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FINAL
ENGINEERING REPORT 4715-98

ABSOLUTE PRESSURE TRANSDUCERS FOR SPACE SHUTTLE AND ORBITER PROPULSION AND CONTROL SYSTEMS

Prepared for

GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Huntsville, Alabama

Prepared Under Contract NAS 8-27442

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14 June 1974

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ABSTRACT

This document is the final technical report as required for Contract No. NAS 8-27442 between NASA, Marshall Space Flight Center and Conrac Corporation, Instrument/Controls Division, 1600 South Mountain Avenue, Duarte, California 91010. Exhibit A, Scope of Work for the contract dated May 19, 1971, required the development of a direct flange mounted absolute pressure transducer for use on the Space Shuttle Booster and Orbiter Propulsion and Control Systems.

The Scope of Work (SOW) specified guidelines for a research and development program divided into three phases.

Phase I

A study leading to the development of one or more design approaches.

Phase II

Perform research and development necessary to substantiate the design approach selected for presentation to and approval by the technical contracting officer's representative.

Phase III

Production of six (6) prototype transducers using information concluded from Phase I and Phase II.

The SOW contained details concerning: mechanical configuration, weight and pressure range; electrical parameters such as transduction, excitation, bridge resistance and sensitivity; performance criteria included

ABSTRACT (continued)

static error and total error; environmental requirements included temperature range, vibration, acceleration, altitude and humidity; documentation and delivery schedule were also indicated.

Phase I of the program was successfully completed with a preliminary design review of such subjects as: the trade studies for media isolation and one sensor vs. two sensors for two bridges; compensation resistors; unit design; hydrogen embrittlement; sealing techniques and test station design. The first phase was completed within the contract allocated three-month period, and Phase II started in August of 1971.

Phase II was a design substantiation phase consisting of testing of a prototype unit and studies of fabrication techniques. A cryogenic test station was implemented and prototype sensor cells were fabricated, sensors assembled and cryogenic tests performed. The formal design review held at the end of Phase II indicated that the fabrication and test of final units in Phase III would encounter difficulties based on the results of the design verification Phase II. However, the results were sufficiently encouraging to warrant the continuation of the program into Phase III.

ABSTRACT (continued)

Phase III began in March 1972 within the 12 months allocated by contract. As a result of the Phase II design review, 22 additional tasks were undertaken with the fabrication and unit tests deferred until the additional investigations were completed. The final phase encountered many fabrication difficulties resulting in a number of formal schedule revisions. The major difficulties centered around bonding materials of the sensor assembly and avoiding thermal shock to the sensor during various fabrication stages. A number of different approaches are described in this report leading to the final conclusion that all developed techniques were inadequate to produce a sensor capable of meeting the SOW requirements. A review of the final design was held with the contracting officer's technical representative in November 1973, resulting in the decision to terminate the program.

1.0 SCOPE OF WORK

The Scope of Work (Figure 1.0) is Exhibit A of the contract and it specifies guidelines for the performance of the program in terms of period of performance, design goal parameters, environmental requirements and deliverable documentation. The Scope of Work was to be completed in three phases.

Phase I	- Design Study	- 3 month duration
Phase II	- Design Substantiation	- 9 month duration
Phase III	- Prototype Fabrication	- 12 months duration

Phase I was a study of the various techniques used by Conrac in numerous previous solid state pressure transducer designs, as they could be extended to high pressure (8000 psi) and cryogenic temperature ranges. This phase was successfully completed in August 1971. Phase II was devoted to the verification, through tests, of the design resulting from Phase I. Transducer cells were built and tested at cryogenic temperatures and a unit housing design was completed. A formal design review was held in February 1972 which indicated that the program should proceed to Phase III, although results of tests in Phase II and a review of fabrication problems indicated serious difficulties could be expected in Phase III fabrication when a final design was to be produced. Phase III was assigned additional tasks, investigatory in nature, which had to be completed before final fabrication and testing was to be initiated. The additional tasks encountered many difficulties in an attempt to produce fabrication techniques which were reproducible and which could deliver units with a reasonable yield. At the program end, the fabrication techniques were

1.0 SCOPE OF WORK (continued)

not adequate to build more than a few laboratory units, and when tested, the units could not meet specification requirements. The program was terminated after a review with Ray Holder, NASA-MSFC in November 1973 and it was agreed that none of the approaches would be fruitful and the program should be terminated.

Figure 1.1 is a schedule of the program tasks by phase and the reported completion dates. These tasks are identified by the original program plan shown in the first monthly progress report, or in the subsequent revisions included in the following monthly progress reports.

EXHIBIT "A"
SCOPE OF WORK

A. STATEMENT OF WORK

Develop a direct flange mounted absolute pressure transducer for use on the Space Shuttle Booster and Orbiter Propulsion and Control Systems. The Contractor shall use his past experience in the pressure measurement field and present state-of-the-art techniques to achieve these research and development goals and guideline specifications of this document.

Requirements in addition to those listed in the guideline specifications should be in general agreement with Government standards, specifications, bulletins, and recommended practices and deviations from these guideline specifications should be noted and discussed with the COR technical representative if the Contractor thinks these deviations might lead to a superior product.

Phase I - The Contractor shall study the development guidelines, specifications, and goals and develop one or more design approaches for a preliminary design review.

Phase II - Perform necessary research and development to substantiate selected design approach and present this information to the technical Contracting Officer's representative for final approval.

Phase III - The Contractor shall produce six (6) prototype transducers using information concluded from results of Phase I and II. Two of these transducers shall be compensated for high temperature pressure measurement, two for medium temperature measurement, and two transducers for low temperature pressure measurement.

GUIDELINE SPECIFICATION

1.0 MECHANICAL

The pressure transducer shall be designed with dual output signals proportional to applied pressure. The pressure medias shall be liquid or gaseous, hydrogen, helium, or oxygen. Hydraulic fluids or gaseous products from combustion of hydrogen or oxygen shall also be considered.

1.1 Configuration - The exact configuration of the transducer shall be determined at the conclusion of Phase II. A typical configuration is shown in Figure 2. (See Attachment No. 2).

1.2 Weight: Maximum of 8 oz.

1.3 Pressure range: 3 ea, 0 to 50 psia and 3 ea, 0 to 8000 psia.

1.4 Proof pressure: 200 percent of range

EXHIBIT "A"
SCOPE OF WORK

1.5 Burst pressure: 300 percent of range

2.0 ELECTRICAL

2.1 Transduction - Two four arm balanced strain gage bridges.

2.2 Excitation nominal - 10 VDC

2.3 Bridge resistance: Not less than 350 ohms or greater than 1500 ohms.

2.4 Sensitivity: 3 mv/v

2.5 Insulation resistance: 100 megohms at 50 VDC.

2.6 Electrical simulation: Shorting of designated pins on electrical connector with 0 psia and 10 vdc applied to the transducer shall produce an electrical output equivalent to the application of 20 ± 1 and 80 ± 1% of full range of pressure, at 25°C ± 15°C. (This requirement is for interchangeability). The shunt to pressure correlation error shall not exceed ±0.5% of full scale range over the compensated temperature range.

2.7 Temperature Output: An output shall be provided for monitoring critical internal temperature effecting transducer performance (propose).

2.8 Electrical connector: TS02WM12-8P-F2 as per MSFC 50M60457 - Wired according to Figure 1. (See Attachment No. 1).

3.0 PERFORMANCE

3.1 Error - The deviation of the transducer calibration curve from the specified reference line shall be the transducer error. The reference line for determining static and total error shall be the straight line connecting the calibrated end points from the initial calibration of the transducer. Zero balance shall be 0 ± 1% of full scale.

3.2 Static error: Static error shall include non-linearity, repeatability, long term stability, and any other errors that can contribute to static error. Static error shall not exceed ±0.5 percent.

3.3 Total error: The total error shall be determined by combining the individual errors by the root mean square method. The total error shall include the individual errors or errors in any combination from temperature, acceleration, vibration thermal shock, altitude, humidity, life test, and any other natural or induced environment experienced onboard a vehicle such as space shuttle. The total error shall not exceed ±2 percent of full scale range.

EXHIBIT "A"

4.0 ENVIRONMENTAL REQUIREMENTS

4.1 Temperature or sensing elements: Limits- 269°C to +205°C compensated range.
Low temperature range: -54° C to - 269°C
Medium temperature range: -54°C to +74°C
High temperature range: +74°C to +205° C.

4.2 Vibration:

Sinusoidal:
5 to 30 Hz @ 0.3 inch double amplitude.
30 to 400 Hz @ 15 g peak
400 to 900 Hz @ 0.00017 inch double amplitude
900 to 3000 Hz @ 70 g peak.

Random
20 to 280 Hz - 0.2 g^2/Hz
280 to 350 Hz - +24 db/octave
350 to 2000 Hz - 1.75 g^2/Hz

4.3 Acceleration: 10 g.

4.4 Altitude: 10^{-6} Torr for periods up to 30 days.

4.5 Humidity: 5 to 100%

4.6 Fungus, Rain, Sand, Dust, and Salt Spray - Protected

5.0 MATERIALS, PROCESSES AND PARTS

The materials, processes, and parts shall be approved by the Contracting Officer's Representative before fabricating the prototype transducers. Special attention shall be given to hydrogen embrittlement so that parts exposed to hydrogen will not suffer structural or performance degradation over the life of the transducer.

B. DOCUMENTATION

The Contractor shall submit six (6) sets of shop drawings plus one (1) set of reproducibles.

NOTE - See NOTE 1. under paragraph D. below.

C. DELIVERY SCHEDULE

Phase I - 3 Months from the effective date of the contract.

Phase II - 9 months from the effective date of the contract.

Phase III - 12 months from the effective date of the contract.

Figure 1.0 (continued)

EXHIBIT "A"

D. REPORTS REQUIREMENTS

1. Monthly Progress: The Contractor shall prepare and submit in twelve (12) copies, a brief and informal status report in letter form within fifteen (15) days following the month being reported upon. This report shall include:

a. A brief resumé in narrative form of work accomplished during reporting period.

b. An indication of any problems which may impede performance, and proposed corrective action.

c. A discussion of the work to be performed during the next reporting period.

d. In addition to the information above, the Contractor shall include the following in the monthly progress letter:

(1) Expendutures ____________

(2) Estimated funds to completion ____________

(3) Problem areas - As an example: Explanation of expected overrun. ____________

2. Final Report: The Contractor shall submit eight copies, plus two reproducibles of the final report within thirty (30) calendar days after the completion of the work called for under this contract. The report shall document in detail all of the work performed under the contract including data, analysis, and interpretations as well as recommendations and conclusions based upon the results obtained. The table shall include tables, diagrams, curves, photos, and drawings in sufficient detail to comprehensively explain the results obtained.

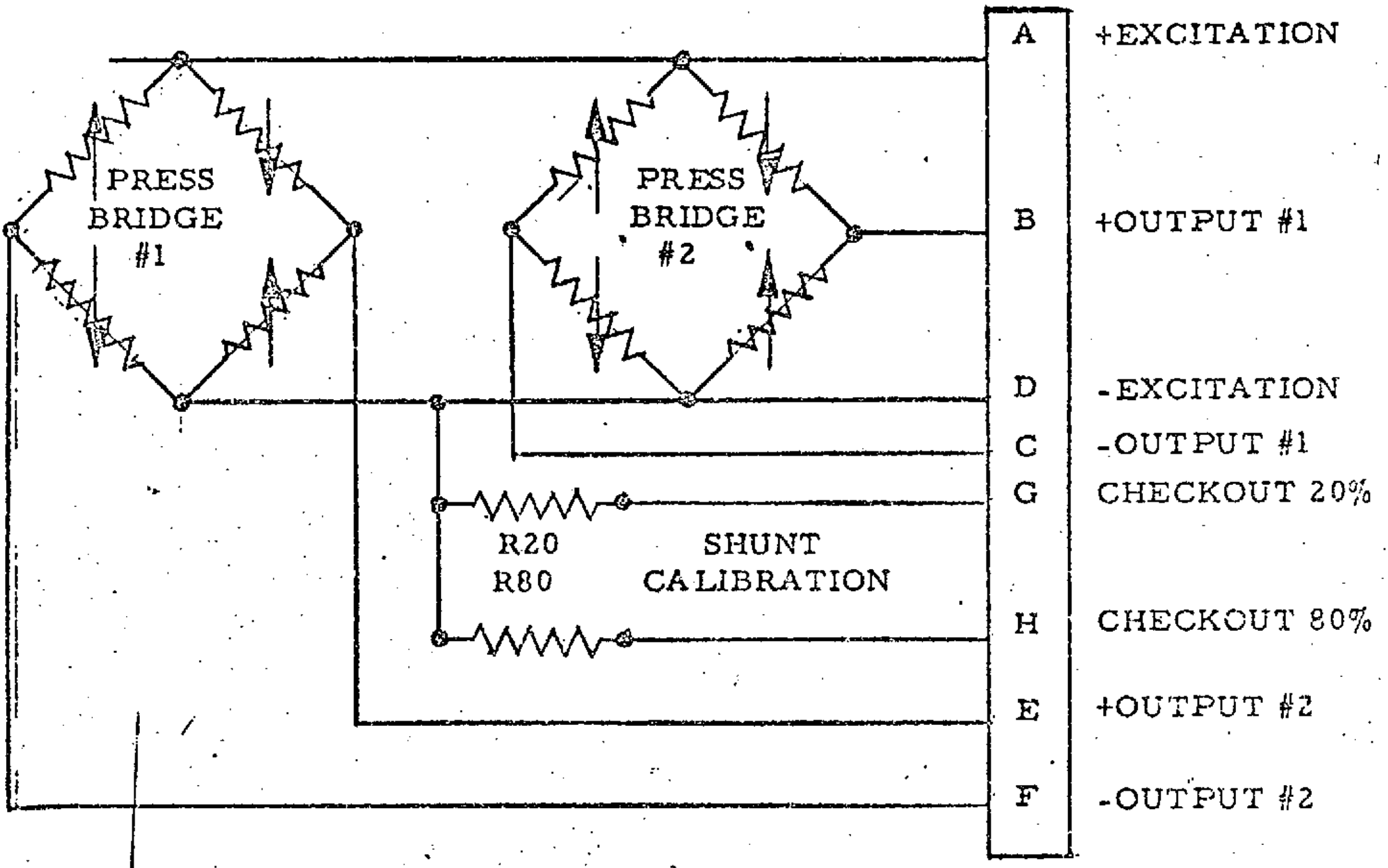
NOTE 1. All technical reports, publications, and visual presentations submitted to MSFC under this contract shall use the International System of Units as the preferred primary system. Expression in both SI units and customary units is acceptable where the use of SI units alone would obviously impair communication or reduce the usefulness of the report to the primary recipients. When both systems of units are used, SI units are to be stated first and customary units afterwards, in parentheses. In each such case, the publication shall state which system of units was used for the principal measurements and calculations. SI units are specified in National Bureau of Standards Technical News Bulletin, Vol. 48, No. 4, Page 61, April 1964; and defined in NASA SP-7012, The International System of Units, Physical Constants, and Conversion Factors, revised 1969. Both of these documents can be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

3. Reports Distribution - Reports distribution will be as follows:

Addressee	Monthly	Final
A&TS-PR-M	1	0
A&TS-MS-IL	1	1
A&TS-MS-IP	0	2
A&TS-TU	0	1
Applicable DCASO	1	1
A&TS-FIN-A	2	0
S&E-ASTR-IM	6	2 plus 2 repro.
S&E-ASTR-ZI	1	1

Figure 1.0 (continued)

ATTACHMENT 1



CONNECTOR WIRING DIAGRAM WITH
COMMON ELECTRICAL SHUNT CHECKOUT RESISTORS

FIGURE 1

Figure 1.0 (continued)

ATTACHMENT 2

Figure 1.0 (continued)

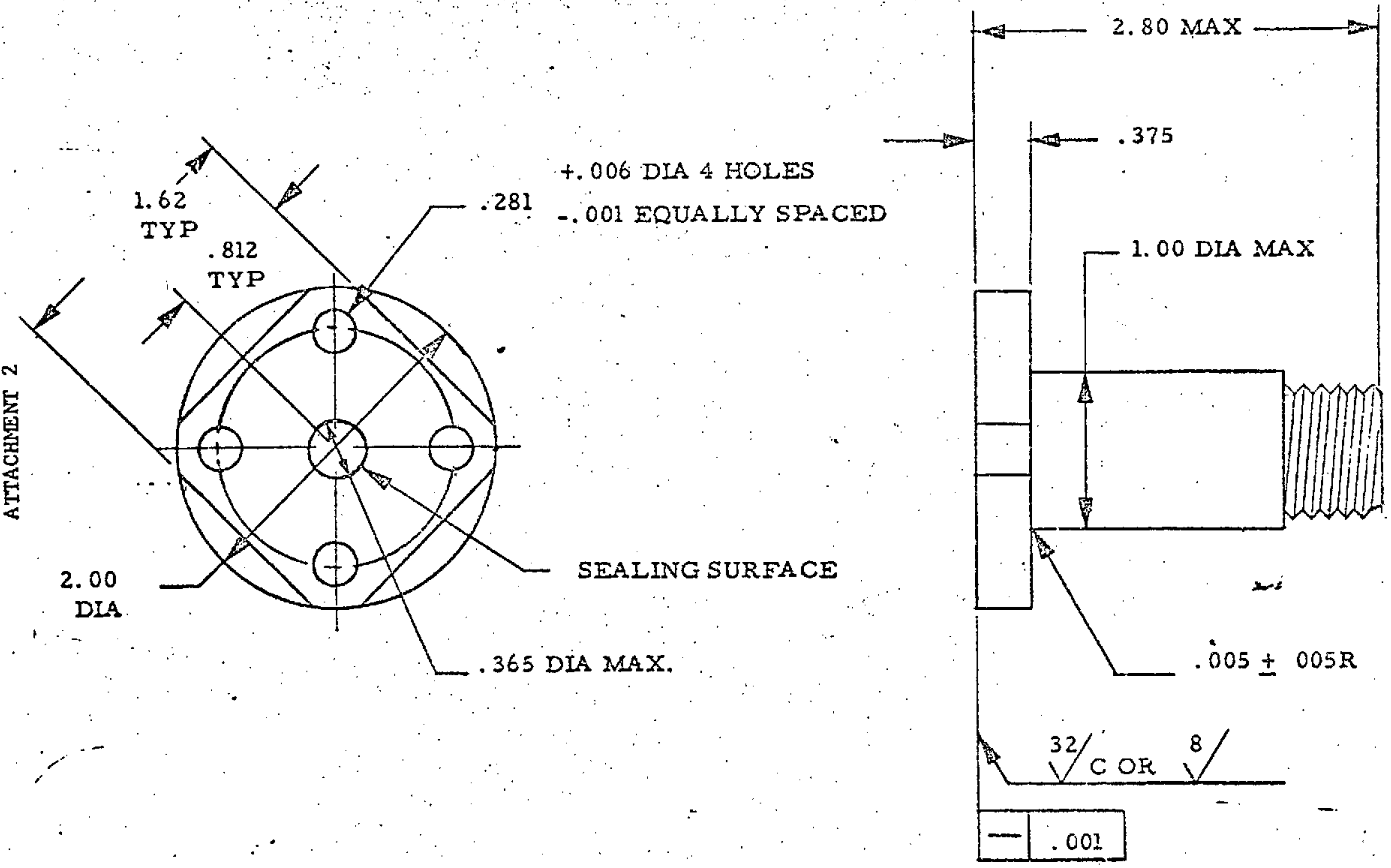


FIGURE 2

Pressure Transducer - Space Shuttle

Schedule

Phase I - Program Plan Tasks	Reported Completion
Design	
1. Trade-offs involved in use of media isolated transducer	7-23-71
2. Trade-offs involved in use of two bridges on one sensor vs. two sensors	7-23-71
3. Selection of compensation resistors	8-16-71
4. Design of 8000 psi	8-16-71
5. Fabricate 8000 psi mask	10-4-71
6. Review of materials for hydrogen embrittlement	8-16-71
7. Preliminary housing design	8-16-71
8. Investigation of si-pyrex-metal sealing	
8a. Sealing parameters	7-10-71
8b. Sensor operation - room temperature	10-11-71
8c. Sensor exposure - LN_2 temperature	10-11-71
9. Cryogenic test station design	10-4-71
10. Preliminary design review	8-16-71

Figure 1.1

Pressure Transducer - Space Shuttle

Schedule

Phase II - Program Plan Tasks	Reported Completion
Design Verification	
1. Build cryogenic test station	
1a. LN_2	10-11-71
1b. He	11-20-71
2. Diaphragm diffusion	11-15-71
3. Cell fabrication	12-27-71
4. Hardware fabrication	2-18-72
5. Assembly and preliminary test	2-18-72
6. Sensor tests	2-18-72
7. Test plan	11-15-71
8. LN_2 tests	3-16-72
9. He tests	deferred
10. Sensor composition studies	12-27-71
11. Housing design	3-16-72
12. Phase II test completed	3-16-72

Figure 1.1 (continued)

Pressure Transducer - Space Shuttle

Schedule

	Phase III - Program Plan Tasks (Revised)	Reported Completion
1.	Evaluation of Corning 7052 Glass	6-1-72
2.	Prepare blanks	6-1-72
3.	Polish	6-1-72
4.	Assemble test units	deferred
5.	Inspect	deferred
6.	Test	deferred
7.	Procure polished 7052 Glass	9-26-72
8.	Test bonds to kovar	9-26-72
9.	Test bonds of quartz to kovar	9-26-72
10.	Test bonds of vycor to kovar	9-26-72
11.	Investigation of graded seals	1-18-73
12.	Geometry change to reduce shear surfaces to one	1-18-73
13.	Fabricate new geometry parts	1-18-73
14.	Test parts for thermal shock damage	1-18-73
15.	Fabricate sensor parts for transducer tests	3-30-73
16.	Assemble transducer	3-30-73
17.	Test transducer	5-10-73
18.	Prepare tooling to avoid thermal shock damage when bonding	8-8-73

Figure 1.1 (continued)

Pressure Transducer - Space Shuttle

Schedule

Phase III - Program Plan Tasks (Revised)		Reported Completion
19.	Test tooling	9-24-73
20.	Redesign glass body to ceramic (AL_20_3)	9-24-73
21.	Fabricate AL_20_3 body	10-15-73
22.	Pressure/temperature test sensor	11-6-73
23.	Reviewed program status with Ray Holder, NASA-MSFC at Conrac	11-14-73

Figure 1.1 (continued)

2.0 PHASE I - DESIGN STUDY

The progress during the initial phase of the program is reported in the immediately following Progress Reports 1, 2, 3 and 4. The technical studies, tests and investigations are reported in the progress reports for the periods in which the work was in process. Comments preceding the reproduced reports are designed to highlight significant events and to provide continuity through each phase.

The trade-off studies indicated in Progress Report 1 were completed with the determination that the media isolated design, while it represented more development risk, did in fact provide an overwhelming advantage when the application was considered. Coupled with this design approach, it was decided that two bridges on one sensor was the most efficient and cost effective approach, and therefore it became the baseline design.

The selection of compensation resistors became an extended program because it became evident there was little information publically available. The investigation continued until August 1971 with the result that resistor types were selected which could meet the cryogenic application. Additionally, a study indicated that hydrogen embrittlement would have no adverse effects on the transducer materials selected.

An investigation into silicon-pyrex-metal sealing indicated that high temperatures were necessary for the process which would lead to fabrication problems throughout the program, in that high temperature shock during sealing and/or wire bonding would cause destruction of the cell. Phase I was completed

2.0 PHASE I - DESIGN STUDY (continued)

with design review at Conrac on August 16, 1971, attended by H. S. Harman, NASA-MSFC. The review included sensor design, housing design, silicon-pyrex-metal sealing, compensation resistors, and the cryogenic test station.

ER 4715-98

Progress Report 1

May 1971

24 June 1971

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER
CONTRACT NO. NAS8-27442

PROGRESS REPORT

May 1971

1. Work Accomplished During Reporting Period

Program was initiated during the last week of May 1971.

1.1 Detailed program plan was prepared and is shown as Figure 1.

1.2 Design trade-off studies were begun relative to the use of standard Semiconductor Strain Gage vs media isolated design and relative to the use of two bridges on one sensor vs two sensors.

1.3 A survey of available zero temperature coefficient resistors for use at cryogenic temperature was begun.

2. Problem Areas

No problem areas were encountered during the month of May 1971.

3. Work Planned for Month of June 1971

3.1 Complete study of trade-offs involved in use of media isolated design (item 1.1 of Program Plan).

3.2 Complete study of trade-offs involved in use of two bridges on one sensor vs two sensors (item 1.2 of Program Plan).

3.2 Select compensation resistors (item 1.3 of Program Plan).

3.3 Begin design of 8000 psi diaphragm and sensor (item 1.4 of Program Plan).

3.4 Begin review of materials for hydrogen embrittlement (item 1.5 of Program Plan).

3.5 Begin investigation of sealing parameters for accomplishing the silicon-pyrex-metal seal that is required for the media isolated sensor design. This seal should be done at as low a temperature as possible to avoid residual stresses during cooling to the operating temperatures (item 1.7.1 of Program Plan).

24 June 1971

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER PROGRESS REPORT, MAY 1971

(continued)

4. Schedule

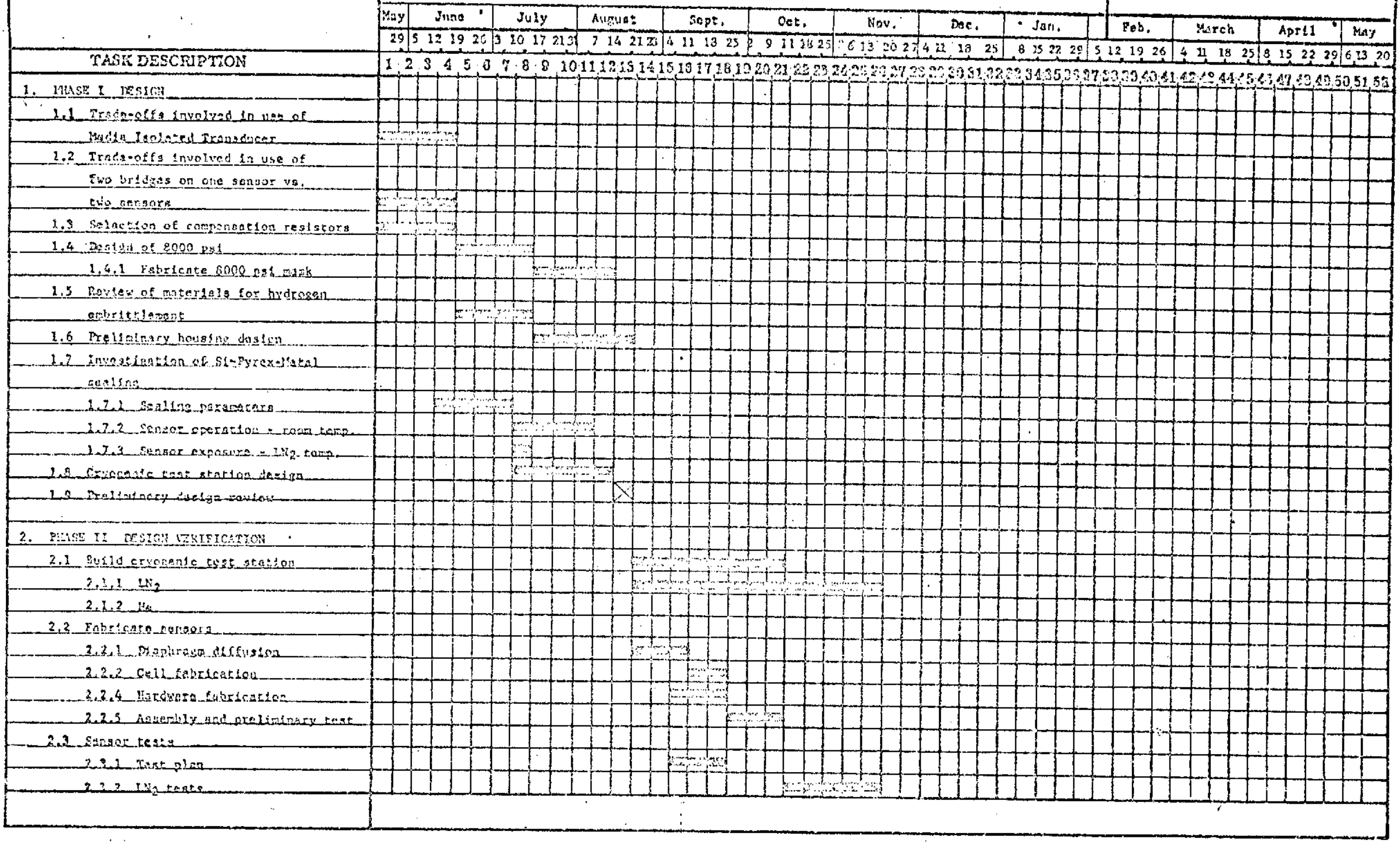
The schedule shown in the Program Plan (Figure 1) is essentially the same as the originally proposed schedule. No schedule adjustments were found to be necessary in May.

FIGURE 1

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER

PROGRAM PLAN

CONTRACT NAS8-27442



TASK DESCRIPTION

1. PHASE I DESIGN
  - 1.1 Trade-offs involved in use of Media Isolated Transducer
  - 1.2 Trade-offs involved in use of Two bridges on one sensor vs. two sensors
  - 1.3 Selection of compensation resistors
  - 1.4 Design of 8000 psi
    - 1.4.1 Fabricate 8000 psi mask
  - 1.5 Review of materials for hydrogen embrittlement
  - 1.6 Preliminary housing design
  - 1.7 Investigation of Si-Pyrex-Metal sealing
    - 1.7.1 Sealing parameters
    - 1.7.2 Sensor operation - room temp.
    - 1.7.3 Sensor exposure - LN_2 temp.
  - 1.8 Cryogenic test station design
  - 1.9 Preliminary design review

2. PHASE II DESIGN VERIFICATION
  - 2.1 Build cryogenic test station
    - 2.1.1 LN_2
    - 2.1.2 He
  - 2.2 Fabricate sensors
    - 2.2.1 Diaphragm diffusion
    - 2.2.2 Cell fabrication
    - 2.2.4 Hardware fabrication
    - 2.2.5 Assembly and preliminary test
  - 2.3 Sensor tests
    - 2.3.1 Test plan
    - 2.3.2 LN_2 tests

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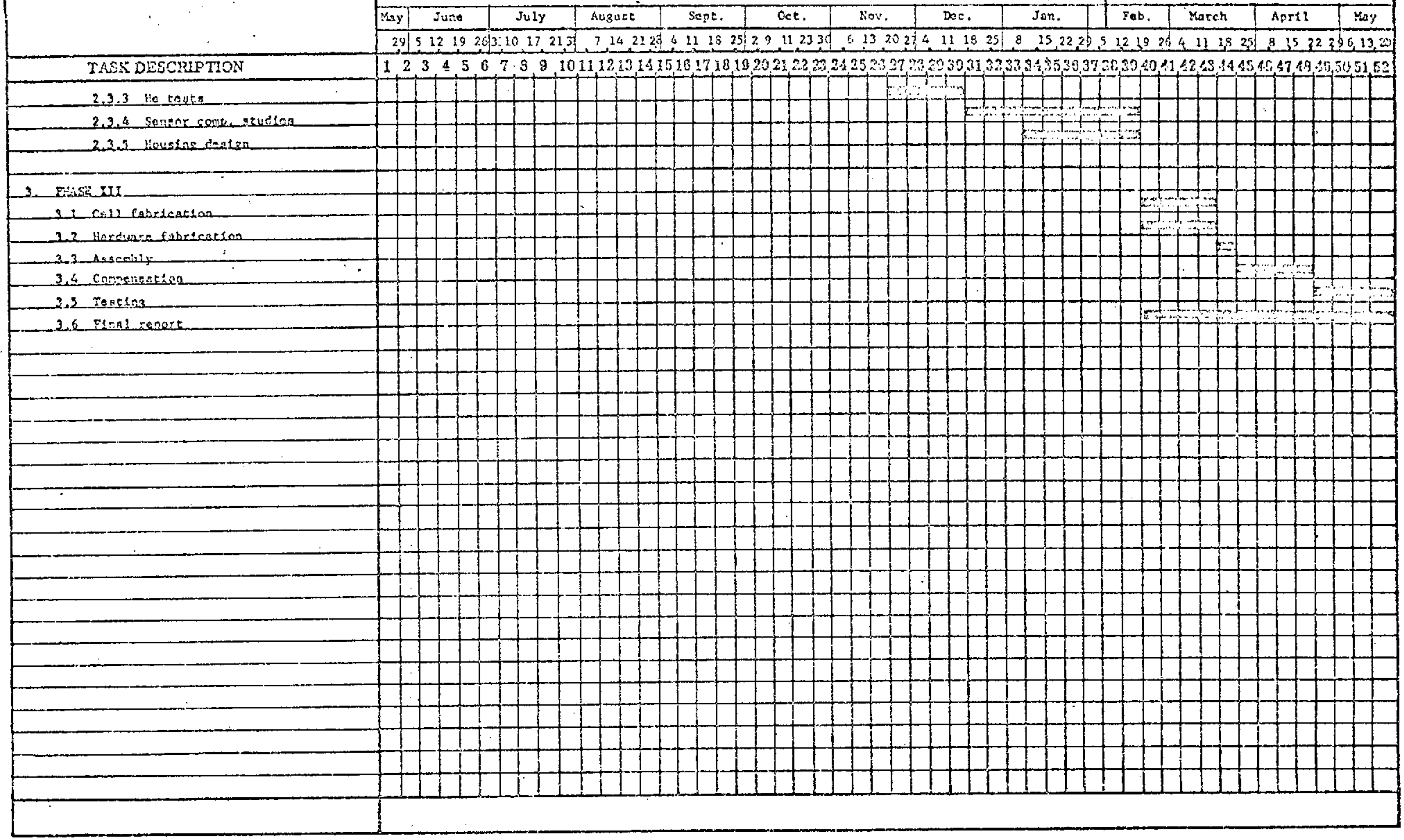
PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER

FIGURE 1 (continued)

CONTRACT NAS8-27442

PROGRAM PLAN



ER 4715-98

Progress Report 2

June 1971

23 July 1971

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER
CONTRACT NO. NAS8-27442

PROGRESS REPORT

June 1971

1.0 WORK ACCOMPLISHED DURING REPORTING PERIOD

1.1 Design Trade-off Studies

1.1.1 Standard vs. Media Isolated Design

The standard Model 4715 transducer design is shown in Figure 1. It consists of a single crystal silicon sensor cell essentially immersed in a hydrostatic pressure field. This design presents some advantages that cannot be secured in any other way - namely the absence of any extraneous insulating material. The use of a sensor fabricated from a single material obviously eliminates any possible differential thermal expansion problems. Along with the advantage, however, there are obvious limitations. The electrical leads are exposed to the pressure media and if these media are electrically conductive, degradation of performance will result.

While Model 4715 transducer has been used successfully in air data (altitude-airspeed) type applications, the question arises as to what will happen when it is exposed, for example, to the combustion products of an engine. There is now data available which bears on this problem. Model 4715 transducer was selected for use of the DC-10 flight test program to measure core and fan exhaust pressures on the engines. Two transducers were mounted in the engine nacelle, one each connected to the core and to the fan exhaust. The transducers were operated at a fixed temperature in the range of 230°F (transducers were rated to 200°F max.) by means of a temperature regulated oven designed and developed for this purpose by MDAC engineers. Electronics (power supply, amplifiers, A-D converters, etc.) were located in the cabin at the end of approximately 50 to 100 feet of cable. The accuracy objective was 0.05% of full scale for the entire system. After several thousand hours of operation, the system accuracy was found by comparing the pressure reading at atmospheric pressure to the barometer reading to be in most instances approximately 0.05% and in the worst case to be no worse than 0.2%. It has not been possible to isolate the cause of the errors. The results do indicate, however, that Model 4715 transducer is capable of making accurate measurements in an engine environment when exposed to engine exhaust gases.

23 July 1971

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER PROGRESS REPORT, JUNE 1971

(continued)

1.1.1 Standard vs. Media Isolated Design (continued)

The media isolated design on the other hand is unproven, but, if successful, will provide a more versatile unit. Therefore the major effort will be toward the media isolated unit with the standard unit as a backup design.

There are a number of possible configurations of the media isolated transducer which have been considered for use in the cryogenic pressure transducer programs. Two of these configurations that appeared most promising are shown in Figure 2. The basic difference between the two configurations is that in configuration A the silicon-pyrex-metal bond is made over a small radius near the center of the sensor and is well isolated from the strain sensing strain gages. The bond is in tension. In configuration B, the bond is in compression. However, it is made at a large radius and is more directly coupled to the strain gages. Configuration A would be clearly preferable if the tensile stress at the joint can be kept within reasonable limits. Considering the pyrex mount to be a cylinder with an inside diameter of .080 inch and an outside diameter of .650 inch, the tensile stress in the joint will be

$$T_s = (.080/.650)^2 \times P .$$

where P is the applied pressure. The maximum stress at proof pressure (200% of full scale) is 242 psi for the 8000 psi range unit. The minimum tensile strength of bonds made by the electrostatic bonding process is reported to be 1000 psi (Journal of Applied Physics, Vol. 40, pp 3946 - 3949, September 1969). A 4 to 1 safety margin exists then for the 8000 psi unit at 200% overpressure.

1.1.2 Redundant Bridges

The standard Model 4715 transducer has 12 strain gages diffused into each diaphragm. From these 12 strain gages it is possible to select 225 different Wheatstone bridge combinations. It is possible to use the extra strain gages to provide an additional, redundant, strain gage bridge. As an alternative, the redundant sensor could be supplied on a completely separate sensor cell as shown in Figure 1. The trade-offs are different for the media

23 July 1971

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER PROGRESS REPORT, JUNE 1971

(continued)

1.1.2 Redundant Bridges (continued)

isolated as opposed to the standard sensor design and are summarized below:

	Standard		Media Isolated	
	2 Sensors	2 Bridges on 1 Sensor	2 Sensors	2 Bridges on 1 Sensor
Redundant diaphragms	Yes	No	Yes	No
Size relative to same design with one bridge.	20% greater	Same	80% greater	Same
Performance	Same	Redundant bridge would have degraded performance.	Same	Redundant bridge would have degraded performance.
Cost in production relative to same design with one bridge.*	60% greater	40% greater	100% greater	40% greater

*Assuming both bridges to meet the same performance.

23 July 1971

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER PROGRESS REPORT, JUNE 1971

(continued)

1.2 Compensation Resistors

A survey of commercially available resistors is under way. Sources of information being considered are vendor information and government evaluation reports. In addition to this search, a number of standard mil spec resistors will be evaluated experimentally. It appears at this time that the evaluation of compensation resistors will be an on-going effort for the duration of the program. Any information that NASA can provide on the evaluation of resistors at cryogenic temperatures will be appreciated.

1.3 Design of High Pressure Sensor

Design is under way on the 8000 psia pressure sensor. Based on trade-off studies described above, the design is based on the configuration shown schematically in Figure 2A.

1.4 Sealing Parameters

Preliminary investigation of sealing parameters indicates acceptable bonding at the following parameters:

Temperature	750°F
Atmosphere	Ambient air
Voltage	1500 V
Time	15 min.

Bonds at 650°F are marginal indicating the necessity of higher temperatures. Work will continue in this area to establish the lowest temperature that will result in reliable bonds. This is important in that lower bonding temperatures will result in lower residual stresses in the finished sensor. It appears that improved surface flatness and finish would possibly permit lower bonding temperature. The effects of the ambient gas media may also be important in forming the pyrex-metal bond.

2.0 PROBLEM AREAS

In the area of compensation resitor evaluation, very little published information has been found. Effort in this area is being increased.

23 July 1971

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER PROGRESS REPORT, JUNE 1971

(continued)

3.0 WORK PLANNED FOR MONTH OF JULY 1971

3.1 Compensation Resistors

(1) Continue search for published information.

(2) Begin experimental evaluation of available resistors.

3.2 Complete design of 8000 psi sensor.

3.3 Continue investigation of sealing parameters for accomplishing silicon-pyrex-metal seal. Preliminary work indicates necessity for temperatures of 700°F or above.

3.4 Begin fabrication of Photolithographic mask for 8000 psi sensor.

3.5 Begin preliminary housing design.

3.6 Begin cryogenic test station design.

4.0 SCHEDULE

The updated program plan is shown as Figure 3. The compensation resistor evaluation is shown as an on-going effort throughout the program. No other changes in schedule have been necessary.

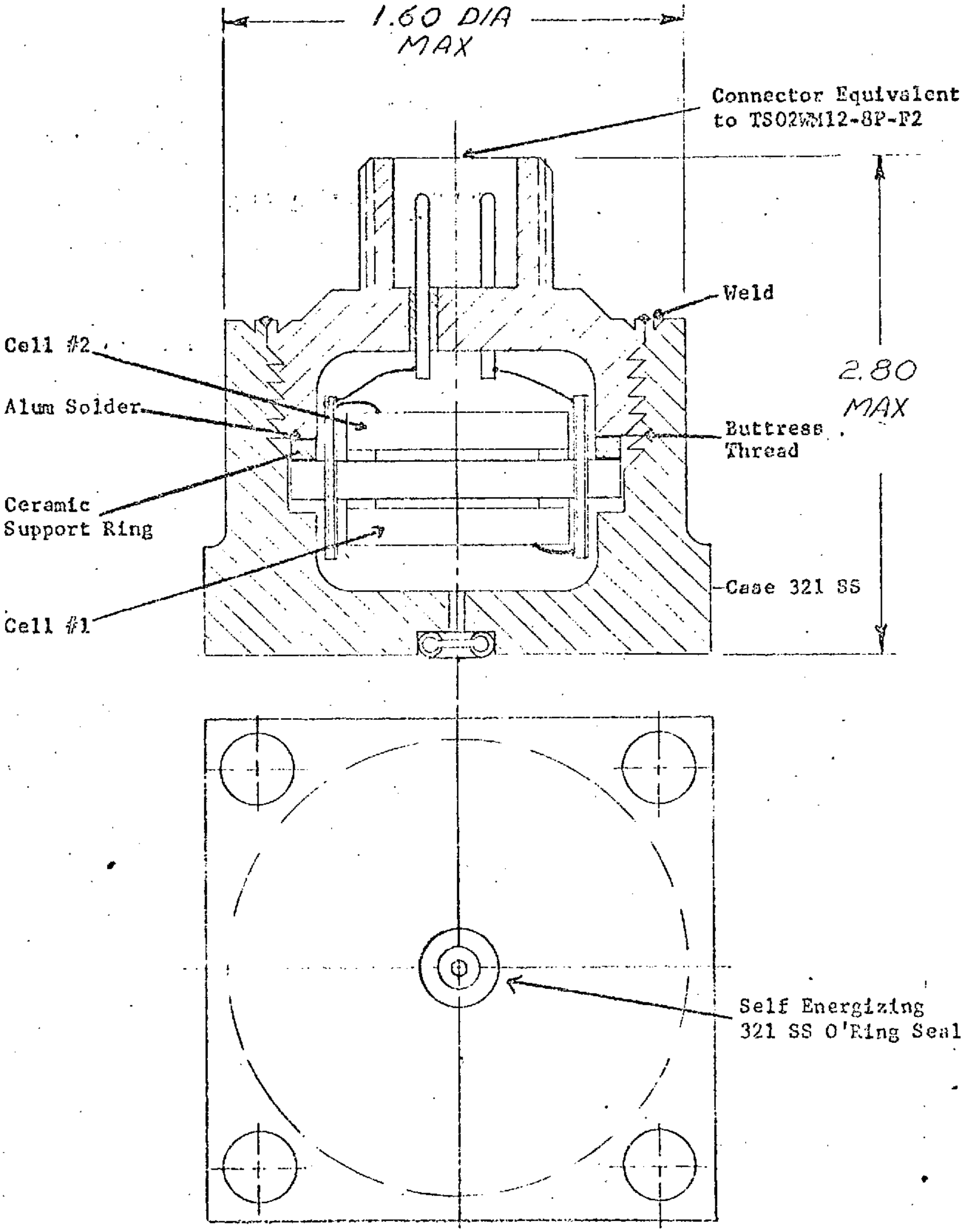
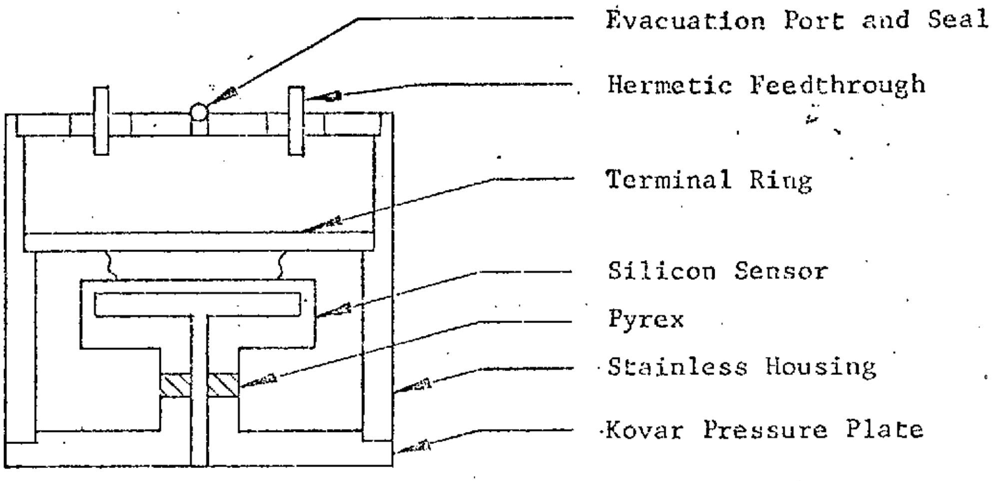
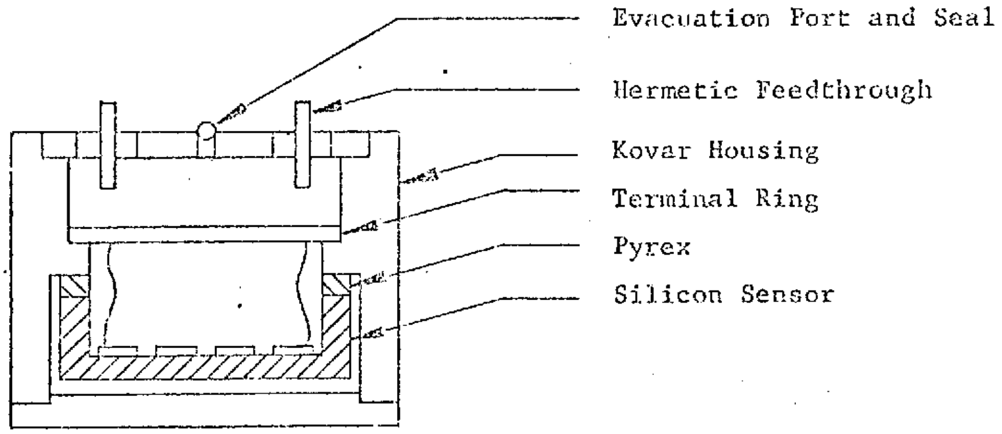


FIGURE 1 - STANDARD SENSOR CELLS



A.



B.

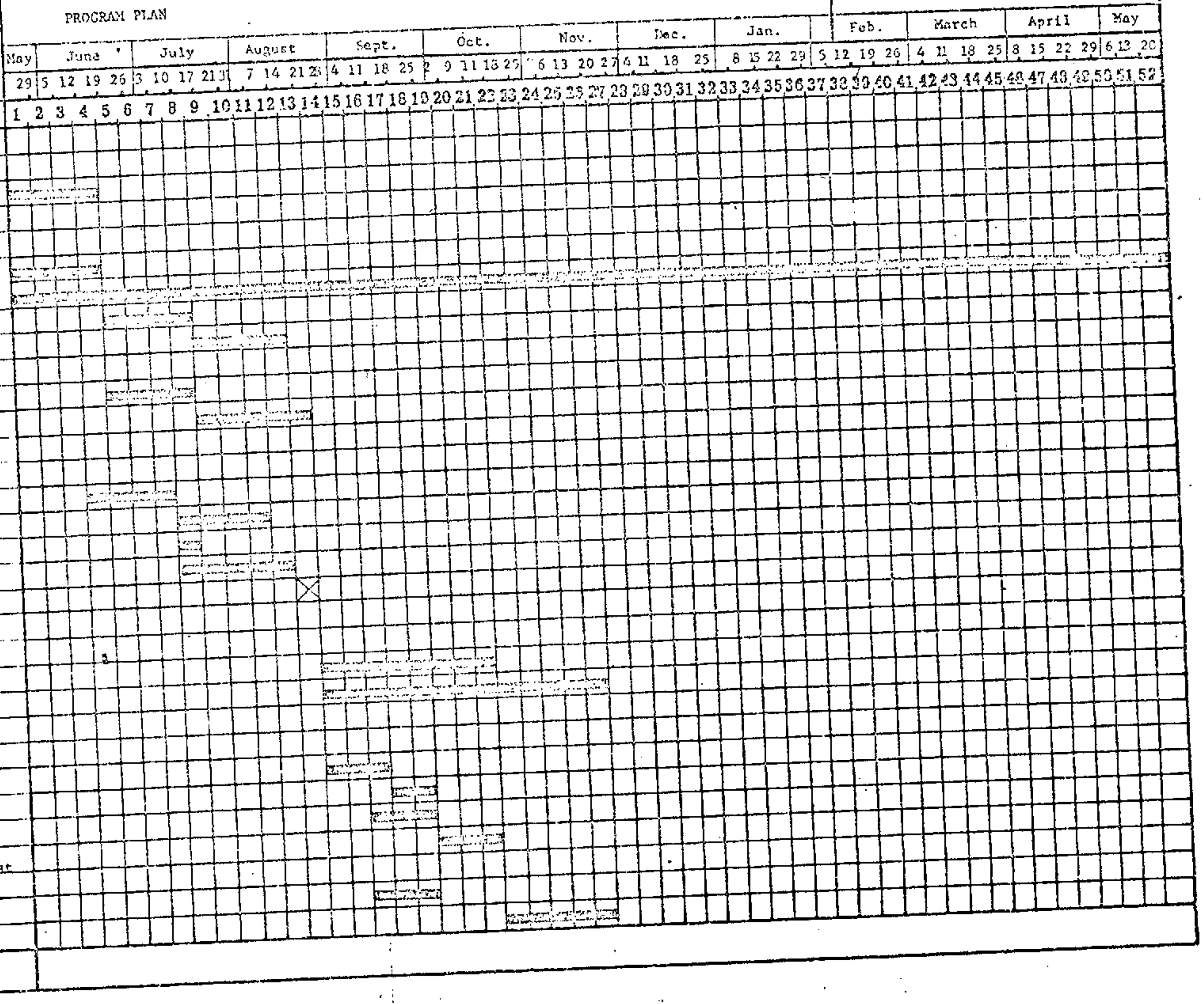
FIGURE 2 ALTERNATE MEDIA ISOLATED CONFIGURATIONS

FIGURE 1

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER

CONTRACT NAS8-27442

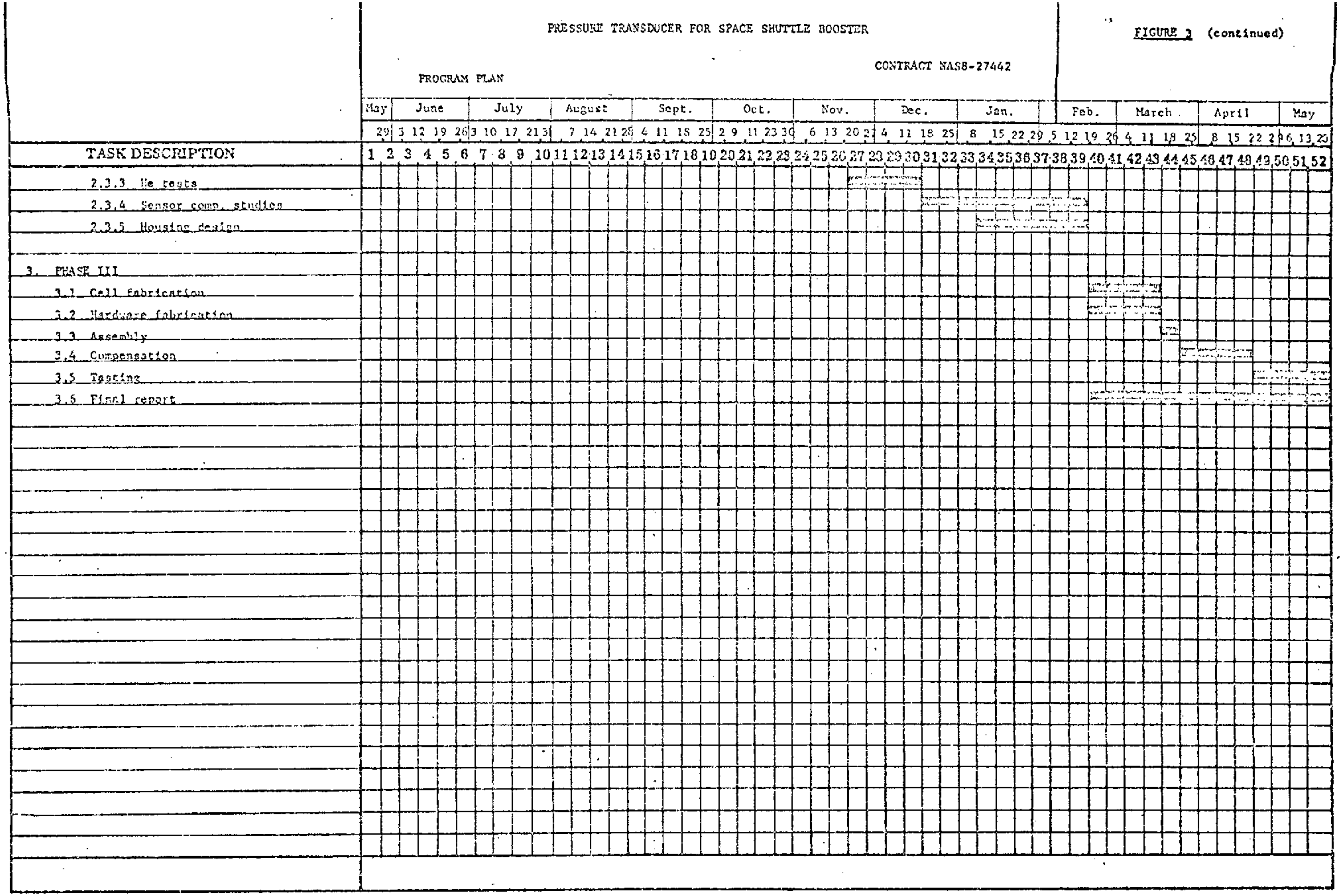
PROGRAM PLAN



TASK DESCRIPTION

1. PHASE I DESIGN
   - 1.1 Trade-offs involved in use of Media Isolated Transducer
   - 1.2 Trade-offs involved in use of two bridges on one sensor vs. two sensors
   - 1.3 Selection of compensation resistors
   - 1.4 Design of 8000 psi
     - 1.4.1 Fabricate 8000 psi mask
   - 1.5 Review of materials for hydrogen embrittlement
   - 1.6 Preliminary housing design
   - 1.7 Investigation of Si-Pyrex-Metal sealing
     - 1.7.1 Sealing parameters
     - 1.7.2 Sensor operation - room temp.
     - 1.7.3 Sensor exposure - LN_2 temp.
   - 1.8 Cryogenic test station design
   - 1.9 Preliminary design review

2. PHASE II DESIGN VERIFICATION
   - 2.1 Build cryogenic test station
     - 2.1.1 LN_2
     - 2.1.2 H_2
   - 2.2 Fabricate sensors
     - 2.2.1 Diaphragm diffusion
     - 2.2.2 Cell fabrication
     - 2.2.4 Hardware fabrication
     - 2.2.5 Assembly and preliminary test
   - 2.3 Sensor tests
     - 2.3.1 Test plan
     - 2.3.2 LN_2 tests



ER 4715-98

Progress Report 3

July 1971

16 August 1971

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER

CONTRACT NO. NAS8-27442

PROGRESS REPORT

JULY 1971

1.0 WORK ACCOMPLISHED DURING THE REPORTING PERIOD

1.1 Selection of Resistors

A report on cryogenic behavior of a number of metal film (RN60D, RN70B, RN70D, RN50C, RN65C, RN60C) resistors was received and reviewed (RADC-TR-65-294; Levi, Mark; "Low Temperature Resistance of Selected Resistors"; August 1965). The results indicate that RN60 or RN50 resistors will be suitable for our application. A number of resistors of these types will be tested.

1.2 Design of 8000 psi Sensor Cell

The diaphragm thickness and unsupported diameter are taken from a standard chart (Figure 1) for Conrac Silicon Sensor design. The diameter is .375 inch with a thickness of .150 inch. The ground rules for the other dimensions have been determined from photoelastic studies on model sensors. Some of the key dimensional relationships are:

$$B-A \leq A$$

$$C-B \leq 2A$$

$$(D-E)/2 \leq 2A$$

where the dimensions are as labeled on Figure 2. As long as these criteria are followed, the theoretical pressure-strain

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER
PROGRESS REPORT, JULY 1971 (continued)

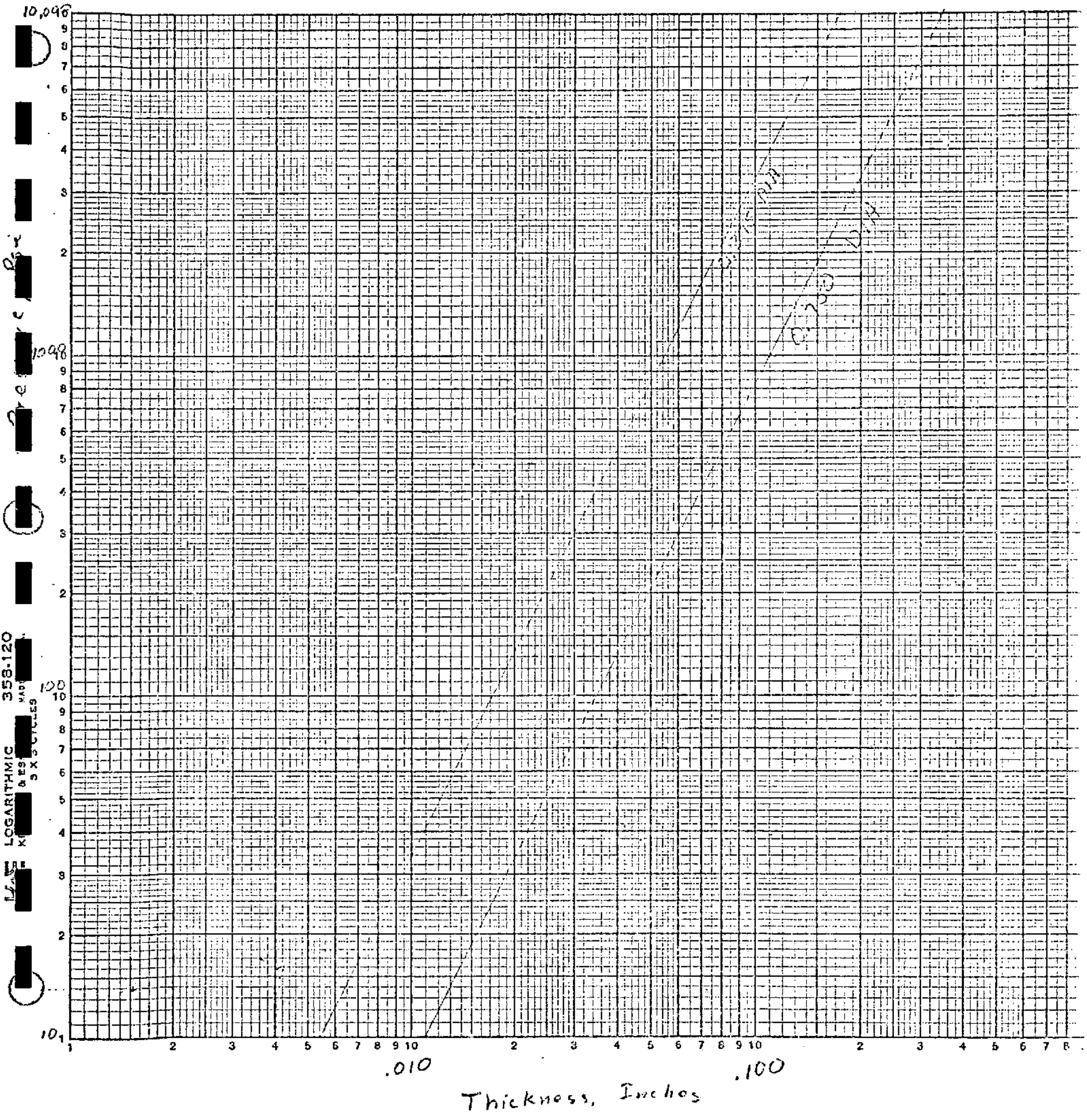


FIGURE 1

Pressure required to give 100 mv output for
10V input vs diaphragm thickness and diameter.

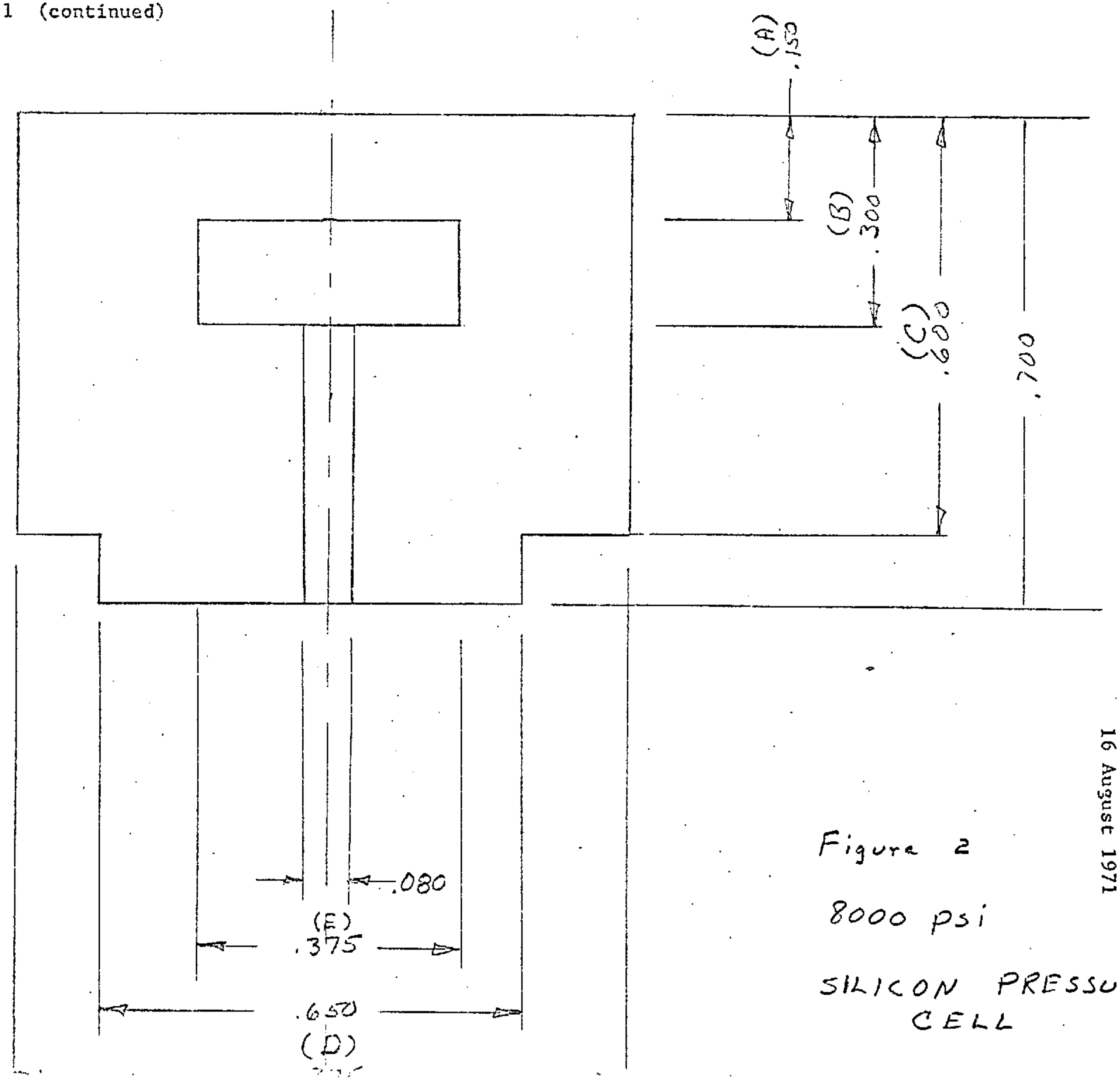


Figure 2

8000 psi

SILICON PRESSURE CELL

1.2 Design of 8000 psi Sensor Cell (continued)

relationships for a clamped diaphragm will hold. The final dimensions are as shown on Figure 2.

1.3 Review of Materials for Hydrogen Embrittlement

A review of the literature shows that hydrogen embrittlement occurs in high carbon type steels. The materials selected for the transducer include 304 stainless steel, kovar, silicon, pyrex glass and a ceramic insulating material (specific ceramic type not yet selected). None of these materials are subject to hydrogen embrittlement. Hydrogen embrittlement will continue to be a key factor in material selection.

1.4 Preliminary Housing Design

Two alternative designs for the 8000 psi unit have been prepared. The first design (Figure 3) uses threaded and welded construction to satisfy the 24,000 psi case burst requirement. The second design utilizes self-energizing rings to confine the pressure to a smaller diameter, thus reducing the axial load on the threads (Figure 4).

1.5 Sealing Parameters

After initially highly successful metal-pyrex-silicon sealing, recent efforts to fabricate a sensor by this method have all failed. The failures appear at this time to be caused by excessive contamination and irregularities in the glass

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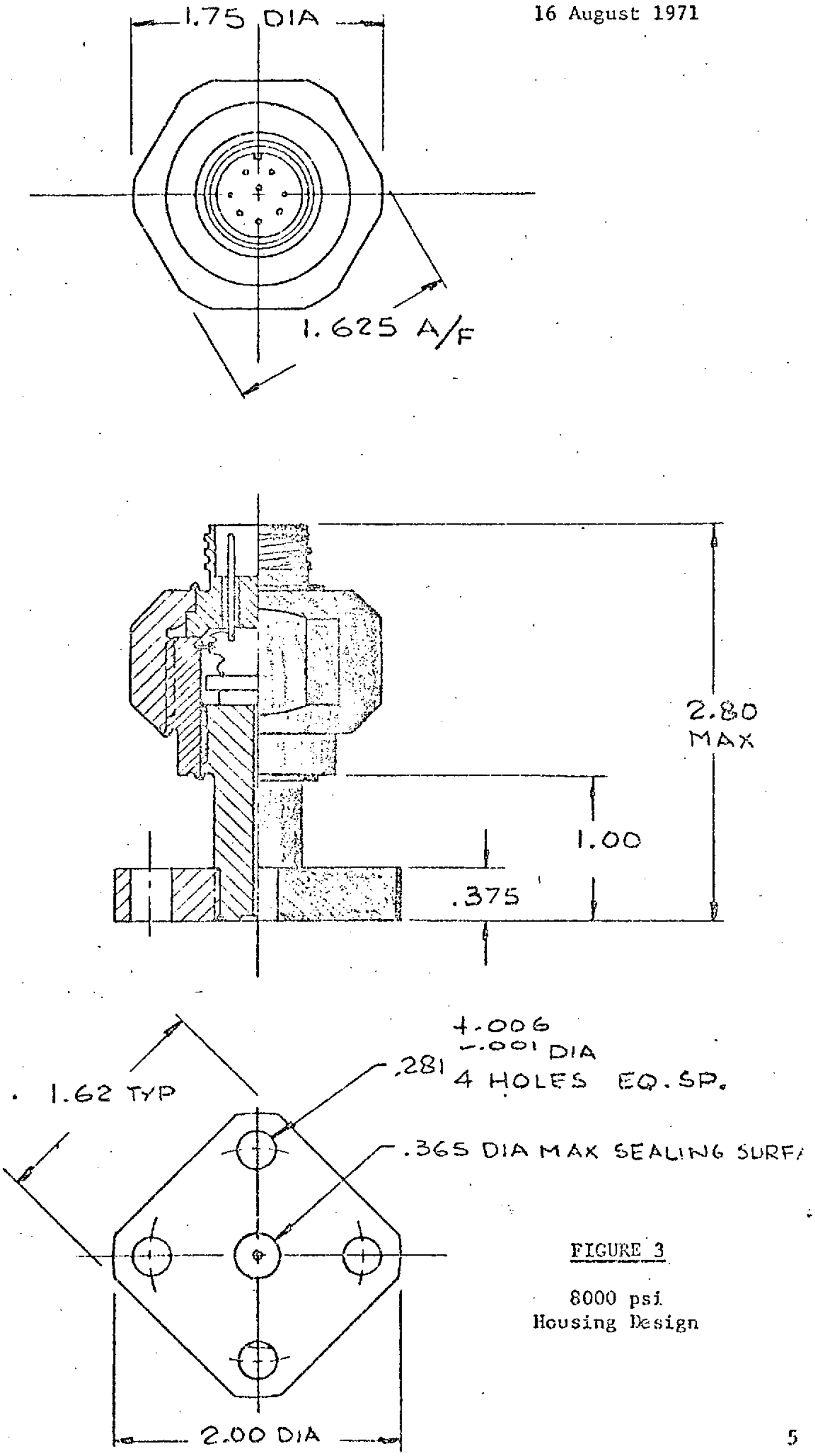


FIGURE 3

8000 psi
Housing Design

16 August 1971

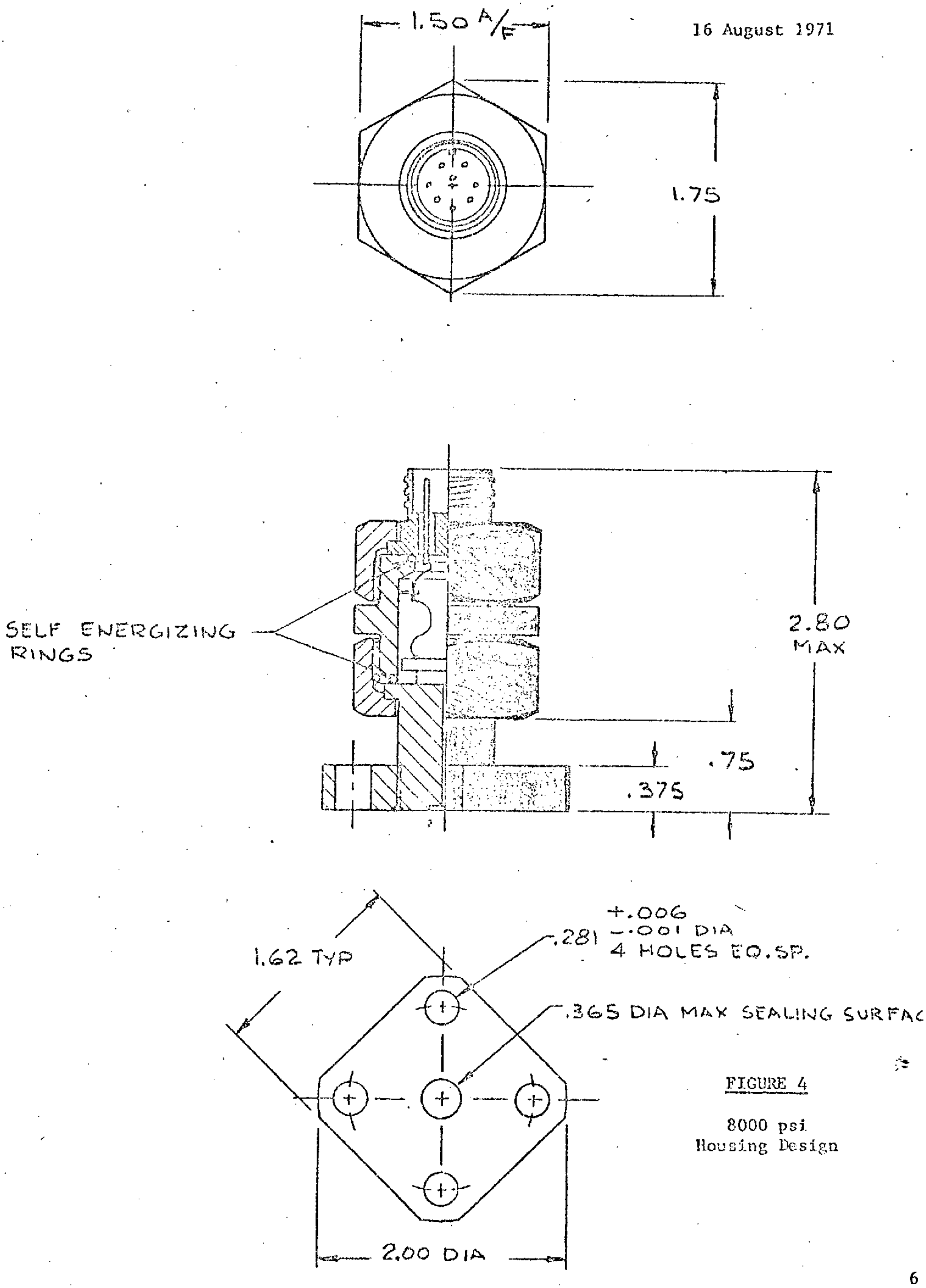


FIGURE 4

8000 psi
Housing Design

1.5 Sealing Parameters (continued)

surface which are visible under a microscope. This includes such things as small glass particles and other debris fused to the surface during the rolling process. Polished glass will be procured to alleviate this problem. As an interim solution, the existing glass stock will be polished prior to use. A preliminary silicon-glass-metal seal procedure is attached to this report as Appendix A.

2.0 PROBLEM AREAS

2.1 Silicon-Glass-Metal Seal

Silicon-glass-metal seals have been unsuccessful due to inadequate glass surface quality. Complete discussion in paragraph 1.5 of this report.

2.2 Expansion Coefficient - Kovar

Kovar may exhibit a phase change (gamma to alpha transformation) at low temperature. The temperature at which this occurs varies from one production heat to the next. In all cases, the transformation is guaranteed to be below -78.5°C. The temperature of minus 78.5° has been selected for convenience, since this is the temperature resulting from an excess of dry ice in acetone. Production testing does not involve determination of the actual temperature of transformation of each heat.

16 August 1971

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER
PROGRESS REPORT, JULY 1971 (continued)

2.2 Expansion Coefficient - Kovar (continued)

Tests of a large number of production heats, however, indicate that the actual temperature of transformation is considerably below minus 78.5°C. On a special test of fourteen production heats, actual determination of transformation was as follows:

1) Six heats showed no transformation at minus 269°C.
2) Five heats showed partial transformation at minus 196°C.
3) Three heats showed partial transformation at minus 120°C.

The above indicates that for experimental purposes there is a good probability of making serviceable seals from stock kovar to operate at depressed temperatures without the costly and time-consuming procedure of using specially selected heats.

For production requirements, special lots of kovar can be supplied by either selection or special production to insure meeting customers' specifications of lower transformation points than the standard guaranteed value (-78.5°C).

The necessity for obtaining special kovar lots will be evaluated after problem 2.1 above is resolved.

16 August 1971

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER
PROGRESS REPORT, JULY 1971 (continued)

3.0 WORK PLANNED FOR MONTH OF AUGUST 1971

3.1 Compensation Resistors

Evaluation of RN type metal film resistors to LN_2 temperature.

3.2 Silicon-Glass-Kovar Bonding

Evaluation of surface preparation effects of the pyrex glass.

3.3 Complete the preliminary housing design.

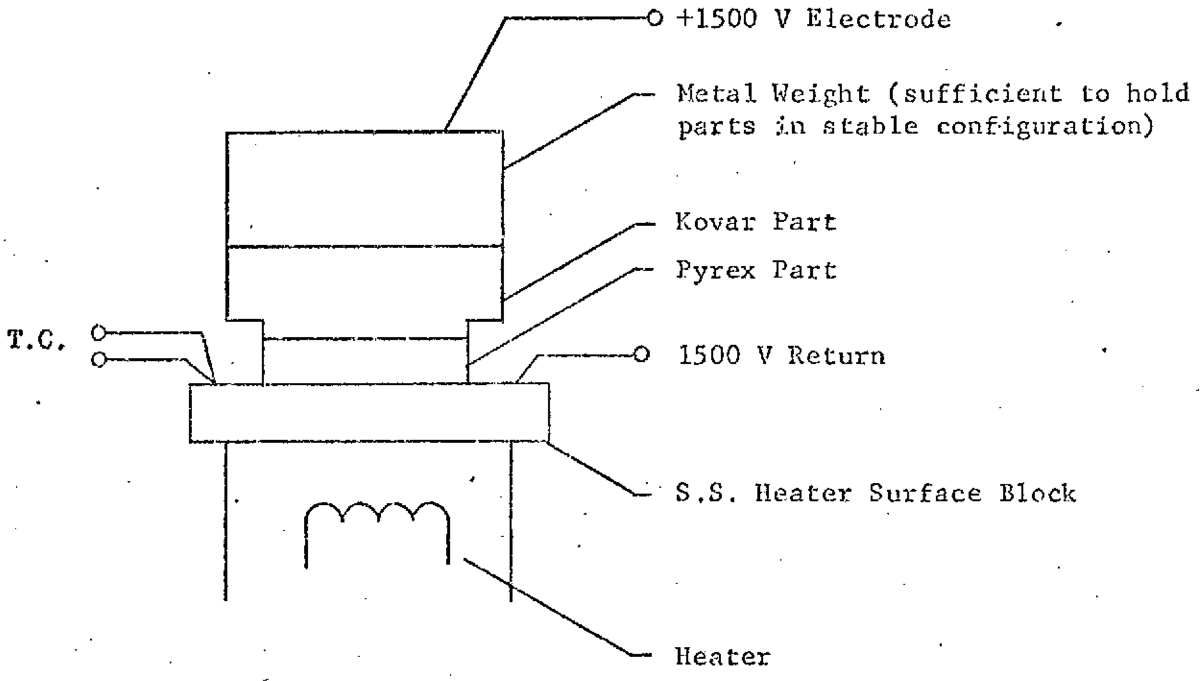
3.4 Complete the cryogenic test station design.

APPENDIX A

SILICON-GLASS-METAL SEAL

1.0 Part 1: Glass-Metal Seal

1.1 Setup



1.2 Procedure

1.2.1 Parts Preparation

1.2.1.1 Glass Part

1. Use as cut - no further polishing required.
2. Cleaning - Degrease thoroughly with TCE or other organic solvent. Rinse with acetone immediately prior to assembly.

1.2.1.2 Kovar Part

1. Lap bonding surface flat.
2. Polish to mirror finish.
3. Quick dip in kovar bright dip.

Acetic Acid	750 cc
Nitric Acid	250 cc
H Cl	15 cc

Time 3 to 5 seconds

Rinse in D.I. water. (Be sure parts are cleaned and degreased before bright dip.)

1.2.2 Assembly

1.2.2.1 Assemble parts in vacuum system as shown in 1.1.

1.2.2.2 Connect high voltage supply with ammeter (Triplett - range approximately 12 ma at beginning). Connect T.C. as shown.

1.2.2.3 Evacuate to $< 5 \times 10^{-5}$.

1.2.2.4 Heat to 800°F as indicated on T.C.

1.2.2.5 Turn on high voltage; bring up to 1500 Vdc. Monitor and record current vs. time. If arcing occurs, turn down voltage.

1.2.2.6 Current should decay away to < 0.1 ma over a period of 5 to 20 minutes.

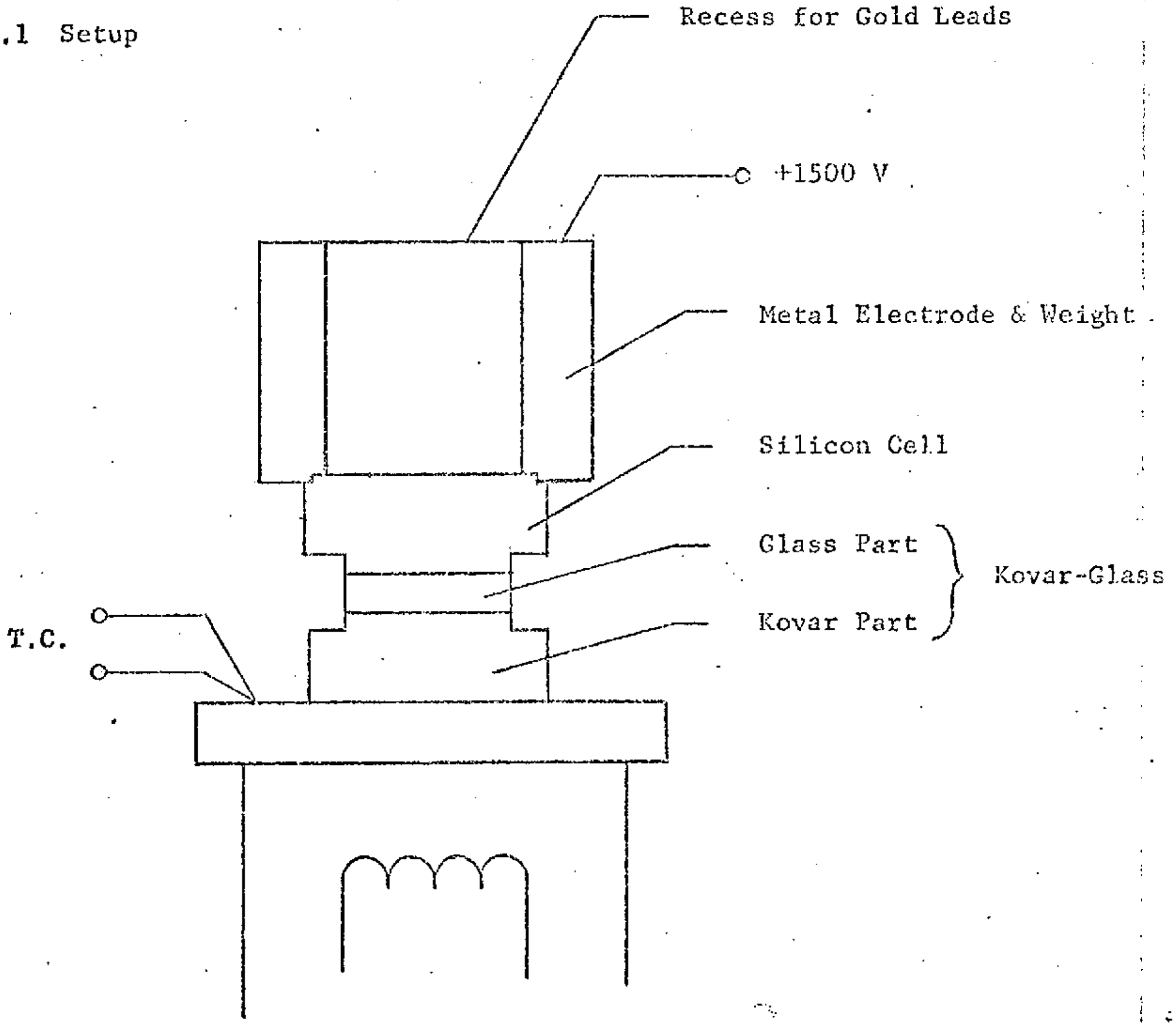
1.2.2.7 Turn off voltage after:

1. Current drops below 0.1 ma, or
2. Current appears to have stabilized for a period of 5 or 10 minutes at some higher value, or
3. 45 minutes.

1.2.2.8 Cool - Break vacuum. Remove and inspect.

2.0 Part 2: Glass-Silicon Seal

2.1 Setup



2.2 Procedure

2.2.1 Part Preparation

2.2.1.1 Kovar Glass Assembly

Clean glass bonding surface (see 1.2.1.1). This surface may be cleaned by polishing with jewelers rouge impregnated in paper if necessary. Do not use hard abrasive.

2.2.1.2 Silicon Bonding Surface

1. Surface should be flat - free of scratches, oxide or metal plating.
2. Degrease (see 1.2.1.1).

2.2.2 Assembly

2.2.2.1 Assemble as shown in 2.1.

2.2.2.2 Repeat basically the steps shown in 1.2.2 except - this bond is generally easier than the glass-kovar and should be done at 700°F if possible.

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Progress Report 4

August 1971

4 October 1971

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER
CONTRACT NO. NAS8-27442

PROGRESS REPORT

August 1971

1.0 WORK ACCOMPLISHED DURING REPORTING PERIOD

1.1 Selection of Resistors

A number of resistors of types RN50, RN60 and wire wound were tested for suitability for use as compensation and trim resistors at cryogenic temperatures. The resistors were soldered to 28 gauge copper leads. The resistance was carefully measured at room temperature with a Fluke Model 8300A Digital Multimeter. The resistors were immersed in LN_2 and the readings were repeated. Three temperature excursions were made to LN_2 temperature. The results were as follows:

Type	Nominal Resistance Value	Slope Room to LN_2	Nonrepeatability Room Temperature	Nonrepeatability LN_2 Temperature
RN60	30K	+3.7%	.007%	.003%
RN60	20K	+.84%	.005%	NIL
RN60	10K	+1.06%	.01%	NIL
RN60	1K	-.33%	.03%	.03%
RN60	100 ohms	+1.04%	.02%	.02%
RN60	51 ohms	-.55%	.04%	.06%
RN60	20 ohms	+.2%	.1%	.1%
RN50	2.9K	-.29%	.02%	.005%
RN50	44K	+.67%	.01%	.007%
RN50	50K	+1.8%	.018%	.018%
RN50	59K	+.93%	.012%	.025%
Wire wound	9 ohms	-6.7%	.55%	.2%
Wire wound	84 ohms	-.32%	.03%	.025%

4 October 1971

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER PROGRESS REPORT, August 1971 (continued)

1.1 Selection of Resistors (continued)

No apparent physical damage was done to any of the resistors by the LN_2 exposure. A report on similar resistors tested by immersion in liquid helium (RADC-TR-65-294; Levi, Mach; "Low Temperature Resistance of Selected Resistors"; August, 1965) indicates a high incidence of mechanical damage after exposure to liquid helium. This was believed to result from superfluid helium entrapment inside the resistor encapsulation followed by the development of high internal pressures when the temperature increased. Since our application and testing methods will not involve exposure of resistors to superfluid helium, this problem should not exist in this program. We conclude, then, that all of the types of resistors tested will be suitable for application in this program.

1.2 Silicon-Glass-Metal Seal

1.2.1 Sealing Parameters

The problem discussed in the last report relative to the silicon-glass-metal seal has been resolved. Polished pyrex glass is now available and successful seals have been made with it.

1.2.2 Fabrication of Test Cells

With the resolution of the sealing problem, it was possible to resume work on the fabrication of test cells. One test

1.2.2 Fabrication of Test Cells (continued)

cell has been completed to date and will be lead bonded and tested during the next reporting period. Additional test cells are being fabricated.

1.3 8000 psi Mask

The photolithographic mask for the 8000 psi cell has been designed. The artwork is complete and the working masks are on order. Delivery is expected by the end of September. A copy of the drawing of this mask (Dwg. No. 1700343) is attached.

1.4 Cryogenic Test Station Design

It has been determined as a result of the Design Review Meeting (paragraph 1.6 of this report) that the cryogenic testing would be done in two ways.

1) The test piece will be immersed in liquid nitrogen and liquid helium to provide calibration points at these temperatures. Testing of the 0-8000 psia unit will be limited to zero pressure calibration only, because of the probable solidification of pressurizing media at that temperature.

2) The test piece will be placed on a manifold and will be subjected to a temperature shock by having liquid nitrogen and liquid helium passed through the manifold. Thus the transducer body remains exposed to ambient temperature while

4 October 1971

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER PROGRESS REPORT, August 1971 (continued)

1.4 Cryogenic Test Station Design (continued)

cryogenic liquids are introduced to the pressure port. It is believed that this test will more accurately simulate actual field conditions than will the immersion test described above.

1.5 Diaphragm Diffusion

Wafers are prepared for diffusion and are awaiting the photolithographic mask described in paragraph 1.3 of this report.

1.6 Preliminary Design Review

A preliminary design review was held at Conrac on 16 August 1971 attended by Mr. H. S. Harman, S & E-ASTR-IM. A copy of the agenda of that meeting is attached.

2.0 PROBLEM AREAS

No new technical problems occurred during this reporting period.

3.0 WORK PLANNED FOR NEXT REPORTING PERIOD

3.1 Test cells at room temperature and at LN_2 temperature.

3.2 Begin fabrication of sensors.

3.2.1 Diffuse diaphragms for the 8000 psia sensor.

3.2.2 Fabricate test cells at 8000 psia range and 50 psia range.

3.2.3 Fabricate hardware for sensor.

3.3 Prepare sensor test plan.

4 October 1971

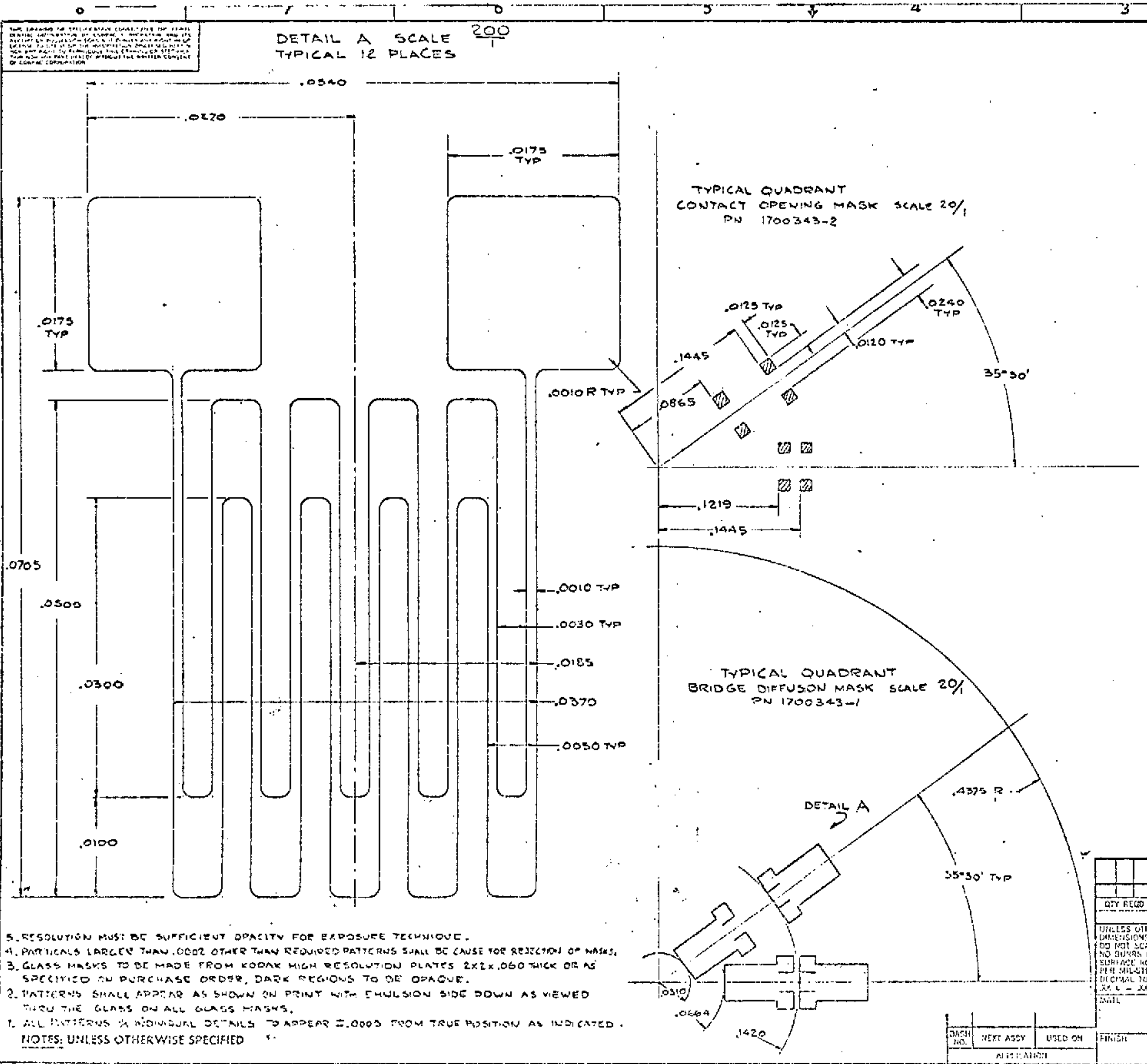
PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER PROGRESS REPORT, August 1971

(continued)

4.0 SCHEDULE

The schedule has been revised as shown to reflect the effect of slippage in Item 1.7.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



5. RESOLUTION MUST BE SUFFICIENT OPACITY FOR EXPOSURE TECHNIQUE.
4. PARTICALS LARGER THAN .0002 OTHER THAN REQUIRED PATTERNS SHALL BE CAUSE FOR REJECTION OF MASKS.
3. GLASS MASKS TO BE MADE FROM KODAK HIGH RESOLUTION PLATES 2X2X.060 THICK OR AS SPECIFIED ON PURCHASE ORDER, DARK REGIONS TO BE OPAQUE.
2. PATTERNS SHALL APPEAR AS SHOWN ON PRINT WITH EMULSION SIDE DOWN AS VIEWED THRU THE GLASS ON ALL GLASS MASKS.
1. ALL PATTERNS & INDIVIDUAL DETAILS TO APPEAR ±.0005 FROM TRUE POSITION AS INDICATED.
NOTES: UNLESS OTHERWISE SPECIFIED

DASH NO.	NEXT ASSY	USED ON
APPLICATION		

QTY REQD	CODE IDENT	PART OR IDENTIFYING NO.	SPECIFICATION	NOMENCLATURE OR DESCRIPTION	NOTE	ITEM NO

PARTS LIST

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
DO NOT SCALE DRAWING
NO BURRS AND SHARP EDGES
SURFACE ROUGHNESS ✓
PER MIL-STD-10
DECIMAL TOL .XX ± .XXX ± ANGULAR TOL ±
MATL
FINISH

DRAWN R. HESTRE 2-75
CHECK
APPD
APPD
APPD
APPD
APPD
APPROVAL
APPROVAL

INSTRUMENT-CONTROLS DIVISION
1600 S. MOUNTAIN AVE., DUARTE, CALIF. 91010
CONRAC CORPORATION

MASK PATTERN - RESISTOR

SIZE D
CODE IDENT NO 72737
1700343

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER

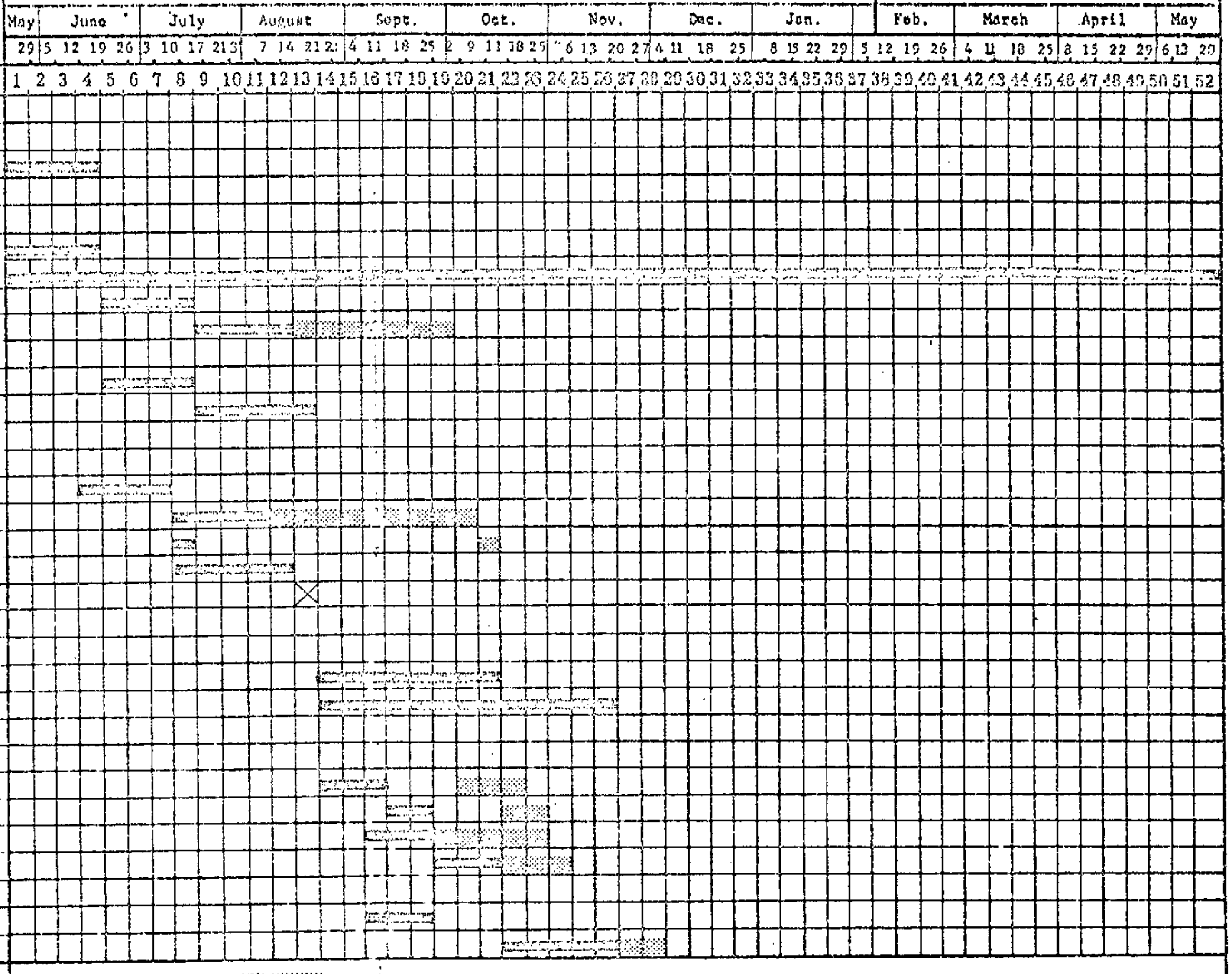
PROGRAM PLAN

CONTRACT NAS8-27442

TASK DESCRIPTION

1. PHASE I DESIGN
    1.1 Trade-offs involved in use of Media Isolated Transducer *
    1.2 Trade-offs involved in use of two bridges on one sensor vs. two sensors *
    1.3 Selection of compensation resistors
    1.4 Design of 8000 psi *
        1.4.1 Fabricate 8000 psi mask
    1.5 Review of materials for hydrogen embrittlement *
    1.6 Preliminary housing design *
    1.7 Investigation of Si-Pyrex-Metal sealing
        1.7.1 Sealing parameters *
        1.7.2 Sensor operation - room temp.
        1.7.3 Sensor exposure - LN_2 temp.
    1.8 Cryogenic test station design *
    1.9 Preliminary design review *

2. PHASE II DESIGN VERIFICATION
    2.1 Build cryogenic test station
        2.1.1 LN_2
        2.1.2 He
    2.2 Fabricate sensors
        2.2.1 Diaphragm diffusion
        2.2.2 Cell fabrication
        2.2.4 Hardware fabrication
        2.2.5 Assembly and preliminary test
    2.3 Sensor tests
        2.3.1 Test plan
        2.3.2 LN_2 tests

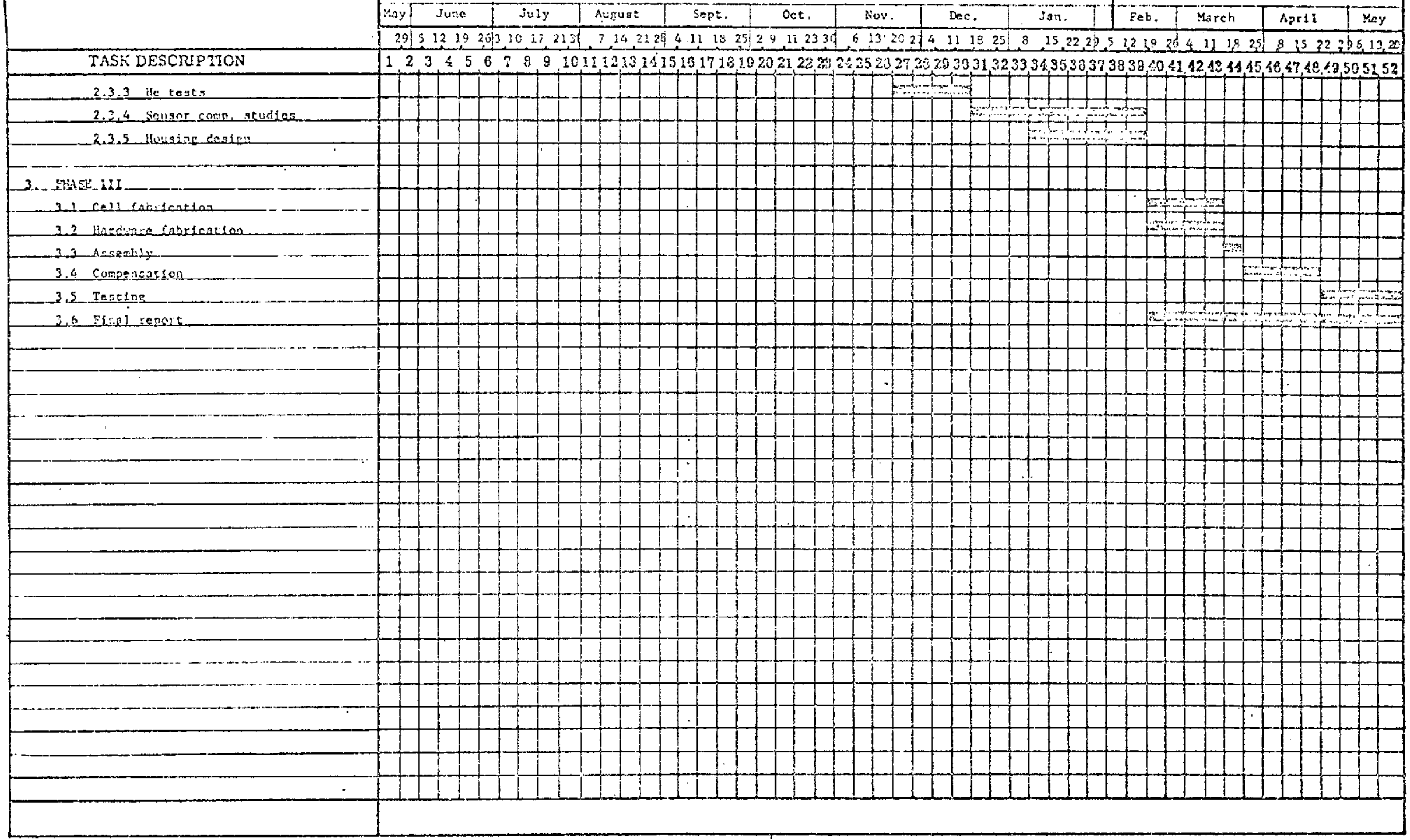


* TASK COMPLETE ▨ RESCHEDULE

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER

PROGRAM PLAN

CONTRACT NAS8-27442



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3.0 PHASE II - DESIGN VERIFICATION

The second phase of the program, design verification, is reported in Progress Reports 5, 6, 7, 8, 9 and 10. New techniques were developed for the process whereby microcircuit leads are ball bonded to the diffused resistor bridge on the silicon wafer. Preliminary units were lost due to thermal shock until better procedures were developed. Preliminary tests on interim designs from -55°C to +80°C indicated that performance was not degraded by the kovar-pyrex-silicon seal construction, compared to the standard Conrac design performance.

A Phase II test plan was developed for wide range testing of 8000 psi cells, and 0 - 15 psi prototype units were tested at low pressure range to calibrate a unit for sensitivity, zero balance, linearity, hysteresis, repeatability and static error band (see Progress Report 7). The low pressure unit was then immersed in LN_2 at ambient pressure to determine temperature compensation requirements and wide temperature range transient response (see Progress Reports 7 and 8). Three low pressure sensors (0-30 in Hg) were tested between -196°C and +90°C with encouraging results (see Progress Report 10), such that at the formal design review held at Marshall Space Flight Center, 24 February 1972, it was decided to continue on to Phase III. Problems still existed in making reliable glass-metal bonds between the kovar and pyrex, but it was agreed that the test results and media compatibility advantages justified proceeding with this approach. It was also agreed that fabrication of final parts in Phase III should not begin until an investigation into glass materials (with a closer match of coefficient or expansion to kovar) was completed.

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Progress Report 5

September 1971

18 October 1971

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER
CONTRACT NO. NAS8-27442

PROGRESS REPORT

September 1971

1.0 WORK ACCOMPLISHED DURING REPORTING PERIOD

1.1 Fabrication of Test Cells

The first test cell was destroyed during lead bonding. The problem was excessive thermal shock when the cell was placed on the hot (400° C) lead bonding machine. This problem, which is described in detail in paragraph 2.0 of this report, has now been resolved and work is proceeding. A new test cell has been fabricated and has passed through the lead bonding stage into final assembly and will proceed into test. This cell will have a 0 - 15 psia range and is intended for interim testing only and will not be end item hardware.

1.2 8000 psi Mask

The 8000 psi mask was received.

1.3 Diaphragm Diffusion

Diaphragm diffusion for 0-50 psia sensors is complete.

Diaphragm diffusion for 0-8000 psia sensors is 30% complete.

1.4 Sensor Test Plan

Sensor test plan is in preparation.

2.0 PROBLEM AREAS - LEAD BONDING

The first test cell was broken in lead bonding. The bonding of leads is accomplished by heating the workpiece to 400°C and applying a standard microcircuit type ball or nail-head bond. The thermal shock resulting from placing the cold workpiece on the 400°C heating column resulted in fracture at the kovar-pyrex bond. The solution is simply to either place the workpiece on a cold heating column and heat slowly, or to preheat the workpiece and transfer to the heating column. It is not felt that the fracture of this cell on the lead bonder indicates a potential design flaw because the 400°C temperature is well above the specified temperature range (200°C maximum). Test specimens of the complete kovar-pyrex-silicon bond have been temperature shocked from a 200°C hotplate to LN_2 temperature and back several times without failure.

3.0 WORK PLANNED FOR NEXT REPORTING PERIOD

3.1 Complete fabrication and testing of cells at room temperature and LN_2 temperature.

3.2 Continue fabrication of sensors.

3.3 Complete sensor test plan - copy to be attached to next progress report.

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER

PROGRAM PLAN

CONTRACT NAS8-27442

TASK DESCRIPTION

1. PHASE I DESIGN
    1.1 Trade-offs involved in use of Media Isolated Transducer *
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    1.9 Preliminary design review *

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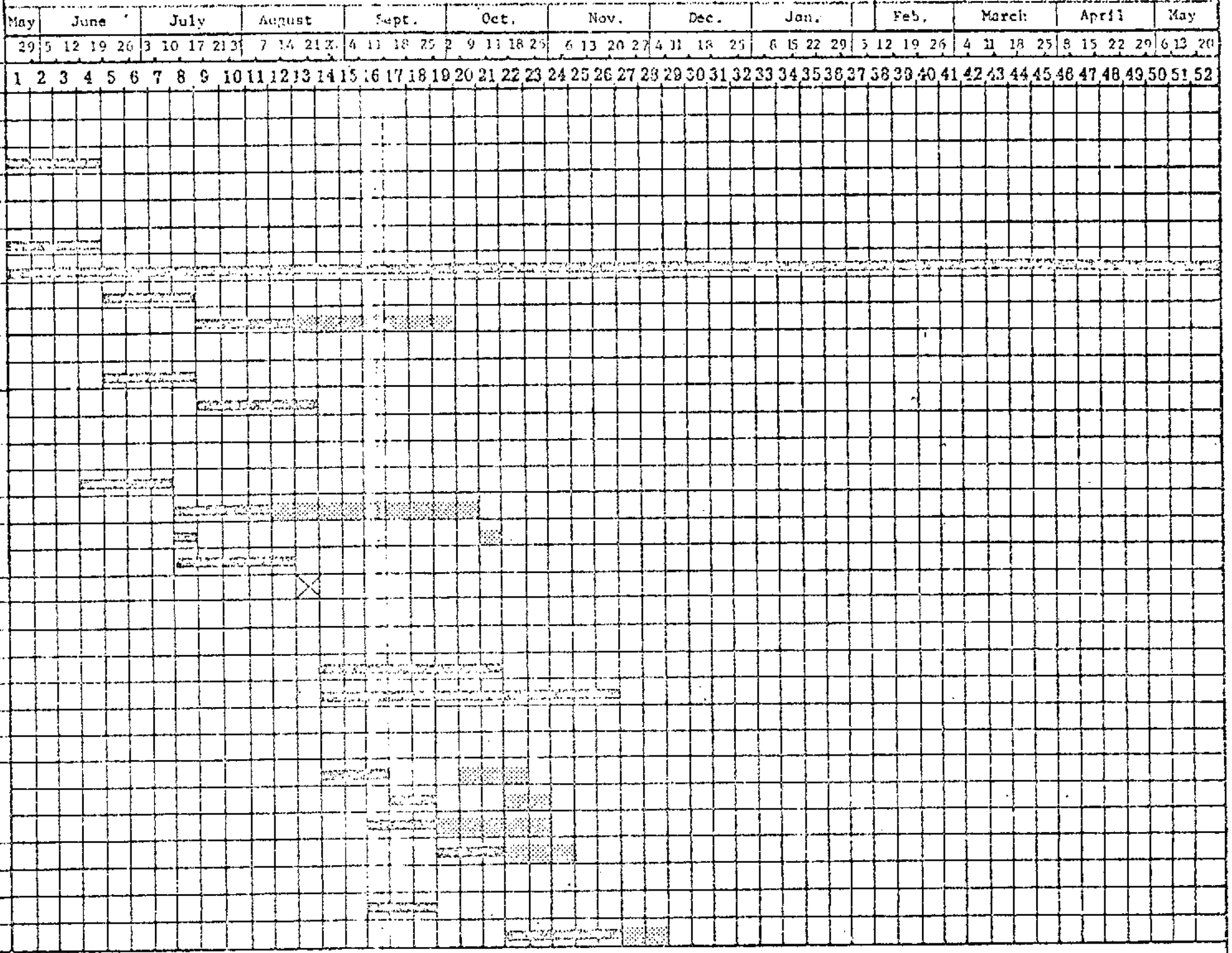
        2.1.1 LN_2
        2.1.2 He
    2.2 Fabricate sensors
        2.2.1 Diaphragm diffusion
        2.2.2 Cell fabrication
        2.2.4 Hardware fabrication
        2.2.5 Assembly and preliminary test
    2.3 Sensor tests
        2.3.1 Test plan
        2.3.2 LN_2 tests

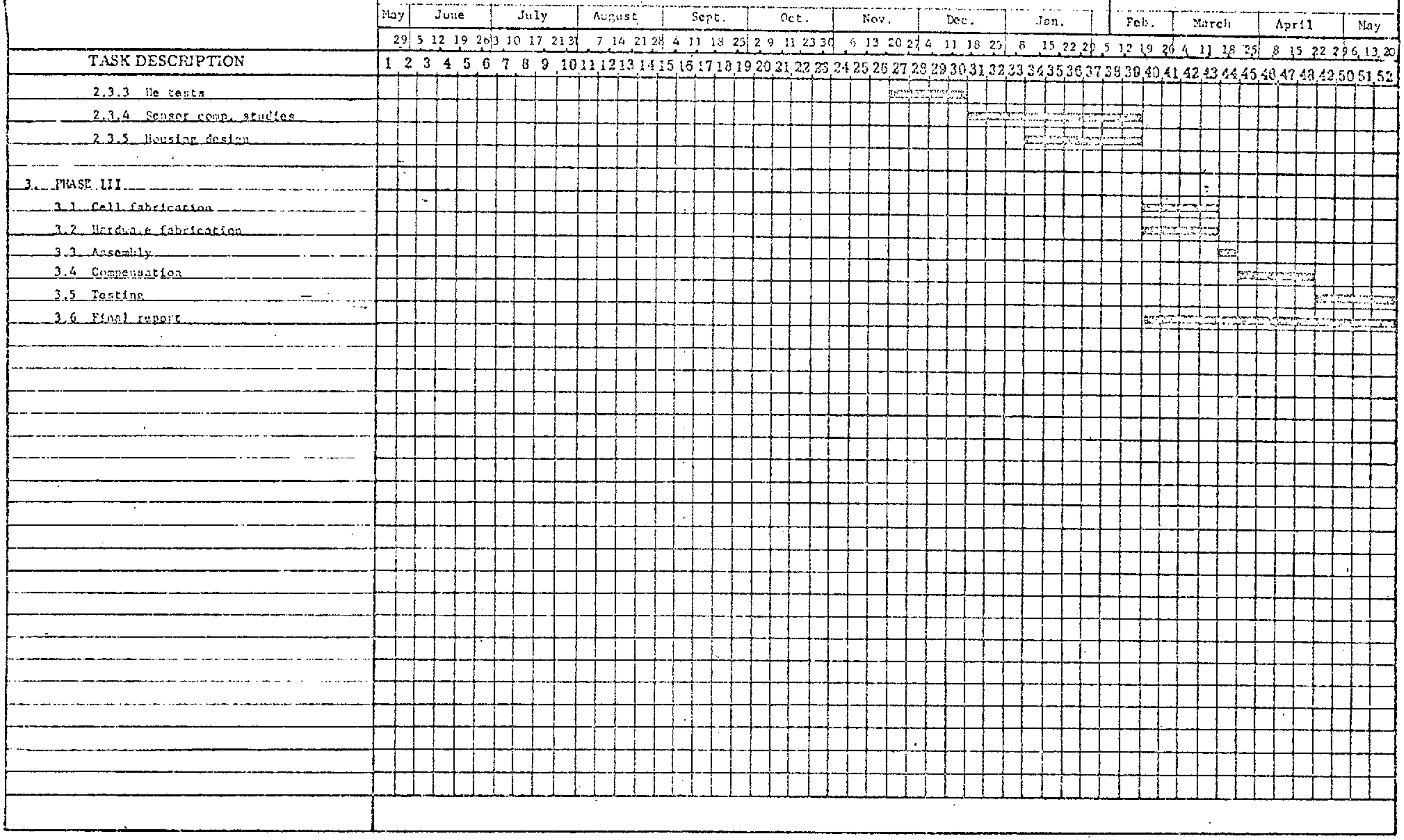


* TASK COMPLETE ▨ RESCHEDULE

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER

PROGRAM PLAN

CONTRACT NAS8-27442



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Progress Report 6

October 1971

15 November 1971

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER
CONTRACT NO. NAS8-27442

PROGRESS REPORT

October 1971

1.0 WORK ACCOMPLISHED DURING REPORTING PERIOD

1.1 Fabrication of Test Cells

One test cell, C/N 268-14, has been fabricated to date as reported last time. Subsequent test cells (5 pieces) have failed in welding the shell to the sensor base. This problem will be described in more detail in section 2.0.

1.2 Test Results

Cell number 268-14 has been subjected to preliminary testing from -55°C to +80°C with the following results:

1.2.1 Resistance Measurement

The resistance of each of the 12 strain gages diffused into the diaphragm of C/N 268-14 was measured at room temperature and at -55°C and +80°C. There are 225 bridges that can be made from these 12 strain gages. The zero pressure output of each of these bridges was computed from the resistance data at the three temperatures.

The average of all the bridges' performance as well as the performance of the bridge selected as the best one to wire up is tabulated as follows:

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER PROGRESS REPORT - October 1971 (continued)

1.2.1 Resistance Measurement (continued)

	Zero Balance	Zero Slope	Linearity of Zero Slope
Average for all bridges	-22.1% F.S.	-3.6% F.S.	±.13% F.S.
Best bridge	-4.3% F.S.	-1.2% F.S.	±.04% F.S.

The data show that over the -55°C to +80°C range, with ideal linear temperature compensation, the average bridge could be compensated to ±.13% F.S. and the best bridge could be compensated to ±.04% F.S. This data is comparable to that obtained on standard Model 4715 sensor cells and is a preliminary indication that the performance has not been degraded by the kovar-pyrex-silicon seal construction.

1.2.2 Bridge Performance Data

The best bridge on C/N 268-14, selected as described above (section 1.2.1), was hard wired and tested over the same temperature range to verify the results obtained from the resistor measurement. It is also possible with the bridge hard wired to measure repeatability after thermal cycling.

Output measurements at zero pressure are tabulated as follows:

15 November 1971

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER PROGRESS REPORT - October 1971 (continued)

1:2.2 Bridge Performance Data

Temp.	Output (mv)	Input Voltage at 5 ma Constant Current
-55°C	-2.964	4.9322
25°C	-3.688	5.4472
+80°C	-4.341	5.9636
25°C	-3.672	5.4419

In this data, the column listed as "Temp." is for reference only. The input voltage reading is taken as being the best indication of actual sensor temperature.

From this data, the zero pressure slope is seen to be 1.4% of full scale (full scale output is nominally 100 mv). Linearity of zero pressure slope is ±.02% so that ideal linear compensation would result in a thermal zero error of ±0.02% of full scale. The room return after hot (+80°C) exposure is within .009% F.S. of the room return after cold. These results verify the conclusion that sensor performance has not been degraded by the kovar-pyrex-silicon seal.

Testing will continue over larger temperature ranges and over pressure during the next reporting period including exposure to LN_2 temperature.

15 November 1971

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER PROGRESS REPORT - October 1971 (continued)

1.3 Diaphragm Diffusion

Diaphragm diffusion is complete for at least 8 pieces each of the 0-50 psia and 0-8000 psia range.

1.4 Cell Fabrication

Fabrication of the cells required for Phase II is approximately 50% complete.

1.5 Hardware Fabrication

Fabrication of hardware required for Phase II is approximately 30% complete.

1.6 Test Plan

Test plan for Phase II testing attached.

1.7 8000 psi Transducer Design

A 10X scale layout of the 8000 psi transducer is attached.

2.0 PROBLEM AREAS - LOSS OF SENSORS IN SHELL WELD

A lot of 5 pieces of test sensors submitted for welding to the housing were found after welding to have fractures in the pyrex standoff. The pyrex-metal bond and the pyrex-silicon bond were both intact indicating that these bonds are strong and reliable.

The problem was caused by excessive thermal shock in the heliarc welding process.

15 November 1971

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER PROGRESS REPORT - October 1971 (continued)

2.0 PROBLEM AREAS - LOSS OF SENSORS IN SHELL WELD

The solutions being implemented are:

(1) Redesign the sensor header to isolate the weld area from the pyrex-metal bond area.

(2) Provide a weld groove in the housing to permit the weld to be done at lower current input.

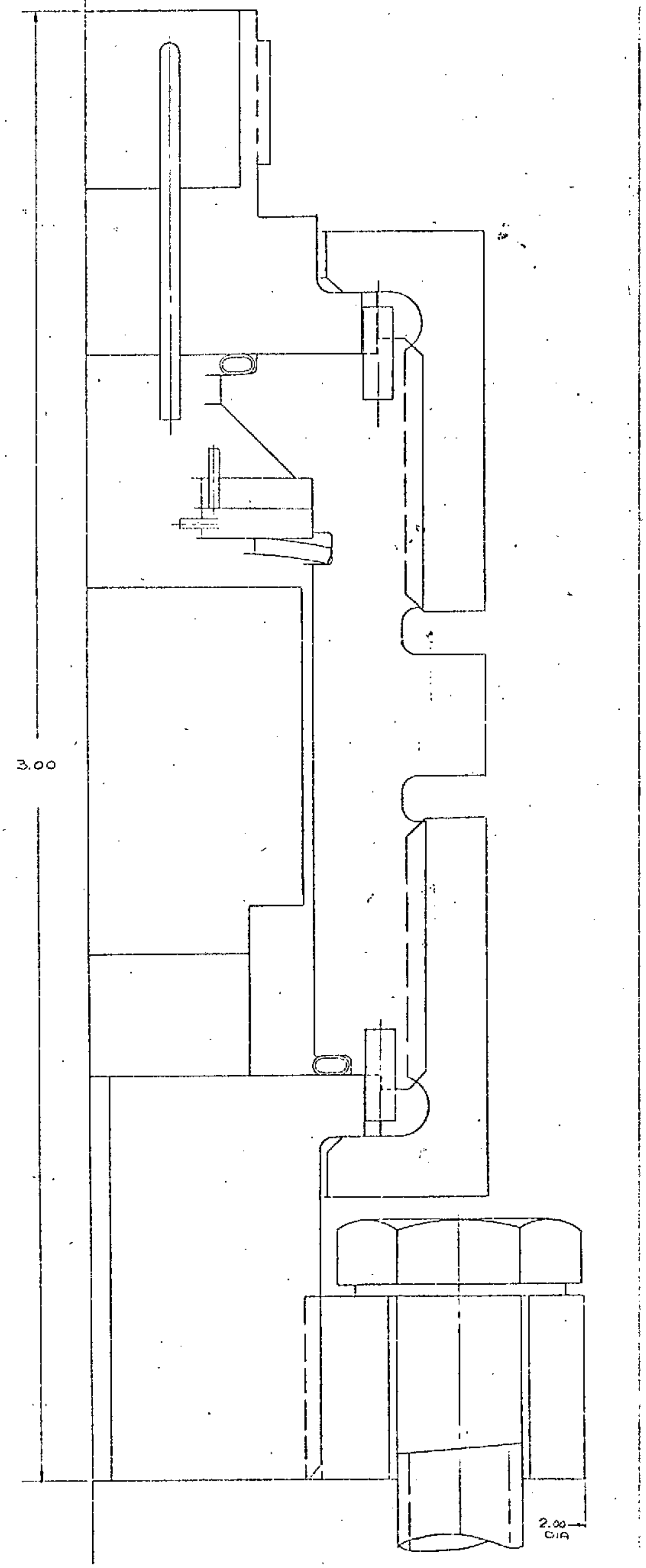
3.0 WORK PLANNED FOR NEXT REPORTING PERIOD

3.1 Cell Testing

Test cells over temperatures from LN_2 temperature to +200°C.

3.2 Continue fabrication of Phase II sensor cells.

3.3 Begin Phase II sensor tests.



10/1 SCALE LAYOUT
8000 PSI TRANSDUCER

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER

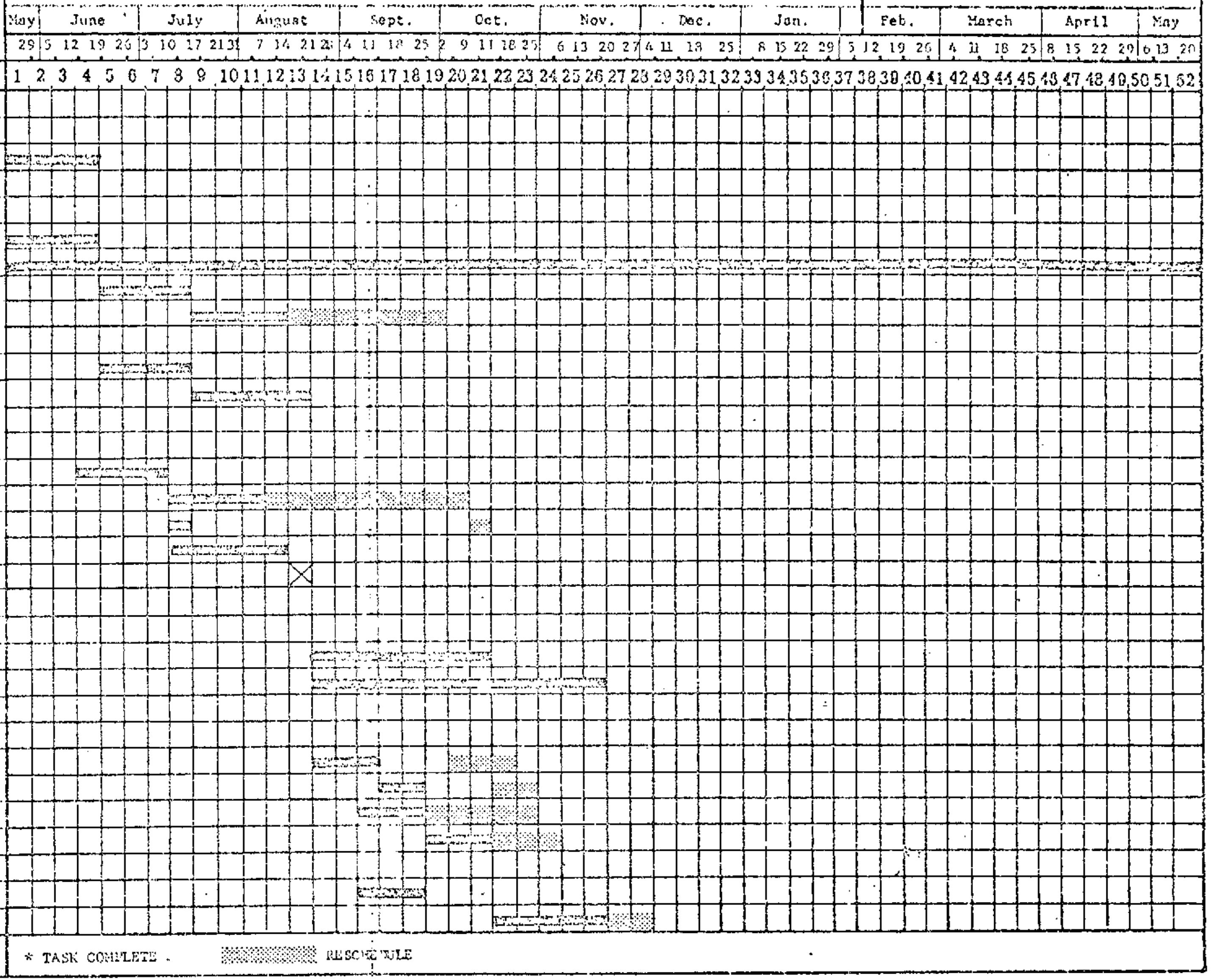
PROGRAM PLAN

CONTRACT NAS8-27442

TASK DESCRIPTION

1. PHASE I DESIGN
    - 1.1 Trade-offs involved in use of Media Isolated Transducer *
    - 1.2 Trade-offs involved in use of two bridges on one sensor vs. two sensors *
    - 1.3 Selection of compensation resistors
    - 1.4 Design of 8000 psi *
        - 1.4.1 Fabricate 8000 psi mask *
    - 1.5 Review of materials for hydrogen embrittlement *
    - 1.6 Preliminary housing design *
    - 1.7 Investigation of Si-Pyrex-Metal sealing
        - 1.7.1 Sealing parameters *
        - 1.7.2 Sensor operation - room temp. *
        - 1.7.3 Sensor exposure - LN_2 temp.
    - 1.8 Cryogenic test station design *
    - 1.9 Preliminary design review *

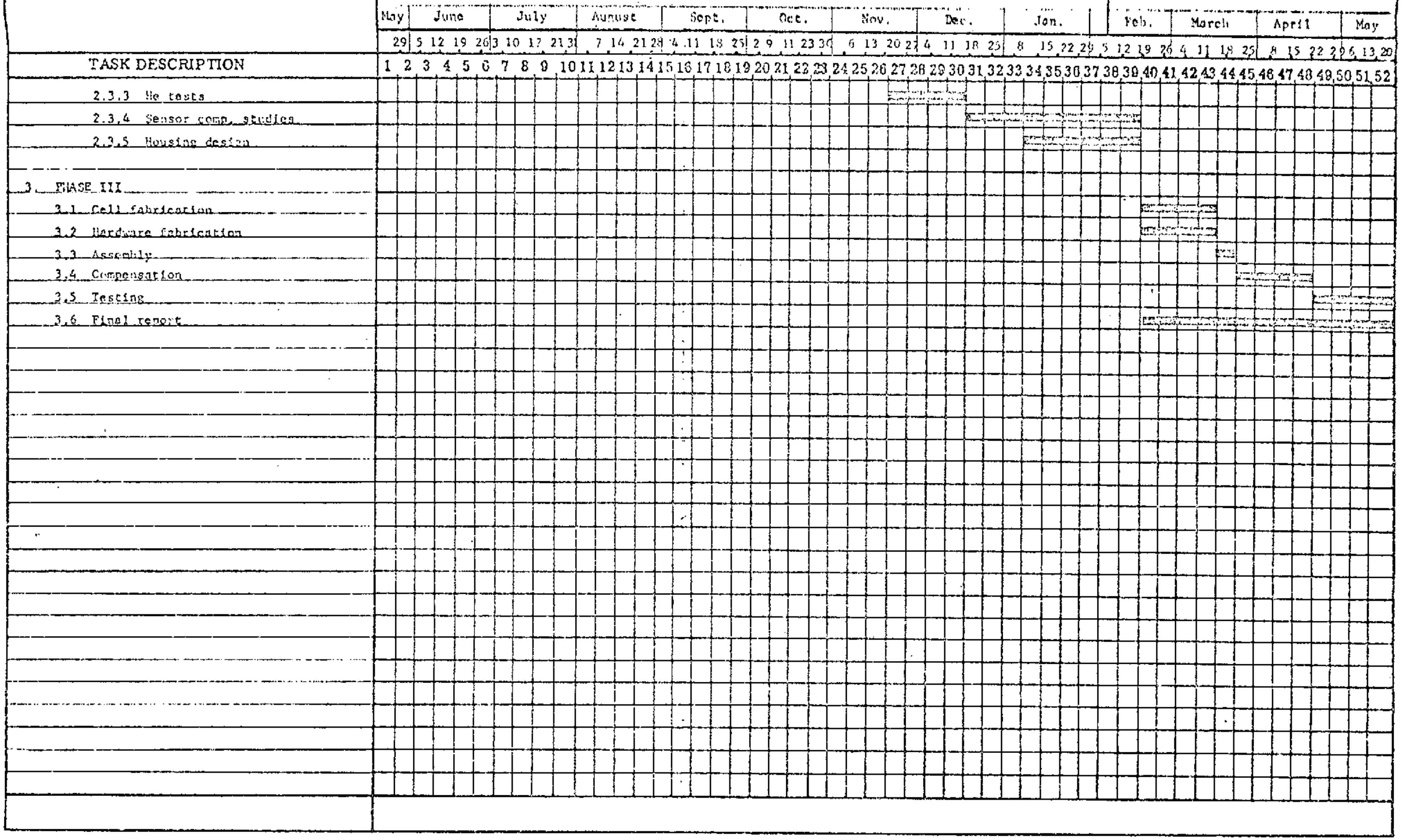
2. PHASE II DESIGN VERIFICATION
    - 2.1 Build cryogenic test station
        - 2.1.1 LN_2 *
        - 2.1.2 He
    - 2.2 Fabricate sensors
        - 2.2.1 Diaphragm diffusion
        - 2.2.2 Cell fabrication
        - 2.2.4 Hardware fabrication
        - 2.2.5 Assembly and preliminary test
    - 2.3 Sensor tests
        - 2.3.1 Test plan
        - 2.3.2 LN_2 tests



PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER

PROGRAM PLAN

CONTRACT NAS8-27442



TASK DESCRIPTION

2.3.3 He tests

2.3.4 Sensor comp. studies

2.3.5 Housing design

3. PHASE III

3.1 Cell fabrication

3.2 Hardware fabrication

3.3 Assembly

3.4 Compensation

3.5 Testing

3.6 Final report

1/C-E-127-8/68

CONRAC
CORPORATION

TP 4715-110-1

15 November 1971

SPACE SHUTTLE TRANSDUCER

PHASE II TEST PLAN

CONTRACT NO. NAS8-27442

PREPARED AND APPROVED BY:

G. L. Vick
Engineering Manager
Solid State Instruments

TP 4715-110-1

15 November 1971

1.0 PURPOSE AND OBJECTIVES

The following tests are planned for the purpose of evaluating the performance of transducers at normal and cryogenic temperatures (+4°K to 473°K). The tests will also provide data necessary for evaluating compensation techniques for these transducers.

2.0 SCOPE AND TEST DESCRIPTION

The tests are to be performed at room temperature unless otherwise specified.

2.1 Resistance Measurement

The resistance of each strain gage of the silicon cell will be measured at -55°C, room temperature and +80°C. This data will be used to select optimum strain gage bridge configurations.

2.2 Pressure Calibration

A five-point ascending and descending calibration shall be performed to determine zero balance, sensitivity, linearity and hysteresis.

2.3 Normal Temperature Operation

End and midpoint calibrations shall be performed at each of the following "normal" temperatures in the following order:

Room
-55°C
Room
+80°C
Room

2.4 Low Temperature Testing

2.4.1 Low Temperature Chamber

End and midpoint calibrations shall be performed at the lowest temperature available in the temperature chamber (approximately -100°C).

2.4.2 LN_2 Temperature

End and midpoint calibrations shall be performed with the transducer immersed in LN_2. Tests on the 8000 psia transducer will be limited to zero pressure reading.

2.4.3 Liquid Helium Temperature

End and midpoint calibrations shall be performed with the transducer immersed in liquid helium. Tests on the 8000 psia transducer will be limited to zero pressure reading.

2.5 Temperature Shock

The transducer shall be connected to a pressure manifold at room temperature. A thermal shock shall be applied by suddenly introducing liquid nitrogen or liquid helium to the transducer pressure port via the pressure manifold. The pressure shall be maintained constant during this test. Output values shall be recorded at time intervals to be determined such as to define the response of the transducer to the temperature transient.

4.0 TEST EQUIPMENT

Test equipment shall include the following or equivalent equipment:

Pressure Calibration
50 psia
Ruska
Model 3508

8000 psia
TBD

Voltage Readout
Fluke Digital Voltmeter
Model 8300A

Power Supply
Hewlett-Packard
Model 6181B

Temperature Chamber
Delta
MK 6300

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PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER
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PROGRESS REPORT
November 1971

1.0 WORK ACCOMPLISHED DURING REPORTING PERIOD

1.1 Test Results

Testing has continued on cell C/N 268-14. Results of preliminary pressure tests are tabulated below:

TEMP.	ROOM	125°C	ROOM	-6°C	-53°C	-75°C	29°C	153°C	ROOM
V_{in}	5.4703v	6.324	5.4346	5.2091	4.8617	4.7070	5.4499	6.5252	5.44
Zero ①	-4.308 mv	-5.373	-4.218	-3.924	-3.506	-3.330	-4.343	-5.570	-4.25
7.05" Hg	14.460	X	14.771	X	X	X	X	X	X
14.55	34.451	33.880	34.745	34.975	35.419	35.670	34.606	33.968	X
22.05	54.346	X	54.622	X	X	X	X	X	X
28.55	71.546	71.399	71.795	71.980	72.490	72.775	71.655	70.5 ②	X
22.05	54.375	X	54.636	X	X	X	X	X	X
14.55	34.490	33.944	34.760	34.983	35.426	35.675	34.622	34.016	X
7.05	14.505	X	14.775	X	X	X	X	X	X
0	-4.301	-5.346	-4.206	3.925	3.511	-3.332	-4.340	-5.554	X
Sensitivity	75.854	76.772	76.013	75.904	75.996	76.105	75.998	X	X

① Both ports open to atmospheric pressure in 29.55" Hg.

② Estimated - pressure hose collapsed from temperature.

From this data, the following parameters may be calculated:

1.1.1 Sensitivity: 76 mv/28.55" Hg.

1.1.2 Zero Balance (untrimmed): -4.3 mv.

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PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER PROGRESS REPORT - November 1971

1.1.3 Linearity: .133% F.S., terminal point as shown in the following tabulation:

PRESSURE	OUTPUT	IDEAL	△	% F.S.
0	-4.308 mv	-4.308 mv	0	0
7.05" Hg	14.460	14.423	.037	.05
14.55	34.451	34.350	.101	.133
22.05	54.346	54.276	.070	.09
28.55	71.546	71.546	0	0

1.1.4 Hysteresis

PRESSURE	WORST CASE HYSTERESIS	AVERAGE HYSTERESIS
0	-.037 mv (.05% F.S.)	-.010 (.013%)
7.05	-.045 (.06% F.S.)	-.025 (.033%)
14.55	-.064 (.09% F.S.)	-.025 (.033%)
22.05	-.043 (.06% F.S.)	-.022 (.03%)

NOTE: Both worst case hysteresis and average of all hysteresis values at a given pressure are reported. It is felt that the average value is of greater significance for the following reasons:

1) The sensor is uncompensated, making it susceptible to small temperature changes.

1.1.4 Hysteresis (continued)

2) The sensor reference port was open to ambient pressure while the calibration standard was an absolute pressure controller. The test results are thus subject to fluctuations in room ambient pressure.

1.1.5 Repeatability/Stability: .09 mv worst case (0.12% F.S.) Repeatability, as such (greatest deviation of 3 successive calibrations), was not measured. Comparison of the zero pressure output for the three room temperature readings gives a measure of stability. The measurements at other pressures cannot be compared because the reference pressure (room ambient) varied from one set of readings to the next.

1.1.6 Static Error Band (sum of above errors): .317% F.S. worst case based on terminal point straight line. ±0.085% F.S, r.s.s based on best straight line.

1.1.7 Thermal Errors

1.1.7.1 Zero Pressure Errors: Figure 1 shows a plot of zero pressure output vs temperature. There are two factors involved in zero pressure thermal error: (1) the slope, which is 2.240 mv (3% of full scale or .013% F.S./°C over the 228°C range),

1.1.7.1 Zero Pressure Errors (continued)

and (2) the nonlinearity or "hook" of the thermal behavior which amounts to 0.15 mv or 0.2% F.S. The slope may be completely eliminated (theoretically) by linear temperature compensation techniques. It is theoretically possible to reduce the thermal zero error over this 228°C span to 0.2% of full scale.

1.1.7.2 Sensitivity Errors

Figure 2 shows a plot of sensitivity vs temperature over a 200°C span from -75°C to +125°C. While this data is subject to error due to the reference port being open to room ambient, it does show that the uncompensated error was 1.23%, compensatable to .55% F.S. by conventional linear passive techniques.

1.2 Liquid Nitrogen Tests

At the conclusion of the above tests, C/N 268-14 was found to have an internal pressure leak. It was disassembled and examined. The leak was found to be at the glass-silicon interface. The sensor was reassembled and the following tests performed at LN_2 temperatures. The disassembly and reassembly procedures resulted in a zero shift of -0.5 mv so that the results of testing before

1.2 Liquid Nitrogen Tests (continued)

and after reassembly are not directly comparable without correction for this zero shift.

The tests were conducted by recording input and output voltages (at 5 ma input current) at the specified temperature. LN_2 temperature was achieved by immersing the sensor in LN_2 at ambient pressure.

The results are tabulated below:

TEMP.	-54°C	LN_2	ROOM	LN_2	ROOM	LN_2	ROOM
V_{in}	4.8799 v	4.0348	5.4267	4.0346	5.4156	4.0343	5.4493
V_{out}	-3.918 mv	-3.040	-4.866	-3.070	-4.850	-3.060	-4.886
Corrected V_{out}	-3.918	-3.040	-4.866	-3.070	-4.864	-3.060	-4.857

Since room temperature was not controlled, a correction was calculated using the input voltage as a measure of actual temperature. The stability of the sensor was within .009 mv at room temperature and within .030 mv at LN_2 temperature. A plot of the zero pressure output vs temperature is shown in Figure 3. The sensor showed a change in output of 1.796 mv (2.4% F.S.) compensatable to .45% of full scale. A composite plot over the entire -196°C to +153°C temperature span is shown in Figure 4, corrected for the change in output resulting from

1.2 Liquid Nitrogen Tests (continued)

reassembling the sensor between the two sets of tests. This plot shows a slope of 3.5 mv (4.7% F.S.) over a 350°C temperature span compensatable to approximately 0.6% of full scale.

1.3 Preliminary Compensation Studies

The standard method of compensating the zero pressure output is to shunt one leg of the bridge with an OTC resistor. Since the computer program for resistor selection has not yet been modified to call out compensation resistors to LN_2 temperature, resistance values were estimated based on hand calculation and installed and tested as tabulated below. Hand calculation of compensation resistors tends to be an iterative or "cut and try" approach and the first two "tries" are tabulated here.

COMP RESISTOR	170K			250K	
Temp, °C	Room	-55°C	LN_2	Room	LN_2
V_{in}, v	5.340	4.915	4.030	5.3906	4.0314
V_{out}, mv	+3.492	+2.885	+1.608	1.100	.212

These results are plotted in Figure 5. It is interesting to note that the -55°C reading lies within .130 mv of the straight line connecting the room and LN_2 temperatures. While these results are preliminary in nature, it is worth noting the 170K temperature run lies within a ±1.2% error band and the 250K run lies

1.3 Preliminary Compensation Studies (continued)

within a 0.6% error band. Extrapolation of these results indicates ideal compensation with a 365K shunt resistor.

1.4 Temperature Transient Response

The sensor, dropped into LN_2 from room temperature, came to equilibrium in approximately 2 minutes. The maximum excursion observed at 0 pressure was approximately 1%. Equilibrium time on removal from LN_2 to room temperature was approximately 20 minutes, again with a 1% output excursion.

1.5 Cell Fabrication

Cell fabrication for Phase II requirements is complete.

1.6 Hardware Fabrication

Hardware fabrication for Phase II is approximately 75% complete.

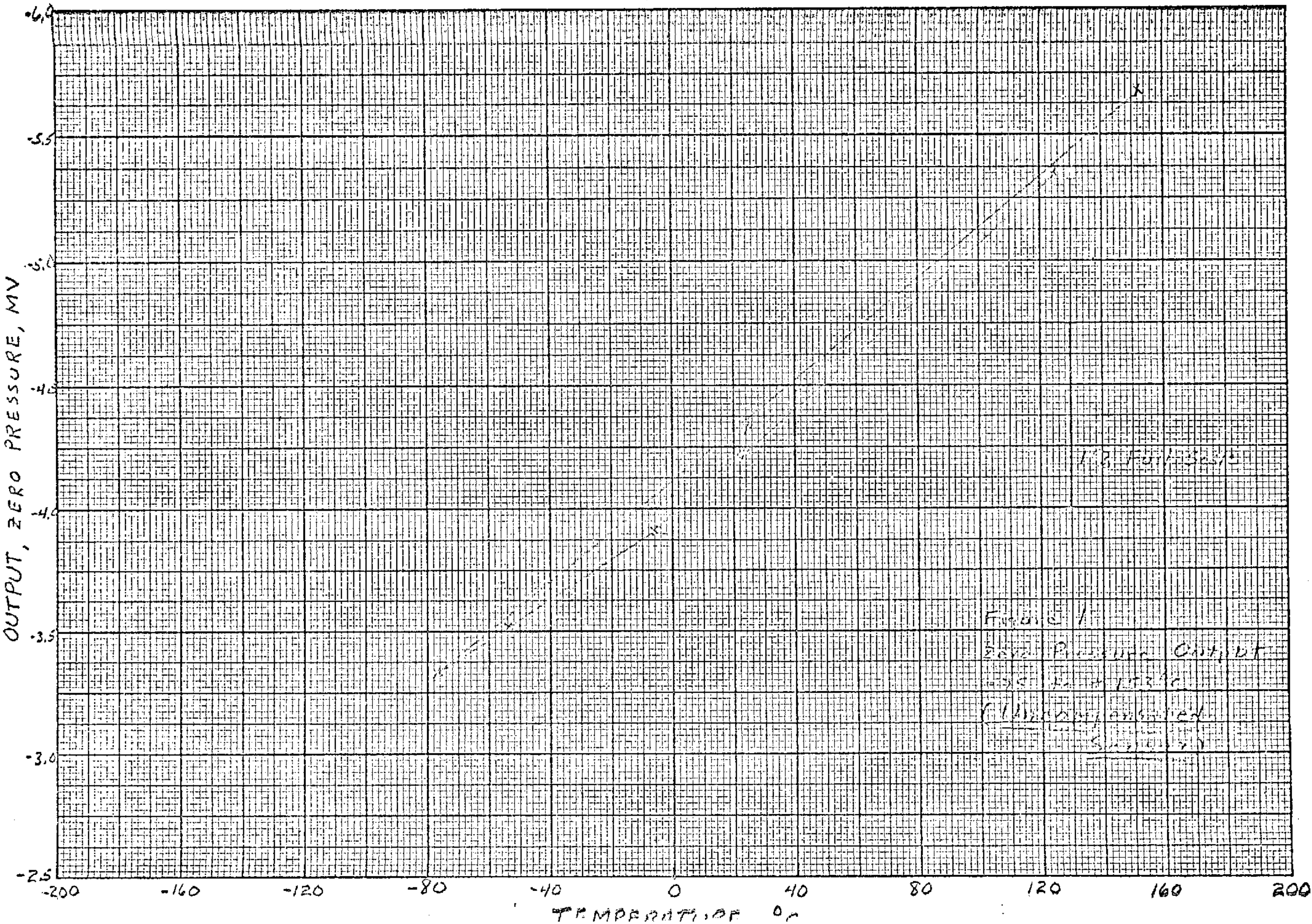
2.0 PROBLEM AREAS

Sensor fabrication for Phase II has been delayed by the difficulty of obtaining sufficiently flat surfaces on the kovar parts. Twelve pieces are on order from Pacific Precision, Inc., Palo Alto, California, and are due on 12/21/71.

3.0 WORK PLANNED FOR NEXT REPORTING PERIOD

3.1 Cell Testing - continue testing and compensation analysis from LN_2 temperature to +200°C.

3.2 Continue fabrication of Phase II sensors.



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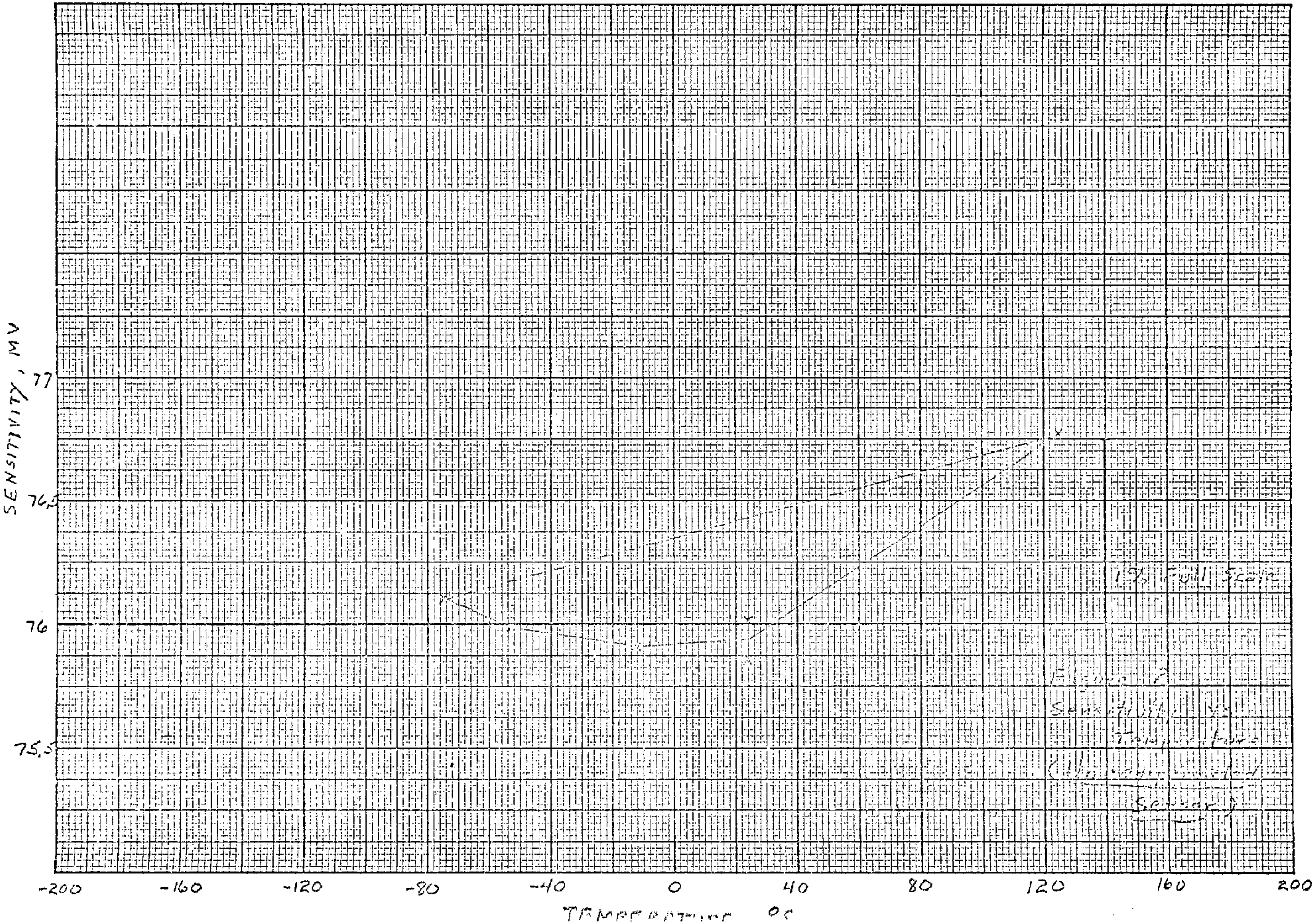

Figure 7
Sensitivity vs Temperature
(Unamplified Sensor)

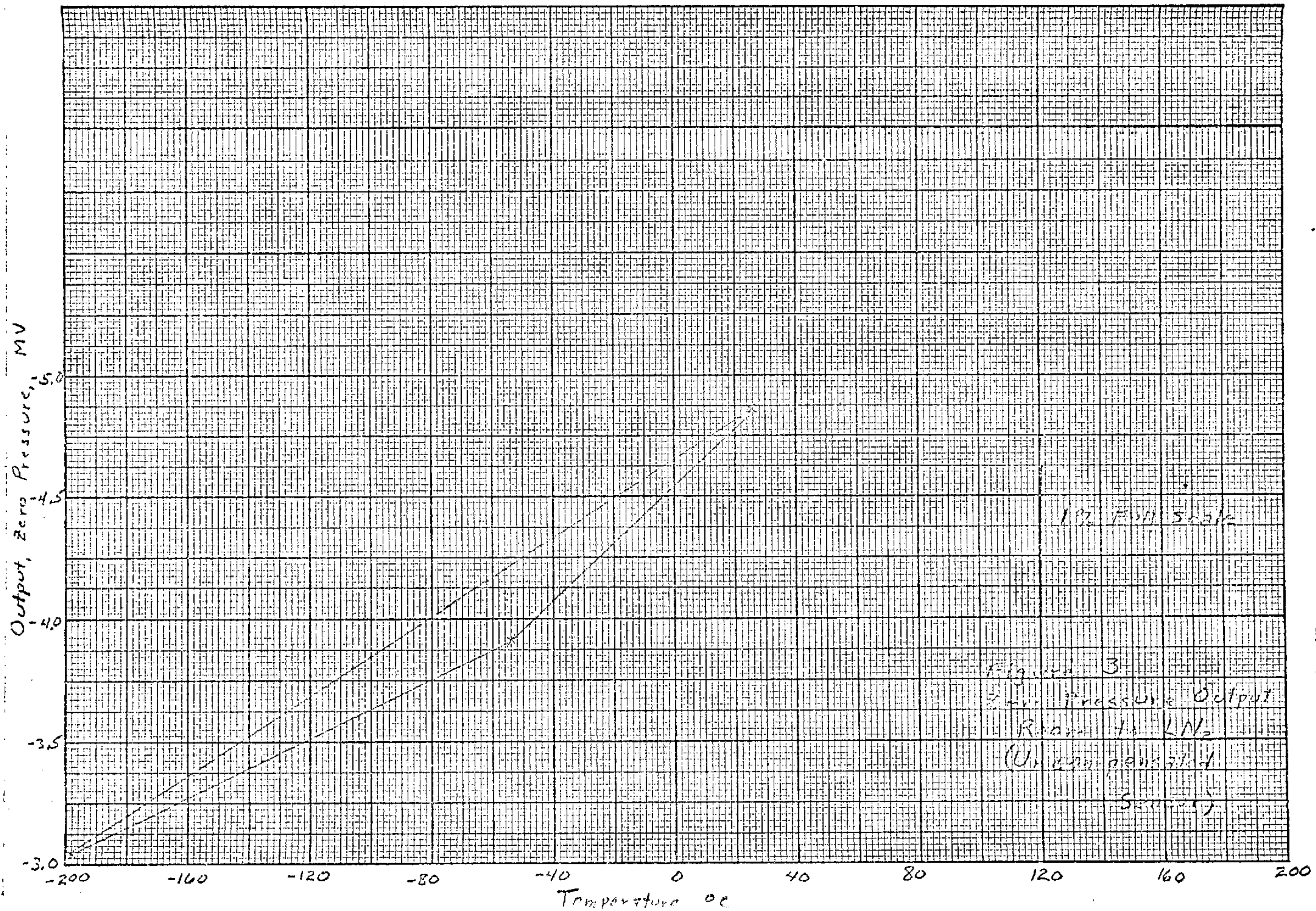

Figure 3
Zero Pressure Output
Range 1, LN$_2$
(Uncompensated
Sensor)

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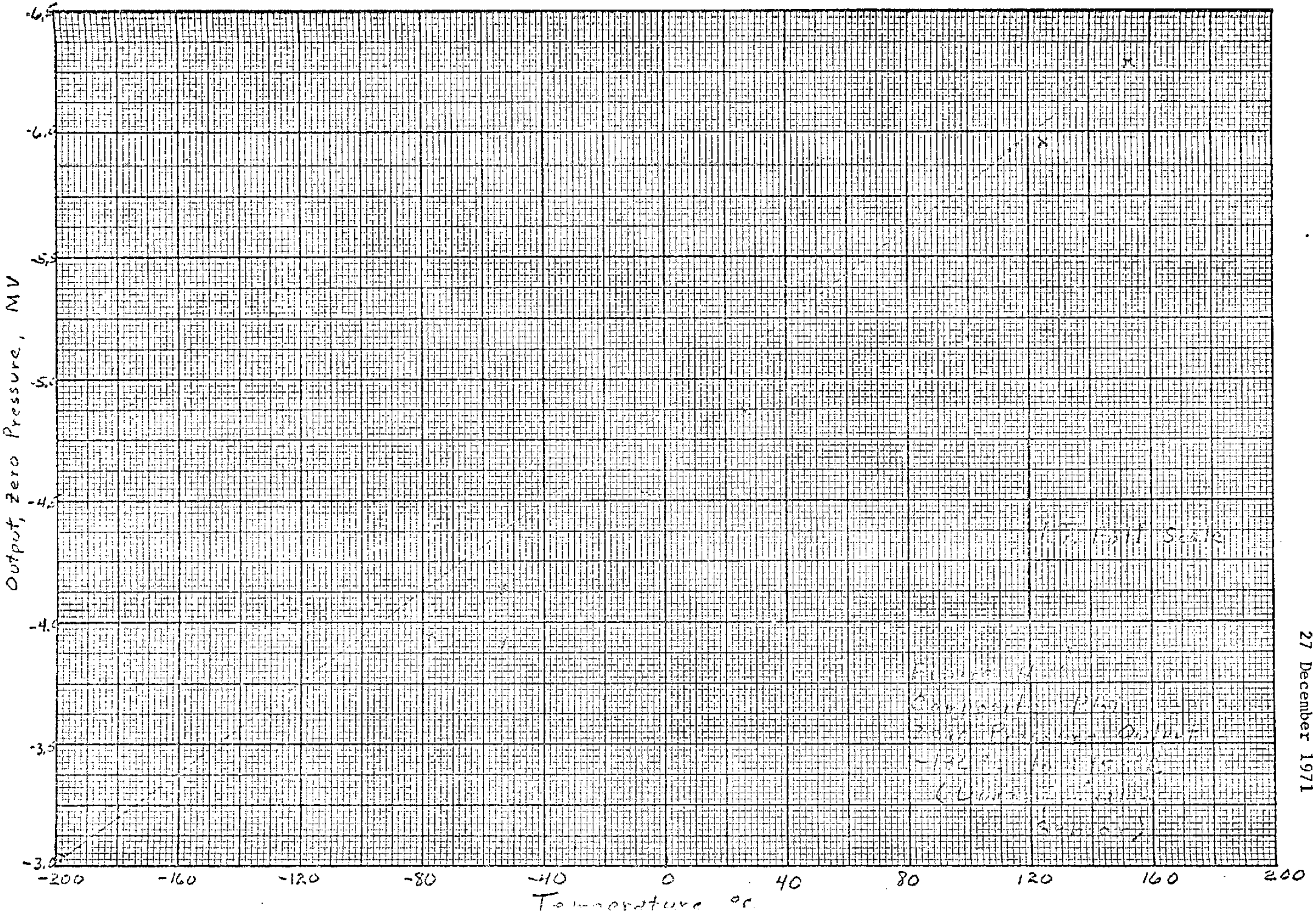

27 December 1971

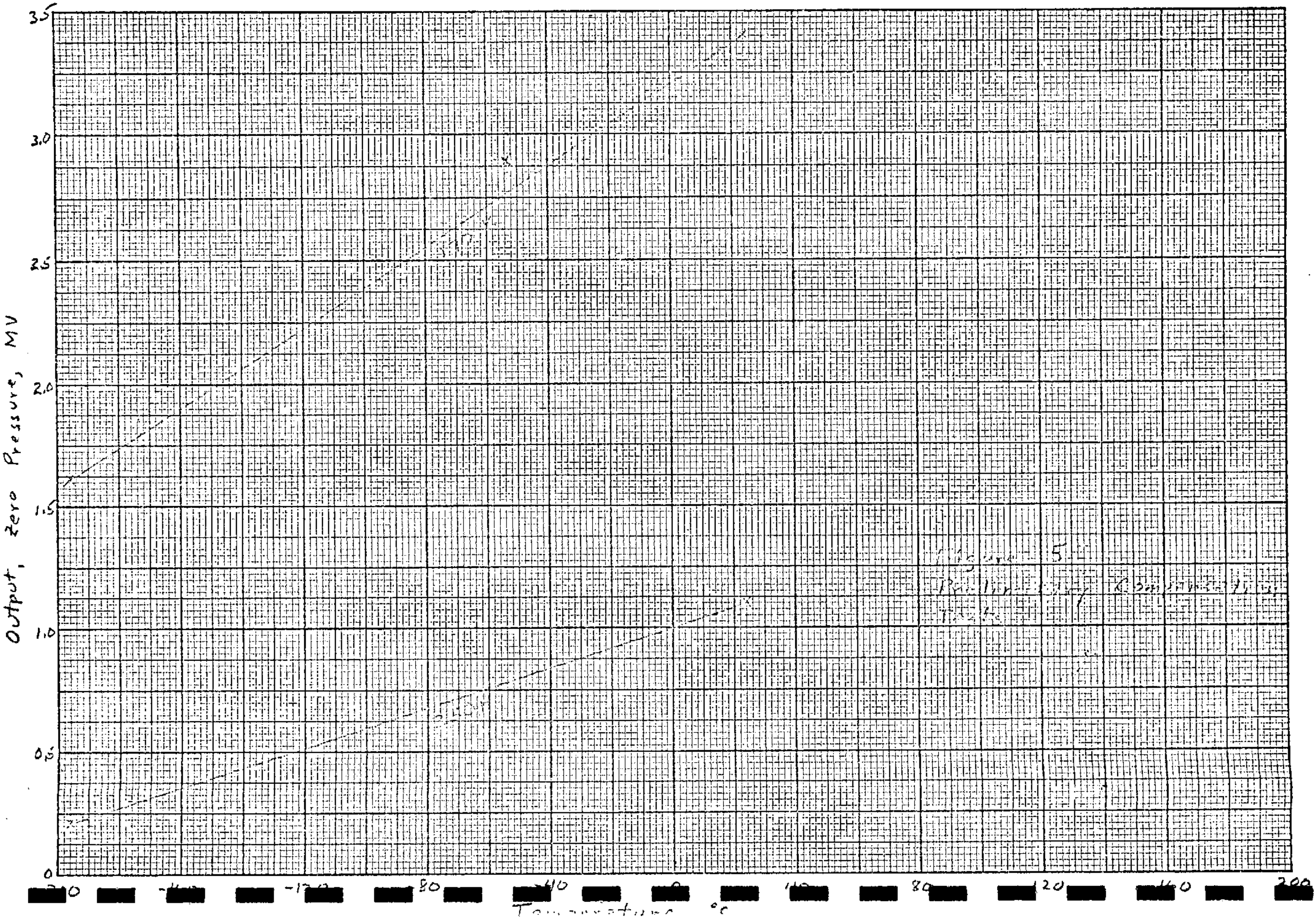

Figure 5

Preliminary Compensation

[illegible]

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25 January 1972

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER
CONTRACT NO. NAS8-27442

PROGRESS REPORT
December 1971

1.0 WORK ACCOMPLISHED DURING REPORTING PERIOD

1.1 Test Results

Cell C/N 268-14 has been subjected to temperature compensation tests from liquid nitrogen temperature to +85°C. Based on results of work reported in the last progress report, it was determined that the required compensation resistor was 363.88 K ohms OTC. This resistor was installed and the transducer tested at zero pressure as indicated in the following table. The results are plotted in Figure 1.

Temp.	Zero Pressure Output (mv)	Zero Shift Percent of Full Scale
Room	-.780	
LN_2	-.779	-.001%
Room	-.766	-.02%
-10°C	-.740	-.05%
-70°C	-.698	-.1%
+45°C	-.738	-.05%
+85°C	-.593	-.24%
Room	-.695	-.1%

Transient behavior was observed when the instrument was suddenly immersed in liquid nitrogen from room temperature and again when

25 January 1972

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER PROGRESS REPORT - December 1971

1.1 Test Results (continued)

the instrument was suddenly removed from liquid nitrogen to room temperature. In either case, the transient excursion was less than 1% (negative on immersion into LN_2, positive when removed). The instrument returned to equilibrium conditions in less than 5 minutes.

1.2 Phase II Sensor Fabrication

Phase II sensor fabrication has been delayed due to problems discussed in previous progress reports. Completion of three sensors is scheduled for 26 January 1972. These sensors have been fabricated with a nominal full scale range of 0 to 30 in. Hg. for accuracy of testing. (A Texas Instruments Pressure Controller is available for testing in this range to an accuracy of 0.015% F.S. In order to prevent program delays, it is anticipated that all temperature testing and compensation studies planned for Phase II be completed using these three instruments.

2.0 PROBLEM AREAS

Problem areas which have been discussed in previous progress reports appear at this time to have been resolved. In order to prevent delays in Phase III of the program, it will be necessary to make a decision by 15 February 1972 whether to use the media isolated design or the standard Model 4715 type sensor cell. In view of the excellent test results obtained on isolated cell C/N 268-14, it is deemed highly desirable to push the fabrication and testing of this type of cell.

25 January 1972

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER PROGRESS REPORT - December 1971

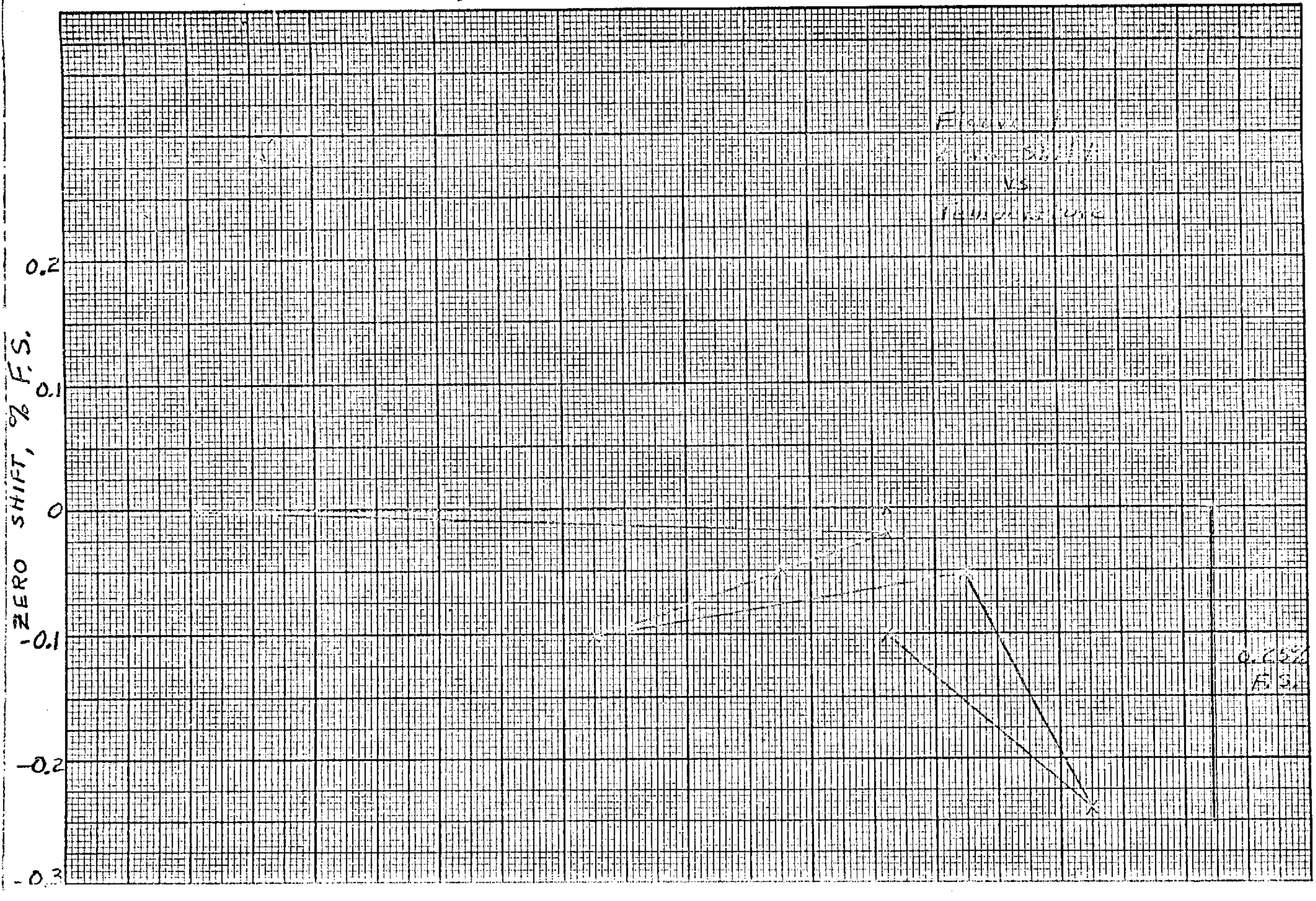
3.0 WORK PLANNED FOR NEXT REPORTING PERIOD

3.1 Complete fabrication of three 0-30 in. Hg. sensors for use in Phase II testing as indicated in paragraph 1.2.

3.2 Begin Phase II temperature testing in accordance with TP 4715-110-1.

4.0 SCHEDULE

Delays resulting from problems previously described have resulted in modification of the program schedule as shown.



25 January 1972

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER

PROGRAM PLAN

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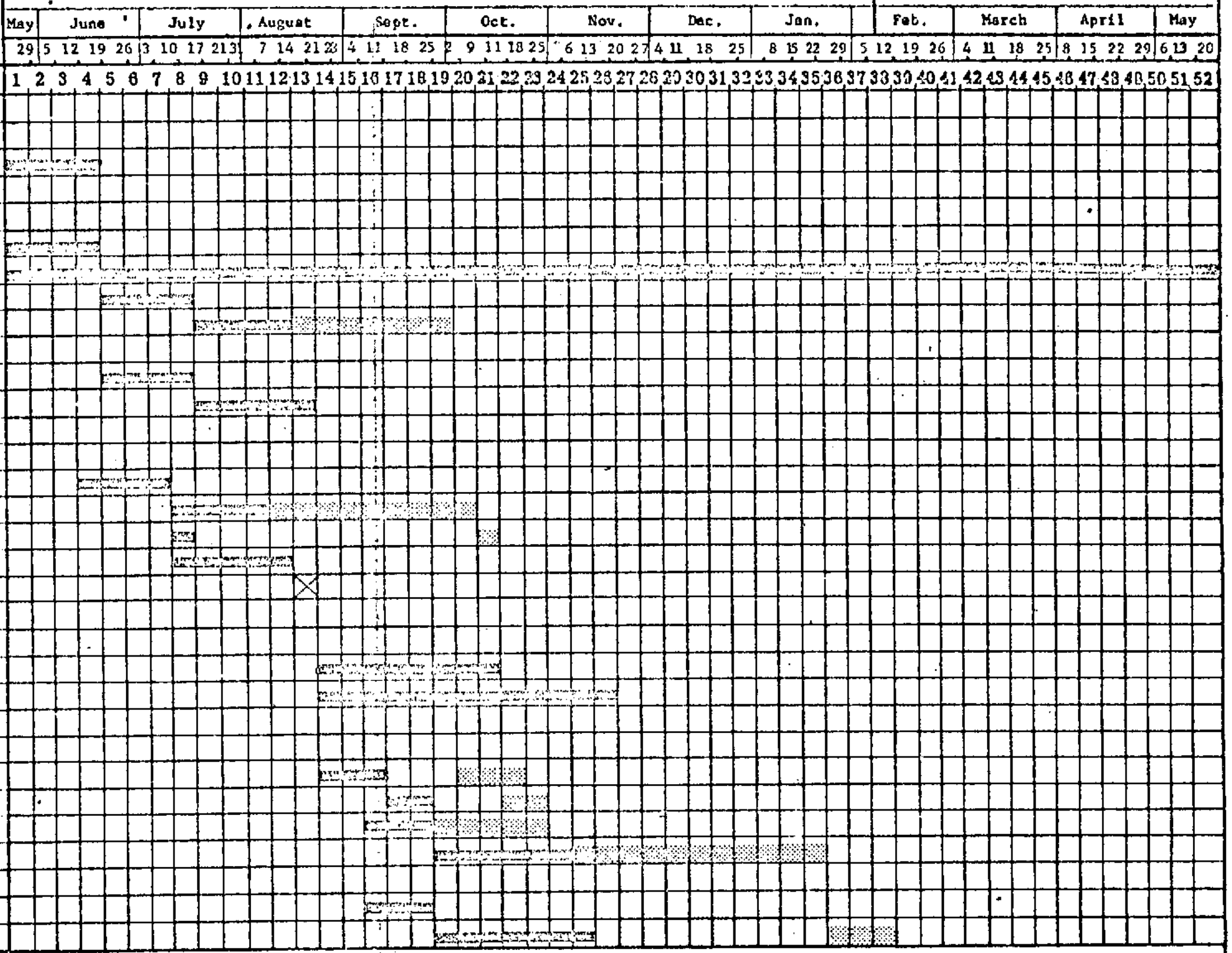

TASK DESCRIPTION

1. PHASE I DESIGN
   - 1.1 Trade-offs involved in use of Media Isolated Transducer *
   - 1.2 Trade-offs involved in use of two bridges on one sensor vs. two sensors *
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   - 1.4 Design of 8000 psi *
     - 1.4.1 Fabricate 8000 psi mask *
   - 1.5 Review of materials for hydrogen embrittlement *
   - 1.6 Preliminary housing design *
   - 1.7 Investigation of Si-Pyrex-Metal sealing
     - 1.7.1 Sealing parameters *
     - 1.7.2 Sensor operation - room temp. *
     - 1.7.3 Sensor exposure - LN_2 temp. *
   - 1.8 Cryogenic test station design *
   - 1.9 Preliminary design review *

2. PHASE II DESIGN VERIFICATION
   - 2.1 Build cryogenic test station
     - 2.1.1 LN_2 *
     - 2.1.2 He *
   - 2.2 Fabricate sensors
     - 2.2.1 Diaphragm diffusion *
     - 2.2.2 Cell fabrication *
     - 2.2.4 Hardware fabrication *
     - 2.2.5 Assembly and preliminary test
   - 2.3 Sensor tests
     - 2.3.1 Test plan *
     - 2.3.2 LN_2 tests

* TASK COMPLETE ▨ RESCHEDULE

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PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER

PROGRAM PLAN

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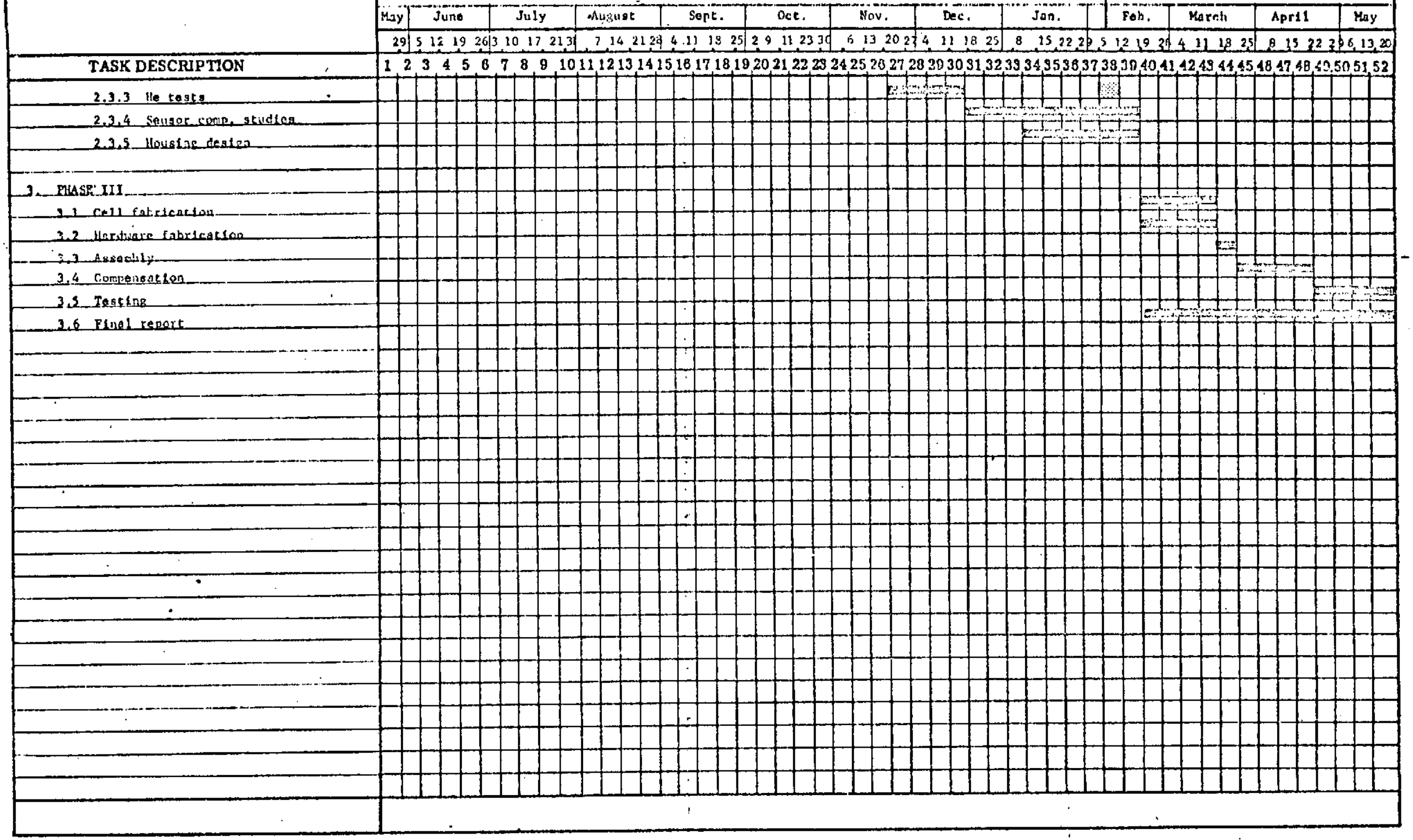

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January 1972

18 February 1972

PRESSURE TRANSDUCER FOR
SPACE SHUTTLE BOOSTER

Contract No. NAS8-27442

Progress Report
January 1972

1.0 Work Accomplished During Reporting Period

1.1 Sensor Fabrication

Fabrication of three transducers for use in Phase II testing was completed.

1.2 Phase II Testing

Phase II testing was begun in accordance with TP 4715-110-1.

2.0 Problem Areas

No new problem areas were encountered during January.

3.0 Work Planned for Next Reporting Period

3.1 Complete Phase II Testing and Compensation Studies.

3.2 A design review is scheduled for Thursday, 24 February 1972 at Marshall Space Flight Center.

3.3 Begin fabrication of Phase III hardware.

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER

PROGRAM PLAN

CONTRACT NAS8-27442

TASK DESCRIPTION

1. PHASE I DESIGN
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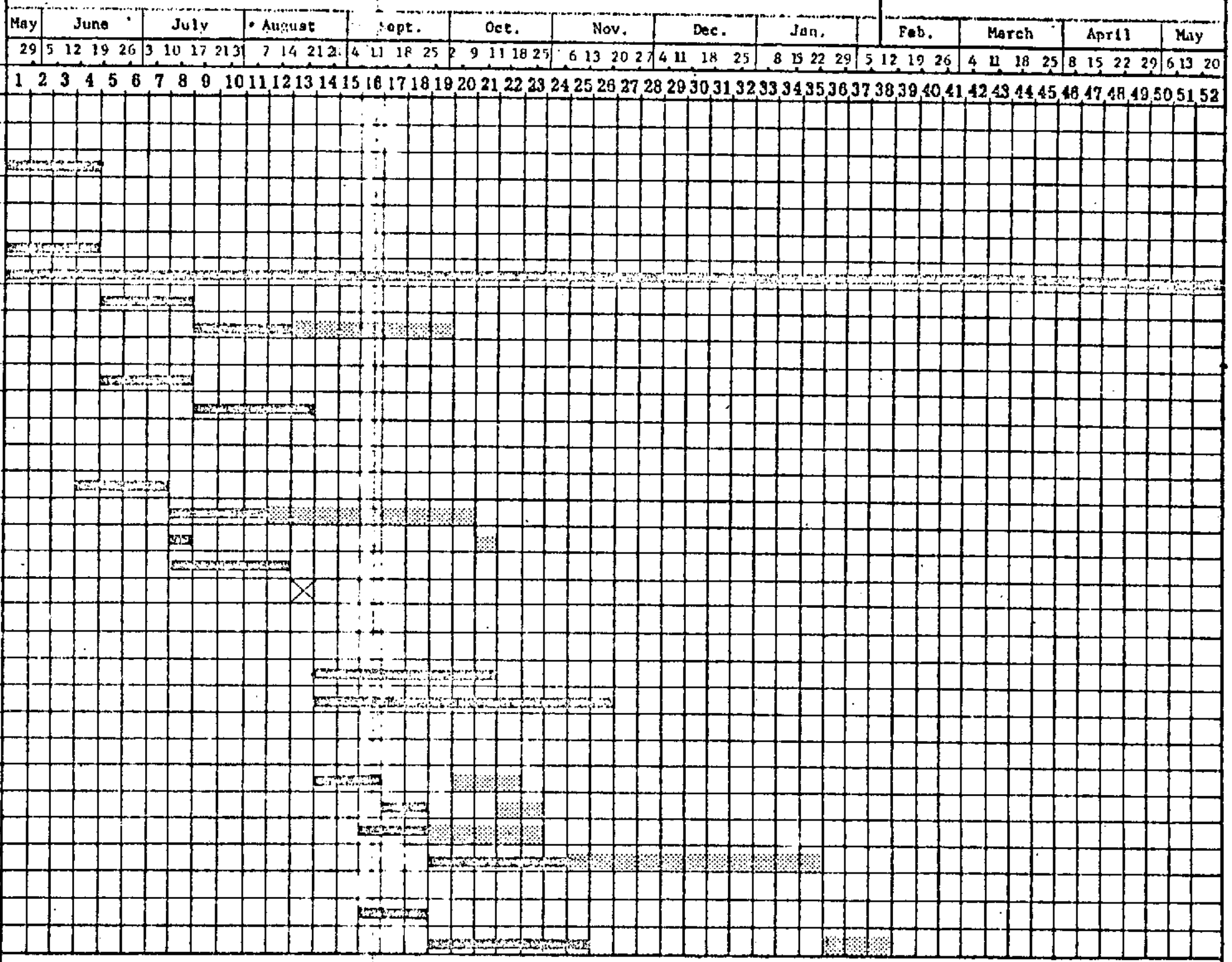
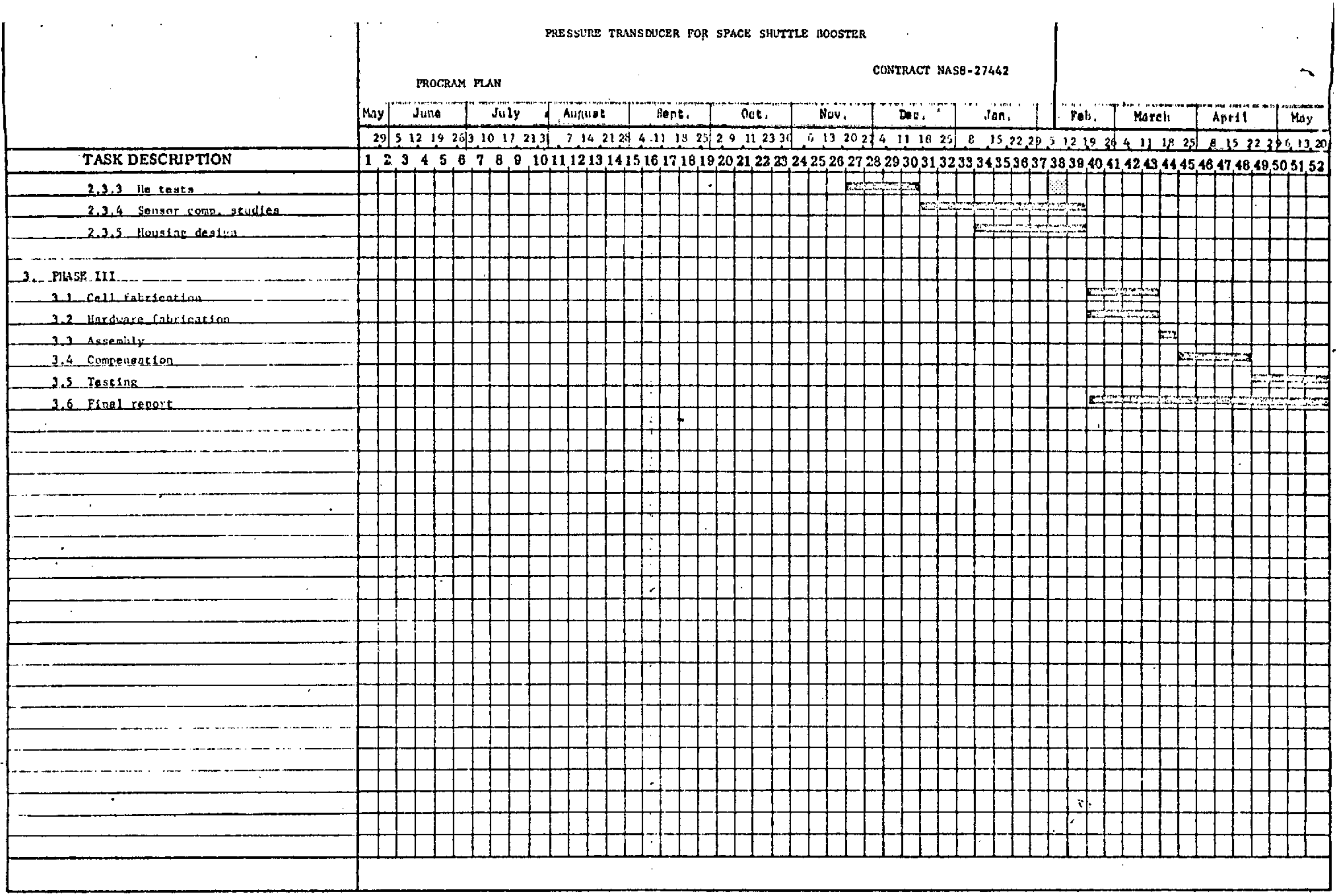
        - 2.3.2 LN_2 tests



* TASK COMPLETE ▨ RESCHEDULE



PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER

PROGRAM PLAN

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Progress Report 10

February 1972

16 March 1972

PRESSURE TRANSDUCER FOR
SPACE SHUTTLE BOOSTER

Contract No. NAS8-27442

Progress Report
February 1972

1.0 Work Accomplished During Reporting Period

1.1 Phase II Testing

Phase II testing was accomplished as follows:

1.1.1 Sensor 301-17

Sensor 301-17 was tested over the temperature range -196°C (LN_2 temperature) to +90°C with the following results:

(1)	Sensitivity (5 ma input, 1 to 30" Hg)	69.4 mv
(2)	Zero Balance	-18.3 mv
(3)	Linearity	.02% (Terminal Point)
(4)	Hysteresis	.02%
(5)	Stability	0.3%

The output at zero and full scale is plotted in Figure 1. The data indicates that with optimum linear compensation the zero output can be held within ±0.3% F.S. and the full scale output within ±0.7% F.S. Calibration data may be found in Table I.

1.1.2 Sensor 301-10

Sensor 301-10 was tested over the range from -70°C to +80°C with the following results:

(1)	Sensitivity (5 ma input)	56.2 mv
(2)	Zero Balance	4.3 mv
(3)	Linearity	.05% F.S. (Terminal Point)

16 March 1972

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER PROGRESS REPORT, February 1972

1.1.2 Sensor 301-10 (continued)

(4)	Hysteresis	.05% F.S.
(5)	Stability	±0.45% F.S.
(6)	Repeatability	±.05% F.S.

Calibration data may be found in Table II. The zero and full scale output are shown in Figure 2. Sensor 301-10 developed a leak during the last pressure cycle.

1.1.3 Sensor 194-2

Sensor 194-2 was tested over the range -196°C (LN$_2$ temperature) to +95°C with the following results:

(1)	Sensitivity (10 ma input)	116.7 mv
(2)	Zero Balance	39.25 mv
(3)	Linearity	0.13% F.S. (Terminal Point)
(4)	Hysteresis	.01% F.S.
(5)	Stability	±.05% F.S.

Calibration data may be found in Table III. The data plotted in Figure 3 indicates that both zero and sensitivity may be compensated within ±1% error bands over the entire 291°C temperature span.

1.2. Design Review Meeting

A design review was held on Thursday, 24 February 1972 at Marshall Space Flight Center. The Phase II test data was presented and discussed. Also discussed were the problems in achieving reliable glass-metal bonds between the kovar and the pyrex parts. It was agreed that, while there is some risk of overrun involved in proceeding with the silicon-glass-metal approach, the test results and media compatibility advantages justify proceeding with this approach.

16 March 1972

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER PROGRESS REPORT, February 1972

2.0 Problems Encountered

While no new problems were encountered during February, new information was brought to light relative to the recurring problem of making reliable glass-metal bonds. Pyrex was selected and is presently being used for the glass parts on the basis of the close match in expansion coefficient with both silicon and kovar. Recent information indicates that glasses are available which provide a much closer match to kovar. Figure 4 shows a comparison in the expansion of kovar; pyrex and two of the "kovar sealing" glasses, Corning code 7056 and 7052. It has been found that temperatures up to 500°C and above are required to make an acceptable seal. A seal made with kovar at this temperature would have a residual strain of approximately 1400 μin./in. when cooled to room temperature. The "kovar sealing" glasses would have virtually no built-in strain. The "strain points" indicated in Figure 4 are defined as the temperature at which strain in the glass will be relieved in 14 hours. Since code 7052 glass is more readily available than 7056, this glass has been placed on order and is due in by 1 April 1972. Tests will be performed to evaluate this glass before the final assembly of hardware for this program.

In order to study the residual strains, a polariscope has been assembled. It has been found that nearly all the strain occurs at the pyrex-kovar interface and virtually none at the pyrex-silicon interface.

3.0 Work Planned for Next Reporting Period

3.1 Begin fabrication of Phase III parts.

3.2 Procure samples of Corning code 7052 glass for evaluation.

16 March 1972

CONRAC CORPORATION

TEST DATA

PROGRAM Space Shuttle Booster

MODEL NO. ________ S/N 301-17

TECH. GLV DATE ________

PROCEDURE & PARA. NO.

Date	2-10-72	2-11-72 →			2-11-72	
Temperature	Initial Room	Room	-35°C	Room	+90°C	Room
V_{in}	5.6061	5.6014	5.1396	5.6136	6.1325	5.6057
Zero Pressure	-18.137	-18.149	-18.852	-18.250	-17.787	-18.136
30" *	-19.396	-18.915	19.807	19.234	-18.752	-19.287
29"	-17.008				-16.337	
22.5"	-1.460				-.602	
15"	16.491				17.555	
7.5"	34.448				35.694	
1"	50.031	50.518	48.949	50.205	51.456	50.141
7.5"	34.458				35.720	
15"	16.505				17.571	
22.5"	-1.444				-.579	
29"	-16.995					
30"	-19.389	-18.911	-19.809	-19.230	-18.738	-19.274
	279.044	281.008	280.195	280.126	280.255	279.495
	18.131	18.143	18.857	18.244	-17.774	-18.128
	69.427	69.433	68.756	69.439	70.208	69.428

REMARKS

Input Current 5 ma

*Pressure applied to low port
Ambient applied to high port

TABLE I

CALIBRATION DATA, C/N 301-17

NOTE: Output reading
in millivolts

16 March 1972

CONRAC
CORPORATION

TEST DATA

PROGRAM Space Shuttle Booster

MODEL NO. ________ S/N 301-17

TECH. GLV DATE ________

PROCEDURE & PARA. NO.

	Current Supply has been adjusted 2-15-72			Current Supply adjusted 2-16-72		
Temperature	Room	LN_2	LN_2	Room	Corrected	
V_{in}	5.6188	4.1700		5.6242	5.6045	
Zero Pressure	-18.181	-20.364		-18.435		
30" *	-19.280	-21.430	-21.482	-19.608		
29"		-19.075	-19.133			
22.5"		-3.900				
15"		13.7	13.85			
7.5"						
1"	50.284	46.4	46.6	50.063		
7.5"						
15"		13.860	13.90			
22.5"						
29"		-19.125				
30"	-19.261	-21.480	-21.444	19.606		
			20.359	18.437		
	69.564		65.733	69.671		

REMARKS

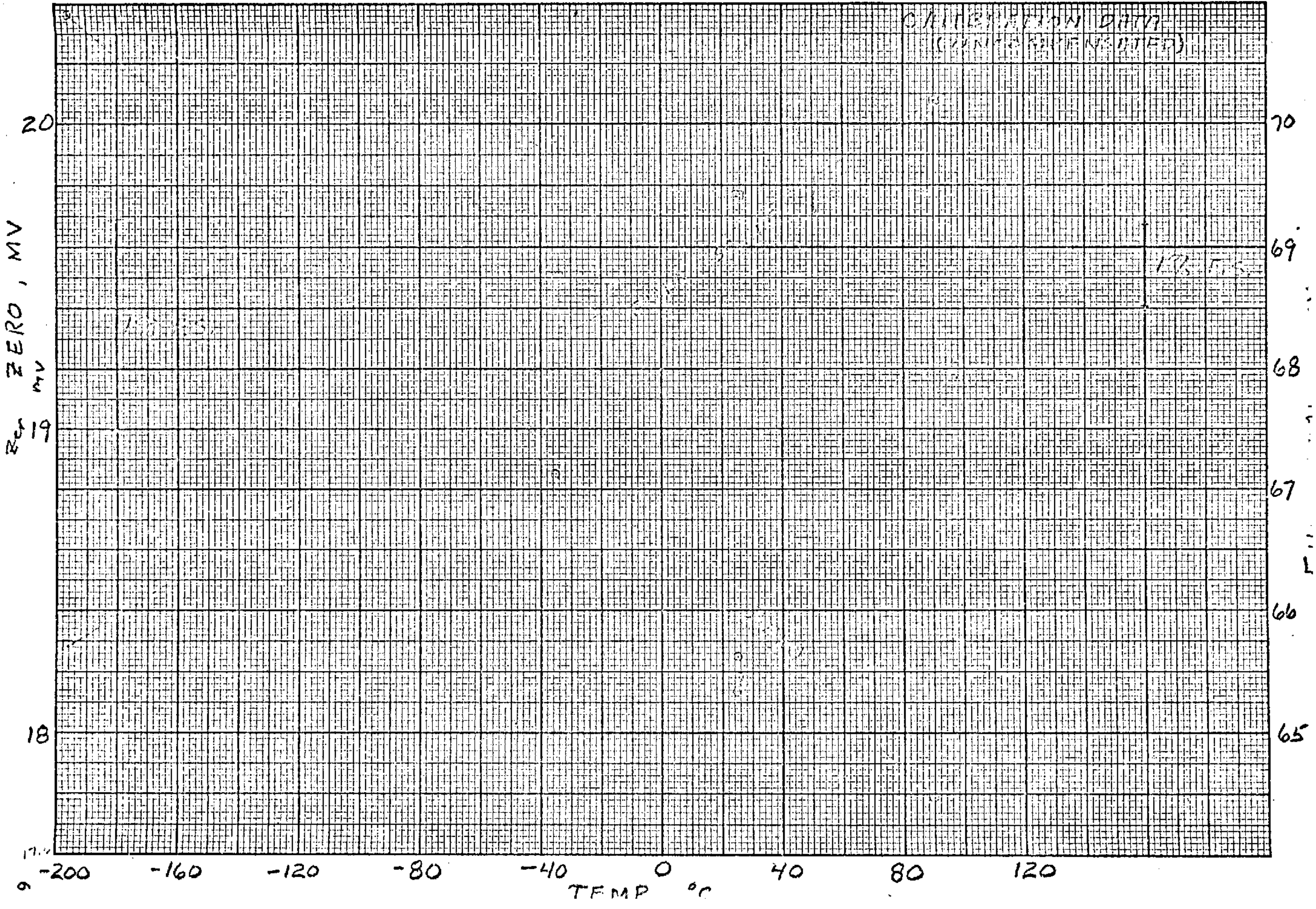
Input Current 5 ma

*Pressure applied to low port
Ambient applied to high port

TABLE I (continued)

NOTE: Output reading
in millivolts

FIGURE I
C/N 301-17



16 March 1972

CONRAC
CORPORATION

TEST DATA

PROGRAM Space Shuttle Booster

MODEL NO. ______ S/N 301-10

TECH. GLV DATE ______

PROCEDURE & PARA. NO.

Temperature	Room	Room	Room			
V_{in}		5.0355	5.0354			
Zero Pressure	4.063	4.065	4.064			
30" *	3.300	3.295	3.276			
29"	5.238	5.226	5.192			
22.5"	17.820	17.785	17.787			
15"	32.354	32.319	32.335			
7.5"	46.898	46.860	46.861			
1"	59.502	59.479	59.468			
7.5"	46.894	46.878	46.880			
15"	32.363	32.344	32.342			
22.5"	17.826	17.794	17.807			
29"	5.239	5.223	5.216			
30"	3.294	3.284	3.265			
		280.210	280.165			

REMARKS

Input Current 5 ma

*Pressure applied to low port
Ambient applied to high port

TABLE II

NOTE: Output reading in millivolts

CALIBRATION DATA, C/N 301-10

16 March 1972

CONRAC
CORPORATION

TEST DATA

PROGRAM Space Shuttle Booster
MODEL NO. S/N 301-10
TECH. GLV DATE

PROCEDURE & PARA. NO.

	2-7-72		2-8-72 →			2-8-72
Temperature	-45°C		Room	+80°C	Room	-45°C
V_{in}	4.5760	4.5737	5.0436	5.4754	5.0510	4.5619
Zero Pressure	2.724	2.708	4.573	6.082	4.423	2.830
30" *	1.932	1.916	3.836	5.304	3.533	1.912
29"	3.862		5.770	7.234	5.462	3.848
22.5"	16.388		18.348	19.909	18.048	16.376
15"	30.878		32.884	34.562	32.594	30.839
7.5"	45.378		47.411	49.190	47.129	45.328
1"	57.949		59.985	61.890	59.669	57.775
7.5"	45.376		47.416	49.200	47.136	45.327
15"	30.874		32.889	34.561	32.600	30.843
22.5"	16.386		18.354	19.921	18.060	16.356
29"	3.845		5.761	7.234	5.449	3.826
30"	1.914		3.824	5.285	3.535	1.900
	280.085		4.559	6.080	4.426	2.817
			280.362	280.135	279.605	279.474

REMARKS

Input Current 5 ma

*Pressure applied to low port
Ambient applied to high port

TABLE II (continued)

NOTE: Output reading
in millivolts

CONRAC CORPORATION

TEST DATA

PROGRAM Space Shuttle Booster

MODEL NO. ______ S/N 301-10

TECH. GLV DATE ______

PROCEDURE & PARA. NO.

	2-9-72	2-9-72				
Temperature	Room	+80°C	Room	-45°C	-70°C	
V_{in}	5.0393	5.4721	5.0664	4.5521	4.3896	
Zero Pressure	4.658	6.134	4.576	2.880	2.443	
30" *	3.705	5.107	3.415	1.727	1.320	
---	----	----				
22.5"	18.208	----				
15"	32.755	----				
7.5"	47.289	----				
1"	59.832	61.721	59.518	57.488	56.970	
7.5"	47.297					
15"	32.762					
22.5"	18.214					
29"	5.639					
30"	3.679	5.109	3.411	1.717	1.300	
	279.344	279.055	278.445	278.408	278.475	

REMARKS

Input Current 5 ma

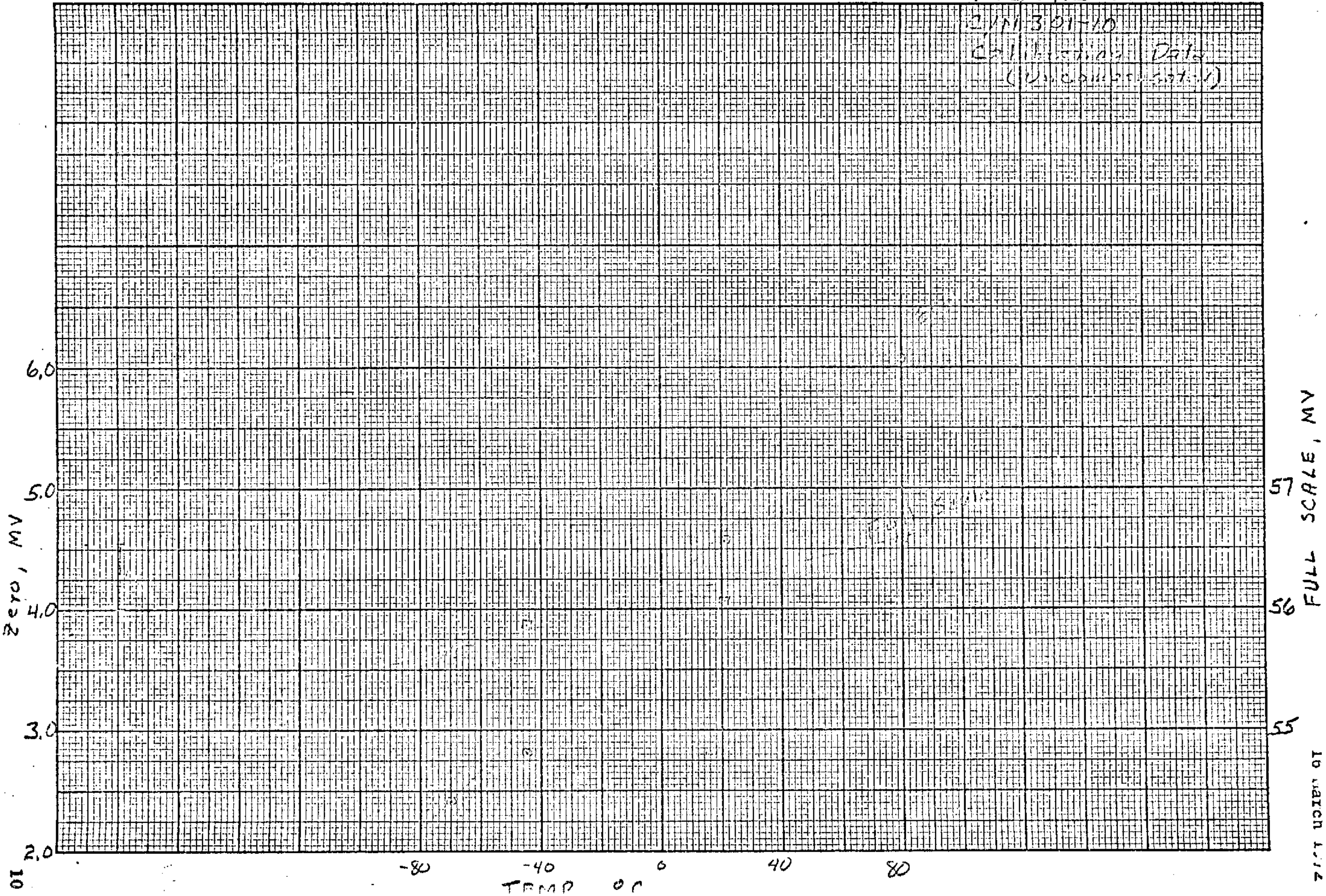
*Pressure applied to low port
Ambient applied to high port

TABLE II (continued)

NOTE: Output reading
in millivolts

CC-IP-4 Rev.

FIGURE 2


2/N 391-10
Calibration Data
(Uncompensated)
Zero, MV
6.0
5.0
4.0
3.0
2.0
FULL SCALE, MV
57
56
55
-80
-40
0
40
80
TEMP °C

CONRAC
CORPORATION

TEST DATA

PROGRAM Space Shuttle Booster

MODEL NO. ____________ S/N 194-2

TECH. GLV DATE ____________

PROCEDURE & PARA. NO.

	← 2-17-72 →		2-18-72	2-18-72		
Temperature	Initial Room	-50°C	Room	+95°C	Room	LN_2
V_{in}	8.1346	7.3908	8.1228	8.7273	8.1386	6.2569
Zero Pressure	39.222	36.30	39.203	37.827	39.296	37.200
30" *	37.066	34.16	37.362	35.999	37.283	35.20
29"	41.074	38.15		40.000		39.22
22.5"	67.131	64.14	67.420	65.965		65.45
15"	97.288	94.22	97.571	95.986		95.920
7.5"	127.54	124.42	127.81	126.08		126.67
1"	153.81	150.70	154.06	152.17	154.03	153.75
7.5"	127.53	124.42	127.81	126.06		127.14
15"	97.279	94.20	97.576	95.962		96.36
22.5"	67.126	64.10	67.430	65.938		65.88
29"						
30"	37.055	34.10	37.364	35.970	37.284	35.62
	278.938		279.625	279.680	279.265	
			39.223	37.798	39.300	37.638
Sensitivity	116.74	116.54	116.70	116.17		118.65

REMARKS

Input Current 10 ma

*Pressure applied to low port
Ambient applied to high port

TABLE III

CALIBRATION DATA, C/N 194-2

NOTE: Output readings
in millivolts

16 March 1972

CONRAC CORPORATION

TEST DATA

PROGRAM Space Shuttle Booster

MODEL NO. ______ S/N 194-2

TECH. GLV DATA ______

PROCEDURE & PARA. NO.

Temperature	LN$_2$					
V_{in}	6.2560					
Zero Pressure	37.612					
30"*	35.62					
29"	39.62					
22.5"	65.86					
15"	96.80					
7.5"	127.11					
1"	153.97					
7.5"	127.11					
15"	96.80					
22.5"	65.87					
29"						
30"	35.60					
	279.300					
	37.62					

REMARKS

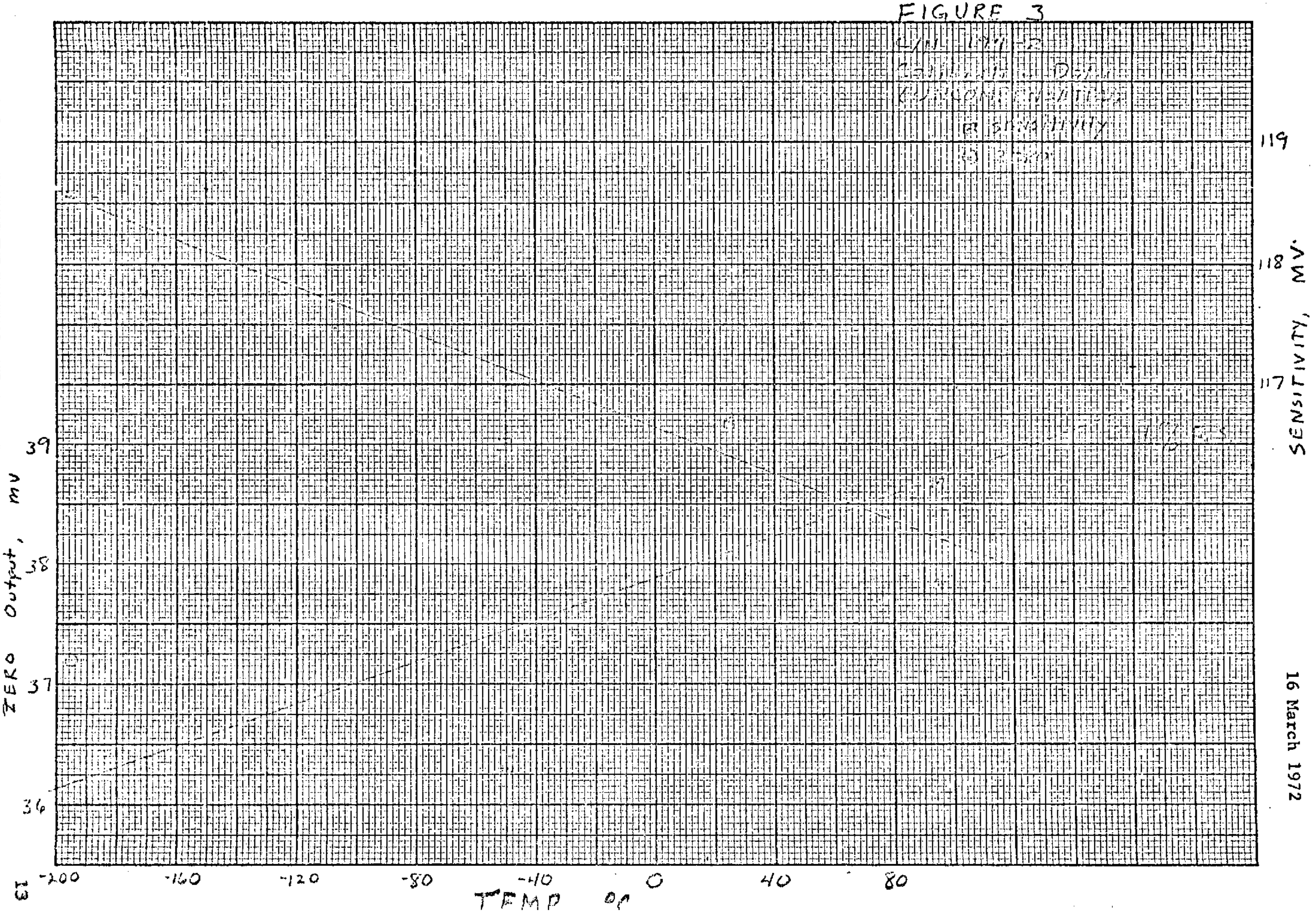
Input Current 10 ma

*Pressure applied to low port
Ambient applied to high port

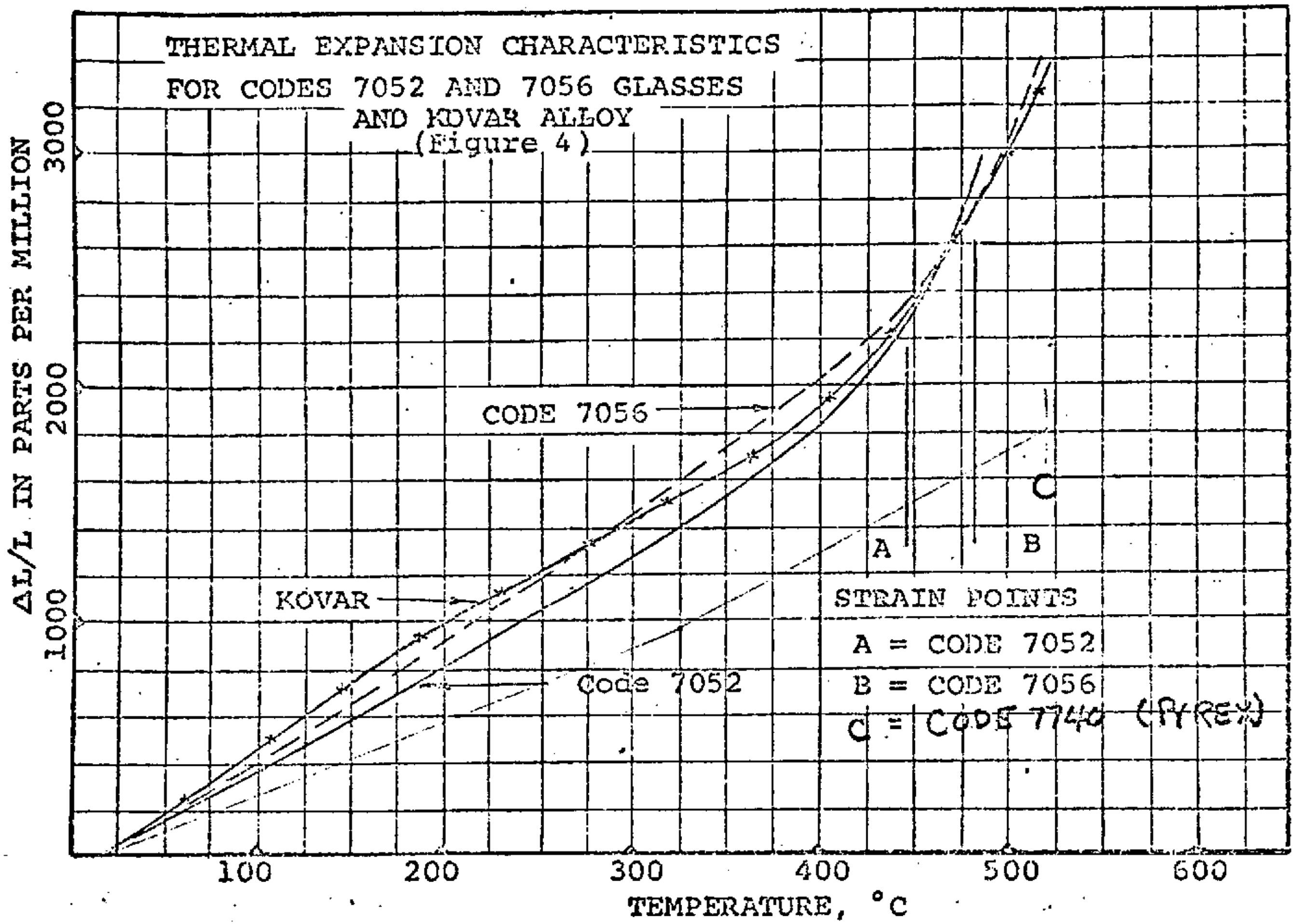
TABLE III (continued)

NOTE: Output readings
in millivolts

FIGURE 3



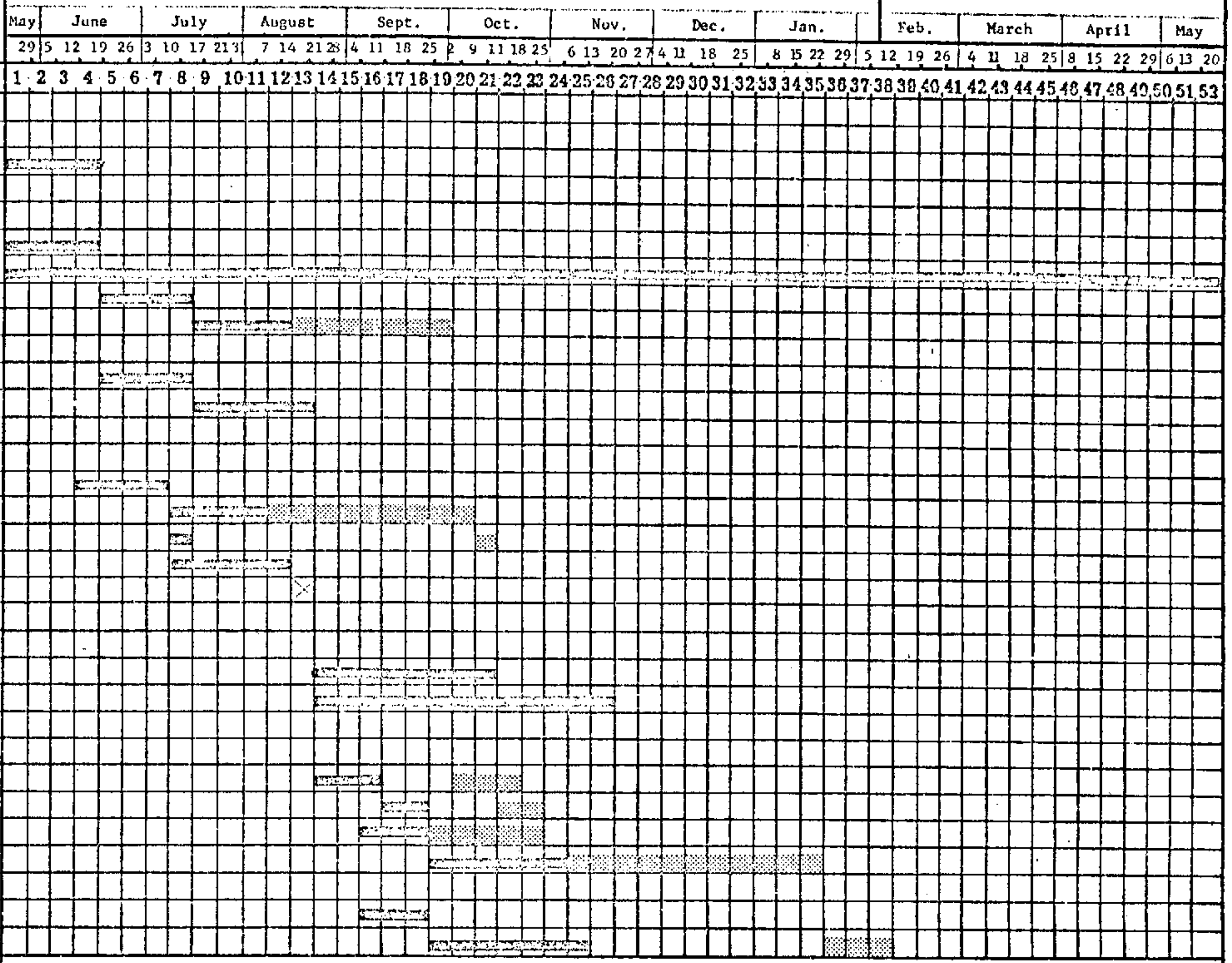
16 March 1972


THERMAL EXPANSION CHARACTERISTICS
FOR CODES 7052 AND 7056 GLASSES
AND KOVAR ALLOY
(Figure 4)
ΔL/L IN PARTS PER MILLION
3000
2000
1000
CODE 7056
KOVAR
Code 7052
A
B
C
STRAIN POINTS
A = CODE 7052
B = CODE 7056
C = CODE 7740 (PYREX)
100
200
300
400
500
600
TEMPERATURE, °C

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER

PROGRAM PLAN

CONTRACT NAS8-27442



TASK DESCRIPTION

1. PHASE I DESIGN
1.1 Trade-offs involved in use of Media Isolated Transducer *
1.2 Trade-offs involved in use of two bridges on one sensor vs. two sensors *
1.3 Selection of compensation resistors
1.4 Design of 8000 psi *
1.4.1 Fabricate 8000 psi mask *
1.5 Review of materials for hydrogen embrittlement *
1.6 Preliminary housing design *
1.7 Investigation of Si-Pyrex-Metal sealing
1.7.1 Sealing parameters *
1.7.2 Sensor operation - room temp *
1.7.3 Sensor exposure - LN_2 temp. *
1.8 Cryogenic test station design *
1.9 Preliminary design review *

2. PHASE II DESIGN VERIFICATION
2.1 Build cryogenic test station
2.1.1 LN_2 *
2.1.2 He *
2.2 Fabricate sensors
2.2.1 Diaphragm diffusion *
2.2.2 Cell fabrication *
2.2.4 Hardware fabrication *
2.2.5 Assembly and preliminary test *
2.3 Sensor tests
2.3.1 Test plan *
2.3.2 LN_2 tests *

* TASK COMPLETE ▨ RESCHEDULE

1/C-C-127-8/68

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER

PROGRAM PLAN

CONTRACT NAS8-27442

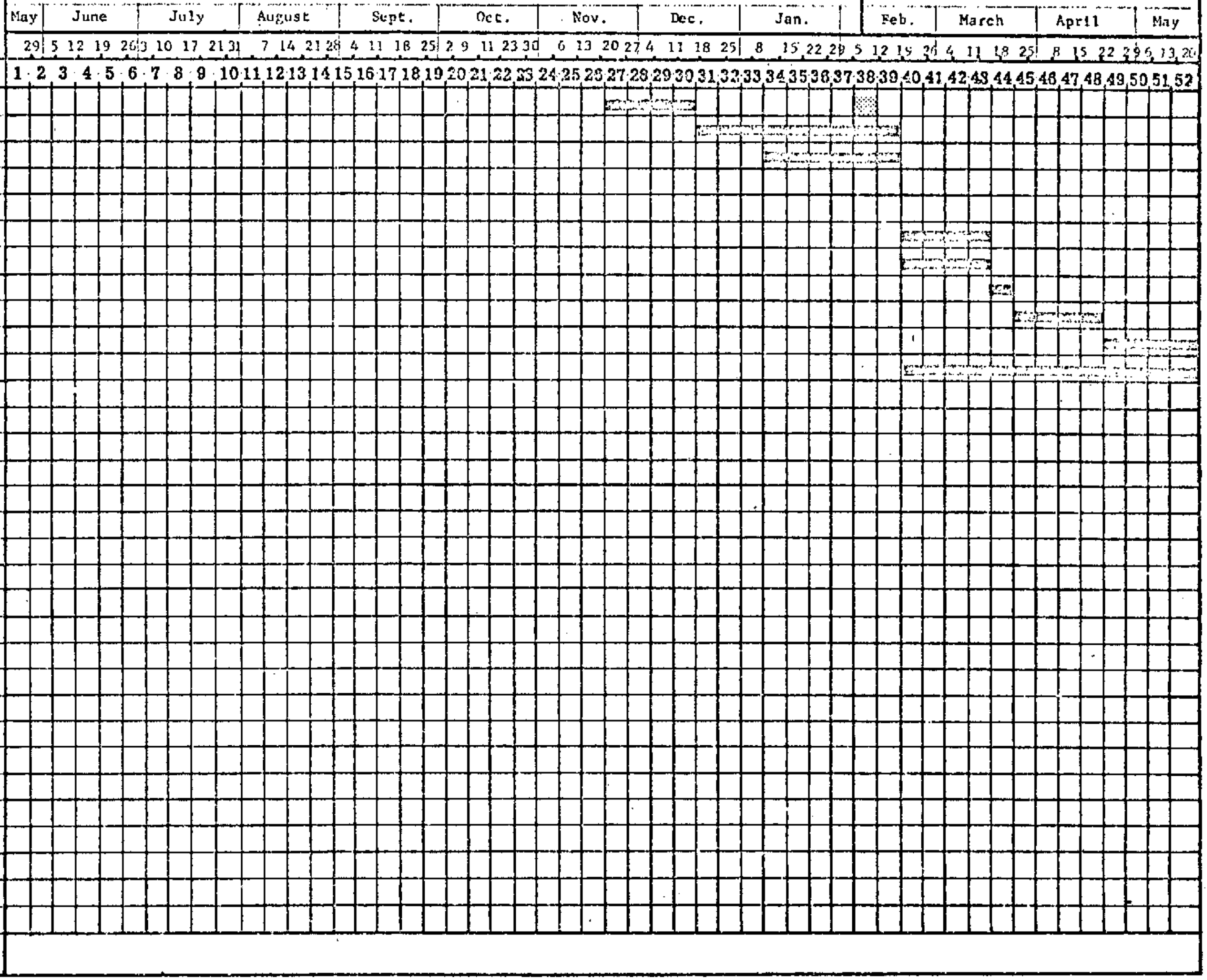
TASK DESCRIPTION

2.3.3 He tests

2.3.4 Sensor comp. studies

2.3.5 Housing design

3. PHASE III
   - 3.1 Cell fabrication
   - 3.2 Hardware fabrication
   - 3.3 Assembly
   - 3.4 Compensation
   - 3.5 Testing
   - 3.6 Final report



1/C-E-127-8/68

4.0 PHASE III - PROTOTYPE FABRICATION

The prototype fabrication phase is reported in Progress Reports 11 through 19. The final results were not formally documented, but will be reviewed herein.

Investigation into substituting a glass such as Corning 7052 caused a slippage in the program schedule, inasmuch as a new sealing procedure had to be developed (Progress Report 11) and glass delivery from vendors (which could not meet exacting polishing requirements) delayed the program approximately ten weeks. When tested it was found that the 7052 glass bonded quite well to kovar and did not crack, even at LN_2 temperatures. However, after many tests in which bonding parameters were varied, it was not possible to bond the 7052 glass to the silicon cell (see Progress Report 14).

An alternate to using the silicon-7052 glass-kovar was investigated and consisted of using a composite glass material which consisted of a sandwich of glass with pyrex on one surface to seal to the silicon and 7052 on the other surface for sealing to the kovar. This approach did not prove practical in that it was developmental in nature, was very expensive, and would require a long development period. This additional program delay was approved and another approach was pursued.

The sensor was redesigned (see Progress Report 15) so that the shear stresses due to thermal expansion were acceptable. Units were built and thermally shocked to liquid nitrogen temperatures without failure. The first unit was damaged during bonding of the gold leads to the silicon cell and tooling was

4.0 PHASE III - PROTOTYPE FABRICATION (continued)

modified to apply heat directly to the cell as opposed to heating the cell from the bottom of the sensor assembly, through the kovar base and the pyrex ring.

The revised tooling was not capable of localizing the high temperature at the cell for gold lead bonding and units were continually destroyed. The cell body was redesigned to replace the glass with AL_2O_3 ceramic which could withstand the thermal shock. New cells were made, ceramic parts fabricated, and sensor tests were run in November 1973. Cells were completed to the extent that we were able to make component selection and to subject them to various pressure levels to record sensitivity, linearity and temperature coefficient. Initial results indicated that the sensitivity was very low, beyond a useful range, and the temperature performance, while linear over a narrow temperature range, would not be effective over a very wide temperature range, particularly when operating at cryogenic temperatures. Apparently in utilizing a new base to support the diaphragm which was capable of withstanding thermal shock (which previously destroyed diaphragms), we distorted cell performance to the point that we rejected this approach.

The program was put on hold because there were no alternatives to pursue. A program review was held at Conrac with Ray Holder, NASA-MSFC on 14 November 1973 and it was agreed that all existing designs tried would not meet the SOW specification, therefore the program was considered completed.

ER 4715-98

Progress Report 11

March 1972

CONRAC
CORPORATION

17 April 1972

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER

Contract No. NAS8-27442

Progress Report
March 1972

1.0 Work Accomplished During Reporting Period

1.1 Evaluation of Corning 7052 Glass

The Corning 7052 Glass has been received and is being cut to shape. The raw glass was 1/4 inch thick and not flat or polished. The cut pieces will be returned to the vendor for polishing to final thickness and flatness.

1.2 Revision of Glass-Metal-Silicon Bonding Procedure

The process for forming this seal has been the subject of continuing development during the course of the program. The procedure as it presently exists is summarized in Appendix A. This procedure supersedes the one reported in the July progress report and will be used in the fabrication of Phase III sensors.

2.0 Problems Encountered

No problems were encountered during this reporting period.

3.0 Activities Planned for Next Reporting Period

Complete preparation of Corning 7052 glass parts for evaluation.

4.0 Schedule

It is necessary to revise the delivery schedule to permit evaluation of Corning 7052 glass prior to assembly of Phase III hardware. The attached schedule is submitted to replace the remainder of the original program plan.

APPENDIX A

SILICON-GLASS-METAL SEAL PROCEDURE

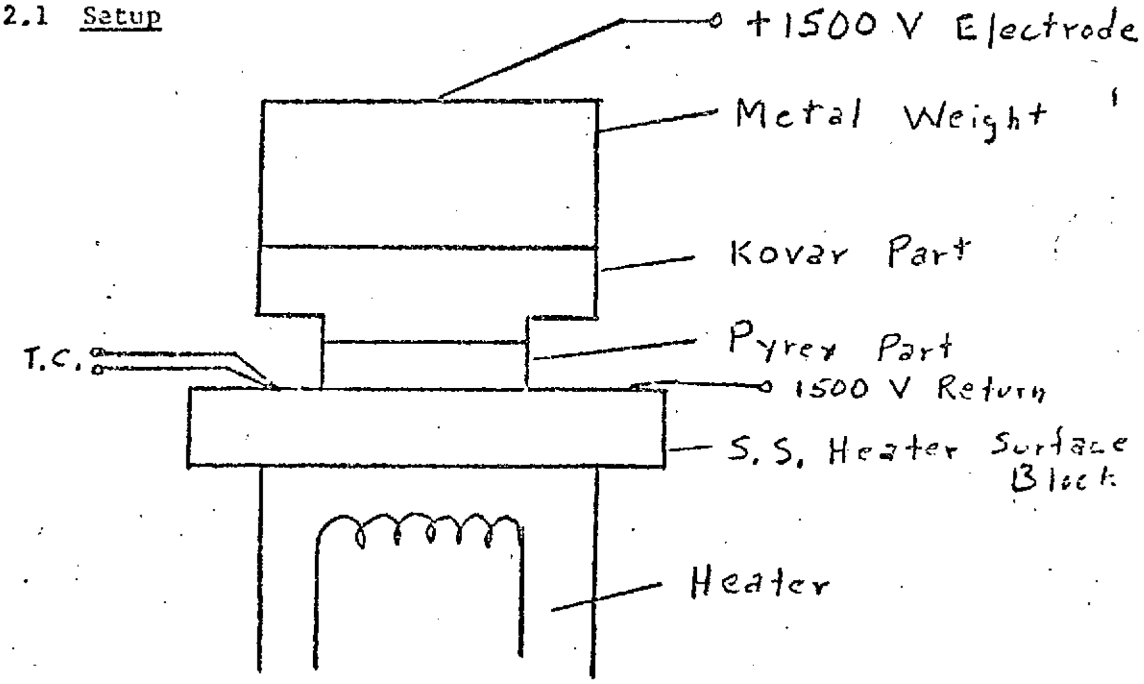
1.0 GENERAL

1.1 Clean and lap electrodes before bonding.

1.2 Mating surfaces must be free of dust.

2.0 GLASS-METAL SEAL

2.1 Setup



2.2 Procedure

2.2.1 Parts Preparation

2.2.1.1 Glass Part

(1) Etch cylindrical edges with 40% HF at room temperature.

APPENDIX A (continued)

2.2.1.1 Glass Part (continued)

(2) Polish to 2 light bands.

(3) Inspect with polariscope for strains.

(4) Cleaning: Degrease thoroughly with TCE or other organic solvent. Rinse with acetone immediately prior to assembly.

2.2.1.2 Kovar Part

(1) Lap bonding surface flat.

(2) Polish to 2 light bands.

(3) Inspect with polariscope for strains.

2.2.2 Assembly

2.2.2.1 Assemble parts in vacuum system as shown in 1.1.

2.2.2.2 Connect high voltage supply with ammeter (Triplett).

2.2.2.3 Evacuate to $< 5 \times 10^{-5}$.

2.2.2.4 Turn on high voltage, bring up to 1500 Vdc. Monitor and record current vs time. If arcing occurs, turn down voltage.

2.2.2.5 Heat to 800°F as indicated on T.C. Current should increase to 3-4 ma.

2.2.2.6 Current should decay away to $<$ 0.1 ma over a period of 5 to 20 min.

2.2.2.7 Cool.

APPENDIX A (continued)

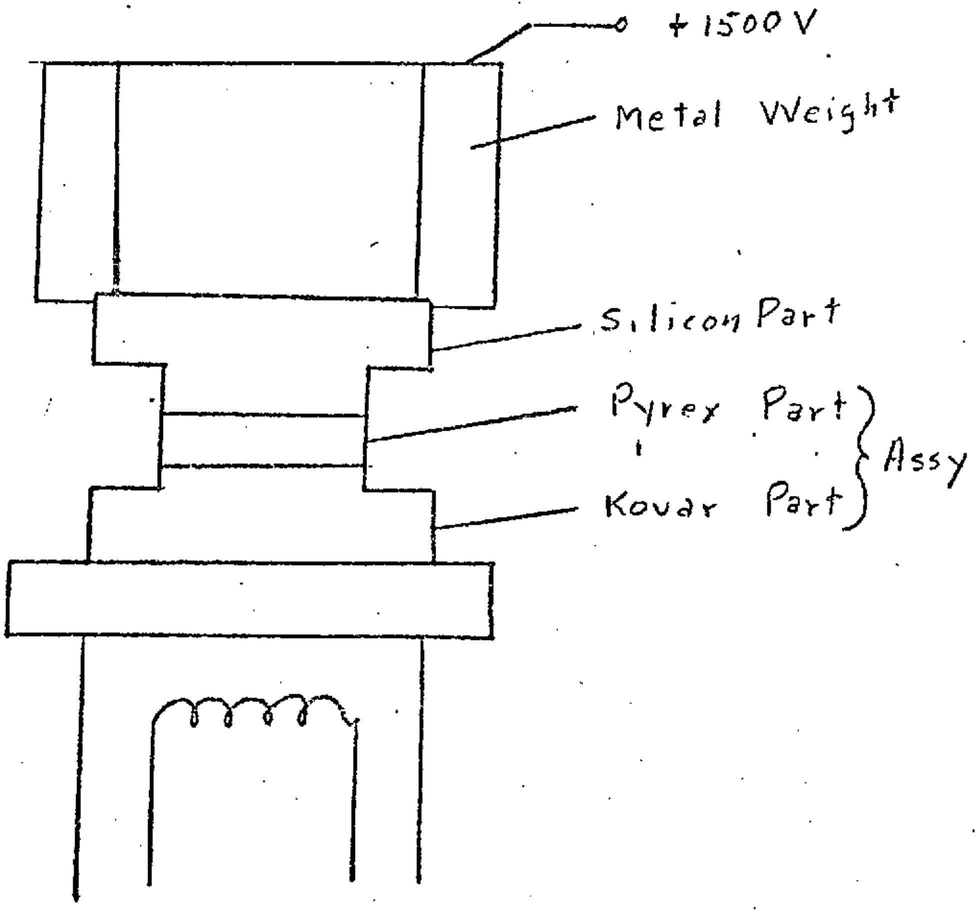
2.2.2.8 Turn off voltage after current drops below 0.1 ma.

2.2.2.9 Break vacuum, remove and inspect.

2.2.2.10 Inspection: Immerse in TCE, inspect under 30X for bubbles and nonbonded surfaces.

3.0 GLASS-SILICON SEAL

3.1 Setup



APPENDIX A (continued)

3.2 Procedure

3.2.1 Part Preparation

3.2.1.1 Kovar Glass Assembly: Clean glass bonding surface (see 2.2.1.1). Use buffered HF and ammonium hydroxide, 5-second dip, rinse D.I. water and alcohol, blow dry.

3.2.1.2 Silicon Bonding Surface

(1) Surface should be polished flat - free of scratches, oxide or metal plating.

(2) Clean same as glass part.

3.2.2 Assembly

3.2.2.1 Assemble as shown in 3.1.

3.2.2.2 Repeat basically the steps shown 2.2.2, except this bond is generally easier than the glass-kovar and should be done at 700°F, if possible. Current draw 1.5 to 2 ma.

3.2.2.3 Inspection - per paragraph 2.2.2.10.

3.2.2.4 Inspection - polariscope - inspect for strain.

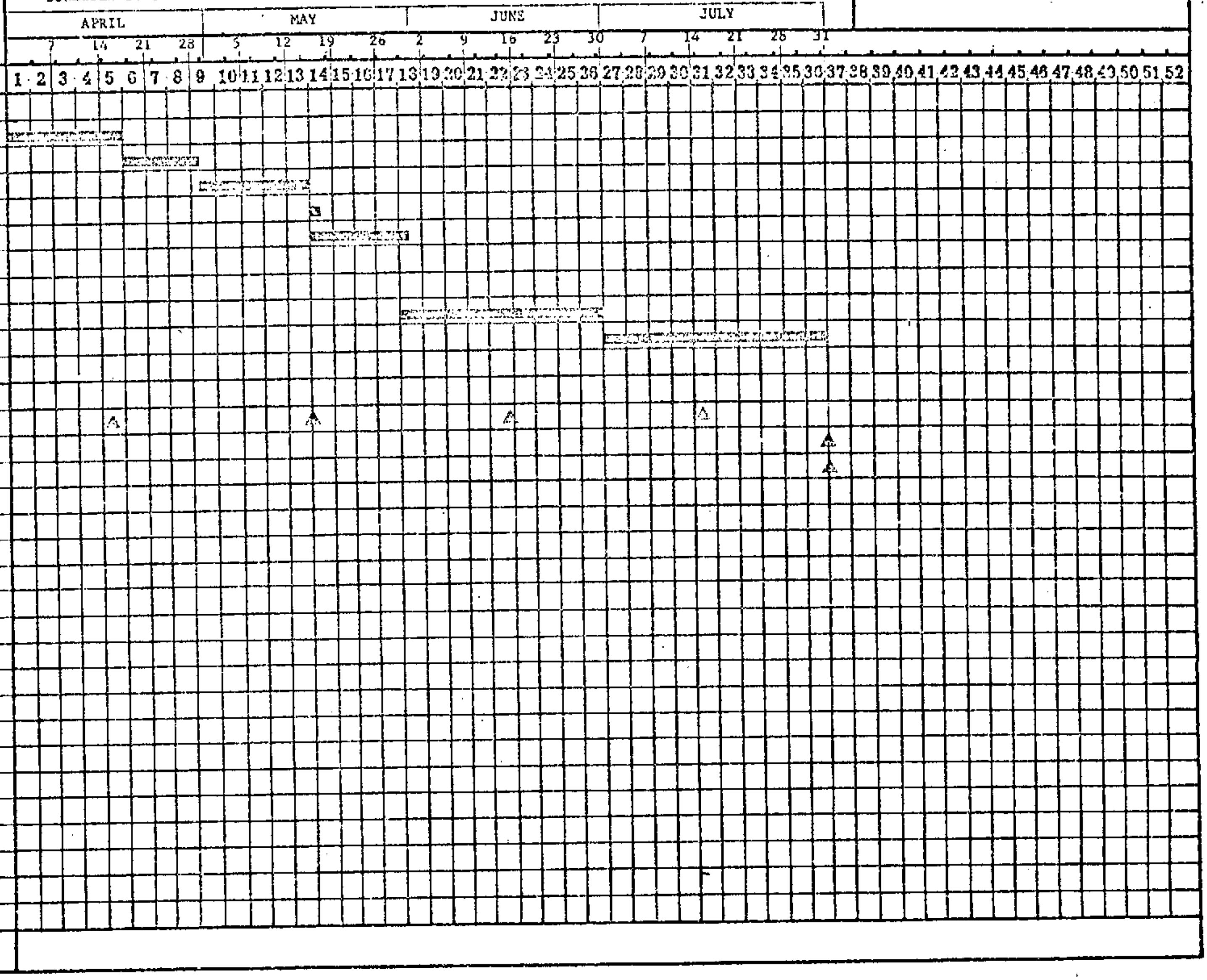
PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER

17 April 1972

SCHEDULE TO COMPLETE

Contract NAS8-27442

TASK DESCRIPTION	
1. Evaluation of Corning 7052 Glass	
1.1 Prepare Blanks	4/18
1.2 Polish	4/29
1.3 Assemble Test Units	5/15
1.4 Inspect	5/16
1.5 Test	5/30
2. Final Hardware	
2.1 Assemble	6/30
2.2 Test	7/31
3. Delivery Dates	
3.1 Monthly Progress Reports	
3.2 Final Report - Draft	7/31
3.3 Hardware	7/31
3.4 Final Report	8/31



ER 4715-98

Progress Report 12

April 1972

CONRAC
CORPORATION

17 May 1972

PRESSURE TRANSDUCER FOR
SPACE SHUTTLE BOOSTER

Contract No. NAS8-27442

PROGRESS REPORT
April 1972

1.0 Work Accomplished During Reporting Period

The Corning 7052 glass has been cut to shape and returned to the vendor for polishing. The parts have not been received back from polishing. They are now due on 1 June.

2.0 Problems Encountered

No technical problems were encountered during this reporting period. Delivery problems on polishing have delayed beginning of assembly of test units by about 4 weeks. This problem points up the need to do the polishing in-house in production.

3.0 Activities Planned for Next Reporting Period

Assemble and test units with the Corning 7052 glass.

ER 4715-98

Progress Report 13

May/June 1972

PRESSURE TRANSDUCER FOR
SPACE SHUTTLE BOOSTER

Contract No. NAS 8-27442

Progress Report
May/June 1972

1.0 Work Accomplished During Reporting Period

The Corning 7052 glass parts have been received back from polishing after a delay of approximately 10 weeks.

2.0 Problems Encountered

No new problems were encountered during this reporting period. Delivery problems on polishing which have been discussed previously have continued to delay the program.

3.0 Activities Planned for Next Reporting Period

Begin assembly of end item sensors.

4.0 Schedule

Delivery delays discussed above will require rescheduling hardware delivery to September 16, 1972.

ER 4715-98

Progress Report 14

September 1972

26 September 1972

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER

Contract No. NAS 8-27442

PROGRESS REPORT
September 1972

1.0 Work Accomplished During Reporting Period

1.1 Glass-Silicon-Metal Hermetic Seal

The polished Corning 7052 Kovar sealing glass parts were received after a delay of nearly 10 weeks.

These parts bonded far more readily to the Kovar than did the pyrex parts previously used. The Corning 7052 Kovar seals were leak free and did not crack even at liquid nitrogen temperature.

It was found, however, that the Corning 7052 glass would not bond to silicon except at high temperature. In order to make a strain free bond, the bonding temperature must be 450°C. Bonding at this temperature will result in a strain due to differential expansion of 800 ppm which is an acceptable design limit. Because of the nonlinear expansion of both Kovar and 7052 glass, a bond made at 500°C will have a strain of 1400 ppm due to differential expansion. This is a marginal value and any bond made above 500°C will fracture during cooling.

It was found that bonding between silicon and Corning 7052 glass will not occur below 500°C even at voltages of 2000V and currents in excess of 2 ma.

26 September 1972

PRESSURE TRANSDUCER FOR SPACE SHUTTLE BOOSTER -
PROGRESS REPORT, September 1972

1.1 Glass-Silicon-Metal Hermetic Seal (continued)

Curves of expansion for these materials vs temperature are shown in Figure 1.

In addition to these experiments, quartz and vycor glass have been evaluated for bonding characteristics as indicated below:

Silicon slices were prepared with sputtered layers of fused quartz (pure SiO_2) and additional slices with vycor glass (approximately 96% pure SiO_2). Either of these glasses showed proper dielectric and conductive properties. That is, the glass layer would withstand adequate voltage to accomplish a seal (150V as compared to 50V minimum required to seal at this thickness of glass). The correct current was drawn (approximately 1 ma per cm^2) at 500°C for proper sealing. However, no seal occurred.

The experiments were repeated with enough variation in parameters to insure that these materials would not seal. Temperature was varied between 400°C and 900°C. Voltages from 50V to 200V were used. Three different control modes were used:

(1) Set temperature and voltage to desired level.

(2) Set temperature and current to desired level. (Control current by manually adjusting voltage.)

(3) Set voltage and current to desired level. (Control current by adjusting temperature.)

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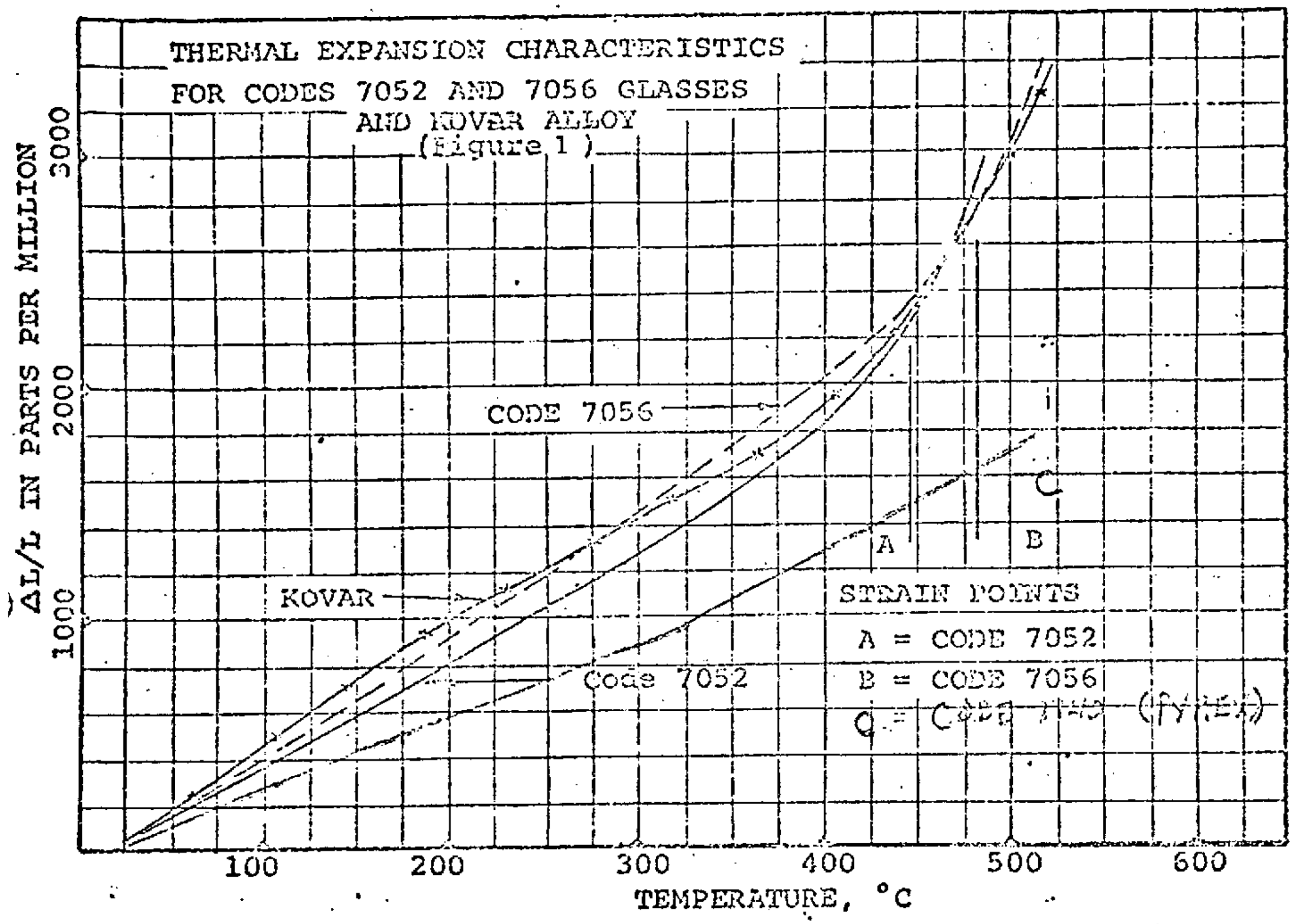
THERMAL EXPANSION CHARACTERISTICS FOR CODES 7052 AND 7056 GLASSES AND KOVAR ALLOY (Figure 1)

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1.1 Glass-Silicon-Metal Hermetic Seal (continued)

None of the combinations of parameters resulted in sealing.

Attention was given to surface preparation and cleaning, using various organic solvents as well as acid cleaning, also with no result.

It is concluded from the above experiments that the Mallory Field-Assisted Sealing Procedure is highly material dependent. This will be discussed further in paragraph 2.0 of this report.

2.0 Problems Encountered

Some pairs of materials do not result in acceptable bonding characteristics. The findings to date in this regard are summarized in Figure 2.

While the pyrex provides an adequate seal to fabricate sensors and demonstrate compliance with the objectives of this program, it is felt that additional work to provide a good reliable design is justified even though it will result in further program delays.

The proposed areas of investigation are as follows:

2.1 Graded Seals

The feasibility of obtaining graded seals, i.e., glass composites having pyrex on one surface for sealing to silicon and 7052 on the other surface for sealing to Kovar, will be investigated.

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FIGURE 2

BONDING PROPERTIES OF DIFFERENT MATERIAL COMBINATIONS

	SILICON	KOVAR
Pyrex (Corning 7740)	Excellent	Moderate
Corning 7052	Poor	Excellent
Vycor	Poor	X
Quartz	Poor	X

2.2 Glass Type

Different types of glass will be obtained and the bonding properties determined. The following two types will be placed on order immediately and a search of the literature will continue for other types with promising properties:

TYPE	1720	7059
Softening Point	915°C	842°C
Annealing Point	715°C	635°C
Strain Point	668°C	587°C
Expansion	$4.2 \times 10^{-6}/°C$	$4.7 \times 10^{-6}/°C$
Composition	Aluminosilicate	Borosilicate

2.3 Surface Treatment

The fact that different glasses of similar expansion coefficient show different bond characteristics to the same metal indicates that the chemical bonds available at the surface play an important part in the bonding process. Experiments will be conducted where the surfaces are modified by various platings to provide chemical compatibility. Some combinations to be evaluated are:

2.3 Surface Treatment (continued)

BASE MATERIAL	PLATING MATERIAL	TO SEAL TO
Kovar Sealing Glass	Pyrex (sputtered)	Silicon
Silicon	Nickel	Kovar Sealing Glass
1720 Glass	Pyrex	Silicon
7059 Glass	Pyrex	Silicon
1720 Glass	Borosilicate (Pyrolytic)	Silicon
7059 Glass	Borosilicate (Pyrolytic)	Silicon
Pyrex	Kovar Sealing Glass	Kovar

3.0 Revised Schedule

3.1	Resolve sealing problem	30 October 1972
3.2	Fabricate transducers	30 November 1972
3.3	Test and deliver transducers	30 December 1972

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Progress Report 15

October-December 1972

18 January 1973

Pressure Transducer for Space Shuttle

Contract No. NAS 8-27442

Progress Report
October-December 1972

1.0 Introduction

During the period covered by this report, an intensive effort has been made to resolve the one remaining technical problem, namely to achieve an acceptable silicon-SiO_2-metal seal. This seal is a key item in permitting the pressure media to be ported to the interior of the sensor cell and prevent the pressure media from coming in contact with the electrical leads. This is not a firm requirement of the present program since the pressure media involved are pure cryogenic gases (oxygen, hydrogen and nitrogen). Obviously the utility of the transducer would be limited if only nonconductive gases could be accepted as pressure media. It has therefore been considered important to proceed with the development as indicated below.

2.0 Silicon-SiO_2-Metal Seal

The use of the silicon-SiO_2-metal seal has been limited by a tendency of the SiO_2 or of one of the interfaces to fail in shear due to thermal expansion mismatches. A program described in the last progress report has been pursued to alleviate this problem by investigating the use of various different material combinations. This program did not result in appreciable improvement.

18 January 1973

Pressure Transducer for Space Shuttle
Progress Report, October-December 1972 (continued)

2.0 Silicon-SiO_2-Metal Seal (continued)

The problem was meanwhile resolved by changing the geometry so that only one of the interfaces is in shear. This interface can then be designed so that the shear stresses due to thermal expansion are acceptable. The other interface is designed so that the glass is in compression and the metal in tension. This configuration is shown in Figure 1. In this configuration, the pyrex-kovar assembly is fused in the conventional manner, leaving the pyrex in compression and the kovar in tension. These materials are both very strong under this kind of loading. The assembly is then polished and the silicon part attached by means of field assisted bonding.

Parts made in this manner have been thermally shocked to liquid nitrogen temperatures without failure. These parts now being assembled into complete sensors for evaluation.

3.0 Schedule

The solution of the Si-SiO_2-metal seal problem has proved much more difficult than origionally anticipated. The time spent in solving this problem has been very worthwhile, in that it will result in a more useful device.

The following schedule can now be met for the completion of the program:

3.1	Fabricate transducers	28 Feb. 1973
3.2	Test and deliver transducers	30 Mar. 1973
3.3	Final report:	
	Draft	30 Mar. 1973
	Final	30 May 1973

18 January 1973

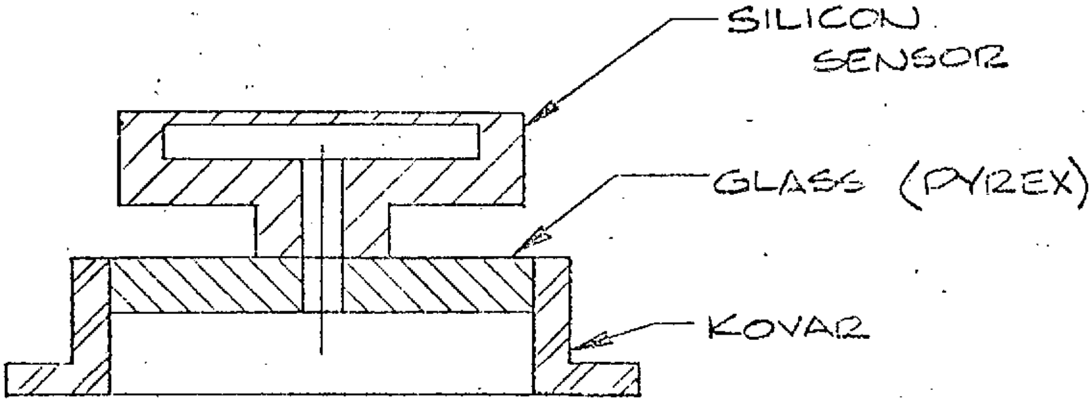

FIG 1
CONFIGURATION,
SILICON - GLASS - KOVAR SEAL

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January-March 1973

30 March 1973

Pressure Transducer for Space Shuttle

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Progress Report
January-March 1973

1.0 Parts Fabrication

Kovar-pyrex assemblies have been fabricated and are ready for assembly into transducers.

2.0 Instrument Assembly

The first of the sensors using the new configuration has been assembled and will be ready for test in early April.

3.0 Activity Planned for Next Reporting Period

3.1 Test the unit presently assembled.

3.2 Complete assembly of remaining units.

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April 1973

10 May 1973

Pressure Transducer for Space Shuttle

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Progress Report
April, 1973

1.0 Parts Fabrication

Parts fabrication is complete.

2.0 Instrument Assembly

The first instrument assembly was lost during bonding of the gold leads to the silicon. Loss of the sensor was attributed to the longer heat path introduced into the assembly to permit welding of the case. The problem is one of tooling. The tooling is being modified to permit applying the heat directly to the silicon rather than to the bottom of the silicon assembly.

3.0 Activity Planned for Next Reporting Period

3.1 Complete lead-bond tooling.

3.2 Complete sensor assembly.

3.3 Testing

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May-July 1973

CONRAC
CORPORATION

8 August 1973

Pressure Transducer for Space Shuttle

Contract No. NAS 8-27442

Progress Report
May-July, 1973

1.0 Parts Fabrication

Parts fabrication is complete.

2.0 Instrument Assembly

Instrument assembly is complete to the point of bonding leads to the strain gages. Tooling has been prepared to facilitate lead bonding and is awaiting testing.

3.0 Activity Planned for Next Reporting Period

3.1 Test lead bond tooling.

3.2 Bond leads.

3.3 Test sensors.

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August-September 1973

24 September 1973

Pressure Transducer for Space Shuttle

Contract No. NAS 8-27442

Progress Report
August-September 1973

1.0 ACTIVITY FROM THIS REPORTING PERIOD

1.1 Tooling produced in the previous reporting period to facilitate the lead bonding was tested on assembled sensors and it was found that inspite of attempts to localize high temperature with this new revised tooling, the high bonding temperatures caused a thermal shock to the glass cell body which destroyed the glass.

1.2 The cell body material was revised to use AL_2O_3 ceramic rather than glass and should be able to take the thermal shock. The design and drawings were revised to incorporate this new material.

1.3 All diaphrams consisting of strain gages on silicon have been fabricated and data accumulated by means of test probes.

2.0 ACTIVITIES PLANNED FOR NEXT REPORTING PERIOD

2.1 Fabricate AL_2O_3 ceramic cell bodies.

2.2 Revised design cell mounts (kovar) will be fabricated and assembled with the AL_2O_3 ceramic cell bodies to proof the high temperature heliarc process without damage to cell body.

2.3 Test fully assembled sensors for functional performance and prepare final data for final report.