UNITED TECHNOLOGIES
HAMILTON STANDARD

SVHSER 14841
Final Report: 158 Pages
Appendix 1: 16 Pages
Appendix 2: 9 Pages
Appendix 3: 14 Pages
Appendix 4: 3 Pages
NASA Form 1626: 1 Page

p- 242

FINAL REPORT

CONCEPTUAL DESIGN STUDY

FOR THE USE OF COBE ROCKET ENGINES

ON THE

TROPICAL RAINFALL MEASURING MISSION

(TRMM)

Prepared by Hamilton Standard
For NASA Goddard Space Flight Center
Contract No. NAS5-31889
GSFC Document No. TRMM-SER-705
June 15, 1992

(NASA-CR-190383) CONCEPTUAL DESIGN STUDY FOR THE USE OF COBE ROCKET ENGINES ON THE TROPICAL RAINFALL MEASURING MISSION Final Report, 10 Jan. - 16 Jun. 1992 (Hamilton Standard) ~~243 p~~ 195

N92-26535

Unclas

G3/47 0096735

UNITED TECHNOLOGIES
HAMILTON STANDARD

Appendix 1: 16 Pages
Appendix 2: 9 Pages
Appendix 3: 14 Pages
Appendix 4: 3 Pages
NASA Form 1626: 1 Page

FINAL REPORT

CONCEPTUAL DESIGN STUDY

FOR THE USE OF COBE ROCKET ENGINES

ON THE

TROPICAL RAINFALL MEASURING MISSION

(TRMM)

Prepared by Hamilton Standard
For NASA Goddard Space Flight Center
Contract No. NAS5-31889
GSFC Document No. TRMM-SER-705
June 15, 1992

ABSTRACT

This document contains a Final Report for the Conceptual Design Study for the use of COBE Rocket Engines on the Tropical Rainfall Measuring Mission (TRMM). It was prepared by Hamilton Standard for NASA Goddard Space Flight Center under Contract NAS5-31889.

CONTENTS

<u>LIST OF FIGURES</u> (Note: Figure prefix is Section #)

LIST OF TABLES (Note: Table prefix is Section #)

APPENDICES

ACRONYMS

BOL	Beginning of Life
CFE	Customer Furnished Equipment
COBE	Cosmic Background Explorer
EJB	Electrical Junction Box
EOL	End of Life
GHe	Gaseous Helium
GN2	Gaseous Nitrogen
GSFC	Goddard Space Flight Center
HPS	Hydrazine Propulsion Subsystem
HS	Hamilton Standard
Ibit	Impulse Bit
IPA	Isopropyl Alcohol
Isp	Specific Impulse
lbf	Pounds Force
lbm	Pounds Mass
MLI	Multi Layer Insulation (Blanket)
NASDA	National Space Development Agency (Japan)
Pi	Inlet Pressure
PSDU	Power Switching and Distribution Unit
RCS	Reaction Control System
REA	Rocket Engine Assembly
REM	Rocket Engine Module
TCA	Thrust Chamber Assembly
TCV	Thrust Control Valve
TRMM	Tropical Rainfall Measuring Mission
VDC	Volts Direct Current
WBS	Work Breakdown Structure

1. OBJECTIVE

The objective of this conceptual design study is to verify that the COBE HPS REAs will satisfy the TRMM mission requirments and to develop a preliminary thruster module design utilizing the existing REAs.

2. INTRODUCTION

The Goddard Space Flight Center (GSFC) is currently working on the spacecraft design for the Tropical Rainfall Measuring Mission (TRMM). The TRMM spacecraft mission is to measure tropical rainfall and correlate the data with ground observations for a better understanding of the earth's climate. In order to minimize the schedule risk and to reduce the overall costs of the RCS, GSFC wishes to utilize the 5 lbf Rocket Engine Assemblies (REA's) from the Cosmic Background Explorer (COBE) Hydrazine Propulsion Subsystem (HPS). The COBE HPS utilized 12 REAs packaged on 3 'quads' in groups of 4 REAs/quad to perform the COBE mission. The TRMM spacecraft design requires 12 Rocket Engine Modules (REMs), each containing a single REA. As a result they will have to be repackaged into a new REM design.

The entire modification process is divided into two phases (programs). Phase 1 program is a conceptual design study which shall verify the thruster performance and establish a preliminary thruster module design. Phase 2 program shall include the detailed design work, fabrication and test of the thruster modules.

This report details the work done by Hamilton Standard on Phase 1 to include 1) Performance Verification; 2) Preliminary Design; 3) Test Requirements; and 4) a Rough Order of Magnitude (ROM) cost for the Phase 2 program.

3. SUMMARY

The major points of this report are summarized below:

1. The performance of the COBE HPS 5 lbf thrusters meet the TRMM mission requirments.
2. The preliminay design consists of a single 5 lbf REA REM which is isolation mounted to a spacecraft interface angle bracket (5 or 10 degree angle). The REM incorporates a catalyst bed heater and sensor assembly, and propellant thermal control is achieved by thermostatically controlled heaters on the thruster valves.
3. A ROM cost of approximately $950K has been estimated for the Phase 2 Program to finalize the design, fabricate and test the hardware (Tasks 1, 2 & 3) using mechanical thermostats for thermal control. In the event that Solid State Thermostats are used, the cost is estimated to be $160K higher. A ROM cost of approximately $145K is estimated to investigate the effects of using Japanese manufactured hydrazine for the TRMM mission (Task 4).

4. CONCLUSION

Assuming satisfactory completion of functional integrity testing of the COBE HPS REAs at GSFC and Hamilton Standard, the thrusters can be packaged into single REA REMs which will satisfy the requirements of the TRMM mission.

5. ISSUES AND RECOMMENDATIONS

The following issues and recommendations are covered in this section.

5.1 Waivers on EMI/EMC tests

5.2 Transportation and Handling

5.3 Japanese Hydrazine

5.4 Task 1 Integrity Testing of the TCAs

5.5 Cold Start

5.1 Waivers on EMI/EMC tests

In the event that mechanical thermostats are selected for the final design of the REM a waiver will be required to the EMI/EMC requirements currently specified in TRMM-733-043 Chapter 6. The ability to meet these requirements would require filtration additions to the design and verification tests, neither of which are planned or estimated. The preliminary design reflected in this study has been satisfactory for EMI/EMC requirements in all other HS programs.

For these reasons it is recommended that the EMI/EMC requirements be waived for the switching effects of mechanical thermostats.

Reviewing data for the COBE thruster valves indicates that they will comply with the magnetic field requirements of the TRMM specification. It must be realized that while HS will exercise sound engineeering practices in the wire cable shielding and cable placement on the REM, the ultimate responsibility for EMC compliance of the valves must rest with GSFC as they are providing the valve driver circuits.

5.2 Transportation and Handling

The COBE REAs to be used on the TRMM mission are neither configured nor qualified for any vibration loads occurring during handling and transportation with the catalyst bed oriented above the valve. If the REMs are subjected to these conditions, contamination of the valve seats could occur from catalyst fines which may result in unacceptable seat leakage.

It is recommended that all handling and transportation of the REMs, at the REM, RCS or spacecraft level, be accomplished to maintain the catalyst beds level with or below the thruster valves. HS cannot assume responsibility for performance degradation or leakage of the thrusters in the event these precautions are not followed.

GSFC should determine as early as possible in the program the spacecraft physical arrangement and the procedures necessary to preclude these conditions from occuring.

5.3 Japanese Hydrazine

There is currently a possibility that the TRMM mission may use hydrazine manufactured in Japan which contains small amounts of toluene. This issue is discussed in Section 11. HS does not assume any responsiblity for the performance of its thrusters using this hydrazine without verification tests.

It is recommended that if hydrazine containing toluene is used then firing performance tests be conducted simulating both a worst case composition of the Japanese hydrazine, and a worst case steady state and pulsing performance duty cycle.

5.4 Task 1 Integrity Testing of the TCAs

Because the COBE REM hardware has been subjected to uncontrolled and/or unknown handling, transportation and storage with NASA/GSFC for a number of years it is planned to do functional integrity testing of the hardware upon return to HS under Task 1 of the Phase 2 Hardware Program. Any problems identified at this point in the program can be addressed with minimal schedule impact. Currently only electrical and leakage testing is planned. Firing tests of flight TCAs are planned at the REM level after vibration. In the event that nominal TCA firing performance during REM acceptance test differs significantly from that expected it could have a major impact upon the program delivery schedule. It is recommended that:

1) All TCAs are fired as soon as they are returned to HS as part of the integrity tests of Task 1.
2) If performance is nominal, then HS recomends no further firing tests at the REM/TCA level during REM acceptance testing. In lieu of firing a liquid flow/delta P test of the REM assembly would be performed after vibration testing.
3) If a TCA fire integrity test is performed during Task 1 with a REM liquid flow test during REM acceptance testing, no net cost impact is anticipated. There would be an estimated $19K cost impact if the TCAs are refired at the REM level.

5.5 Cold Start

The minimum predicted catalyst bed temperature upon spacecraft separation, at which time the thrusters would be fired to control tip-off torques, is estimated by HS to be 18°F. This prediction is based on the following assumptions:

1. Catalyst bed heaters are not activated.
2. Thrusters are exposed to deep space for the period from fairing separation (3 minutes after launch) to spacecraft separation (28 minutes after launch).
3. Spacecraft temperature is a constant 59°F (15°C) during this period.

Based on the possibility that thruster firing may not occur immediately upon spacecraft separation, and the relatively rapid catalyst bed cooldown rate, the actual pre-fire temperature will most likely be less than 18°F. In order to preclude potential damage to the catalyst bed due to a cold start at this temperature (minimum commandable pulse width of 125 ms), HS recommends that the catalyst bed heaters be activated early in the launch profile to provide a minimum pre-fire temperature of 60°F.

It is noted that GSFC has assured HS that heater power will be made available prior to initial (post separation) thruster firing so that adequate time exists to warm the catalyst beds.

6. CONSIDERATIONS

The following are offered to GSFC for consideration in finalizing the Phase 2 Hardware Program for TRMM.

6.1 Qual Mission Firing

6.2 Contingency Costs and Schedule

6.3 Integration of REMs with Wagon Wheel

6.4 Nozzle Alignment Verification and Adjustment

6.5 Final RCS Integration Arrangment

6.6 Thrust Chamber Heater Reusability

6.7 Firing Performance Issues

6.1 Qual Mission Firing

A determination must be made as to the most appropriate qual REA to use for this test and whether or not any test limitations must be made based on past qualification testing on the COBE program. Mission life requirements for the REA are defined by GSFC specification TRMM-713-030 para. 5. (See Table 7-III and the Compliance Matrix in Appendix 1 herein). The COBE Qual REAs cannot be subjected to a mission firing life test to satisfy these requirements without undue risk. If mission firing life qualification testing is desired by GSFC, the Qual REM will have to be built with a flight spare REA.

Based on a comparison with other REA 39 series life tests, HS feels that there is sufficient qualification data to establish compliance with the life requirements for TRMM and no additional life testing for qualification is necessary.

6.2 Contingency Costs and Schedule

There is no cost consideration given in the ROM estimate for resolution of contingencies that may develop because of failure of the returned hardware to perform correctly. Such events will have to be dealt with contractually as they occur. In the event that new flight valves or chamber heaters have to be ordered, a schedule impact of approximately 6 months would likely occur.

6.3 Integration of REMs with Wagon Wheel

It has been mentioned by GSFC that there is consideration being given to integration of six of the flight REMs to the Wagon Wheel at HS. The ROM costs given in Section 12 do not include an estimate to accomplish that integration.

6.4 Nozzle Alignment Verification and Adjustment

It is currently unknown as to what the nozzle alignment accuracy of the installed REM will be, especially given that they are isolation (soft) mounted. The REA nozzle is capable of +/- 3^{o} adjustment about its nominal axis as installed in the REM. Adjustment can take place at HS at the REM level or at GSFC at the spacecraft level depending on the accuracy desired. Some loss of accuracy due to hysteresis in the isolation mount Belleville stackups can be expected after adjustment. GSFC will have to determine what alignment accuracy and verification procedure is required for their spacecraft level control dynamics.

6.5 Final RCS Integration Arrangment

As discussed in Section 11.7 the four REM design configurations can be integrated into the RCS in a number of different combinations that will meet both the thrust vector requirements and handling and transportation constraints. Each of these combinations requires a different number of each of the four REM configurations.

The Phase 2 Hardware Program will require a determination by GSFC of the final integration arrangement so that the proper number of each REM configuration can be built.

6.6 Thrust Chamber Heater Reusability

Final acceptability concerning reuse of the COBE catalyst bed heater will be made following evaluation of the updated REM environmental fluxes, to be supplied by GSFC in the Phase 2 Hardware Program. The TRMM heater voltage is unregulated, 21 vdc to 35 vdc, whereas the COBE heater voltage (catalyst bed only) was regulated, 28 vdc $\pm$ 2%. As a result, at the minimum voltage of 21 vdc, the COBE catalyst bed heater power is reduced by about 32%. For the conservative condition in which the environmental fluxes are assumed to be zero, the equilibrium catalyst bed temperature is 52°F with one element powered at minimum voltage. This temperature is below the minimum acceptable pre-fire temperature of 90°F required to provide essentially unlimited cold start capability. At the nominal voltage of 28 vdc, the equilibrium catalyst bed temperature is 126°F, providing margin on the pre-fire temperature requirement. Consideration of the final environmental fluxes to be provided by GSFC is necessary to establish reusability of the COBE catalyst bed heater. A requirement to replace these heaters has not been accounted for in the costing or schedule presented in the ROM.

6.7 Firing Performance Issues

Minor firing performance issues, relative to compliance with the pulsing Isp and Minimum Ibit repeatability requirements, have been identified. In both instances, the demonstrated performance of the COBE HPS thrusters violate the requirements under certain conditions as discussed in Section 7. Since the COBE HPS thrusters are existing hardware and no improvement in their documented performance is realistically feasible, a revision to the specifications is required. GSFC is aware of this and intends to reflect hardware capability in their specification requirements for the Phase 2 Hardware Program.

7. PERFORMANCE VERIFICATION

The conceptual design study included verifying that the performance of the COBE HPS thrusters satisfies the TRMM mission requirements. The performance verification was accomplished by examining HPS thruster qualification and acceptance test data and establishing a relative comparison with TRMM requirements. Performance requirements which exceeded the qualification levels of the COBE HPS thrusters were evaluated against supporting test data from other Hamilton Standard test programs to establish compliance with TRMM requirements.

Table 7-I presents a summary of the capability of the COBE HPS thruster (REA 39-5), based on the demonstrated performance of the REA 39 series thruster, versus TRMM performance requirements. These requirements reflect a compilation of the thruster performance specifications contained in Appendix 1, Specification Compliance Matrix, which includes a compliance review of the following documents: TRMM-713-030, TRMM-713-031, and TRMM-713-032, as well as updates received separately. The available data shows that the performance of the COBE HPS thruster matches or exceeds the TRMM requirements in most cases. Duty cycle characterization testing is recommended to establish the HPS thruster performance for specific TRMM mission duty cycles.

The REA 39 series thruster has demonstrated substantial margin on the TRMM life requirements utilizing both monopropellant grade and high purity grade hydrazine.

Therefore, mission life testing to establish the performance of the COBE HPS thruster using monopropellant grade, as specified for TRMM, instead of high purity grade, as originally qualified, is not felt to be necessary.

7.1 Steady State Performance

Thrust - The COBE HPS thruster produces a nominal thrust of 21.59 N (4.854 lbf) and 8.07 N (1.815 lbf) at an inlet pressure of 1.93 MPa (280 psia) and 0.517 MPa (75 psia), respectively, as shown in the acceptance test data summary presented in Table 7-II. The corresponding 3-sigma thrust variability is less than $\pm$ 5% at both inlet pressures, satisfying the module-to-module thrust repeatability requirement. Figure 7-1 provides the specified thrust blowdown characteristic and shows that the thruster acceptance test data is consistent with this requirement.

The nominal thruster inlet pressure is set by the propellant tank pressure which is initially regulated to 1.309 MPa (190 psia) with a slight blowdown to 0.899 MPa (130 psia) at mission completion. The corresponding BOL and EOL thrust requirements of 15.6 N (3.51 lbf) and 11.7 N (2.63 lbf), respectively, are coincident with the delivered thrust levels of the COBE HPS thruster. Propellant tank temperature excursions over the range of $10^{o}C$ ($50^{o}F$) to $40^{o}C$ ($104^{o}F$) result in pressure excursions over the range of 0.621 MPa (90 psia) to 2.4 MPa (348 psia). The REA 39 series thruster is qualified to operate over an inlet pressure range of 0.517 MPa (75 psia) to 2.41 MPa (350 psia).

Specific Impulse - The COBE HPS thruster provides a steady state Isp of 230.97 sec ± 1.14% and 224.32 sec ± 0.79% at an inlet pressure of 1.93 MPa (280 psia) and 0.517 MPa (75 psia), respectively, as presented in Table 7-II. Figure 7-2 presents the TRMM requirement for steady state Isp as a function of inlet pressure and shows that the COBE HPS thruster data is within specification.

7.2 Pulsing Performance

Specific Impulse - The TRMM requirement for pulsing Isp as a function of on-time, for a fixed off-time of 2 sec, is provided in Figure 7-3. This figure reflects the GSFC requirement in the RCS specification TRMM-713-031. The COBE HPS thruster qualification testing did not extensively map pulsing performance and, as a result, full compliance with this requirement cannot be established without additional characterization testing. However, a comparison of the pulsing Isp requirement of Figure 7-3 at an on-time of 1 sec (which approaches steady state performance) with the steady state Isp requirement of Figure 7-2 (which is consistent with the COBE HPS thruster performance) shows that the two requirements are inconsistent. A reduction in the pulsing requirement of Figure

7-3 at relatively long on-times to match the demonstrated steady state Isp of Figure 7-2 is recommended. These compare with Figure numbers 3-4 and 3-3 respectively in TRMM-713-031.

Impulse Bit - The nominal equilibrium Ibit as a function of on-time, for a fixed off-time of 2 sec, extrapolated from thruster acceptance test data at a duty cycle of 0.10 sec on, 1.90 sec off, is presented in Figure 7-4. Additional duty cycle characterization testing is required to verify the predicted Ibit over the indicated on-time range. At a duty cycle of 0.125 sec on, 2 sec off, the specified Ibit for inlet pressures between 1.93 MPa (280 psia) and 0.66 MPa (95 psia) is 2.82 N-sec (0.634 lbf-sec) to 1.11 N-sec (0.25 lbf-sec). Including thruster-to-thruster variability, the COBE HPS thruster provides an impulse bit of 2.82 N-sec (0.634 lbf-sec) to 1.25 N-sec (0.281 lbf-sec) at the specified conditions, satisfying the requirement. The 3-sigma Ibit variability at an on-time of 0.125 sec is less than ± 8.13%, based on acceptance test data. Due to a reduction in the corresponding minimum Ibit (MIB) repeatability requirement by GSFC from ± 10% maximum to ±5% maximum, this requirement is no longer satisfied. Since the COBE HPS thrusters are existing hardware with known performance characteristics, a change in the Ibit repeatability requirement to reflect the thruster performance has been recognized as a necessary change by GSFC (see para. 6.7). Figure 7-5 presents the predicted maximum and minimum impulse bit as a function of inlet pressure for an on-time of 0.125 sec and an off-time between 0.125 sec and 20 sec, including thruster-to-thruster variability.

<u>Off-Impulse Bit</u> - The predicted off-impulse bit as a function of off-time is provided in Figure 7-6. The off-impulse bit of the COBE HPS thruster is based on TOPEX 22.2 N (5 lbf) thruster (also an REA 39-5) protoflight test data at a duty cycle of 1 sec on, 0.28 sec off.

7.3 Life

The TRMM life requirements include specifications for propellant throughput, total impulse, maximum burn duration, total burn time, and total pulses, as summarized in Table 7-III. Qualification testing of the COBE HPS thruster demonstrated margin on each of these requirements utilizing high purity grade hydrazine. Supporting data from other Hamilton Standard thruster test programs verified that the life capabilities of the REA 39 series thruster exceed the TRMM requirements utilizing monopropellant grade hydrazine, presently specified for the TRMM mission. Specifically, qualification testing of the Mark II REA 39-3 and extended life testing of the IR&D REA 39-2, both using monopropellant grade hydrazine, demonstrated acceptable performance without any evidence of steady state washout or pulse fadeout, characteristics of aniline poisoning, each over a total impulse well in excess of the TRMM requirement. The IR&D REA 39-2 demonstrated a maximum burn duration of 7200 sec, over 2.5 times the TRMM requirement of 2710 sec. The life data for the REA 39 series thrusters, summarized in Table 7-III against the TRMM requirements, verifies that the COBE HPS thruster will meet the life requirements using monopropellant grade hydrazine. No additional life testing to qualify these thrusters is necessary.

8. Preliminary Design

8.1 Mechanical Design

8.1.1 Arrangement

The TRMM Rocket Engine Module (REM), shown in Figure 8-1 and sheet 8 of SVL17492 (Appendix 4), consists primarily of a Thrust Chamber Assembly (TCA), a Thrust Control Valve (TCV), a chamber heater and temperature sensor, a valve heater and thermostat assembly, a valve temperature sensor, an engine support bracket, an angle bracket, Multi-layer Insulation (MLI) and a spring pack vibration isolation system connecting the angle bracket to the engine support bracket. The MLI, not shown in Figure 8-1, is described in Section 8.2. A more detailed parts list including a weight breakdown is shown in Table 8-I.

Four REM configurations are required. The configurations are identical except for the slope (5 degrees or 10 degrees) and the orientation (left or right) of the angle bracket.

The engine support bracket and the angle bracket are machined from aluminum alloy. They are connected by a Belleville spring isolation system consisting of four spring packs in a rectangular pattern. The symmetry of this pattern allows the same part number angle bracket to be used in left or right handed configurations by reversing its orientation. The angle bracket has four lugs which serve as attach points to the spacecraft and also provide four threaded holes for attachment of a ground handling protective cover.

The isolation system is provided to reduce the REM response to launch vibration which, if not attenuated, would be high enough to cause the TCV to open. Vibration analyses are presented in Appendix 2. Each of the four mounts consists of sixteen Belleville springs, a pair of flanged bushings mounted end-to-end, washers, three o-rings, a screw and a nutplate. When assembled, the screw preloads the stack-up of the angle bracket, bushings and nutplate which can all be visualized as being rigidly connected to the spacecraft. The Bellevilles are compressed to a height controlled by the thickness of the bushings, engine support bracket and washers. The engine support bracket and its contents are free to "float" on the Belleville springs. The three o-rings allow angular motion and provide damping.

The isolation system is identical to that flown regularly on the IUS REM. Like TRMM, the isolation system was found to be necessary on IUS to prevent valve opening during launch.

8.1.2 Installation and Envelope

The installation and envelope of the four REM configurations are shown in Figure 8-2 and sheet 9 of SVL17492 (Appendix 4). Each REM is mounted to the spacecraft by four CFE number ten (.190) fasteners. The mounting lugs on the angle bracket protrude from the sides so that access to the opposite side of the spacecraft mounting surface is not required for installation. Each lug provides a plain through hole for mounting. As currently configured, the engine support bracket slightly overhangs the spacecraft mounting holes due to the required five and ten degree mounting angles. This limits the mounting bolt length to about 1.25 inches. Bolt length can be increased if the mounting lug footprint is enlarged slightly. Each lug also has an extension containing a threaded hole for attachment of a protective cover for ground use only. Sketches of a cover are shown in Figure 8-3.

The electrical interface consists of pigtail leadwires for all components. The electrical schematic is shown in Figure 8-4. The leadwire cables have been bundled into two groups for integration into the spacecraft. The groups separate sensor leads from power leads. The sensor group consists of the catalyst bed temperature sensor and the valve temperature sensor. The power group consists of the catalyst bed heaters, the valve heaters/thermostats and the valve power (command) leads. REM egress points have been selected to minimize the impact on the MLI. The sensor group (two cables) exits the REM at the fluid inlet tube. The power group (5 cables) exits the REM at a corner where inherent inefficiencies in the MLI occur. The peak REM electrical power requirements at maximum spacecraft voltages are: valve heater (both elements) - 8.8 watts maximum; catalyst bed heater (both elements) - 14.4 watts maximum; valve solenoid (both coils) - 35.7 watts maximum.

The fluid interface consists of a .250 inch (6.35 mm) diameter x .035 inch (.889 mm) wall tube of AISI 304L material suitable for welding. In order to enhance interchangeability, the angle of the fluid inlet has been made common for all the engine support brackets. Thus the angle of the inlet tube varies +/- 10^{o} with respect to the spacecraft. If necessary, the angle and configuration of the tubes can be unique for each REM. For reference, the RCS fluid schematic is shown in Figure 8-5. Table 8-II lists the current interfaces and their source.

Each TCA has provision for adjustment of the nozzle alignment. The TCA is secured to the engine support bracket by a three-point mount consisting of a fixed spherical spacer, a fixed spherical spacer in a slot and a shim stack as shown in Figure 8-6. Fluid connection to the TCV is through a single small ductile tube which deforms slightly to accommodate the adjustment. The azimuth angle is adjusted by pivoting the TCA about the fixed spherical spacer. The rotation centerline for this adjustment is parallel to the thrust chamber centerline. Slots in the TCA mounting flange and in the engine support bracket provide clearance for rotation. This adjustment is secured by tightening two opposing set screws at the fixed spherical spacer in slot. Pitch angle is adjusted by adjusting the thickness of the shim stack. Pivoting takes place about both spherical spacers during this procedure. Conical counterbores in the engine support bracket provide a surface in which the spherical spacers pivot. When adjustment is complete, the threaded fasteners at all three locations are torqued to their prescribed values. The thruster is capable of +/- 3^{o} adjustment about nominal in both directions. Adjustment can take place at Hamilton Standard at the REM level or at GSFC at the spacecraft level depending on the accuracy desired. Some loss of accuracy due to hysteresis in the Belleville stackups can be expected.

8.1.3 Weight

The current predicted weight is 3.18 lb (1.44 kg) per REM. This results in a shipset weight of 38.2 lb (17.3 kg). The weight breakdown is shown in Table 8-I and includes the weight of leadwires within the REM envelope, but excludes the weight of leadwires outside the REM envelope. The weight is considerably higher than initial predictions due to the need for vibration isolation, but has been somewhat reduced by incorporating pigtail leadwires instead of the electrical connectors that were in initial configurations. The leadwire definition and weight is shown in Table 8-III to assist GSFC in assessing RCS weight. Where hardware is intended to be reused from COBE, leadwire lengths are given. It should be noted that these leadwires have already been trimmed to the lengths indicated and the RCS design must accommodate these existing lengths.

8.1.4 Component Description

8.1.4.1 Rocket Engine Assembly

The TRMM REA, manufactured for the COBE mission, is shown in Figure 8-7. It is a long life version of the STS qualified MMS

Mark II 5 lbf thruster. The thrust chamber assembly, shown in Figure 8-8, utilizes design features derived from the REA 23 and REA 39 family of engines. The designation of the TRMM engine is REA 39-5.

Valve thermal isolation is provided by a tube welded to the thruster mounting flange at the propellant manifold. This serves to reduce heat soakback from the thruster to the valve, as well as minimize the valve heater power required to prevent propellant freezing. An orifice plate is permanently installed between the isolation tube and the mounting flange for thrust calibration.

The injector manifold is thermally isolated from the hot reaction chamber by a perforated thin wall thermal standoff and 12 capillary tubes. This minimizes heat soakback to the manifold and valve and reduces catalyst bed heater power.

The injector consists of 12 capillary tubes with penetrating diffusers. This design, common to all Hamilton Standard flight engines, injects low velocity, uniformly distributed propellant into the catalyst bed. This increases catalyst wetted surface area, improves start response, provides smoother operation and reduces catalyst attrition to enhance thruster life and performance. The dual screen diffusers act as a filter to keep catalyst fines from migrating upstream into the injector and valve during handling and vibration. It should be noted however, that although the 325 over 80 mesh diffuser screen provides excellent protection for the valve and injector, it has not been qualified for a vibration environment with the thrust chamber located above the valve/injector. Qualification requires not only qual vibration tests, but more importantly, rigorous inspection during production fabrication, including a bubble point check. Because the COBE REAs have not been qual tested nor received in-process production fabrication tests they can not be recommended for such service.

The catalyst bed uses a split bed composed of Shell 405 20-35 mesh catalyst in the upstream bed and 14-18 mesh catalyst in the downstream bed. This design has been proven effective for rapid starts, smooth decomposition and minimal bed pressure drop, thus ensuring repeatable performance over a long life.

The mid-screen and end-screen material is 85/15 platinum/iridium. This material has been shown to be beneficial for long life applications since it is not susceptible to nitriding. The mid-screen prevents mixing of the two catalyst bed mesh sizes and minimizes bed voiding at the injector to prolong life.

The thruster utilizes a maximum thrust, truncated perfect bell nozzle with an area ratio of 60:1 for improved specific impulse. This contour was designed with a low exit angle specifically to reduce the plume angle and resultant plume drag on the COBE vehicle.

8.1.4.2 Thrust Control Valve

The valve, shown in Figure 8-9, is a normally closed, solenoid operated shutoff valve, capable of both continuous operation and pulsing. It is a dual seat configuration furnished by Wright Components, Inc. The valve has an all-welded assembly with a common coil spool body and a through bore. The valve seat is a circular metallic sealing surface which mates with a soft AF-E-411 Ethylene Propylene Terpolymer (EPT) poppet. The plunger closing force is provided by a spring. Dropout characteristics are controlled by a non-magnetic washer which is installed between the plunger and the bottom of the solenoid core bore minimizing residual magnetism effects by assuring an "air gap."

All materials used in the valve which are in contact with the flowing propellant are compatible with hydrazine. All joints in the hydrazine flow paths are electron beam welded to provide maximum joint integrity, long term storage capability and high thermal compatibility. A 25-micron absolute filter with adequate dirt retention capacity is utilized at the valve inlet to protect both the valve seats and the injector against contamination.

8.1.4.3 Thrust Chamber Heater/Sensor

The heater, shown in Figure 8-10, is an integral part of a clamp which fits around the thrust chamber. This type of installation minimizes the overall thrust chamber mass and envelope. The function of the heater is to raise the catalyst bed temperature to a level which will eliminate catalyst bed degradation associated with cold starts thus improving thruster life. The heater assembly has dual elements. The basic heater assembly consists of: a heater resistance element and housing; a sheathed leadwire; a transition joint and soft leadwire. The heater type is of the free standing coil design which eliminates the stress imposed on the resistance wire common to a rigid plasma coated design. Each heater resistance element is a fixed length of Nichrome V resistance wire coiled in the form of a spring to achieve the necessary wire length in the required distance. The coiled heater resistance element is retained in position by locating the element in an alumina mandrel. Alumina powder is packed around the coiled element providing support but does not rigidly retain and strain the element under thermal shock. The element assembly is contained within an Inconel 600 housing. The heater external leadwires are encased in an Inconel 600 sheath. The sheathed leadwires are isolated from the sheathing by magnesium oxide. The leadwires are attached to the resistance element prior to enclosing the heater element assembly in the housing.

At the other end of the sheathed leadwires a transition joint is assembled permitting both the attachment of the soft insulation leadwires and the hermetic sealing of the heater at the sheathed leadwire end. The leadwire sheath is brazed to the transition joint and, in combination with a glass bead seal, forms the final hermetic seal. The soft insulated leadwires are encased within a potting compound at the transition joint and strain relief is provided to prevent wire breakage.

The chamber temperature sensor is a platinum probe encased in a metal sheath and attached to the chamber by a press fit in a split sleeve which is brazed to the clamp. The leadwire configuration is identical to that used on the heater.

8.1.5 Reusability Status

Hardware from the COBE Quads is reusable as follows:

* Thrust Chamber Assembly
* Thrust Control Valve
* Alignment Adjustment Buttons
* Chamber Htr/Sens Leadwire Clamping Bracket
* Thrust Chamber Heater/Sensor

The thrust chamber heater/sensor is anticipated to be reusable at this time. Final determination of reusability can be made when the heater power requirements are determined. There is also a possibility that a few small fasteners, clamps and similar hardware may be reusable, however, for conservatism, it has been assumed they may be damaged or misplaced during disassembly and will be replaced. The valve thermal spacers may be reusable, however because they are non-metallic and subject to compression set over long periods of time, it is recommended that they be replaced. Because the self-locking feature of fasteners of the type used on COBE is cycle-limited, it is recommended that all self-locking threaded fasteners be replaced. Replacement of the O-Ring sealing the valve to the thrust chamber is also recommended. All other REM constituents are either not installed on the COBE Quad or have a high probability of damage during disassembly and must be procured for TRMM.

8.1.6 Solid State Thermostat Option

A solid state thermostat (SST) manufactured by TAYCO Engineering can be used for valve heater control. The thermostat, shown in Figure 8-11, is available with a remote sensor option which would be bonded to the TCV. The thermostats themselves would be mechanically attached to the engine support bracket as shown in Figure 8-12. A small weight savings would be expected. Determination of mechanical or solid state thermostats will be made during the next phase of the TRMM REM Program.

Because an internal sensor is also available, another packaging option would be to bond the sensors directly to valve clamps as is currently done for the mechanical thermostat assemblies. In this case, because of their size, the packaging of four SSTs would occupy the same volume as 2 mechanical thermostats thus simplifying the REM packaging slightly.

A cost delta for this design option is described in Section 12.

8.2 Thermal Design

The thermal design established for the TRMM REM is similar to the design qualified for the COBE Quad, resulting in a low risk thermal management approach. In addition, utilizing a similar design allows the maximum reuse of existing hardware and precludes the need to remove existing thermal control platings (such as the gold plating on the thrust control valve [TCV]). A combination of passive and active thermal control features are utilized on the TRMM REM to minimize heater power consumption required to prevent propellant freezing, and limit heat soakback during thruster firing to provide unlimited duty cycle capability. Figure 8-13 illustrates the REM thermal design features.

The passive thermal control features serve to decouple the REM and the TCV from their respective conductive and radiative interfaces, minimizing valve heater power consumption. Thermal isolation between the REM and the spacecraft is provided by the inherently high thermal resistance of the vibration isolators.

A multi-layer insulation blanket (MLI) covers the majority of the REM bracket surfaces and shields the internal fluid components from deep space. The TCV is thermally decoupled from its mechanical interfaces by G3HT phenolic washers (two in parallel) at each valve mount location, and an adapter tube between the valve and thrust chamber assembly (TCA) which provides significant thermal resistance. Both the interior bracket surfaces and the valve are gold plated or taped as required to radiatively decouple these items.

Heat soakback during firing from the thrust chamber to the temperature sensitive injector manifold (hold-up volume immediately upstream of the injector tubes) is limited by a thin-walled, perforated thermal standoff. The thermal standoff also serves to minimize catalyst bed heater power consumption. This feature is common to every Hamilton Standard thruster design and decouples the thrust chamber from the thruster mount flange. The COBE Quad incorporated a copper thermal shunt between the injector manifold and the REM bracket to short-circuit the relatively high thermal resistance provided by the thruster mount alignment mechanism and provide a means of heat dissipation during peak soakback periods. The need for this thermal shunt in the TRMM REM has not been definitively resolved.

The MLI blanket consists of multiple flat patterns (2 or 3) fitted over the REM bracket to cover the majority of the exposed surfaces. The thruster mount surface may require a tailored thermal control treatment to moderate the injector manifold temperature during peak soakback periods, depending on the outcome of the final REM thermal analysis conducted in the Phase 2 Hardware Program. Sufficient overlap will be provided at the edges of the insulation blanket and the number of penetrations for mechanical, electrical and fluid interfaces will be minimized to optimize the overall thermal efficiency and provide an effective emittance within the specified range of 0.005 to 0.03. A separate MLI blanket is required to cover the angle bracket and integrate with the spacecraft insulation blanket. The blanket cross-section, which was utilized on the COBE HPS, consists of 10 internal layers of 0.5 mil aluminized Kapton film separated by alternating layers of polyester knit, enclosed in 2 external layers of 2 mil aluminized Kapton film. Figure 8-14 shows the details of the insulation blanket cross-section.

The active thermal control features consist of electrical resistance heaters, located on the thrust control valve and the thrust chamber, to prevent propellant freezing and provide an acceptable pre-fire catalyst bed temperature, respectively. The valve heater contains redundant Inconel 600 elements sandwiched in a Kapton lamination, bonded directly to the valve. Each element is controlled by a series pair of thermostats, one to provide the cut-out function (typically, at a slightly higher temperature setpoint) if the control thermostat fails closed. This arrangement automatically protects against a single failed thermostat or a single failed heater element and does not required ground detection or response under normal operation in which both primary and secondary elements are powered. The four thermostats are bonded to a single clamp which is mechanically attached to the valve. The valve heater is a new design, tailored to the TRMM voltage and power requirements, and is sized to provide a minimum power of 1.5 watts per element at the minimum operating voltage of 21 vdc. The valve heater design limits the watt density (power per unit area) to prevent self-damage at maximum power should the heater locally separate from the valve. The thermostat open and close temperature setpoints will be selected in the Phase 2 Hardware Program to provide margin on the minimum valve temperature requirement of $8^{\circ}C$ ($46^{\circ}F$) while optimizing average power consumption and thermostat cycle life. A valve thermistor, as required, is bonded to the inlet tube for diagnostic purposes.

The catalyst bed heater contains redundant Nichrome V elements retained in an alumina mandrel within an Inconel housing. The heater is attached to the thrust chamber via a circumferential clamp and is shimmed with gold foil to enhance the contact conductance. Each heater element is independently commandable with temperature telemetry provided by a platinum probe which is encased in a metal sheath that is brazed to the heater clamp. Presently, the COBE catalyst bed heater and temperature sensor are baselined for reuse in the TRMM REM. However, due to the difference in supply voltage between TRMM (21 vdc to 35 vdc) and COBE (28 vdc $\pm$ 2%), this heater provides 32% less power at the minimum sizing condition. Depending on the final environmental fluxes, the COBE catalyst bed heater may be undersized to satisfy the minimum pre-fire temperature requirement of 32°C (90°F). The preliminary results of the TRMM REM thermal analysis, provided in Appendix 3, show that the COBE catalyst bed heater is marginally sized, when considering the environmental fluxes supplied by GSFC during this study, to meet the minimum temperature requirement at the sizing condition. Evaluation of the final environmental fluxes is necessary to establish ultimate reusability of this heater. Table 8-IV summarizes the rated power, peak power, and average power for both the valve and catalyst bed heaters.

9. TRADE STUDY

Several design trades were made to arrive at the current preliminary design described in Section 8 of this report. The three mentioned herein are:

9-1 Electrical Interface Trade

9.2 Thermal Control Trade

9.3 RCS Integration Arrangment Trade

The RCS Integration Arrangment Trade selected a radial arrangment of the REMs which established an optimum bracket comonality.

The Electrical Interface Trade resulted in a recommendation by HS to use a pigtail arrangment to simplify packaging and weight.

The thermal control trade has not been finalized. The options considered are shown in Table 9-I. The current baseline design for which a ROM cost has been estimated utilizes Thermal Control Option TC1.1 mechanical thermostats to control valve heater power. A delta configuration cost has been submitted for thermal control option TC2.3 with solid state thermostats from TAYCO. Final selection of the thermal control option shall be accomplished in the Final Design (Task 2) during the Phase 2 Hardware Program.

A discussion of the trade effort follows.

9.1 Electrical Interface Trades

9.1.1 REM Electrical Connectors Versus Pigtails

The baseline REM configuration utilizes pigtail leadwires. REM's having electrical connectors were studied. Figure 9-1 shows a REM configuration with connectors. The schematic for such a configuration is shown in Figure 9-2. Some advantages of connectors are:

* Ease of REM installation on the spacecraft
* On-vehicle REM checkout is simplified
* Ease of valve heater/thermostat interconnection

Disadvantages are:

* Higher weight - 8.2 lbm (3.8 kg) in the REM's plus 2.4 lbm (1.09 kg) for spacecraft mating connectors.
* More complicated REM packaging and thermal design.
* Higher REM cost.
* Requires larger envelope to accommodate the spacecraft mating connectors.

9.1.2 Valve Heater/Thermostat Interconnection

The various possible configurations are represented by the schematics in Figures 9-2, 9-3, 9-4 and 9-5. If REM electrical connectors are selected, interconnection is relatively easy by utilizing jumper wires in the mating connector to complete the circuitry. This is depicted in Figure 9-2.

Figure 9-3 represents an arrangement with splices that provide the interconnection. Splices, in general, are felt to adversely affect reliability. This configuration could also be executed by incorporating an EJB within the REM. Although only about eight connections need to be made, it is felt that the size of such an EJB would be too large to be readily accommodated within the REM.

Figure 9-4 is an arrangement that does not interconnect the circuit in the REM, but instead leaves the connection to be done by GSFC in a spacecraft EJB. This has the disadvantage of complicating the EJB, adding weight to the EJB, adding weight to the spacecraft heater power wires which effectively must be run to the REM twice, and increasing potential EMI problems because of the additional wire runs.

Figure 9-5 shows a configuration in which the wiring is integral with the heater/thermostat package. This has been termed the "monolithic" approach and has the disadvantage of being cumbersome for the heater manufacturer to assemble, cumbersome to install in the REM, more susceptible to damage during installation and makes shielding of the single wire between the heater and thermostat difficult.

The selected baseline configuration (Figure 8-4) combines features found in Figures 9-3 and 9-5. It is basically a monolithic design but does incorporate four splices per REM. The configuration is similar to those used on COBE, but replaces a difficult-to-manufacture solder joint with a crimp splice. All splices are contained within the potting which surrounds the thermostats. This design was used successfully on the Topex propulsion system. Although it is somewhat cumbersome to install on the REM, it has the following advantages:

1) The heater supplier can attach and ground a simple two-wire cable instead of a partial three-wire and a single conductor.
2) Separate shielding for the single conductor need not be provided.
3) All circuit pairs are twisted within shielded cables.

9.2 Thermal Control Trade Study

Heaters may be controlled by mechanical or solid state thermostatic devices. A trade study was conducted to evaluate each approach in terms of performance, efficiency and reliability. Consideration was also given to a Positive Thermal Coefficient Heater as a possible alternative to traditional thermostatic thermal control.

9.2.1 Mechanical Thermostats

HS has successfully used mechanical thermostats to control heaters in many propulsion programs. The military specification MIL-S-24236 is used as a basis for selection of thermostats with the slash sheets /1 and /20 being the most appropriate for packaging and performance on propulsion systems. Both of these devices carry dual current ratings which means they are characterized for both their full current rating and also for low current level applications. With average heater powers of about 1.5 watts, the currents that will be switched are in the order of 70 milliamperes which is considered low level. These relays are rated from 100,000 switching cycles (/1 unit) to 250,000 cycles (/20 unit). The temperature open/close switch point differentials range from 2 degrees (/20 unit) to greater that 10 degrees (/1 unit). If the REM thermal characteristics were to require 3 cycles per hour to maintain temperature control, the unit with a 100,000 cycle life would yield over 3.8 years continuous operation.

Mechanical thermostats offer the advantage of not requiring external power to operate, they are inherently hardened to radiation exposure, and the only power loss is due to the switch contact resistance which, in this application, dissipates less than 1 milliwatt. Thermal Control Option TC1.1, which baselines mechanical thermostats is selected as a baseline configuration for preliminary design in this study as described in Section 8.

Mechanical thermostats have the advantage of having operated reliably on many space flight missions. In this case it appears they have adequate cycle life for the intended mission profile. Disadvantages are that they complicate (crowd) packaging in a case where redundancy is required on a single engine REM. Also a mechanical thermostat causes broadband electromagnetic interference by the arcing it produces. Rigorous compliance to the TRMM EMI/EMC requirements of Chapter 6 of TRMM-733-043 will probably require that a waiver be granted for the use of mechanical thermostats.

Table 9-I represents the two thermal control options considered for mechanical thermostats. They are discussed briefly below.

<u>TC1.1</u> Mechanical Thermostats with a New Valve Heater

This design has always been the front runner and the baseline against which HS made its preliminary design. It is the standard qualified design that HS has used on all of its propulsion systems. Because of the requirement for single engine REMs and circuit redundancy to protect against single point failure, the packaging had a higher density than usual as shown in the figures of Section 8. Also, because power for TRMM was at a premium as well, alternative thermal control options were considered to simplify packaging and save power.

The Mechanical thermostat option is the baseline REM which has been ROM costed in this study.

TC1.2 Mechanical Thermostats with the COBE Valve Heater

The COBE valve heater when used in a single engine REM as baselined for TRMM would be tremendously overpowered for this application unless the voltage source were reduced to 5 vdc. Because this would have required additional electronics GSFC directed that this trade would be reviewed in conjunction with use of a Solid State Thermostat (SST). Therefore consideration of the use of the COBE valve heater is made under the discussion of Solid State option TC2.1. The final determination is that use of the COBE valve heater is not possible for TRMM.

9.2.2 Solid State Thermostats (SST).

As indicated in Table 9-I the identifying feature of the three TC2 options is solid state control. The appeal of solid state control is the ability to precisely control the temperature regulating set points while having no devices to inherently wear out or fail due to fatigue. The ability to regulate the REM temperature to a lower average temperature with deadbands of less than $1^{o}F$ (large deadbands of $10\text{-}20^{o}F$ are characteristic of mechanical thermostats) results in a potential power savings of as much as 15% (assuming $41^{o}F$ average REM temperature vs. $54^{o}F$ average for mechanical thermostats). There are several potential disadvantages to SSTs.

One major disadvantage is that SSTs appear not to have been used before in thermal control of a spacecraft system. Their use on TRMM would require REM and component qualification.

Another potential disadvantage is a requirement for converters and filters. TRMM specification TRMM-733-043 preliminary draft #3 permits "heaters and thermostats" to be powered directly from the vehicle power buss. Should an interpretation of this specification be made which permits the SST to be considered under this heading, the implementation would be greatly simplified by not requiring a dc/dc converter circuit.

Should dc/dc isolation be required by GSFC, the TAYCO SST (option TC2.3) would require both control and heater power to be conditioned at an estimated power loss of 30% due to controller inefficiencies. However, in the case of the HS design (TC2.2), only the low power control circuit need be isolated through a dc/dc converter, while the high current heater circuits could be powered directly from the vehicle buss. This would significantly minimize power loss due to dc/dc converter inefficiency. It is estimated that conversion losses in the TAYCO SST approach would be .45 watts for each operating REM heater element compared with .1 watts per "on" heater element in the HS SST approach.

Further ± considerations for the solid state options listed in Table 9-I are discussed below.

TC2.1: SST with the COBE Valve Heater

The TC2.1 option (as well as TC1.2 option) appeal lay in utilization of the COBE valve heater. This would eliminate the requirement for their removal and the costs associated with the design, procurement, assembly and test of a new valve heater. Unfortunately, inherent in the use of the heater is the need to reduce the input voltage to approximately 5 vdc. The reason an 18 vdc supply was satisfactory for the COBE design was that four valve heaters were wired in series, one circuit for each of the four valves on a COBE Quad, therefore the total minimum voltage drop across each heater was only 18/4= 4.5 vdc. With a nominal circuit resistance of 15.5 ohms this produced a power of 1.3 watts/REA. In the TRMM configuration, each REM must have its own individual thermal control. With spacecraft power at 21-35 vdc, this would cause the COBE valve heater to be substantially overpowered (i.e. $21^2/15.5=$ 28 watts of power), where a worst case thermal condition for TRMM would only require approximately 1.5 watts.

The ability to utilize the COBE valve heater is thus predicated on obtaining a 5 vdc supply. Unfortunately the 5 vdc regulated supply from the TRMM power bus is for temperature telemety only and cannot support the load required for spacecraft thermal control.

This heater could still be accomodated if HS incorporated a separate regulated 5 vdc supply in the design. This has several drawbacks that were felt to be unacceptable. 1) The design would be more complicated and expensive, involving a converter and filters for EMI/EMC control; and 2) More importantly, the losses suffered in going through the converter and filter circuit would negate any real power savings, which is the motive for the SST option.

TC2.2 An HS SST with a New Valve Heater

This option would utilize solid state control designed and fabricated by HS and a new valve heater specially sized to deliver 1.5 watts at 21 vdc, which represents a worst case power and voltage condition. If the HS SST could be catagorized as a "Heater & Thermostat" it could be powered from the vehicle power bus, without a dc/dc converter. The control section could then be powered from a simple zener regulator driven from the vehicle buss. If it is required that a buffered signal from the control thermistor be provided, then an isolated dc/dc converter power supply would have to be constructed as part of the SST controller circuit.

While dc/dc converters would provide isolation from the power bus noise, a disadvantage is that dc/dc converters require filtering due to their tendency to generate electromagnetic interference. In addition there would be a requirement for an additional volume to house 6 square inches of electronics which would provide power for the 12 REM heater controllers. Reliability considerations may require this volume be doubled if a secondary source of power is required. This additional circuitry will also have an adverse effect upon reliability and weight of the package, as well as costs. Depending upon the strength of the converter required, power consumption is also a major drawback.

The thermal control schematic is shown on Figure 9-6. It was breadboarded and tested for a closed circuit below 40.5°F and an open circuit above 41.5°F, i.e. a 1°F deadband. The prototype circuit, which HS electrical engineering fabricated, compares a fixed voltage across R4, which represents the desired control temperature, to the voltage generated across the thermistor. This thermistor is in series with a fixed resistor R1 and generates a linear voltage over the limited temperature range of interest (see Figures 9-7 & 9-8). Amplifier A1a is used to demonstrate that buffering could be added to the circuit to provide a telemetry signal; it can be eleminated along with R2 without affecting the operation of the circuit. Amplifier section A1b is configured as a comparator with hysteresis. In this section the reference voltage is compared to the voltage across the thermistor and will demand heat if the sensed temperature is too low. A total hysteresis band of 1°F was added to prevent rapid limit cycling about the set point. The hysteresis is provided by a small amount of positive feedback provided by R3. When the temperature drops below the setpoint, the A1b comparator output goes positive which turns on the 4N49 opto-coupler. This device provides isolation of the control circuit from the 28 vdc vehicle power bus. The optical isolator drives on the output transistor Q1 which provides power to the heater. If GSFC determines that bus isolation is not required for an SST, the 4N49 opto-coupler can be eliminated along with support circuitry. However, in this mode a buffered output temperature signal from the control thermister would not be available for telemetry due to lack of isolation. If bus isolation is required the optical isolator would have to be retained. It should be noted that breadboard component types were selected from those available in our engineering inventory. In all cases suitable components are available from MIL-STD-975 and GSFC PPL-19.

Test results indicate the control points were within 0.2^{o}F of desired using standard 1% tolerance parts. The measured control band is shown in Figure 9-8.

An additional attractive feature is that this design is similar in design to the HS designed Nozzle Heater on the Shuttle APU Water Spray Boiler and thus would have prior spacecraft usage history.

Although not estimated in the ROM the HS design is still a viable option. To be determined is whether the cost of final design, manufacture, and qual test by Hamilton Standard is competitive with commercial procurment of the TAYCO SST discussed below.

TC2.3 - A TAYCO SST with a New Valve Heater.

This option has been costed in the ROM as a thermal control option in lieu of mechanical thermostats. A discussion of the design and packaging is made in Section 8 and a TAYCO spec sheet is contained in Figure 8-11. While the actual circuit design is unknown for this SST, the same advantages/disadvantages noted for the HS design and SSTs in general would apply.

Some distinctions regarding the TAYCO SST are: 1) This SST could not provide a thermistor telemetry signal; 2) The thermistor can be either internal to the SST body or remotely located; 3) The unit is currently in qual test program for NASA as a component on the Shuttle APU. NASA qualification is expected to be complete by the end of 1992.

The TAYCO product was selected for a ROM cost because it is preferred to purchase a qualified commercial part if available in lieu of a unique HS design and fabrication. In the event a solid state approach is taken in TRMM thermal control, an exercise will be accomplished to determine whether an HS SST or a TAYCO SST best meets design, performance and cost needs.

9.2.3 Thermal Control Option 3: PTC Self-Regulating Heater

The PTC (Positive Thermal Coefficient) heater is a doped barium titanate based ceramic thermistor which is used as a temperature dependant semi-conductor resistor. Its resistance increases rapidly with increasing temperature after a defined reference temperature called the Curie Temperature. The Curie temperature is approximately 125°C (257°F) for the barium titanate thermistor. Resistance of the thermistor can be tailored by proper design of the shape (surface area and thickness). The Curie temperature can be altered by modifying the level and/or type of dopants used in the ceramic.

PTC heaters are currently in extensive use in commercial non-space applications such as: Household (refrigerators, dishwashers, hot plates, liquid heaters, coffee machines, egg boilers, hand dryers, mirror heating, curling irons, hairdryers, ventilators), Automobile (windscreen heating, doorlock defroster, external mirror heating, choke, inlet air heating), and Industrial applications (LCD heating, soldering tools, thermostats, vulcanization tools, plastic foil welding tools, oil preheating, adhesive pistol).

There are several attractive features of the PTC heater that could be realized in thermal control of a REM, to include:

1) The PTC heater would replace both the conventional soft heaters and thermostats currently utilized in thermal control and it is also a very inexpensive device when purchased in bulk, thus reducing design/procurment/ assembly costs;
2) Thermistors are used extensively and reliably in the aerospace environment with very little risk of failure;

Unfortunately there are also several disadvantages to the PTC heater which removes it from viable consideration for the TRMM mission:

1) The first and most important disadvantage is the Curie temperature is too high for PTCs currently in production. The switch point would result in an average temperature well above that achieved with current thermostatically controlled heaters. This translates into greater power consumption for thermal control. While the Curie temperature can be lowered with dopants, this also lowers the rate of resistance change with temperature. Ideally, for TRMM, it would be desirable to have a heater that delivered 1.5 watts at 41°F but near zero watts at temperatures in excess of 60°F.

During initial investigation efforts several samples were optained from Keystone Carbon and Seimans. Prior to doing extensive empirical testing an analysis was done to determine the feasability of constructing an arrangment of PTCs that would yeild both 1.5 watts at 21 vdc and stabilize to low power consumption at 50 to 60°F. A Seimans P390-A48 was selected because it had a very sharp curve at the Curie temperature and a resistance value of about 175 ohms prior to the Curie point temperature. Figure 9-9 depicts the curve of the PTC. Figure 9-10 is an equalibrium thermal balance calculation of two possible configuration options. It is fairly straightforward to achieve a configuration that gives 1.5 watts at 21 vdc. As the REM temperature (item 6 - T sink) rises the power draw of the PTC (item 15) declines. However the rate of decline is simply not sharp enough to be acceptable. Going from a REM sink temperature of 41 to 81^{o}F the PTC power draw has dropped by no more than 25%.

2) A second important disadvantage is the cost associated with the development, production lot run and qualification of a PTC heater. A commercial thermistor house would have to generate a special formulation for a PTC thermistor that would control in the temperature region of interest. A production lot would then be made of probably several thousand thermistors, although individual prices would be low, the bulk price would be higher than acceptable for TRMM. Lastly, there would have to be a REM qualification program. Although the qualification risk is estimated to be low, the time and cost would not be amenable to TRMM.

9.3 RCS Radial vs. Parallel REM Arrangment

At the beginning of this design study GSFC was baselining two REAs per REM. During this design study GSFC decided to switch to a single REA per REM configuration.

In order to complete a preliminary design of the REM it was necessary to establish an installation arrangment meeting thrust vector and handling and transportation needs. HS proposed two alternatives: a radial arrangment shown on Figure 9-11 and a parallel arrangment shown on Figure 9-12. HS advised GSFC that the radial arrangment offered more simplicity and commonality of the adapter (angle) bracket.

The trade effort was conducted by GSFC who selected the radial arrangment for the purpose of this design study.

10. TESTS

Table 10.I is a summary of the proposed tests that shall be run on the hardware for the Phase 2 program.

Upon return of the Quads (3 flight and 1 qual) and 2 spare REAs a leakage and electrical function test are planned to verify the functional integrity of the units.

The REAs shall then be removed from the quads and the valve heaters removed from the valve. The electrical and leakage tests on these 16 REAs (14 flight, 2 qual) shall be repeated.

For reasons of schedule risk it is recommended (although not planned at this time) to perform a TCA fire during Task 1 Integrity Tests as discussed in Para. 5.4.

10.1 REM Acceptance Tests

After REM assembly the flight units shall undergo testing in accordance with Table 10.I. GSFC requires 8 thermal vacuum cycles, a vibration, firing and functional tests. Because proof and leakage tests have already been accomplished on the COBE program, the REMs shall be subjected to the thermal and vibration tests immediately. In order to comply with GSFC's desire not to expose the flight valves to any further hydrazine prior to mission operation, HS shall remove the TCA from the REM and test it on a workhorse valve to establish nominal operation. Subsequently the TCA shall be reassembled into the REM and after the Pc (Pressure Chamber) tap has been removed the

REM shall be tested for electrical function and leakage tests prior to shipment.

The specific requirements for the acceptance tests have not been finalized. As known to date they are:

Thermal Vacuum shall be 8 cycles ranging from -40 to +50°C with one hour at each temperature as required by TRMM-713-031 para 5.4.2. The REM shall not be powered and no component operation shall be required at the temperature extremes.

Acceptance Vibration shall consist of a random and a sine burst spectrum. The random vibration shall be to an overall Grms of 11 per the spectrum specified in TRMM-713-031 para. 5.4.3.1. The sine burst requirements have not been determined.

The acceptance firing duty cycles for the TCA firing tests are to be determined. It shall likely consist of pulsing and off pulsing firings. The minimum on time shall be 125 ms pursuant to TRMM-713-031 para. 4.1.1., and Isp, thrust, and Ibit requirements per para. 3.2 shall be verified at 190 and 130 psia. A TCA firing during REM acceptance test could be eliminated if done during the Integrity Test. A liquid flow test after vibration in lieu of firing would verify nominal flow/delta P (see para. 5.4).

Acceptance Leakage testing shall meet the requirements of TRMM-713-031 para. 3.2.10 which are 5 scc/hr internal leakage and $1x10^{-4}$ scc/sec external leakage at 250 and 100 psia GN2.

Acceptance Electrical Function testing. The valve, temperature sensors, valve heater and catalyst bed heater shall all be subjected to continuity and insulation resistance tests.

The valve shall additionally be tested for pullin, dropout and response.

10.2 Qual REM Tests

One Qual REM shall be used to satisfy Task 3 Mission Qualification tests. It shall be similar to the acceptance tests except as noted in Table 10-I and as described below:

Qual Thermal Balance tests shall be run to verify the thermal control design of the REM. It shall consist of a cold thermal vacuum environment with -22^{o}F mounting plate and -270^{o}F walls to simulate a space environment. Once stabilized the unit shall be allowed to complete a minimum of 4 thermal cycles with one valve heater element operating to verify the REM thermal design under worst cold case environmental conditions.

Qual Vibration shall be 3 db higher than the acceptance spectrum per TRMM-713-031 para. 5.4.3.1. Overall Grms is 15.3, and max Power Spectral Density is .2 g^2/hz.

Qual Mission Performance Firing shall be at the REM level and shall consist of expected mission duty cycle firings. Because of the extensive life already on the COBE qual REAs it is not recomended that a life mission firing be done. A performance baseline identical to the acceptance firing sequence shall be performed prior to Thermal Balance, after Vibration and after any Mission duty cycle or life (if done) firings.

A determination shall be made as to the most appropriate qual REA to use for this test and whether or not any test limitations must be made based on past qualification testing on the COBE program and what firing tests GSFC desires.

As noted the problem in mission qual life simulation firings is the life already put on the COBE Qual REAs. Mission life requirements are defined by GSFC specification TRMM-713-030 para. 5. For example impulse life fire of 74,634 lbf-sec (332,000 N-s) is required by specification para. 5. The COBE qual REAs (REA 39-5) which will be built into the TRMM Qual REMs have approximately 116,554 lbf-sec impulse life. The IR&D 39-2 REA was tested to 263,728 lbf-sec. This would appear to give some life margin for the firing tests. However, because a qual level vibration will be run in conjunction with firing tests in an entirely new REM package, HS would not subject the Qual REM to a TRMM qual mission firing life. An analogous argument can be made for Propellant Throughput, Maximum Burn, Total Burn Time, and Total Pulses. A summary of these parameter requirements and their accumulated value on the COBE Qual REAs may be found in this report in Table 7-III and the Compliance Matrix in Appendix 1. If a full mission firing life verification is desired by GSFC it shall be necessary to build a Qual REM using a flight spare REA.

<u>Toluene Qualification</u>. In the event that GSFC deems it neccessary, a firing test shall be done on the second qual REM to determine the effect on firing performance when simulated Japanese hydrazine is used. The hydrazine shall be simulated

using ultra hi purity hydrazine doped with .01% toluene. It is proposed to purchase a 40 gallon barrel. This should permit a complete mission firing of 326 lbm of propellant maximum as specified in TRMM-713-030 para. 5. This test would also be run at the REM level. Specific firing duty cycles are to be determined. Further discusion of this issue is contained in para.s 11.4 and 5.3.

11. SUPPLEMENTARY INFORMATION

This section contains information which is reflective of work done germane to this study phase but which may not be conveniently located in other sections. The following are convered in the subparagraphs herein:

11.1 Program Participants

11.2 Program Correspondance Review

11.3 Action Items - Issues and Resolution

11.4 Japanese Hydrazine

11.5 System Pressure - Limits and Regulation

11.6 Thrust Vector Orientation

11.7 RCS/REM Physical Integration

11.8 COBE Nozzle Contour

11.9 Valve Related Issues

11.1 Program Participants

The following individuals were involved at Hamilton Standard in the Phase 1 Conceptual Design Study:

Position	Name
Program Manager	Charles Beal
Contracts	Leslie LeBlanc (replacing Mary Joyce)
Project Engineer	Roger Emerick
Design Engineer	Robert Barnett
Analysis Engineer	Jeff Godward
Electrical Design	Bruce Sable
Operations*	Kevin Montemagni
Quality Assurance*	Jeff Johnson

(* For costing)

The following individuals were primarily involved at NASA/GSFC during this study:

Lead Engineer	Scott Glubke
I&T Engineer	Ken Yienger
Analyses	John Gagosian
Analyses	Chuck Zakrzwski
Component Engineer	Jim Free
Thermal Design & Analysis Engr.	Walt Ancarro

11.2 - Program Correspondance Review

Note: Unless otherwise mentioned, Communications are between Roger Emerick (HS) and Scott Glubke (GSFC).

Date	Source	Description
101691	HS	Telecon - Ray Simmons/Scott Glubke re: COBE Alignment Stands disposition.
121191	HS	Telecon - Ray Simmons/Scott Glubke re: Replace Preliminary Report w/Pitch.
010392	HS	Telecon - R. Simmons/S. Glubke re: Program Start.
011792	HS	IC from R. Emerick for telecon 1-22-92 to address 1-3-92 letter from S.Glubke.
012192	GSFC	FAXs J.Free to R.Emerick re: GSFC Prel. Dsgn Audit Agenda and Q's for HS to expect.
012292	GSFC	FAX re: Telecon discusion of TRMM mission overview.
012392	HS	Meeting Minutes - 1-22-92 telecon re: COBE REA performance range (press, elect, orientation)
013092	HS	Meeting Minutes - 1-29-92 telecon re: Reg. System, Vib, transportation, valve seats, valve op @21 vdc, cold starts.
020392	GSFC	FAX J.Free to R.Emerick re:Random Vibration Spectrum
020392	HS	FAX re: 11 issues addressed by HS at GSFC Dsgn Audit.
020492	HS	FAX re: HS proposed thruster arrangement.
020492	GSFC	FAX re: Thruster Storage Information.
020592	HS	Action Items - 2-4-92 telecon re: Set up Action Items 1-14.
020592	GSFC	FAX re: Thruster Storage and HPS de-intergration.
020792	HS	Meeting Minutes - Telecon 2-7-92 re: valve life and op. issues and testing.
021892	GSFC	FAX J.Free to R.Emerick re:Vib and HPS de-integration.
021992	HS	FAX to S. Glubke re: qual valve tests, COBE valve test procedures.
021992	HS	Meeting Minutes - Telecon 2-18-92. Closed AI 1,2,7,9,10; opened 15,16. Attachments 1:AIs from 2-5-92 and 2:2-7-92.
022092	HS	FAX J.Gagosian to R.Emerick re:thruster mission requirements and thrust direction cosines.
022092	GSFC	FAX J.Free to R.Emerick re: ground transport loads.
022192	HS	Internal Comm re: Midphase Review on 3-11-92.
022192	HS	Internal Comm re: Incorporate Latch Valve Pos. Ind on EJBs 1/2.
022692	GSFC	FAX re: EJB interface requirements.
022792	HS	FAX re: thruster direction cosine errors.
022792	HS	Mailed SVSK103757 electrical driver schem.

030292	HS	FAX re: HS facilities maps.
030292	HS	FAX Meeting Min - Telecon 2-28-92. Add AI 17, closed 11.
030592	GSFC	FAX J.Gagosian to R.Emerick re: updates to TRMM-713-030.
030592	HS	Telecon re: nozzle plugs, mission pulses, regulated pressure.
030692	HS	Internal re: Midphase presentation.
030992	HS	FAX re: 3-11-92 Midphase Agenda.
031192	GSFC	FAX J.Free re: GSFC Valve Test Plan
031292	HS	FAX Meeting Min re: 3-11-92 Midphase Presentation. Closed AI 15, added 18-23.
031392	HS	Internal to EE re: COBE EJB usage and telemetry noise.
031692	HS	Contract mailing of 3-11-92 Midphase Meeting Minutes.
031792	HS	FAX to S.Glubke re: AI 18, 21.
031892	HS	Telecon re: AIs 16,17,23, SST and Cat. Bed preheat.
031992	HS	Internal to EE re: Solid State Control.
032092	HS	Contracts mailed closure of AIs 18,21.
032792	GSFC	FAX from J. Free re: Solid State Thermal Control Circuit.
032192	GSFC	FAX from J.Free re: revised vib spectrum.
033192	GSFC	FAX from J.Free re: Response to AIs.
040192	HS	FAX to S.Glubke re: REM views, wt., Japanese Hydrazine.
040792	HS	FAX to S.Glubke re:REM views, therm profile, elect schem.
040892	GSFC	FAX from J.Gagosian re:Firing Simulations & Fairing Temp.
040892	HS	FAX Meeting Min of 4-7-92 telecon. AIs - Opened 24,25, Closed 6,8,13,17,18,21.
040892	HS	FAX to S.Glubke re: AI 24.
040992	HS	FAX to S.Glubke re: Thermal Control Trades
041392	HS	Telecon re:Therm. Cntrl, Elec cnctr, Wagon Wheel, Sched.
041492	GSFC	FAX from J.Free re:transportation loads.
041592	HS	FAX to S.Glubke re:Report due date, summary of tasks for ROM Cost estimates.
041592	HS	Telecon C.Beal/S.Glubke re: Phase 2 start 10-1-92, 6-15-92 Report.
041692	HS	Telecon R.Barnett/Tayco re:Valve Heaters.
042192	GSFC	FAX from J.Gagosian re:valve testing & EMI req.
042192	HS	Contracts re: Final Report due 6-16-92.
042392	GSFC	FAX from J.Gagosian re:Valve test circuit schem.
042392	HS	FAX Meeting Min. 4-22-92 Telecon re:AIs closed 4,19,22,24,25, Opened 26,27. Attch COBE nozzle contour and Elect Interface Options.
042392	HS	Telecon R.Barnett/S.Glubke re:COBE nozz contour, REM dim.
042392	HS	FAX to J.Gagosian re: Supression Circuit.
042492	HS	FAX to S.Glubke re: COBE HPS testing.\

042792	HS	Telecon re: SST, Solar Fluxes, Supression Circuit, Tests, Cat Bed Htr Power.
042892	HS	FAX re: Telecon B.Sable/C.Chidekel Elect & EMI.
042892	HS	Telecon re: Vib, Jap. Hydrazine, Testing
042992	GSFC	FAX from S.Glubke re:Jap. Hydrazine.
050492	GSFC	FAX from J.Free re:Valve test procedure.
050492	HS	Internal Pre-Concept Review.
052992	HS	FAX Meeting Minutes 5-29-92 Telecon re:Close all AIs.
060292	GSFC	FAX from S.Glubke re:RCS schematic.
060392	GSFC	FAX from S.Glubke re: Qual Valve test results.

11.3 Action Items - Issue and Resolution

Note: The following is a brief disscussion of the numbered Action Items. Numbering system began with Meeting Minutes of 2-4-92 Telecon.

AI # Issue and Resolution

1. Valve Operation. Worst Case pressure and temperature conditions for valve operation at 18 vdc. COBE valves spec'd for op at 24-28 vdc. TRMM mission 21-35 vdc with min of 18 vdc at valve. Valve seat life also an issue. GSFC qual valve testing verified op at 18 vdc. Closed 2-18-92.
2. Valve Operation. HS summarized WCI review of valve opreration under expected TRMM conditions. Closed 2-18-92.
3. Environmental Fluxes for the Thruster Module. Discussions between J.Godward (HS) and W.Ancarro (GSFC) re: thermal issues. For Final Report a 5 watt/REM heat dump to spacecraft, a -30 to +50°C structure, and 1.5 watts/REM avg. orbital power shall be asssumed by HS. Closed 4-22-92.
4. Handling and Transportation Spectrum. GSFC provided expected land, sea, air vibration and load spectrums to determine if REMs were in jeapardy. At issue was acceptability of orientating the REMs with catalyst beds above the valves thus risking catalyst fines contaminating the valve seats and causing leakage. Resolution is to avoid such orientation during transportation and handling. Closed 4-22-92.
5. Document Updates. Ongoing action by GSFC re: TRMM spec updates. Closed from further input on 6-3-92 for Final Report inclusion. Closed 6-3-92.
6. Duty Cycles and IBIT requirements. Information provided by GSFC. Closed 4-7-92.
7. REA low pressure operation. HS provided information on 2-18-92 that the REA would operate acceptably at 70 psia without duty cycle limitations. Closed 2-18-92.
8. Random Vibration Levels. GSFC was to clarify acceptance and qual vibration spectrum for REM. Final resolution was a prototype qual level vib 3 db greater than acceptance vib will be done. Closed 4-7-92.
9. Acceleration Loads. GSFC noted that static acceleration and random vibration loads are applied seperately. HS provided information 2-18-92 re: factors of safety over anticpated loads. Closed 2-18-92.
10. Deintegration Procedure of COBE HPS. To determine the storage history of the COBE HPS regarding concerns for valve seat deterioration and REA integrity. It was determined that the COBE quads were not kept in a GN2 environment. Ultimately valve seat and REA integrity will be determined by hardware test. Closed 2-18-92.

11. EJB Enable Connector. HS noted that with Enable Connector connected the REA circuit continuity could be checked on launch pad without valve actuation. Closed 2-28-92.
12. Qual Valve Tests: HS recomended testing required on the qual valve to address issues of storage life and seat acceptability. These tests, performed by GSFC, indicated the Qual valve functioned acceptably.
13. Cold Starts. HS provided information 2-18-92 re: catalyst bed warming duty cycles and cold start of the thruster for tip-off control in the event no power was available to the catalyst bed heaters. GSFC has determined that power will be made available prior to tip-off firing to achieve a pre-fire bed temperature of 60°F. Closed 4-7-92.
14. Launch Thermal Profile. GSFC provided thermal profile of vehicle from launch to seperation and predicted 15-25^C at seperation with a max of 25 minutes exposure to deep space. It was combined with AI 13.
15. Midphase Presentation Agenda discussed. Closed 3-11-92.
16. REM Bracket design. HS provided continuous updates to REM design with bracket configurations for 5 and 10 degree cant angles. Closed 5-29-92.
16. Off Impulse Characteristics. HS provide information on Ibit v. Pi for .125 sec on/off pulses. Closed 5-29-92.
17. COBE REA nozzle plugs. GSFC verified that they had the nozzle plugs used for testing. These will be shipped to HS for Phase 2 Hardware Program. Closed 4-7-92.
17. REM Mounting. GSFC determined that the module shall be a front mount. Closed 4-17-92.
18. Valve Soft Heater Removal. HS noted that the COBE REA soft Kapton valve heaters could be mechanically removed (destructively) and cleanup up with Hysol EA 934 NA. A hot knife might be used in removal. Closed 4-7-92.
19. Thermal Requirements between REM and spacecraft. HS will assume a 5 watt/REM heat flow from REM to spacecraft. Closed 4-22-92.
20. Module Level Tests. HS and GSFC decided on a preliminary test sequence for the qual and flight REMs. Closed 5-29-92.
21. EJB Usage: HS noted that series redundant diodes may be removed from EGBs to increase voltage to REAs and a schematic clarified the 3 pins used for the REA valve return circuitry at J1/J2 connectors. Closed 4-7-92.
22. Japanese Hydrazine. GSFC noted that Japanese wish to provide complete launch facilities to include their hydrazine which contains toluene but not anniline. Various technical material flowed between HS and GSFC. Ultimately if their hydrazine will be used then firing tests will be accomplished with hydrazine doped with Toluene. Closed 4-22-92.
23. Electrical Connectors. Variety of discussions re: wiring to incorporate heaters on one group and valve/sensors on another as well as various connector/pigtail combinations. Ultimately HS has proposed an all pigtail configuration in the Final Report. Closed 5-29-92.

24. Use of COBE valve heater. As a cost savings the possibility of using this heater was explored. The costs of incorporating a 5 volt dc-dc converter and associated filters to accomodate this existing heater was determined not to be an optimum trade. Closed 4-22-92.
25. Ground Protective Cover. HS shall provide a non-flight REM cover with new hardware. Closed 4-22-92.
26. Thermal Control Options: HS investigated the use of alternative thermal control options to include solid state control and Positive Thermal Coefficient (PTC) thermistor heaters. A solid state design is proposed as a viable option for the final configuration. Closed 5-29-92.
27. Qual Valve Tests. GSFC provide information re: results of qual valve tests. Test results on the qual valve indicate that concerns regarding seat acceptability and operation at 18 vdc should not be a problem. Closed 5-29-92.

11.4 Japanese Hydrazine

The TRMM mission is a joint NASA/NASDA venture with Japan (NASDA) supplying the launch services. GSFC has noted that the Japanese would like to provide the hydrazine for mission which they manufacture. This raises the issue of whether hydrazine as manufactured by Japan is acceptable for use in HS catalytic thrusters.

The comparison of Japanese v. American manufactured hydrazine is presented below.

Material	Max Limits (% wt)	
	Japanese	US
Hydrazine	99	98.5
Water	1	1
Particle	1 (mg/l)	1 (mg/l)
Chloride	.0005	.0005
Aniline		.5
Toluene	.01	
Iron	.002	.002
Non Volatile Residue	.005	.005
Carbon Dioxide	.02	.003
Other Volatile Carbonaceous Material	.02	.02

There are two issues raised by the use of this hydrazine: 1) Compatability with EPR material and 2) Affect on firing performance.

As regards to the first issue. NASDA performed a test of storing EPR in its hydrazine. The results of this test, as provided by GSFC FAX to HS dated 4-29-92, indicated there should be no problem.

More problematic for HS is the second concern regarding affect on thruster performance. American hydrazine contains aniline, with a .05% max for monopropellant. It is known that aniline causes washout over long steady states. Although the Japanese hydrazine has no aniline, it does have .01% toluene by weight. The Japanese have tested 50 Newton catalytic thrusters to about 46,000 pulses, but nothing is known regarding the duty cylces or engines involved.

In this TRMM study the use of Japanese hydrazine was explored as Action Item #22. By FAX dated 4-1-92 HS presented the following information for consideration regarding this issue.

Aniline is an amino benzene, which is an NH2 group attached to a benzene ring. It is an oily substance with a low vapor pressure and a high sea level boiling point of 184^{o}C (363^{o}F). As regards to catalyst poisoning it is unknown what the exact poisoning mechanism of aniline is, but it is theorized that it progressively coats rather than chemically interacts with the catalyst. Coating begins at the cool injector exit and progresses downstream during long steady state firings. The bed can be restored with a pulsed firing duty cycle that permits a hot thermal soakback to the injector area. This will boil away the aniline when the boiling point temperature is reached at the resident chamber pressure.

Toluene, the contaminant in Japanese Hydrazine, is a methyl benzene, which is a CH3 molecule attached to a benzene ring. It is a watery substance with a relatively high vapor pressure and a sea level boiling point of 110^{o}C (230^{o}F), considerably lower than aniline. If the poisoning mechanism is the same as theorized for aniline, i.e. coating, it would tend to boil away at a lower temperature than aniline during soakback. Given the fact that it is watery in nature, however, it may not tend to coat the hydrazine at all. However, it is known that catalyst, (iridium on a alumina substrate) is poisoned by carbonaceous organics. Again, the exact mechanism is unknown. Testing with MMH (monomethyl hydrazine) was found to poison the bed very quickly. MMH is CH3N2H3, i.e. a methyl group (CH3) replacing one of the hydrogens on N2H4. If this methyl group reacts in the same manner on hydrazine as it does with MMH, poisoning may be a problem, albeit tempered by the low level concentration.

Recommendation: In the event that Japanese hydrazine will be used on this mission, HS would require firing tests to ensure there is no detrimental affect on performance.

In the event that Japanese hydrazine cannot be obtained, the best way to determine if toluene is a problem is to take aniline free (ultra pure) hydrazine, dope it with a max concentration

(.01%) of toluene and run some firing tests on a qual or non-flight engine. A long steady state firing is recomended to observe any decrease in performance, as well as low and high temperature pulsing duty cycles.

11.5 System Pressure - Limits and Regulation

During the midphase Design Review on 3-11-92 HS addressed a question by GSFC as to the optimum system regulated pressure. In response HS presented the following effects of reducing pressure and recomendation:

Parameter	Effect of Reducing Pressure
ISP	Decreases, more fuel used.
Impulse	Decreases, longer on times.
Thermal	No significant effect.
Life/Throughput	Reduces bed loading, increases life.
Duty Cycle	No effect in the range of 100-400 psia.

Recomendations: 100-400 psi range acceptable except where:

- Burn durations in excess of 7000 sec. (incl off pulses) because potential washout w/mono grade N2H4.
- Fuel capacity cannot meet total impulse requirements becauses of lower ISP.

Additionally, HS presented a technical memo on 2-18-92 addressing the ability of the REA to operate acceptably at 70 psia, as had been demonstrated by qualification testing.

11.6 Thrust Vector Orientation

During the midphase Design Review on 3-11-92 HS presented its understanding of the proposed spacecraft REM arrangement in order to verify our understanding of the REM installation. This was necessary in order to establish preliminary design concepts which account for all required thrust vector angles. Figures 11-1a and 11-1b represent the REM installation and thrust vector direction cosines. These direction cosines represent corrected information based on HS review.

11.7 RCS/REM Physical Integration

As discussed in Section 8 there are four REM configurations to meet the thrust vector needs of the RCS. These four configurations can be arranged on the spacecraft in a variety of ways that meet the thrust vector requirements. An additional requirement that must be met in this integration arrangement is the ability to maintain catalyst beds level with or below the valves/injectors during handling and transportation.

Several integration arrangements are possible that meet both the thrust vector requirement and the handling and transportation requirement. Figures 11-2 represent a variety of installation scenerios that will do the job. Configurations A, B, C, D represent the four possible REM configurations. The number of REMs required of each configuration is listed based upon what axis may be up during handling and transportation.

Figures 11-3 thru 11-10 represent various axis up considerations.

For the -z axis up, the number of each configuration required are determined by Figures 11-3 and 11-4. Likewise, the +z axis up uses Figures 11-5 and 11-6; the -y up uses Figures 11-7 and 11-8, and the +y up uses Figures 11-9 and 11-10. The alternate configurations are based upon considering A or B options where depicted.

The Phase 2 Hardware Program will require a determination by GSFC of the final integration arrangement so that the proper number of each REM configuration can be built.

11.8 COBE Nozzle Contour

During a telecon on 4-23-92 GSFC requested the COBE nozzle contour definition. HS presented the equation from which the nozzle contour was generated and a tabulation which verified the contour used on the nozzle drawings to manufacture the nozzles.

The curve from which the COBE nozzle was generated is:

$$.0983746338 + .54980469\ B - .18421936\ B^2 + .026000977\ B^3$$

B= The axial distance from a reference point. The nozzle contour is calculated from the throat to the nozzle exit where B= -.0106 (throat) to B=2.4094 (exit plane). The design engineer's original tabulation is shown on Table 11-I.

11.9 Valve Related Issues

During the Mid Phase Presentation on 3-11-92, HS presented 3 issues involving the use of the thruster valve on TRMM. They were:

1. Valve - Life
2. Valve - Electrical
3. Valve - Launch Opening

1) Valve - Life

Because the COBE thrusters had been in an uncontrolled storage environment since 1987 it was uncertain what the condition of the AF-E-411 seats were as caused by long term exposure to an oxygen rich environment and compression set. To determine valve seat accepatability it was decided to test them. An initial test was done at NASA GSFC on a qual valve according to a test plan outlined by HS. The test was successful. Further tests will be conducted on the flight valves on their return to HS.

2) Valve - Electrical

The TRMM voltage supply of 21-35 vdc after taking driver and line losses to the thruster valves predicted a minimum required valve operation voltage of 18 vdc at system pressure. During the above noted valve seat tests at GSFC the qual valve was successfully operated at 18 vdc with 100, 140, 150, and 340 psig liquid inlet pressure. The flight valves shall also be checked for valve opening under minimum voltage on return to HS.

3) Valve - Launch Opening

Review of the vibration requirements indicated a 127 G's expected 3 sigma launch response. The current valve design predicts the valve will open at 69 G's with a 150 psig liquid load. This problem is resolved by going to REM vibration isolation mounts as discussed in Section 8.

4) Valve - Exposure to Hydrazine

GSFC expressed a strong desire to eliminate any testing that would expose the valve seats to hydrazine prior to launch. As the program study progressed it was determined by GSFC that a firing test was desired. Addressing GSFC's concern HS found it acceptable to test the TCA for nominal firing performance. A workhorse (non-flight) valve would be used. The TCAs would then be mated to the flight valves to make an REA assembly.

12. ROM COSTS and SCHEDULE

As a requirement of the Final Report for the Phase 1 Program a Rough Order of Magnitude (ROM) for the Phase 2 Program is provided. In order to clearly understand the costs the Phase 2 Program has been broken down into 4 Tasks as directed by NASA/GSFC. They are:

Task 1: Integrity Tests

Task 2: Final Design

Task 3: Fabrication/Test/Ship

Task 4: Toluene Firing Tests

The Work Breakdown Structure (WBS) for the manpower and cost estimates for each of these tasks is further broken down into four possible subcategories as applicable. They are:

1.1 Non-Recurring Hardware

1.2 Non-Recurring Program

2.1 Recurring Hardware

2.2 Recurring Program.

The estimate provides for the production of REMs with a qualified thermal control design that utilizes a 'soft' valve heater with mechanical thermostats. A delta price impact is given for a REM with solid state control of the 'soft' valve heaters.

A summary of the ROM costs for the Phase 2 Program is presented on Tables 12-I, 12-II and 12-III. The ROM costs for the Integrity Tests, Final Design and Fabrication/Test/Ship (Tasks 1, 2 3) are $952K using mechanical thermostats for thermal control. In the event that solid state thermostats are desired there will be a $158K increase. For the investigation of Japanese Hydrazine on the thruster performance there is an additional cost of $144K.

There is no cost consideration given in this estimate for the following:

1: Filtering of mechanical thermostats to meet TRMM-733-043 Draft 3 Chapter 6 EMI/EMC. See Issue and Recommendation Section para. 5.1.

2: An additional TCA fire test as described in Issue and Recommendation Section para. 5.4.

3: Resolution of contingencies that may develope because of failure of the returned hardware to perform correctly. Such events will have to be dealt with contractually as they occur. In the event that new flight valves or chamber heaters have to be ordered, a schedule impact of 6 months or more would likely occur. See Consideration Section para. 6.2.

4: Integration of REMs onto a CFE Wagon Wheel as described in Consideration Section para. 6.3.

5: The requirement to replace the thrust chamber heaters with a new design heater as described in Consideration Section para. 6.6.

6: Any converters or filters that would be required for bus isolation from the spacecraft power supply.

The estimates given in this report were based on the inputs of the various functional groups (Engineering, Operations, Quality Assurance, Contracts, Financial Control). Guidelines for estimating as noted below were given to these functional groups for making labor and material ROM estimates for the Phase 2 Hardware Program.

Hardware

1: Configuration

2: Parts and Fixtures

3: Dissassembly/Assembly Operations

4: Tests

Tasks and Work Breakdown Structure

Proposed SDRL's

Schedule.

A description of these guidelines are described on the following pages and represent the requirements of the Phase 2 Hardware Program as currently percieved.

HARDWARE - 1: CONFIGURATION OPTIONS

Base REM Configuration:

A single COBE REA mounted to a generic REM bracket with a catalyst bed heater/sensor assembly and 1 REM temperature sensors. The REM Bracket Assembly shall be mounted to an Angle Bracket (2 configurations) with isolation hardware (like IUS) in between to complete the REM Assembly. There will be a Multi Layer Insulation Bracket (MLI) which may be shipped separately. The Preliminary Design REM Assembly has 2 thermal control options for this ROM:

Thermal Control Options (TC):

TC1 A new mechanical thermostat and valve heater assembly on each REM. Requires design and procurment of these components, HS assembly and removal of old valve heater from COBE REA. The ROM will baseline this thermal control configuration.

TC2 Utilizes a TAYCO Solid State Thermostat with a new valve heater on each REM. As with TC1, the SST will be integrated with the heater to form a Heater/Thermostat Assembly. The ROM will show this configuration as a delta cost.

HARDWARE - 2: PARTS & FIXTURES

Parts Lists are contained in Appendix 4.

The following fixtures (new and existing) are considered:

Reusable:

-COBE nozzle plugs available for proof and leak.

New:

-Task 3: Conditioning Plate for Thermal Balance Test of qual REM. -22°F (-30°C) cold case.

-Task 3: A vibration plate to hold the REM during vibration.

-Task 4: Pressure tank and inlet line for testing Toluene doped hydrazine (approximately 10 gallons minimum for steady state fire).

Notes:

-Additional REM Assy and Test Fixtures should not be required.

HARDWARE - 3: REM DISSASSEMBLY/ASSEMBLY OPERATIONS

<u>Task 1</u>: COBE REA Integrity Tests

1. Return COBE flight (3) and qual (1) quads, and 2 spare REAs.
2. Test REAs on all quads (electrical and int'l/ext'l leakage) and 2 spare REAs. (assume need electrical connectors)
3. Dssy of Quads and retest 14 REAs (12 flt, 2 qual)
    - Remove REA's
    - Remove Heaters from valves
    - Dispose of old hardware (per contract?)

<u>Task 3</u>: Fabrication/Test/Ship

1. Fabricate Heater/Thermostat Assy
2. Assy of REM's (13 Flt and 2 Qual)
    - Attach REA valve heaters
    - Mount REA's to Module Bracket
    - Assy Mount Bracket to Angle Bracket w/isolation hardware (bellevilles, bushings, washers, nut plate, screws)
3. Multi layer Insultation Blankets (fit check, qual thermal test, ship separate)
4. Test Flight REM's (Thermal Vac., Vib).
5. Remove TCA from flight REM's only for Fire Test.
6. Reassembly flight REMs and continue testing.
7. Qual REM testing (x1).

<u>Task 4</u>: Toluene/Hydrazine Firing Test

1. Conduct Tests

HARDWARE - 4: TESTS

TASK 1: INTEGRITY TESTS

All 14 REAs on quads shall be tested on the quads and after removal from the quads. The 2 spare REAs shall shall be tested once. Currently EOP/Elect/Leakage (Int'l, Ext'l) are planned.

TASK 3 & 4:

TESTS:	TASK 3: Flight REA	TASK 3: Flight REM	TASK 3: Qual REM	TASK 4: Qual Toluene REM
-EOP		X	X	X
-Proof				
-Elect			X	X
-Leakage (Int'l, Ext'l)			X	X
-REM Fire			X	
-Thermal Vacuum (8 cycles)		X	X	
-Thermal Balance			X	
-Vibration (Random/Swp/Brst)			X	
-Vibration (Random/Brst)	X	X		
-TCA Fire (verify nominal op)	X	X		
-REM Fire (Typ. Mssn. Duty Cylces)			X	
-REM Fire (Toluene)				X
-Pc Tap Removal		X		
-Elect	X	X	X	X
-Leakage (Int'l, Ext'l)	X	X	X	X
-EOP (weight)	X	X	X	

TASKS AND WORK BREAKDOWN STRUCTURE
TASK 1: REA INTEGRITY TESTS

WBS # — Task

1.1 NONRECURRING COSTS

1.1.1 Hardware (Rcv/Test)
- Receive Hardware (3 flt. quads, 1 qual quad, 2 spare REAs)
- Test Plan Inputs
- Operations Sheets and Shop Orders (1 for Quads, 1 for REAs)
- Test Procedures and LTRs (will utilize existing procedures)
- Quad Test/Dssy/REA Test (qual hardware- 1 quad w/2 REAs)

1.2 RECURRING COSTS

1.2.1: Hardware (Rcv/Test)
- Quad Test/Dssy/REA Test (flight hardware - 3 quads, 14 REA's)
- Test Data Review (flight hardware - 14 REA's)
- Malfunction Notification Reports (flight hardware)
- Photos

1.2.2: Program
- Weekly Status Meetings (HS internal)
- Maintain Program Records (Cost, Schedule, Program Doc.)
- Maintain Group Notebooks (ie Project Notebook)
- Customer Weekly Communications (Telecon, Reports, SDRLs)

TASKS AND WORK BREAKDOWN STRUCTURE
TASK 2: DESIGN

WBS #	Task
2.1	NONRECURRING COSTS
2.1.1:	Hardware Design
	Breadboard testing (EE group A/R for SST)
	Final REM design
	Thermal Analysis
	Power Budget
	Support customer FMECA
	Component Spec.s (Heater and thermostat)
	Test Plans (Accept. REM & REA, Qual REM)
	Released Drawings (17 new, + ICD)
	Eng. Changes (est. 4 design phase)
	PMP
2.1.2:	Program
	Vendor Communications (Telecons/Meetings)
	CDR
2.2	RECURRING COSTS
2.2.2:	Program
	Weekly Status Meetings (HS internal)
	Maintain Program Records (Cost, Schedule, Program Doc.)
	Group Records (ie Progect Notebook)
	Customer Weekly Communications (Telecon, Report, SDRLs)

TASKS AND WORK BREAKDOWN STRUCTURE
TASK 3: FAB/TEST/SHIP

WBS #	Task
3.1	NONRECURRING COSTS
3.1.2:	Hardware (Assy/Test/Ship)
	Component Procurment (qual)
	Operations Sheets and Shop Orders (Htr/Thermostat, REM)
	Material Reviews (Qual hardware)
	Test Plans (Accept REM/REA, Qual REM)
	Test Procedures and LTRs (Accept/Qual)
	Fixtures (Design & Mfg thermal plate)
	Assembly and Test (2 Qual REMs)
	Test Data Review (2 Qual REMs)
	Malfunction Notification Reports (Qual hardware)
	Photos (Qual hardware)
	FACI (int'l on flight REM)
	Acceptance Data Packages (2 qual REMs)
	EE Parts Stress Analysis and Where Used (TC2 only)
3.1.2:	Program
	Program Operating Plan
	Plans (QA, Config. Mgmnt, Tracability, Cleanliness, Operations)
	Eng. Qualification Test Report
	Contract Finalization effort
3.2	RECURRING COSTS
3.2.1:	Hardware (Assy/Test/Ship)
	Component Procurment (purchase and support)
	Possible return of 7 htr/sensors assy's for rebend
	Material Reviews (13 Flt REMs, 1 Spare REA)
	Engineering Changes (est. 6 production phase)
	Assembly and Test (13 Flt REMs, 1 Spare REA)
	Dssy/ReAssy 13 flt. REM TCAs for Fire Test
	Test Data Review (13 flt. REMs, 1 REA)
	Malfunction Notification Reports (est. x17 flight hardware)
	Photos
	Customer Pre-Ship Review (FCA & PCA)
	Acceptance Data Packages (13 flt. REMs, 1 REA)
	Pre-launch Pedigree Review
3.2.2:	Program
	Weekly Status Meetings (HS internal)
	Mx & Review Program Records (Cost, Schedule, Program Doc.)
	Group Program Records (ie Progect Notebook)
	Customer Weekly Communications (Telecon & Report)
	Vendor Communications (Telecons/Meetings)
	Quarterly Status Presentations (1 day review @ HS w/Customer)

TASKS AND WORK BREAKDOWN STRUCTURE
TASK 4: TOLUENE FIRE TEST

WBS #	Task
4.1	NONRECURRING COSTS
4.1.1	Hardware (Assy/Test)
	Operations Sheets and Shop Orders (x1)
	Modify Qual Test Plan for Qual REM #2
	Modify Test Procedures and LTR for Qual REM #2
	Fixtures (Design & Mfg seperate tank & line)
	Test (Qual REM #2 hardware)
	Test Data Review (Qual REM #2 hardware)
	Malfunction Notification Reports (est. 1)
	Photos (Qual REM #2 hardware)
4.2	RECURRING COSTS
4.2.2:	Program
	Weekly Status Meetings (HS internal)
	Maintain Program Records (Cost, Schedule, Program Doc.)
	Group Program Records (ie Progect Notebook)
	Customer Weekly Communications (Telecon & Report)

SUPPLIER DATA REQUIREMENTS LIST (SDRL)

1.0 Reports

- Weekly
- Quarterly
- Design Review (@ CDR)
- Pre-Ship Review
- EC's (AR)
- Mass Properties (@ CDR)
- Non-Conformance (AR)
- Financial (in weekly AR)

2. Procedures and Plans (*=req. approval)

- Managment Plan
- Configuration Managment Plan* (@ CDR)
- Verification (Quality Assurance) Plan* (@ CDR)
- Contamination Control Plan
- Assurance Implementation Plan* (@ CDR)
- Acceptance Test Plan* (30 days prior to test)

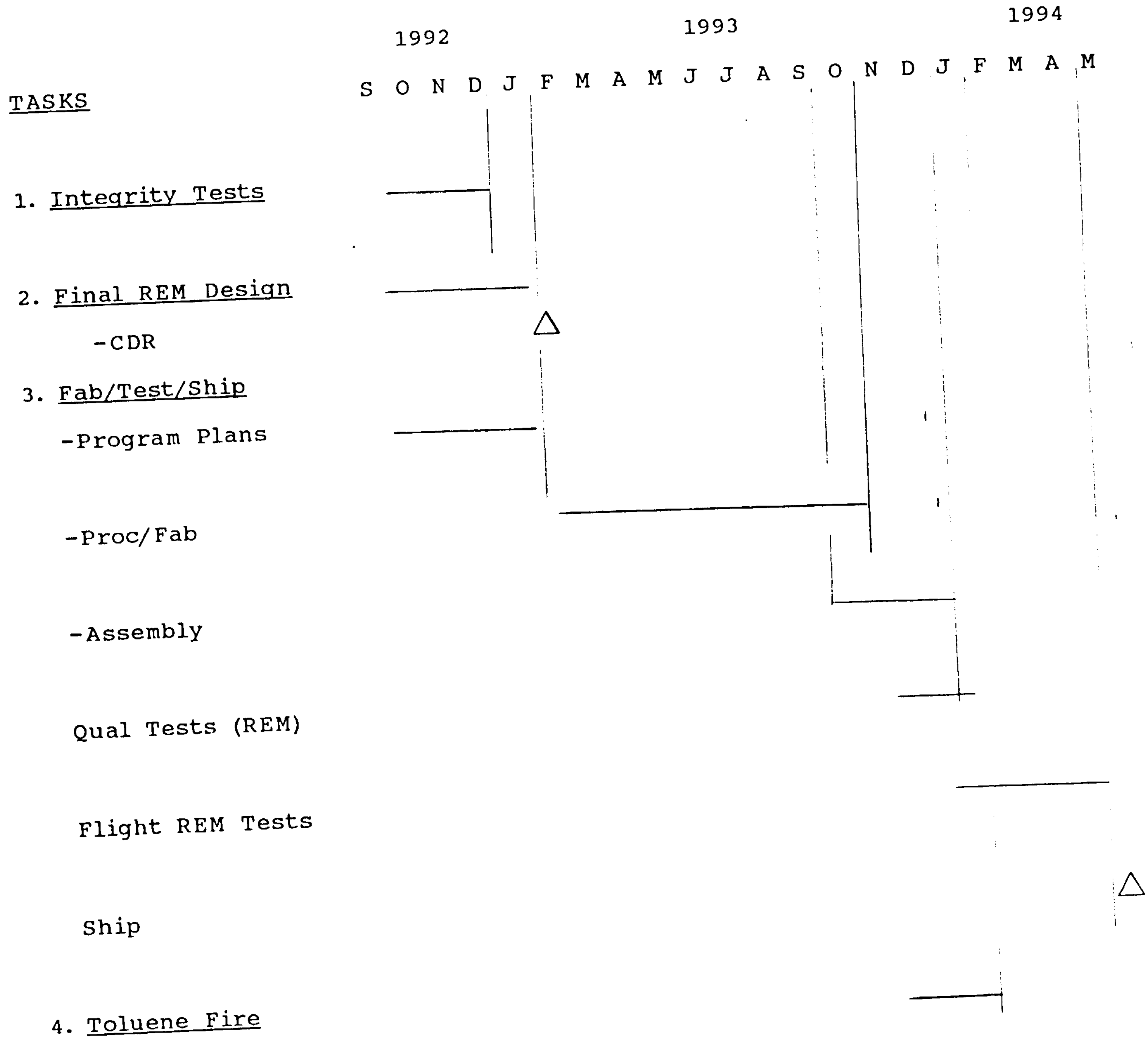
3. Drawings and Lists

- Component and Assembly and Parts Lists (CDR and PSR)
- ICD (CDR and PSR)
- Milestone List (w/proposal)

4. Packages

- Acceptance Data Package (PSR)

7. TASK AND SCHEDULE



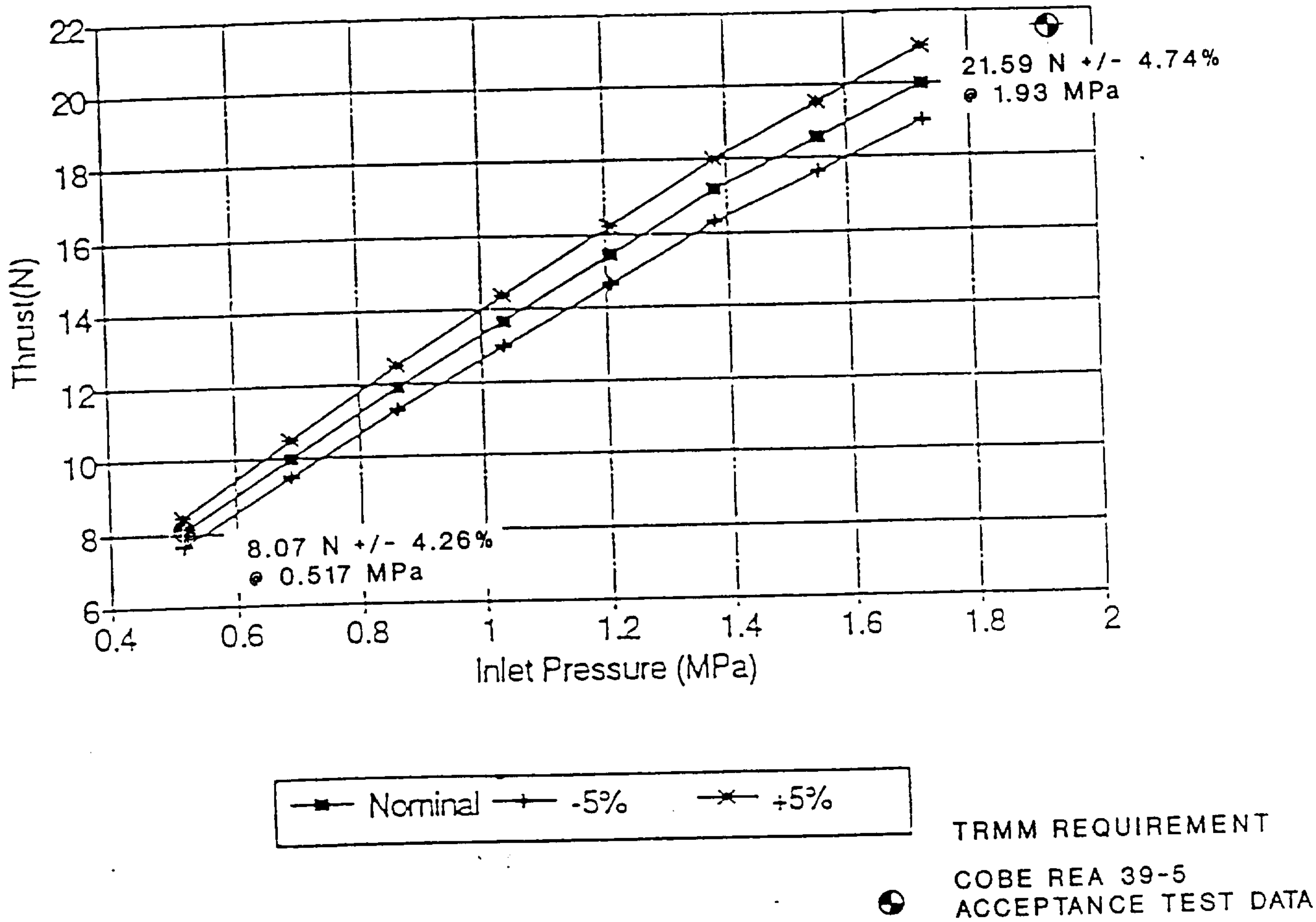


FIGURE 7-1
5 LBF REA THRUST BLOWDOWN CHARACTERISTIC

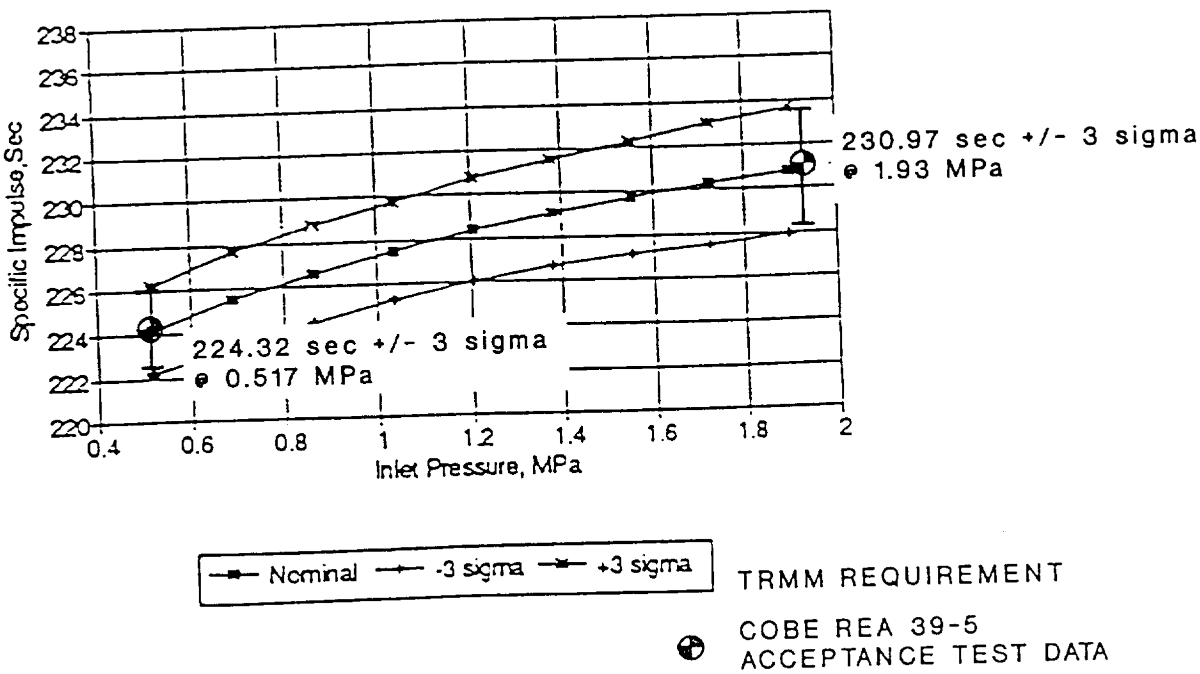


FIGURE 7-2
5 LBF REA STEADY STATE SPECIFIC IMPULSE
VS. INLET PRESSURE

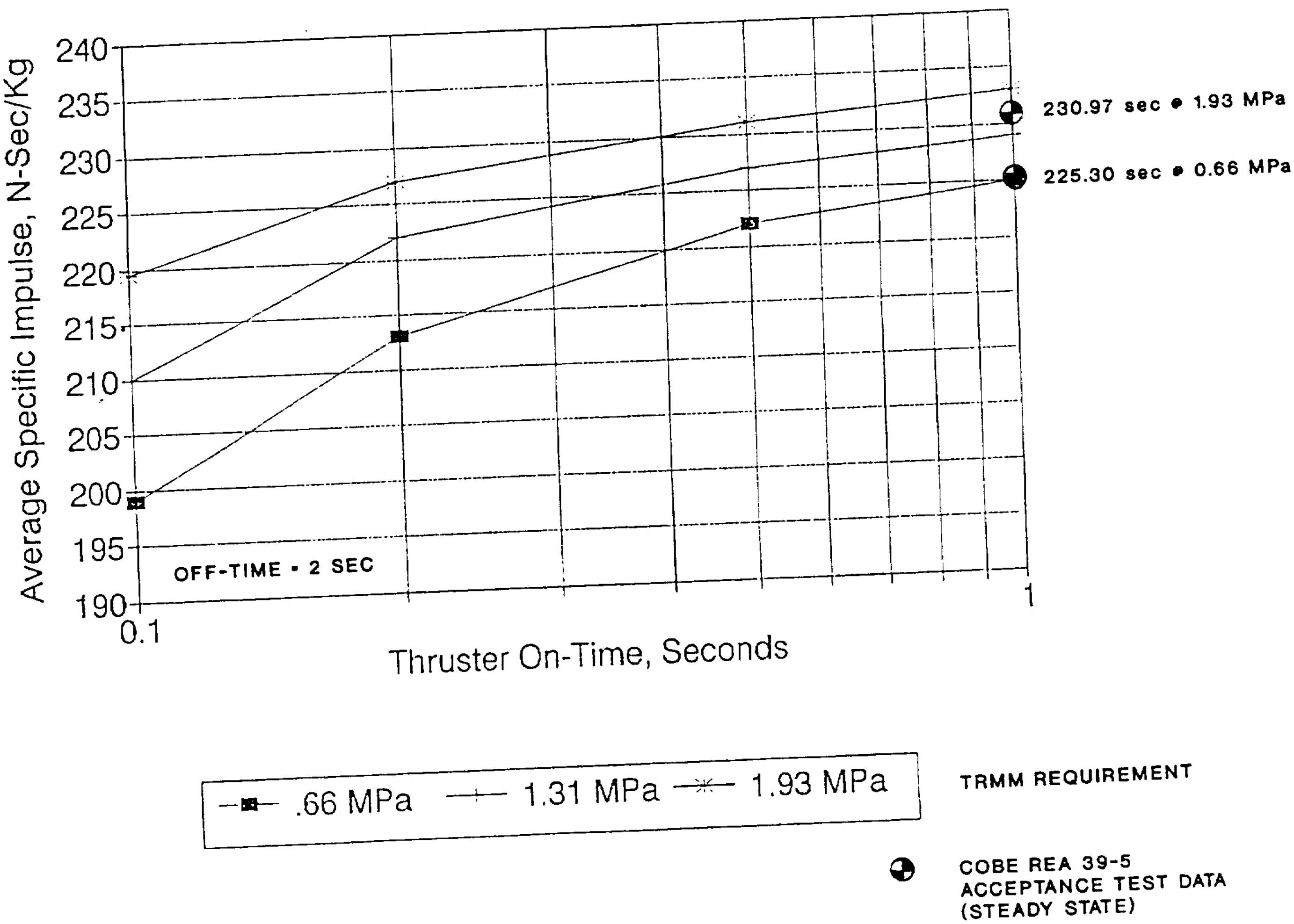


FIGURE 7-3
5 LBF REA PULSING SPECIFIC IMPULSE
VS. ON-TIME

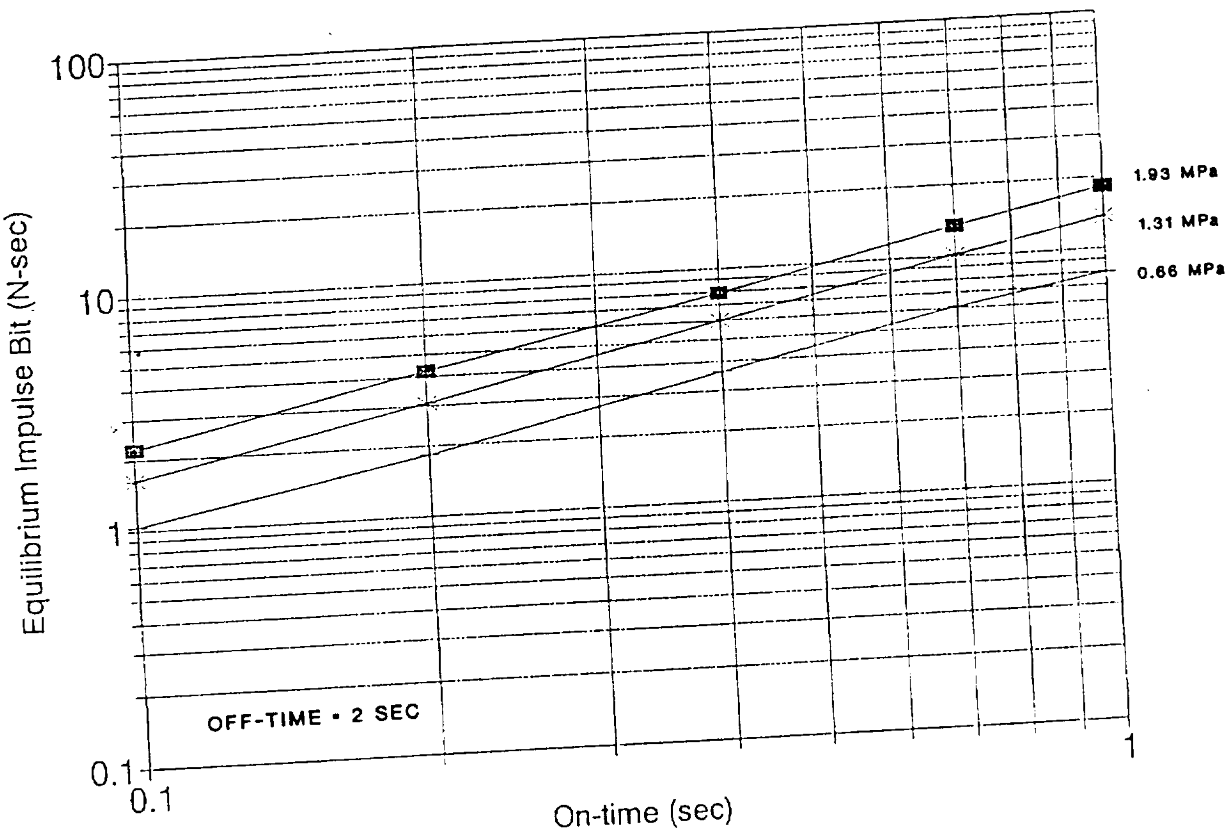
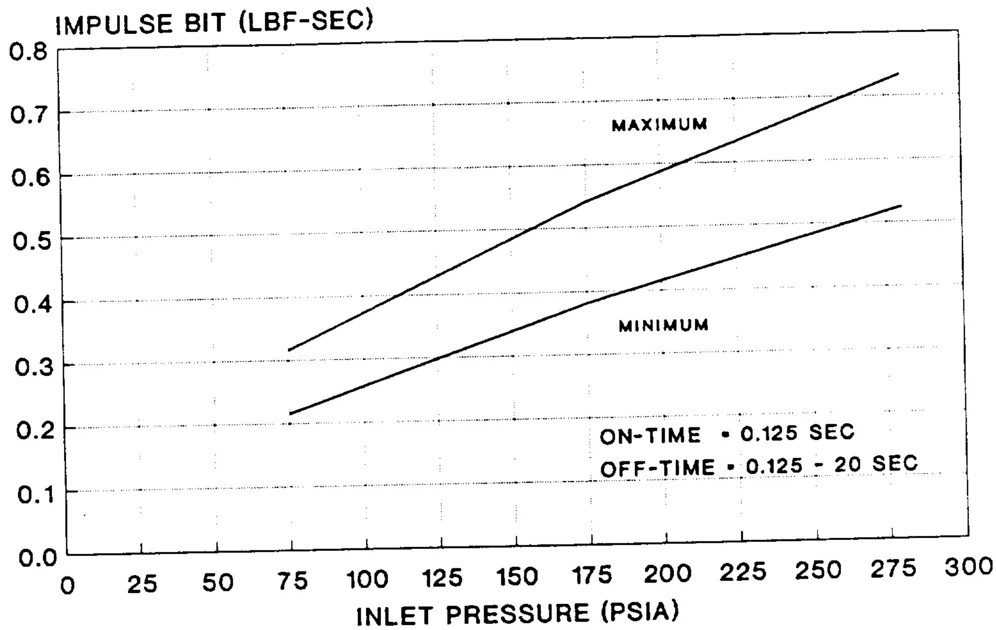
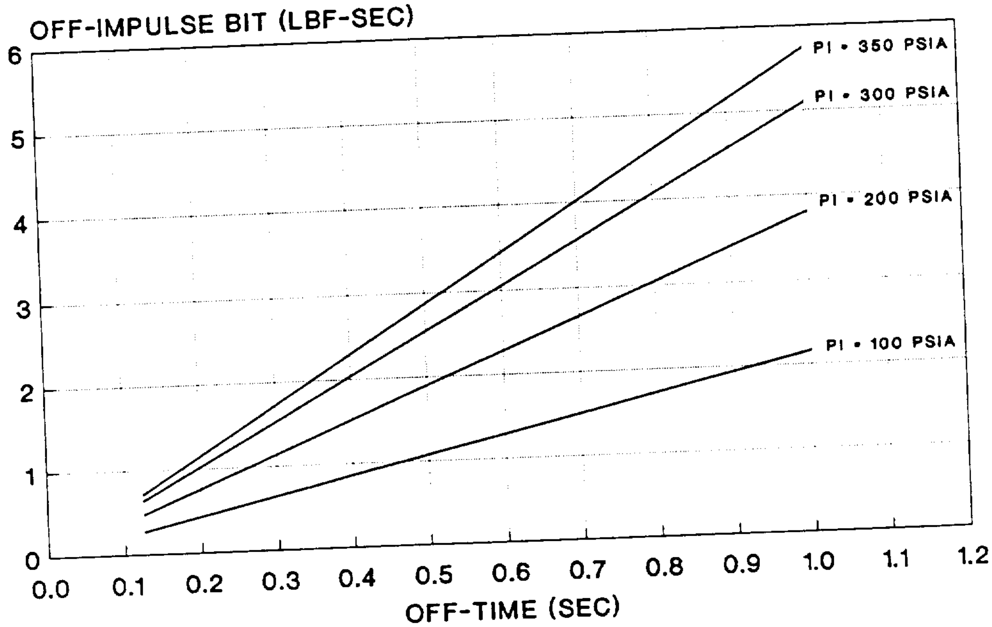


FIGURE 7-4
5 LBF REA EQUILIBRIUM IMPULSE BIT
VS. ON-TIME



BASIS: COBE 5 LBF REA ACCEPTANCE TEST

FIGURE 7-5
5 LBF REA 39-5 PREDICTED IMPULSE BIT
VS. INLET PRESSURE



BASIS: TOPEX 5 LBF REA PROTOFLIGHT TEST

FIGURE 7-6
5 LBF REA 39-5 PREDICTED OFF-IMPULSE BIT
VS. OFF-TIME

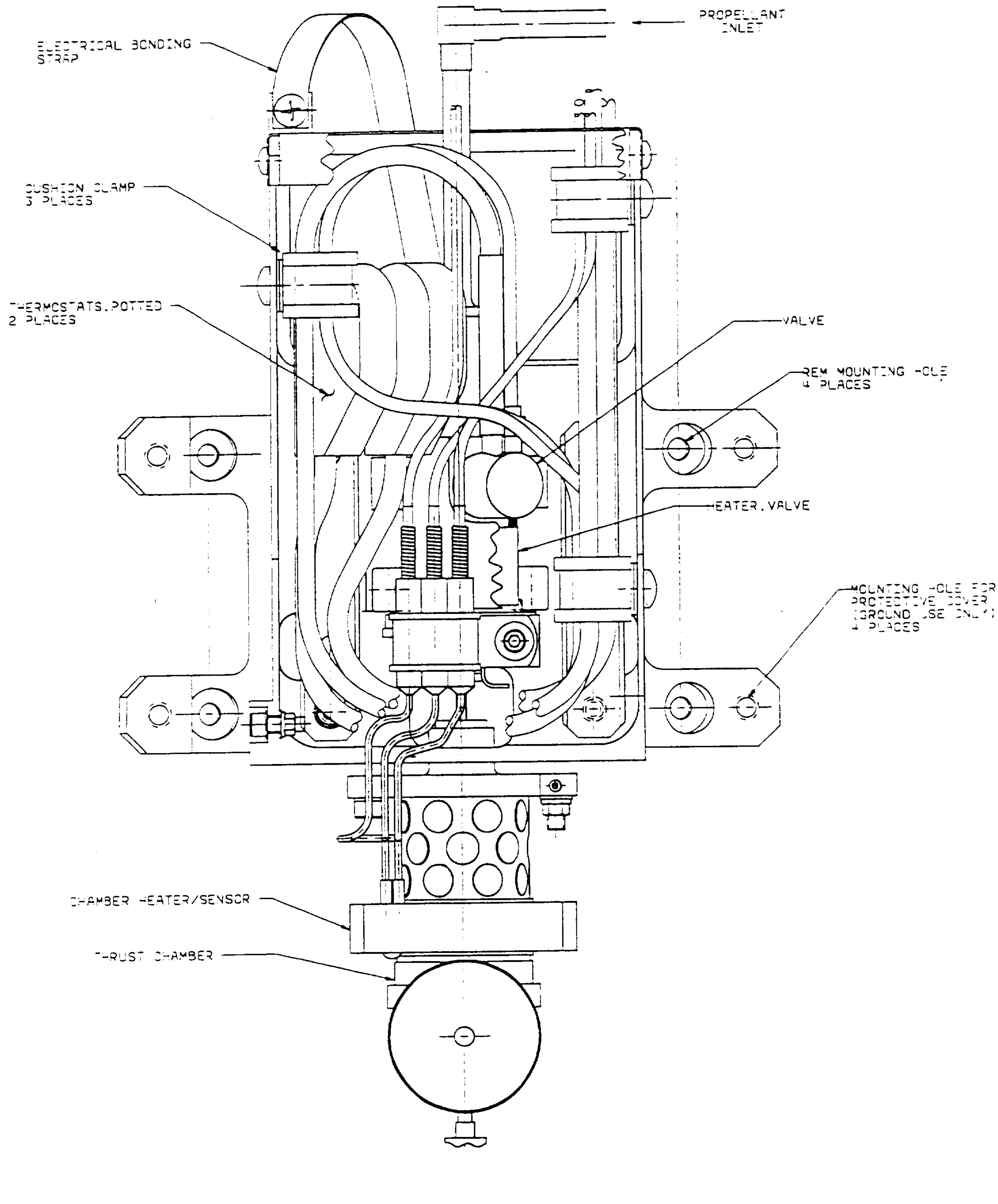


Figure 8-1a TRMM 10 Degree Left REM

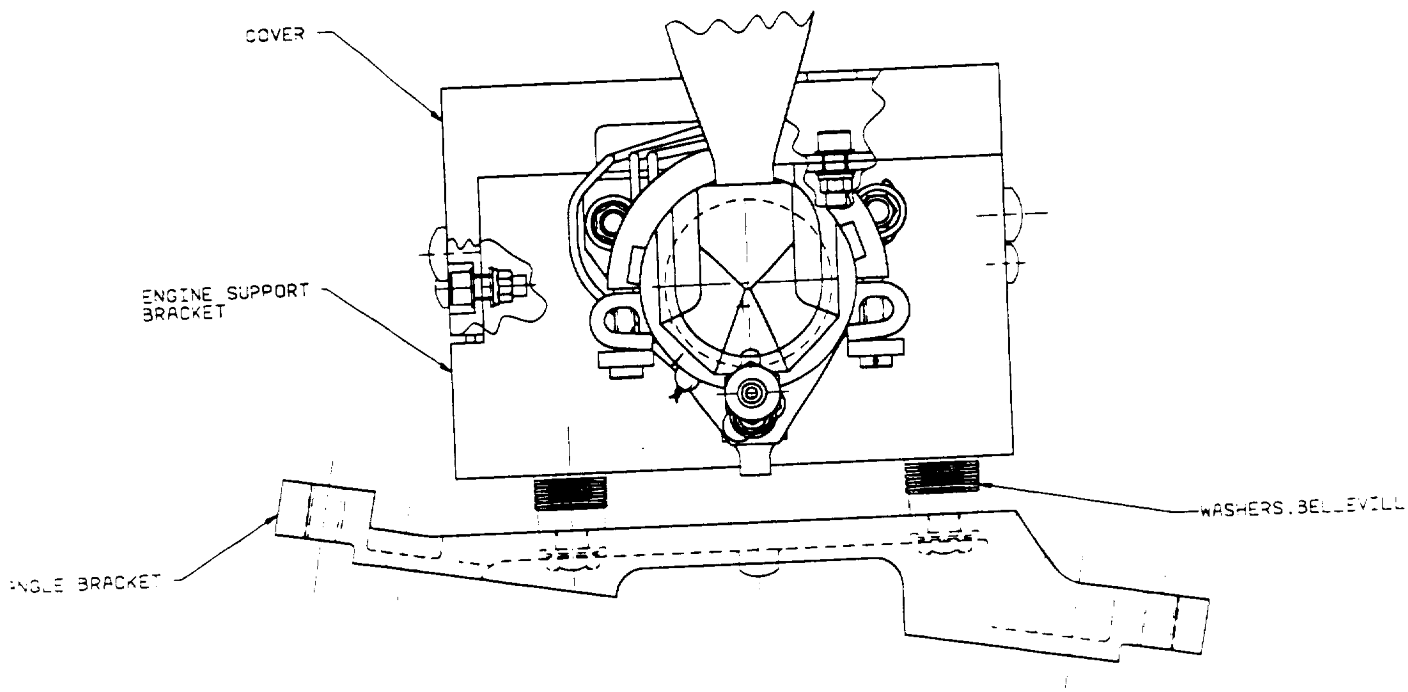


Figure 8-1b TRMM 10 Degree Left REM

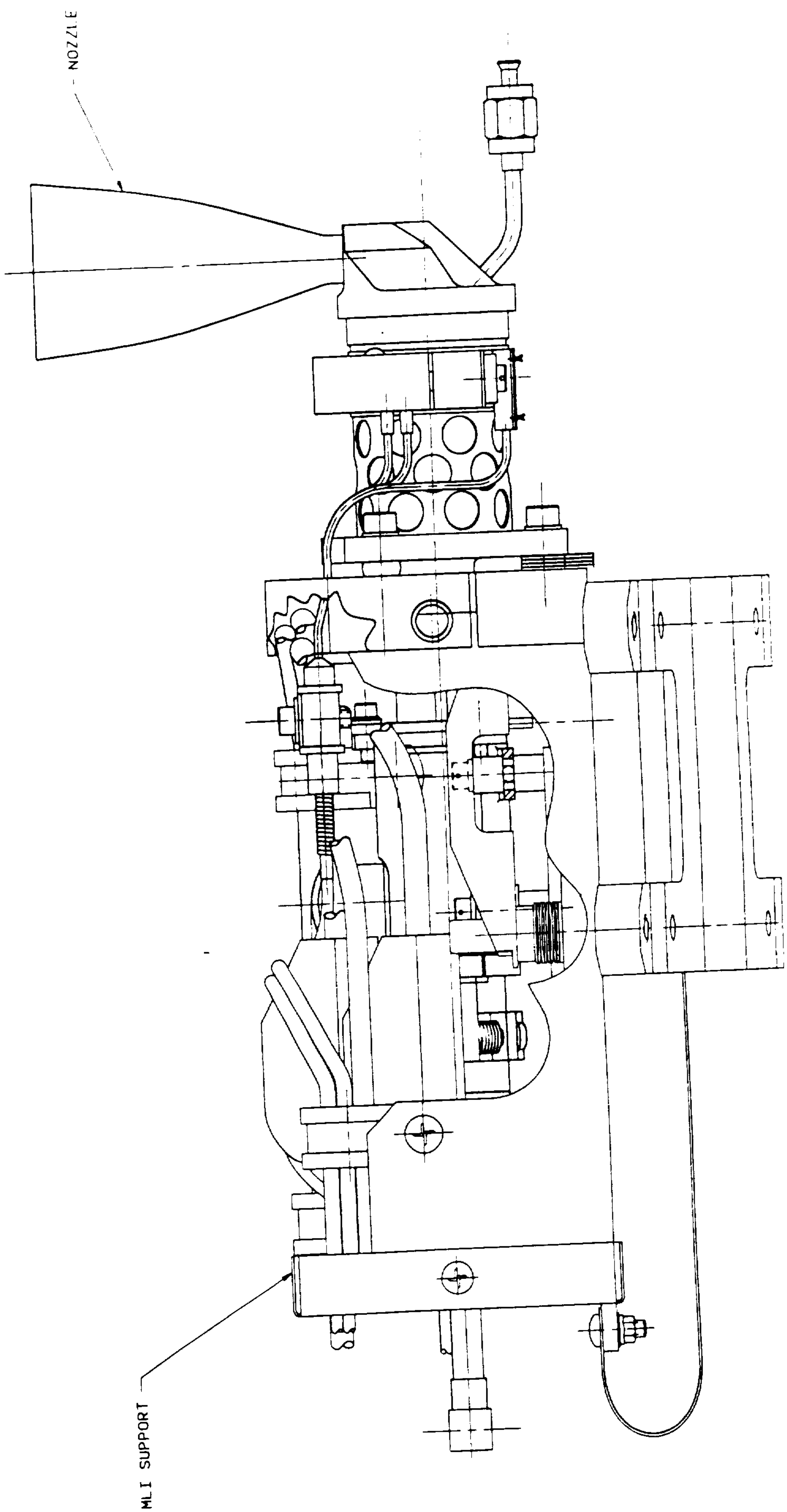


Figure 8-1C TRMM 10 Degree Left REM

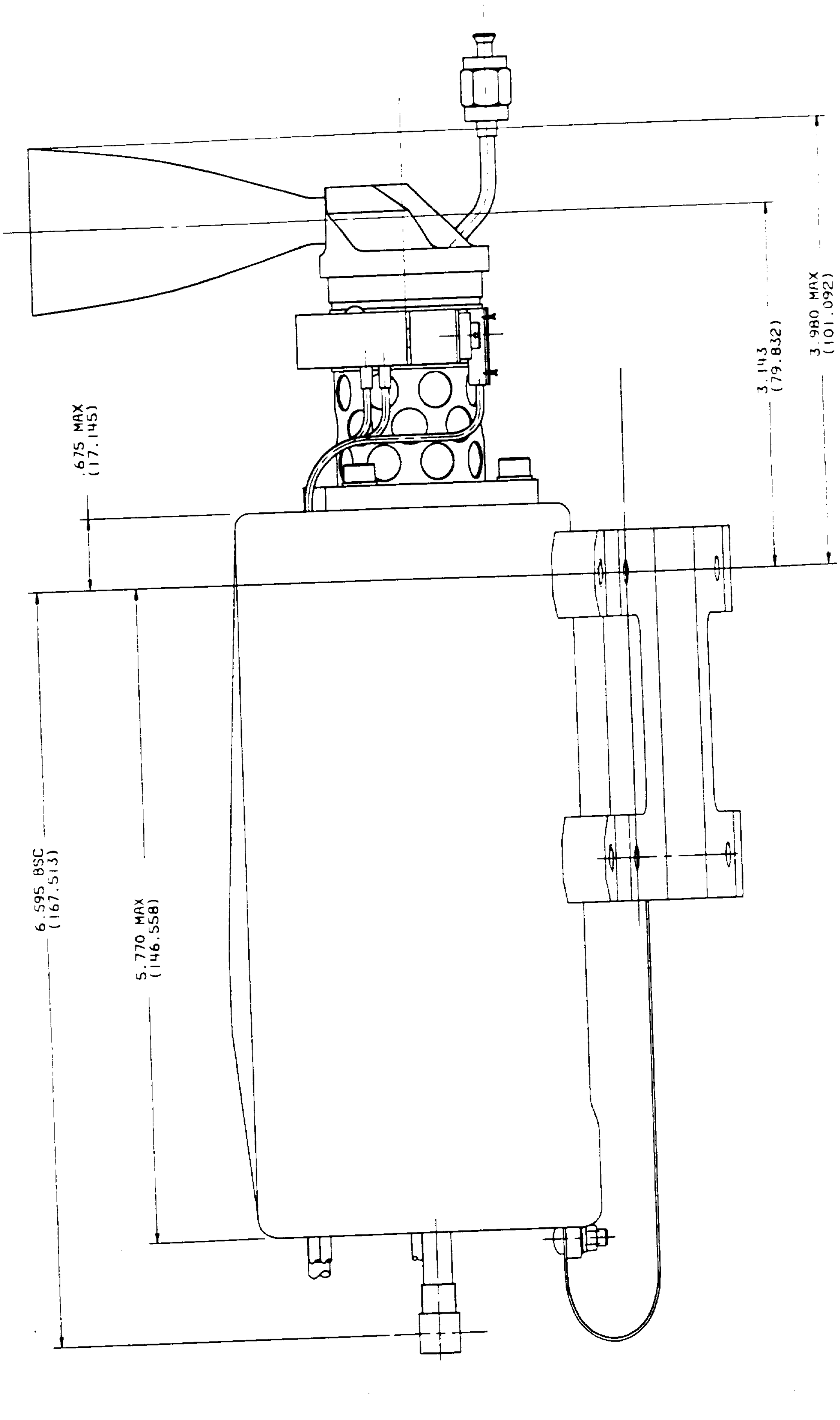


Figure 8-2a TRMM 10 Degree Left REM Installation

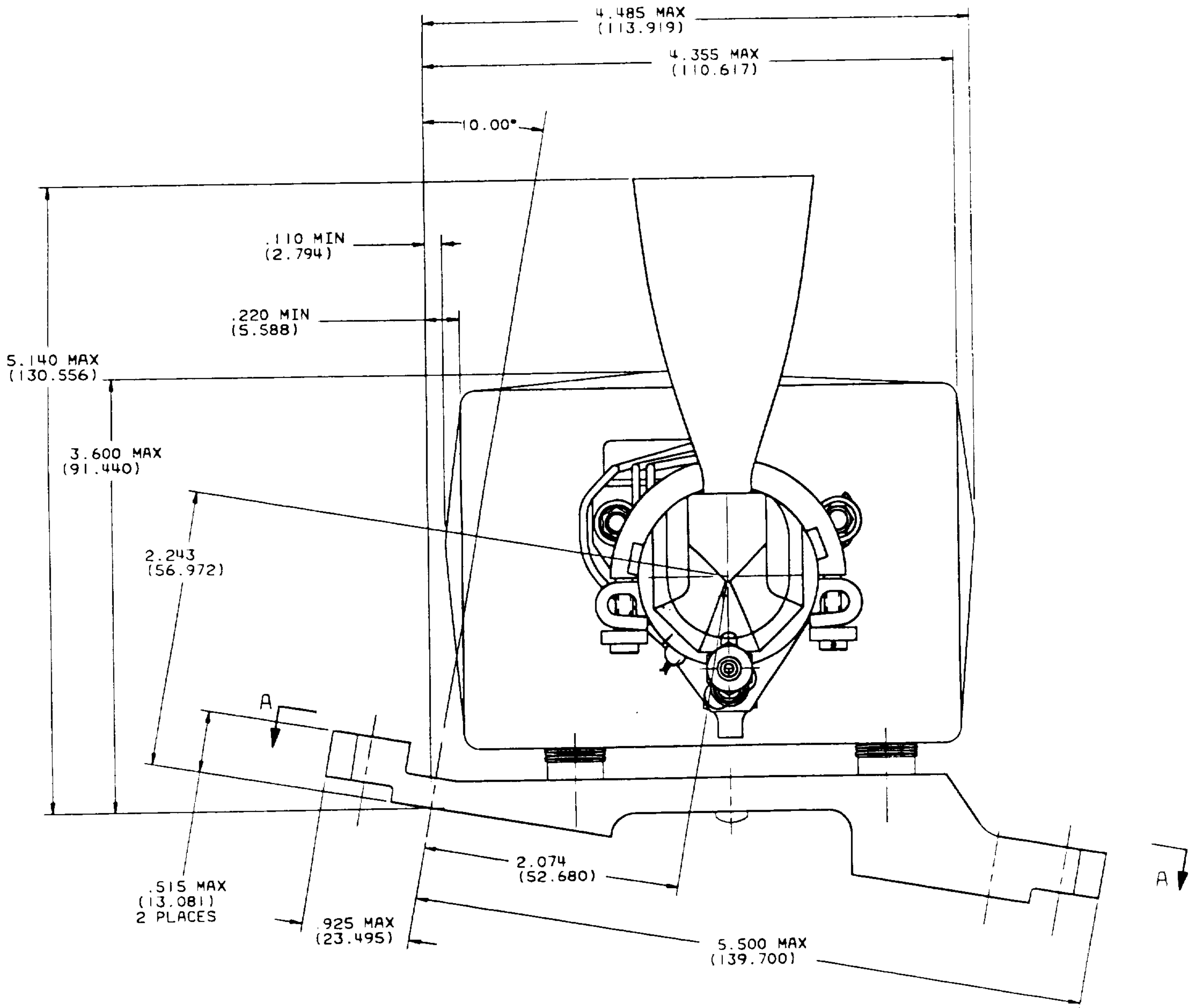


Figure 8-2b TRMM 10 Degree Left REM Installation

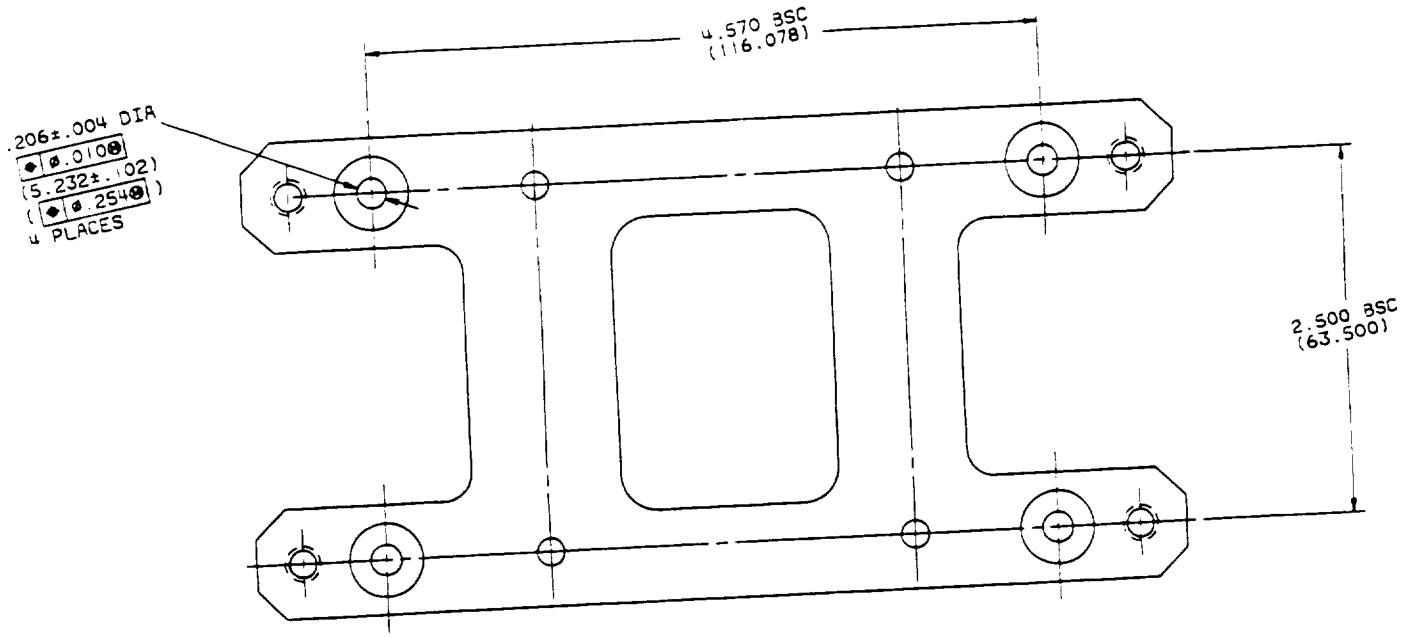


Figure 8-2c TRMM 10 Degree Left REM Installation

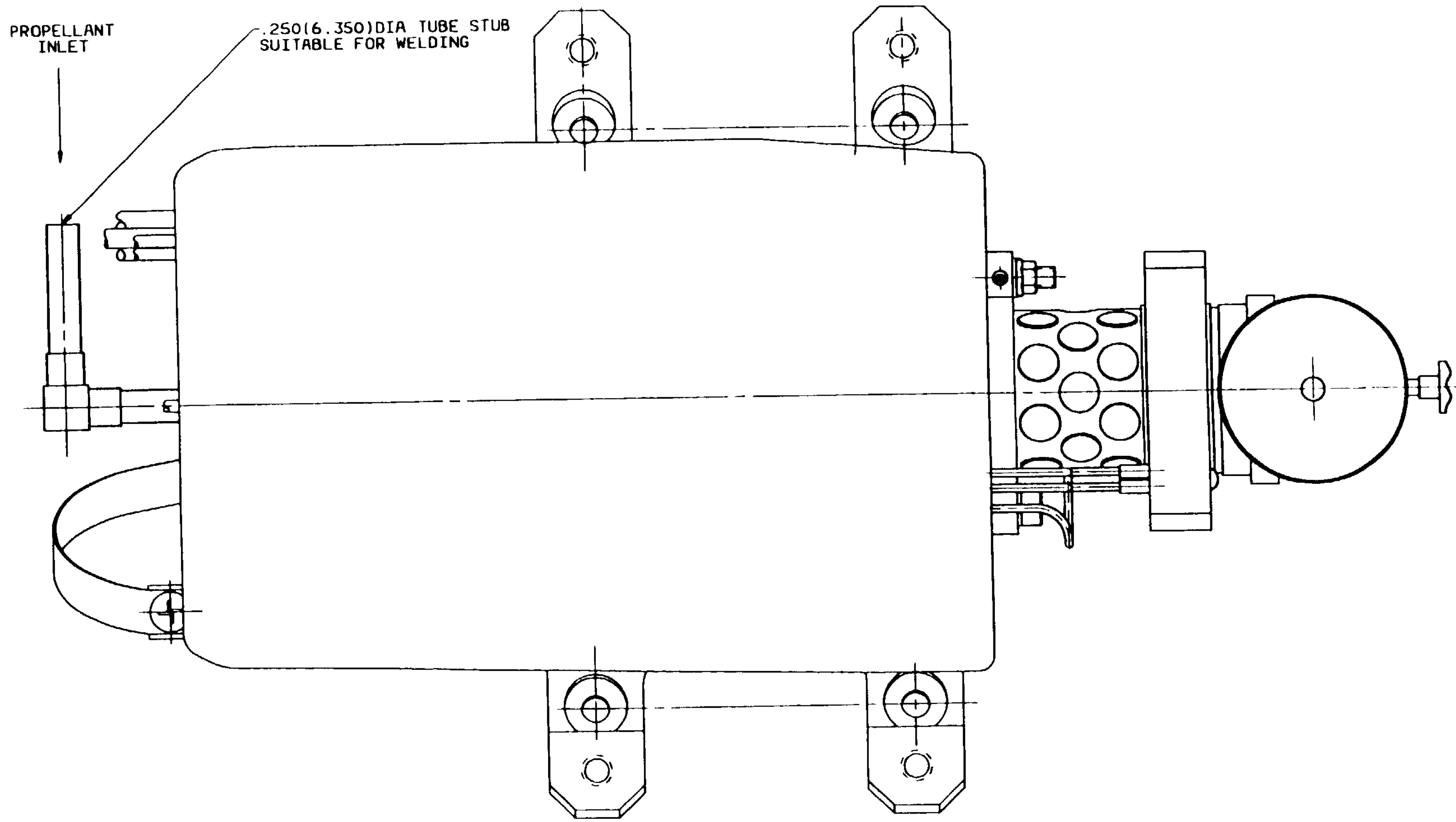


Figure 8-2d TRMM 10 Degree Left REM Installation

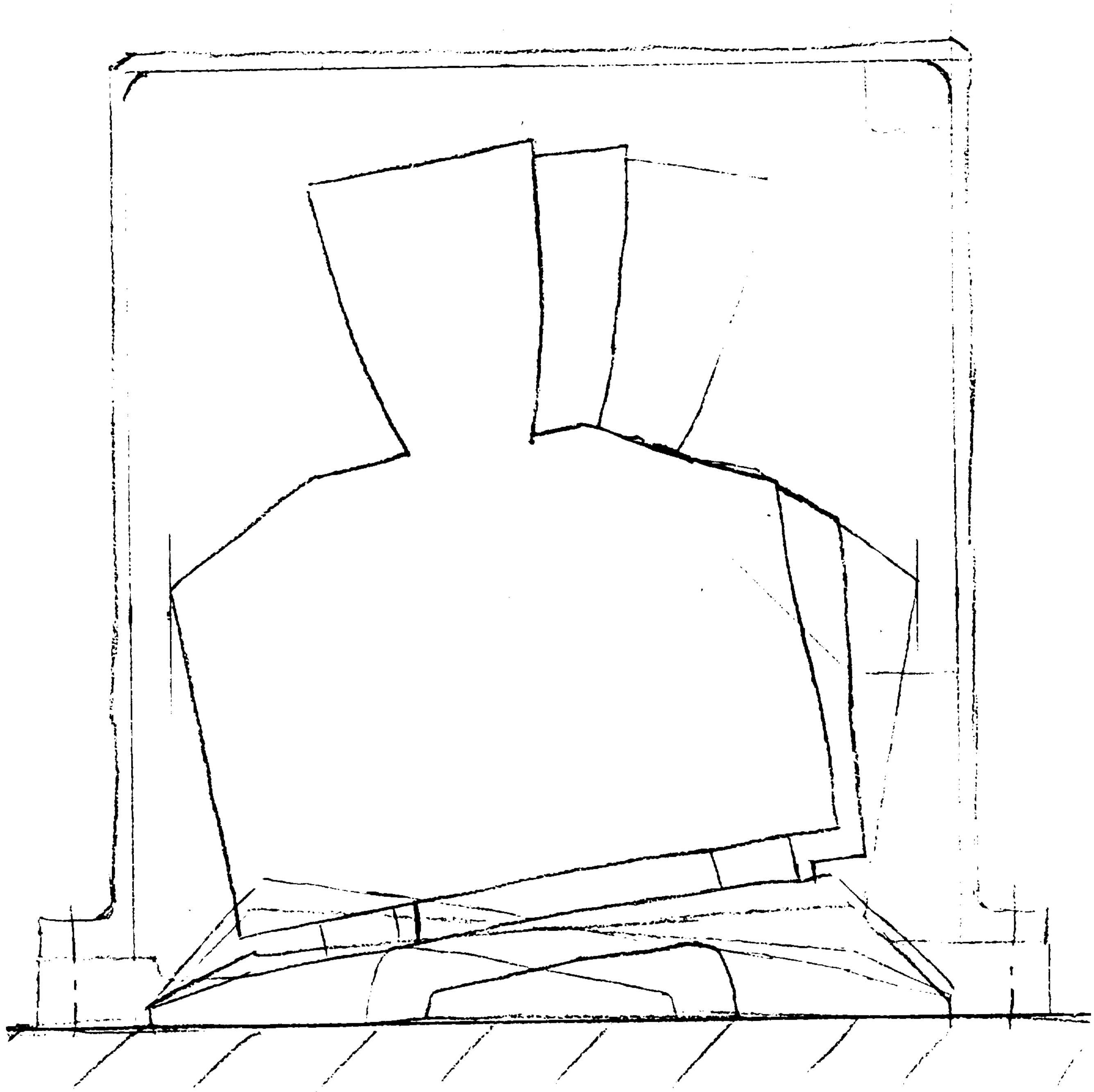
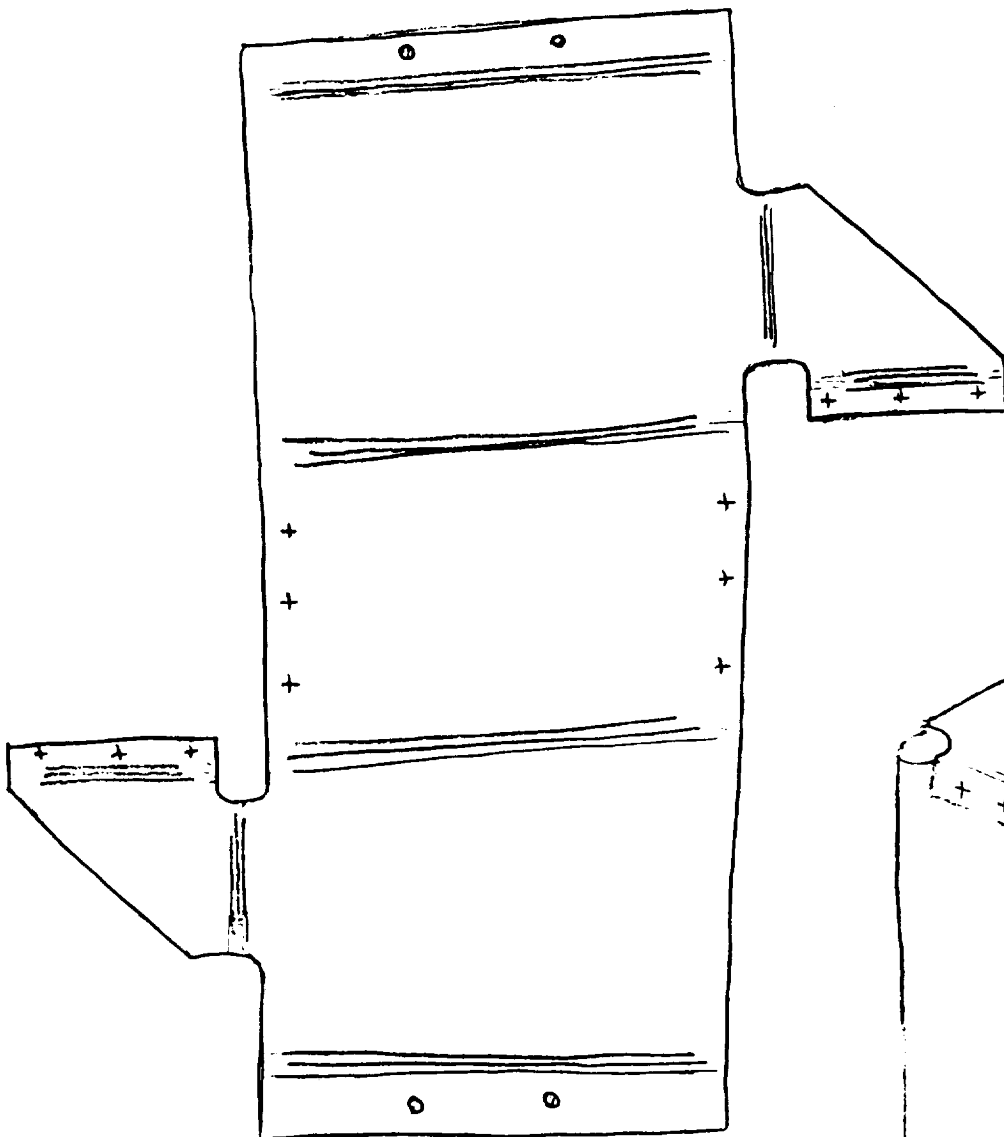
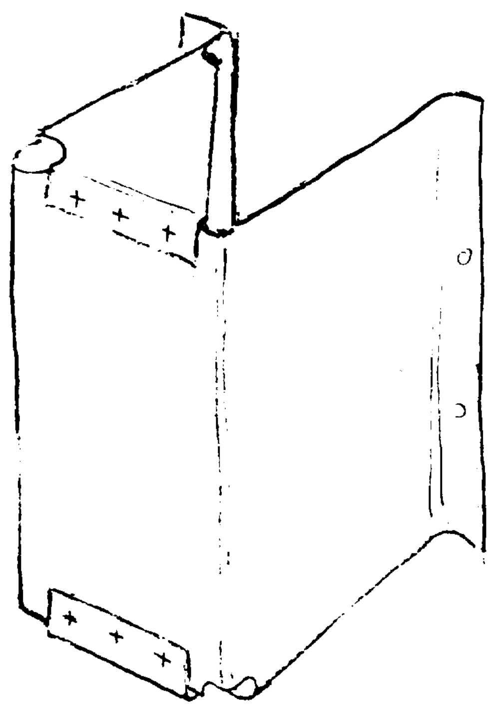


Figure 8-3a REM Protective Cover



Developed
View



Isometric

Figure 8-3b REM Protective Cover

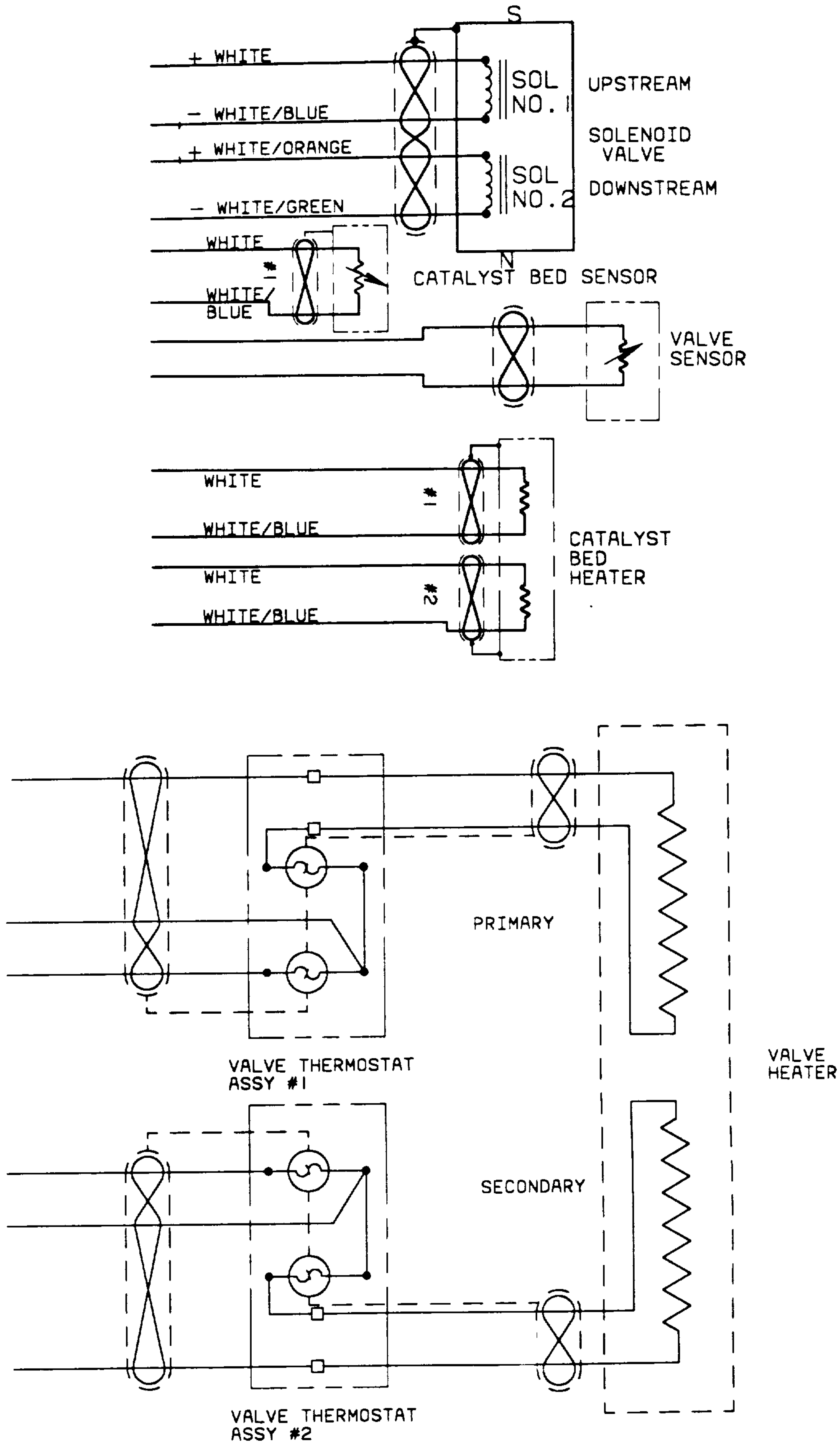


Figure 8-4 TRMM REM Electrical Schematic

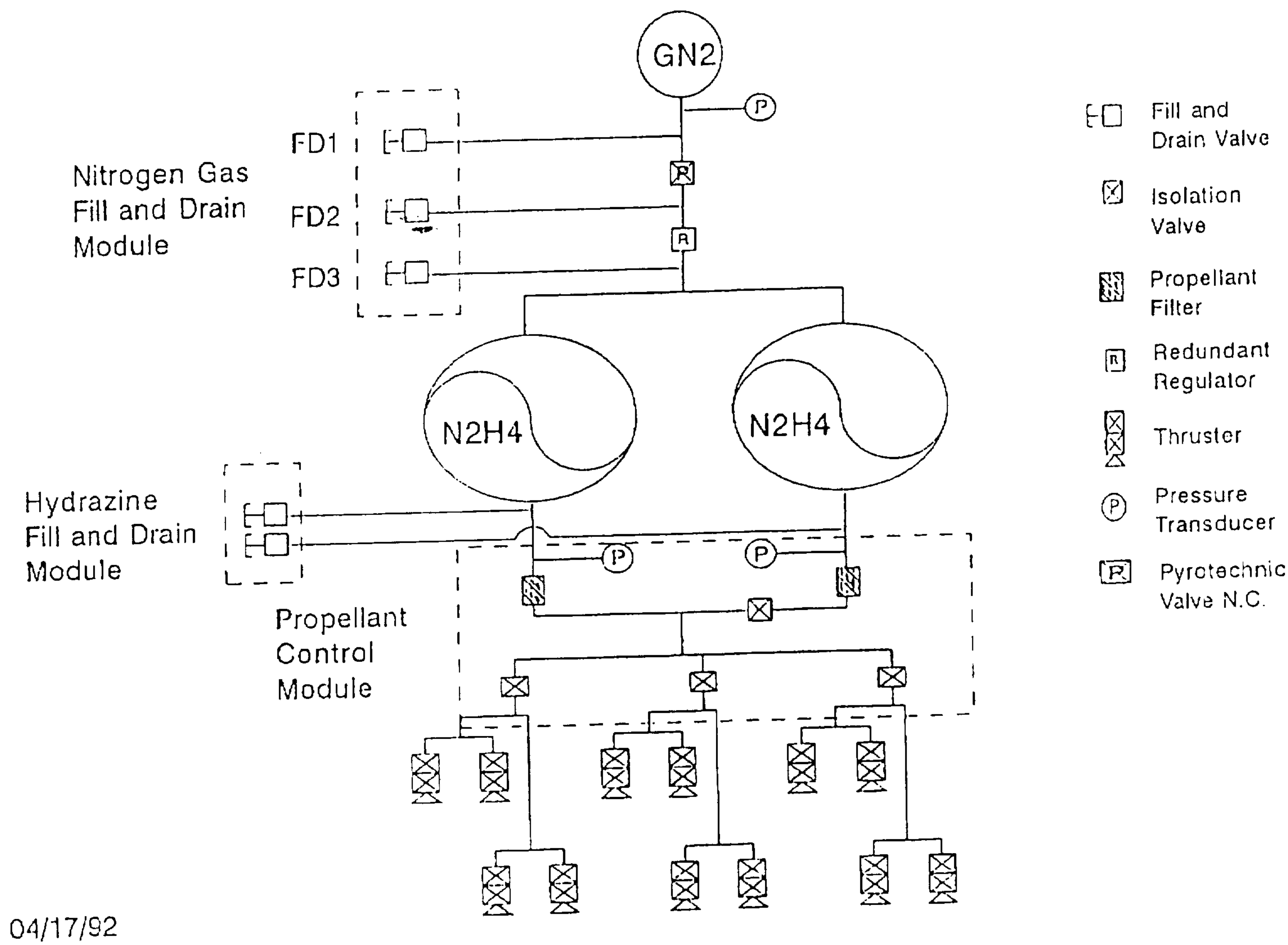


Figure 8-5 TRMM RCS Fluid Schematic

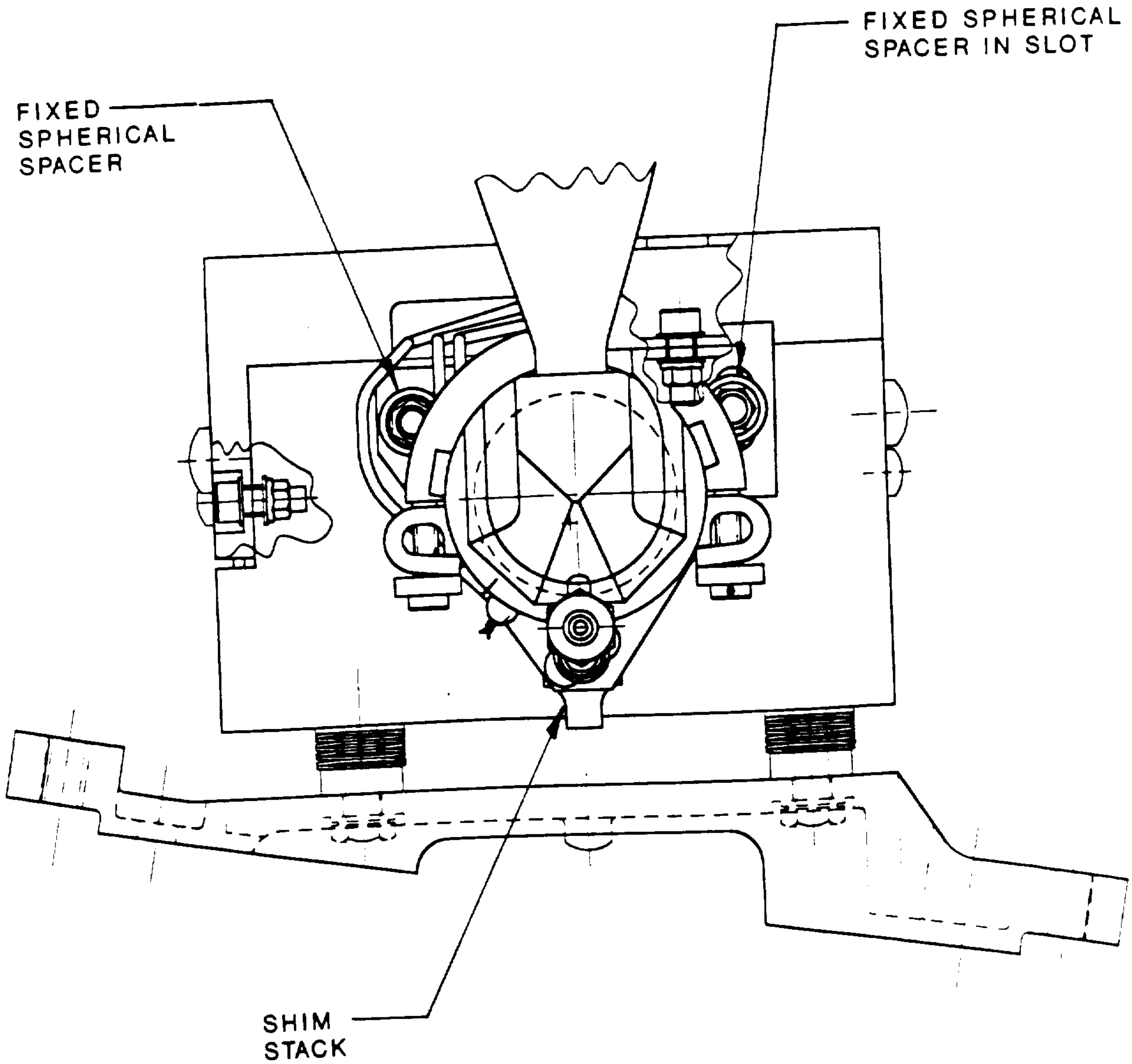


Figure 8-6 Nozzle Angle Adjustment

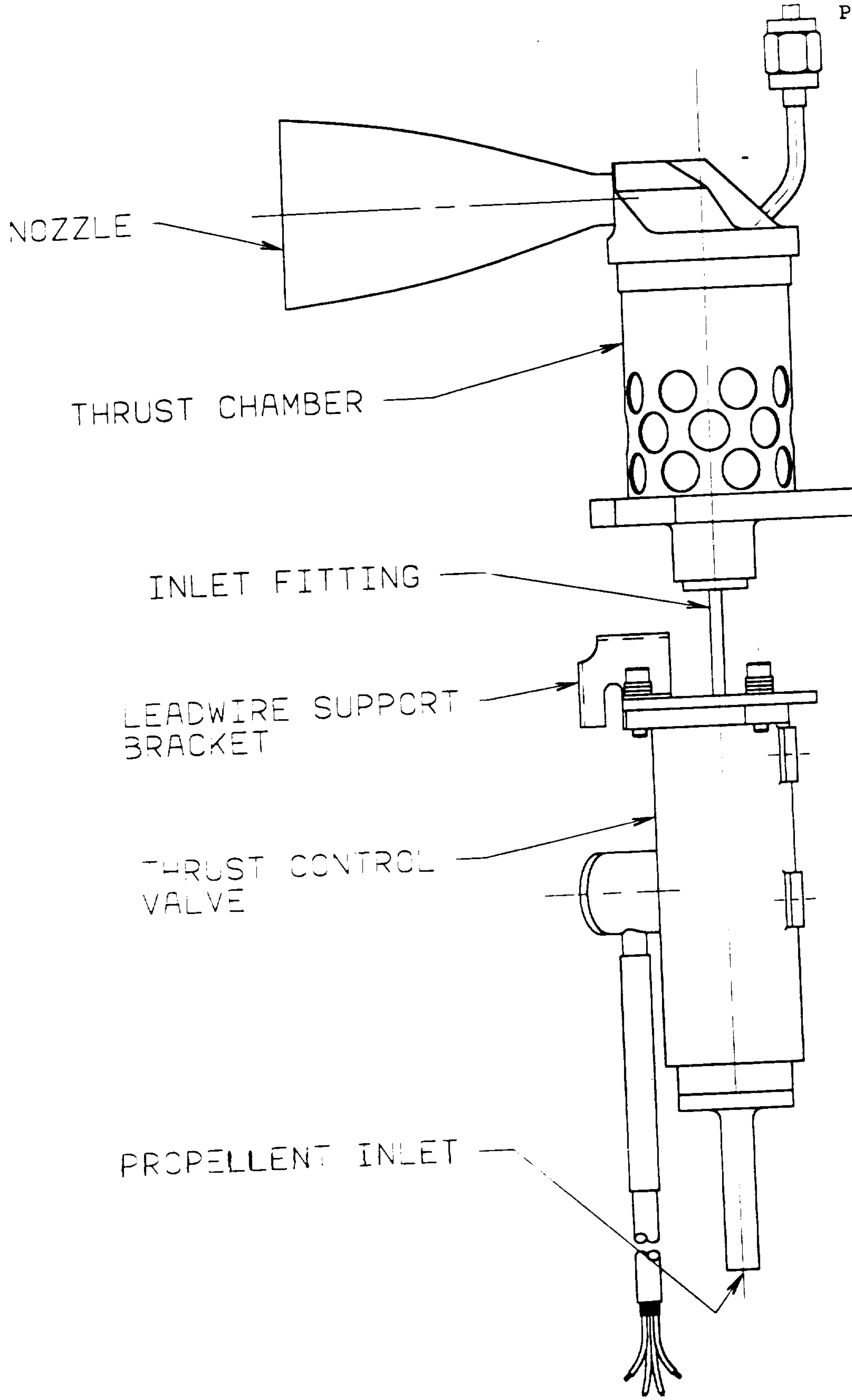


Figure 8-7 TRMM Rocket Engine Assembly (REA)

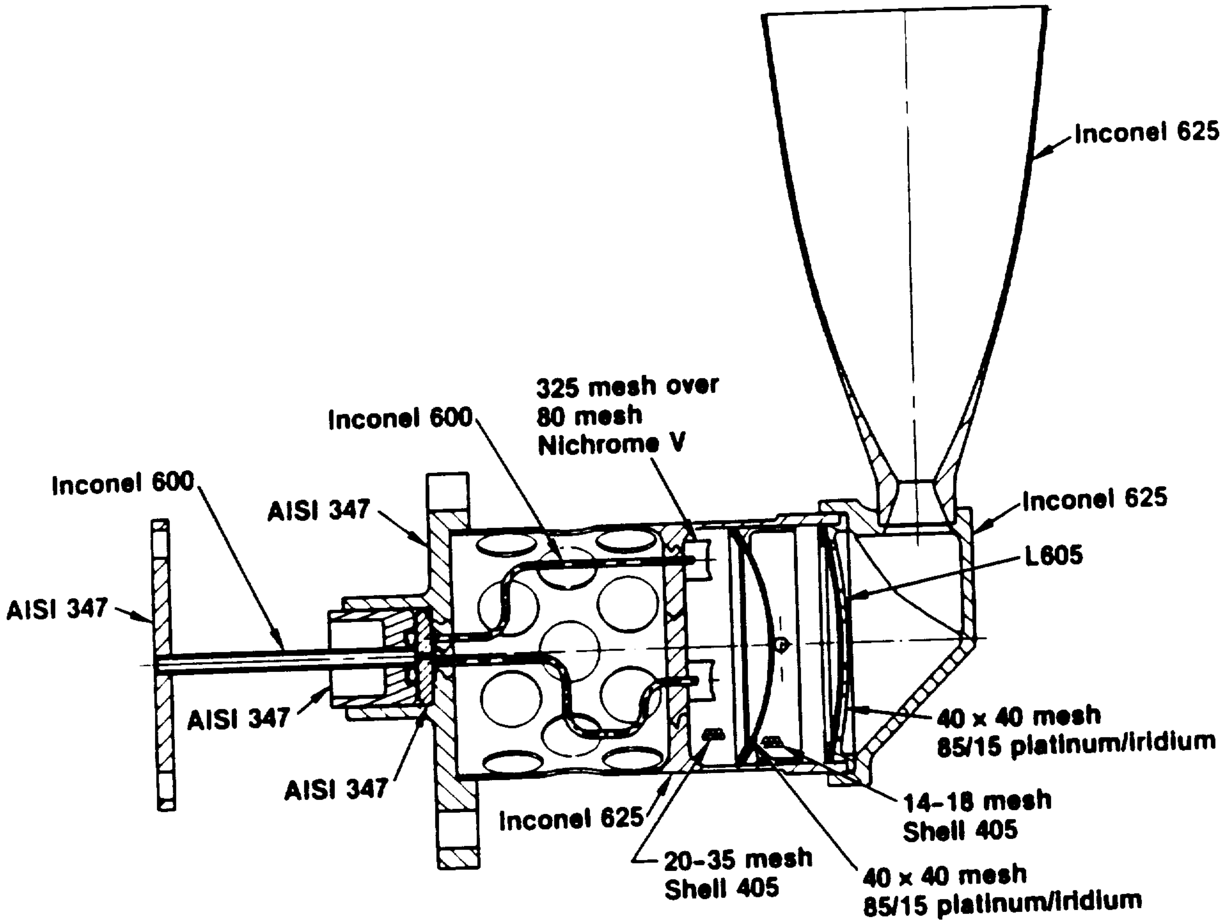


Figure 8-8 TRMM Thrust Chamber Assembly (TCA)

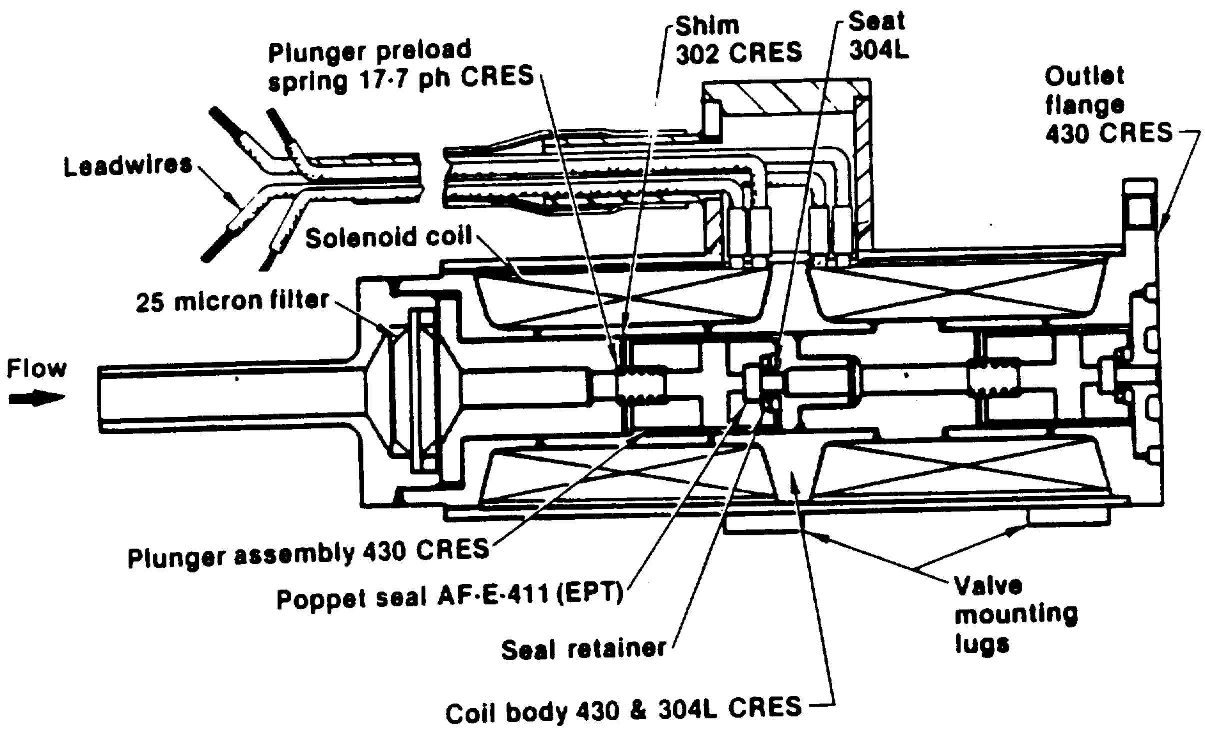
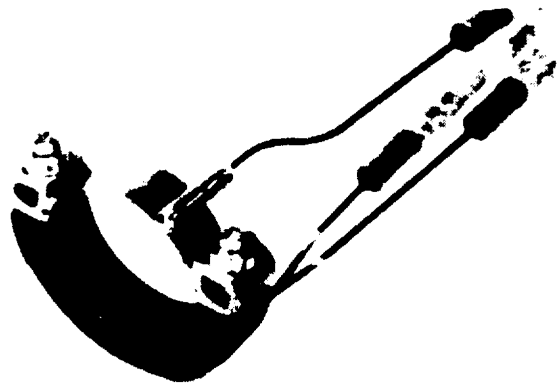


Figure 8-9 TRMM Thrust Control Valve (TCV)



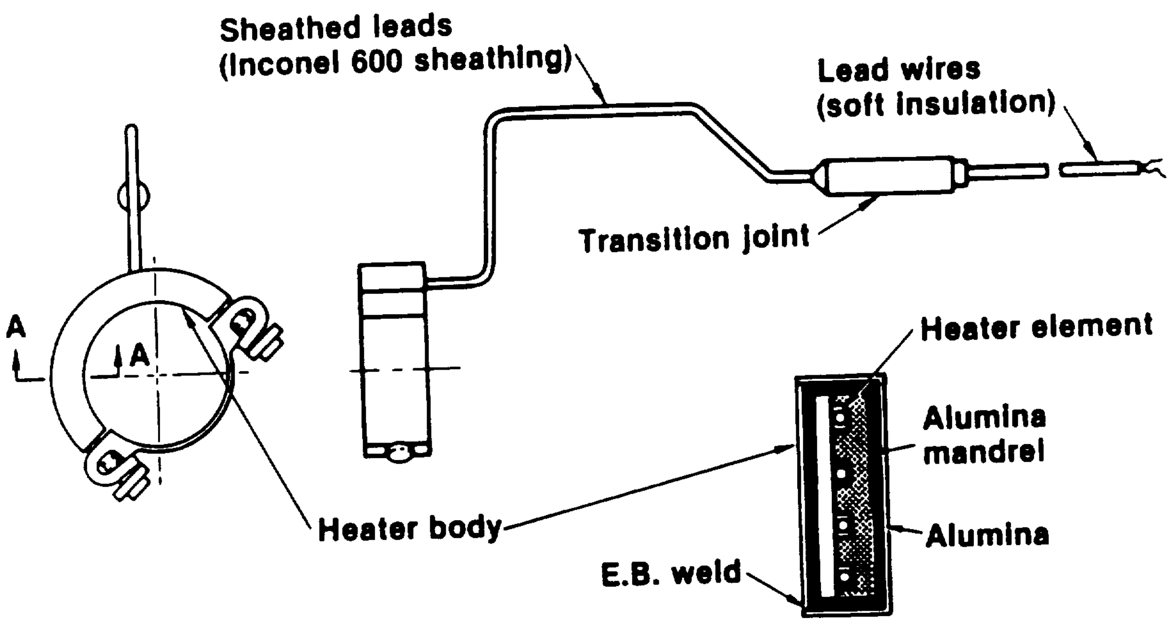
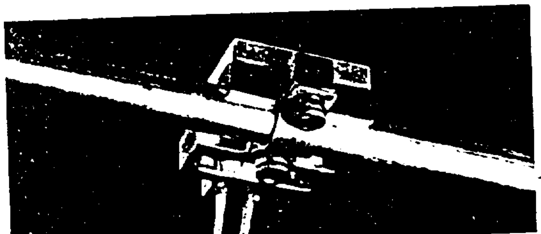


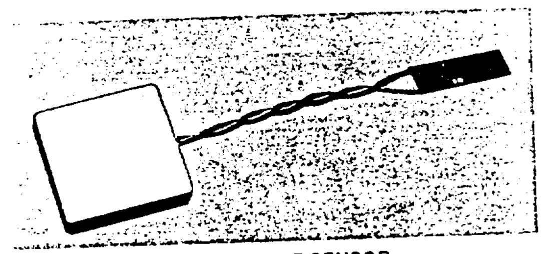
Figure 8-10 TRMM Thrust Chamber Heater/Sensor

TAYCO NEW PRODUCT REPORT

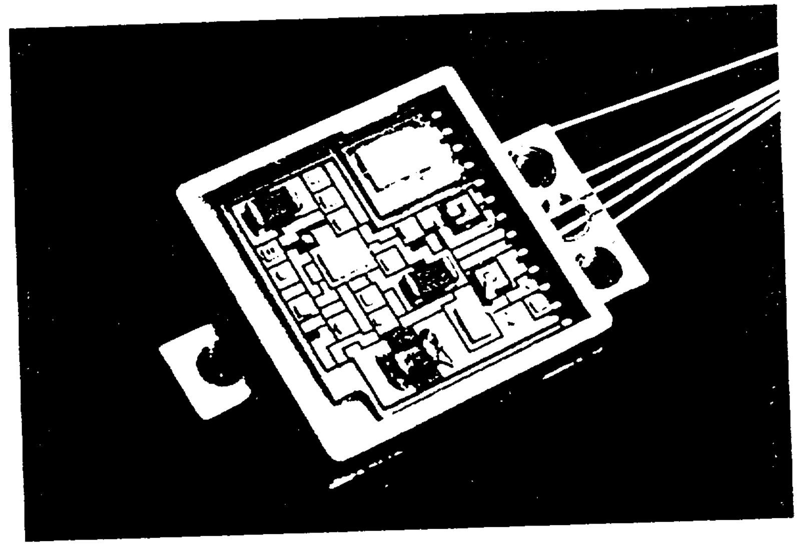
Solid State Thermostat (SST)



MOUNTED TO 1/4" TUBE (ACTUAL SIZE)



WITH REMOTE TEMPERATURE SENSOR



HYBRID CIRCUIT

Celebrating our 20th year of engineering excellence and commitment to aerospace, Tayco is proud to present the Solid State Thermostat (SST). Offering many advantages over mechanical themostats, the SST uses hybrid microelectronic technology in the smallest precision On/Off temperature switch available.

QUALIFICATION STATUS:	Preliminary NASA qualification (Summer 1992)
QUALITY LEVEL:	Available to S-Level
MTBF:	$\geq 70 \times 10^{6}$
SIZE:	.15 X .75 X .75 inches
MASS:	≤ 20 grams including mounting bracket
SET POINT RANGE:	-67°F to 257°F (Internal Sensor) -250°F to 1500°F (Remote Sensor)
SET POINT ACCURACY:	± 2°F
HEATER LOAD:	Up to 160 watts @ 32 VDC (5 amps)
SUPPLY VOLTAGE:	28 ± 4 VDC
VIBRATION:	80g peak, 3 hours per axis
RADIATION HARDENING:	Available
LIGHTNING PROTECTION:	Included
TEMPERATURE SENSING:	Platinum RTD: Internal for use as thermostat, external for remote placement
QUIESCENT CURRENT:	≤ 10mA

The SST is designed as a cost effective replacement for mechanical thermostats. Specific improvements include increased reliability, longer life, better vibration resistance, smaller envelope, remote temperature sensing, contolled ramp rate and availability of custom housings and temperature settings.

TAYCO
ENGINEERING, INC.

10874 Hope Street Post Office Box 6034, Cypress, California 90630 714-952-2240 Fax 714-952-2042

Figure 8-11 Solid State Thermostat (SST)

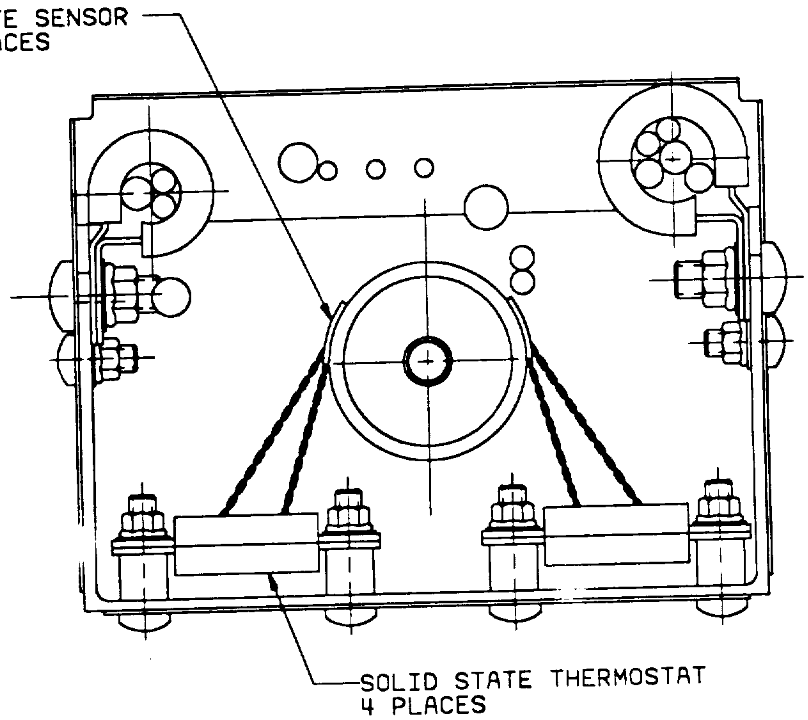


Figure 8-12 Solid State Thermostat Option

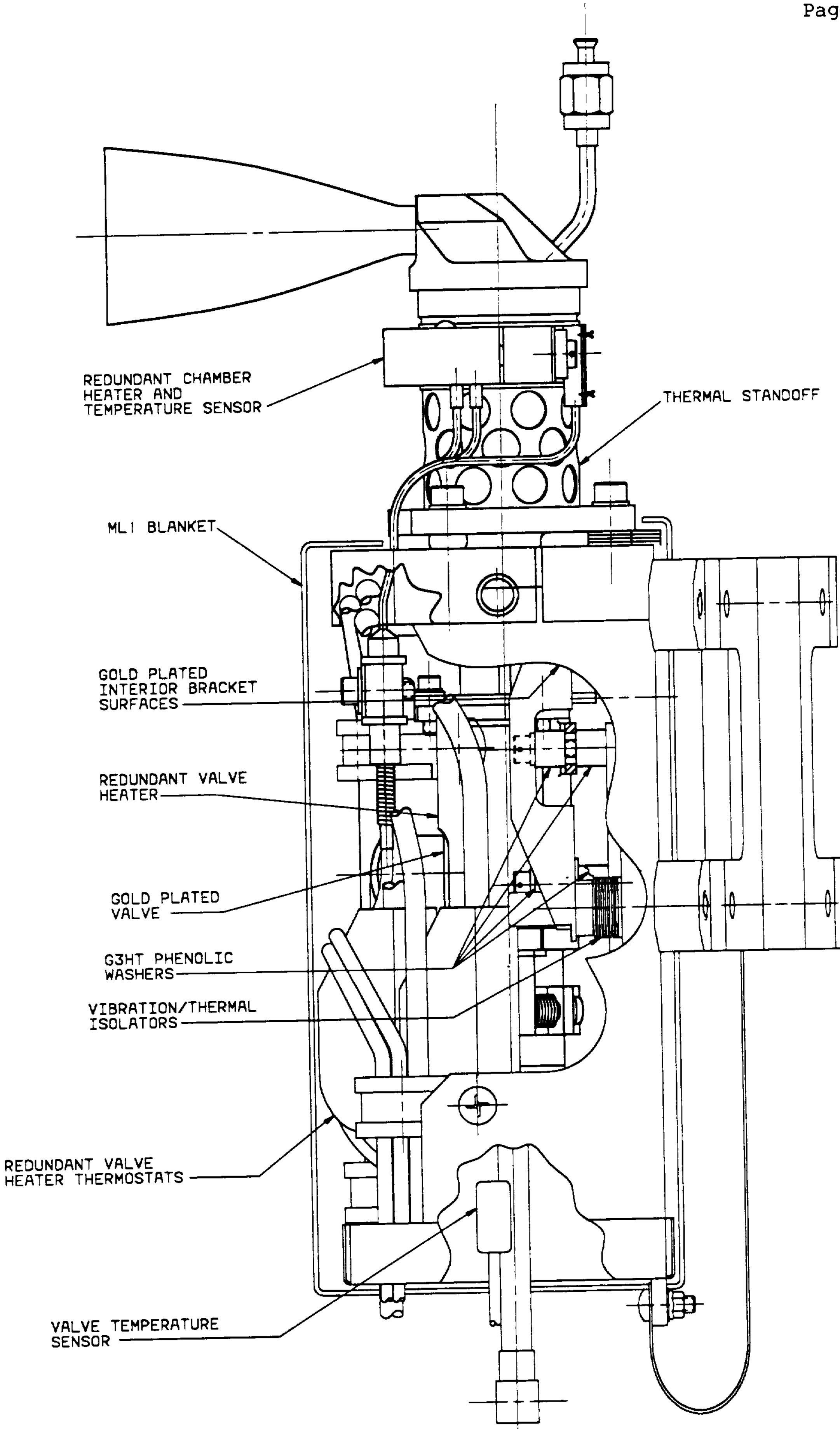


FIGURE 8-13 REM THERMAL DESIGN FEATURES

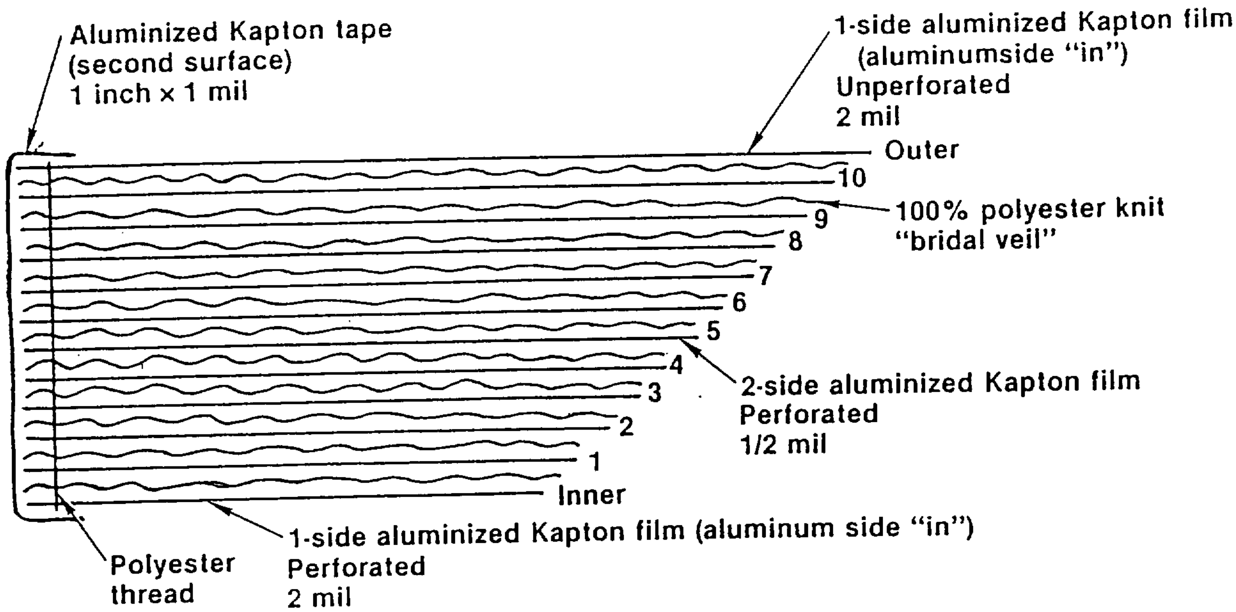


FIGURE 8-14
THERMAL BLANKET CROSS-SECTION

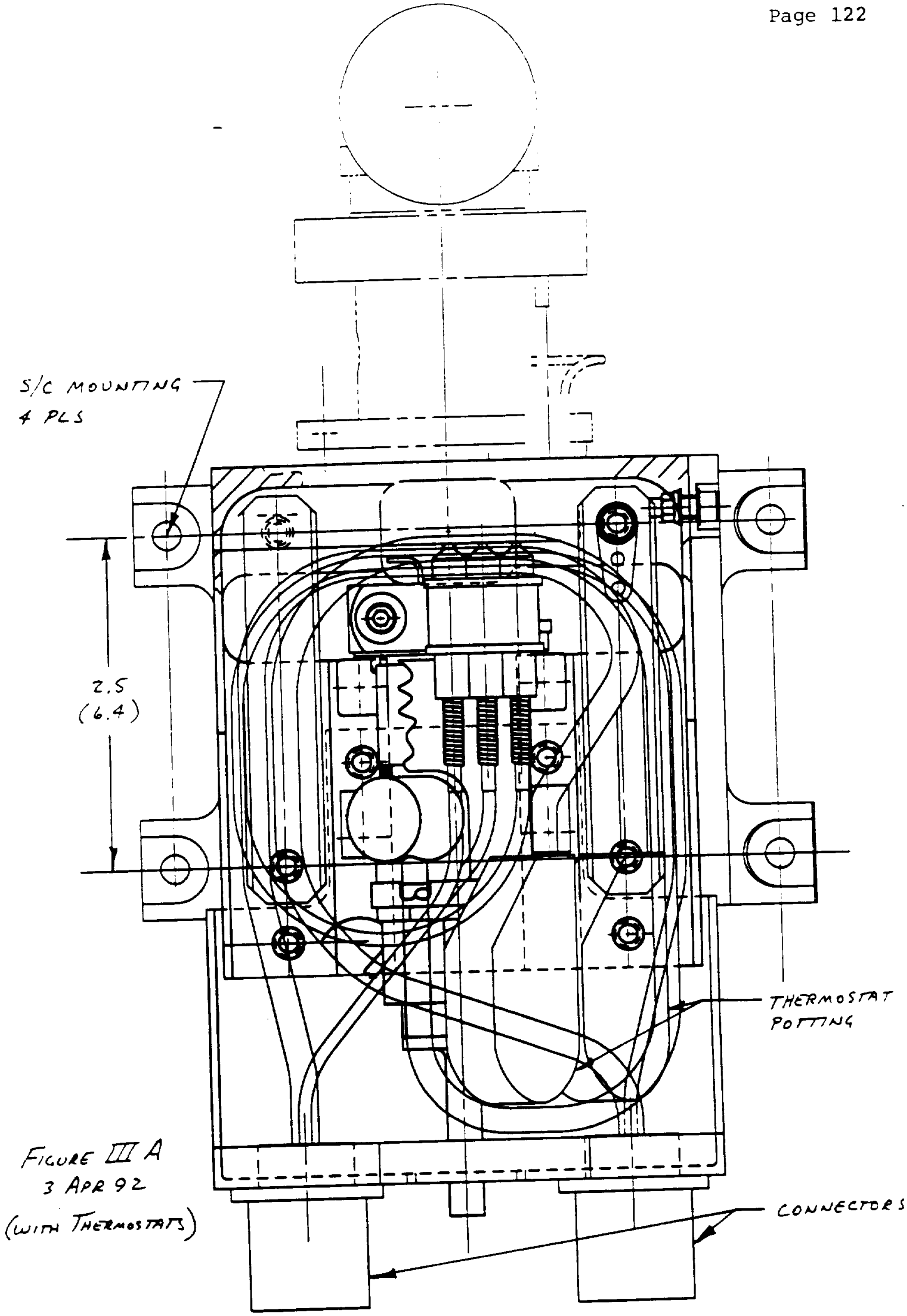


Figure 9-1a REM With Connectors

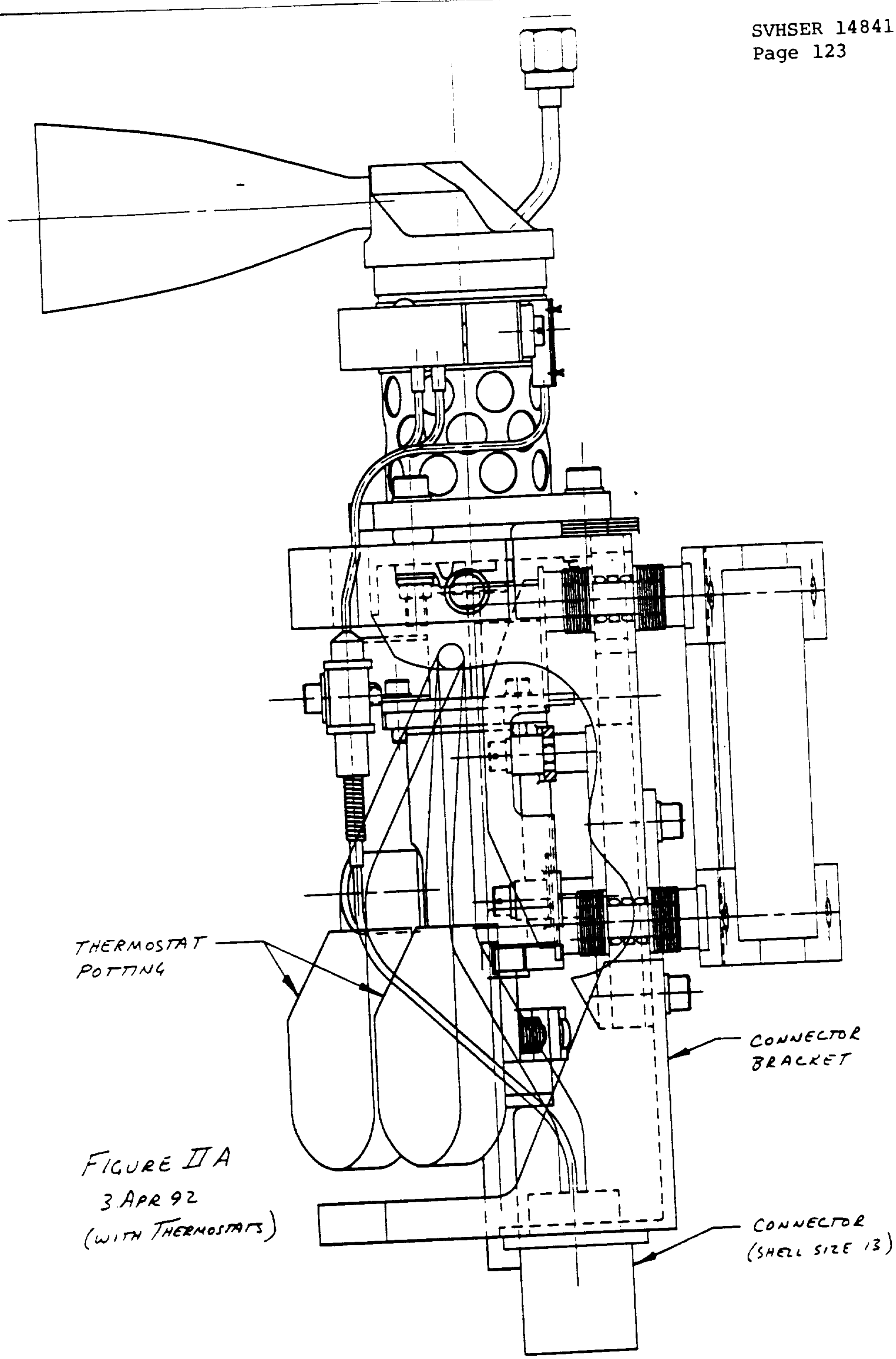


Figure 9-1b REM With Connectors

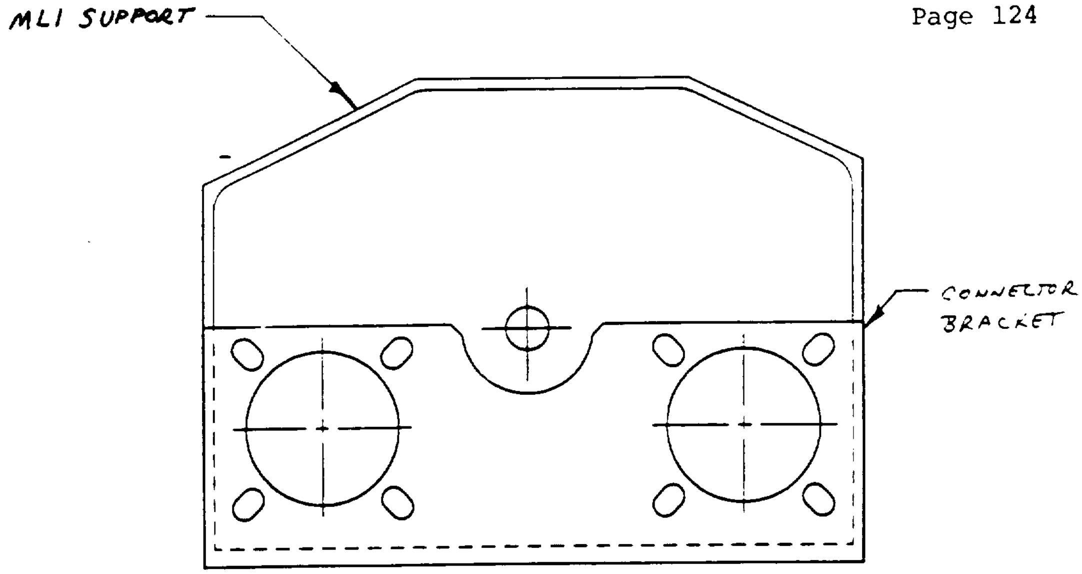


FIGURE V
3 APR 92

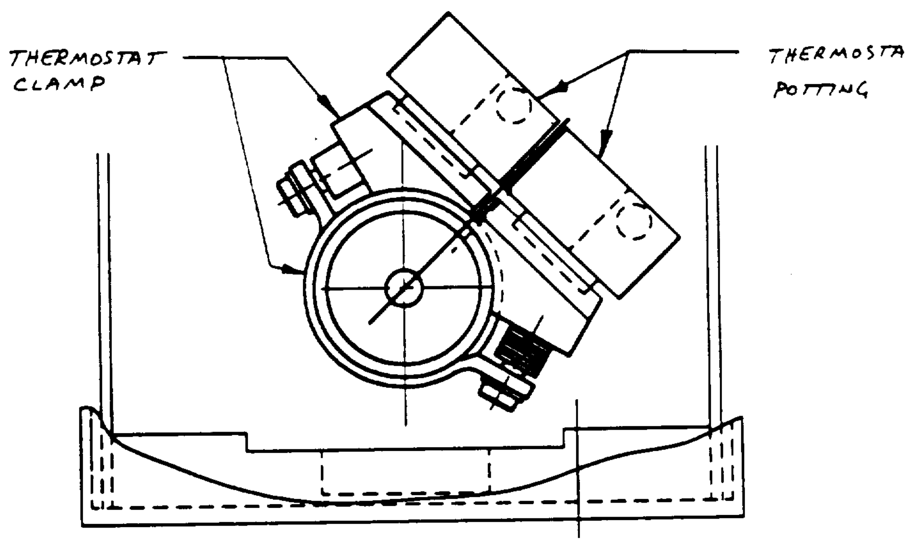


FIGURE IV A
3 APR 92
(WITH THERMOSTATS)

Figure 9-1c REM With Connectors

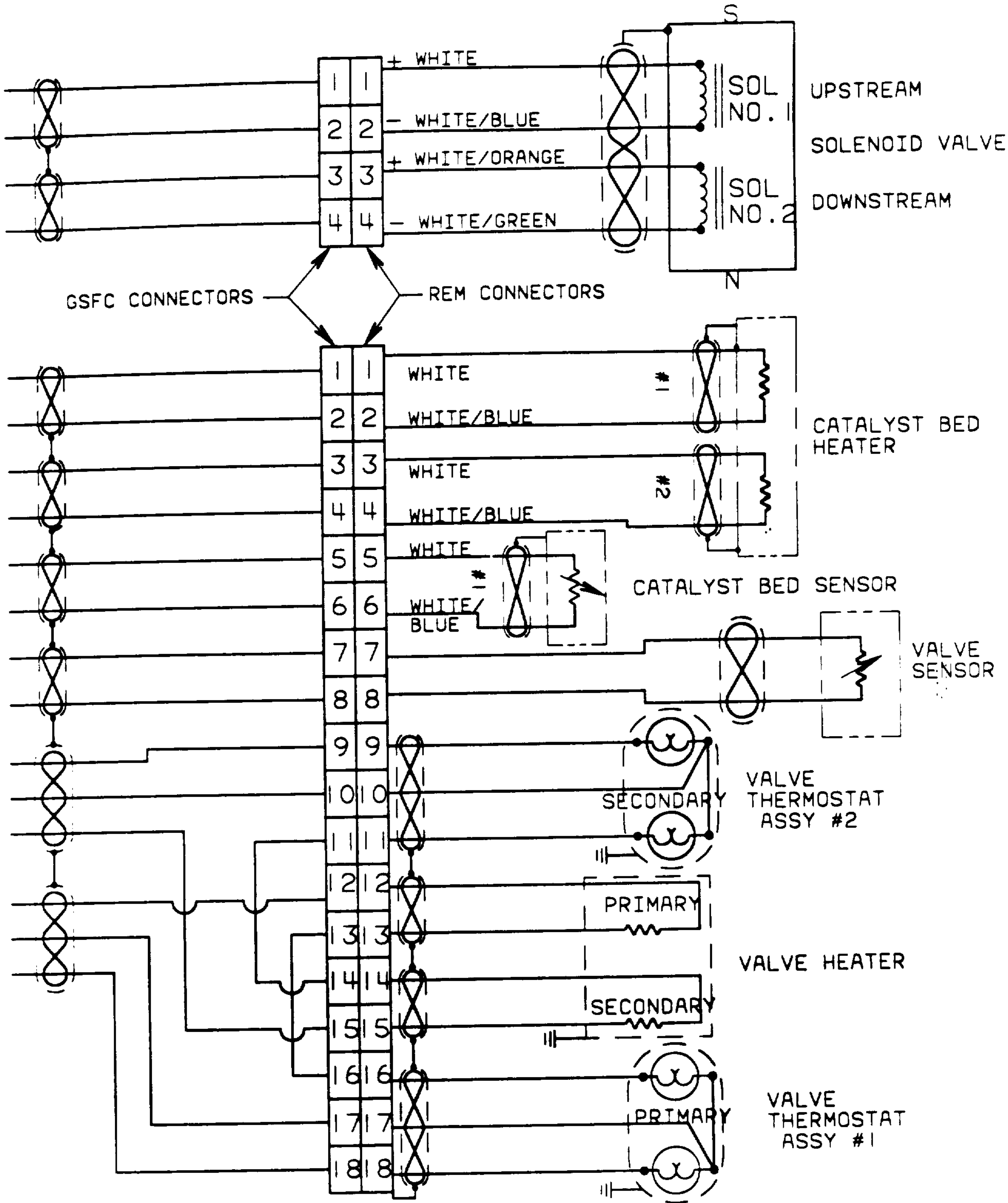


Figure 9-2 Electrical Schematic For REM With Connectors

16 APR 92
R. BARNETT

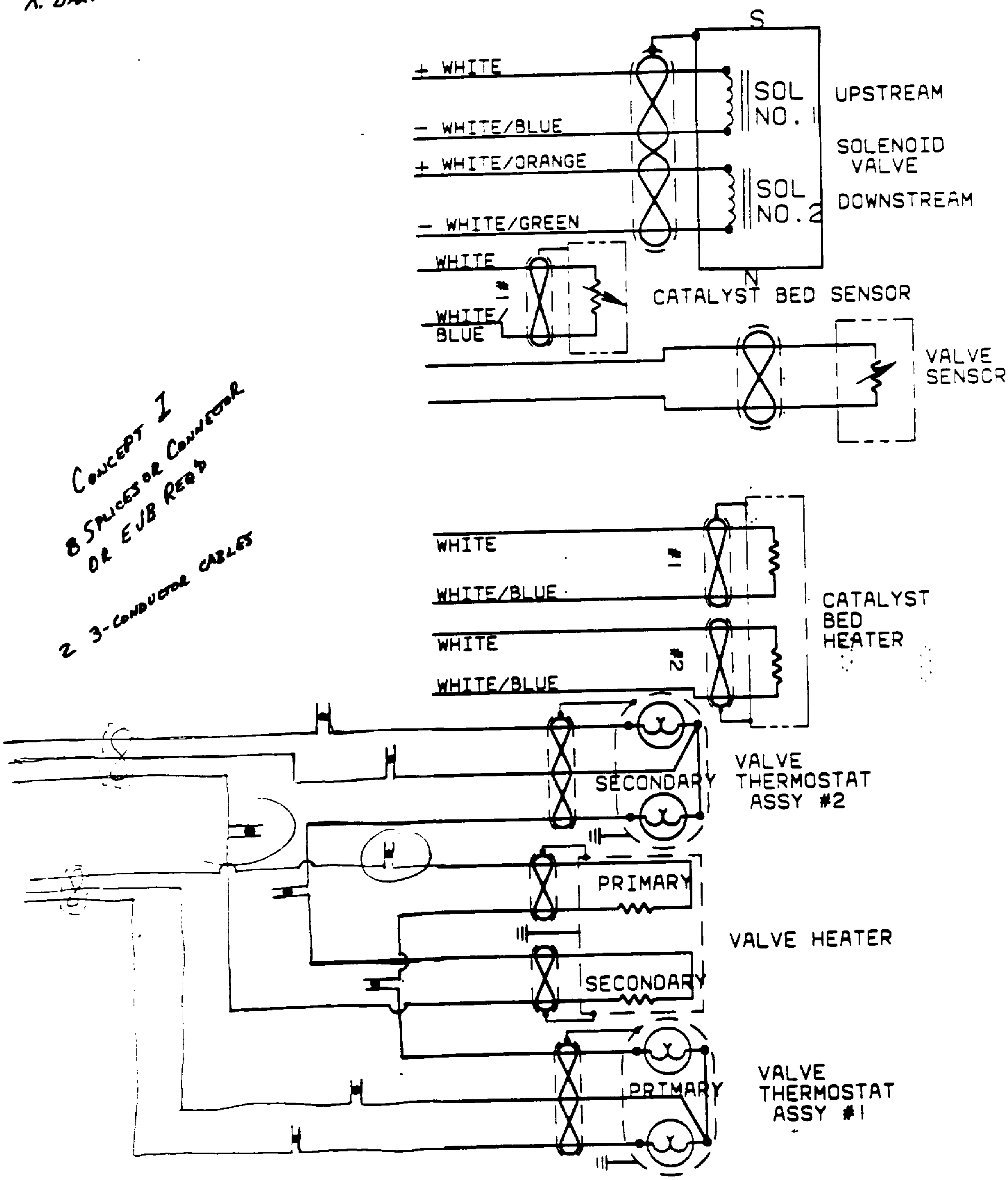
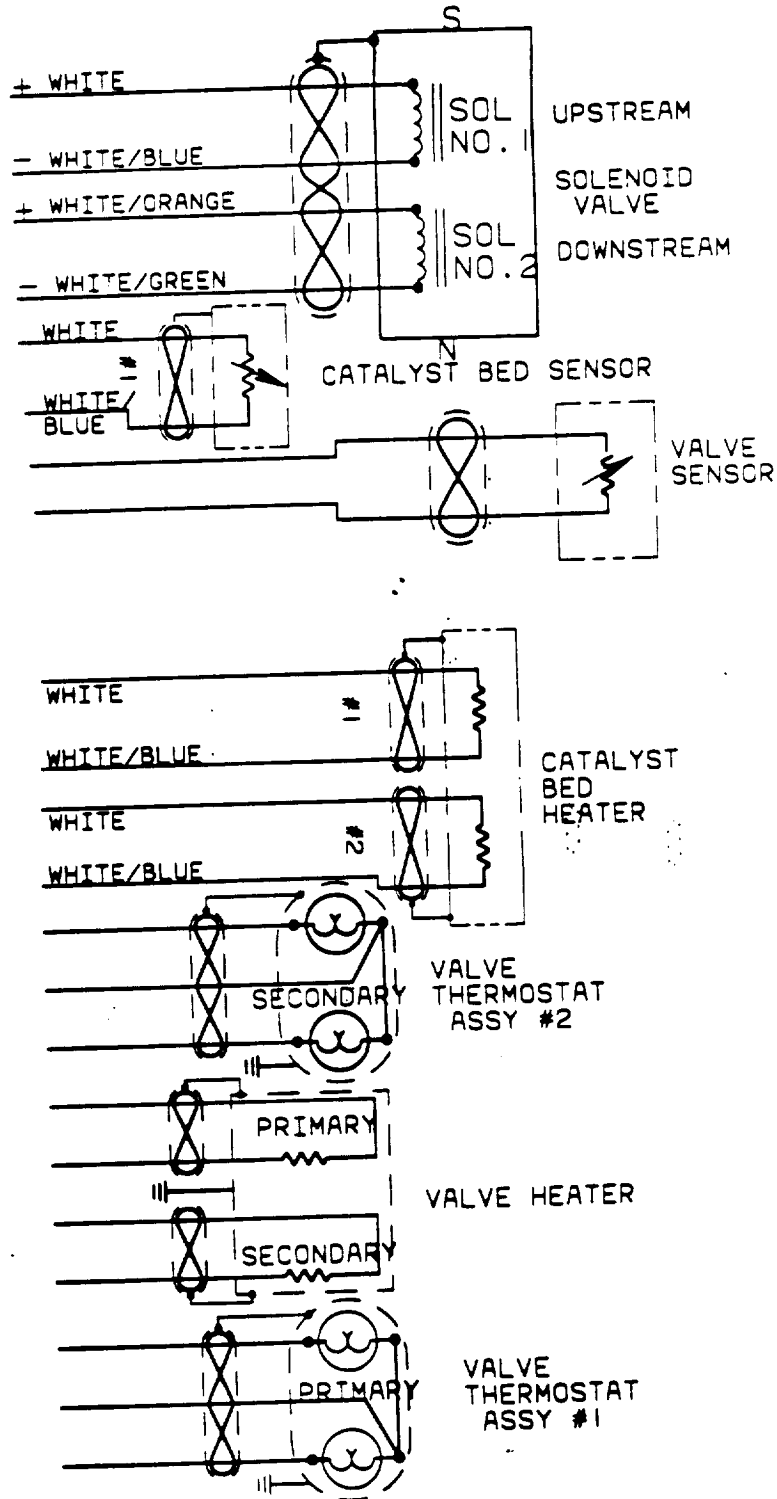


Figure 9-3 Splice Configuration

16 Apr 92
R. Barnett



Concept II
Circuit Connections
Made by GSFC

2 3-Conductor Cables
+ 2 2-Conductor Cables

Figure 9-4 Non-integrated Configuration

22 APR 92
R BARNETT

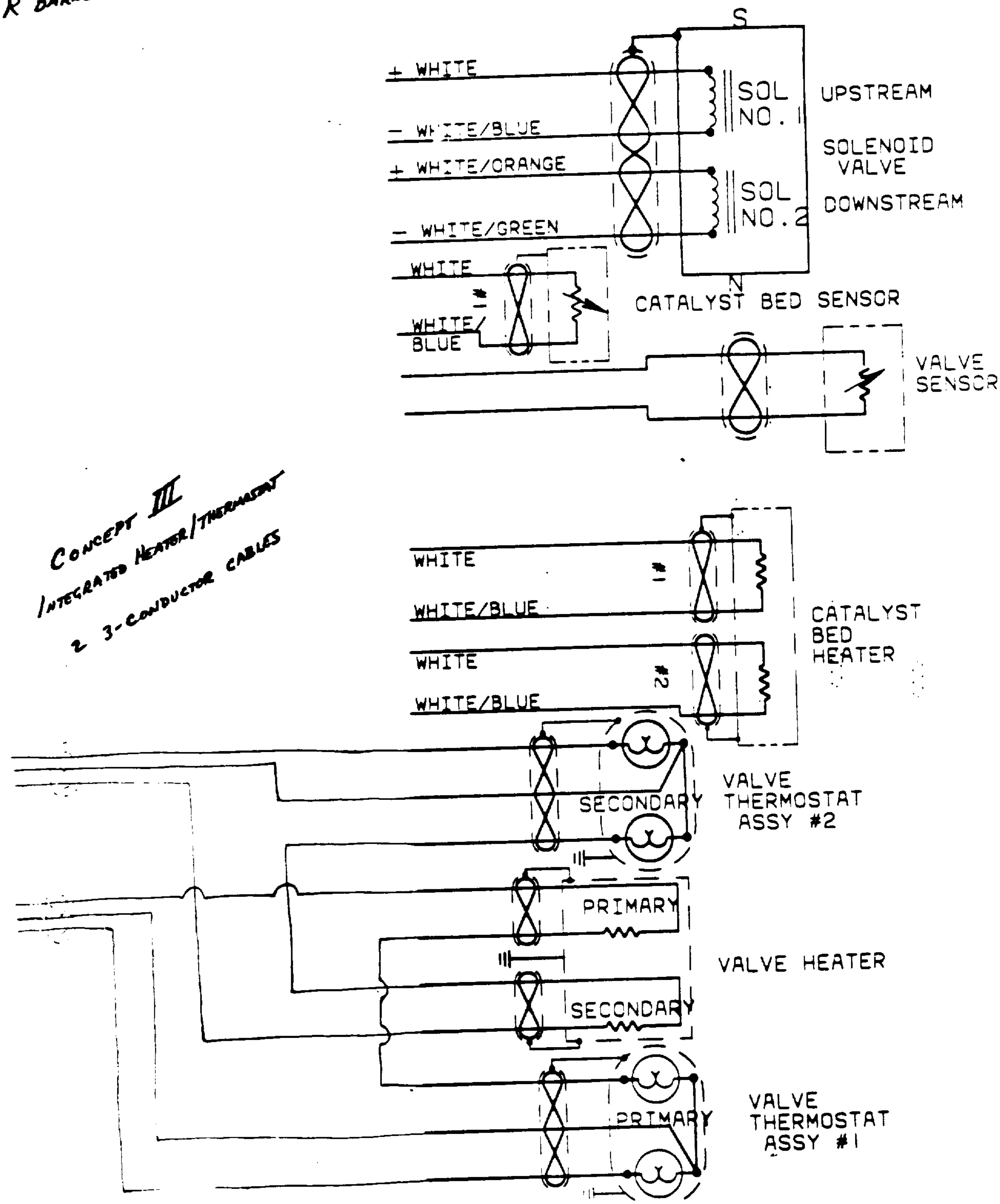
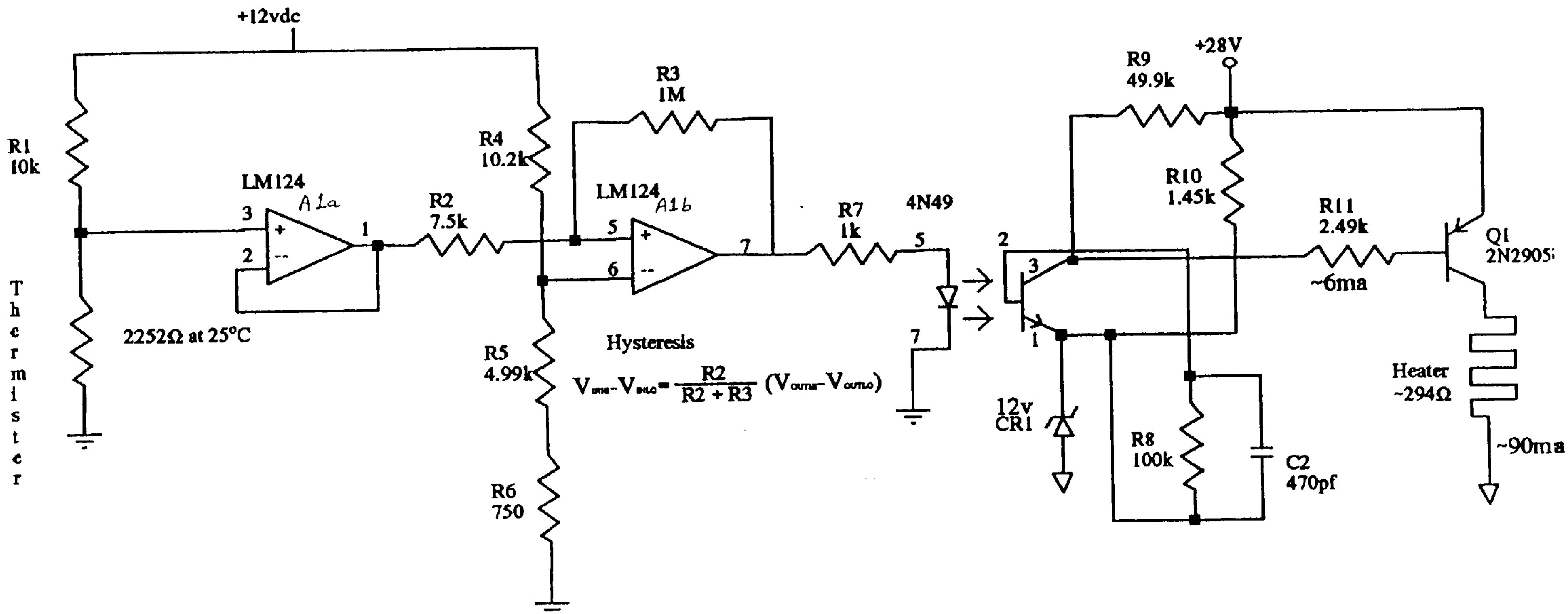


Figure 9-5 Monolithic Configuration



Turn on at 40.5°F
Turn off at 41.5°F

F temp	VDC pin 3 calc	actual
40.5	4.405	4.418
41.5	4.328	4.334

see attached plot

current drain on 12VDC
heater off 2.16ma
heater on 11.16ma

Temp °C	°F	Res Ω
4	39.2	6011
4.44	40	5881
4.72	40.5	5800
5	41	5719
5.28	41.5	5642
5.56	42	5566
6	42.8	5444

FIGURE 9-6 HS SOLID STATE THERMOSTAT SCHEMATIC

TRMM Breadboard Heater Controller

Temperature Degrees F.	Resistance ohms	Thermistor Voltage
39.2	6011	4.505
40	5881	4.444
40.5	5800	4.405
41	5719	4.366
41.5	5642	4.328
42	5566	4.291
42.8	5444	4.230

FIGURE 9-7 HS SST VOLTAGE V. TEMPERATURE

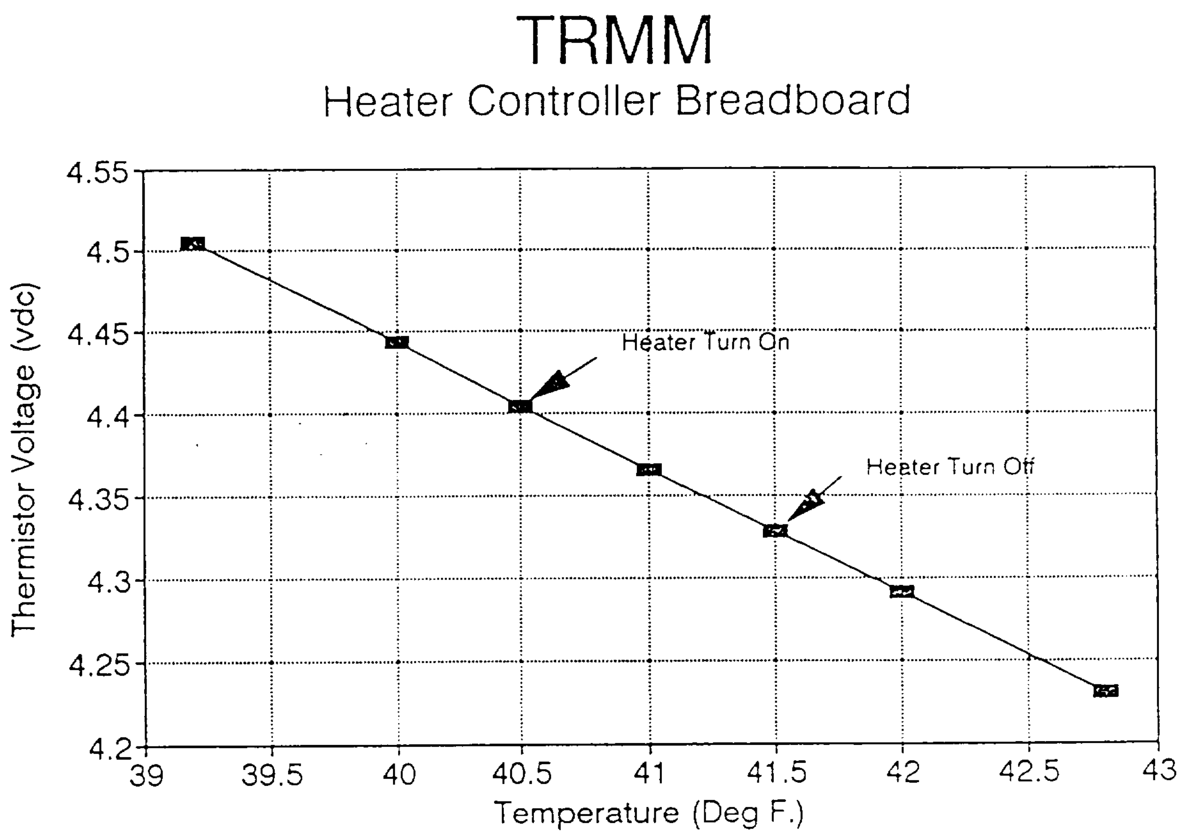


FIGURE 9-8 HS SST TEMPERATURE CONTROL BAND

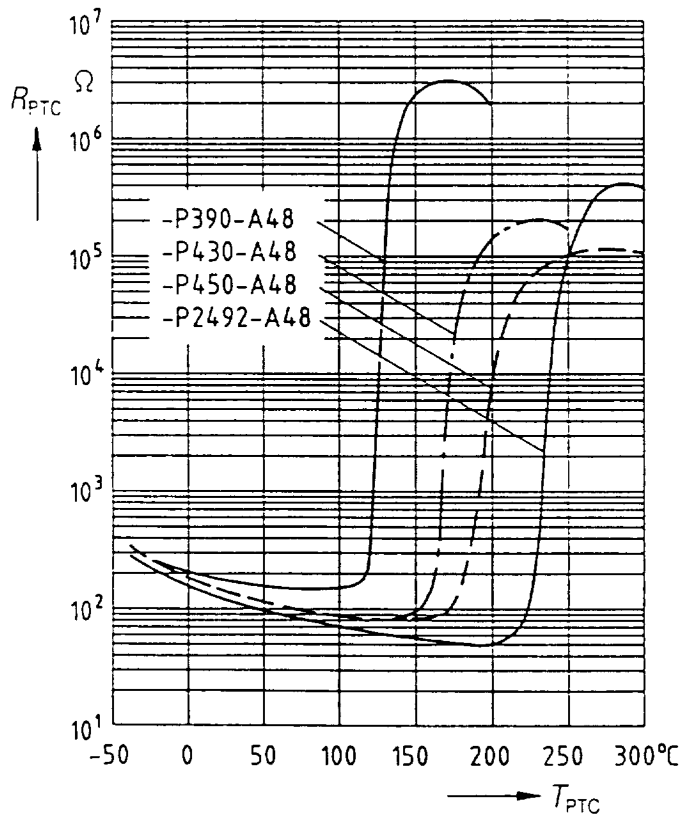


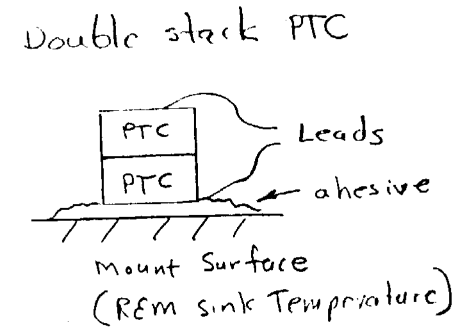
FIGURE 9-9
Seimans PTC Resistance v. Temperature Curve

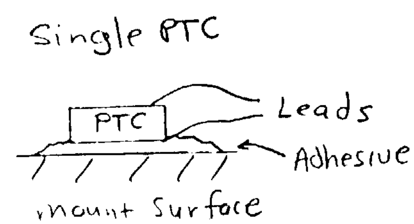
PTC Heater Calculations
Date: 5-2-92, R. Emerick, File: PTCCALC

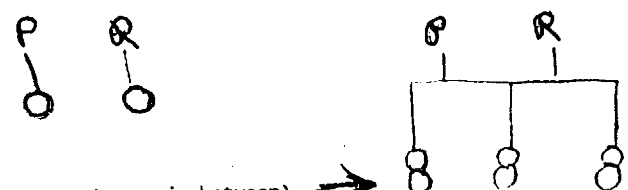
Flight Configuration

SEIMENS P390-A48: Note: R=175 until switch at 120 deg C

				Single	Single	Single	Single	Double*	Double*	Double*	Double*
	Constants:										
1	Wire:Kcu	BTU-in hr-in^2-F		16.700	16.700	16.700	16.700	16.700	16.700	16.700	16.700
2	Adh. K	BTU-in hr-in^2-F		0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
2.1	Insul K	"		0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069
3	Wire L	in		5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
4	Wire Dia	in		0.010	0.010	0.010	0.010	0.020	0.010	0.010	0.010
5	Adhesive	" thick		0.010	0.010	0.010	0.010	0.022	0.022	0.022	0.022
5.1	Insul	" thick		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	T sink	*F		41.000	61.000	71.000	81.000	41.000	61.000	71.000	81.000
7	T PTC	*F		248.000	248.500	248.700	249.000	248.000	249.000	249.100	249.400
8	T PTC	*C	swtch@120	120.000	120.278	120.389	120.556	120.000	120.556	120.611	120.778
9	R PTC	ohms	175.00	175	193	201	214	350	427	436	463
10	Volts	vdc		21.000	21.000	21.000	21.000	21.000	21.000	21.000	21.000
11	PTC Dia.	in		0.138	0.138	0.138	0.138	0.138	0.138	0.138	0.138
	Conduction Out										
12	Wire	watts	2xKAdT/L	0.032	0.029	0.027	0.026	0.127	0.029	0.027	0.026
13	Adhesive	watts	dT/+L/KA	2.541	2.302	2.181	2.062	1.129	1.026	0.972	0.919
14	Total	watts		2.573	2.330	2.209	2.088	1.257	1.055	0.999	0.945
15	Power in	watts	PTC V^2/R	2.520	2.281	2.192	2.064	1.260	1.032	1.012	0.953







*Note: double stack requires 2 insul. layers (w/conductor in between)

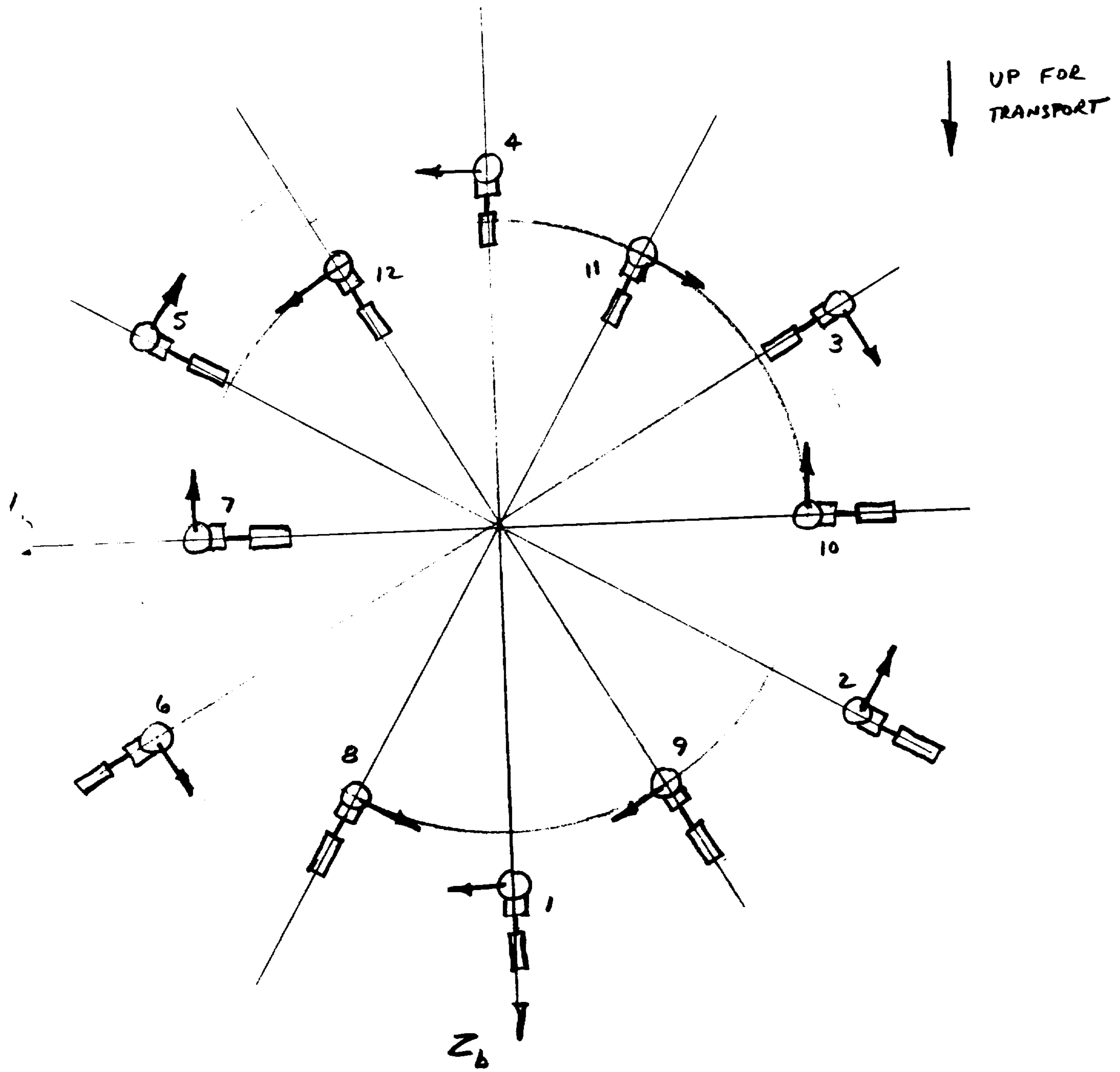
P: Primary Power
R = Redundant Power

FIGURE 9-10
PTC HEATER CALCULATIONS

TRMM THRUSTER ARRANGEMENT

6 + 6

RADIAL ALIGNMENT



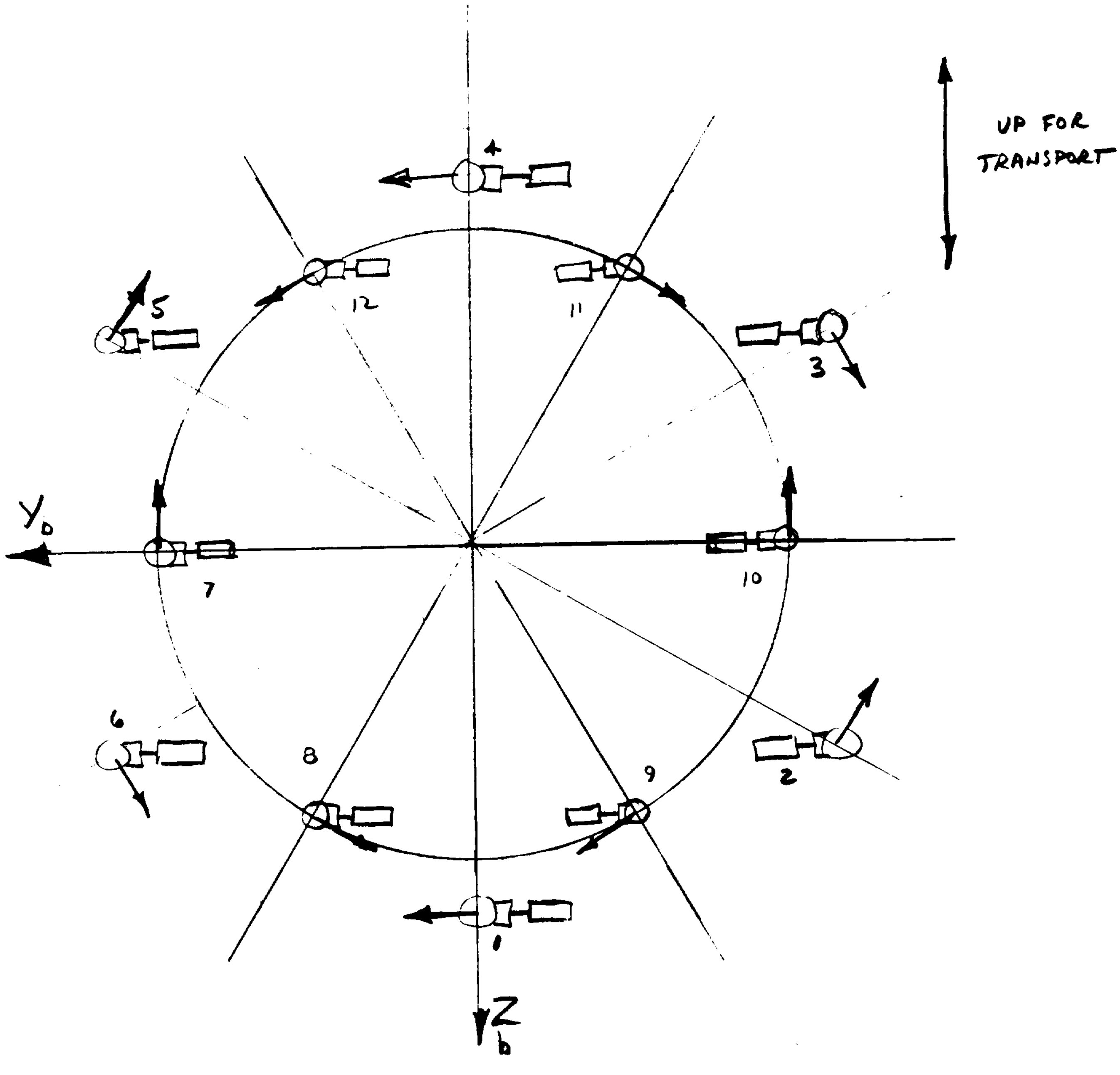
VIEW LOOKING AFT

FIGURE 9-11 REM RADIAL INTEGRATION ARRANGMENT

3 FEB 92
R. BARNETT
SVHSER 14841
Page 135

TRMM THRUSTER ARRANGEMENT
6+6

PARALLEL ALIGNMENT



VIEW LOOKING AFT

FIGURE 9-12 REM PARALLEL INTEGRATION ARRANGMENT

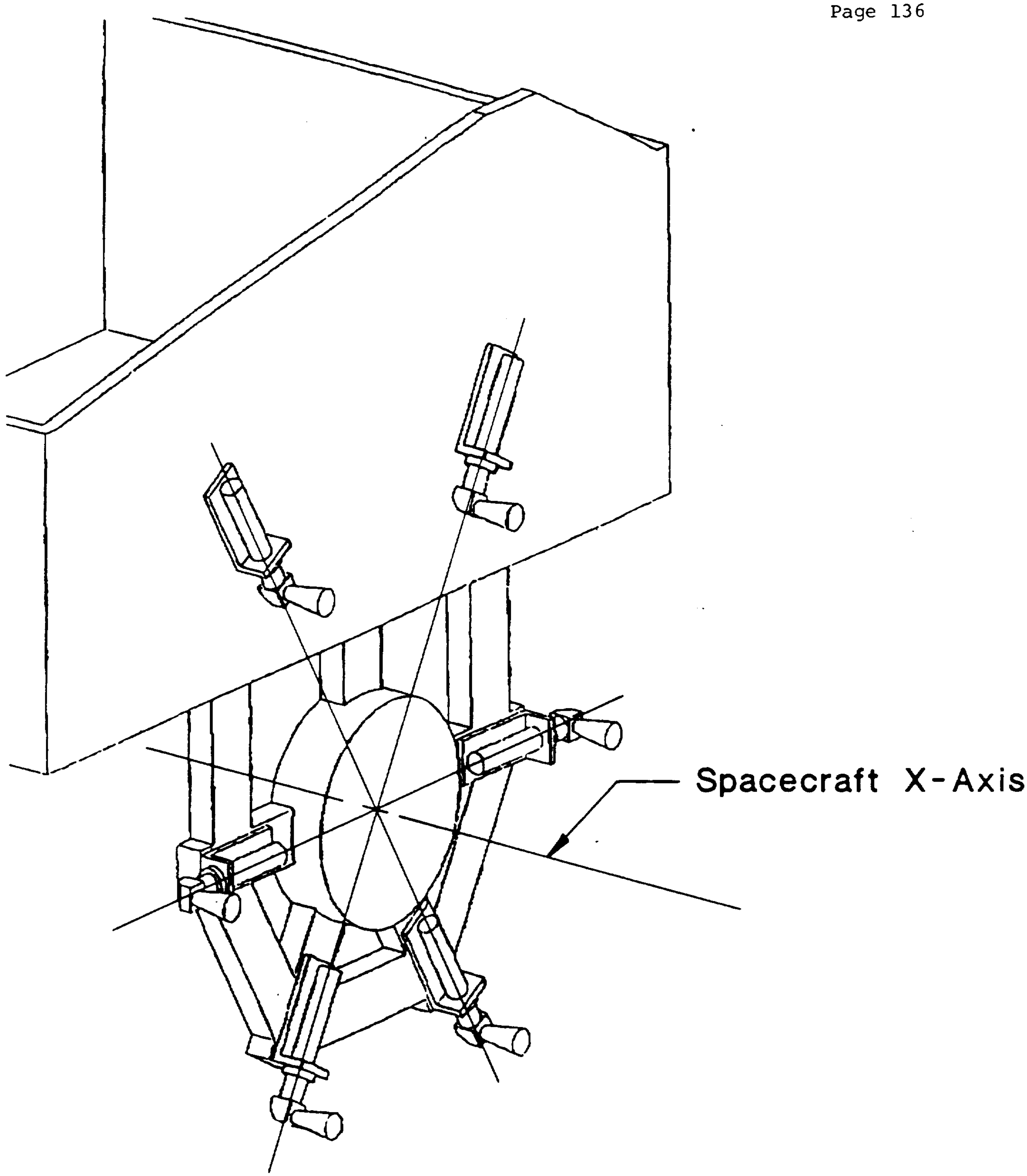


FIGURE 11-1a

THRUST VECTOR ORIENTATION

THRUST VECTOR ORIENTATION

Table 2-2
Spacecraft Thruster Location and Orientation Data

Thruster	Location Coordinates X (m)	Y (m)	Z(m)	Force Vector Direction Cosines X	Y	Z
1	.425	0.000	1.085	.984808	.173648	0.000000
2	.425	-1.096	.633	.984808	-.086824	-.150375
3	.425	-1.096	-.633	.984808	-.086824	.150375
4	.425	0.000	-1.085	.954808	173648	0.000000
5	.425	1.096	-.633	.984808	-.086824	-.150375
6	.425	1.096	.633	.984808	-.086824	+.150375
7	4.462	.400	0.000	-.996195	0.000000	-.057156
8	4.462	.200	.346	-.996195	-.075479	.043578
9	4.462	-.200	.346	-.996195	.075479	.043578
10	4.462	-.400	0.000	-.996195	0.000000	-.087156
11	4.462	-.200	-.346	-.996195	-.075479	.043578
12	4.462	.200	-.346	-.996195	.075479	.043578

CORRECTED AS SHOWN

- Radial TCA orientation (TCA CL's pass through spacecraft X-Axis)
- Rotate TCA about its CL
  Fwd: +/- five degrees
  Aft: +/- ten degrees
- Direction cosines verified

Axis Up For Transport	Thruster Configurations Req'd				Alternate Configurations				Alt II			
	A	B	C	D	A	B	C	D	A	B	C	D
−Z	4	2	4	2	2	4	4	2	3	3	4	2
+Z	4	2	2	4	2	4	2	4	3	3	2	4
−Y	2	4	4	2	2	4	2	4	2	4	3	3
+Y	4	2	4	2	4	2	2	4	4	2	3	3

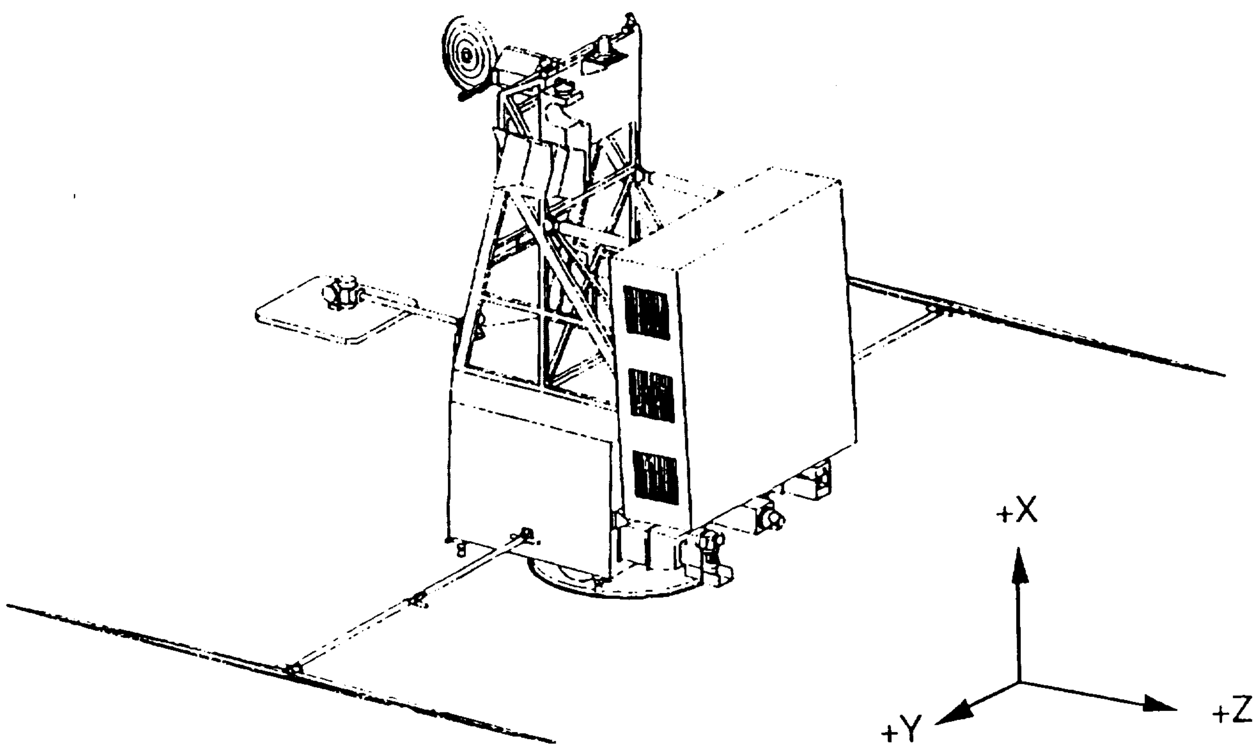
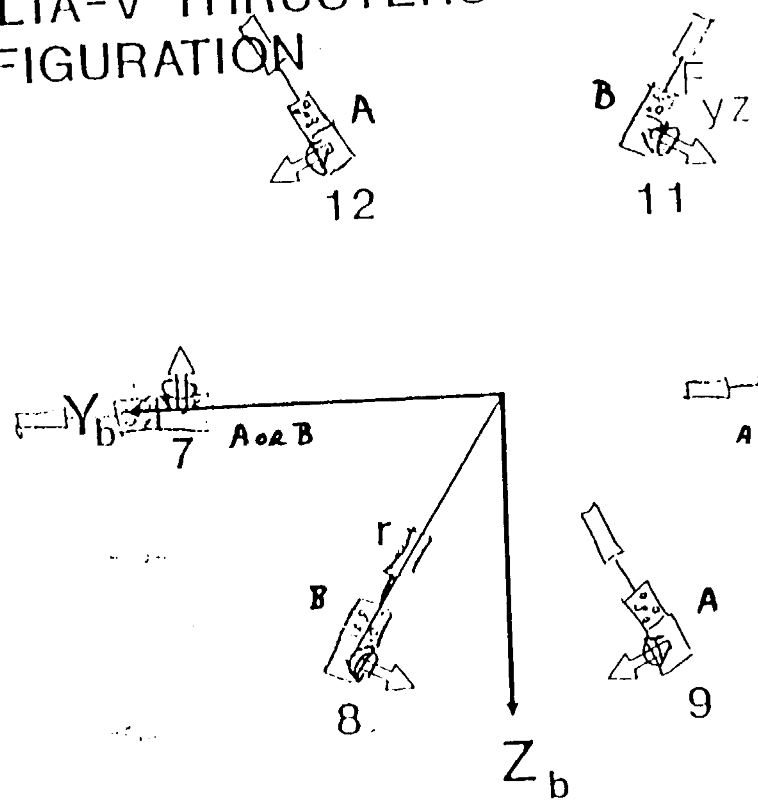


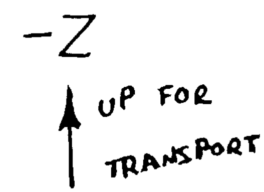
Figure 11-2a RCS/REM Physical Integration

TRMM Reaction Control Subsystem

Preliminary Design Audit

CANT ANGLES
FRONT DELTA-V THRUSTERS
6 + 6 CONFIGURATION





$r = 0.4$ m

$F_{yz} = |F| \sin 5^{o}$

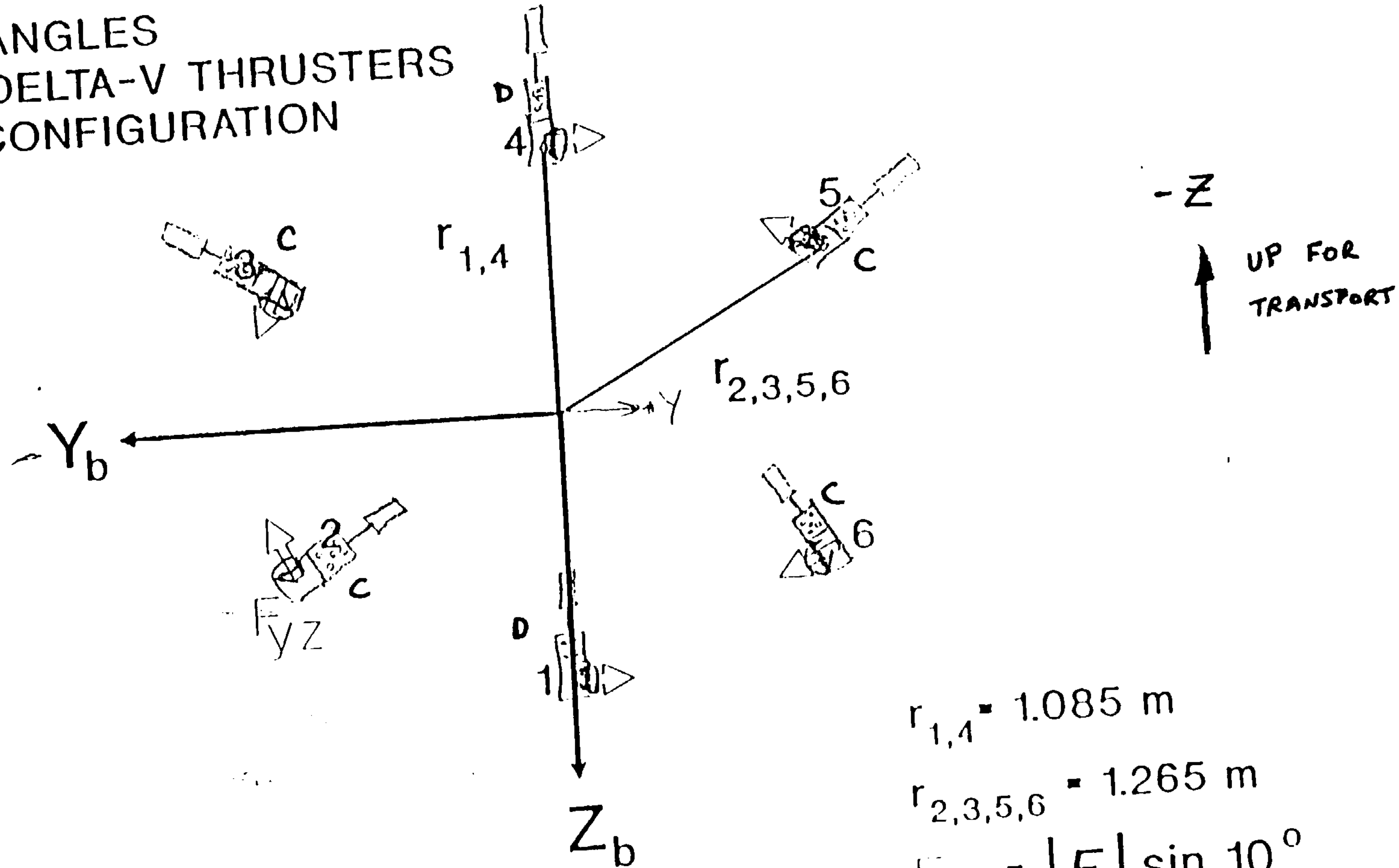
F = thruster thrust vector

1/29/92 jsg

Figure 11-2b RCS/REM Physical Integration

TRMM Reaction Control Subsystem
Preliminary Design Audit

CANT ANGLES
REAR DELTA-V THRUSTERS
6 + 6 CONFIGURATION



$r_{1,4} = 1.085$ m

$r_{2,3,5,6} = 1.265$ m

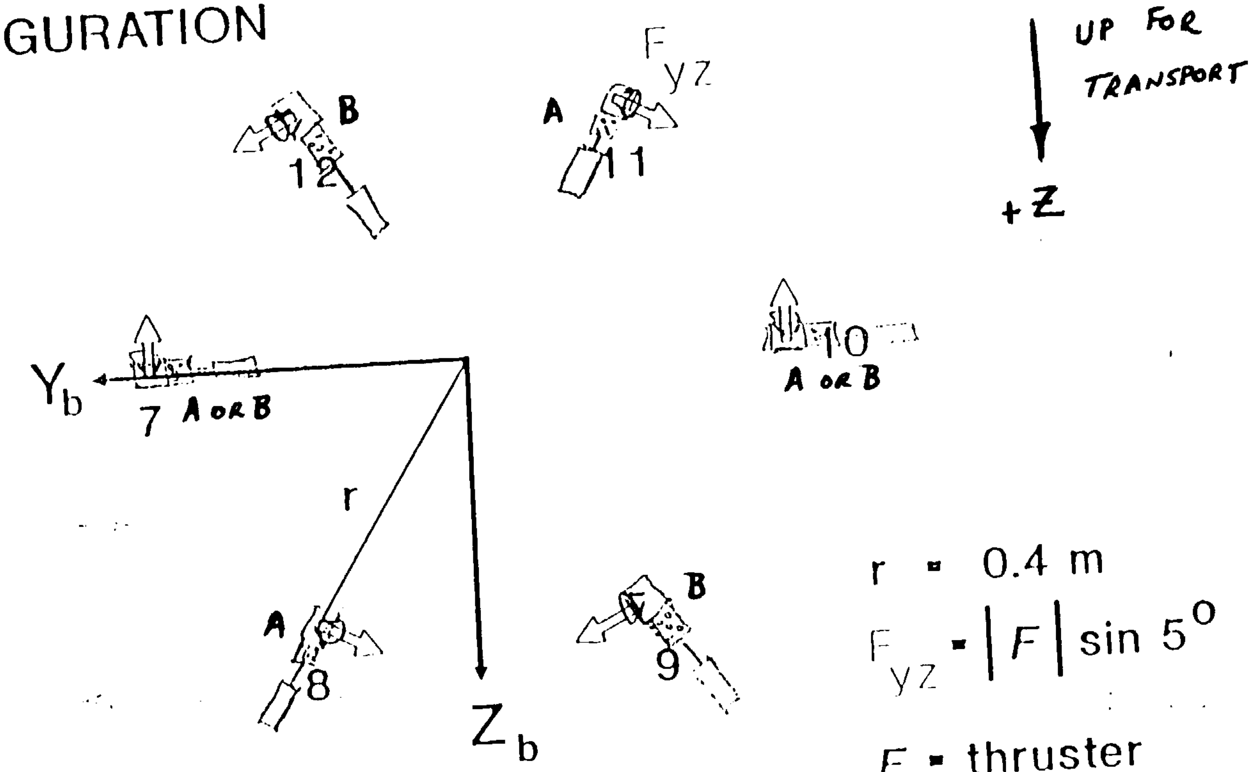
$F_{YZ} = |F| \sin 10^\circ$

1/29/92 jsg

Figure 11-2c RCS/REM Physical Integration

TRMM Reaction Control Subsystem
Preliminary Design Audit

CANT ANGLES
FRONT DELTA-V THRUSTERS
6 + 6 CONFIGURATION



$r = 0.4$ m

$F_{yz} = |F| \sin 5^{o}$

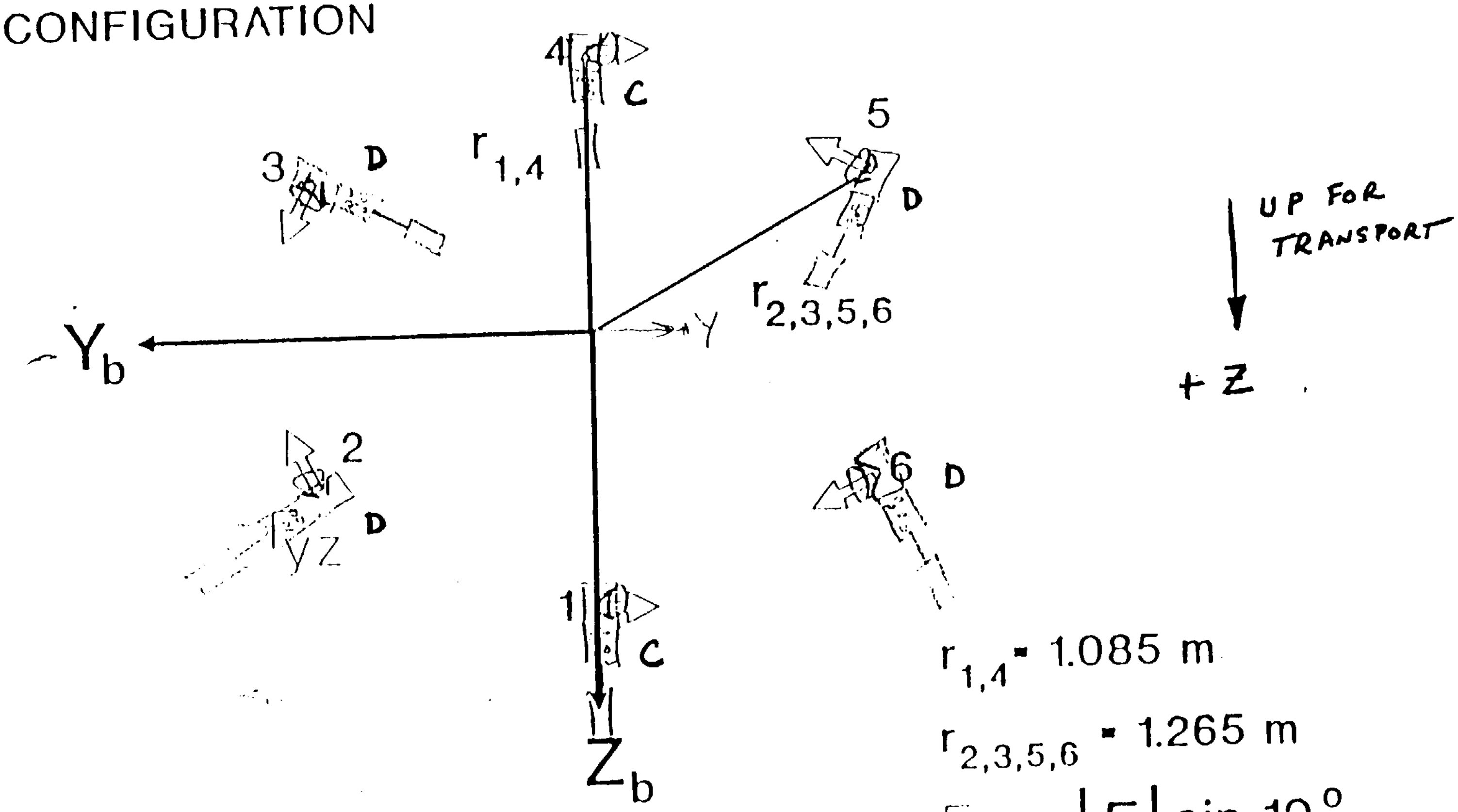
F = thruster thrust vector

1/29/92 jsg

Figure 11-2d RCS/REM Physical Integration

TRMM Reaction Control Subsystem
Preliminary Design Audit

CANT ANGLES
REAR DELTA-V THRUSTERS
6 + 6 CONFIGURATION



$r_{1,4} = 1.085$ m

$r_{2,3,5,6} = 1.265$ m

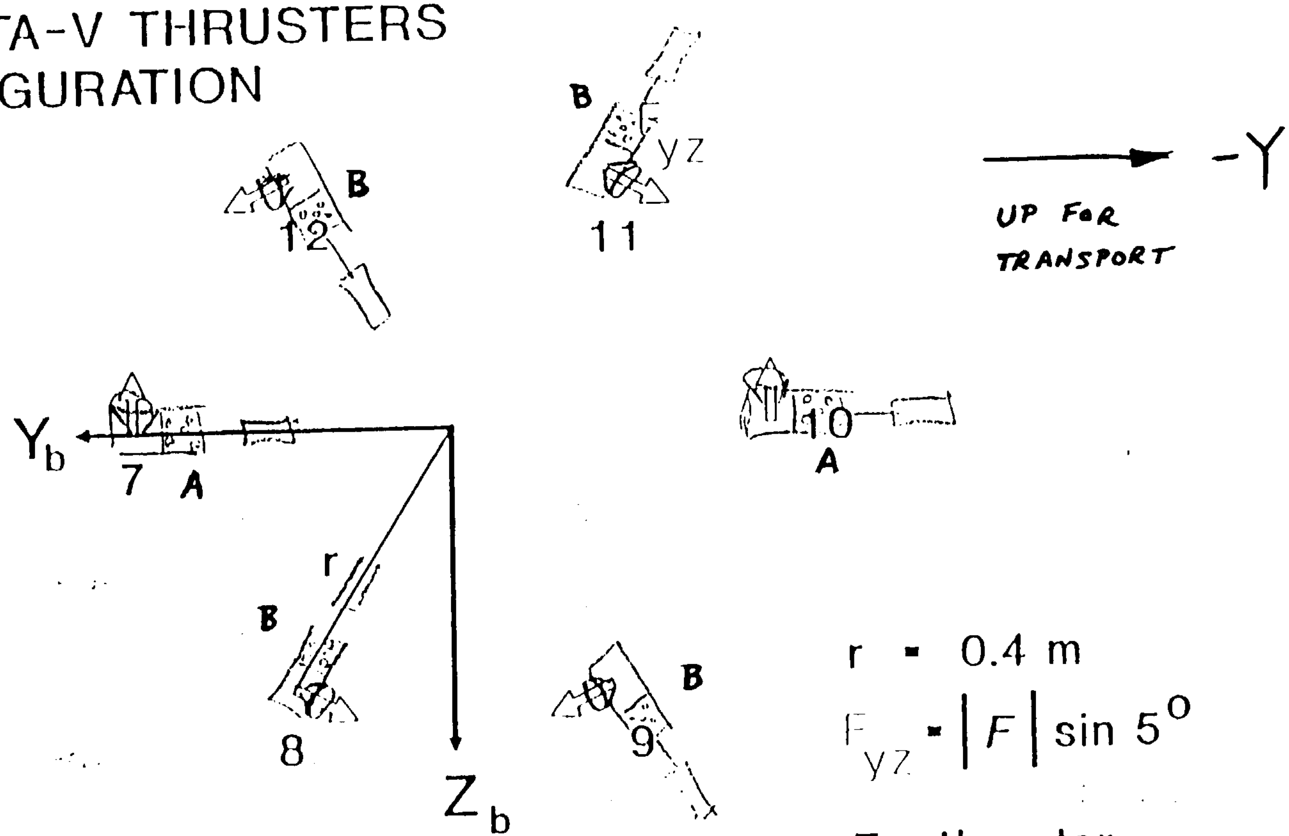
$F_{YZ} = |F| \sin 10^{\circ}$

1/29/92 jsg

Figure 11-2e RCS/REM Physical Integration

TRMM Reaction Control Subsystem
Preliminary Design Audit

CANT ANGLES
FRONT DELTA-V THRUSTERS
6 + 6 CONFIGURATION



r = 0.4 m

$F_{yz} = |F| \sin 5^{\circ}$

F = thruster thrust vector

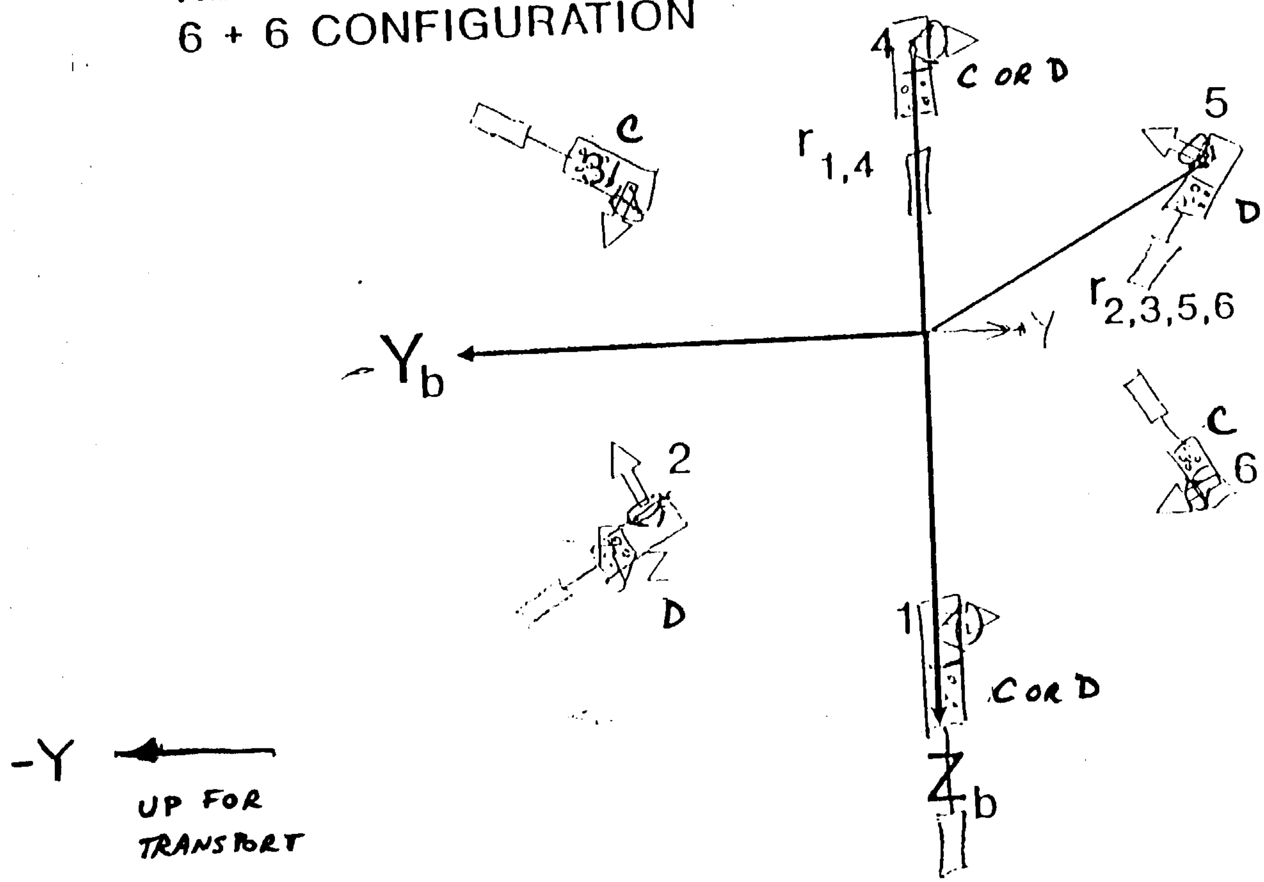
1/29/92 jsg

Figure 11-2f RCS/REM Physical Integration

TRMM Reaction Control Subsystem

Preliminary Design Audit

CANT ANGLES
REAR DELTA-V THRUSTERS
6 + 6 CONFIGURATION



$r_{1,4} = 1.085$ m

$r_{2,3,5,6} = 1.265$ m

$F_{YZ} = |F| \sin 10^{\circ}$

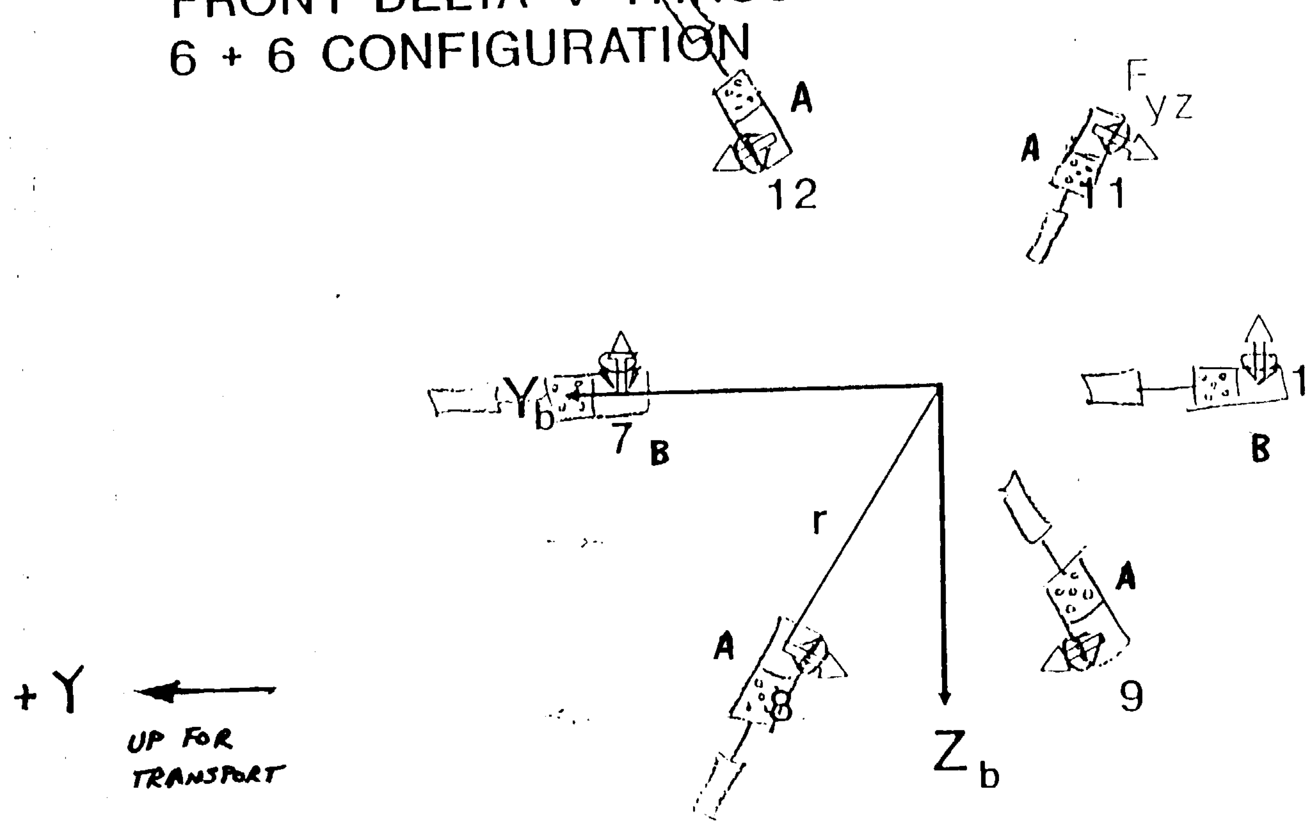
1/29/92 jsg

Figure 11-2g RCS/REM Physical Integration

TRMM Reaction Control Subsystem

Preliminary Design Audit

CANT ANGLES
FRONT DELTA-V THRUSTERS
6 + 6 CONFIGURATION



$r = 0.4$ m

$F_{yz} = |F| \sin 5^o$

F = thruster thrust vector

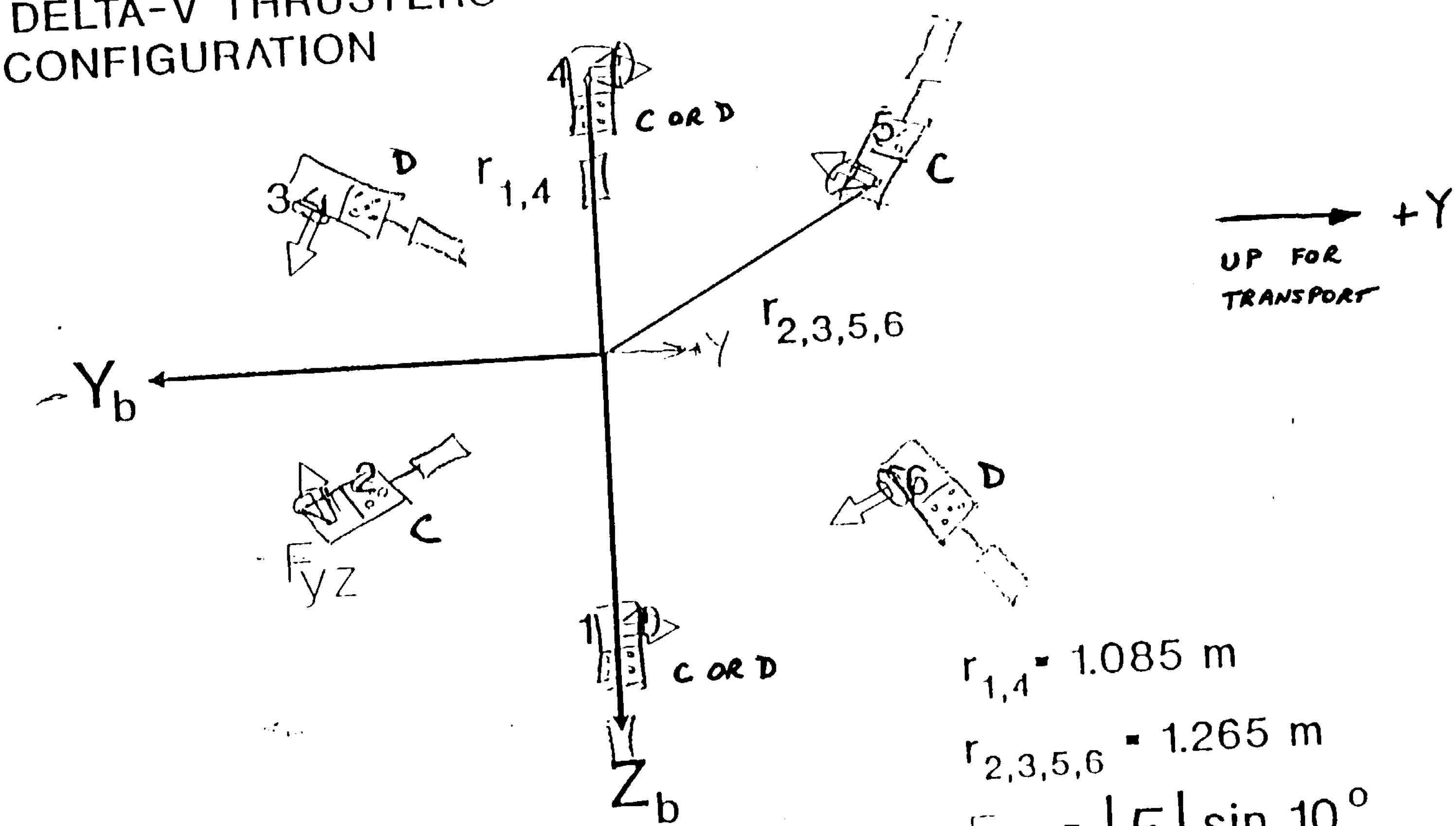
1/29/92 jsg

Figure 11-2h RCS/REM Physical Integration

TRMM Reaction Control Subsystem

Preliminary Design Audit

CANT ANGLES
REAR DELTA-V THRUSTERS
6 + 6 CONFIGURATION



$r_{1,4}$ = 1.085 m

$r_{2,3,5,6}$ = 1.265 m

$F_{YZ} = |F| \sin 10^\circ$

1/29/92 jsg

Figure 11-2i RCS/REM Physical Integration

TABLE 7-I. REA FIRING PERFORMANCE SUMMARY

Parameter	Requirement	Demonstrated
Inlet Pressure	2.4 MPa (348 psia) to 0.621 MPa (90 psia)	2.41 MPa (350 psia) to 0.517 MPa (75 psia)
BOL Thrust	15.6 N (3.51 lb_f) min @ 1.309 MPa (190 psia)	15.6 N (3.51 lb_f) min @ 1.309 MPa (190 psia)
EOL Thrust	11.7 N (2.63 lb_f) min @ 0.899 MPa (130 psia)	11.7 N (2.63 lb_f) min @ 0.899 MPa (130 psia)
Thrust Repeatability (Module-to-Module)	± 5% max	± 4.74%
Steady State Specific Impulse	228.0 sec min @ 1.9 MPa (276 psia) 222.2 sec min @ 0.52 MPa (75 psia)	228.3 sec min @ 1.93 MPa (280 psia) 222.5 sec min @ 0.52 MPa (75 psia)
Pulsing Specific Impulse	Reference Figure 7-3	Reference Figure 7-3
Equilibrium Impulse Bit	2.82 N-sec (0.634 lb_f-sec) to 1.11 N-sec (0.25 lb_f-sec) @ 0.125 sec on / 2 sec off	2.82 N-sec (0.634 lb_f-sec) to 1.25 N-sec (0.281 lb_f-sec) @ 0.125 sec on / 2 sec off
MIB Repeatability	± 10% max @ 0.125 sec on	± 8.13% @ 0.125 sec on
Off-Impulse Bit	TBD	Reference Figure 7-6
Pulse Width	0.125 sec to 2710 sec	0.050 sec to 7200 sec
Total Pulses	32,200	117,984
Fuel Throughput	154 kg (340 lb_m)	237 kg (522 lb_m)
Total Impulse	332,000 N-sec (74,634 lb_f-sec)	511,339 N-sec (114,949 lb_f-sec)

TABLE 7-II
COBE REA 39-5 FIRING TEST DATA

FOR TESTING AT PI=280

		STEADY STATE					PULSING (.05/1.95/200 and Tbed>200)			PULSING (.1/1.90/200 and Tbed>200)		
QUAD	REA	PI	F	Fn	ISP	RIPPLE	IBIT	T50rise	T20decay	IBIT	T50rise	T20decay
A1	26	280.92	4.8670	4.855	230.48	1.85	0.256	0.044	0.069	0.498	0.037	0.052
A2	25	276.63	4.7913	4.833	229.70	1.96	0.250	0.047	0.070	0.489	0.044	0.063
A4	19	281.34	4.7979	4.781	231.00	1.75	0.241	0.038	0.044	0.477	0.035	0.043
A3	22	276.83	4.9614	5.001	231.70	1.72	0.254	0.035	0.043	0.500	0.032	0.040
B3	23	279.73	4.8150	4.818	231.70	2.09	0.240	0.042	0.061	0.482	0.030	0.038
B4	20	278.98	4.9074	4.920	231.00	1.89	0.255	0.039	0.049	0.496	0.034	0.042
B1	27	279.23	4.7623	4.792	230.10	1.94	0.251	0.039	0.050	0.495	0.035	0.049
B2	28	278.83	4.6994	4.714	229.70	1.98	0.245	0.035	0.040	0.479	0.033	0.041
C4	21	277.08	4.8751	4.911	232.60	1.57	0.253	0.036	0.042	0.499	0.032	0.043
C3	24	275.98	4.9477	4.977	232.36	1.92	0.262	0.038	0.043	0.510	0.033	0.043
C2	29	277.87	4.7982	4.825	230.90	2.09	0.252	0.041	0.055	0.489	0.040	0.051
C1	30	279.57	4.8244	4.830	230.60	1.83	0.247	0.035	0.043	0.487	0.032	0.042
SPARE	32	277.29	4.8084	4.842	230.80	1.28	0.253	0.040	0.059	0.494	0.028	0.037
Average				4.854	230.97	1.84	0.251	0.039	0.051	0.492	0.034	0.045
Min Value				4.714	229.70	1.28	0.240	0.035	0.040	0.477	0.028	0.037
Max Value				5.001	232.60	2.09	0.262	0.047	0.070	0.510	0.044	0.063
(3 sigma/Avg.)x100				4.739	1.14	34.72	7.062	27.022	58.631	5.452	35.417	45.705

FOR TESTING AT PI=75

		STEADY STATE					PULSING (.05/1.95/200 and Tbed>200)			PULSING (.1/1.90/200 and Tbed>200)		
QUAD	REA	PI	F	Fn	ISP	RIPPLE	IBIT	T50rise	T20decay	IBIT	T50rise	T20decay
A1	26	72.32	1.7690	1.816	224.90	2.65	0.118	0.052	0.127	0.216	0.052	0.109
A2	25	76.47	1.8184	1.792	223.20	2.28	0.111	0.053	0.180	0.217	0.054	0.149
A4	19	73.33	1.7618	1.791	223.90	2.09	0.109	0.050	0.100	0.200	0.047	0.077
A3	22	72.51	1.8220	1.866	224.40	2.17	0.115	0.049	0.087	0.207	0.044	0.071
B3	23	74.98	1.8085	1.809	224.90	2.37	0.110	0.046	0.070	0.200	0.040	0.065
B4	20	74.74	1.9466	1.851	224.80	2.26	0.114	0.049	0.102	0.209	0.046	0.078
B1	27	72.25	1.7465	1.795	224.90	2.64	0.117	0.052	0.124	0.212	0.050	0.099
B2	28	72.62	1.7304	1.772	223.20	2.42	0.114	0.050	0.096	0.201	0.045	0.073
C4	21	75.73	1.8470	1.834	224.70	2.07	0.111	0.047	0.095	0.205	0.046	0.078
C3	24	72.90	1.8061	1.843	224.30	2.64	0.114	0.050	0.099	0.210	0.048	0.084
C2	29	73.32	1.7739	1.804	224.00	2.87	0.109	0.052	0.143	0.207	0.051	0.108
C1	30	72.67	1.7646	1.806	224.10	2.46	0.108	0.049	0.100	0.201	0.047	0.082
SPARE	32	74.52	1.9064	1.815	224.90	1.45	0.114	0.047	0.072	0.203	0.039	0.063
Average				1.815	224.32	2.34	0.113	0.050	0.107	0.207	0.047	0.087
Min Value				1.772	223.20	1.45	0.108	0.046	0.070	0.200	0.039	0.063
Max Value				1.866	224.90	2.87	0.118	0.053	0.180	0.217	0.054	0.149
(3 sigma/Avg.)x100				4.260	0.79	44.27	8.130	12.616	80.427	8.131	26.801	78.049

TABLE 7-III

FIRING LIFE VERIFICATION

Parameter	Requirement	Demonstrated	Basis *
Propellant Throughput	154 kg (340 lbm)	530 lbm	COBE REA 39-5^h
		522 lbm	Mark II REA 39-3^m
		1,153 lbm	IR&D REA 39-2^m
Total Impulse	332,000 N-s (74,634 lbf-s)	116,554 lbf-s	COBE REA 39-5^h
		114,949 lbf-s	Mark II REA 39-3^m
		263,728 lbf-s	IR&D REA 39-2^m
Maximum Burn Duration	2,710 sec	12,480 sec	COBE REA 39-5^h
		7,200 sec	IR&D REA 39-2^m
Total Burn Time	25,706 sec	36,667 sec	COBE REA 39-5^h
		72,396 sec	IR&D REA 39-2^m
Total Pulses	32,200	68,389	COBE REA 39-5^h
		117,984	Mark II REA 39-3^m

*Superscript: h= hi purity hydrazine
m= monopropellant grade hydrazine

Table 8-I TRMM Preliminary Parts, Weight and Materials List

No. Req'd	Part Identification	Weight (lb)	Material Description
		-	-
1	SVXXXXXX-1 ROCKET ENGINE MODULE, 10 DEGREE, LEFT	0.350	AMS4027 (AA6061-T6)
1	SVXXXXXX-1 BRACKET, ANGLE, 10 DEGREE	-	AISI304 per MIL-I-8846
4	MS21208C1015 INSERT, SCREW THREAD (Protective cover attachment)	-	-
1	SV792570-5 ENGINE ASS'Y, ROCKET	0.570	*
1	SV792505-1 VALVE, SOLENOID	0.031	-
	VALVE LEADWIRES	0.518	*
1	SV792525-1 THRUSTER, HYDRAZINE	0.005	*
1	SV792556-1 BRACKET, CLAMP SUPPORT	0.005	AMS5612 per HS17°
3	69287-103 BOLT, INTERNAL WRENCHING	-	AISI302 or AISI304
AR	MS20995C20 WIRE, SAFETY OR LOCK	0.003	Any 300 series CRES
14MAX	NAS620C4 WASHER, FLAT	-	*
1	STSV047M009 PACKING, PREFORMED	0.157	-
1	SVXXXXXX-1 HEATER AND THERMOSTATS (Similar to SV792622-1)	-	-
4	SVXXXXXX-1 THERMOSTAT	-	*
2	STSV513C2A09 CLAMP, MULTIPLE LOOP	0.027	*
AR	M27500-22SB3T23 CABLE, ELECTRICAL	-	Any 300 series CRES
2	NAS620C4L WASHER, FLAT	-	AMS5737 except HT 160
2	NAS1101E04-6 SCREW, MACHINE	-	AMS5735, AMS5737 or AMS5525 Ag plt
2	MS21043-04 NUT, SELF-LOCKING	-	*
AR	M22759/34-22-9 WIRE, ELECTRIC	-	*
1	SVXXXXXX-1 HEATER	0.033	-
	VALVE HEATER WIRES	-	*
2	SVXXXXXX-200 SPLICE, CRIMP (Make from STSV468-58)	-	*
2	SV723317-1 TERMINAL, ELECTRIC	-	*
AR	STSV089A12M21 TUBING, SHRINKABLE	-	*
AR	STSV089A11M01 TUBING, SHRINKABLE	-	*
AR	STSV089A07M21 TUBING, SHRINKABLE	-	*
AR	STSV128R2 TAPE, PRESSURE SENSITIVE	-	*
2	STSV508-1 STRAP, CABLE	0.448	AMS4027 (AA6061-T6)
1	SVXXXXXX-1 BRACKET, ENGINE SUPPORT (Main REM Bracket)	-	AISI304 per MIL-I-8846
4	MS21209C0615 INSERT, SCREW THREAD (Valve attachment)	0.128	AMS4027 (AA6061-T6)
1	SVXXXXXX-1 COVER, BRACKET (Hog-out attachment for blanket support)	0.035	AMS4027 (AA6061-T6)
1	SVXXXXXX-1 SUPPORT, MLI (.020 sheet for blanket support)	0.052	AMS4027 or AMS4117 (AA6061-T6)
2	SV777198-1 STRAP, NUT PLATE	0.068	HS279H925 chrome plated
8	SV714000N20 BUSHING, SHOULDERED	0.050	AISI302 spring temper
64	SV723310-4 SPRING, BELLEVILLE	0.011	MIL-S-5059, AMS5510 or AMS5512
8	AN960C416L WASHER, FLAT	0.002	HS701 Class 1
12	SV791184-202 PACKING, PREFORMED (Make from 69494J10)	0.185	*
1	SV792506-1 HEATER AND SENSOR, CHAMBER (6 H/S's must be reworked from -2)	0.012	-
	HEATER AND SENSOR LEADWIRES	0.013	*
1	NAS1714CT3-4K CLAMP, LOOP-CUSHIONED	0.002	AMS5735, AMS5737 or AMS5525 Ag plt
3	MS21043-06 NUT, SELF-LOCKING	0.004	AMS5731 or AMS5737 except HT 160
1	NAS1352N06-8 SCREW, CAP, SOCKET HEAD	0.002	MIL-S-5059, AMS5510 or AMS5512
2	AN960C6 WASHER, FLAT	0.038	*
2	SV748535-3 BUTTON, PIVOT	0.029	Glass reinforced phenolic G3HT
8	SV748716-78 SPACER, FLAT (Valve thermal isolation)	-	*
1	SV784102-2 FOIL, CONDUCTIVE (Chamber heater)	-	Any 300 series CRES
16	NAS620C6L WASHER, FLAT	-	AMS5731 or AMS5737 except HT 160
4	NAS1352N06H14 SCREW, CAP, SOCKET HEAD	0.006	AMS5731 or AMS5737 except HT 160
2	NAS1352N06-6 SCREW, CAP, SOCKET HEAD	-	*
AR	STSV128AH4 TAPE, PRESSURE SENSITIVE (Valve heater)	0.050	*
1	SVXXXXXX-1 CLAMP, THERMOSTAT (Similar to SV792559-1)	0.003	*
1	SV792280-2 SENSOR, TEMPERATURE	-	*
AR	STSV128AC4 TAPE, PRESSURE SENSITIVE (Wire bundles)	0.002	Any 300 series CRES
9	NAS620C6 WASHER, FLAT	-	AMS5731 or AMS5737 except HT 160
2	NAS1352N08-16 SCREW, CAP, SOCKET HEAD (TCA mounting)	-	Any 300 series CRES
2	NAS620C8 WASHER, FLAT	-	AMS5735, AM°5737 or AMS5525 Ag plt
3	MS21043-08 NUT, SELF-LOCKING	-	*
1	SV748536-5 SCREW, SHOULDER (TCA mounting)	-	*
2	AN565AC4H7 SETSCREW, HEXAGON (TCA adjust)	-	*
4	SV755456-1 SHIM (TCA adjust)	-	*
1	SV755456-2 SHIM (TCA adjust)	-	*
AR	SV726501 TAPE, LACING	0.003	AMS5737 except HT 160
1	NAS1101E06H10 SCREW, MACHINE (Thermostat mounting)	-	*
1	STSV266-113 LABEL, ELECTRICAL HARNESS IDENT	-	*
1	STSV266-114 LABEL, ELECTRICAL HARNESS IDENT	0.002	MIL-S-5059, AMS5510 or AMS5512
4	AN960C8 WASHER, FLAT	0.004	*
1	SV792748-1 SHUNT, THRUSTER	0.052	AMS5731 or AMS5737
4	NAS1802-3-24 SCREW, HEX (Belleville stack-up)	0.012	AISI302/Glass reinforced silicone
1	STSV445S3T07 CLAMP, CUSHIONED	0.009	AISI302/Glass reinforced silicone
1	STSV445S3T04 CLAMP, CUSHIONED	0.018	Any 300 series CRES
14	NAS620C10L WASHER, FLAT	0.004	AMS5735, AMS5737 or AMS5525 Ag plt
6	MS21043-3 NUT, SELF-LOCKING	0.012	AMS5737
4	NAS1190E3P8 SCREW, PAN HEAD (MLI support bracket)	-	Copper
1	SVXXXXXX-1 STRAP, BONDING	-	AMS5731 or AMS5737 except HT 160
2	NAS1351N3-10 SCREW, CAP, SOCKET HEAD (Bonding strap)	0.021	AISI304L CRES
1	SVXXXXXX-1 ELBOW, FLUID, .250 DIA	0.103	*
1	SVXXXXXX-1 MLI THERMAL BLANKET	0.100	-
AR	MISC		
	Total	3.179	

* Same as Cobe

Table 8-II Interface Sources

Interface	Defined or Derived	Source	Current Requirement/Definition
Structural	Defined	Interim Review--11-Mar-92	Four #10 Fasteners--Front Mounted
Fluid	Defined	Interim Review--11-Mar-92	.250 Dia x .035 Wall Tube Suitable For Welding
Electrical	Derived	-	Seven Pigtail Cables
Envelope	Derived	-	See SVL17492 sh 9
Ground Cover	Defined	TelCon--23-Apr-92	Provide Ground Handling Cover
Vibration	Defined	Telefax--31-Mar-92	11.0 Grms Acceptance--15.5 Grms Qualification
Acceleration	Defined	TRMM-713-031 Draft #8--28-Jan-92	26 G
Thermal	Defined	TelCon W/NASA GSFC/W. Ancarrow	-30 Deg C to +50 Deg Spacecraft Temperature

Table 8-III TRMM REM Leadwire Data

Component	Number of Leadwire Cables	Cable Part Number	Cable (1) Weight (Grams/Meter)	Existing (2)(3) COBE Cable Length (Meters)
Catalyst Bed Sensor	1	M27500-22SB2T23	17.9	4.85
Catalyst Bed Heater	2	M27500-22SB2T23	17.9	4.85
Valve Temp Sensor	1	M27500W-22SB2T23	17.9	-
Valve Power	1	M27500-22SB4T23	29.6	4.57
Valve Htr/Thermo	2	M27500-22SB3T23	23.8	-

(1) Based on supplier data
(2) Excludes length inside REM
(3) Based on blueprint minimums. Actual lengths may vary.

TABLE 8-IV. REM HEATER POWER SUMMARY

Heater	Rated Power (per element, 28 vdc)	Peak Power (both elements, 35 vdc)	Average Power
Valve	2.7 Watts minimum	8.8 Watts	1.3 Watts
Catalyst Bed	4.4 Watts minimum	14.4 Watts	N/A

TABLE 9-1: REM Thermal Control Options

		Mechanical Thermostat Options		Solid State Thermostat Options			PTC Heater
	Base REM w/o Thermal Control	TC1.1	TC1.2	TC2.1	TC2.2	TC2.3	TC3
Parts	REA, Cat. Bed H/S Brackets (REA/Angle) Iso hardware, clamps Tele. Sensor	Mech Thermostat & Clamp New Valve Heater (monolithic constructn)	Mech Thermostat & Clamp COBE Valve Heater	SST 5 vdc Converter, Filters COBE Valve Heater	HS SST New Valve Heater 2 control sensors (If isolation req'd need converters/filters)	TAYCO SST New Valve Heater (If isolation req'd need converters/filters)	PTC Valve Heater (replaces thermostat and soft valve heater)
Weight	N/A	REM Baseline	Increase because of large 5 vdc dc-dc converters and filters	Increase because of large 5 vdc dc-dc converters and filters	Slight increase due to addition of controller. If isolation req'd, >incr. for converters & filters	Same as TC2.2	Less
Voltage Supply	21-35 heater 5 vdc sensor	21-35 unregulated	Heater-5 vdc regulated	Heater-5 vdc regulated	21-35 vdc unregulated If isolation req'd: 21 vdc regulated	Same as TC2.2.	21-35 vdc unregulated
Power	N/A	Baseline 1.5 watts @21 vdc & 41^F Avg REM temp=50	Increase to provide power for converters and filters	No net power reduction because of losses to power converters	15% power savings. If isolation req'd, loose .1 watts/element op.	Same as TC2.2. But if isolation req'd, loose .45 watts/element op.	Greater
Reliability	good	Baseline	Less because of more components	Less because of more components, also no previous REM qual	Less because of more components, also no previous REM qual	Same as TC2.2	System-Improved REM-Improved, 1<component
Costs	N/A	Baseline	The cost of electronics probably greater than cost of new valve heater	Greater SST $ > new valve heater Add EE effort	> than mech thermostats Add EE effort	Cost trade has to be done to determine if more or less than TC2.2	Production- Improved no mech therm/htrs Non-Recur: Hi (Dev/Qual)
Considerations and Issues	Elect cnctr v. pigtail	-clamp redundancy -integral htr/therm. -Waiver on EMC rad/cond emissions	-can't use sc 5 vdc -EMI problems w/cnvrtrs rad/cond emissions	-Same as TC1.2 -pkg: remote or REM -X strap or isolated	cannot use sc 5/12 vdc can use tele. sensor -pkg: remote or REM -X strap or isolated	cannot use sc 5/12 vdc cannot use tele. sensor -pkg: REM -X strap or isolated	-$ for devel/qual -Xstrp or isolated

TABLE 10-I

HARDWARE TESTS

<u>TASK 1:</u> INTEGRITY TESTS

All 14 REAs on quads shall be tested on the quads and after removal from the quads. The 2 spare REAs shall be tested once. Currently EOP/Elect/Leakage (Int'l, Ext'l) tests are planned. It is recommended to perform a TCA fire test also (see para. 5.4)

<u>TASKS 3 & 4:</u>

	|<--- TASK 3	--->|		TASK 4
	Flight		Qual	Qual Toluene
<u>TESTS</u>	<u>REA</u>	<u>REM</u>	<u>REM</u>	<u>REM</u>
-EOP		X	X	X
-Proof				
-Elect			X	X
-Leakage (Int'l, Ext'l)			X	X
-REM Fire			X	
-Thermal Vacuum (8 cycles)		X	X	
-Thermal Balance			X	
-Vibration (Random/Swp/Brst)			X	
-Vibration (Random/Brst)	X	X		
-TCA Fire (verify nominal op)	X	X		
-REM Fire (Typ. Mssn. Duty Cycle)			X	
-REM Fire (Toluene)				X
-Pc Tap Removal		X		
-Elect	X	X	X	X
-Leakage (Int'l, Ext'l)	X	X	X	X
-EOP (weight)	X	X	X	

Table 11-I Nozzle Contour Definition

UNITED TECHNOLOGIES HAMILTON STANDARD

MODEL		TITLE	BY	
FILE			DATE	12-21-84
JOB			PAGE	6 OF

$R = .0925 + 5.8746338E{-}03 - 5.4980469E{-}01\,B - 1.8421936E{-}01\,B^2 + 2.6000977E{-}02\,B^3$

2.420 - B/P Axial

Blueprint Dia / 2

L	B	$-5.498E{-}01\,B$	$-1.8422E{-}01\,B^2$	$-2.6E{-}02\,B^3$	$+ .098375 = R$
0	-.0106	-5.8279 E-03	-2.0699 E-05	-3.0966 E-08	.0925
.2	.1894	1.0413 E-01	-6.6084 E-03	1.7665 E-04	.1961
.4	.3894	2.1409 E-01	-2.7934 E-02	1.5352 E-03	.2861
.6	.5894	3.2405 E-01	-6.3997 E-02	5.3236 E-03	.3633
.8	.7894	4.3401 E-01	-1.1480 E-01	1.2790 E-02	.4304
1.0	.9894	5.4397 E-01	-1.8034 E-01	2.5182 E-02	.4872
1.2	1.1894	6.5393 E-01	-2.6061 E-01	4.3748 E-02	.5354
1.4	1.3894	7.6389 E-01	-3.5562 E-01	6.9736 E-02	.5764
1.6	1.5894	8.7385 E-01	-4.6538 E-01	1.0439 E-01	.6112
1.8	1.7894	9.8381 E-01	-5.8986 E-01	1.4897 E-01	.6413
2.0	1.9894	1.0938 E 00	-7.2909 E-01	2.0471 E-01	.6678
2.2	2.1894	1.2037 E 00	-8.8305 E-01	2.7287 E-01	.6919
2.4	2.3894	1.3137 E 00	-1.0518 E 00	3.5468 E-01	.7150
2.420	2.4094				.7173

ϵ = 60.13
EXIT ANGLE = 6.56

THIS CURVE USES 3 DATA POINTS BEYOND EXIT OF NOZZLE TO REDUCE EXIT ANGLE (-1), (-2), (-3))

TABLE 12-I
TRMM ROM PRICE ESTIMATE FOR PHASE 2 HARDWARE PROGRAM (6-15-92)
($/1000)

TASKS	Non-Recurring	Recurring	Total
1. Integrity Tests	19	57	76
2. Design	166	19	185
3. Fab/Test/Ship	165	526	691
Totals	350	602	952
OPTIONAL COSTS			
Deltas for REM w/SST	12	146	158
4. Testing w/Toluene	140	4	144

TABLE 12-II

TRMM ROM PRICE ESTIMATE - BREAKDOWN BY TASKS (6-15-92)

TASK 1 - INTEGRITY TESTS
($/1000)

Non Recurring	Labor	Material	Total
1.1.1	19		19
1.1.2			
Total	19		19
Recurring			
1.2.1	42		42
1.2.2	15		15
Total	57		57

TASK 1 TOTAL = 76

TASK 2 - DESIGN
($/1000)

Non Recurring	Labor	Material	Total
2.1.1	133	8	141
2.1.2	25		25
Total	158	8	166
Recurring			
2.2.1			
2.2.2	19		19
Total	19		19

TASK 2 TOTAL = 185

TASK 3 - FAB/TEST/SHIP
($/1000)

Non Recurring	Labor	Material	Total
3.1.1	130	9	139
3.1.2	26		26
Total	156	9	165
Recurring			
3.2.1	300	117	417
3.2.2	106	3	109
Total	406	129	526

TASK 3 TOTAL= 691

TASK 4 - TOLUENE TESTING
($/1000)

Non Recurring	Labor	Material	Total
4.1.1	58	82	140
4.1.2			
Total	58	82	140
Recurring			
4.2.1			
4.2.2	4		4
Total	4		4

TASK 4 TOTAL = 144

TABLE 12-III
TRMM ROM PRICE SUMMARY for Phase 2 Hardware Program (6/15/92)
($/1000)

Task Suffix			1. Intgrty	2. Design	3. Fab/Test	Total 1+2+3	3.* w/SST	4.** Toluene
Non-Recurring								
.1.1	Hardware	Labor	19	133	130	282	12	58
		Mat'l: Cadam		8		8		
		Mat'l: Fixture			9	9		10
		Mat'l: N2H4/Toluene						72
.1.2	Program	Labor		25	26	51		
		Material						
	Total	Labor	19	158	156	333	12	58
		Material	0	8	9	17	0	82
		Lab/Mat'l	19	166	165	350	12	140
Recurring								
.2.1	Hardware	Labor	42		300	342		
		Mat'l: Purc Prt			68	68		
		Mat'l: Sub Cntrct			47	47	144	
		Mat'l: Misc Raw			2	2		
.2.2	Program	Labor	15	19	106	140	2	4
		Mat'l: Computor			3	3		
	Total	Labor	57	19	406	482	2	4
		Material	0	0	120	120	144	0
		Lab/Mat'l	57	19	526	602	146	4
Task Totals		Labor	76	177	562	815	14	62
		Material	0	8	129	137	144	82
		Lab/Mat'l	76	185	691	952	158	144

* 3.* are increased delta costs for REM with solid state thermostats.
** Task 4 is an optional task for testing with hydrazine doped with toluene.

APPENDIX 1

SPECIFICATION COMPLIANCE MATRIX

FOR USE OF THE COBE THRUSTERS ON THE TRMM RCS

Prepared by Hamilton Standard for NASA/GSFC
Rev. C, dated 6-15-92

Specifications Reviewed: TRMM-733-030, -031, -032

TRMM SPECIFICATION COMPLIANCE MATRIX
Draft: Rev. C, dated 6-15-92

Document: TRMM-713-030 (RCS Mission Rrequirements)

Para.	Requirements	Issues	Compliance Status
2.1	Spacecraft Design Data		
2.1.1	Prop. System Description = 12 x 22N (4.9 lbf) Thrusters per T2.1 shown below.		
	Nominal Propellant Wt. = 725 kg (1598 lb)		COBE: 1750 lbm nominal, 1900 lbm max.
	Max Propellant Cap = 890 kg (1962 lb)$\geq$1.1 x Mission Req.		
	Nominal Op. Press. Range @ 15°C = 1.72-.69 MPa (250-100 psia)		COBE 280-75 psia; TOPEX 350-75
	Max Dsn. Press. = 2.4 MPa (348 psia) @ 40°C		COBE Max Dsgn.=338; TOPEX (tested)=350; Mark2 (tested)=400
	Min Dsgn. Press. = .621 MPa (90 psia) @ 10°C		COBE/TOPEX = 75 psia; Mark2 = 70 psia
	Temperature Range: Op.= 8-40°C; Survival = 8-50°C		COBE was designed for 8-65 deg. C (wet).
	Leakage (external excluding valves) = 1 x 10^{-6} GHe sccs.		
	Thruster Alignment = $\pm$0.5°		
	Power = 55 watts RCS orbit avg for heaters (1.5 watts/REM), excluding catalyst bed heater.		Note:COBE valve 22.8-25 watts, cat bed heater 4.28-4.7 watts
	S/C Bus Voltage (unregualted) = 21-35 Vdc	*	COBE Soft heaters: 18-28 vdc, R=15.5$\pm$.5 ohms @70F Cat. Bed Htrs: 28 $\pm$2% vdc, R=179 +0/-5% ohms @70F REA Valves: 24-28 vdc, R=64.8 $\pm$2 ohms @70F Issue of valve operation over expected voltage and pressure range to be resolved by test of flight and qual valves.

TRMM SPECIFICATION COMPLIANCE MATRIX

Draft: Rev. C, dated 6-15-92

TRMM REQUIREMENTS	Issues	COMPLIANCE STATUS
Component Design Safety Factors: Proof = 1.5 Burst = 2.5		
Thrust (BOL) = 23.5N (5.28 lbf) @ 2.4 MPa (348 psia)		4.85 lbf @280 psia (PAT avg); 5.69 lbf @348 psia.
2.1.2 Spacecraft Reference Axes		
2.1.3 Thruster Location and Orientation		
2.1.4 Spacecraft CG		
2.1.5 Spacecraft Mass - 3500 kg max at launch		
2.1.6 Thrust: (BOL) =15.6N (3.51 lbf) min @ 1.309 MPa (190 psia) (EOL) = 11.7N (2.63 lbf) min @ .899 MPa (130 psia)		(BOL) =15.6N (3.51 lbf) min @ 1.309 MPa (190 psia) (EOL) = 11.7N (2.63 lbf) min @ .899 MPa (130 psia)5.21 lbf @
2.1.7 Thruster Plume Impingement - TBD		
2.2 Spacecraft Design Reference Mission		
2.2.1 Mission Orbit Acquisition:		
2.2.1.1 Tipoff Rate Null Tipoff rate $\geq$ 2 deg/sec: Thrusters used to null tipoff rate.		
2.2.1.2 Initial Deorbit: Thrusters used for transfer from 380 km to 360 km.		

TRMM SPECIFICATION COMPLIANCE MATRIX

Draft: Rev. C, dated 6-15-92

	TRMM REQUIREMENTS	Issues	COMPLIANCE STATUS
2.2.2	On-Orbit Operations: Mission Life = 3 years. a. Altitude makeup every 2 wks BOL, every 2 days EOL. b. Thrusters used as backup for Yaw maneuvers. c. Thrusters used as backup for momentum unloading. d. Momentum Unloading in safe hold mode.		COBE not stated in years. TOPEX = 3 years with a 5 year goal.
2.2.3	EOL Disposal a. Thrusters used for momentum unloading. b. Thrusters off modulated for AC on final re-entry.		
3.	Delta Velocity Maneuver Requirements		
3.1	Mission Orbit Acquisition: Isp = 220 sec.		COBE 229 sec nominal at 190 psia (1.3 MPa).
3.1.1	Delta Velocity, 2 burns for approx. 12 m/s		
3.1.2	Burn Times (in seconds): Assumes approx 9% loss and altered burn times to maintain argument of perigee. Max burn time = 484 sec		See para. 5 for individual thruster requirements.
3.1.3	Thruster Starts: Deleted. See Summary Table 5-1		
3.1.4	Total Impulse Req.: 50,000 N-s max.		See para. 5 for individual thruster requirements.
3.1.5	Attitude Error:+/- 2 degrees.		
3.1.6	Thrust Vector Misalignment Tolerance: .5 degrees.		
3.1.7	Thrust Imbalance: 10% max between any two during firing.		COBE: 6% @280 psia; 5.3% @ 75 psia.
3.2	Obit Control: Reboost from 348.75 to 351.25 km.		
3.2.1	Delta Velocity: 2 burns = 1.5 m/s total		

TRMM SPECIFICATION COMPLIANCE MATRIX

Draft: Rev. C, dated 6-15-92

	TRMM REQUIREMENTS	Issues	COMPLIANCE STATUS
3.2.2	Burn Time (in seconds): Assumes approx. 9% loss and altered burn times to maintain argument of perigee. Max burn time = 66 sec.		See para. 5 for individual thruster requirements.
3.2.3	Thruster Starts: Deleted. See Summary Table 5-1.		
3.2.4	Total Impulse Required: 1.62E6 N-s (3.64E5 lbf-sec) max.		See para. 5 for individual thruster requirements.
3.2.5	Attitude Error: +/- 2 degrees.		
3.2.6	Thrust Vector Misalignment Tolerance: .5 degrees.		
3.2.7	Thrust Imbalance: 10% max between any two during firing.		6% @ 280 psia; 5.3% @ 75 psia.
3.3	Controlled Re-Entry: From 200 to 50 Km. Spacecraft = 2750 kg max. Isp = 220 sec.		
3.3.1	Delta Velocity: Total delta v = 44 m/s in 1 or 2 burns.		
3.3.2	Total Burn Time: 2710 sec max.		See para. 5 for individual thruster requirements.
3.3.3	Thruster Starts: Deleted. See Summary Table 5-1.		
3.3.4	Total Impulse Required: 140,000 N-s (3.15E4 lbf-s) max.		See para. 5 for individual thruster requirements.

	TRMM REQUIREMENTS	Issues	COMPLIANCE STATUS
3.3.5	Attitude Error: +/- 2 degrees.		
3.3.6	Thrust Vector Misalignment Tolerance: .5 degrees.		
3.3.7	Thrust Imbalance: 10% max between any two during firing.		6% @ 280 psia; 5.3% @ 75 psia.
3.3.8	Max and Min Thrust Levels: TBD		
4.	Attitude Control Requirements		
4.1	Tipoff Rate Null: Same as 2.2.1.		
4.1.1	Number of Pulses: TBD.		See para. 5 for individual thruster requirements.
4.1.2	Total Impulse Required: Approx. 1000 N-s (225 lbf-s).		
4.1.3	Impulse Bit: Magnitude TBD, Repeatability within 5%.	*	GSFC will modify 5% Ibit repeatability requirement to accomodate thruster capability. COBE has demonstrated for a 50 ms pulse: .269 lbf-sec BOL @ 309 psia, ±7% all REAs .143 lbf-sec EOL @ 104 psia, ±8% all REAs
4.2	Attitude Control During Delta V Maneuvers:		
4.2.1	Duty Cycle: No limitations (0-100% capability) Min. pulse req'd is .125 sec.		COBE demonstratd 50 ms pulsewidths. No duty cyle limitations.
4.2.2	Total Impulse Required: Included in margin, which takes into account attitude errors, thrust vector misalignments, thrust imbalance, nominal cant angle losses, etc.		
4.2.3	Limit Cycle: +/- 2 deg. attitutde error by off modulation.		

	TRMM REQUIREMENTS	Issues	COMPLIANCE STATUS
4.2.4	Impulse Bit: Magnitude TBD, Repeatability within 5%.		Same as Para. 4.1.3
4.3	Momentum Unloading During Dragdown: TBD.		
4.4	Backup Yaw Maneuver: Thrusters used as backup. Impulse required = TBD.		
4.5	Backup Momentum Unloading: Thrusters used as backup. Impulse required = TBD.		
4.6	Safe Hold Mode: No requirement for thrusters.		
5.	Propulsion Requirements: per T5-1b and T5-2. -Per Thruster (T5-1b): Propellant = 148 kg max (326 lbm) Total Impulse = 320,000 N-s max (71940 lbf-s) Max Burn Duration = 2710 sec Max Total Burn = 24758 Total Pulses = 32,200		- Max propellant (Assuming 220 Isp Avg.): COBE=530 lbm; Mark2=522 lbm; IR&D=1153 lbm -Total Impulse: COBE (REA 39-5) = 116,554 lbf-sec (518,763 N-s) (hi purity) Mark2 (REA 39-3) = 114,949 lbf-sec (511,339 N-s) (mono grade) IR&D (REA 39-2) = 263,700 lbf-sec (1,173,688 N-s) (mono grade) - Max Dur. Burn: COBE = 208 minutes (12,480 sec) (hi purity) REA 39-2 (IR&D) = 120 minutes (7200 sec) (mono grade) - Max Total Burn: COBE = 611.12 min (36,667 sec), REA 39-2 (IR&D)= 20.1 hrs (72,396 sec) - Total Pulses: COBE = 68,389 pulses, MARK2 = 117,984 pulses

TRMM SPECIFICATION COMPLIANCE MATRIX

Draft: Rev. C, dated 6-15-92

TRMM REQUIREMENTS	Issues	COMPLIANCE STATUS
Document: TRMM-713-031 (RCS Spec.)		
3.0 Requirements		
3.1 Functional Overview		
3.2 Performance Requirements		
3.2.1 Total Impulse for RCS: $\geq$5.07E5 N-s (1.14E5 lbf-s)		The following has been demonstrated: COBE (REA 39-5) = 116,554 lbf-sec (hi purity) Mark2 (REA 39-3 = 114,949 lbf-sec (monopropellant grade) IR&D (REA 39-2 = 263,700 lbf-sec (monopropellant grade)
3.2.2 Impulse Bit: 2.82 N-s (.634 lbf-s) to 1.11 N-s (.25 lbf-s) Per Fig. 3-2 for fixed off time = 2 sec. Repeatability: < $\pm$5% at 125 ms on time.	*	GSFC will modify 5% repeatability requirement to accomodate thruster capability. COBE has demonstrated: 2.82 N-s (.634 lbf-s) to 1.25 N-s (.281 lbf-s) for .125 sec on/2 sec off. COBE flight REA Ibit repeatability was: $\pm$5.5% BOL @ 280 psia. $\pm$8.1% EOL @ 75 psia.
3.2.3 Specific Impulse Steady State (> 1 sec on): Per Fig. 3-3 Pulsing: Per Fig. 3-4.	*	Comply. GSFC will modify Fig. 3-4 so that pulsing Isp for long on times will match steady state Isp.
3.2.4 Thrust Level: Per Fig. 3-5. Temp. Range: 8-40 deg. C Inlet Press.: 2.4 MPa (348 psia) to .689 MPa (100 psia). Note 348 psia is for max start only due to worst case thermal conditions. Pressure will fall quickly to 190 psia regulated operating. S.S. Thrust variation between modules $\leq\pm$5%.		COBE thrust complies per Fig 3-5. Pressure Ranges: COBE = 280-75 psia; TOPEX = 350-75; Mark2 = 400-70. COBE thrust repeatability = $\pm$4.74% @ 280 psia; 4.26% @75 psia.

TRMM SPECIFICATION COMPLIANCE MATRIX

Draft: Rev. C, dated 6-15-92

	TRMM REQUIREMENTS	Issues	COMPLIANCE STATUS
3.2.5	Operating Pressure 1.72MPa (250 psia) to .689MPa (100 psia) at 12°C.		Note inconsistant with para.3.2.4. Pressure Ranges: COBE = 280-75; TOPEX = 350-75; Mark2 = 400-70. COBE blowdown ratio is 3.73.
3.2.6	Temperature Limits RCS op. range of 8-40 °C with max soakback to a REA valve ≤300 °F. Ground test without fluid -40 to 50 °C (-40 to +122 °F).		COBE design operating range was 8-65 °C with a valve soakback of 300 °F max. Qual Quad thermal cycle test at -35 to 50 °C.
3.2.7	Power: Worst case average orbital power for the RCS subsystem (i.e. heaters) is ≤55 watts at 21 vdc.		Predict 1.5 watts/REM average orbital = 18 watts for 12 REMs.
3.2.8	Propellant: Tank load of 890 kg (1962 lbm) monopropellant grade N2H4.		COBE: 1900 lbm max, 1750 lbm nominal.
3.2.9	Pressurant Gas: 1.38 MPa (200 psia) at 12 °C with GN2.		COBE used 309 psia GN2.
3.2.10	Max Leakage for REM: External = 1xE-4 scc/sec GHe; Int'l Leakage = 5 scc/hr GN2.		Comply.
3.2.11	Duty Cycle: There shall be no duty cycle limitations.		COBE REAs are not duty cycle limited.
3.3	Component Requiremnts		
3.3.8	Thruster Modules: Shall comply with TRMM-713-039 Thruster Module Spec.		Shall comply by design.

	TRMM REQUIREMENTS	Issues	COMPLIANCE STATUS
4	RCS Interfaces		
4.1	RCS/Satellite: Intergrated System		
4.1.1	Attitude Control: Min pulse width 125 ms.		COBE demonstrated 50 ms pulsewidth.
4.1.2	Power: 21-35 Vdc from spacecraft power bus.	*	COBE: Valve = 24-28 vdc, soft heaters 18-28 vdc, cat. bed htrs 28±2% vdc. TOPEX: Valve= 22-35 vdc. Acceptability of COBE valve operation for TRMM shall be satisfied by test.
4.1.2.1	RCS Heater Power Requirments: 55 watts @ 21 Vdc average orbital.		REM dual element valve heater shall be sized for 1.5 watts/element at 21 vdc. 36 watts for all elements operating at 21 vdc.
5	Operability: Shall operate after exposure to transportation, testing, storage and launch.	*	COBE REA's are not qualified for vibration loads with the catalyst bed above the valve. REA's will have to be kept in horizontal position, or, rebuilt with qualified injector screens, or, not be subjected to any valve opening after transport until in orbit (provided that the transport vibration and shock loads are acceptable).
5.1	Mission Life: At least 3 years in orbit.		COBE did not specify an on orbit time life. TOPEX = 3 yrs. with a 5 year goal.
5.2	Maintainability: Std. Misc.		
5.3	Storage Life: 10 yrs storage then 3 years in operation.	*	There is a question of valve seat (AFE 411) acceptability after prolonged storage. Resolution shall be by test. A qual valve has passed test at GSFC. Flight valves shall be verified at HS. If ground tests gives acceptable results, there should be no further degradation in a space invironment.

	TRMM REQUIREMENTS	Issues	COMPLIANCE STATUS
5.4	Environmental:		
5.4.1	Pressure: Sea Level to deep space (760-1xE-10 torr), with internal pressure from vacuum (<5 torr) to proof (3.6 MPa (525 psia)). Spec. req. for deep space.		COBE tested SL to 2 x 10E-5 torr. Proof of 650 (valve open) and 1025 (valve closed) at ambient temperatures.
5.4.2	Thermal Vacuum: Operate after exposure to thermal test over range of -40 to +50 °C.		COBE thermal cycle test was -35 to 50°C with 4 cycles and 1 hour at each cycle. TRMM verification by test: -40 to 50°C.
5.4.3	Vibration:		
5.4.3.1	Module Random Vib. per below.		HS shall demonstrate compliance by acceptance and qual vibration tests on the REMs.

Hz	Acceptance	Hz	Protoflight
20-80	.04	20-80	.08
80-160	+3dB/Oct	80-160	+3dB/Oct
160-504	.08	160-504	.16
504-630	+3dB/Oct	504-630	+3dB/Oct
630-1000	.1	630-1000	.2
1000-2000	-9dB/Oct	1000-2000	-9dB/Oct
2000	.0126	2000	.0252
Overall GRMS	11		15.5

5.4.3.2	Acoustic: 141 db overal sound pressure.		COBE requirement was 146 db overal by design. It was not tested.
5.4.4	Shock: Not required for thruster modules.		
5.4.5	Vibration (Sine, Burst, Sweep): Levels TBD.		Shall be verified by test.
5.4.6	Humidity: TBD.		Comply by Design.
5.4.7	Acceleration: 26 g's on the module in any direction.	*	Shall comply by analysis. At 26 g's the minimum factor of safety is calculated to be 7.25 for the REA.

	TRMM REQUIREMENTS	Issues	COMPLIANCE STATUS
5.4.8	Transportability: Shall be designed for transport by common carrier with special packaging as necessary.	*	Design consideration must be given to COBE REM packaging. REA's are not qualified for handling, transportation or vibration with orientation of thrust chamber above the valve.
5.5	Safety: The RCS shall be designed and fabricated per MIL-STD-1574A, MIL-STD-1522A, and MISC-003 (Japanese Safety DEsign Req.).		Shall comply by design.
6	Design and Construction		
6.1	Gen'l Design Features: RCS summarized. Propellant monopropellant grade per MIL-P-26536D and GN2 per MIL-P-27401 Grade B.		Shall comply.
6.1.1	Redundancy: No single point failure which would cause the loss of the spacecraft.		No single point failure of the REA exists which could cause loss of the spacecraft. A COBE FMEA exists. The TRMM REM design will be single point failure tolarant.
6.1.2	Dimensions: REM shall fit in a control volume of 345 mm (L) x 180 mm (W) x 165 mm (H) (13.6x7x6.5").		Shall comply by design.
6.1.3	Weight: RCS $\leq$155 kg dry weight.		Note: Current estimated REM weight = 3.179 lbm (1.447kg) w/MLI, and w/o external leadwires. Estimated shipset weight (12 REMs) is 38.15 lbm (17.32kg).
6.1.4	Fluid Compatibility: Compatible with N2H4, distilled water, GN2, GHe and IPA.		
6.2	Material Parts and Processes: See Text.		COBE PMP exists.
7	Reliability: Per TBD.		
8	Quality: Design, Manufacture and Test Per TRMM-303-006.		Shall comply.

	TRMM REQUIREMENTS	Issues	COMPLIANCE STATUS
9	Verification:		
9.2.1	Component Qualification Tests: Per TBD.		Proposed TRMM REM qual tests are: REM Fire, Thermal Vac, Thermal Balance, Vibration (random, sine sweep, sine burst), REM Fire, Electrical, Leakage, Weight
9.2.2	Acceptance Tests: TBD		Proposed TRMM REM acceptance tests are: Thermal Vac, Vibration (Random, sine burst), TCA Fire, Electrical, Leakage, Weight
9.3	Subsystem Flight Acceptance Tests: RCS tested for proof, int'l/ext'l leakage, electrical/functional, flow impedance.		

TRMM REQUIREMENTS	Issues	COMPLIANCE STATUS
Document TRMM-713-032 (RCS Interface)		
3. Structural Interface		
3.1 Method of Attachment		
3.1.5 Thruster Modules: 12 REA's individually mounted on module brackets. To accomodate cant angles, the generic thruster module will be isolation mounted to a angle bracket permitting 4 different mounting configurations. 6 REA's will be mounted to the ISP for delta-v and 6 to the LBS for roll control and delta-v maneuvers.		Shall comply by design.
3.2 Load Environment		
3.2.5 Thruster Module: - Steady State Acceleration: 26 g's in any direction. - Random Vib. per Table 3-1 below.	*	TRMM REM design features a thruster module mounted to an angle bracket with vibration isolators. TRMM random vibration requirements shall be verified by test, steady state acceleration requirements shall be verified by analysis.

Hz	Acceptance	Hz	Protoflight
20-80	.04	20-80	.08
80-160	+3dB/Oct	80-160	+3dB/Oct
160-504	.08	160-504	.16
504-630	+3dB/Oct	504-630	+3dB/Oct
630-1000	.1	630-1000	.2
1000-2000	-9dB/Oct	1000-2000	-9dB/Oct
2000	.0126	2000	.0252
Overall GRMS	11		15.3

- On-Orbit Cycles: TBD.

TRMM SPECIFICATION COMPLIANCE MATRIX

Draft: Rev. C, dated 6-15-92

	TRMM REQUIREMENTS	Issues	COMPLIANCE STATUS
3.3	Mass Properties: 18.6 kg for 12 REMs.		Current TRMM REM weight estimate is 17.3 kg exclusing leadwires external to the REM.
4.	Thermal Interface		
4.1	Temperature		
4.1.5	Thruster Module: the interface between the thruster module and the spacecraft bus shall not exceed the survival limits of 8-50 °C. This includes a max. soakback temperature from the thruster to the thermal standoff of 50 °C. The lower limit at the interface shall be maintained by redundant thermally controlled heaters which are located on the propellant valves.		COBE quad interface was -25 to +25 °C on the lower deck. The 50 °C interface will be satisfied by design.
4.2	Insulation		
4.2.5	Thruster Modules: TBD		Shall comply by design.
4.3	Heaters/Thermostats: Thermally controlled heaters for 1.5 watts average orbital power.		Shall comply by design.
5.	Electrical Interfaces		
5.1	Heater Electrical Power Requirements		
5.1.5	Thruster Module		
5.1.5.1	Valve Heater Thruster Module shall be heated with a dual thermostatically controlled heater segment, primary and secondary, each capable of maintaining minimum temperatures. Each heater segment operates from 21-35 vdc with 1.5 watts minimum at 21 vdc. Electrical connections with TBD AWG copper wire. Grounding per TRMM-733-043 and wires twisted shielded pair.		For TRMM new valve heaters shall be used which shall comly by design. The COBE quad had a redundant valve heater circuit. Each circuit consisted of 4 heaters covering each of 4 valves. The COBE valve heaters could not be used for TRMM because their power rating required a 5 vdc input which is not currently feasible.

TRMM REQUIREMENTS	Issues	COMPLIANCE STATUS
5.1.5.2 Catalyst Bed Heater Each Catalyst Bed shall be heated with a dual heater segment, primary and secondary, each capable of maintaining minimum temperatures. Each heater segment operates from 21-35 Vdc with 2.5 watts at 21 volts. Electrical connections with 22 AWG copper wire. Grounding per TRMM-733-043 and wires twisted shielded pair.		COBE catalyst bed heater is 4.28 to 4.7 watts at 28±2% vdc. Performance verification shall be by test.
6 Command And Telemetry Interface		
6.1 Thermister Telemetry Requirements		
6.1.5 Thruster Module		
6.1.5.1 Propellant Valve: 12 telemetry thermistors. 1 thermistors per valve. Standard thermistor per GSFC311-P18-0187R6.		COBE temperature sensors are thermistors per GSFC 311-P18-0187R6, with 2252 ohms and a (-) temperature coefficient. The TRMM REM will use the same design.
6.1.5.2 Catalyst Bed: 1 per bed. Platinum probe RTD. Req't TBD.		COBE temperature sensors are platinum probe and will be reused for the TRMM mission.
6.1.5.4 Propellant Valve Command Lines: 24 lines (twisted pair), 2/REA. Signals from redundant drivers. Command line shall provide a square wave with min pulse length of 125 ms at +18 to +31 Vdc at valve interface. Grounding is TBD in a twisted shielded pair.	*	COBE valve voltage 24-28 vdc. TOPEX valve voltage 22-35 vdc. Satisfactory operation of COBE valves for TRMM mission shall be verified by test.

Appendix 2

Vibration Analysis

Figure 1 shows the originally specified TRMM vibration spectrums for acceptance and protoflight. Also shown is the vibration input for qualification of the COBE Quad. It can be seen that the COBE qualification level is well below TRMM requirements and is insufficient to validate the TRMM REM. In addition, the COBE Quad was mounted on a trusswork of long titanium alloy tubes which significantly attenuated the vibration input making the environment rather benign for the REA's. This figure also shows an approximation of the Quad response based on data from accelerometers placed on the COBE REM (engine support) bracket. This also is insufficient for verification of the TRMM environment and a verification test is therefore recommended.

The originally predicted weight of the REM was 1.75 pounds. Based on an empirical database, the predicted natural frequency of a hard mounted REM weighing 1.75 pounds is 300-600 Hz. The 3-Sigma (limit load) response at 600 Hz is 127 G's. The calculation is attached as Figure 2.

The weakest structural feature of the REA is the thermal standoff. A summary of stress and safety factors for the standoff is shown in Figure 3. These data indicate structural acceptability of the REA for both the vibration environment and the 26 G acceleration.

Based on data from the valve manufacturer, the inlet pressure required to keep the valve from opening at 127 G's is calculated to be over 900 PSI. The calculation is attached as Figure 4.Conversely, an unpressurized valve will open at about 55 G's. It is apparent that the valve will have a high probability of opening during TRMM vibration. Not only will there be a risk of leakage during vibration, but significant damage to the sealing surface can be expected. It is therefore prudent to take action to prevent the valve from opening. Since it is desired to utilize existing hardware, the only remaining approach is to prevent valve exposure to the vibration environment. The selected approach is to provide attenuation by isolating the REA on a set of springs to lower the natural frequency. Isolation of this sort has been successfully employed on other programs and the baseline configuration is identical to that used on the IUS REM.

Subsequent to determining the need for vibration isolation, the proposed vibration requirement was reviewed. Due to the fact that the validation vibration testing is to be qualification rather than protoflight, it was recommended that additional margin be put into the qualification spectrum in order to assure that acceptance level vibration be lower than qualification level throughout the spectrum. Consequently, the spectrum was modified slightly to provide the suggested margin and the current vibration requirement is shown in Figure 5.

The natural frequency for the IUS spring-isolated REM is calculated in Figure 6 based on the calculated spring rate of the Belleville stackup. Using the same spring rate, the calculated natural frequency of the TRMM REM is 36 HZ to 42 Hz. The maximum 3-Sigma response at 42 Hz is 22 G at qualification. These calculations can be seen in Figure 7.

Recent information from GSFC indicates that natural frequencies of all equipment on the spacecraft may need to be kept above 50 Hz. If the spring rate of the stackup is adjusted to raise the natural frequency to, say, 50 Hz to 80 Hz, the maximum 3-Sigma response at 80 Hz would be 30 G. This calculation is also shown in Figure 7. A 30 G response is well within the standoff structural limit and also provides acceptable margin against valve opening.

Comparison of TRMM Module Vibration Reqt vs. COBE TQU Qual Vibration

27 JAN 92
R. BARNETT

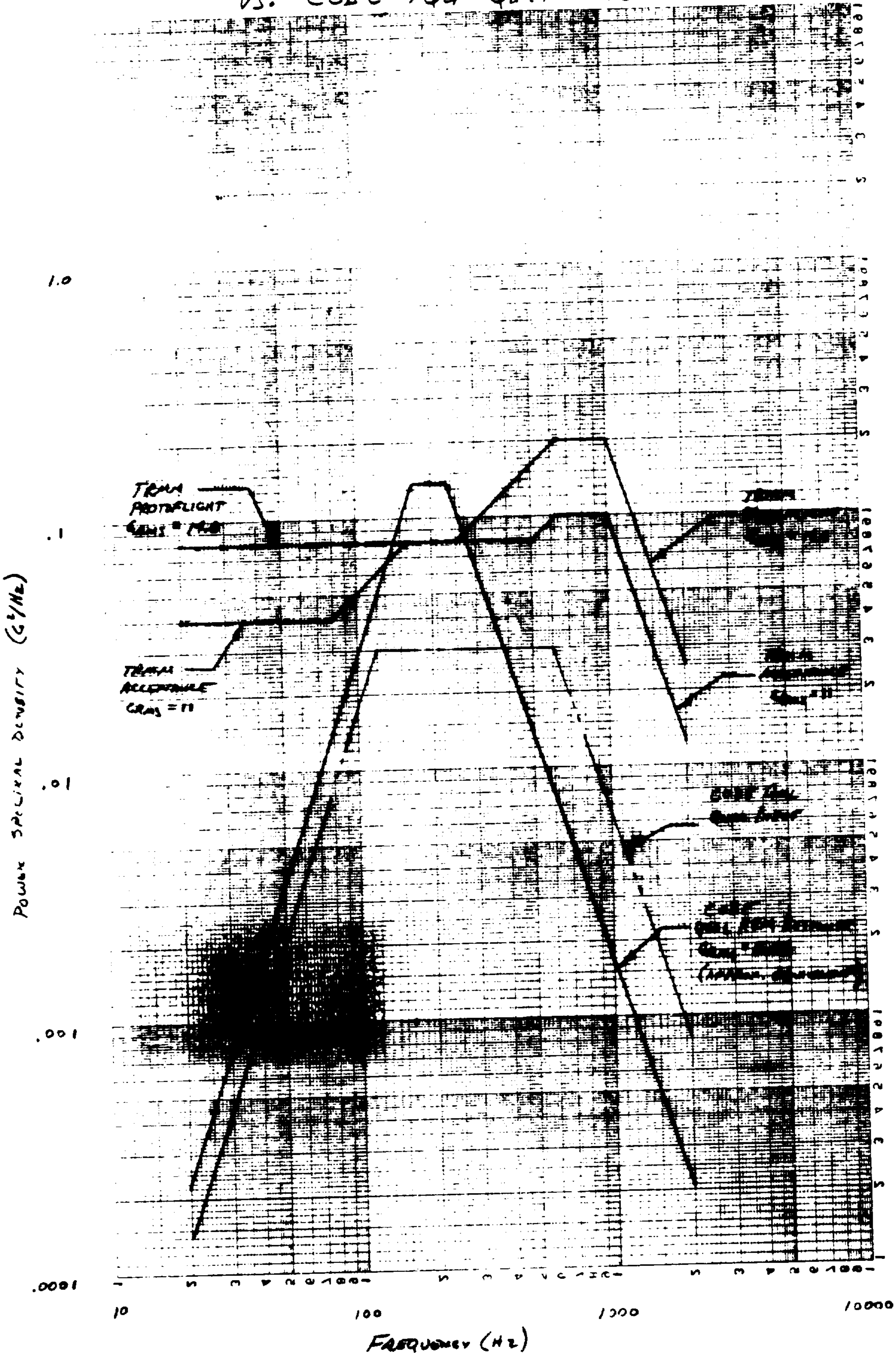


Figure 1

HAMILTON STANDARD

MODEL		TITLE	RMS PROGRAM	BY	B. M[illegible]
FILE				DATE	2-[illegible]-92
JOB				PAGE	1 OF

ESTIMATE OF f_n (REVISED FROM 1-30-92)

NEW WEIGHT = 1.75# TOTAL

f_n — 300-600 Hz

CALCULATE g_{rms} BASED ON 600 Hz

$$g_{rms} = \sqrt{\left(\frac{\pi}{2}\right)(10)(600)(.096)} = 30.08 \; g_{rms} \text{ ACCEPTANCE}$$

$$g_{rms} = \sqrt{\left(\frac{\pi}{2}\right)(10)(600)(.19)} = 42.32 \; g_{rms} \text{ PROTOFLIGHT}$$

	~~g_{rms}~~ ACCEPTANCE	PROTOFLIGHT
1σ	30.08	42.32
2σ	60.16	84.64
3σ	90.24	126.96

Figure 2

14.2

R. BARNETT

TRMM REM VIBRATION

SINGLE ENGINE REM

WEIGHT = 1.83 LB

WEIGHT W/O MLI = 1.75 LB

ESTIMATED f_n = 300 - 600

CYCLES = 600 · 60 = 36,000

RESPONSE	ACCEPTANCE	PROTOFLIGHT (QUAL)
1σ	30.08 g	42.32 g
2σ	60.16 g	84.64 g
3σ	90.24 g	126.96 g

MAXIMUM STRESS IN STANDOFF RESULTS FROM WEB BENDING DUE TO COMBINATION OF GROSS BENDING AND TORSION. $S_{MAX} = 318.5\,g$

FOR 36,000 CYCLES, $\sigma_{ALL} = 46,700$ PSI

MAX ACCEL = 26 g

	ACCEPTANCE					QUALIFICATION					FLIGHT				
	COND	g	σ	σ_{ALL}	SF	COND	g	σ	σ_{ALL}	SF	COND	g	σ	σ_{ALL}	SF
FATIGUE	2σ	60.16	19,200	46,700	2.43	2σ	84.64	27,000	46,700	1.73	2σ	60.16	19,200	46,700	2.43
LIMIT LOAD	3σ	90.24	28,700	69,000	2.09	3σ	126.96	40,400	69,000	1.49	30+26	116.24	37,000	69,000	1.62

NOT ADDITIVE R.J.B. 10 JUN 92

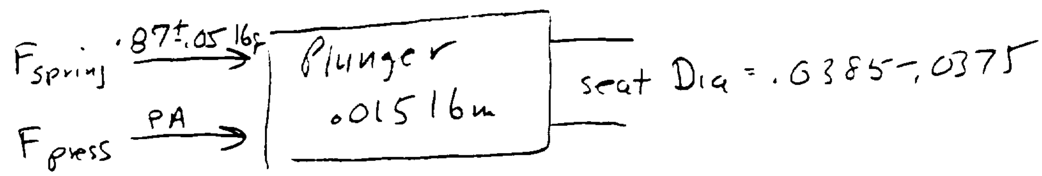
IF QUALIFICATION IS LENGTHENED TO 3 MINUTES: CYCLES = 108,000 = $1.08(10)^5$

σ_{ALL} = 40,000

SF = 1.48

figure 3

Valve Opening



$$m \times A = F$$

$$.015 \text{ lbm} \times 127 \text{ G's} = 1.905 \text{ lbf}$$

$$- \; .865 = \text{spring load}$$

$$1.040 = \text{needed pressure load to keep closed}$$

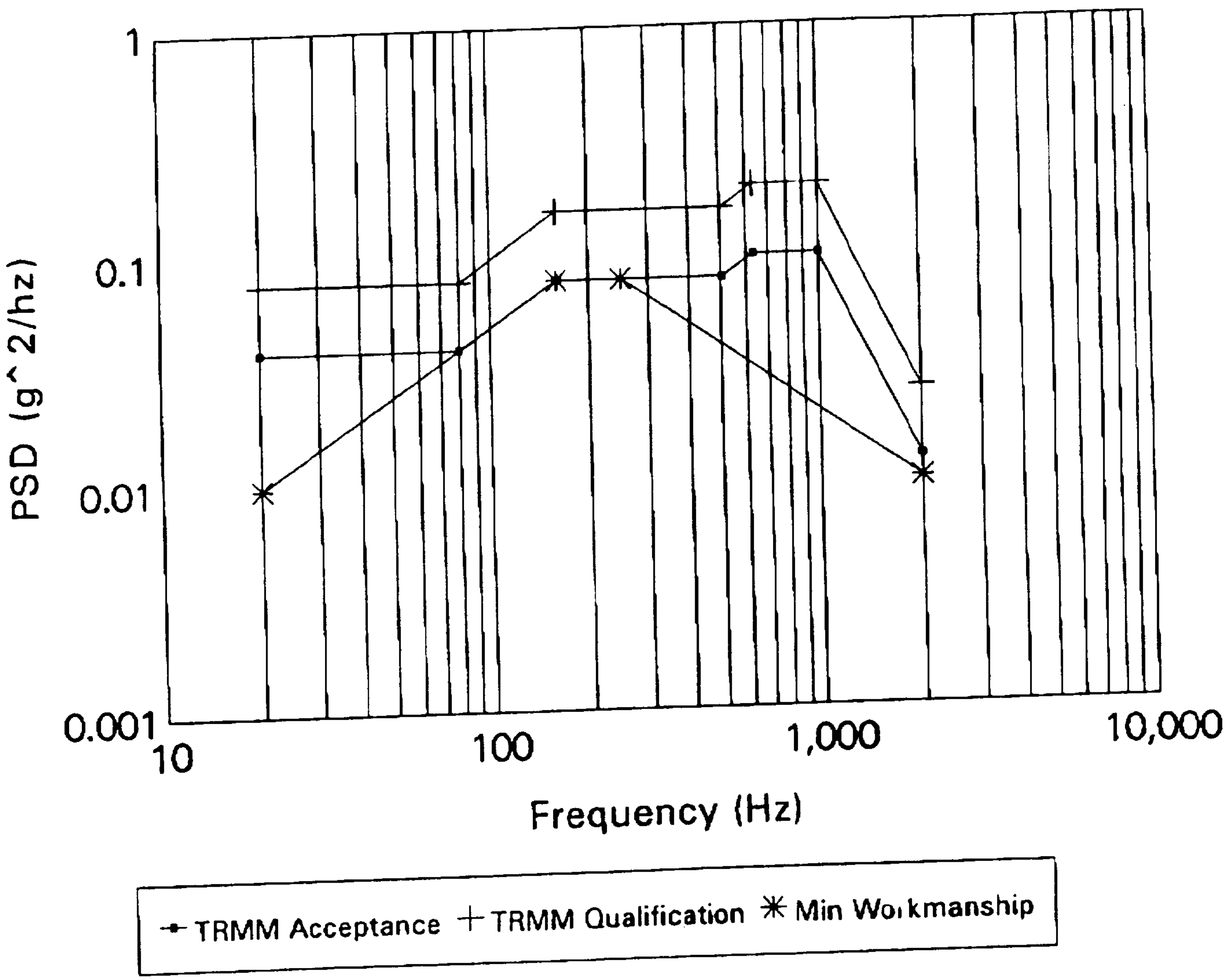
$$\text{Pressure Load} = 1.040 = PA$$

$$A = 1.104 \times 10^{-3} \text{ in}^2$$

$$\therefore P = 942 \text{ psig}$$

Figure 4

Thruster Module Vibration Spectrum



Frequency (Hz)	Acceptance (G2/Hz)	Qualification (G2/Hz)
20 - 80	0.04	0.08
80 - 160	+3 dB/oct	+3 dB/oct
160 - 504	0.08	0.16
504 - 630	+3 dB/oct	+3 dB/oct
630 - 1000	0.10	0.20
1000 - 2000	-9 dB/oct	-9 dB/oct
2000	0.0125	0.025
OAGRMS	11.0	15.5

Figure 5

UNITED TECHNOLOGIES HAMILTON STANDARD

MODEL		TITLE	BY	K [illegible]
FILE		TRMM Program	DATE	3-26-[illegible]
JOB			PAGE	1 OF

TRMM Isolation Calculations:

Proposal – Add Belleville Style Washers to move the resonant frequency of the system to a lower value.

The reason is high [illegible] valve [illegible] [illegible] vibration loads. This spring system was used with success on [illegible]. A sketch is attached.

Approach #1 → Check the [illegible] system.

Ref SV 723310-4 Belleville Spring.

Requires preload of 38-52 lbs @ .026" δ.

There are $\underline{\underline{16}}$ in series.

For 1 spring: $K = \frac{P}{\delta} = \frac{38/52}{.026} = 1461 - 2000$ lb/in

Equivalent spring for 1 leg:

$$\frac{1}{k_{eq}} = \Sigma \frac{1}{K} = \frac{16}{k} \qquad k_{eq} = \frac{k}{16}$$

Now assume 4 legs:

$$K_{eq_{total}} = 4 K_{eq} = \frac{4k}{16} = \frac{k}{4}$$

$$K_{system} = 365.25 - 500 \text{ lb/in}$$

Calculate f_n (assume weight = 6 lbm)

$$f_n = \left[365.5 \cdot \frac{386.4}{6}\right]^{\frac{1}{2}} \cdot \frac{1}{2\pi} = 24.4 \text{ Hz}$$

$$= \left[500 \cdot \frac{386.4}{6}\right]^{\frac{1}{2}} \cdot \frac{1}{2\pi} = 28.6 \text{ Hz}$$

HSF 214.2

Figure 6

NATURAL FREQUENCY

THE CURRENT REM WEIGHT (LESS MLI & ANGLE BRACKET) IS 2.726 LB

BASED ON THE CALCULATED SPRING RATE TOLERANCE OF 365-500 LB/IN,

$$f_{n\ MIN} = \frac{1}{2\pi}\sqrt{365 \cdot \frac{386.4}{2.726}} = 36.2 \text{ Hz}$$

$$f_{n\ MAX} = \frac{1}{2\pi}\sqrt{500 \cdot \frac{386.4}{2.726}} = 42.4 \text{ Hz}$$

RESPONSE

$$G_{RMS} = \sqrt{\frac{\pi}{2}(.04)(42.4)(10)} = 5.16 \ G_{RMS} \text{ ACCEPTANCE}$$

$$G_{RMS} = \sqrt{\frac{\pi}{2}(.08)(42.4)(10)} = 7.30 \ G_{RMS} \text{ QUALIFICATION}$$

	ACCEPTANCE	QUALIFICATION
1σ	5.16	7.30
2σ	10.32	14.60
3σ	15.48	21.90

IF THE SPRING RATE IS INCREASED TO ADJUST THE NATURAL FREQUENCY TO 50-90 Hz,

$$G_{RMS} = \sqrt{\frac{\pi}{2}(.04)(90)(10)} = 7.09 \ G_{RMS} \text{ ACCEPTANCE}$$

$$G_{RMS} = \sqrt{\frac{\pi}{2}(.08)(90)(10)} = 10.03 \ G_{RMS} \text{ QUALIFICATION}$$

	ACCEPTANCE	QUALIFICATION
1σ	7.09	10.03
2σ	14.18	20.06
3σ	21.27	30.09

Figure 7

UNITED TECHNOLOGIES
HAMILTON STANDARD

ANL 92-142
File: 2.5
5.7

APPENDIX 3

TRMM ROCKET ENGINE MODULE
CONCEPTUAL DESIGN STUDY

PRELIMINARY THERMAL ANALYSIS REPORT

June 15, 1992

Prepared by: Jeffrey Godward
Jeffrey Godward
Analytical Engineer

SUMMARY

A preliminary thermal analysis was conducted as part of the conceptual design study to develop a thermal design for the REM which satisfies the TRMM requirements. The thermal analysis consisted of the following elements: 1) developing a preliminary thermal math model of the REM conceptual design, 2) modeling the worst case thermal environments for the REM configuration, and 3) evaluating the preliminary temperatures for both firing and non-firing conditions, and optimizing the REM thermal design as necessary to satisfy the TRMM requirements. In conjunction with the thermal analysis, an electrical power analysis was performed to estimate the heater power required to maintain all wetted surfaces above the minimum specified temperature, as well as the heater power and duration required to warm the catalyst bed to an acceptable start temperature prior to thruster operation. The results of the preliminary thermal analysis of the REM, summarized in Table I, show that all TRMM requirements are satisfied.

THERMAL REQUIREMENTS

The thermal requirements are a combination of requirements imposed by both NASA/GSFC, documented in the TRMM specifications and separate updates, and Hamilton Standard. The thermal requirements, as well as the basis for each, are listed in Table II.

THERMAL ENVIRONMENT

Definition of the thermal environment to support the REM thermal analysis has been primarily established by discussions between Hamilton Standard and NASA/GSFC, since the TRMM specifications contain only limited information. The REM thermal environment is represented by the spacecraft interface temperature, the incident flux levels, and the supply voltage. Table III defines each of these parameters for the assumed worst case cold and hot environments.

The spacecraft interface temperature is defined as ranging from a minimum of -30°C (-22°F), which reflects the remote REM locations on the "wagon wheel" (pointing away from nadir), to a maximum of 50°C (122°F). Incident flux levels have been supplied by NASA/GSFC for the "4+4" RCS configuration which, although not current, is felt to be representative of at least the worst case cold thermal environment. The flux levels will be updated in the second phase of the hardware modification program to reflect the current "6+6" RCS configuration. The minimum average orbital flux levels occur for a beta angle of 0° (maximum shadow duration). Similarly, the maximum average orbital flux levels occur for a beta angle of 58.5° (minimum shadow duration). The specified supply voltage is 21 vdc to 35 vdc.

THERMAL MODEL

The thermal math model of the REM design incorporates an existing model of the REA 39-5, developed and verified during the COBE HPS program. The preliminary REM thermal model includes a nodalization of the thruster, the support bracket, and the multi-layer insulation (MLI) blanket enclosure, as shown in Figure 1. The node breakdown is as follows:

42 internal nodes (including radiosity nodes)
5 boundary nodes
79 connections

Hamilton Standard's Generalized Heat Transfer Program, H179, was used to solve for nodal temperatures and heat flows. Nodes are simply defined by a thermal mass, surface area, and emissivity. Thermal connections are input as a total conductance for conduction and view factor for radiation. Temperature-variable convection is handled by defining the coefficient and exponent that provides the best power curve fit. Radiosity nodes are created internally to model gray body radiation, greatly simplifying the generation of the radiation connections. A Newton-Raphson method of solution is used so that the time step is insensitive to the magnitude of the thermal mass and conductance product. This heat transfer program allows thermal connections, heat generation rates, and boundary temperatures to be input as a function of time so that pulsing duty cycles can be simulated.

THERMAL ANALYSIS

The valve heater is sized to deliver a minimum power per element of 1.5 Watts at the minimum voltage of 21 vdc. This power level provides 33% margin on the minimum power required to maintain the valve temperature above 8°C (46°F) in the worst case cold environment, ensuring that the control thermostat cycles the valve heater on/off so that power is never consumed continuously. Assuming an 11°C (20°F) maximum difference between the open and close temperature setpoints, the predicted average power consumption for the worst case cold environment is 1.3 Watts. Final selection of the thermostats will consider reducing this dead band to lower average power consumption while not exceeding their qualified cycle life. Figure 2 presents the average REM temperature profile for the cold case.

The function of the catalyst bed heater is to produce a minimum pre-fire temperature of 32°C (90°F), providing essentially unlimited cold start capability, in the worst case cold environment. Presently, the COBE catalyst bed heater is planned to be reused on the TRMM REM. For the conservative condition in which the incident fluxes are assumed to be zero, the equilibrium catalyst bed temperature is 11°C (52°F) with one element powered at the minimum voltage of 21 vdc. The catalyst bed warm-up transient for one element powered at both minimum voltage (21 vdc) and nominal voltage (28 vdc), assuming zero incident flux, is presented in Figure 3. Consideration of the incident fluxes in the cold case is estimated to result in a minimum equilibrium catalyst bed temperature of approximately 32°C (90°F), consistent with the pre-fire temperature requirement. Evaluation of the updated incident flux levels, to be supplied by NASA/GSFC in the second phase of the hardware modification program, is necessary to establish final reusability of the COBE catalyst bed heater. The REM heater power summary, showing rated, peak, and average levels, is presented in Table IV.

The maximum REM component temperatures are established by a thruster firing soakback analysis for the worst case hot environment. Figure 4 presents the equilibrium temperatures of the injector manifold and thrust control valve as a function of firing duty cycle. The maximum manifold temperature is 136°C (277°F) and the maximum valve temperature is 81°C (177°F), both occurring at a duty cycle of about 1%. The heat flow from the REM to the spacecraft under these conditions is also provided as a function of firing duty cycle as shown in Figure 5. The maximum REM heat flow is 4.3 Watts, below the maximum heat flow requirement of 5 Watts.

THERMAL RESULTS

Table I presents a summary of the results of the preliminary thermal analysis and shows compliance with the TRMM requirements.

TABLE I. THERMAL ANALYSIS RESULTS SUMMARY

Parameter	Requirement	Prediction
Thrust Control Valve Temperature	8°C (46°F) min 149°C (300°F) max	8°C (46°F) min 81°C (177°F) max
Injector Manifold Temperature	177°C (350°F) max	136°C (277°F) max
Catalyst Bed Temperature	32°C (90°F) min pre-fire	32°C (90°F) min pre-fire (assuming incident fluxes)
Valve Heater Power	1.5 Watts avg	1.3 Watts avg
Catalyst Bed Heater Power	2.5 Watts max per element at 21 vdc	2.5 Watts max per element at 21 vdc
REM Heat Flow	5 Watts max	4.3 Watts max

TABLE II. TRMM THERMAL REQUIREMENTS

Parameter	Requirement	Source	Basis
Thrust Control Valve Temperature	8°C (46°F) min	NASA/GSFC	Specified minimum RCS operational temperature
	149°C (300°F) max	NASA/GSFC	Specified maximum soakback temperature
Injector Manifold Temperature	177°C (350°F) max	HS	Demonstrated safe hot restart temperature - unrestricted duty cycle operation
Catalyst Bed Temperature	32°C (90°F) min pre-fire	HS	Essentially unlimited cold start capability (no attendant performance degradation)
Valve Heater Power	1.5 Watts avg	HS & NASA/GSFC	Predicted average orbital power
Catalyst Bed Heater Power	2.5 Watts max per element at 21 vdc	HS & NASA/GSFC	COBE catalyst bed heater power level
REM Heat Flow	5 Watts max	HS & NASA/GSFC	Predicted heat flow to spacecraft

TABLE III. WORST CASE THERMAL ENVIRONMENTS

Parameter	Cold Case	Hot Case
Spacecraft Interface Temperature	-30°C (-22°F)	50°C (122°F)
Incident Flux Levels	Zero	58.5° beta angle
Supply Voltage	21 vdc	35 vdc

TABLE IV. REM HEATER POWER SUMMARY

Heater	Rated Power (28 vdc)	Peak Power (35 vdc)	Average Power
Valve	2.7 Watts min per element	8.8 Watts	1.3 Watts
Catalyst Bed	4.4 Watts min per element	14.4 Watts	N/A

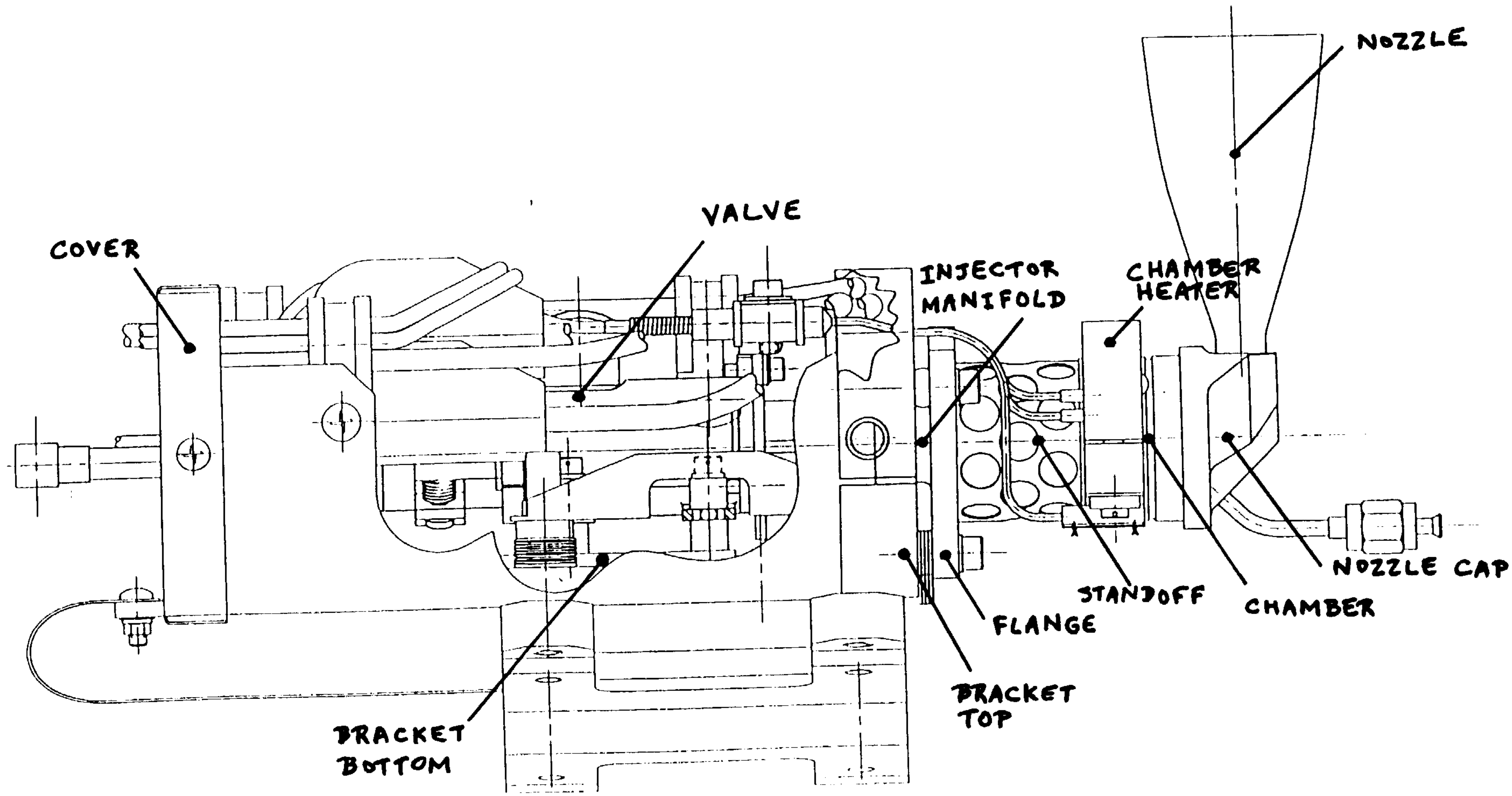


FIGURE 1. THERMAL MODEL NODALIZATION

NOTE : °C (°F)

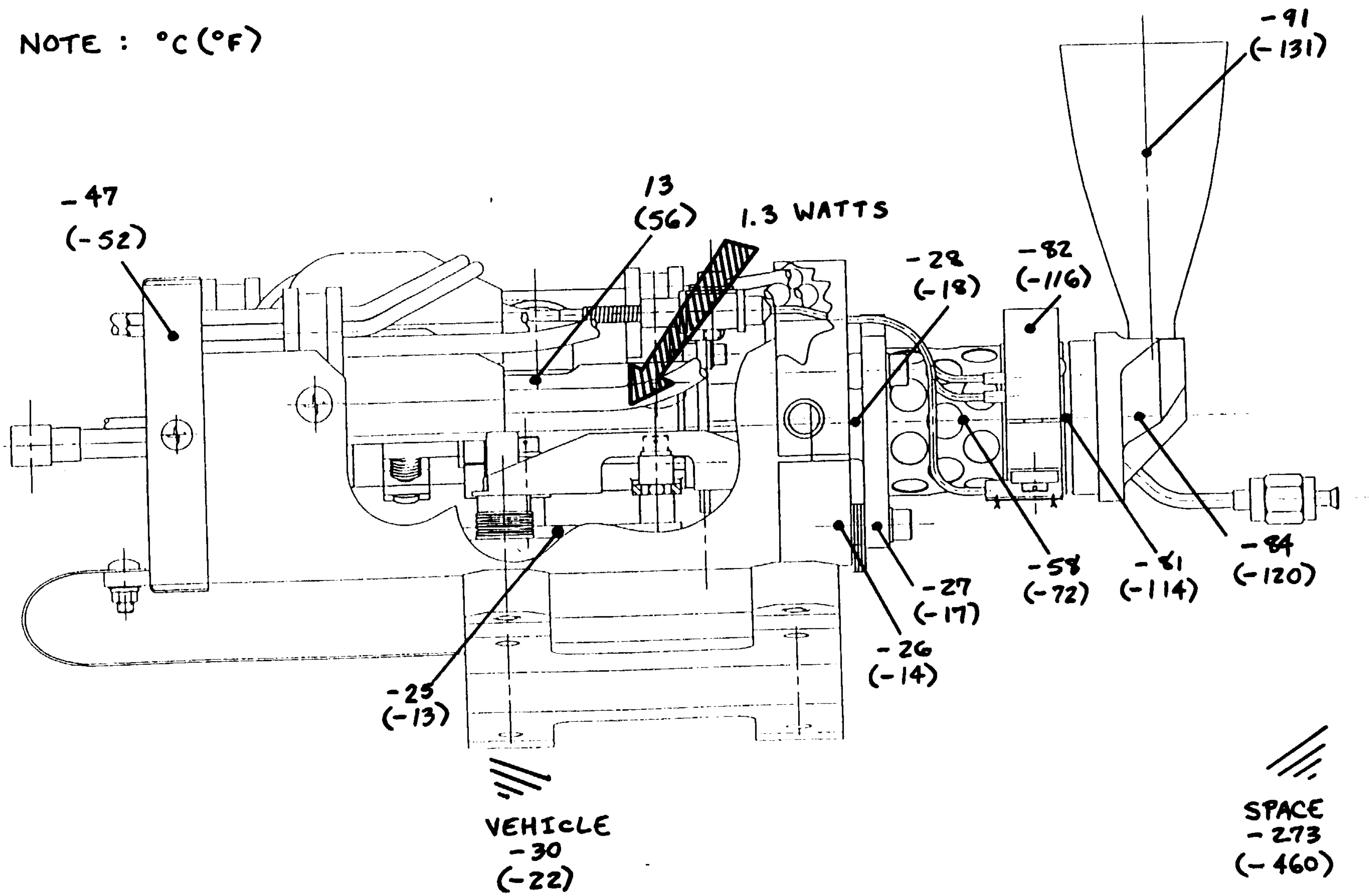
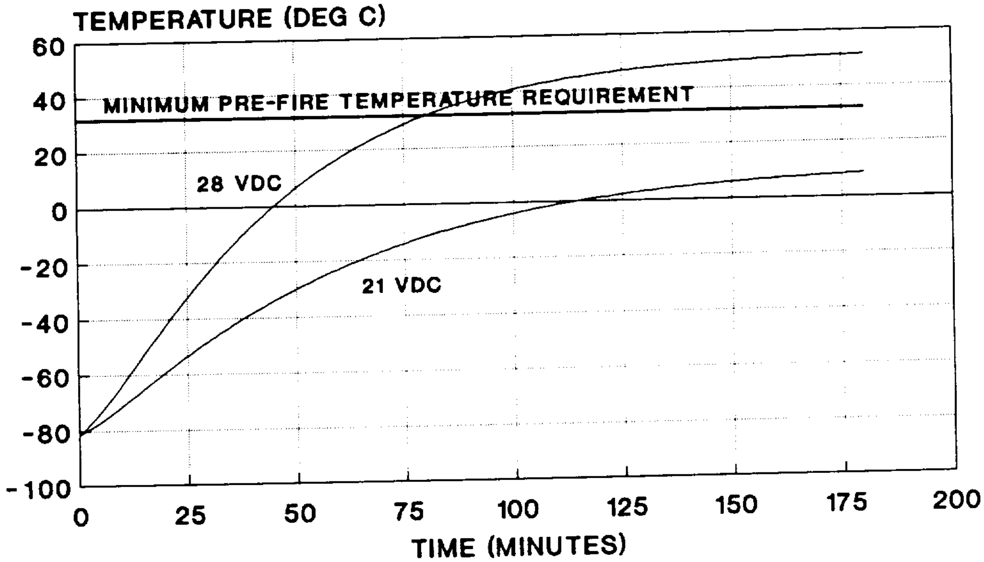


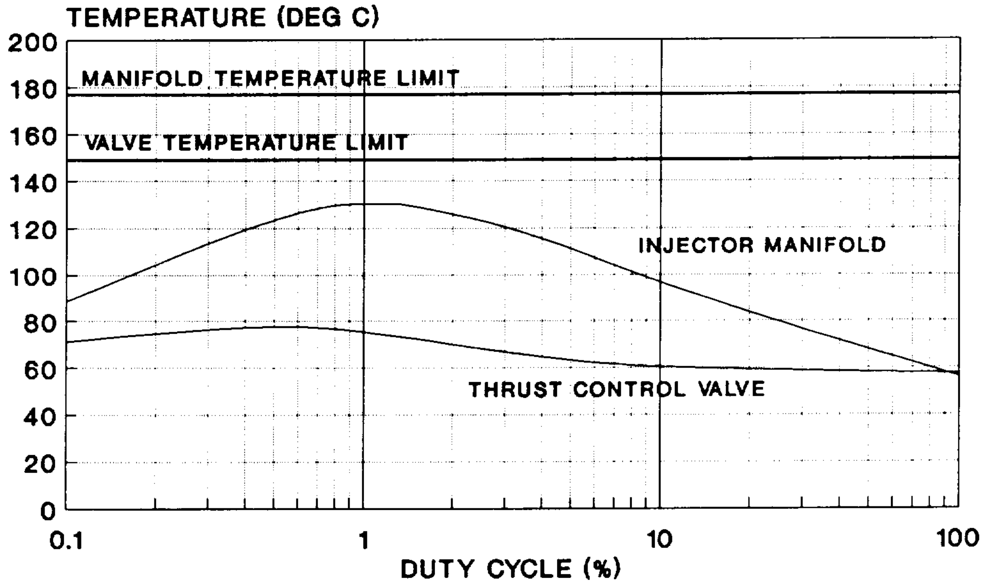
FIGURE 2. COLD CASE AVERAGE TEMPERATURE PROFILE (ZERO INCIDENT FLUX)

FIGURE 3
CATALYST BED WARM-UP TRANSIENT
SINGLE ELEMENT POWERED



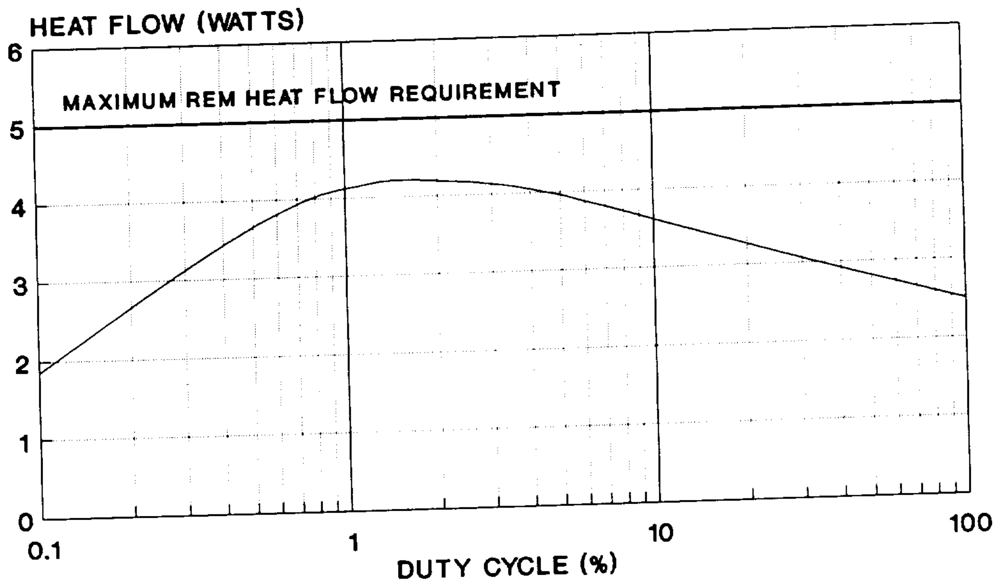
WORST CASE COLD ENVIRONMENT
(ZERO INCIDENT FLUX)

FIGURE 4
EQUILIBRIUM THRUSTER TEMPERATURES VS. FIRING DUTY CYCLE



WORST CASE HOT ENVIRONMENT

FIGURE 5
EQUILIBRIUM HEAT FLOW TO SPACECRAFT VS. FIRING DUTY CYCLE



WORST CASE HOT ENVIRONMENT

TRMM Preliminary Parts, Weight and Materials List

No. Req'd	Part Identification	Weight (lb)	Material Description
1	SVXXXXXX-1 ROCKET ENGINE MODULE, 10 DEGREE, LEFT	-	-
1	SVXXXXXX-1 BRACKET, ANGLE, 10 DEGREE	0.350	AMS4027 (AA6061-T6)
4	MS21208C1015 INSERT, SCREW THREAD (Protective cover attachment)	-	AISI304 per MIL-I-8846
1	SV792570-5 ENGINE ASS'Y, ROCKET	-	-
1	SV792505-1 VALVE, SOLENOID	0.570	*
	VALVE LEADWIRES	0.031	-
1	SV792525-1 THRUSTER, HYDRAZINE	0.518	*
1	SV792556-1 BRACKET, CLAMP SUPPORT	0.005	*
3	69287-103 BOLT, INTERNAL WRENCHING	0.005	AMS5612 per HS179
AR	MS20995C20 WIRE, SAFETY OR LOCK	-	AISI302 or AISI304
14MAX	NAS620C4 WASHER, FLAT	0.003	Any 300 series CRES
1	STSV047M009 PACKING, PREFORMED	-	*
1	SVXXXXXX-1 HEATER AND THERMOSTATS (Similar to SV792622-1)	0.157	-
4	SVXXXXXX-1 THERMOSTAT	-	-
2	STSV513C2A09 CLAMP, MULTIPLE LOOP	-	*
AR	M27500-22SB3T23 CABLE, ELECTRICAL	0.027	*
2	NAS620C4L WASHER, FLAT	-	Any 300 series CRES
2	NAS1101E04-6 SCREW, MACHINE	-	AMS5737 except HT 160
2	MS21043-04 NUT, SELF-LOCKING	-	AMS5735, AMS5737 or AMS5525 Ag plt
AR	M22759/34-22-9 WIRE, ELECTRIC	-	*
1	SVXXXXXX-1 HEATER	-	*
	VALVE HEATER WIRES	0.033	-
2	SVXXXXXX-200 SPLICE, CRIMP (Make from STSV468-58)	-	*
2	SV723317-1 TERMINAL, ELECTRIC	-	*
AR	STSV089A12M21 TUBING, SHRINKABLE	-	*
AR	STSV089A11M01 TUBING, SHRINKABLE	-	*
AR	STSV089A07M21 TUBING, SHRINKABLE	-	*
AR	STSV128R2 TAPE, PRESSURE SENSITIVE	-	*
2	STSV508-1 STRAP, CABLE	-	*
1	SVXXXXXX-1 BRACKET, ENGINE SUPPORT (Main REM Bracket)	0.448	AMS4027 (AA6061-T6)
4	MS21209C0615 INSERT, SCREW THREAD (Valve attachment)	-	AISI304 per MIL-I-8846
1	SVXXXXXX-1 COVER, BRACKET (Hog-out attachment for blanket support)	0.128	AMS4027 (AA6061-T6)
1	SVXXXXXX-1 SUPPORT, MLI (.020 sheet for blanket support)	0.035	AMS4027 (AA6061-T6)
2	SV777198-1 STRAP, NUT PLATE	0.052	AMS4027 or AMS4117 (AA6061-T6)
8	SV714000N20 BUSHING, SHOULDERED	0.068	HS279H925 chrome plated
64	SV723310-4 SPRING, BELLEVILLE	0.050	AISI302 spring temper
8	AN960C416L WASHER, FLAT	0.011	MIL-S-5059, AMS5510 or AMS5512
12	SV791184-202 PACKING, PREFORMED (Make from 69494J10)	0.002	HS701 Class 1
1	SV792506-1 HEATER AND SENSOR, CHAMBER (6 H/S's must be reworked from -2)	0.185	*
	HEATER AND SENSOR LEADWIRES	0.012	-
1	NAS1714CT3-4K CLAMP, LOOP-CUSHIONED	0.013	*
3	MS21043-06 NUT, SELF-LOCKING	0.002	AMS5735, AMS5737 or AMS5525 Ag plt
1	NAS1352N06-8 SCREW, CAP, SOCKET HEAD	0.004	AMS5731 or AMS5737 except HT 160
2	AN960C6 WASHER, FLAT	0.002	MIL-S-5059, AMS5510 or AMS5512
2	SV748535-3 BUTTON, PIVOT	0.038	*
8	SV748716-78 SPACER, FLAT (Valve thermal isolation)	0.029	Glass reinforced phenolic G3HT
1	SV784102-2 FOIL, CONDUCTIVE (Chamber heater)	-	*
16	NAS620C6L WASHER, FLAT	-	Any 300 series CRES
4	NAS1352N06H14 SCREW, CAP, SOCKET HEAD	-	AMS5731 or AMS5737 except HT 160
2	NAS1352N06-6 SCREW, CAP, SOCKET HEAD	0.006	AMS5731 or AMS5737 except HT 160
AR	STSV128AH4 TAPE, PRESSURE SENSITIVE (Valve heater)	-	*
1	SVXXXXXX-1 CLAMP, THERMOSTAT (Similar to SV792559-1)	0.050	*
1	SV792280-2 SENSOR, TEMPERATURE	0.003	*
AR	STSV128AC4 TAPE, PRESSURE SENSITIVE (Wire bundles)	-	*
9	NAS620C6 WASHER, FLAT	0.002	Any 300 series CRES
2	NAS1352N08-16 SCREW, CAP, SOCKET HEAD (TCA mounting)	-	AMS5731 or AMS5737 except HT 160
2	NAS620C8 WASHER, FLAT	-	Any 300 series CRES
3	MS21043-08 NUT, SELF-LOCKING	-	AMS5735, AMS5737 or AMS5525 Ag plt
1	SV748536-5 SCREW, SHOULDER (TCA mounting)	-	*
2	AN565AC4H7 SETSCREW, HEXAGON (TCA adjust)	-	*
4	SV755456-1 SHIM (TCA adjust)	-	*
1	SV755456-2 SHIM (TCA adjust)	-	*
AR	SV726501 TAPE, LACING	-	*
1	NAS1101E06H10 SCREW, MACHINE (Thermostat mounting)	0.003	AMS5737 except HT 160
1	STSV266-113 LABEL, ELECTRICAL HARNESS IDENT	-	*
1	STSV266-114 LABEL, ELECTRICAL HARNESS IDENT	-	*
4	AN960C8 WASHER, FLAT	0.002	MIL-S-5059, AMS5510 or AMS5512
1	SV792748-1 SHUNT, THRUSTER	0.004	*
4	NAS1802-3-24 SCREW, HEX (Belleville stack-up)	0.052	AMS5731 or AMS5737
1	STSV445S3T07 CLAMP, CUSHIONED	0.012	AISI302/Glass reinforced silicone
1	STSV445S3T04 CLAMP, CUSHIONED	0.009	AISI302/Glass reinforced silicone
14	NAS620C10L WASHER, FLAT	0.018	Any 300 series CRES
6	MS21043-3 NUT, SELF-LOCKING	0.004	AMS5735, AMS5737 or AMS5525 Ag plt
4	NAS1190E3P8 SCREW, PAN HEAD (MLI support bracket)	0.012	AMS5737
1	SVXXXXXX-1 STRAP, BONDING	-	Copper
2	NAS1351N3-10 SCREW, CAP, SOCKET HEAD (Bonding strap)	-	AMS5731 or AMS5737 except HT 160
1	SVXXXXXX-1 ELBOW, FLUID, .250 DIA	0.021	AISI304L CRES
1	SVXXXXXX-1 MLI THERMAL BLANKET	0.103	*
AR	MISC	0.100	-
	Total	3.179	

* Same as Cobe

NASA Report Documentation Page

1. Report No. TRMM-SER-705	2. Government Assession No.	3. Recipient's Catalog No.
4. Title and Subtitle Final Report - Conceptual Design Study For the use of COBE Rocket Engines on the Tropical Rainfall Measuring Mission		5. Report Date 16 June 1992
		6. Performing Organization Code
7. Author(s) Hamilton Standard		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address Hamilton Standard Windsor Locks, Connecticut 06096		11. Contract or Grant No. NAS5-31889
12. Sponsoring Agency Name and Address NASA/Goddard Space Flight Center Greenbelt Road Greenbelt, MD 20771		13. Type of Report and Period Covered Final Report (1/10/92 thru 6/16/92)
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This document contains a Final Report for the Conceptual Design Study for the use of COBE Rocket Engines on the Tropical Rainfall Measuring Mission (TRMM). It was prepared by Hamilton Standard for NASA/Goddard Space Flight Center under contract NAS5-31889. The report concludes that the COBE thrusters can be used for the TRMM mission and a preliminary design of a Rocket Engine Module is described.

17. Key Words (Suggested by Author(s)) TRMM REM COBE REA		18. Distribution Statement Unclassified - Unlimited	
19. Security Classif. (of this report)	20. Security Classif. (of page)	21. No. of Pages 200	22. Pric

NASA FORM 1626 Oct 86