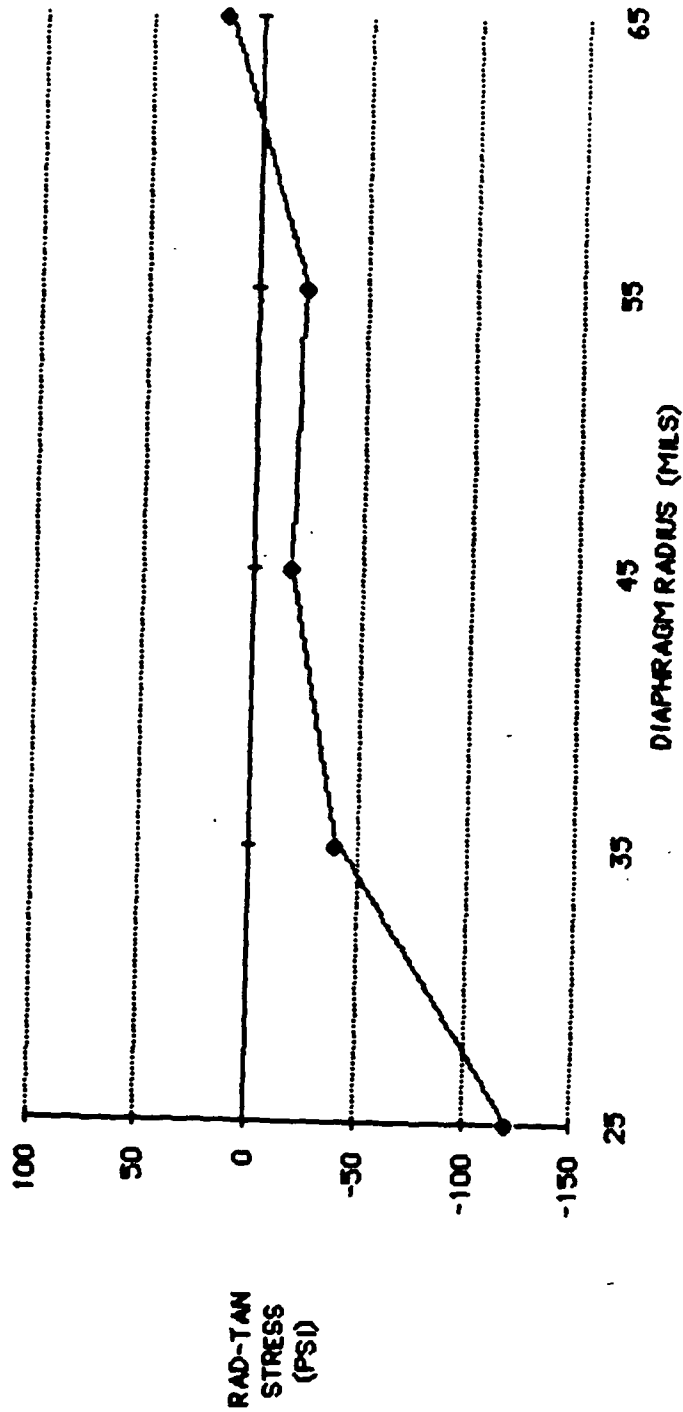
STRESS DUE TO V-RING COMPRESSION
 RAD & TAN SYMMETRIC LOAD 250 LB/IN



◆ Radial - Tangential
 ○ Radial Data
 ■ Tangential Data

PLOT #1

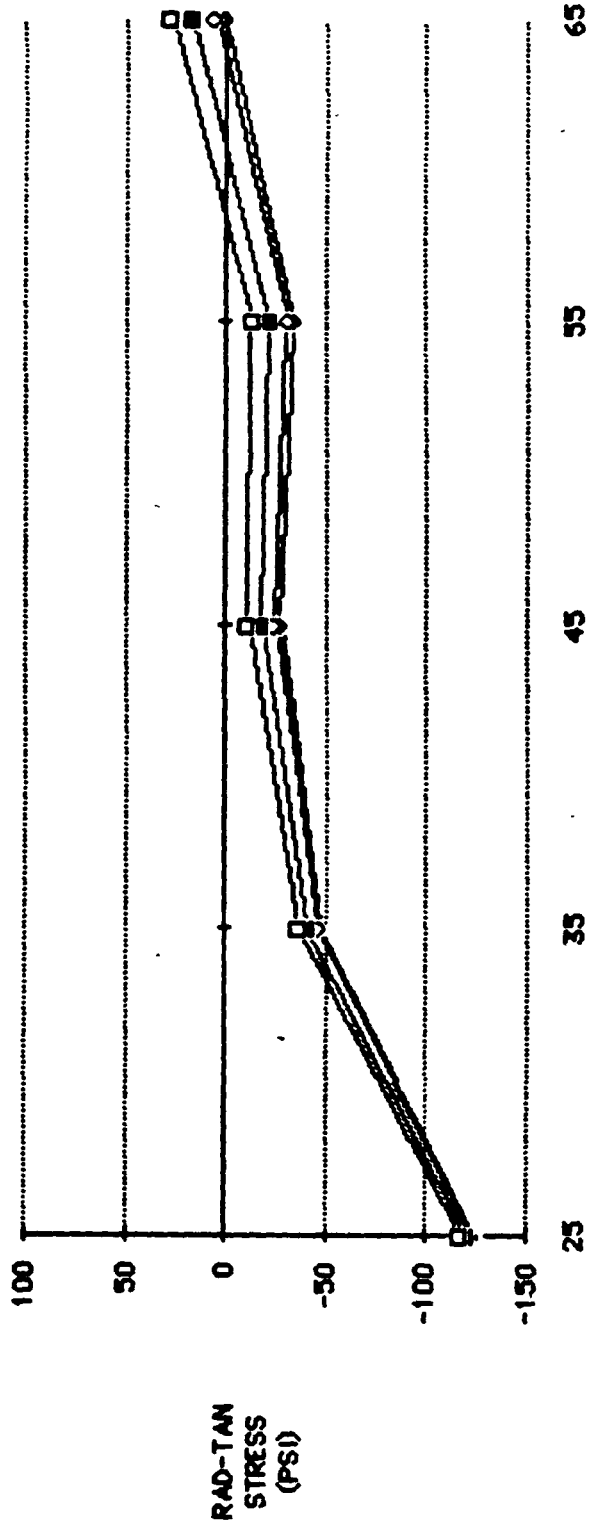
STRESS DUE TO V-RING COMPRESSION
SYMMETRIC LOADING AT 250 LB/IN



PLOT #2

GEG

STRESS DUE TO V-RING COMPRESSION
ASYMMETRIC LOADING AT $[50 + \cos(\theta)]$ PSI



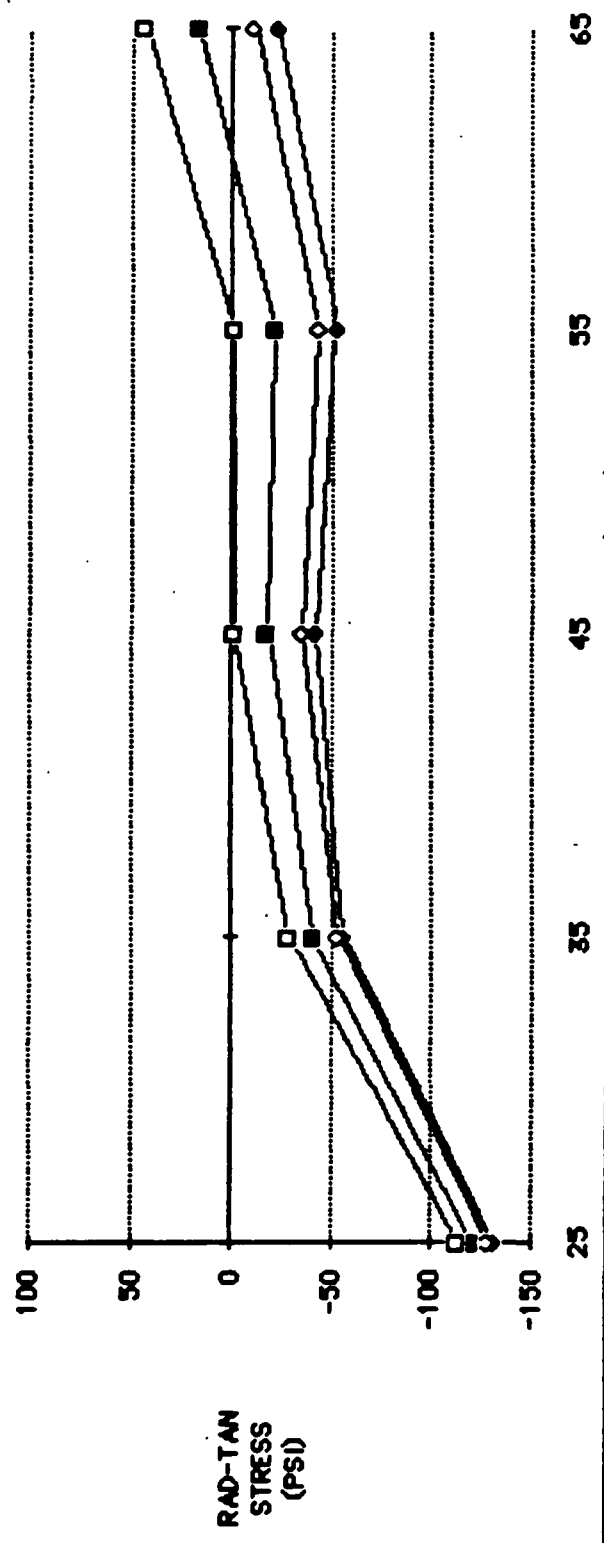
- ◆- ANGLE 0°
- ANGLE 45°
- ANGLE 90°
- ANGLE 135°

EACH PLOT AT 180° FROM THOSE ABOVE ARE -1 TIMES THE PLOTTED VALUES

PLOT #3

GEG

STRESS DUE TO V-RING COMPRESSION
ASYMMETRIC LOADING AT $[125 * \cos(\theta)]$ LB

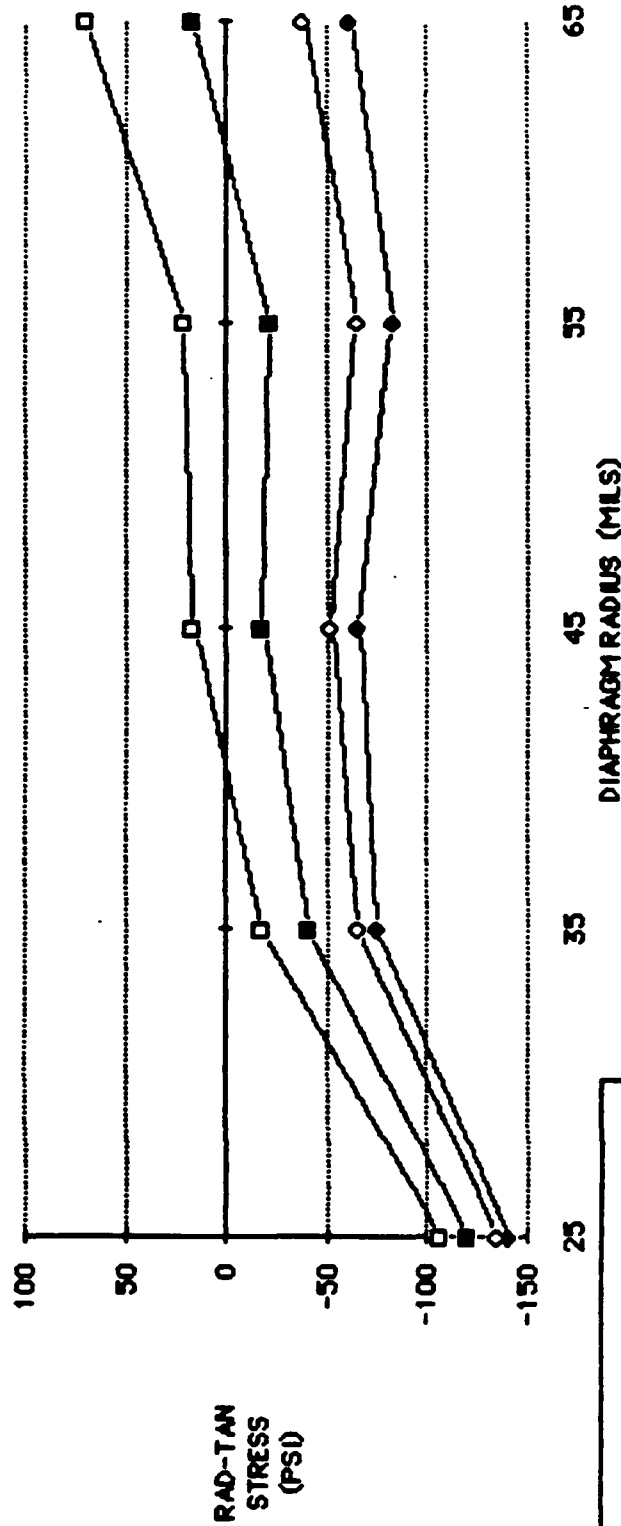


- ANGLE 0°
- ANGLE 45°
- ANGLE 90°
- ANGLE 135°

EACH PLOT AT 180° FROM THOSE ABOVE ARE -1
TIMES THE PLOTTED VALUES

PLOT #4

STRESS DUE TO V-RING COMPRESSION
ASYMMETRIC LOADING AT $[250 * \cos(\theta)]$ PSI



- ANGLE 0°
- ANGLE 45°
- ANGLE 90°
- ANGLE 135°

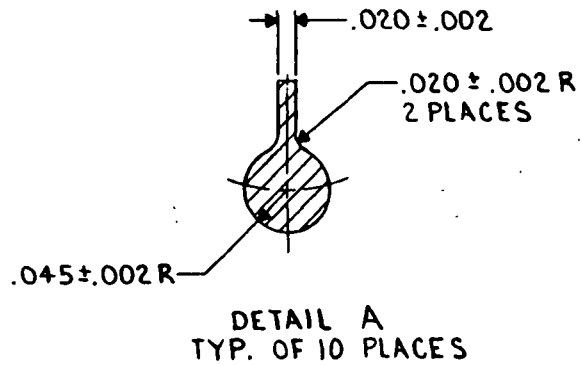
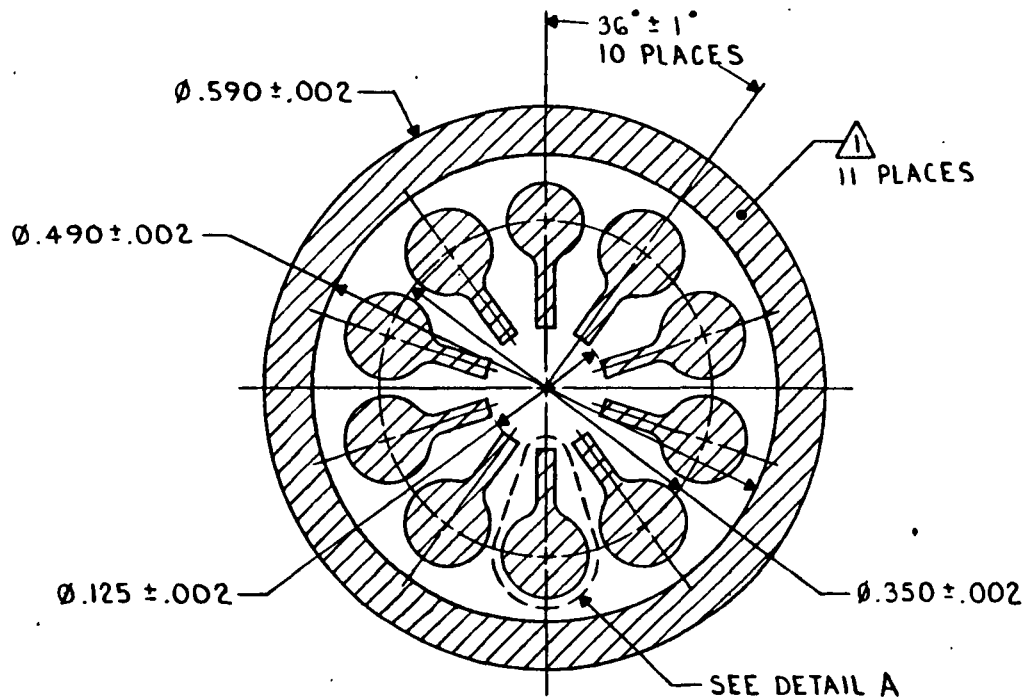
EACH PLOT AT 180° FROM THOSE ABOVE ARE -1
TIMES THE PLOTTED VALUES

PLOT # 5

ATTACHMENT D
NEW METALIZATION MASK
FOR TERMINAL BOARD #1

DASH NO	HONEYWELL NO
-001	22004561

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED



D-1

UNRELEASED
NOT UNDER
ECO CONTROL

⚠ - BLACK ON A CLEAR FIELD

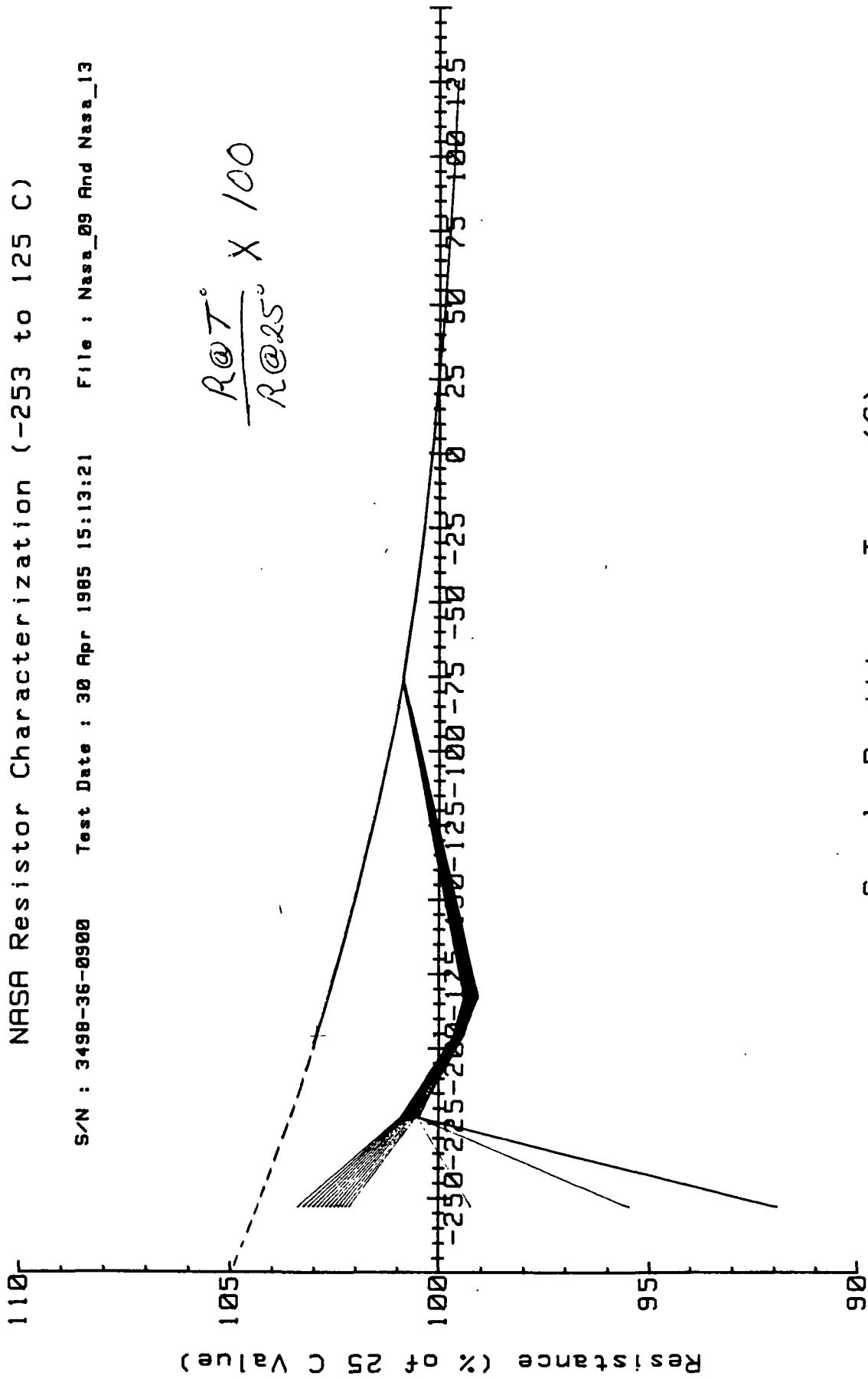
QTY REQD	CODE IDENT	PART OR IDENTIFYING NO	DESCRIPTION OR IDENTIFICATION	REMARKS	ITEM NO.
PARTS LIST					
			DRAFTSMAN <i>AB</i> 6-13-85	HONEYWELL INC. SOLID STATE ELECTRONICS CENTER MINNEAPOLIS, MINNESOTA	
			CHECKER		
			DEV ENGR <i>J</i> 6-13-85	METALIZATION MASK -TERMINAL BOARD #1	
			PROD ENGR		
			PHOTO ENG	SIZE	CODE IDENT NO
			QUAL ENG	C	34168
			ENG MGMT	DRAWING NO	22004561
			DEV ENGRG MGMT	SCALE	10 / 1
			PROD ENGRG MGMT	SHEET	1 OF 1
			APPLICATION		

ATTACHMENT E
CHARACTERISTIC OVER TEMPERATURE FOR
CIRCUIT COMPENSATION RESISTORS AND DIODES

NASA Resistor Characterization (-253 to 125 C)

S/N : 3498-36-0900 Test Date : 30 Apr 1985 15:13:21 File : Nasa_09 And Nasa_13

$$\frac{R@T}{R@25^{\circ}} \times 100$$



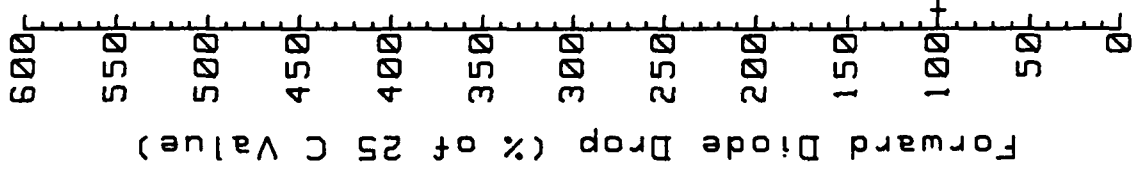
Sample Positioner Temp. (C)

NASA Diode Characterization (-253 to 125 C)

S/N : 1412-02-01 Test Date : 30 Apr 1985 15:13:21 File : Nasa_09 And Nasa_13

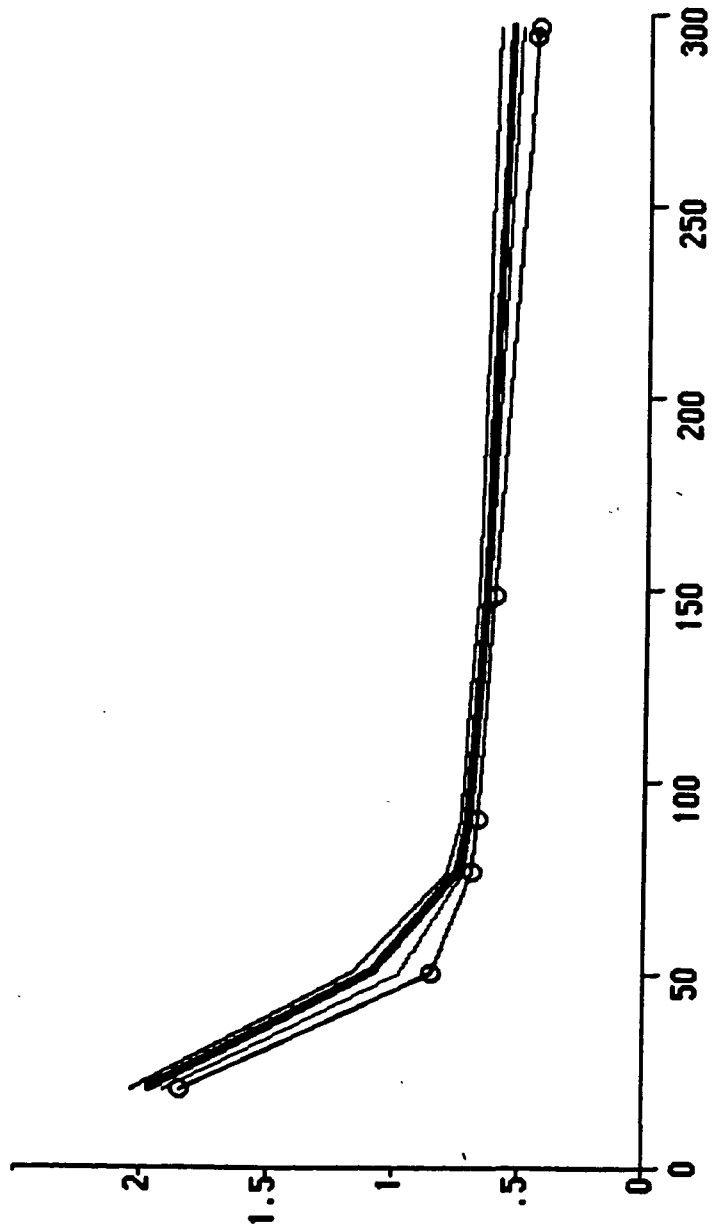
Standard Diode

$$\frac{D_v @ T^{\circ}}{D_v @ 25^{\circ}} \times 100$$



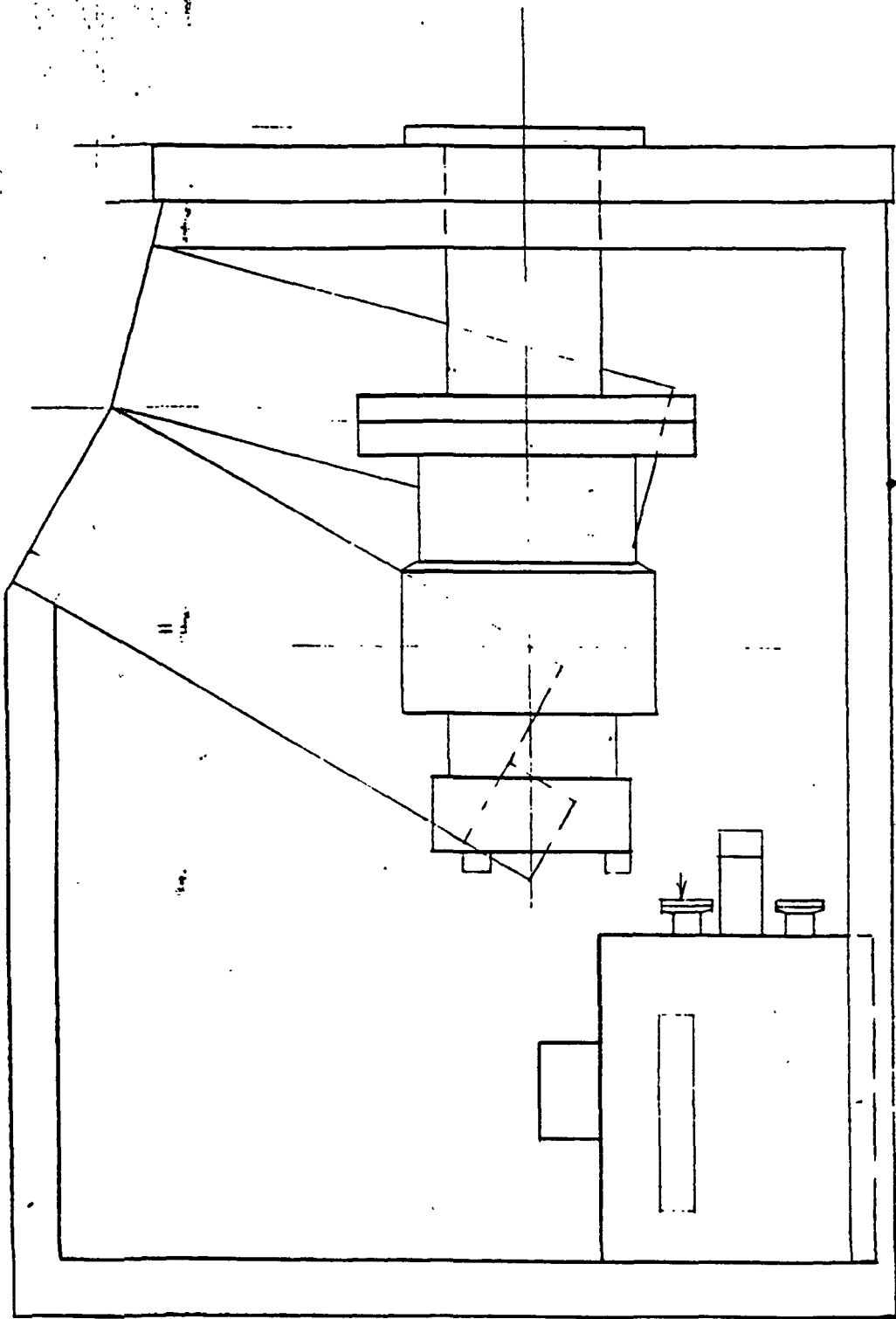
Sample Positioner Temp. (C)

Schottky Diode



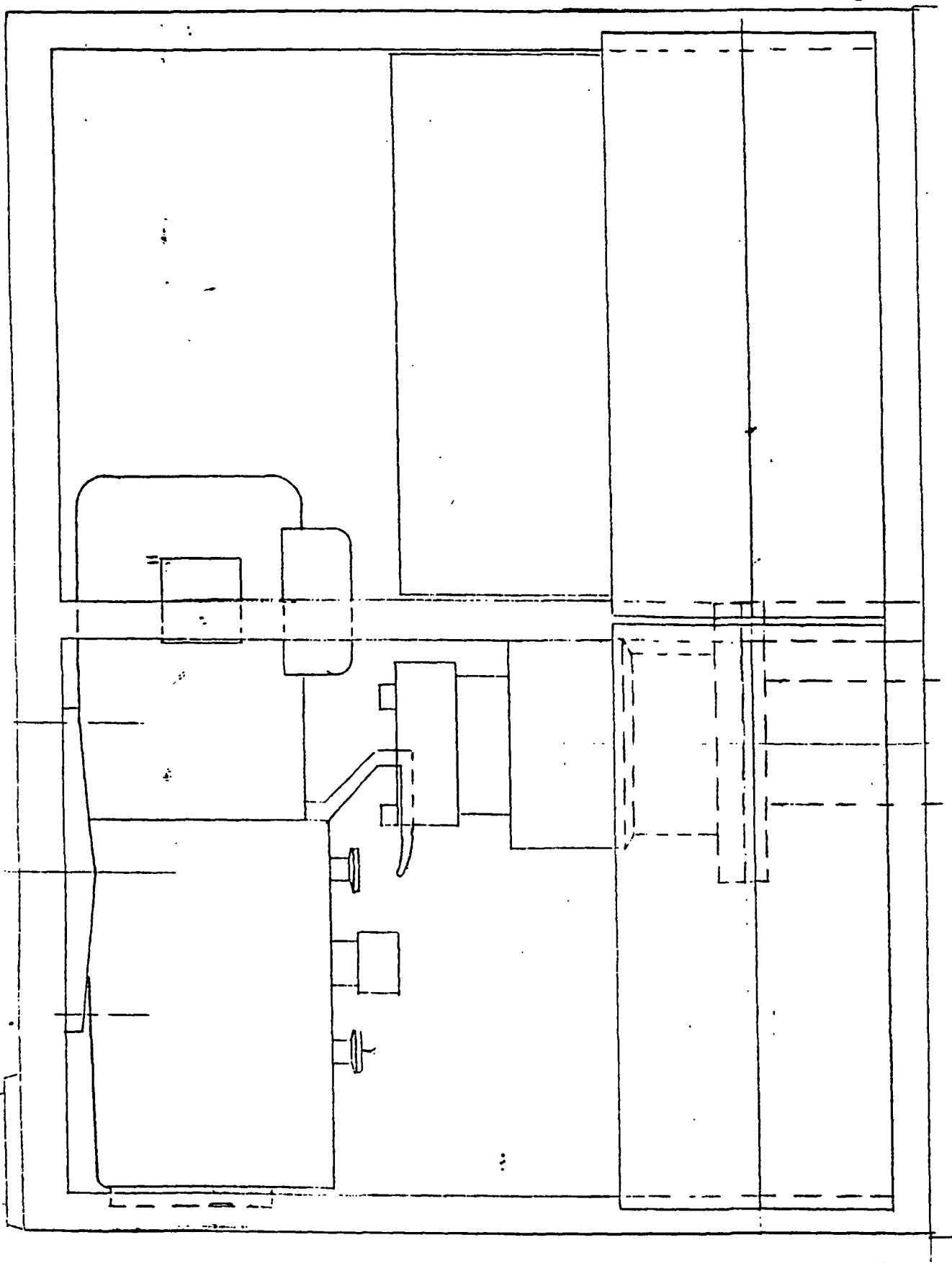
Diode Curves 1, 2, 3, & 4 mA Constant Current

ATTACHMENT F
VACUUM PUMPING STATION SKETCHES



F-1 Reference Pressure Vacuum Pumping Station
(Side View)

Reference Pressure Vacuum Pumping Station
(Front View)



ATTACHMENT G

LETTER TO NASA DOCUMENTING CONCERN
WITH DEUTSCH CONNECTOR NUMBER

Honeywell

June 28, 1985

Mr. Thomas Marshall
NASA
Marshall Space Flight Center
Huntsville, AL 35812

Dear Tom:

Enclosed are the connector prints we discussed in our recent phone conversation. Our concern is that the print on Page 2 of the Amendment 1 to RC7001 references connectors RES1231-E1005N and RES1231-D1005N and the print we received from Deutsch (77014-10-5PN) references RES131-A1005*(1).

We have asked Deutsch to confirm what connector they are currently supplying to Rocketdyne but we have not yet received a reply from them.

We would like you to see if you can determine the current Rocketdyne connector print number and if possible the corresponding Deutsch print number. If Deutsch sends us a print number, we will send it to you for confirmation that it is the one you need for your transducer.

We have two related questions for you that are related to the connector. In our conversations with Deutsch, they said that the connector 77014-10-5PN will not withstand 20,000 PSI and it is not what they would consider a cryogenic connector. The questions we have are:

1. Do you want or need a 20,000 PSI connector?
2. Do you want or need a cryogenic connector?

We are looking forward to hearing from you soon concerning these questions we have about the connector.

Sincerely,

HONEYWELL, INC.



John J. Shea
Sensor Engineer

cc: P.J. Anderson, MN14-4C40
P. Nussbaum, MN14-3B35
P. Towne, MN14-4C45

jsnasaltr

PREPARED BY J. Berroterán <i>JKB</i>	FSCM NO. 02602 Rockwell International Corporation Rocketdyne Division Canoga Park, California SPECIFICATION	NUMBER 7001	AMENDMENT 1	
APPROVALS <i>RA-Preau</i>		TYPE PROCUREMENT		
<i>ST Kincaid</i> <i>MFP</i> <i>QA</i> <i>J.P. Johnson</i> <i>D. J. ...</i>		DATE 28 July 1981		SUPERSEDES SPEC. DATED:
		REV. LTR.	PAGE 1 of 2	
TITLE		TRANSDUCER, PRESSURE - LOW LEVEL ANALOG OUTPUT		

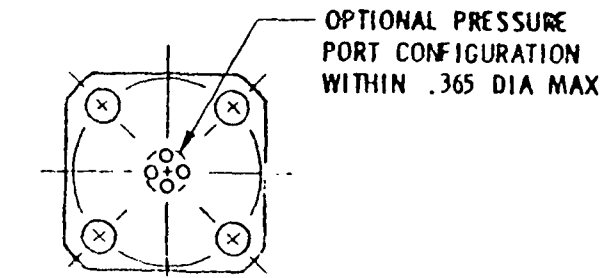
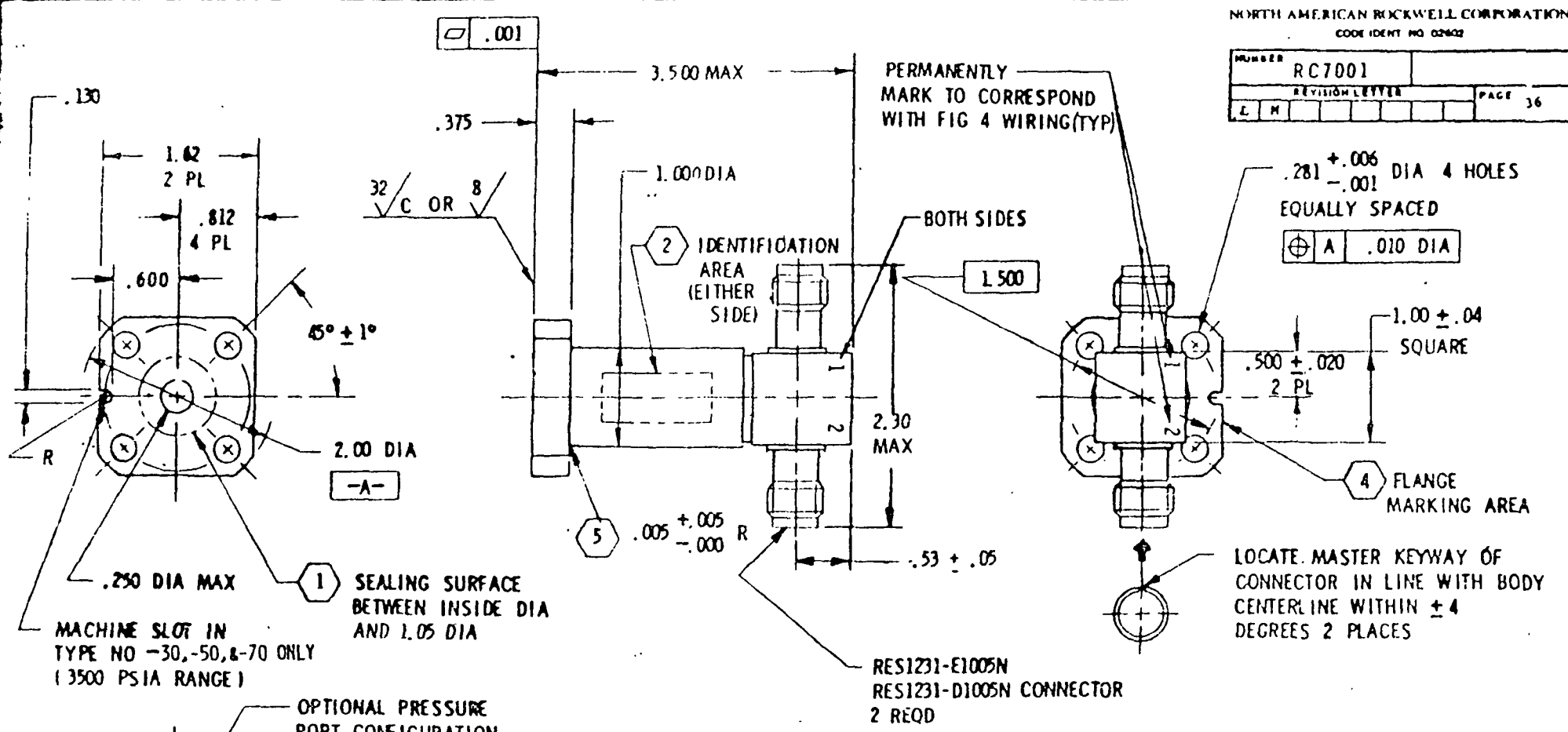
NOTE: THIS AMENDMENT FORMS A PART OF AND SHALL BE ATTACHED TO SPECIFICATION RC7001, REVISION M, DATED 3 APRIL 1981.

Page 36, Figure 1A [DELETE THE EXISTING FIGURE AND REPLACE WITH THE FIGURE 1A ATTACHED HERETO]

RELEASED
DOCUMENT

NORTH AMERICAN ROCKWELL CORPORATION
CODE IDENT NO 02602

NUMBER		RC7001		PAGE 36	
REVISION LETTER					
L	M				



B FIGURE 1A
(THREADED CONNECTOR CONFIGURATION)

- 5. OPTIONAL CONFIGURATION SUBJECT TO ROCKETDYNE APPROVAL.
- 4. MARK EDGE OF FLANGE PER PARA 3.3.3.2 (OPPOSITE SIDE OPTIONAL)
- 3. TOLERANCES: .XX - $\pm .03$, .XXX - $\pm .010$.
- 2. IDENTIFY PER PARA 3.3.3.1 WITHIN CONFINES OF SPACE LIMITATIONS.
- 1. THIS SURFACE TO BE FREE OF NICKS, SCRATCHES AND OTHER IMPERFECTIONS WHICH WOULD IMPAIR ITS SEALING FUNCTION

NUMBER RC7001	REVISION LETTER						PAGE 38
	X	M					

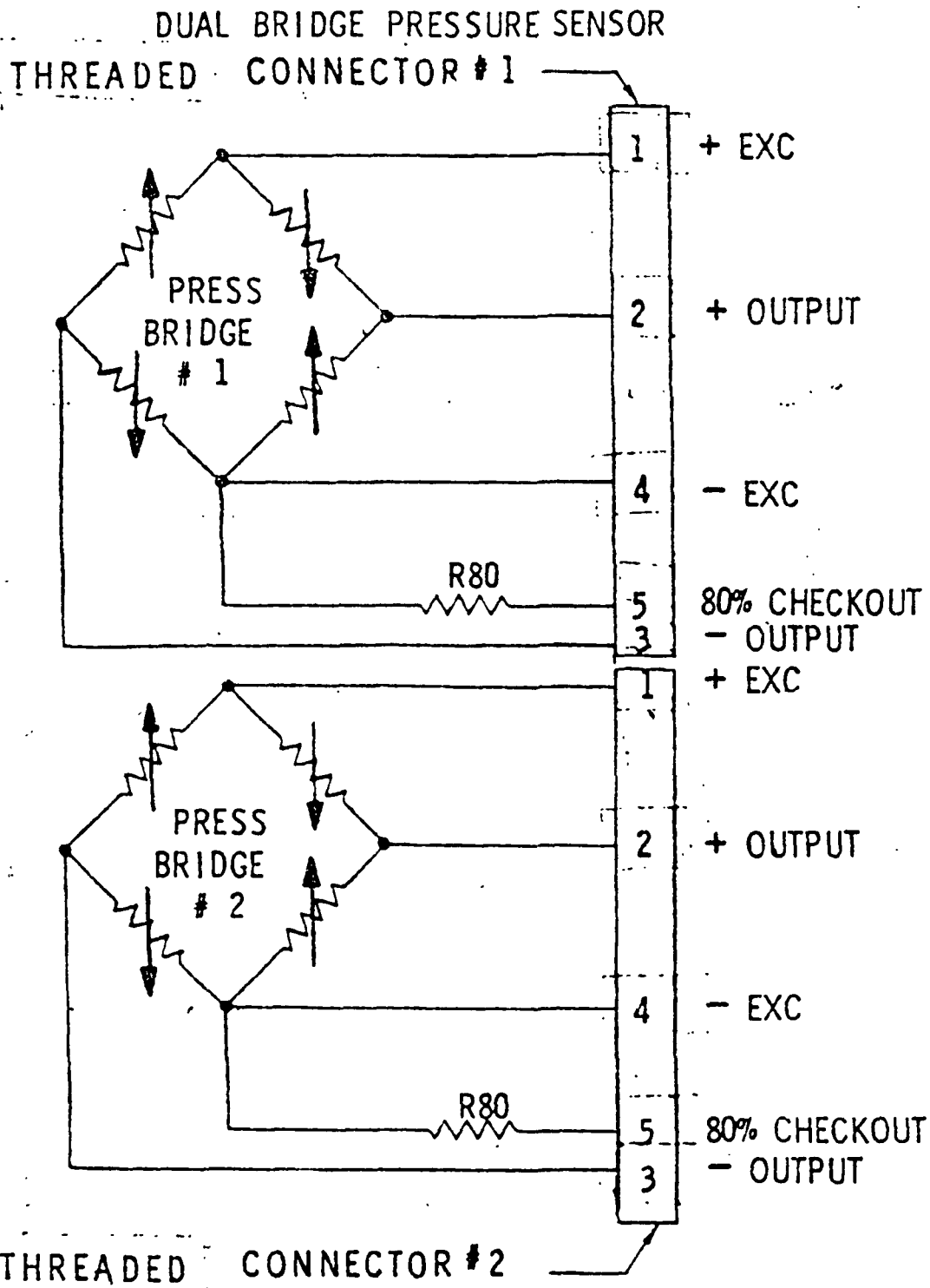
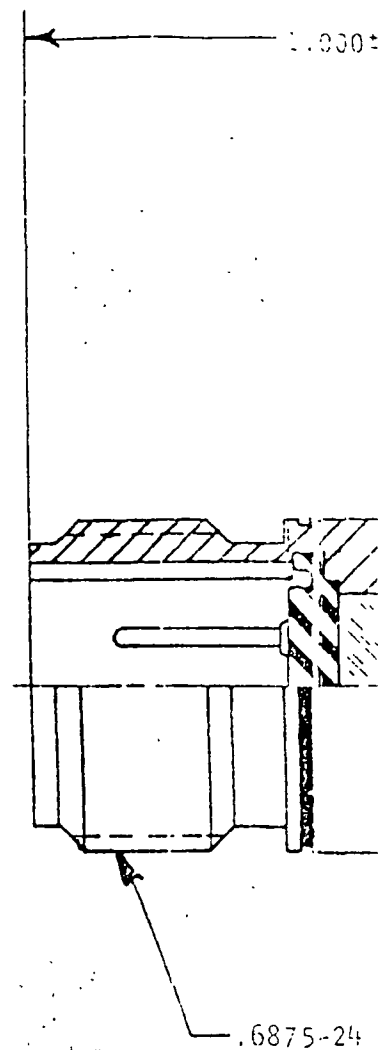
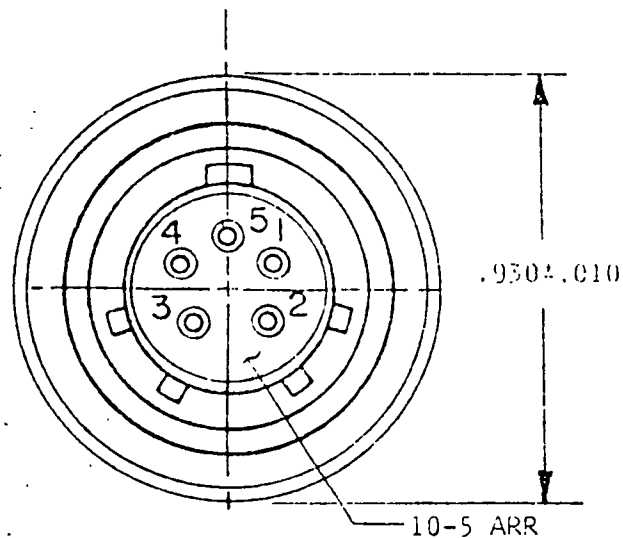


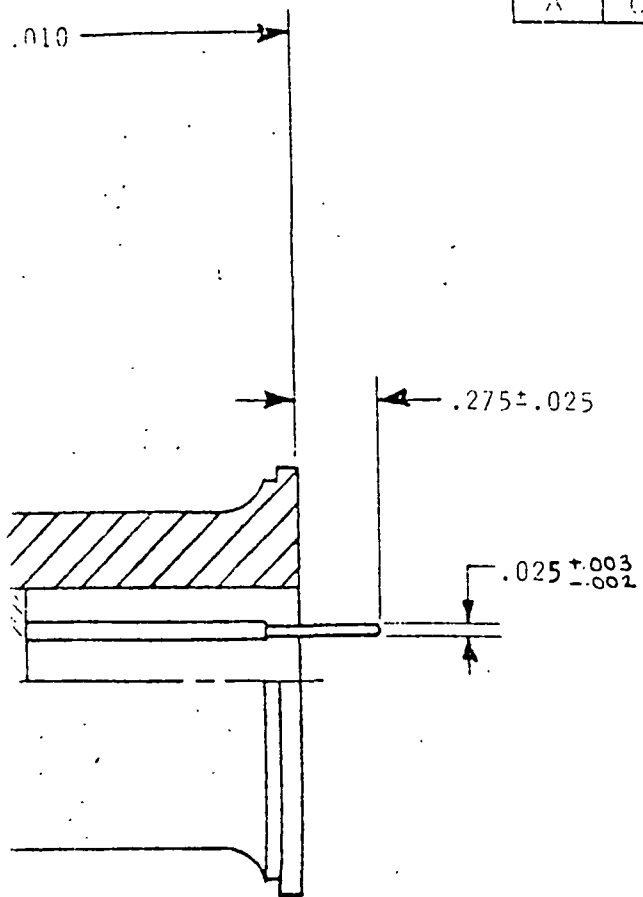
FIGURE 2A




4. FINISH:
SHELL-ELECTRO POLISH
CONTACTS-GOLD PLATED
3. MATERIAL:
SHELL- STAINLESS STEEL
CONTACTS - HIGH NICKEL IRON ALLOY
INSERTS - COMPRESSION GLASS AND RUBBER:
2. CONTACT IDENTIFICATION IS IN CONTRASTING COLOR TO
INSERTS.

NOTE: 1. INSERTS ARE CONTINUOUS DIELECTRIC.

N/C	NEW RELEASE PER E.O. 11759	10-8-76	up
A	CHANGE PER E.O. 11759	11/4/76	up



INEF-2A

SIGNATURE & DATE		RECEPTACLE, CONNECTOR THREADED COUPLING WELD MOUNTING SPECIAL HERMETIC DBA SERIES REFERENCE ROCKETDYNE # RES 1231- A1005*(1)	CP	MATL. CODE 73	
DR	<i>W. Painter</i> 10-6-76		The Deutsch Compan ELECTRONIC COMPONENTS DIVISION  Municipal Airport Banning, California		
CHK	<i>W. Painter</i>		B 77014-10-5PN	DWG SIZE CODE 11139	SHEET 1 OF
PE					
APPO					
SCALE NONE	WT	- ENVELOPE -			

Page Seven -- to be inserted into the May Monthly Report

2.7 Miscellaneous

2.7.1 Vibration Requirements

- Re: 1. NASA Contract No. NAS8 34769, 8/26/82
Exhibit 'A', Section B.1
2. Honeywell's Technical Proposal, 7/12/83,
Sections 2.3 (Pages 2-5 to 2-7), 2.6.1.2 (Pages
2-15 to 2-18), 2.6.1.4 (Page 2-36 and 2-37).
3. Working session at NASA/MSFC, 9/26/84
Attendees:
- P.J. Anderson Honeywell Inc.
P. Golley NASA/MSFC
H. Burke NASA/MSFC
B. White NASA/MSFC
C. Kirby NASA/MSFC
4. September Monthly Report, Section 2.7.1.
5. Working Session at NASA/MSFC, 11/20/84

Attendees: P.J. Anderson, Honeywell Inc.
T. Marshall, NASA/MSFC
C. Kirby, NASA/MSFC
B. White, NASA/MSFC

During a November working session (Reference 5), Honeywell proposed a "half-sine pulse" shock test method to satisfy NASA's TSRS requirement as described in Reference 4. The details of Honeywell's proposal were outlined in Attachment 'F' of our November monthly report. T. Marshall, et al accepted the Honeywell proposal for the shock testing and evaluation of the Experimental Transducer.

2.7.2 Test Plans: Experimental Transducer

- Re: 1. Attachment 'F', August Monthly Report
Working Session at NASA/MSFC 11/20/84

Attendees: P.J. Anderson, Honeywell, Inc.
T. Marshall, NASA/MSFC
B. White, NASA/MSFC