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RESEARCH PRESSURE INSTRUMENTATION

FOR

NASA SPACE SHUTTLE MAIN ENGINE

NASA CONTRACT NO. NAS8-34769

MODIFICATION NO. 5

MONTHLY REPORT

GEORGE C. MARSHALL SPACE FLIGHT CENTER

MARSHALL SPACE FLIGHT CENTER, ALABAMA 35812

APRIL 1984

Prepared By:

P.J. ANDERSON, PROGRAM MANAGER
P. NUSSBAUM, TECHNICAL DIRECTOR
G. GUSTAFSON, DEPUTY TECHNICAL DIRECTOR

HONEYWELL INC.
SOLID STATE ELECTRONICS DIVISION
12001 STATE HIGHWAY 55
PLYMOUTH, MN 55441

HONEYWELL INC.
SOLID STATE ELECTRONICS DIVISION
CONTRACT NO. NAS8-34769
MODIFICATION NO. 5

RESEARCH OF PRESSURE INSTRUMENTATION FOR NASA SPACE SHUTTLE MAIN ENGINE

Monthly R & D Progress Report April 1984 - Report No. 7

A. Technical Progress and Plans

- See attachment 'A'

B. Schedule

- See attachment 'B'

C. Status of Funds

Total Baseline Plan

Total Funded

Cost Incurred to 5/06/84

Inception to Date Plan

Estimate at Completion

D. Estimated percent of physical completion: 56%

E. At the present time the comparison of the cumulative costs to the percent of physical completion does not reveal any significant variance requiring explanation.

ATTACHMENT 'A'

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

1.0 Introduction and Objective

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

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

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

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

1. Transducer Package Concept and Materials Study

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

2. Silicon Resistor Characterization at Cryogenic Temperatures

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

3. Experimental Chip Mounting Characterization

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

4. Frequency Response Optimization

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

5. Prototype Transducer Design, Fabrication, and Test

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

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

6. Reports

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

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

2.0 Work Performed and Plans

In addition to the progress reported below, we completed an on-site, six (6) month Program Review at NASA/MSFC on 4/12/84. Copies of our presentation view-graphs were left with Mr. T. Marshall and the meeting attendees; therefore, the entire presentation is not included again in this report. However, I have included, in Attachment 'C', some selected view-graphs which outline and summarize our presentation.

Three technical issues were presented at our 4/12/84 review meeting. See Attachment 'C'. The resolution of the "Chip Design/Fabrication" and "Diaphragm Shaping" issues are covered in the sections below. The issue entitled "Chip Mounting Material" is not resolved as planned; however, critical experiments are underway to achieve that resolution. See Sections 2.3.1 and 2.3.2 for more detail.

2.1 Transducer Package Concept and Materials Study

This task was completed per plan during January 1984.

2.2 Silicon Resistor Characterization at Cryogenic Temperatures.

2.2.1 Work performed in April.

The major accomplishment during this reporting period was the resolution of the helium cryostat performance issue. This was achieved with the help of an engineer from Janis Research who was on-site at SSED until the problem was resolved. The failure mode was the burn-out of a heater coil which controls the temperature of the helium vapor and ultimately the temperature of the test samples.

A trial run was successfully completed which verified the system performance over the temperature range where failure had previously been experienced. This allowed the characterization of test samples to start at cryogenic temperatures. To date, one run for data acquisition from test samples has been completed. The data has not been reduced or displayed at this time, however, a cursory review of the raw data does not reveal any unexpected characteristics.

The delay in achieving an acceptable operational status of the cryostat has adversely impacted the schedule for completing this task; however, it will not have an adverse impact on the design schedule of the design task for the feasibility sensor. See Section 3.0 for more details.

2.2.2 Plans for May

The plans are as follows:

- Complete the characterization of the test samples at cryogenic temperatures.
- Reduce and display the results from this characterization testing in support of selecting a dose for the feasibility sensor design.
- Select the implant dose to be used in the feasibility sensor design.
- Close this task.

2.3 Experimental Chip Mounting Characterization

2.3.1 Work performed in April

The design of the experimental sensor (electrically non-functional) piece-part hardware was completed except for the mounting details of the electrical connector. The vendor has located detailed, interface drawings for the connector of interest and will be forwarding them to us within the next few weeks.

The fabrication of the piece-part hardware for the experimental sensor continued during this reporting period. The status of this activity is as follows:

- Stainless steel housing: Complete except machinery for the electrical connector.
- Stainless steel base: Complete
- Metal C-ring: Received
- Silicon nitride part: Ordered
- Pyrex cover glass: Ordered
- Pyrex washer: Ordered
- Au/Ge performs: Ordered
- Invar mounting plate: Ordered

Regarding the development of assembly processes for Concept #5, it was established during the previous reporting period that TE bonding could not be used to attach the sensor chip to silicon-nitride. Therefore, some alternate assembly concepts were developed, one of which was discussed in last month's report. See Attachment 'D' (Alternate D). The concern here is the potential performance degradation that may be caused by creep in the Au/Ge solder joints. Fabrication has started for test samples to determine the existence of solder creep and its impact on sensor performance.

Concepts for three (3) additional assembly configurations have been developed which use only silicon and pyrex materials. See Attachments 'E', 'F', 'G'. Alternate configurations A and B in Attachments 'E' and 'F' use TE bonding exclusively. Alternate B in Attachment 'G' uses a Au/Ge solder joint to attach the two pyrex pieces. While there is concern about solder creep here, as well as with Alternate D, the impact is expected to be less because the joint is further removed from the sensor chip.

Finite stress analyses were completed for the structures depicted in Attachments 'E' - 'G'.

The primary structural concern is the fracture of the pyrex or silicon components under pressure loading. Tensile stress levels in the various components can reach 10,000 to 16,000 psi in localized areas when exposed to the 20,000 psi overpressure load. With pyrex, structures should be designed to keep surface tensile stress levels less than ≈ 10,000 psi. The main area of concern with the alternatives in Attachments 'D' - 'G' is the pyrex window where surface stresses are > 10,000 psi in localized spots when the system is loaded to 20,000 psi. It is not clear at this time what the best design approach is in order to assure that the glass cover has adequate strength under 20,000 psi overpressure loading. Further work on these approaches will not be pursued until the outcome of the solder creep experiments has been evaluated.

2.3.2 Plans for May

The plans are as follows:

- Receive prints for electrical connector from Deutsch Connector Co.
- Complete design of Stainless Steel Housing.
- Complete design and start the fabrication of these test fixtures:
  - Vibration testing
  - High pressure testing
  - High pressure leak checking
- Complete design of Stainless Steel Housing upon receipt of the interface drawings from Deutsch.
- Complete test sample fabrication for the solder creep experiments and start the testing and evaluation of results.
- Continue the development of assembly processes.
- Start assembly of the sensor mounting subassembly.

2.4 Frequency Response Optimization

This task was completed per plan in February 1984.

2.5 Temperature Sensor Network Concept Study.

This task was deleted when the contract was negotiated.

2.6 Prototype Transducer Design, Fabrication and Test

2.6.1 Feasibility Evaluation of Transducer Concepts.

2.6.1.1 Define/Finalize Concept for Feasibility Transducer.

.1 Work performed in April

Two chip designs were defined that will satisfy the 20,000 psi overpressure rating and provide output signals that are expected to meet the pressure sensitivity design goal. The designs are as follows:

- 100 MIL thick silicon chip with a 40 MIL diameter, 15 MIL thick etched diaphragm (See Attachment 'H-1'.
- 35 MIL thick silicon slab (See Attachment 'H-2'.)

The radial (σ_R) and tangential (σ_θ) surface stress levels are shown as a function of radial position in Attachment 'I' and 'J' for a 10,000 psi pressure load. The sensor output is proportional to the value of (σ_θ - σ_R) at the location of the piezoresistors. The (σ_θ - σ_R) curves in Attachments 'I' and 'J' together with the vertical axis on the right side of each figure give an indication of the expected bridge sensitivity as a function of the radial position of the bridge piezoresistors.

With both chip designs, the diaphragm is being defined by the inner diameter of the support ring (See Attachment 'H') and [σ_θ - σ_R] has a maximum value near the edge of this diaphragm. However, the 100 MIL thick chip with an etched diaphragm also has a relative maximum of (σ_θ - σ_R) in the region between the etched diaphragm and the inner edge of the support ring. The main disadvantage of the structure in Attachment 'H-2' is that the wire bonds, low TCR resistors, and metal interconnect must all be on surface areas that are being stressed. (See Attachment 'J'.) With the etched diaphragm, the low TCR resistors, wire bonds and metal interconnects can be placed in regions with lower surface stress than for the case of the slab. The etched diaphragm does not offer stress free regions as was thought would be the case. Attachment 'K-1' compares the advantages and disadvantages of the two sensor design approaches. With either design, special silicon wafers are needed since both thicknesses are much greater than the standard material being turned out in volume today for the semiconductor industry.

The foregoing discussion presented two design approaches that satisfy the design goals for the highest pressure range sensor in SSME pressure sensor family, i.e., 9000 psi. For the purposes of designing and building the feasibility sensors as well as the deliverable sensors (600 psi, 3000 psi), we have selected the slab design approach. The primary reasons for this decision are:

- Two design approaches have been exercised to the extent that the design data supports the conclusion that this technology approach is capable of meeting the mechanical and sensitivity requirements of the 9,000 psi sensor. (See Attachments 'H' - 'J'.)

- The fabrication of a 9,000psi sensor is beyond the scope of the current contract. This activity could be pursued in a follow-on contract or by adding scope, funding, and schedule to the current contract.

- The slab design approach, using starting materials and process fixturing that are considered standard in the industry, will meet the design requirements for the 600 psi and 3500 psi sensors.

.2 Plans for May

The plans are as follows:

- Start the layout of the sensor design in support of mask fabrication.

- Procure silicon starting material to support the fabrication of the feasibility sensor.

- Complete a replan of this task

2.6.1.2 "Prototype" Transducer Design

.1 Work performed in April

The follaowing activities were completed during this reporting period:

- Define the most promising plumbing configuration between sensor and the SSME port.

- Developed frequency response characteristics when gaseous medium is oxygen.

- Defined design guidelines for the use of side-ports to reduce the amplitude of acoustic resonances. A discussion of the details of these items is provided in the paragraphs to follow.

The best plumbing configuration with respect to avoiding low frequency acoustic resonance is where the sensor housing cavity has a diameter of 0.9 cm which is 0.076 cm (≈30 MIL) greater than the diagonal of the silicon sensor chip. The fundamental resonant frequency (i.e., lowest reasonant frequency) of this plumbing configuration increases as the length of the sensor housing cavity decreases. The approximate variation of fundamental reasonant frequency with sensor housing cavity length is shown in Attachment 'K-2'. The value of F_o, the resonant frequency of the SSME test fixture port (i.e., section of length L(2)), will vary with the type of gas, temperature, and pressure. For example, with oxygen at 273 K and $P=10^6$ dyne/cm^2, the value of F_o is ~5000 Hz. The calculated acoustic frequency response for an oxygen gas medium at 273°K and $P=10^6$ dyne/cm^2 is shown in Attachments 'L' and 'M' for two different values of the sensor housing cavity length L(1). As indicated, the fundamental resonant frequency shifts from ~3000 Hz to ~2000 Hz as L(1) is increased from 1 cm to 2.425 cm. Thus, a basic design goal for the pressure transducer is to keep the length L(1) of the sensor housing cavity as small as possible.

By keeping the diameter of the sensor housing cavity at the minimum value needed to clear the corners of the silicon sensor chip (i.e., diameter = 0.9 cm), low frequency resonances due to Helmholtz structures can be avoided. This is demonstrated in Attachment 'N' where a small diameter port at the entrance to the sensor housing cavity causes an acoustic resonance at ~1000 Hz versus > 2000 Hz without such a port.

The use of baffles in the sensor coupling port, to reduce adiabatic heating effects of pressure pulses, could cause low frequency resonances through the formation of a Helmholtz cavity. Proper design and placement of such baffles can maximize the fundamental resonant frequency and permit reduction of adiabatic heating effects.

In summary, the most promising plumbing configuration is as shown in Attachments 'L' and 'M' with the length L(1) minimized within the constraints imposed by the packaging requirements.

The effect of gas temperature on the coupling structure shown in Attachment 'L' is as shown in Attachment 'O'. As the temperature decreases, the acoustic velocity decreases. Therefore, the wavelength corresponding a certain frequency decreases, and the acoustic resonance frequency spectrum shifts to lower frequencies. With the large diameter tubes of Attachments 'L' and 'M' the effects of viscous damping are not significant. However, if tube segements with a diameter of $\leq$ 1 mm are included in the coupling structure, increased damping with increased temperature would also result.

Side-ports can be used to reduce the amplitude of acoustic resonances. (See attachments 'P' and 'Q'.) The main design goal with respect to the use of Helmholtz resonator side-ports is to have the resonant frequency of the Helmholtz resonator track the resonance of the main coupling structure as the gas parameters vary. Since the resonant frequency of these two structures are both linearly dependent on the acoustic velocity, the resonant frequencies will track if viscous damping effects are not significant. Viscous damping will be most significant in the entrance port to the Helmholtz resonator. Therefore, the Helmholtz resonator must be designed with the diameter of the entrance port at a maximum, consistent with the geometrical constraints imposed by the packaging design.

.2 Plans for May

The plans are as follows:

- Close this task.

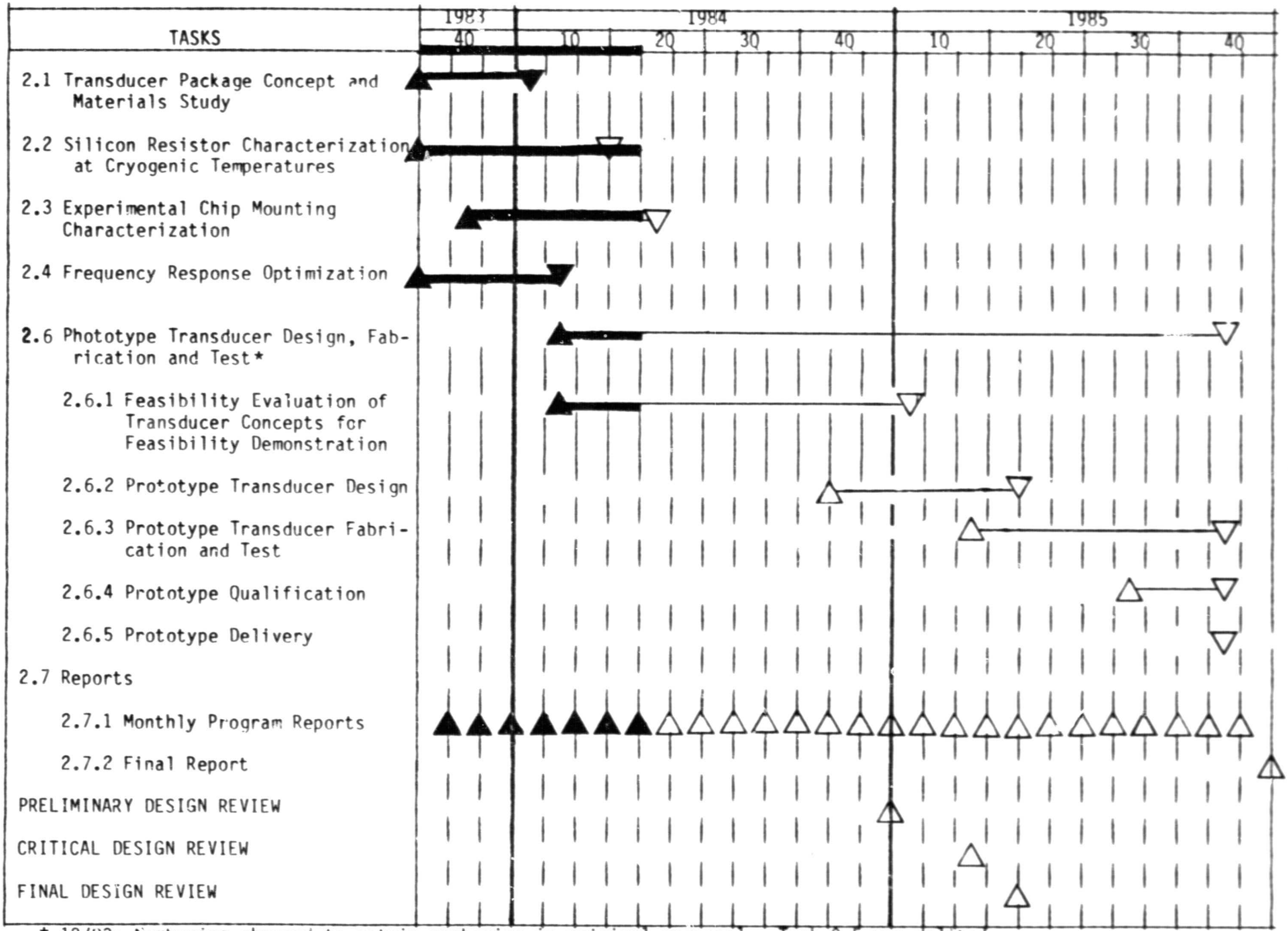
3.0 Schedule -- See Attachment 'B'.

As reported in Section 2.2.1, the task "Silicon Resistor Characterization at Cryogenic Temperature" was not completed in March as planned. The delay in completing this task was achieving an operational status of the Helium Cryostat. The cryostat is operational now and the cryogenic testing is underway. Given that the cryostat continues to perform properly, it is estimated that the testing and data acquisition will be completed in May 1984, and the data reduced, displayed a dose selection completed by June 1984.

The design task for the feasbility sensor has taken longer than expected because of the supporting work performed to assure, from mechanical and pressure sensitivity aspects, that this technology can be used to develop the 9,000 psi SSME sensor. There may be a schedule impact relative to completing the "Feasibility Evaluation Task" (2.6.1 on Attachment 'B'). A replan is in progress to minimize any schedule impacts. A more definative schedule assessment will be available in the next report.

ATTACHEMENT B

RESEARCH PRESSURE INSTRUMENTATION FOR NASA SPACE SHUTTLE MAIN ENGINE
SCHEDULE



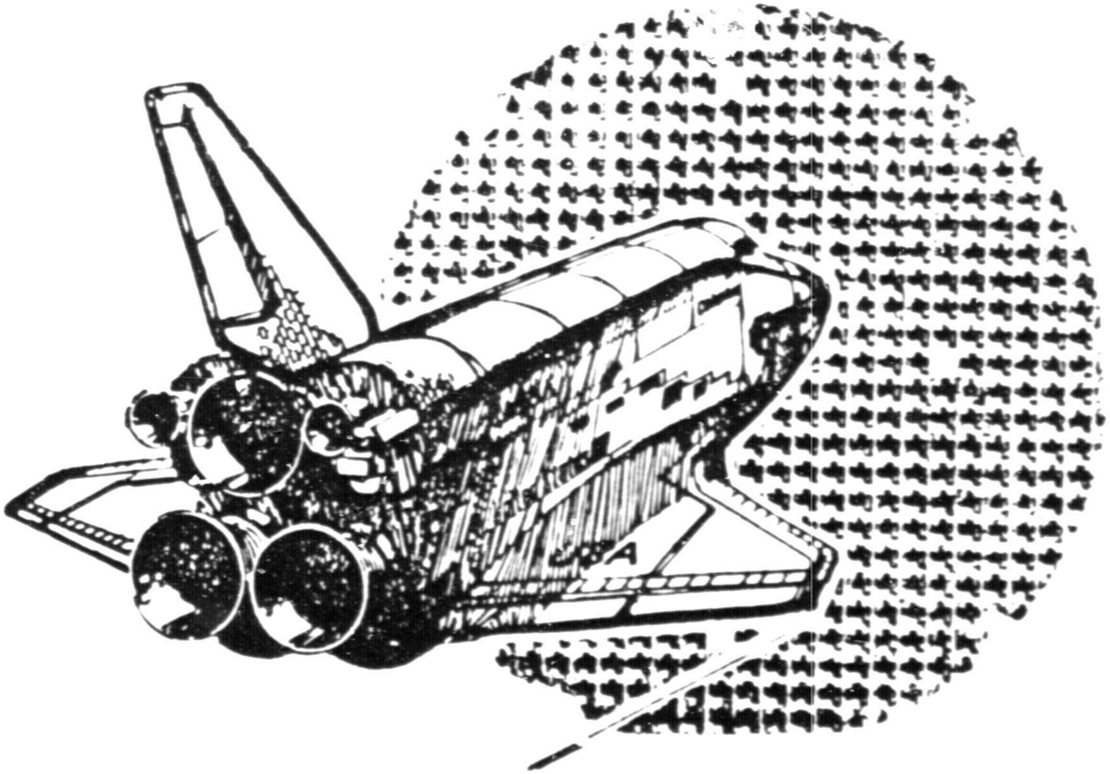
* 12/83: Numbering changed to retain numbering in original proposal. Task 2.5 was deleted during contract negotiations.

ATTACHMENT "C"

NASA PRESSURE TRANSDUCER PROGRAM
SIX MONTH REVIEW

Honeywell

04/12/84



Research of
Pressure Instrumentation
for
Space Shuttle Main Engine

ATTACHMENT "C"

NASA PRESSURE TRANSDUCER PROGRAM

AGENDA: 4/12/84

● INTRODUCTION	P. J. ANDERSON
● PROGRAM OVERVIEW	P. J. ANDERSON
● TECHNICAL PROGRESS/STATUS	D. WAMSTAD G. GUSTAFSON
● CONCLUDING REMARKS	P. J. ANDERSON

ATTACHMENT "C"

NASA PRESSURE TRANSDUCER PROGRAM
PROGRAM OVERVIEW: OUTLINE

- HONEYWELL, INC.
- OBJECTIVES/DELIVERABLES
- MAJOR THRUSTS/GOALS
- HONEYWELL'S CONCEPT
- APPROACH
- MAJOR TASKS/EXPECTED RESULTS
- PROGRAM ORGANIZATION
- COST
- SCHEDULE

ATTACHMENT "C"

NASA PRESSURE TRANSDUCER PROGRAM
OBJECTIVE/DELIVERABLES

- **Objective:**

  To Design, Build, Test, Calibrate And Deliver 10 Absolute Pressure Transducers To NASA/MSFC With Performance Targeted To Meet NASA's Design Goals For Space Shuttle Main Engine Applications

- **Deliverables:**

  - Five (5) Transducers: 0-600 Psia
  - Five (5) Transducers: 0-3500 Psia
  - Monthly Reports
  - Final Report

ATTACHMENT "C"

NASA PRESSURE TRANSDUCER PROGRAM
CONCLUDING REMARKS

- Concept/Materials Study
  - Task Completed Per Plan
  - Chip Mounting And Package Concepts Selected (Concepts #5)
  - Materials List Defined
- Silicon Resistor Characterization
  - Completed For -100°F-To-250°F
  - Encountering Helium Cryostat Start-Up Problems
  - Cryogenic Testing Will Not Delay Sensor Chip Design Activity
- Sensor Chip Mounting Characterization
  - Methods For Fabricating Sensor Subassembly Defined (Combination Of Te Bonding And Soldering)
  - Design Change Made To Minimize Impact Of Assembly Induced Stresses (Invar Insert/"V"-Ring)
  - Impact Of Solder Creep Is A Concern
- Frequency Response
  - Task Completed Per Plan
  - Design Guidelines Established
    - o Increased Frequency Response
    - o Reduce Magnitude Of Undesirable Resources

ATTACHMENT "C"

NASA PRESSURE TRANSDUCER PROGRAM
CONCLUDING REMARKS (CONT'D.)

- Feasibility Sensor Design
    - Concept #5 Requires Diaphragm Configuration
    - Reconsidering Use Of "Slab" Approach
    - Requires Unusually Thick (>>15 Mils) Starting Material
    - Meeting Both Overpressure Requirement And Pressure Sensitivity Is A Concern
- Technical Issues
    - There Are Some
        - o Sensor Chip Design/Fabrication (Feasibility)
        - o Sensor Chip Mounting Design/Fabrication (Feasibility)
    - These May Impact Schedule
- Cost: On Plan
- Schedule
    - ~ On Plan
    - Resolution Of Technical Issues May Delay Some Intermediate Milestones
    - Impact Of Resolution Plans For Technical Issues Should Be Available By End-April
    - EAC (Contract): 9/85

ATTACHEMNT "C"

NASA PRESSURE TRANSDUCER PROGRAM
TECHNICAL ISSUES: FEASIBILITY SENSOR CHIP DESIGN AND FABRICATION

- Piezoresistor Design For Cryogenic Operation
  - Cryostat Start-Up Problems Have Delayed Characterization Of Piezoresistors At Cryogenic Temperatures
  - Low Temperature Information Helpful In Designing Feasibility Chip (Not On Critical Path)
  - Plan: Feed Data From Task 2000 Into Design Team As It Becomes Available, Design With Best Data Available

- Silicon Material
  - Concept 5 Requires Chip With Custom Thickness Silicon Material-Exact Thickness Being Determined
  - Honeywell Purchases Single Crystal Silicon Starting Material From External Vendors: Best Lead Time For Custom Material Is 8-16 Weeks
  - Plan
    - Define Exact Material Thickness By April 30
    - Expedite Wafer Processing Consistent With Acceptable Risk
    - Replan To Address Custom Material Lead Time

ATTACHMENT "C"

NASA PRESSURE TRANSDUCER PROGRAM
TECHNICAL ISSUES: FEASIBILITY CHIP DIAPHRAGM SHAPING

- Concept 5 Is Not Compatible With Originally-Proposed Conventional Slab Sensor Chip
- Concept 5 Chip Requires 20 mil Thick Diaphragm In 50-100 mil Thick Chip For Sensitivity And Overpressure
- Anisotropic Etch Process Must Be Used To Shape Diaphragm
  - Nonstandard Process (At SSED)
  - Slow Process (~40 Hours To Etch 80 mils)
- Plans
  - Continue Internal IR&D Anisotropic Etch Development Program Begun In 1983
  - Explore Electrochemical Anisotropic Etch Technique With High Etch Rates
  - Reconsider Slab-Type Approach To Replace Etched-Diaphragm (Requires Metal Features On Stressed Area)
  - Plan On ~40 Hours To Etch Feasibility Chips
  - Select Primary Approach By April 30, 1984

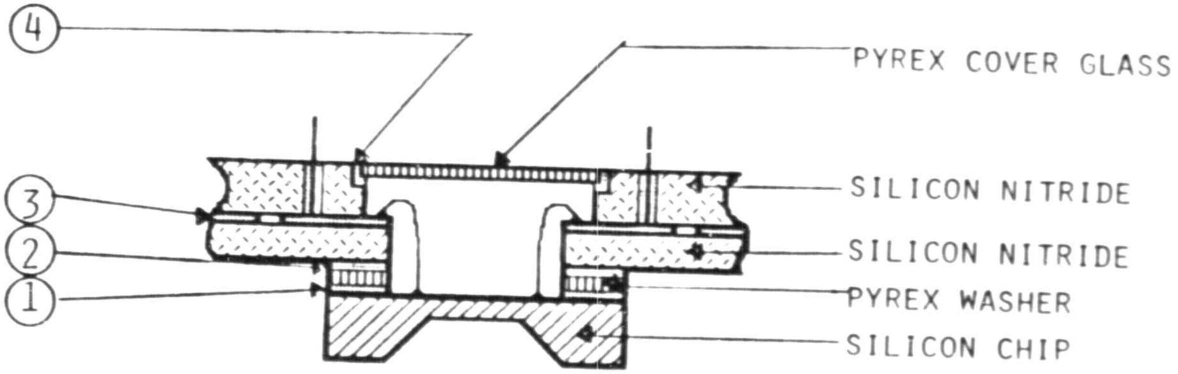
ATTACHMENT "C"

NASA PRESSURE TRANSDUCER PROGRAM
TECHNICAL ISSUES: CHIP MOUNTING MATERIAL

- Modeling Analysis Of Concept 5 Indicates Pyrex Washer-To-Silicon Nitride Solder Joint May Creep unacceptably Under 20 K psi Compression
- No Alternative Joining Process Identified
- Plans
  - Determine Magnitude Of Solder Joint Creep On Test Vehicle
  - Analyze Alternative Materials For Concept 5 Which Eliminate Washer-To-Nitride Solder Joint
    - Replace Silicon Nitride With Silicon, Pyrex Washer With Thin Film Of Pyrex, Solder Joint With TE Bond
    - Replace Silicon Nitride With Pyrex, Eliminate Washer, TE Bond Silicon Chip Direct To Pyrex Terminal Board
    - Replace Silicon Nitride With Combination Of Pyrex And Silicon And Replace All Soldered Hermetic Joints (Except Electrical Leadouts) With TE Bonds
  - Select Alternative By April 30, 1984

Attachment "D"

NASA PRESSURE TRANSDUCER PROGRAM
CONCEPT 5: PACKAGE MATERIALS AND ASSEMBLY
ALTERNATIVE D



Hermetic Seals And Electrical Lead Outs

① Direct Silicon To Pyrex Thermal-Electric Bond (TE Bond)

② Pyrex-To-Silicon Nitride

- Both Surfaces Metalized: Ti/Pt/Au
- Solder: Au/Ge

③ Silicon Nitride To Silicon Nitride -- Hermetic Seal Plus Electrical Lead Outs

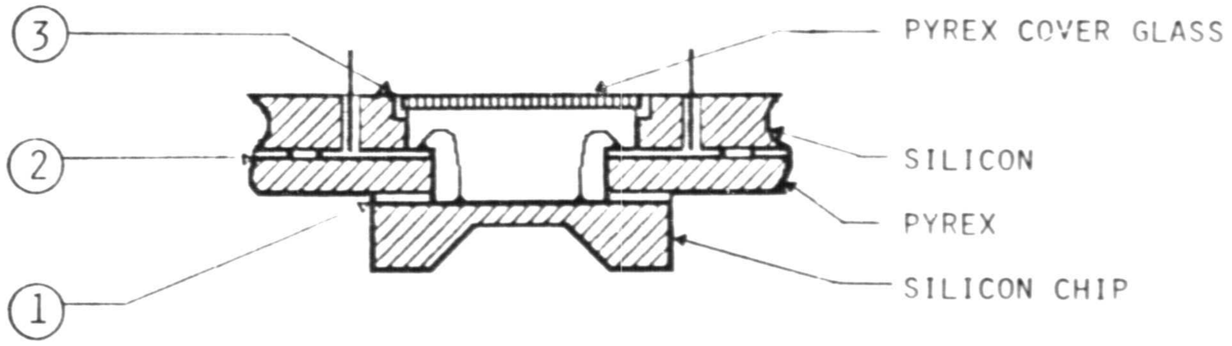
- Both Surfaces Metalized: Ti/Pt/Au
- Solder: Au/Ge

④ Pyrex To Silicon Nitride

- Both Surfaces Metalized: Ti/Pt/Au
- Solder: Pb/Sn/Ag

NASA PRESSURE TRANSDUCER PROGRAM
CONCEPT 5: MATERIAL/ASSEMBLY ALTERNATES
ALTERNATIVE A

- SILICON/PYREX VERSUS SILICON NITRIDE



- HERMETIC SEALS AND ELECTRICAL LEAD OUTS

① DIRECT SILICON TO PYREX: THERMAL ELECTRIC BOND (TE BOND)

② SILICON TO PYREX

  - TOP SILICON SURFACE: SILICON THERMAL OXIDE
  - BOTTOM PYREX SURFACE
    - o ELECTRICAL LEAD OUTS: EXTEND PYREX WITH TI/PT/AU LEAD OUTS
    - o HERMETIC SEALS: THERMAL ELECTRIC BOND (TE BOND)

③ PYREX COVER GLASS TO SILICON: THERMAL ELECTRIC BOND (TE-BOND)

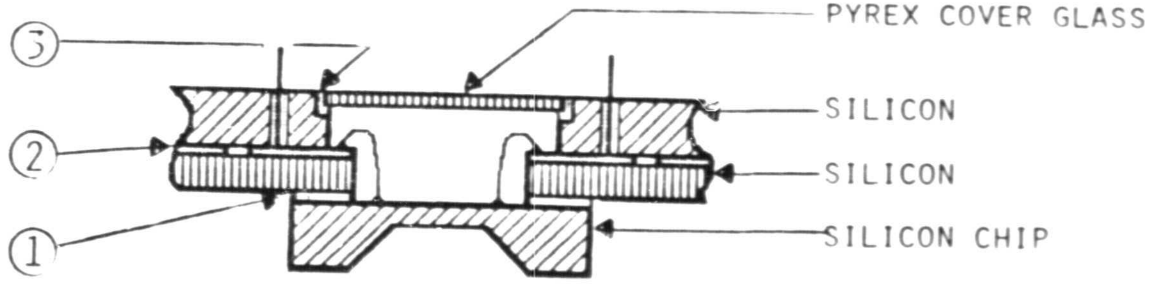
- V-RING SEAL: LOAD DISTRIBUTION ON PYREX -- REPLACE V-RING WITH:
  - METAL O-RING
  - METAL C-RING

ALTERNATIVE "E"

ATTACHMENT "F"

NASA PRESSURE TRANSDUCER PROGRAM
CONCEPT 5: MATERIAL/ASSEMBLY ALTERNATIVES
ALTERNATIVE B

- <u>SILICON VERSUS SILICON NITRIDE</u>



- <u>HERMETIC SEALS AND ELECTRICAL LEAD OUTS</u>

① SILICON TO SILICON WITH PYREX INTERFACE

  - SILICON SURFACE: SPUTTERED PYREX
  - THERMAL ELECTRIC BOND (TE-BOND)

② SILICON TO SILICON

  - TOP SILICON SURFACE: SILICON THERMAL OXIDE
  - BOTTOM SILICON SURFACE
    - o ELECTRICAL LEAD OUTS: TI/PT/AU CONTACTS WITH DIFFUSED LEAD OUTS
    - o HERMETIC SEAL:
      - LEAD OUT SEAL: THICK FILM METALIZATION WITH AU/GE SEAL
      - SILICON TO SILICON SEAL: SPUTTERED PYREX AND TE BOND

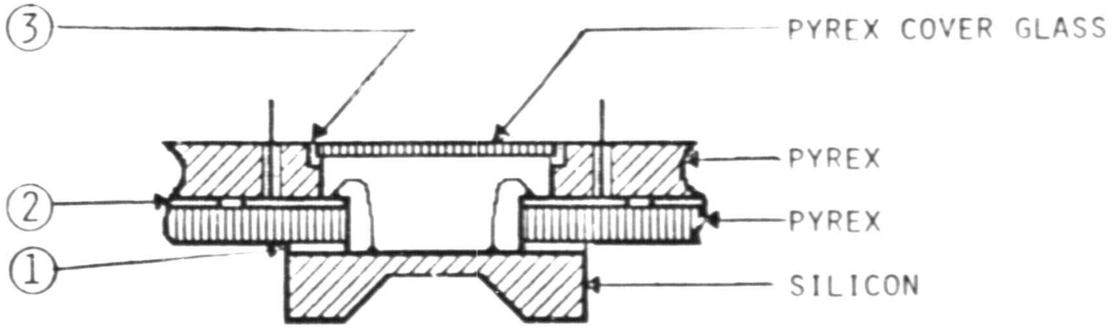
③ SILICON TO PYREX COVER GLASS

  - BOTH SURFACES METALIZED: TI/PT/AU
  - SOLDER: PB/SN/AG

ATTACHMENT "G"

NASA PRESSURE TRANSDUCER PROGRAM
CONCEPT 5: MATERIAL/ASSEMBLY ALTERNATES
ALTERNATIVE C

- PYREX VERSUS SILICON NITRIDE



- HERMETIC SEALS AND ELECTRICAL LEAD OUTS

① DIRECT SILICON TO PYREX: THERMAL ELECTRIC BOND (TE BOND)

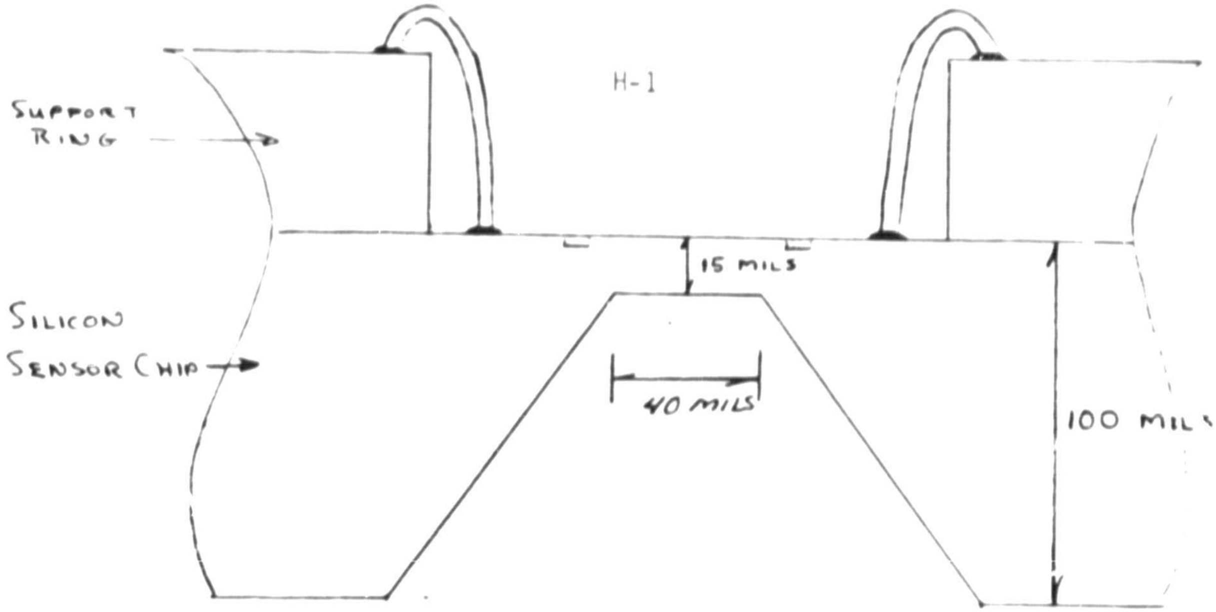
② PYREX TO PYREX
  - BOTH SURFACES METALIZED: Ti/Pt/Au
  - SOLDER: Au/Ge

③ PYREX TO PYREX
  - BOTH SURFACES METALIZED: Ti/Pt/Au
  - SOLDER: Pb/Sn/Ag

- V-RING SEAL: LOAD DISTRIBUTION ON PYREX -- REPLACE V-RING WITH:
  - METAL O-RING
  - METAL C-RING

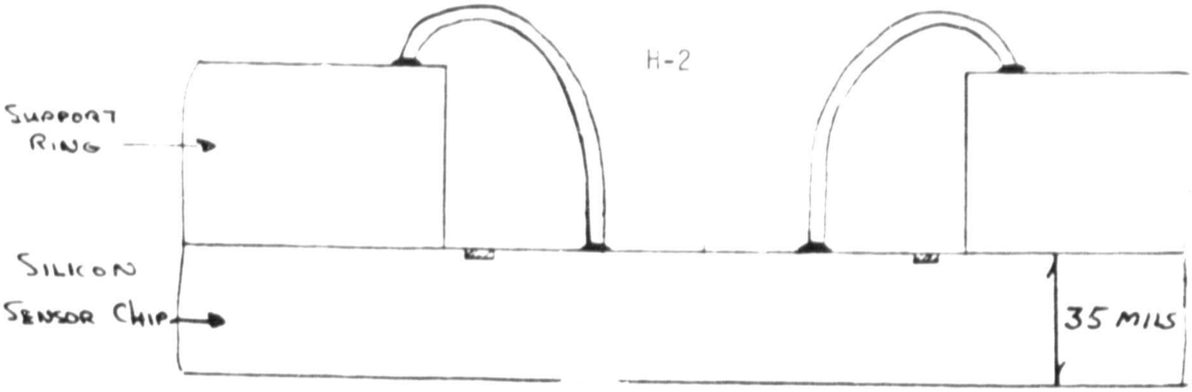
ATTACHMENT "H"

Two sensor chip designs that satisfy the 20,000 psi overpressure rating.



H-1

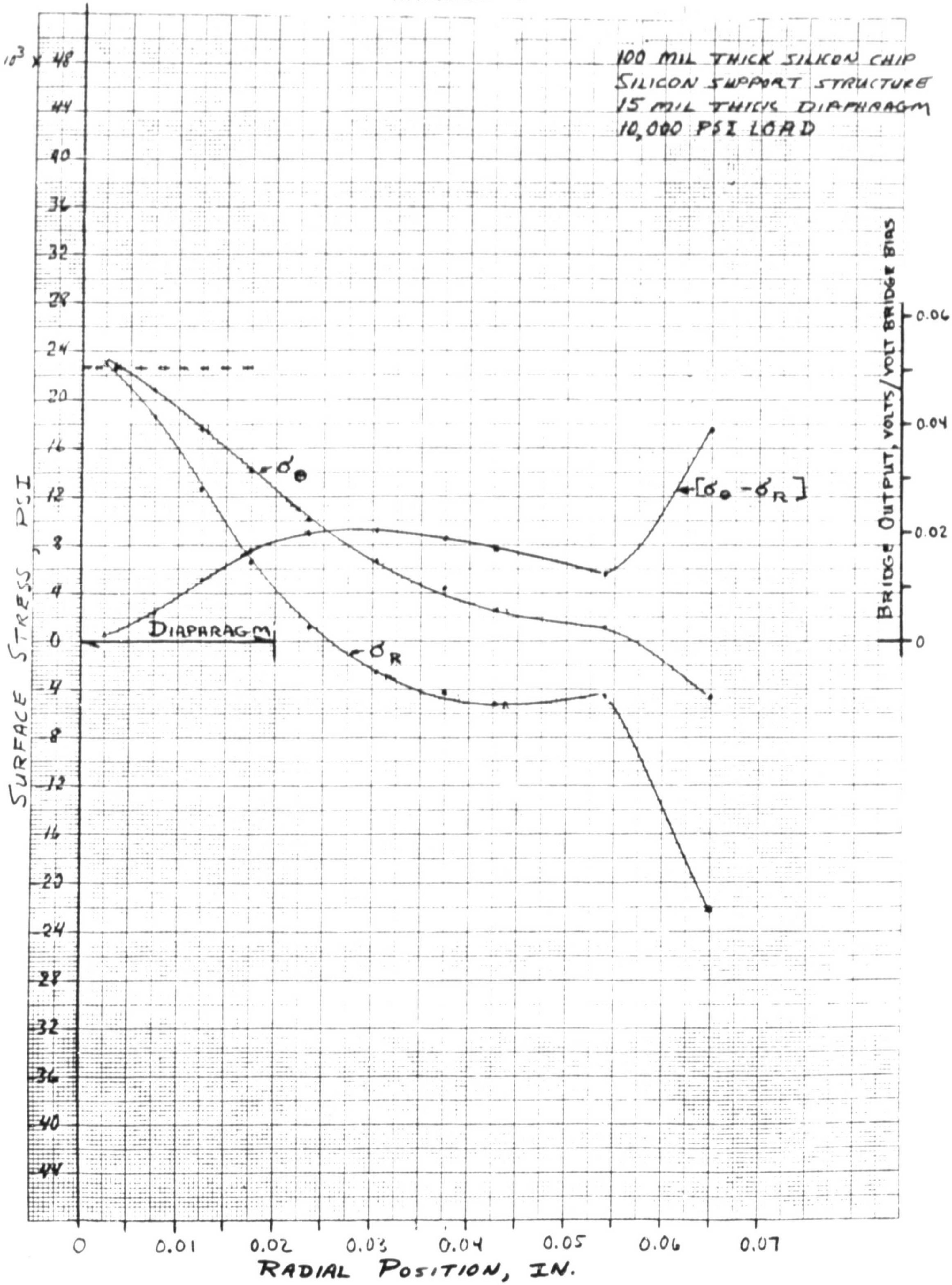
V(out) = 20 mv/v @



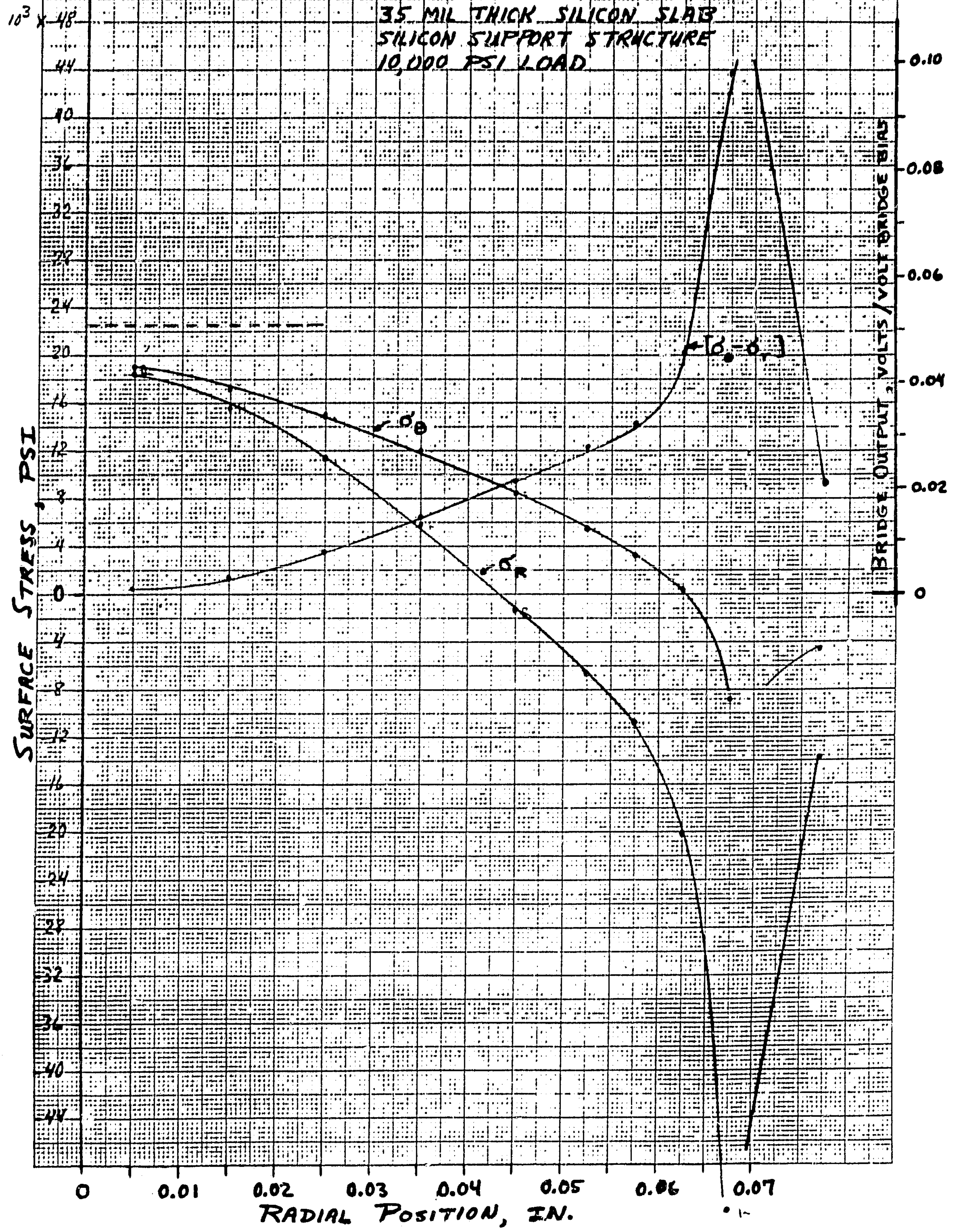
H-2

V(out) ≈ 35 mv/v @

ATTACHMENT "I"



ATTACHMENT "J"



ATTACHMENT "K'-1

COMPARISON OF TWO SENSOR DESIGNS

Sensor Design Concept	Advantages	Disadvantages
100 MIL thick silicon chip with etched diaphragm (15 MIL thick, 20 MIL radius)	● Packaging process can have larger tolerances. ● Metal pads in lower surface stress region. ● Wire bond sites in more conventional location. - 0.0001" displacement with pressure application. - Wire bonds in lower surface stress region. ● Use 100 MIL thick wafers used for Class 41 Sensor - no special wafer order.	● Less sensitivity - smaller output signal ● Anisotropic etch development required. ● Long backside processing procedure - about 30 hours to etch diaphragms. ● Lower die yield due to backside processing
35 MIL thick silicon slab.	● More sensitive - larger output signal. ● Easier to fabricate - No etching process development - No back side processing. ● Larger die yield - no backside processing.	● Special wafer order - up to sixteen weeks for delivery. ● Metal pads in high surface stress region. ● Wire bonds near center of diaphragm. - 0.0002 to 0.0003" Displacement with pressure application. - Wire bonds in high surface stress region. ● Requires tighter tolerance on packaging steps (chip to support placement).

ATTACHMENT "K-2"

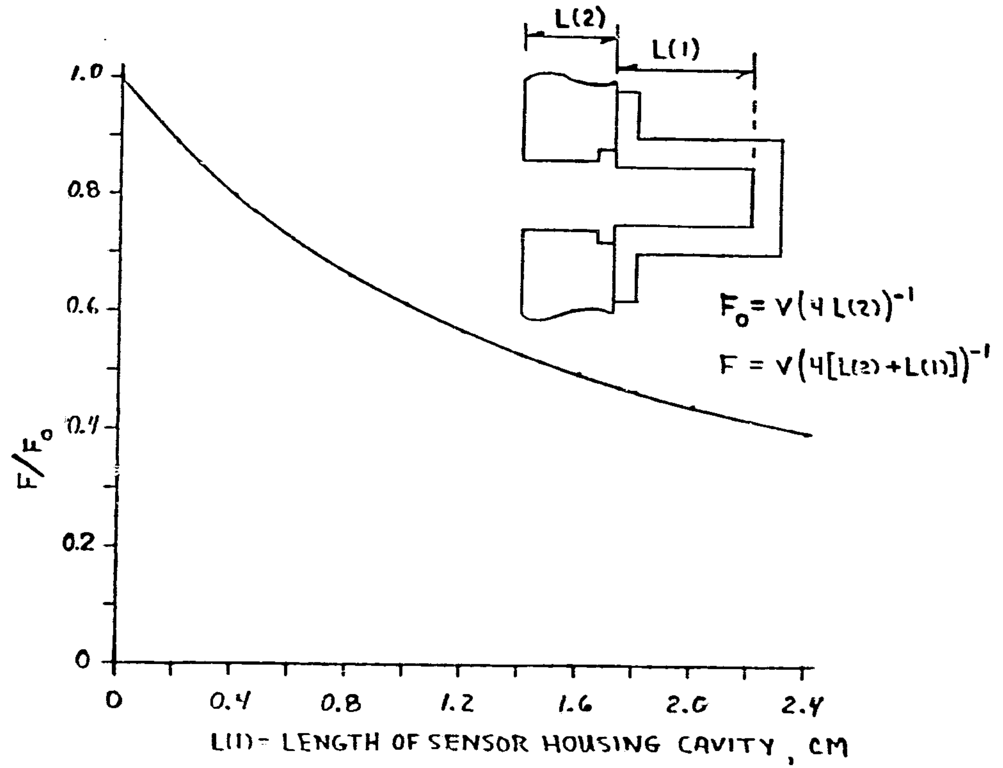
NASA PRESSURE TRANSDUCER PROGRAM
THEORY OF ACOUSTIC MODEL

FUNDAMENTAL RESONANT FREQUENCY OF A CLOSED TUBE

$F = V\ (4L)^{-1}$

V = SOUND VELOCITY

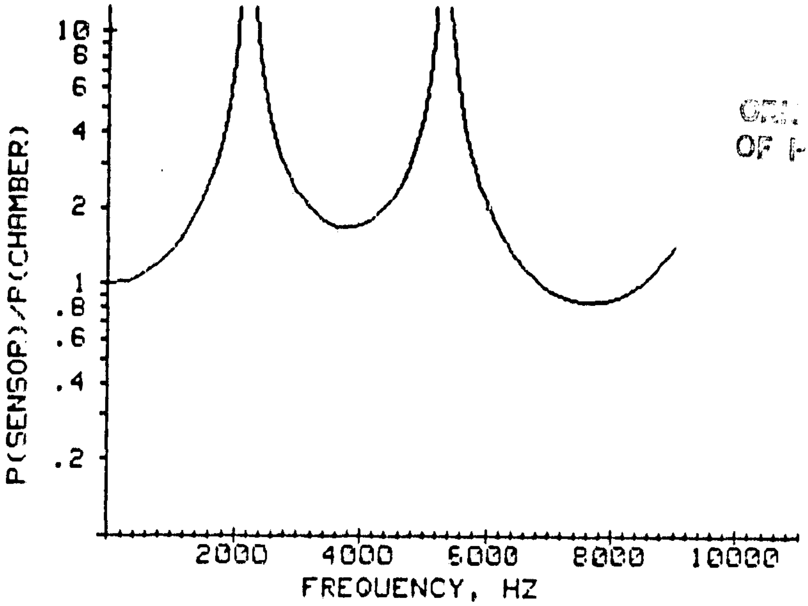
L = LENGTH OF CLOSED TUBE



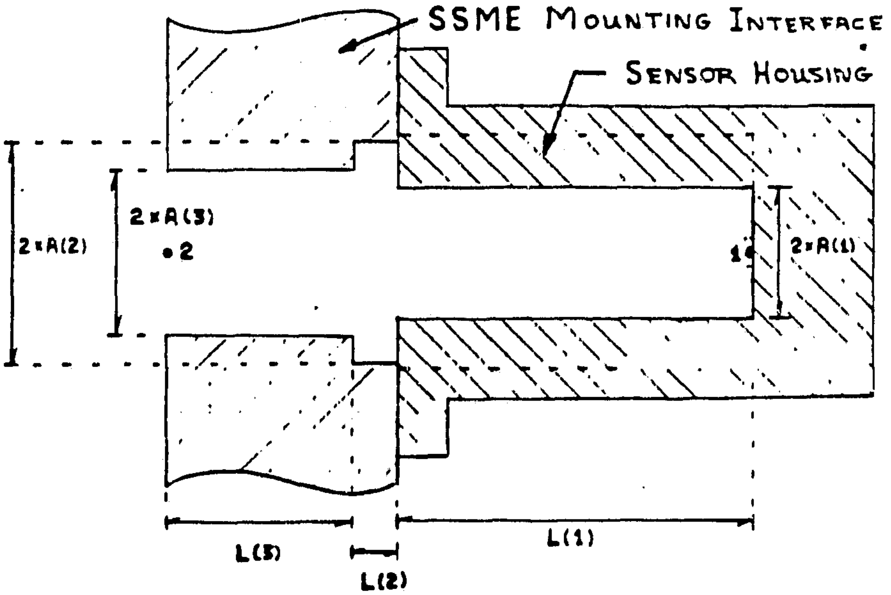
ATTACHMENT "L"

NASA PRESSURE TRANSDUCER PROGRAM

Acoustic Pressure Frequency Response of the SSME Mounting Interface/Sensor Housing System



RADIUS,CM	LENGTH,CM
A(1)= .451	L(1)= 2.425
A(2)= .762	L(2)= .305
A(3)= .559	L(3)= 1.27

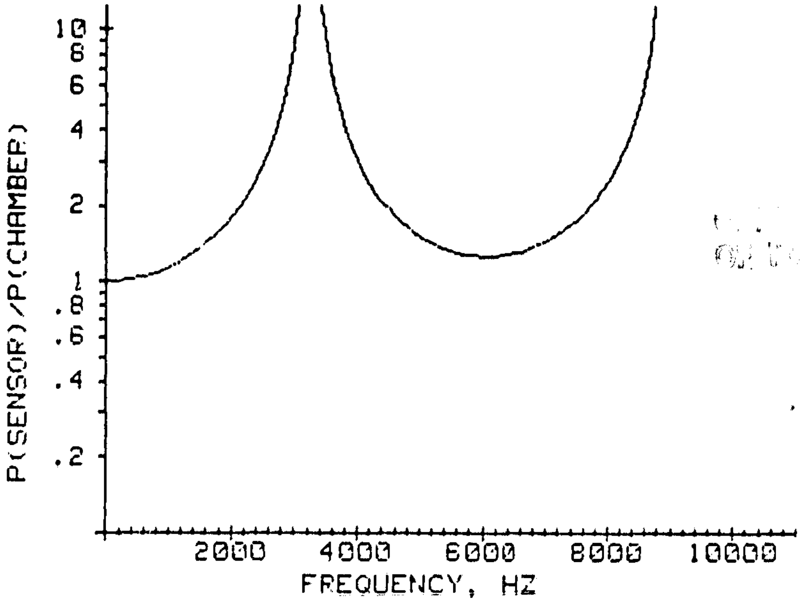


P(sensor) = Acoustic pressure at point 1

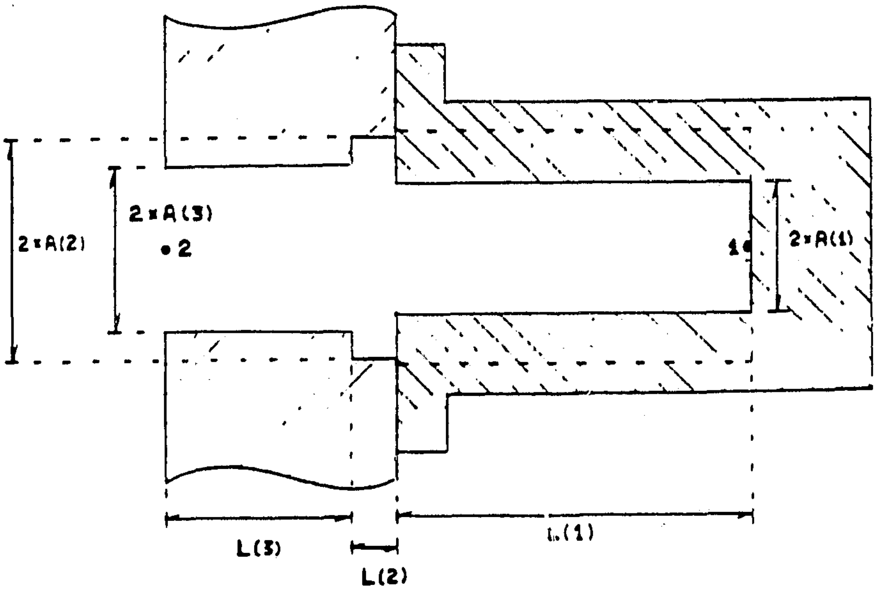
P(chamber) = Acoustic pressure at point 2

ATTACHMENT "M"

ACOUSTIC PRESSURE FREQUENCY RESPONSE OF THE SSME MOUNTING INTERFACE WITH A SHORTER SENSOR HOUSING



RADIUS,CM	LENGTH,CM
A(1)= .451	L(1)= 1
A(2)= .762	L(2)= .305
A(3)= .559	L(3)= 1.27



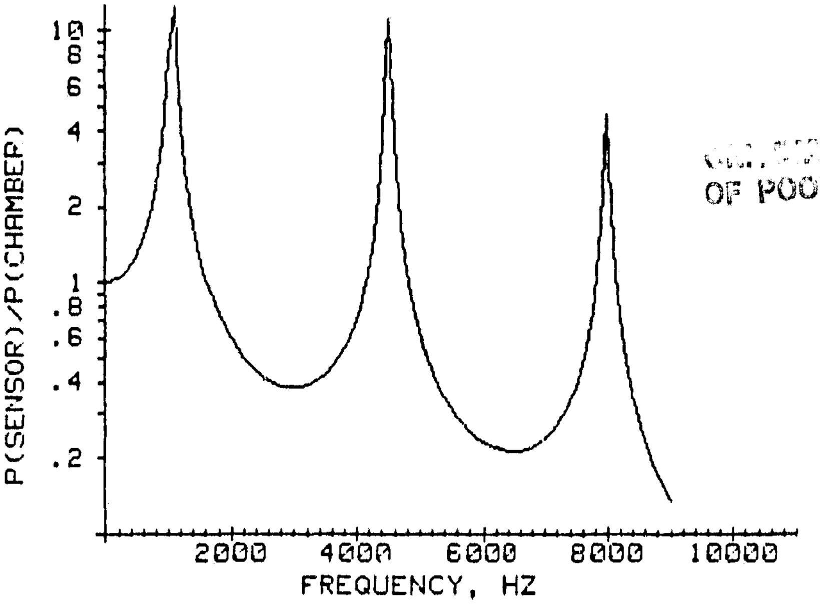
P(SENSOR) = ACOUSTIC PRESSURE AT POINT 1

P(CHAMBER) = ACOUSTIC PRESSURE AT POINT 2

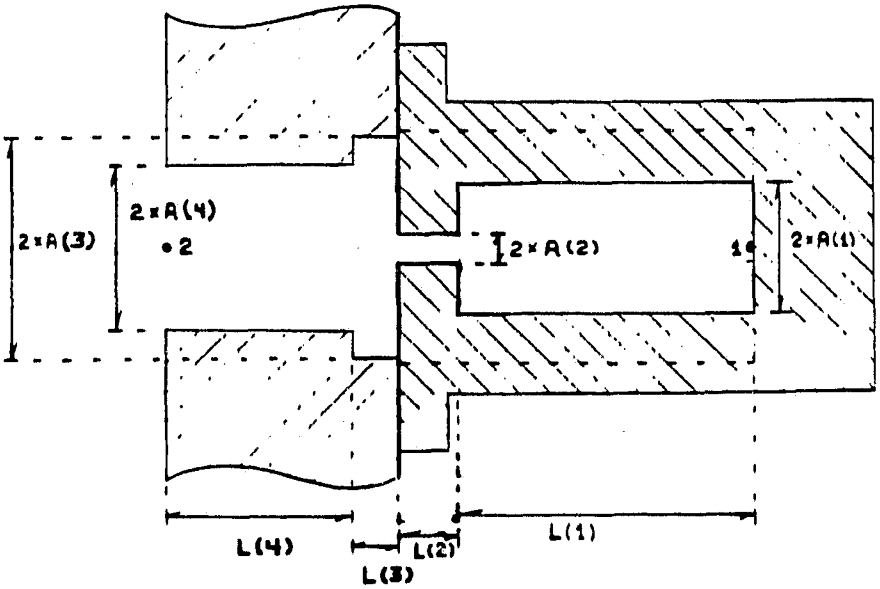
ATTACHMENT "N"

NASA PRESSURE TRANSDUCER PROGRAM

Acoustic Pressure Frequency Response of the SSME Mounting Interface/Sensor Housing with a Reduced Diameter Connecting Port



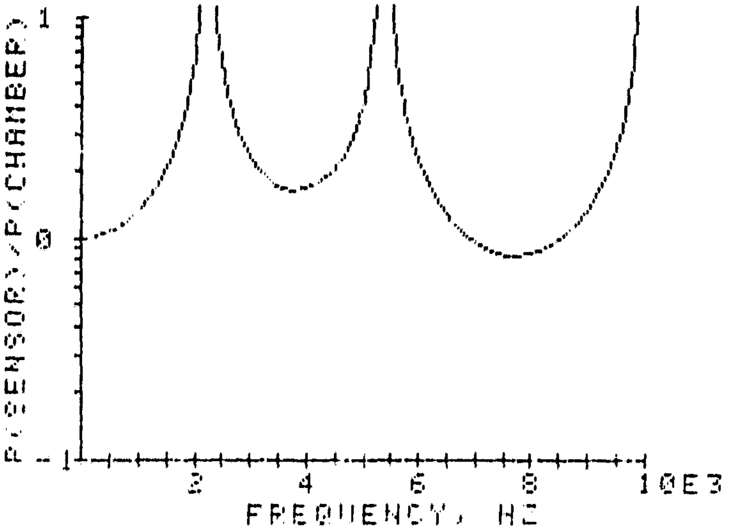
```
RADIUS,CM                   LENGTH,CM
A( 1 )= .451                L( 1 )= 2
A( 2 )= .1                  L( 2 )= .425
A( 3 )= .762                L( 3 )= .305
A( 4 )= .559                L( 4 )= 1.27
```



P(sensor) = Acoustic pressure at point 1

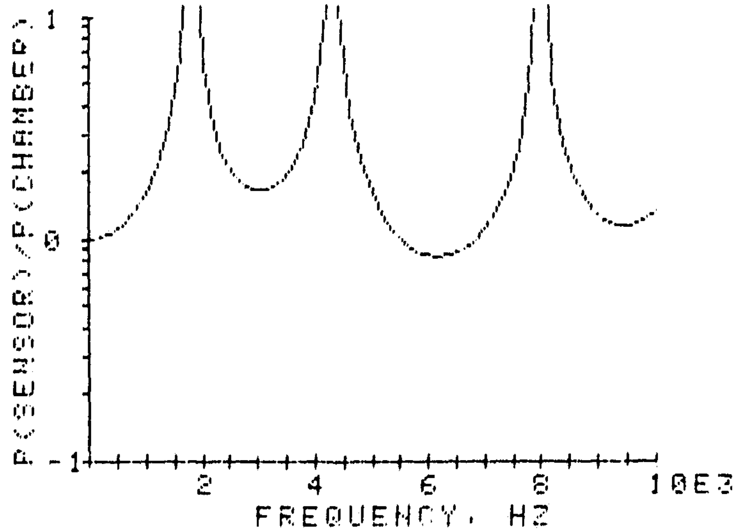
P(chamber) = Acoustic pressure at point 2

ATTACHMENT "O"



OXYGEN GAS AT
T = 273 K
P = 10^6 DYNE/cm^2
ACOUSTIC VELOCITY =
31468 cm/SEC

```
RADIUS,CM      LENGTH,CM
A( 1 )= .451   L( 1 )= 2.425
A( 2 )= .762   L( 2 )= .305
A( 3 )= .559   L( 3 )= 1.27
```



OXYGEN GAS AT
T = 175 K
P = 10^6 DYNE/cm^2
ACOUSTIC VELOCITY =
25195 cm/SEC

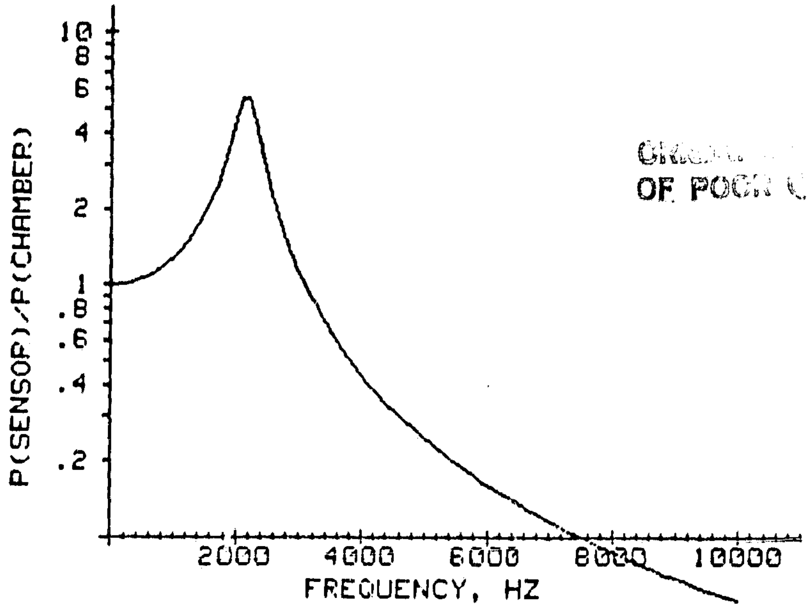
```
RADIUS,CM      LENGTH,CM
A( 1 )= .451   L( 1 )= 2.425
A( 2 )= .762   L( 2 )= .305
A( 3 )= .559   L( 3 )= 1.27
```

ACOUSTIC PRESSURE FREQUENCY RESPONSE OF THE SSME MOUNTING INTERFACE / SENSOR HOUSING SYSTEM CONFIGURATION OF ATTACHMENT "L" FOR TWO DIFFERENT TEMPERATURES.

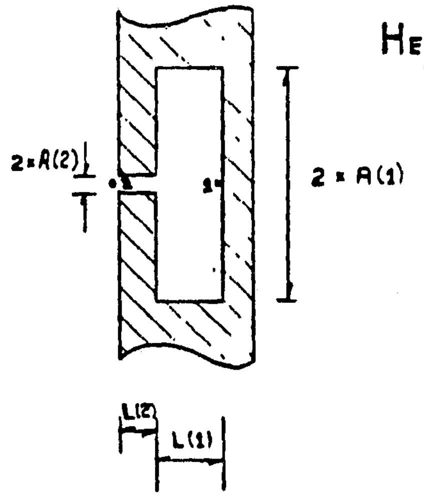
ATTACHMENT "P"

NASA PRESSURE TRANSDUCER PROGRAM

ACOUSTIC PRESSURE FREQUENCY RESPONSE OF A HELMHOLTZ RESONATOR



RADIUS,CM	LENGTH,CM
A(1)= .39	L(1)= .218
A(2)= .03	L(2)= .125



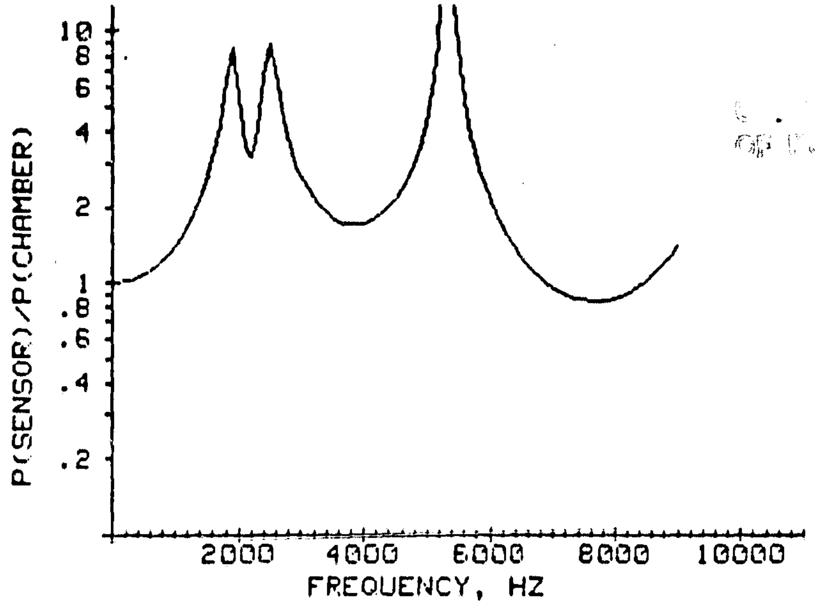
HELMHOLTZ RESONATOR

P(SENSOR)= ACOUSTIC PRESSURE AT POINT 1
P(CHAMBER)= ACOUSTIC PRESSURE AT POINT 2

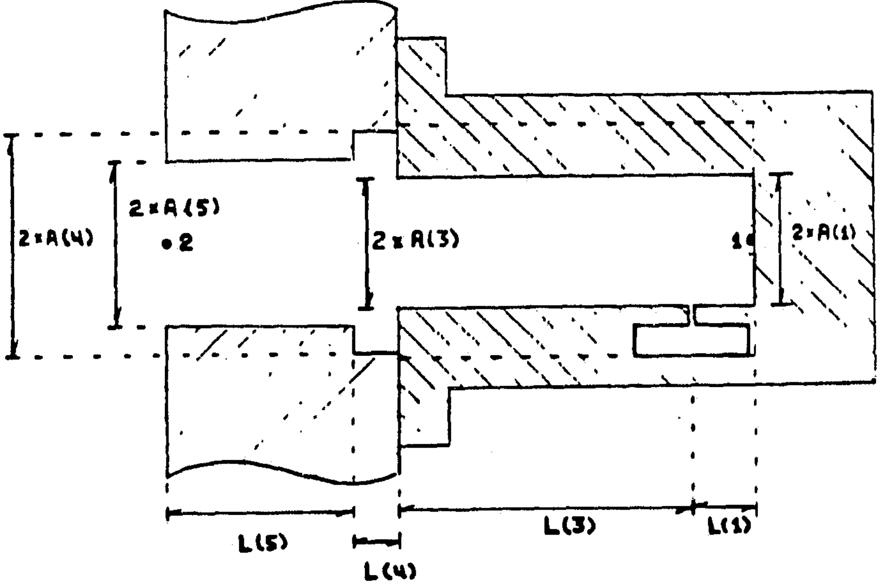
ATTACHMENT "Q"

NASA PRESSURE TRANSDUCER PROGRAM

Acoustic Pressure Frequency Response of the SSME Mounting Interface/Sensor Housing with a Helmholtz Resonator Side Chamber



```
RADIUS,CM                   LENGTH,CM
A( 1 )= .451                L( 1 )= .425
HELMHOLTZ RESONATOR SIDE PORT
A( 3 )= .451                L( 3 )= 2
A( 4 )= .762                L( 4 )= .305
A( 5 )= .559                L( 5 )= 1.27
```



P(sensor) = Acoustic pressure at point 1

P(chamber) = Acoustic pressure at point 2