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FINAL REPORT

APOLLO SERVICE MODULE REACTION CONTROL SYSTEM ENGINE INJECTOR/CHAMBER SEAL STUDY [redacted]

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APOLLO SERVICE MODULE
REACTION CONTROL SYSTEM ENGINE
INJECTOR/CHAMBER SEAL STUDY

June 1966

Contract NAS 9-4775

TMC 3008

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I. INTRODUCTION

This final report, submitted in partial fulfillment of Contract NAS 9-4775, summarizes the work performed on this contract during the period from 12 July 1965 through 12 May 1966. The purpose of the Injector/Chamber Seal Study was to develop and evaluate an injector head-to-combustion chamber seal for the Apollo Service Module Reaction Control System (S/M RCS) Engine that has a thermal resistance of 5 Hr-°F/BTU consistent with required sealing and structural integrity.

The Apollo S/M RCS Engine is radiation cooled. During "ENGINE-OFF" periods, heat conducted from the space vehicle to the injector head of the engine is further conducted through the injector/combustor seal to the combustion chamber with subsequent radiation to space. If heat flow is excessive, the injector head temperature is depressed and propellant in the injector head assembly may freeze. Use of heaters would correct this problem. An alternate approach, consistent with the objective of this program, is to provide thermal blockage at the injector/combustor interface.

II. SUMMARY

The program, which was performed in general accordance with the program schedule, Figure 1, during the period from 12 July 1965 through 12 May 1966, successfully met the technical objectives.

Two (2) out of six (6) various seal design/material combinations, developed and evaluated in the program exceeded the objective seal thermal resistance (R = 5.0 Hr-°F/BTU) consistent with meeting structural and leakage requirements.

Three different seal design configurations, generically identified as: 1) Composite, 2) Straight Thinwall, and 3) Conical Thinwall were developed. Each configuration was fabricated from two (2) materials and/or material systems resulting in a total of six (6) design material combinations. Figure 2 describes these combinations and Figure 3 illustrates the application of these designs to the Apollo S/M RCS Engine. Current Apollo Engine seals, used in the production of qualified engines, have a thermal resistance of 0.5 Hr-°F/BTU. The six (6) combinations, with their respective demonstrated thermal resistances are tabulated below. As shown, the composite designs demonstrated resistances approximately six times greater than the current Apollo seals.

SEAL TYPE	MATERIALS	SEAL RESISTANCE (Hr-°F/BTU) DEMONSTRATED
Conical Thinwall	6AL-4V Ti	6.6 (6.7)
Conical Thinwall	Rene' 41	5.2
Composite	6AL-4V Ti + Zirconium Oxide	3.0 (2.9)
Composite	Rene' 41 + Zirconium Oxide + 6AL-4V Ti	2.8
*Straight Thinwall	6AL-4V Ti	2.1
*Straight Thinwall	Rene' 41	1.3

* = Seals designed with R $\leq$ 5.0 to demonstrate the potential of a simple monolithic design in combination with the existing seal cavity.

( ) = Parenthetical values were obtained with seals contained in actual Apollo S/M RCS qualification-type engines. Other values shown were obtained in simulated engine tests.

Although the contract did not place a constraint on the seal dimensional envelope, it was desirable to meet program objectives with seals that fit the current seal cavity. Composite and straight thinwall seals were designed to utilize the existing seal cavity. Conical thinwall seals were designed to fit an extended seal cavity which requires a simple modification to the engine injector component to facilitate retrofit, as shown in Figure 3.

All of the seals met mechanical design objectives by demonstrating acceptable structural and leakage performance within Apollo S/M RCS engine operational limits.

Positive structural margins were also demonstrated by all seals after exposure to combined compressive and tensile loadings and temperatures corresponding to conditions exceeding ultimate design factors.

The program combined design and analytical studies with test evaluation of materials and full scale seals. Experimental full scale seals were subjected to structural and non-structural bench tests in addition to thermal and firing tests in qualification-type Apollo S/M RCS engines.

The following itemization describes concisely the approximate chronology of events which took place:

A. Establishment of Design Criteria

B. Preliminary Design and Analytical Studies

C. Materials Selection, Procurement and Testing

D. Design Layout, Analysis and Design Review which resulted in the selection of six (6) candidates for full scale seal evaluation.

E. Fabrication of Full Scale Seal Specimens and Special Test Hardware

F. Formulation and Implementation of Development Test Plans - designed to screen the structural, thermal, vibration and corrosion performance of all candidate seals.

G. Selection of, and Subsequent Final Evaluation Testing of Two (2) Seal Designs - which exhibited the best performance and/or showed the best potential for meeting program objectives. These seals, chosen from the original six candidates, were subjected to thermal and firing tests utilizing Apollo S/M RCS Qualification-type engines.

H. Throughout the program period, design and conceptual study effort was maintained on an intermittent basis. These studies, supported by evaluation test results, were aimed at improving the performance of seal designs undergoing test evaluation as well as new conceptual designs. The studies also considered the possibility that intermediate seal thermal resistances ($\leq$ 5.0 Hr-°F/BTU) might be acceptable to NASA.

In the final phase of this effort, a redesigned composite seal configuration (Figure 4) was established which is typical of a design concept theoretically capable of meeting the thermal resistance objective within the existing Apollo S/M RCS engine seal cavity.

III. CONCLUSIONS

For all six (6) various seal design/material combinations developed and evaluated in the program, the best overall thermal, structural and leakage performances, consistent with program objectives, were demonstrated by the conical thinwall seals fabricated from 6AL-4V Titanium and René 41 materials. Seal thermal resistances = 6.7 and 5.2 Hr-°F/BTU, respectively, were achieved.

These configurations, as can be seen in Figure 3, require a simple modification to the injector head component to obtain the additional seal cavity length required for this design.

The straight thinwall seal fabricated from 6AL-4V Titanium demonstrated what is believed to be the highest thermal resistance obtainable for a simple monolithic design capable of fitting the existing seal cavity. To increase the resistance of this single heat path design from the demonstrated 2.1 to the objective 5 Hr-°F/BTU, the overall (heat path) length of the seal would have to be increased proportionally. The resultant configuration would therefore share the same retrofit disadvantage as the conical thinwall design, i.e., engine component modification would be required. However, component modifications may not necessarily be required if an intermediate resistance ($\geq$ 2.1 but $\leq$ 5.0) is acceptable.

The only configuration showing promise of meeting the objective thermal resistance within the existing seal cavity is the composite type fabricated from 6AL-4V Titanium and Zirconium Oxide materials.

Although the present composite design failed to achieve the predicted thermal performance (seal R = 3.0 Hr-°F/BTU was demonstated, 4.67 to 5.26 was predicted), the concept and the materials used therein were proven to be practical. The design concept employs two (2) conductive heat paths. One heat path uses the Titanium jacket and the other parallel heat path uses the Zirconium Oxide (Zircoa "C") compression members. The cause of the low resistance, which was verified by tests that successfully isolated these internal heat paths, was attributed to the unexpected high thermal conductivity of the Zircoa "C" material (K = 1.2 instead of .54 BTU-ft/ft^2/Hr/°F, as used in the thermal analysis for this design). Structural properties of this material, however, are suitable for application to this design concept, as indicated by various tests conducted on small scale material specimens and full scale seal evaluation tests.

Attempts at reducing the thermal conductivity of the Zirconium Oxide material were only partially successful. Experimental Zirconium Oxide materials, with lower bulk densities aimed at achieving a K $\leq$ .54 consistent with F_{cu} (Ultimate compressive strength) $\geq$ 150,000 psi were tested and it was concluded that the required high degree of porosity (low bulk density) would result in less than adequate compressive strength. As a result, the material found to be most suitable, both structurally

and thermally, was the original Zircoa "C" fully dense material selected for use in composite seals.

A redesign of the composite seal was initiated to increase its thermal resistance to R = 5.0 Hr-°F/BTU. This design utilized the original Zircoa "C" material for compression elements but through a unique design concept lengthened the thermal flow path through the compression members. This design required Zircoa "C" cylinders smaller in diameter and length than those previously used. Unfortunately, preliminary structural tests completed just before the close of the program indicated that these cylinders would not provide the same compression ultimate as the previous cylinders and did not satisfy structural requirements. No further investigations were possible due to program limitations.

The basic design concept is considered to be potentially suitable for raising the composite design to the required resistance level.

All full scale seals, evaluated in this program, demonstrated structural and leakage performance equal to or greater than required.

During firing tests with two (2) Apollo S/M RCS qualification-type engines which contained the conical thinwall seal fabricated from Titanium and the composite seal made from Titanium and Zirconium Oxide, engine temperatures during steady state and soakback after steady state operation were within acceptable limits. Temperatures agreed reasonably well with computer predictions of engine soakback transients following steady state runs.

During pulse mode operation with a 50 milliseconds ON/50 milliseconds OFF duty cycle, which was arbitrarily chosen to demonstrate 5500 engine starts, the engine that contained the conical thinwall seal, exhibited what is believed to be a sensitivity to the magnitude of the seal resistance. The second engine, similarly tested but containing the composite seal, did not exhibit behavior which would indicate restrictions to this duty cycle. It was deduced that the high thermal resistance of this seal (R = 6.7 Hr-°F/BTU) reduced thermal conduction from the combustor to the injector head such that after 980 pulses of the first pulsing run, the combustor flange temperatures reached an unexpected level of 1100°F. At this point extreme caution was exercised and the run was terminated prematurely. Subsequent pulsing runs, with this engine, were limited arbitrarily to 600 cycles each until a total of 5500 pulses was accumulated. The second engine, which contained the composite seal (R = 2.9 Hr-°F/BTU) tested at the same 50/50 duty cycle, exhibited combustor flange temperatures of only 330°F at the conclusion of 1400 cycles (pulse tank capacity).

These limited tests suggested a variance of duty cycle limitation with seal thermal resistance. The extent to which this limit on the number of pulses may vary with different duty cycles, O/F ratio, and seal thermal resistance was not determined in these tests.

IV. RECOMMENDATIONS

On the basis of knowledge gained in this program, it is recommended that additional test evaluation and analysis of engines containing the seals developed in this program be made to further predict and/or demonstrate their potential for meeting the Apollo S/M RCS engine specification requirements.

Utilizing the seals developed in this program, further development tests to demonstrate their capability for meeting Apollo S/M RCS Qualification Firing Test requirements are recommended:

A. Conduct development tests in accordance with the Apollo Qualification Test Plan. These firing tests would include:

   1. Mission Duty Cycle, including off-limit, O/F and thrust
   2. Propellant temperatures ranging from 40°F to 100°F
   3. Pulse widths ranging from 10 milliseconds to 5 seconds.

In conjunction with these firing tests, if pulsing duty cycle sensitivity is detected, it is further recommended that:

B. A determination be made on the extent to which seal resistance may limit pulsing duty cycles. A matrix, mapping the duty cycle and maximum number of pulses obtainable within acceptable engine temperatures, can be generated for each seal resistance.

In concert with these tests, additional analytical effort is also recommended. This would include:

C. Modification and verification of the computer thermal model of the Apollo S/M RCS engine, developed on this program, to extend its use in analytically evaluating the effects of different seal resistances on the thermal behavior of the engine during:

   1. Non-Operating Modes (cold soak and sun soak)
   2. Operating Modes (steady state and pulsing)

D. Compilation and analysis of cold soak test data to verify the combustion chamber thermal radiation properties which have been used by Marquardt and the Industry for this engine.

E. Analytical investigation be conducted on alternate methods for reducing engine "cold soak" heat loss and/or minimizing suspected side effects such as the link between engine hard starts with depressed combustor temperatures that might result from placing a high thermal resistance between the injector head and combustion chamber. Thermal isolation of the combustor from the expansion bell, for example, should be considered as a possible alternate approach.

Should further consideration be made by NASA to incorporate a seal with a high thermal resistance in the Apollo S/M RCS engine at the injector head/combustor interface, it is recommended that:

F. Additional design trade-off studies be made to determine which seal resistance or seal designs and engine component modifications (if required) are best suited for:

1. New production engines only.
2. Retrofit of engines in the field only.
3. Both

If permissible, for seals (R = 5.0) which require engine component modifications to achieve an extended seal cavity, the simple conical thinwall type seals, which have demonstrated superior overall performance consistent with program objectives, are recommended. Consideration however, should be given to increasing the hoop strength capability equivalent to the present Apollo S/M RCS engine seal capacity in the event that high seal cavity pressures occur. If this seal is adopted, the preliminary design of this improved configuration (shown in Figure 5) should be completed and evaluated in full scale tests.

If a seal suitable for direct retrofit is required and an intermediate thermal resistance ($R \geq 0.5$ but ≤ 5.0) is acceptable, simple monolithic designs (such as straight thinwalls) are recommended.

If a seal with (R = 5.0) and direct retrofit is required, the modified composite seal design concept (Figure 4) is recommended for further study.

V. TECHNICAL DISCUSSION

Work performed during the program period (12 July 1965 through 12 May 1966) consisted of phases and tasks, as itemized by the program schedule, Figure 1. The original program period (12 July 1965 through 12 April 1966) shown in Figure 1, was extended through 12 May 1966 by supplemental agreement with NASA. In consideration for this extension, Marquardt performed additional studies and tests required to augment the program achievements at no additional cost to the Government.

Accomplishments on each item are categorized and discussed separately in conformance with the program schedule.

PHASE I

3.1 Material Selection & Design Studies

3.1.1 Design Criteria

Injector head/combustor seals, for the Apollo S/M RCS engine, have three (3) primary functions:

1. Prevent gas from leaking out of the combustion chamber at the joint between the chamber and the head.
2. Provide for structural mounting of the combustor to the injector head by supplying adequate compression loading in combination with attach hardware.
3. Control* conductive heat transfer between the injector head and combustion chamber. (*Interpreted to mean "minimize" for high thermal resistance seals.)

On the basis of these functions, temperature and load criteria were established for the present seal contained in the now qualified Apollo S/M RCS engine. Figure 6, tabulates the very high safety margins calculated for various points on this seal and adjacent components for conditions deemed most critical. These loads, temperatures and margins represent a base point from which new design criteria were established.

Figure 7 summarizes the basic design criteria developed specifically for high thermal resistance seals in this program. These criteria were derived from the Apollo S/M RCS engine specification requirements in combination with analyses previously performed by Marquardt in the Apollo Program (on separate contract) in addition to analyses conducted on this program. Those analyses completed under this contract are discussed in other portions of this text.

Seal leakage criteria, not listed in Figure 7, was in conformance with acceptance requirements for Apollo S/M RCS engines currently in production. The acceptance requirement was used only as a basis for judging leakage performance of seals developed and tested in this program and not used as design criteria.

3.1.2 Establish Materials Mechanical & Physical Property Data

Literature surveys were conducted in the search for materials and/or material property data suitable for application to high thermal resistance seals. Figure 8 summarizes these materials and data from which four (4) candidate materials, listed below, were selected:

1. 6AL-4V Titanium Alloy
2. René 41
3. L-605, Cobalt Base Alloy (20% cold worked)

4. Zirconium Oxide (Zircoa "C", full dense)

All of these materials were proven to be suitable for high thermal resistance seals developed in this program by test substantiation.

The F_{c_u} and K values for Zirconium Oxide, shown in Figure 8, were found to be inconsistent with Marquardt test results which indicated that F_{c_u} ranged from 130 to 148 ksi and K (thermal conductivity) was 1.2 instead of .54 BTU-ft/ft^2/Hr/°F. The bulk density of this material was 347 lbs/ft^3. Marquardt tests established the K = 1.2 value at 0°F to 160°F. This value agreed reasonably well with additional survey information obtained later in the program and shown in Figures 9a and 9b. These figures indicate the variation in Zirconium Oxide thermal conductivity with bulk density and temperature.

More recent survey and test information revealed a relationship between mechanical properties, viz., compressive strength and thermal conductivity versus bulk density. Alternate materials with lower bulk densities (269 and 275 lbs/ft^3) aimed at meeting thermal and structural requirements were procured and tested. Test results, reported in detail in Attachments 6 & 11 indicated that:

a. The relationship of bulk density and thermal conductivity was not in conformance with Figures 9a and 9b.

b. Mechanical properties (compressive strength) consistent with meeting the required K = .54, were unattainable.

A comparison of all Marquardt test data on Zirconium Oxide and consideration of the inconsistencies between these data and literature survey information led to the conclusion that the best low conductivity material, suitable for composite seal designs, was the fully dense (347 lbs/ft^3) Zirconium Oxide (Zircoa "C") originally selected.

3.1.3 Design Layout and Conceptual Studies

Initially, design studies were aimed at design concepts suitable for consideration as candidates for subsequent evaluation in this program. Follow-on effort, aimed at improving the performance of these candidate designs, continued throughout the program period on an intermittent basis. In addition to improvement of seal designs, new concepts were also studied.

These studies were supported by evaluation test results obtained in later phases of the program. In the final phase of this effort, made possible by a negotiated schedule extension, an improved composite seal design was established which employed proven design features and materials.

Attachment 14 summarizes various design concepts and approaches considered in meeting the technical objectives. Details and supporting analyses for the improved composite seal design are also presented.

An important facet in establishing the initial seal design concepts was the formulation of design criteria specifically suited to high thermal resistance seals. As part of the design study effort and in conjunction with Item 3.1.1, various analyses were conducted which established the basic design criteria (Figure 7). Attainment of these criteria required dynamic, structural and heat transfer analytical support. The bases for these analyses are briefly described below:

1. Dynamic Analysis

The seal designs must all be capable of withstanding high internal pressure. Two separately distinct phenomena can be responsible for generating high seal cavity pressures. The first, a pressure originating in the combustion chamber, is due to engine ignition overpressure which is transmitted to the seal cavity. The second phenomenon is attributed to pressures generated in the seal cavity resulting from reaction of accumulated propellants within the cavity.

Analysis indicates a seal cavity maximum of 1200 psia due to a combustion chamber pressure of 1500 psia. 1500 psia is the chamber design pressure. The design criteria of 10,000 psi for this phenomena is based on the capabilities of the present Apollo engine L-605 seal. Analysis shows this pressure could be attained with a seal cavity propellant fill of 20%.

Attachment 1 reports the analysis and its conclusions which resulted in establishing the above important parameters in the design criteria for high thermal resistance seals.

2. Thermal Analysis

The presence of a high thermal resistance seal in the Apollo S/M RCS engine design (current seal resistance is 0.5 Hr-°F/BTU) prompted a thermal analysis of thermal gradients at the injector head/combustor joint. Parameters of particular importance are the temperature transients of the injector head, seal, combustor flange and attach hardware during the engine heat soakback period following a steady state engine firing. These transients, combined with the expansion characteristics of the hardware at the joint, have a direct affect on the seal clamping loads.

The thermal model analysis, Attachment 2, employing an analytical thermal model of the engine, showed that the peak temperature of the combustor flange will increase from 600°F to approximately 750°F as the seal resistance is increased from 0.5 to 5.0 Hr-°F/BTU. The peak temperature of the injector head (at a time coincident with the 750°F flange temperature) will decrease from 230°F to 190°F for the same

increase in seal resistance. These temperatures were considered in subsequent seal structural analyses and found to be acceptable.

The thermal analyzer model, methods employed in conducting the analyses and analytically computed results are also described in Attachment 2.

PHASE II

3.2 Test of Candidate Designs and Materials for Thermal and Structural Properties

3.2.1 Detail Drawings - 3 Design/2 Materials

The effort associated with this task resulted in the completion of three (3) candidate seal designs, each employing two (2) materials and/or material systems. Drawings for these six (6) seals were released for fabrication and test evaluation. Figure 3 illustrates the three (3) design configurations, as applied to the Apollo S/M RCS engine. Four (4) of these seals, two (2) composite types and two (2) straight thinwall types, utilize the existing seal cavity. The remaining two (2) seals, conical thinwall types, require minor engine modification (injector head only) to extend the seal cavity length.

Analytical estimates of thermal resistance for these seals were:

SEAL TYPE	MATERIALS	PREDICTED SEAL RESISTANCE (Hr-°F/BTU)*
Conical Thinwall	6AL-4V Ti	5.30/6.20
Conical Thinwall	René 41	3.68/4.33
Composite	6AL-4V Ti + Zirconia	4.67/5.26
Composite	René 41 + Zirconia + 6AL-4V Ti	3.77/4.30
Straight Thinwall	6AL-4V Ti	1.82/2.21
Straight Thinwall	René 41	1.21/1.48

(*) - Denotes values for internal seal resistance only; contact resistances, minor and in the positive direction, are neglected.

Detail drawings of these seals are presented in Figures 10 through 20.

The above design/material combinations were designed to satisfy a seal cavity pressure (1200 psi limit) consistent with the Apollo S/M RCS engine combustion chamber design criteria for (10σ = 1500 psia). It was decided to use the high pressure criteria (10,000 psi), corresponding to the maximum pressure capability (yield) of the present Apollo S/M RCS engine seal, for follow-on conceptual designs.

It is noted that not all six combinations were calculated to meet the objective thermal resistance = 5.0 Hr-°F/BTU. Taking into account the fact that all contact resistances were neglected in the calculations, a probability existed that all designs, with the exception of the straight thinwall seals, would attain or closely approach the thermal objective under actual test. Straight thinwall seals were purposely designed to fit the existing seal cavity in order to demonstrate the structural and thermal capabilities of a simple monolithic design. To increase the resistance of this single heat path design, analytical determinations utilizing thermal test data can be made to establish what length of seal or engine modifications are required to meet the R = 5.0 Hr-°F/BTU or intermediate resistances if desired.

Stress and thermal analyses were conducted concurrently with the detail design of the six candidate design/material combinations.

Stress analysis, Attachment 3, was based on the original Apollo S/M RCS qualified engine design criteria. These criteria were consistent with load and temperature conditions for an engine equipped with a seal having a thermal resistance of 0.5 Hr-°F/BTU.

Stress analysis, Attachment 4, was based on a review of Attachment 3 and temperature criteria derived from the thermal model analysis, Attachment 2. This analysis verified that clamping loads, as affected by new thermal gradients, did not change beyond acceptable design limits. Structural safety margins for these seals have, in fact, been increased over those previously calculated in Attachment 3.

Thermal analysis (heat transfer) for each seal design is presented in Attachment 5. The minimum and maximum thermal resistances and the methods used in the analyses are presented therein.

3.2.2 Fabricate NASA-Approved Designs - 3 Design/2 Materials

Fabrication and inspection of all seals approved by NASA for evaluation testing (Figures 10 through 20) was completed with four (4) specimens manufactured for each of the six (6) design/material combinations. Figures 21, 22, and 23 are photographs of typical composite, straight thinwall and conical thinwall seals.

An extensive dimensional inspection was performed on each seal and/or seal component. All components exhibited good agreement (in the unrestrained condition) with blueprint specifications. Composite seal jackets (Figures 11 & 16), however, were distorted by residual machining stresses as expected. Figure 24 describes the type of distortion which prevailed. Clamping loads were estimated to be sufficiently high to eliminate or minimize this distortion while assembled. Composite seals have been successfully assembled and tested with no apparent problems resulting from these distortions.

PHASE II (Ref.)

3.2.3 Structural Testing - Seals* and Bearing Tests***

3.2.4 Thermal Testing - Seals*

PHASE III

EXPERIMENTAL TESTING OF SEALS

3.3.1 Fabricate NASA-Approved Designs** - 2 Design or 1 Design/2 Materials

3.3.2 Buildup Rocket Engine and Fabricate Components that have Design Changes

3.3.3 Tests of Approved Seals*

3.3.3.1 Thermal - 2 Design or 1 Design/2 Materials

3.3.3.2 Pressure Check (Leakage) - 3 Design/2 Materials

3.3.3.3 Vibration - 3 Design/2 Materials

3.3.3.4 Compression - 2 Design or 1 Design/2 Materials

3.3.3.5 Additional Tests - 3 Design/2 Materials

--- NASA/TMC Final Approval - Firing Test Plan

* = Phase II and III Evaluation Tests of Full Scale seals were combined.

** = Fabrication of additional seals was not required.

*** = A limited number of small scale specimen tests of candidate seal materials were performed to obtain material property data.

Use of full scale seals for Phase II testing was made possible by the unexpected availability of seal materials in proper sizes. The discussion, which follows, separates full scale seal tests from small scale specimen tests.

3.2.3, 3.2.4 & 3.3.3 Full Scale Seal Tests (3 Design/2 Materials)

A test plan, MTP 0041 (Marquardt Test Plan), was formalized and issued to control all Phase II and III testing of full scale seals in this program. The test plan, Attachment 15, is divided into six (6) appendices which define detailed evaluation test specifications. Appendices A thru D defined the bench tests designed to screen the structural, thermal, vibration and corrosion performance of all six candidate design/material combinations while contained in special test rigs and/or

non-fireable engines. Appendices E and F defined the detailed test specifications for thermal and firing tests of seals while contained in Apollo S/M RCS qualification type engines. Prior to issuance of Appendix F, NASA review and approval was obtained. The latter two tests (E and F), discussed later in this text, are excluded from the following discussion.

Figure 25, Seal Evaluation Test Matrix, describes the test plan in concise form. Test objectives, test conditions, variables, etc. of the test plan, as well as completion status of evaluation tests, are tabulated in the matrix.

Initial steps taken to implement the test plan consisted of design and fabrication of special test rigs and preparation of test facilities. Figures 26 and 27 are layouts describing special test rigs utilized in structural, thermal and corrosion tests (plus seal load tests not defined in the test plan). All testing was performed in Marquardt facilities.

The test report, Attachment 8, documents the test results obtained in the static structural evaluation of full scale seals per MTP 0041, Appendix A. For convenience, this report also covers evaluation of leakage versus preload data for seals exposed to cold soak (sub-zero), high vacuum environments experienced in thermal tests (seal thermal resistance measurement) per MTP 0041, Appendix B. The test report shows that all seals tested met design objectives by demonstrating structural performance within elastic limits under combinations of compressive and tensile loadings and temperatures corresponding to ultimate design factors. Additionally, all seals exhibited leakage performance equal to or greater than required within Apollo S/M RCS engine operational limits. Positive structural margins were also demonstrated by all seals after exposure to combined compressive and tensile loadings and temperatures corresponding to conditions exceeding ultimate design factors, thus verifying analytical predictions.

Exhibited in Test Report, Attachment 7, are test results obtained in thermal tests of all seals per MTP 0041, Appendix B, while contained in simulated engines.

Demonstrated seal resistances are summarized below for all six design/material combinations tested:

SEAL P/N and TYPE	MATERIAL	SEAL RESISTANCE (Hr.-°F/BTU) Demonstrated	Predicted
T-13622 Conical Thinwall	6AL-4V Ti	6.6	5.30/6.20
T-13621 Conical Thinwall	Rene' 41	5.2	3.68/4.33
T-13618 Composite	6AL-4V Ti + Zirconia	3.0	4.67/5.26
T-13619 Composite	René 41 + Zirconia + 6AL-4V Ti	2.8	3.77/4.30
T-13611 Straight Thinwall	6AL-4V Ti	2.1	1.82/2.21
T-13612 Straight Thinwall	Rene' 41	1.3	1.21/1.48

Four (4) of the designs performed as predicted by design analysis. Two (2) designs, P/Ns T-13618 (Titanium + Zirconium Oxide) and T-13619 (Rene' 41 + Zirconium Oxide), indicated approximately 50 percent of the design resistance.

The low thermal resistances (3.0 and 2.8 Hr-°F/BTU) demonstrated by the composite seals, P/Ns T-13618 and T-13619 respectively, were investigated. The investigation included a review of the thermal analysis (Attachment 5) and thermal property data of the materials contained in these seals (Figure 8). The analysis review indicated that the composite seals, as designed, should perform as predicted providing that the assumed thermal conductivities (K) of the materials were correct. The K values of the metallic materials were confirmed by heat transfer tests performed on the thinwall seals. Dimensional inspection confirmed that all components of the composite seals conformed to blueprint requirements. Therefore, the K of the Zircoa "C" (Zirconium Oxide) material was suspected to be the cause of the problem.

A heretofore unplanned thermal test was performed on composite seals to determine the cause of the low resistance. The test was designed to isolate and measure the thermal resistances of internal heat transfer paths. The setup contained two (2) thermal test rigs. One test rig contained a fully assembled composite seal (except T-13615 Titanium bumper set was purposely left out) preloaded in accordance with established procedures. These bumpers were omitted to permit rerun of the seal test with the possibility of a bumper induced thermal short eliminated. The second test rig was assembled with only a complete set of sixty (60), T-13617 Zirconium Oxide (Zircoa "C") cylinders between the combustor and the head (the remaining seal components, the jacket and bumper set were purposely left out). This setup was to measure the cylinder conductivity directly. Preload on these cylinders was the same as used previously for the composite seal thermal tests.

The test proved that the actual resistance through the Zirconia heat path was 3.5 instead of 8.0 Hr-°F/BTU, as assumed in Attachment 5. Therefore, thermal conductivity of the Zirconia was approximately 1.2 instead of 0.54 BTU-ft/ft^2/Hr/°F, (Figure 8), which was used as thermal design criteria. Further, the test confirmed that the Titanium bumper set (P/N T-13615) contributes insignificantly to the total heat transfer, thus validating the thermal design concept for composite seals.

The thermal test series substantiated the practicality of each design concept and verified the accuracy of analytical predictions.

On the basis of recommendations presented in Attachment 7, plans were made and implemented to reduce the thermal conductivity of the Zirconium Oxide. These plans included:

1. Procurement of two (2) experimental ZrO_2 materials, with approximately 15% lower bulk density than the present material for new cylindrical elements in the composite seals. The new material was aimed at maximum F_{cu} (greater than 150,000 psi) consistent with $K \leq .5$ BTU-ft/ft^2/Hr/°F.

2. Fabrication of new cylinders and evaluation by additional tests.

Supplemental thermal tests, reported in Attachment 11, indicated that neither of these experimental materials exhibited sufficiently high thermal resistances to meet the program objective within the existing seal cavity with the original composite seal design. The materials, Zircoa "C" (modified) and Zircoa 1027 (modified), with bulk densities of 269 lbs/ft^3 and 275 lbs/ft^3 respectively, would produce seal

thermal resistances of about 3.6 and 2.8 Hr-°F/BTU. These test results, combined with compression test results of these materials reported later in this text, led to the conclusion that alternate methods of increasing thermal resistance for this heat path should be considered.

Vibration tests, per MTP 0041, Appendix C, are reported in Attachment 9.

As indicated in the seal evaluation test matrix, Figure 25, tests were limited to the Titanium versions of each seal type. Titanium mechanical properties are generally similar, but somewhat lower than Rene' 41; the Titanium fatigue strength (endurance limit) is comparatively higher at the test temperature (70°F). Notch sensitivity for Titanium is high and other physical properties (viz, lower K) are better than Rene'41. Tests on Rene' 41 seals were therefore eliminated based on design similitude.

The vibration tests, which utilized non-fireable engines, indicated that no structural deterioration was exhibited by any of the seals after exposure to the Apollo S/M RCS specification boost vibration spectrum. Leakage performance was virtually unaffected.

MTP 0041, Appendix D, Test Specifications, were designed to evaluate performance of seals after exposure to a salt-fog environment. Test report, Attachment 10, reports that none of the materials contained in the six design/material combinations showed any signs of corrosive attack after exposure to this environment.

The test was conducted with two composite seals, one with a Rene' 41 jacket (P/N T-13619) and one with a Titanium jacket (P/N T-13618). These composite seals embodied all the various material combinations and galvanic couples represented by all six design/material variations in the candidate seals. Tests, therefore, (as indicated in the seal evaluation test matrix, Figure 25) were not performed on straight thinwall and conical thinwall seals.

For these tests, seals were contained in test rigs previously used to conduct seal heat transfer tests (Ref. MTP 0041, Appendix B) which adequately simulated the head/seal/combustor interface of the Apollo S/M RCS engine.

3.2.3 Small Scale Specimen Tests

As indicated earlier, a limited number of small scale specimen tests on candidate materials were performed to obtain material property data. Data from these tests were used to verify analytical predictions of structural safety margins.

Early in the program, four (4) candidate materials were chosen as best suited for high thermal resistance seals. These materials were:

*1. 6AL-4V, Titanium alloy
*2. Rene' 41
*3. L-605, Cobalt base alloy (20% cold worked)
**4. Zirconium Oxide (Zircoa "C", full dense)

(*) Denotes: Metallic
(**) Denotes: Non-Metallic

Later in the program, additional non-metallic materials were evaluated in addition to those listed on the previous page. These materials were:

5. Zirconium Oxide (Zircoa "C", modified)
6. Zirconium Oxide (Zircoa 1027, modified)

All of these six materials were tested to determine specific structural properties and failure modes as applied to seals developed in this program. Informal test outlines were used in lieu of formal test plans in order to facilitate the flexibility to test setups and test procedures.

Analysis of test data obtained from these tests indicated that sufficient structural safety margins were attained with the metallic materials in combination with the Disilicide-coated Molybdenum combustion chamber material. Of the non-metallic specimens, two (2) of them (Zircoa "C", full dense and Zircoa 1027, modified) demonstrated compressive strengths commensurate with requirements for composite type seals. The third material (Zircoa "C", modified) demonstrated compressive strength equivalent to 78% of the required value.

The tests, test procedures and test results are presented in detail in Attachment 6.

3.3.4 Fabrication and Engine Installation of Final Two Seal Designs

3.3.5 Test Final Two Seals for Thermal Resistance and Leakage

3.3.6 Hot Fire Final Two Seals in Rocket Engine

With NASA-approval of MTP 0041, Appendix F, Firing Test Plan, two (2) seal designs were selected from the original six (6) design/material combinations for additional testing while contained in fireable, qualification-type Apollo S/M RCS engines.

Selection of the two seals was based on results obtained from previous tests of all seals per Test Plan MTP 0041, Appendices A through D. Seals which exhibited the best performance and/or showed the best potential for meeting program objectives were:

1. Conical Thinwall, P/N T-13622, Fabricated from Titanium
2. Composite, P/N T-13618, Fabricated from Titanium and Zirconium Oxide (Zircoa "C")

Specifically, the basic reasons for selecting these two designs were:

1. Conical: Exceeded program objectives (Resistance = 5.0 Hr-°F/BTU) during simulated engine tests with a thermal resistance of 6.6 Hr-°F/BTU. However, minor modification to the engine injector head is necessary to lengthen the seal cavity so that it can accommodate this seal.

2. Composite: Although this seal exhibited a thermal resistance of 3.0 Hr-°F/BTU, 2.0 Hr-°F/BTU short of the program objective, this resistance is six times the R = 0.5 Hr-°F/BTU of the current S/M RCS engine seal. This seal concept also shows promise of achieving the program objective by appropriate design modification. Further, it fits into the existing seal cavity in the Apollo S/M RCS engine injector head.

The seals were built up in separate engine assemblies and, prior to combustion testing, were simultaneously tested for their thermal resistance in Marquardt's high vacuum, cold wall, space simulator chamber per MTP 0041, Appendix E.

A summary of the results obtained, together with seal resistance obtained during the previous cold soak tests (per MTP 0041, Appendix B) with simulated engines is presented in the following table:

SEAL CONFIGURATION	PART NUMBER	SEAL THERMAL RESISTANCE Hr-°F/BTU	
		(Appendix E) Fireable Engine	(Appendix B) Simulated Engine
Conical Thinwall	T-13622	6.7	6.6
Composite	T-13618	2.9	3.0

Attachment 12 presents a detailed discussion of this thermal test.

Following the thermal test, the same two seals, contained in the same two engine assemblies, were combustion tested per the NASA-approved firing test plan, MTP 0041, Appendix F, to determine:

1. Effects of increased seal thermal resistance on engine temperature distribution.
2. Capability of the seals to structurally withstand steady state engine operating and soakback temperatures.
3. Capability of the seals to structurally withstand loadings resulting from more than 5500 engine starts.

Although dynamic structural performance of the seals was not observed during the runs, post-fire leakage tests and examination of the seals indicated that no structural degradation took place after each engine was combustion tested for a total of approximately 900 seconds at O/F ratios ranging from 1.8 to 2.2, and started more than 5500 times.

Both engines were extensively instrumented for temperature measurement at various stations on the valves, injector head, injector head/combustor joint, and combustor throat.

Temperature transients during engine heat soakback following steady state runs with O/F = 1.8 agreed reasonably well with analytically computed predictions. However, the 50 milliseconds ON/50 milliseconds OFF duty cycle chosen to generate the 5500 engine starts exhibited what is believed to be a sensitivity to the magnitude of the seal resistance. This apparent sensitivity was demonstrated only by the engine which contained the conical thinwall seal with a thermal resistance of 6.7 Hr-°F/BTU. The second engine containing the composite seal (R = 2.9 Hr-°F/BTU) did not exhibit thermal behavior which would indicate restrictions to this duty cycle. Analysis of temperature test data of the former led to the deduction that the high thermal resistance (R = 6.7 Hr-°F/BTU) reduced thermal conduction from the combustor to the injector head such that after 980 pulses of the first pulsing run, the combustor flange temperatures reached an unexpected level of 1100°F at which point extreme caution was exercised and the run terminated. Although the second engine, which contained the composite seal (R = 2.9 Hr-°F/BTU) exhibited low combustor flange temperatures (330°F at the conclusion of 1400 cycles), temperatures were rising moderately. The point to which they would have risen with further pulses was not determined due to the limited capacity of the pulse tanks used.

The firing test series, reported in complete detail in Attachment 13, proved the adequacy of the two designs although a duty cycle limitation was suggested by one. The extent to which this limit on the number of pulses may vary with different duty cycles, O/F ratio, and seal thermal resistance was not within the scope of this test program and therefore was not investigated.

REFERENCES

1. Syracuse University - Aerospace Structural Metals (Non-Ferrous) Book

2. Alcoa Aluminum Handbook

3. Alcoa Structural Handbook

4. Syracuse University - Aerospace Structural Metals (Ferrous Metals) Book

5. MPM14.154 - TMC data on Coated P/S Molybdenum

6. General Electric Company - Form Q10-863

7. American Lava Corporation - Chart No. 631

8. TMC Structural Analysis Data

9. Zirconium Corporation of America - High Temperature Materials Technical Data Sheet No. 6

10. TMC Data Compilation - 10 October 1962, IOM - M. Carey from H. I. Thompson and U. S. Polymeric Company

11. Handbook of Thermophysical Properties of Solid Materials, Vol. III, A. Goldsmith, T. E. Waterman, and H. J. Hirschhorn.

12. Refractory Ceramics of Interest in Aerospace Structural Applications - A Materials Selection Handbook, Report No. ASD-TDR-63-4102, October 1963

PROGRAM SCHEDULE

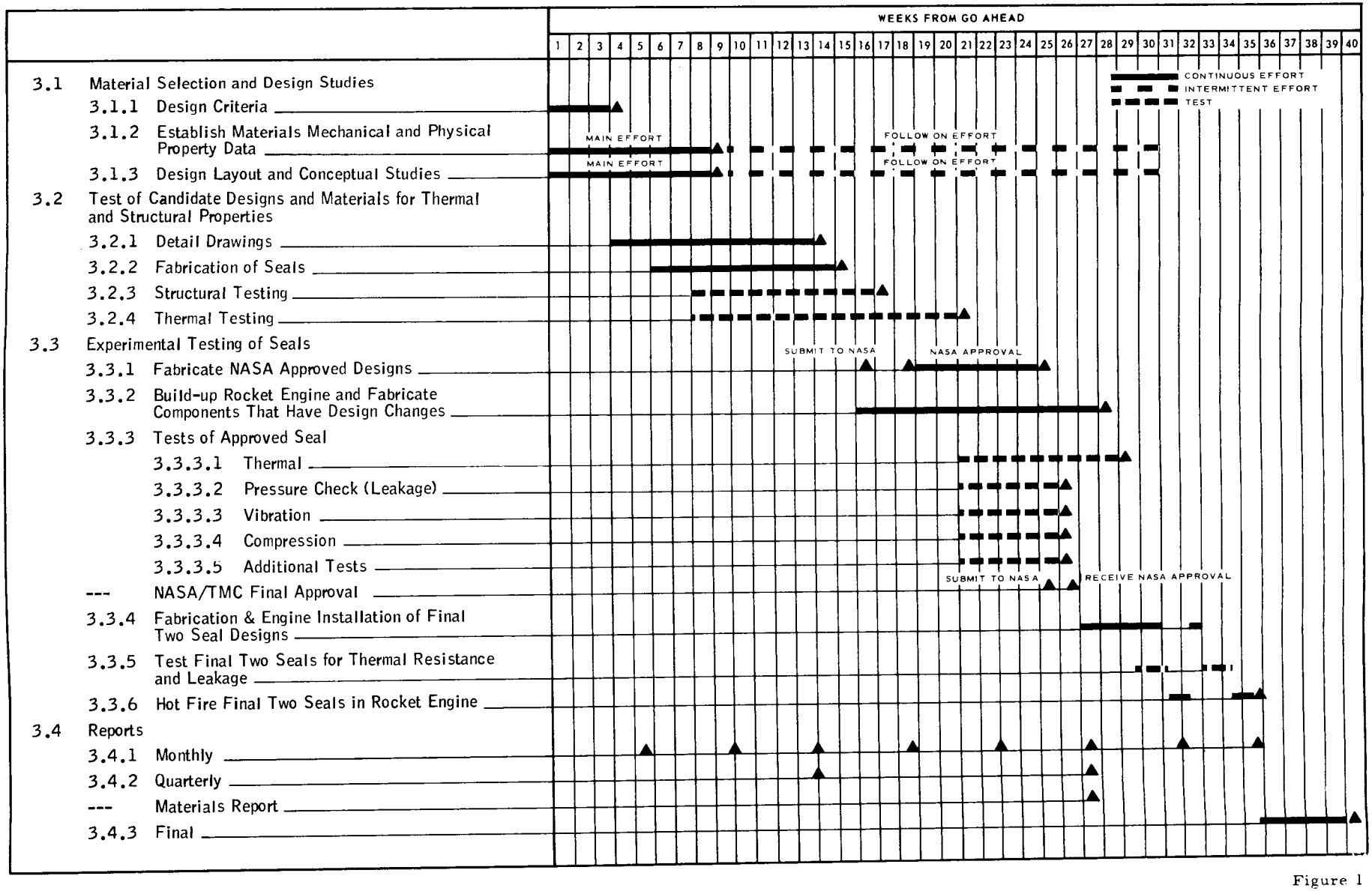
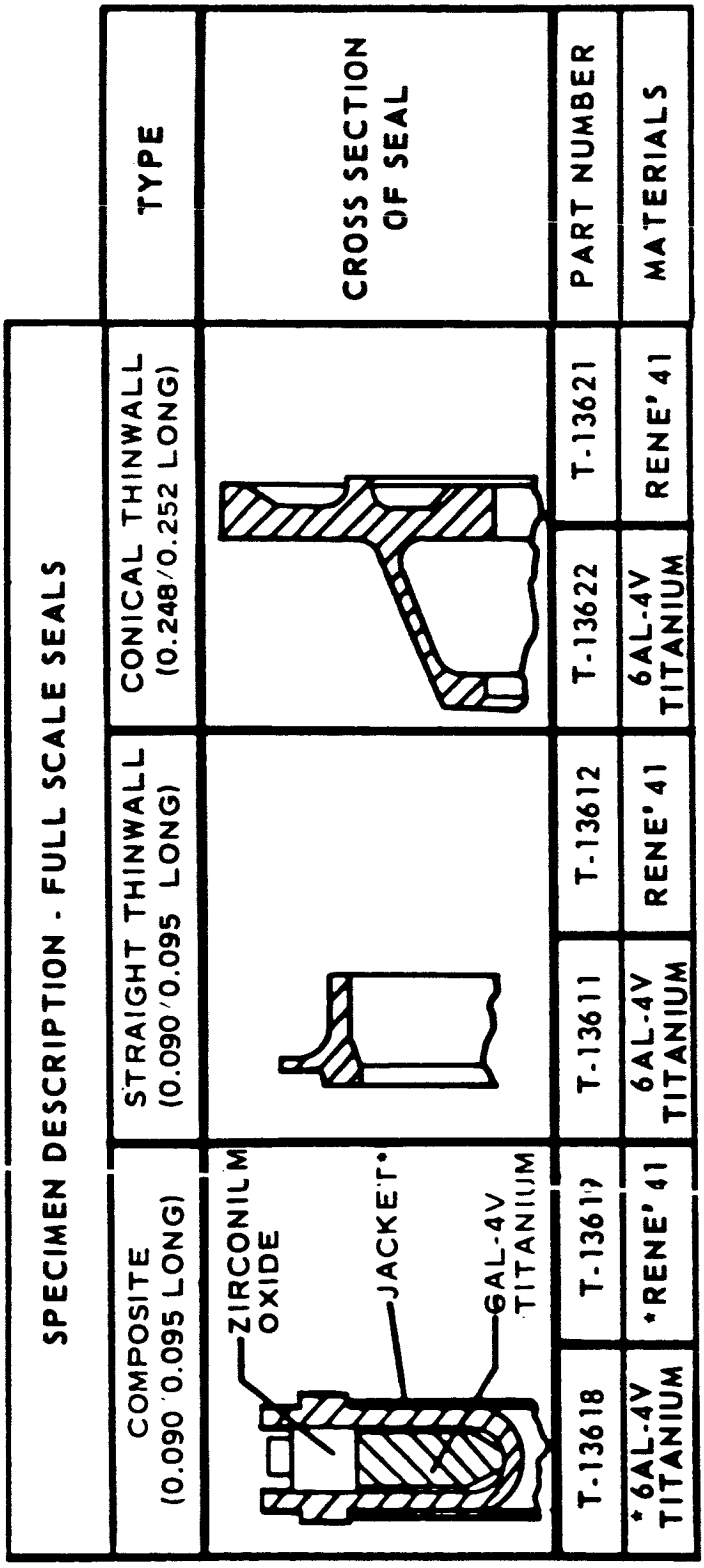


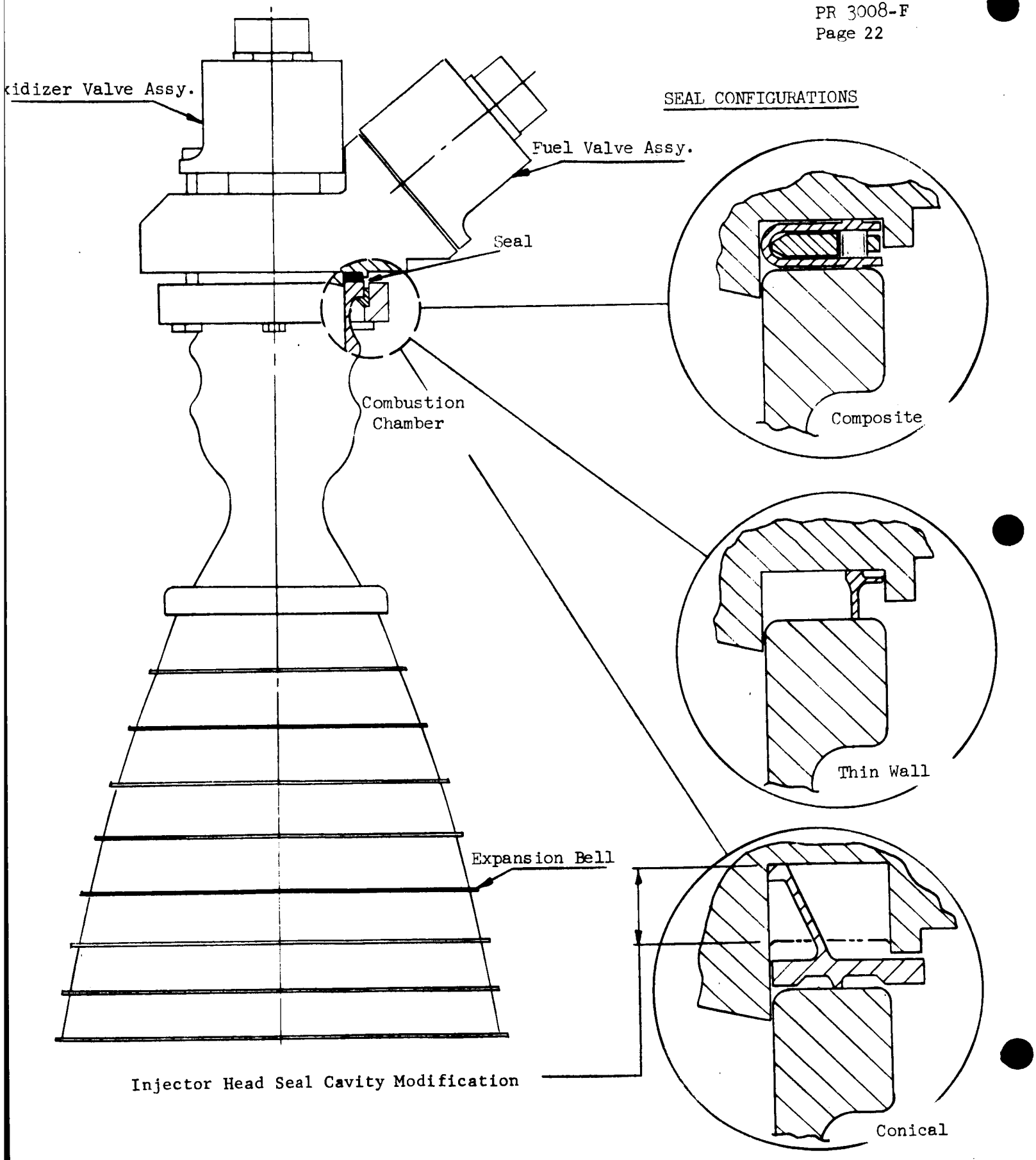
FIGURE 1

Figure 1



SEAL DESIGN/MATERIAL COMBINATION

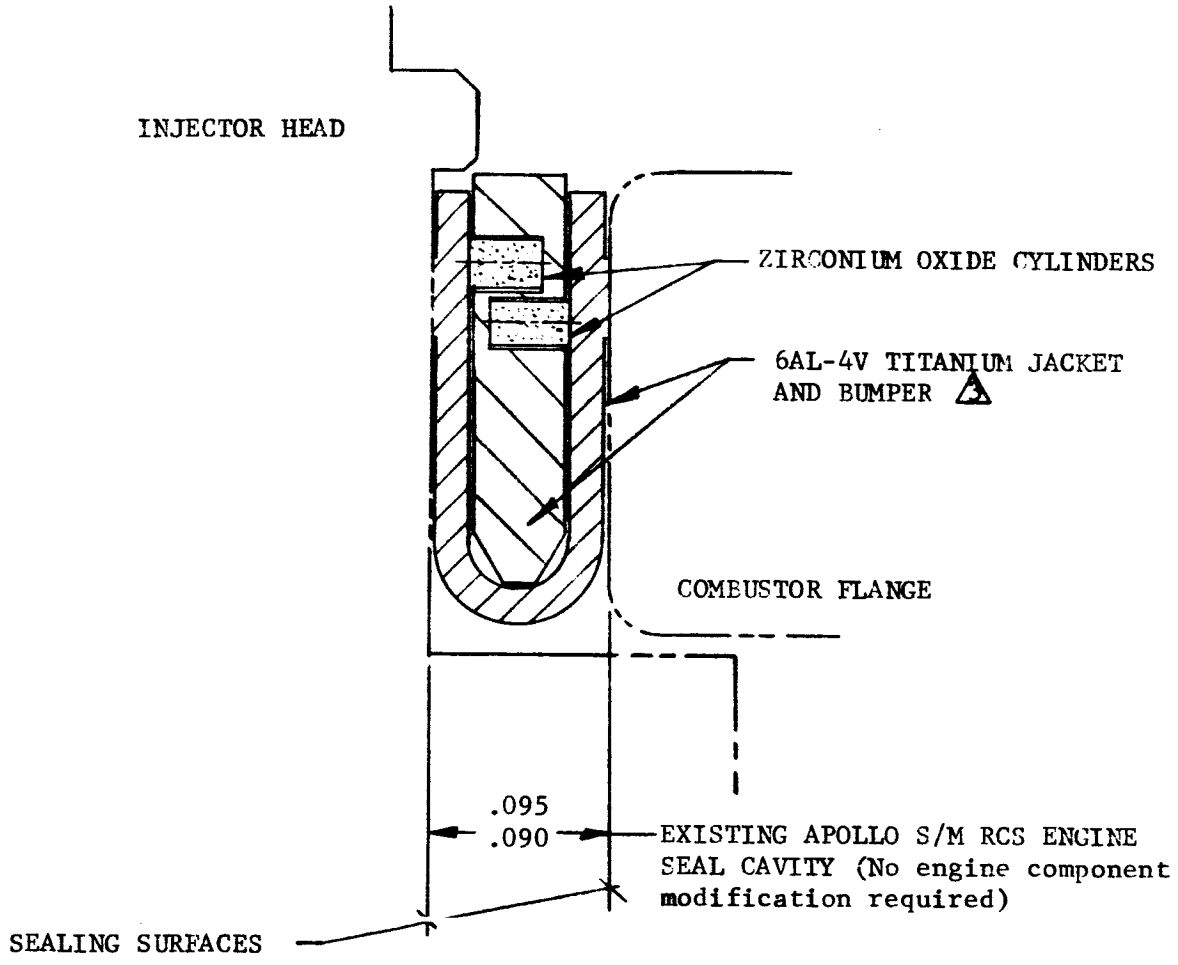
FIGURE 2



Injector Head Seal Cavity Modification

FIGURE 3

MODIFIED COMPOSITE SEAL DESIGN



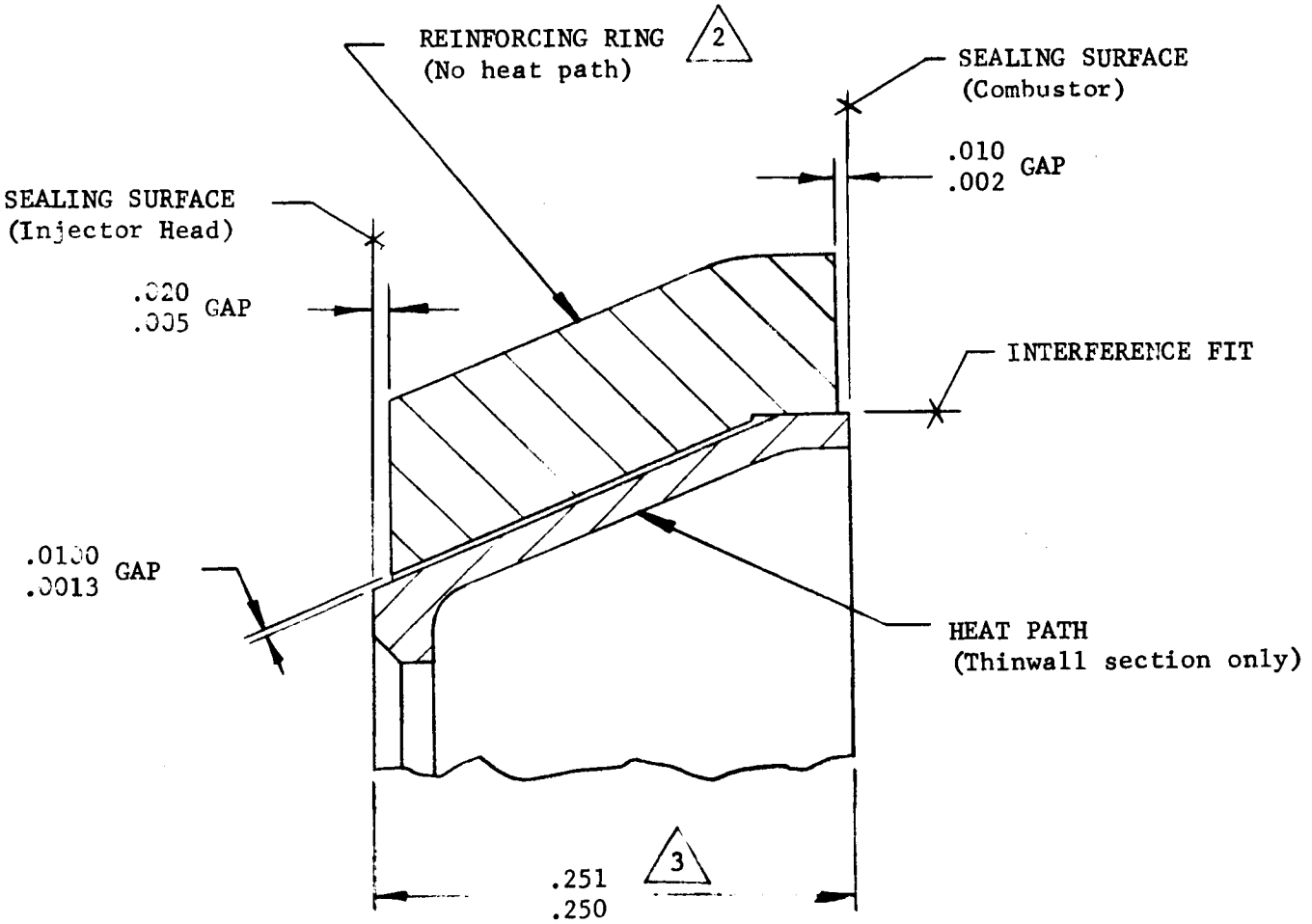
COMMENTS:

1. Seal contains dual heat path.
2. Calculated seal thermal resistance = 4.3/5.0 Hr-°F/BTU. (All contact resistances are neglected)

3. Jacket and Bumper combination designed to contain 10,000 psia seal cavity pressure.

FIGURE 4

IMPROVED CONICAL THINWALL SEAL DESIGN



COMMENTS:

1. Typical materials and thermal resistances* (R = Hr-°F/BTU)

   6AL-4V Titanium ------ 6.6
   Rene' 41 ------------ 5.2
   L-605 --------------- 5.8

   *Contact resistances neglected.

2. Reinforcing Ring (Bumper) designed to contain 10,000 psia seal cavity pressure.

3. Extended Seal Cavity (engine component modification is required).

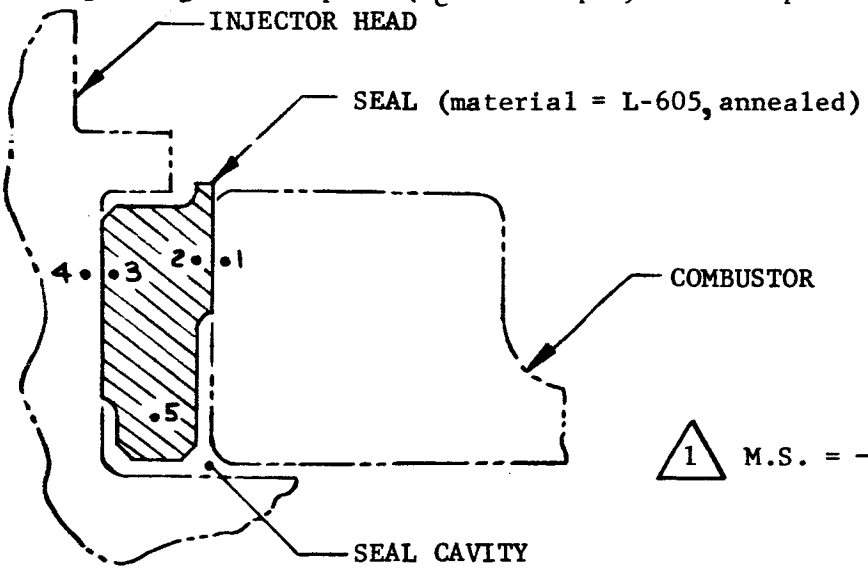
FIGURE 5

TABULATION - STRUCTURAL SAFETY MARGINS

QUALIFIED APOLLO S/M RCS ENGINE SEAL

LOCATION POINTS	TEMPERATURE ~ °F	MARGIN OF SAFETY (1) (COMPRESSIVE) PRELOAD + ΔT
1	650**	2.0
	150*	2.3
2	650**	1.7
	150*	2.2
3	350**	5.3
	150*	5.3
4	350**	4.2
	150*	4.3
5	0***	5.8

*Launch Boost (engine not operating)
**Soakback after Steady State Run (engine not operating)
***Engine Ignition Spike (P_c = 1500 psi, head temperature = 20°F)



(1) M.S. = $\frac{\text{Allowable Stress (psi)}}{\text{Induced Stress x 1.5 (psi)}}$ -1

FIGURE 6

SUMMARY - DESIGN CRITERIA

HIGH THERMAL RESISTANCE HEAD/COMBUSTOR SEAL

Seal Thermal Resistance
@ 0°F = 5.0 Hr-°F/BTU

Compressive Preload Generated
During Engine Assembly @ 70°F = 5880 lbs. max. limit

Compressive Preload + Thermal Load Resulting from
Engine Heat Soakback with Seal @ 470°F = 8286 lbs. limit

Compressive Load Resulting from Apollo Launch Boost
Vibration + Aerodynamic Pressure with Seal @ 150°F = 1500 lbs/in. limit
2250 lbs/in. ultimate

Steady State Chamber Pressure with
Seal Temperature @ 250°F = 100 psia limit

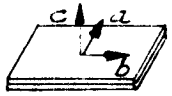
Seal Cavity Peak Pressure Resulting from
Chamber Pressure Ignition Spike @ 0°F = 1200 psia limit
1800 psia ultimate

Seal Cavity Peak Pressure Resulting from
Seal Cavity Propellant Explosion @ 70°F = 10,000 psia

FIGURE 7

N. A. = Not Available

TABLE I (CANDIDATE SEAL MATERIALS)

Materials	α in/in/°F (10^6)	K BTU-Ft/Ft^2/HR/°F	F_{cu}* Ksi R. T.	F_{cu}* Ksi 600°F	E Psi (10^6)	Room Ksi Uts	Room Ksi Yield	Room % Elong.	600°F Ksi Uts	600°F Ksi Yield	600°F % Elong.
L605 (1)	6.5 (Room) 7.5 (600°F)	5.6 (Room) 8.5 (600°F)	N. A.		33 (Room) 31 (600°F)	181	152	14	165	132	12
304L (4)	8.7 (Room) 9.4 (600°F)	8.((Room) 11.((600°F)	N. A.		29 (Room) 26 (600°F)	120	90	30			
Rene 41 (1) Aging 1,400°F - 16 HRS.	6.7 (Room) 7.0 (600°F)	6.((Room) 8.4 (600°F)	N. A.		32 (Room) 30 (600°F)	195	145	18	190	135	15
Waspaloy (1) Aging 1,400°F - 16 HRS.	6.5 (Room) 7.4 (600°F)	6.5 (Room) 8.9 (600°F)	N. A.		31 (Room) 29 (600°F)	180	115	20	170	112	16
6A14V Ti (1)	4.5 (Room) 4.8 (600°F)	4.((Room) 6.((600°F)	180	130	15.8 (Room) 13.5 (600°F)	160	150	18	125	96	18
Fused Quartz (6)	0.31 (Room)	0.3 (Room)	160	-	10.4	7	-	-	-	-	-
Cordierite (202)	1.2 (Room) 1.5 (600°F)	0.73 (Room)	30	-	-	3.5	-	-	-	-	-
 Pryolytic Graphite (8)	"a-b" direction 1.0 (Room) "c" direction 13.3 (Room)	"a-b" direction 228 (Room) "c" direction 1.37 (Room)	"a-b" 15 "c" 60	-	"a-b" 4.5 (Room) "c" 1.5 (Room)	"a-b" 15 (Room) "c" 1.5 (Room)	-	-	-	-	-
Zirconium Oxide (9)	5.6 (Room)	0.54 (Room)	303	-	21.5	20	-	-	-	-	-
Phenolic USP 5067 (10)	Parallel to Lamina, 2.2 Perp. to Lamina, 10.6	Perp. to Lamina, 0.17 (300°F) 45° Laminations, 0.2 (300°F)	39	-	2.3	8-12	-	-	-	-	-
6061-T6 (1) Aluminum Injector Head	12.6 (Room) 14.0 (600°F)	90 (Room)	68 (3)	-	10.8 (Room) 7.2 (600°F)	(2) 45	(2) 40	(2) 17	(2) 4.5	(2) 2.5	(2) 85
Molybdenum Comb. Chamb.	(1) 2.9 (Room) 3.0 (600°F)	(1) 80 (Room) 78 (600°F)	-	-	(5) 45 (Room) 9 (1000°F)	(5) 65	(5) 58	(5) 4	(5) 32 1,000°F	(5) 17 1,000°F	(5) 34.5 1,000°F

*F_{cu} = Ultimate compressive strength

FIGURE 8

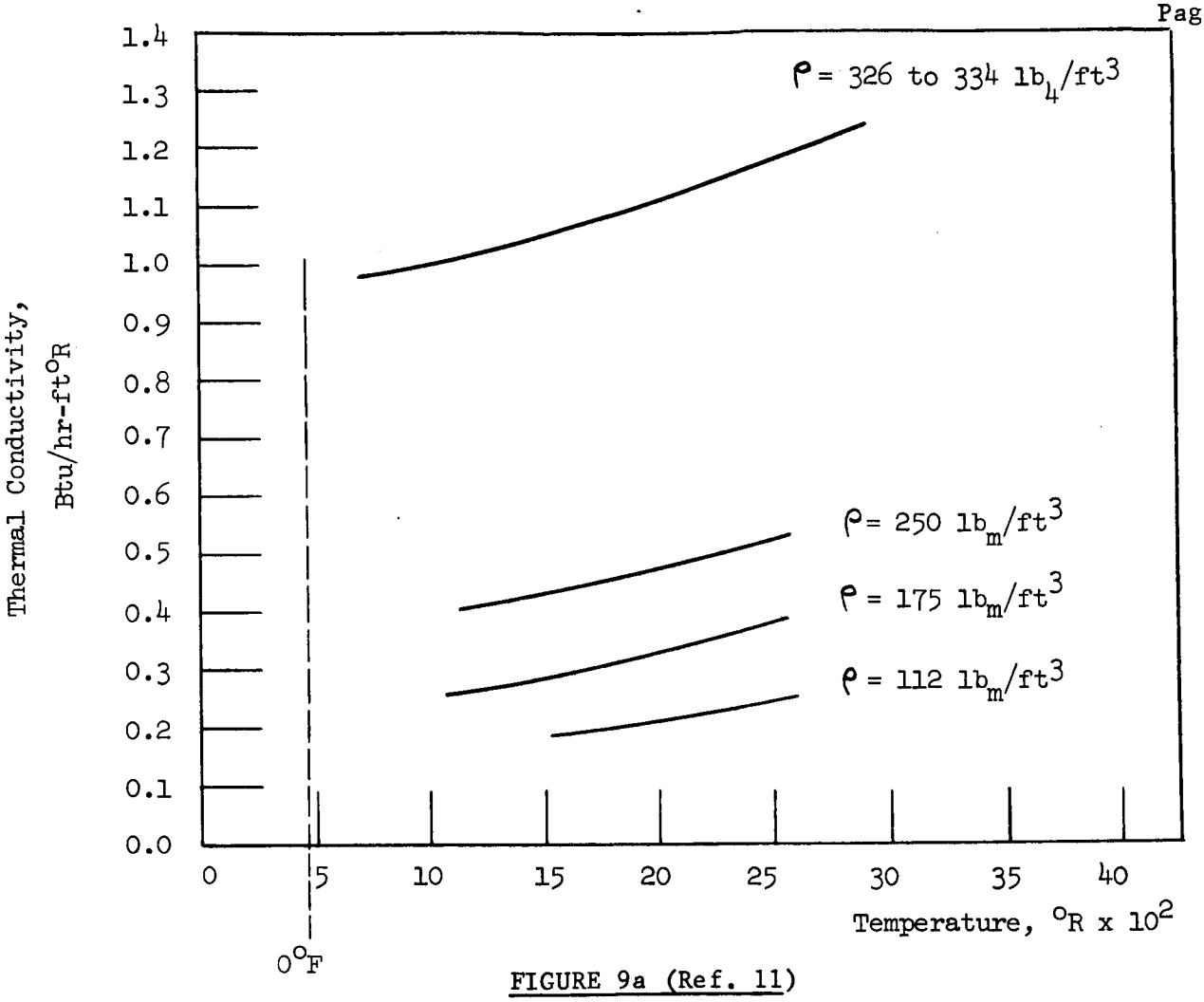


FIGURE 9a (Ref. 11)

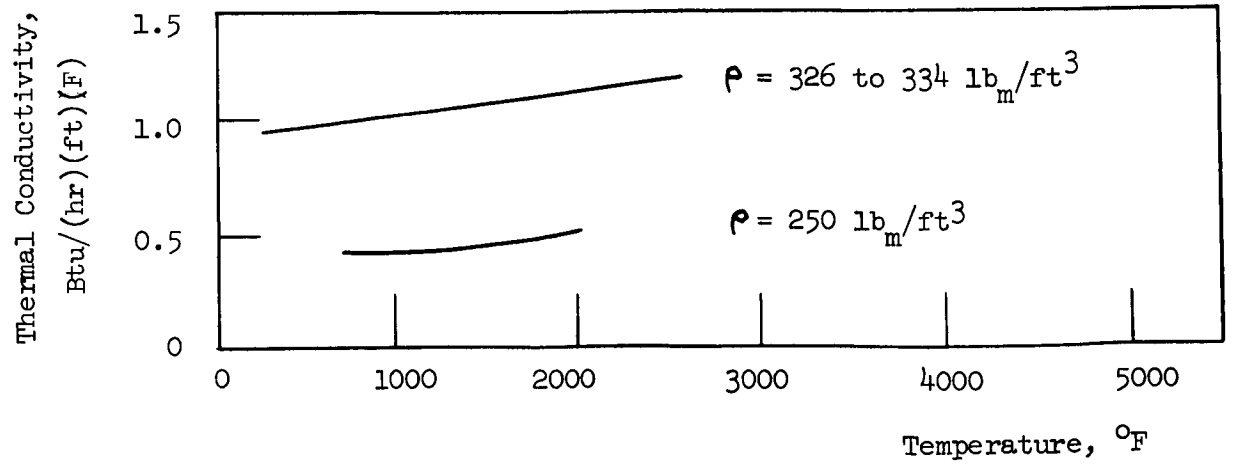


FIGURE 9b (Ref. 12)

THERMAL CONDUCTIVITY - ZIRCONIUM OXIDE

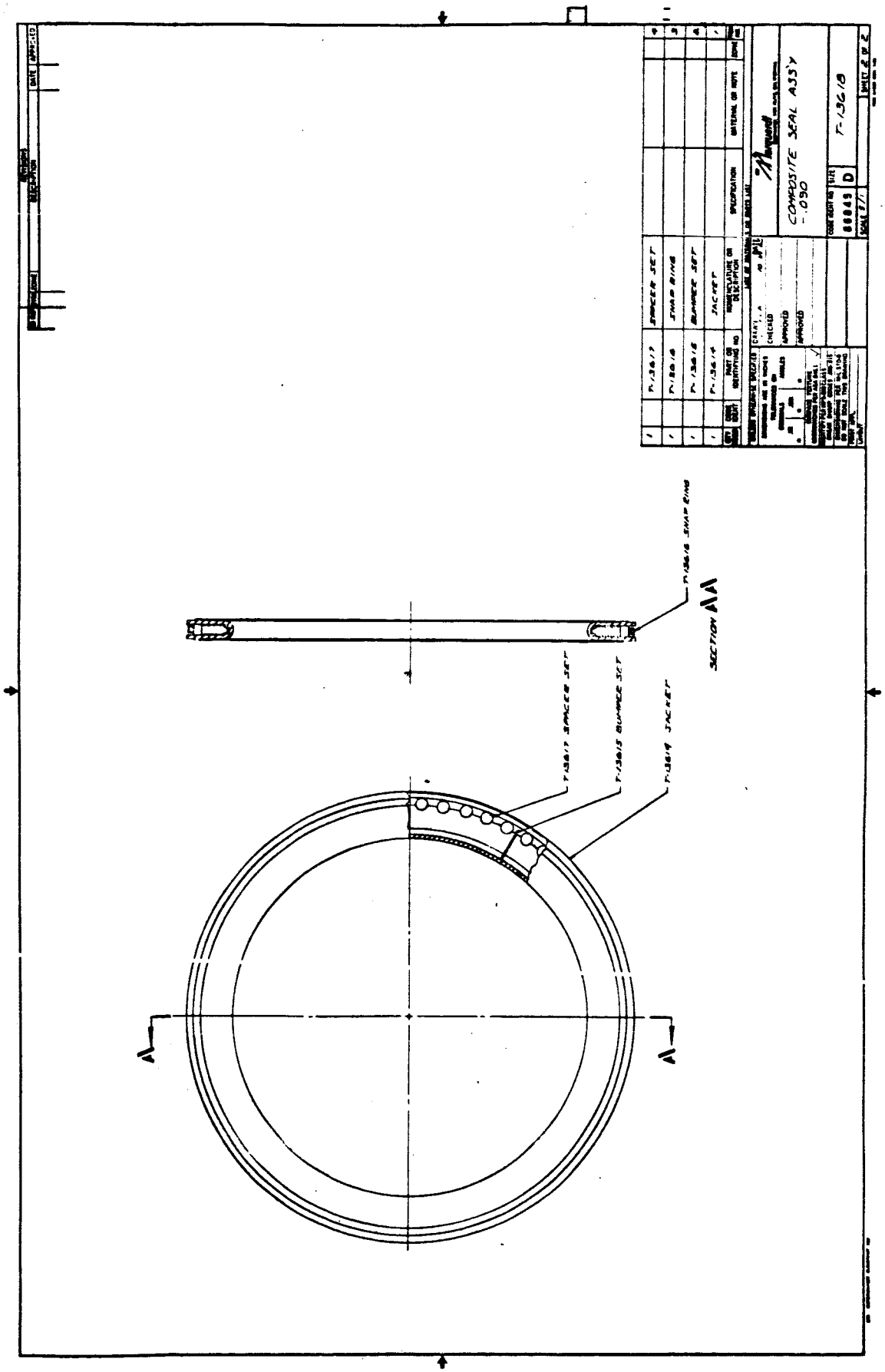

COMPOSITE SEAL ASSY
-.090
P-1361B
SECTION A-A
P-1361B SNAP RING
P-1361F SPACER SET
P-1361E BUMPER SET
P-1361H JACKET

FIGURE 10

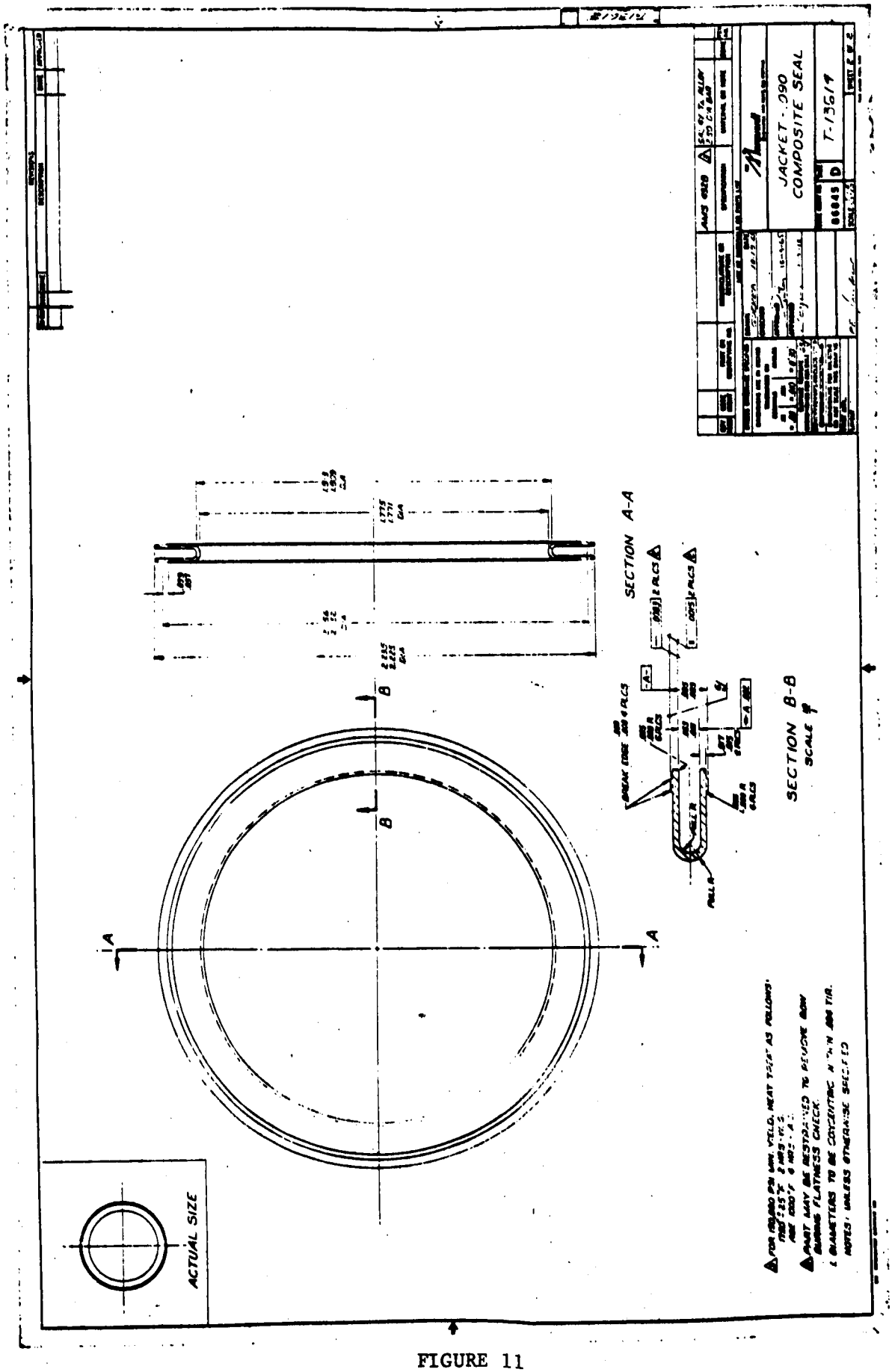

JACKET - .090
COMPOSITE SEAL
T-13614
SECTION A-A
SECTION B-B
SCALE 1
ACTUAL SIZE

FIGURE 11

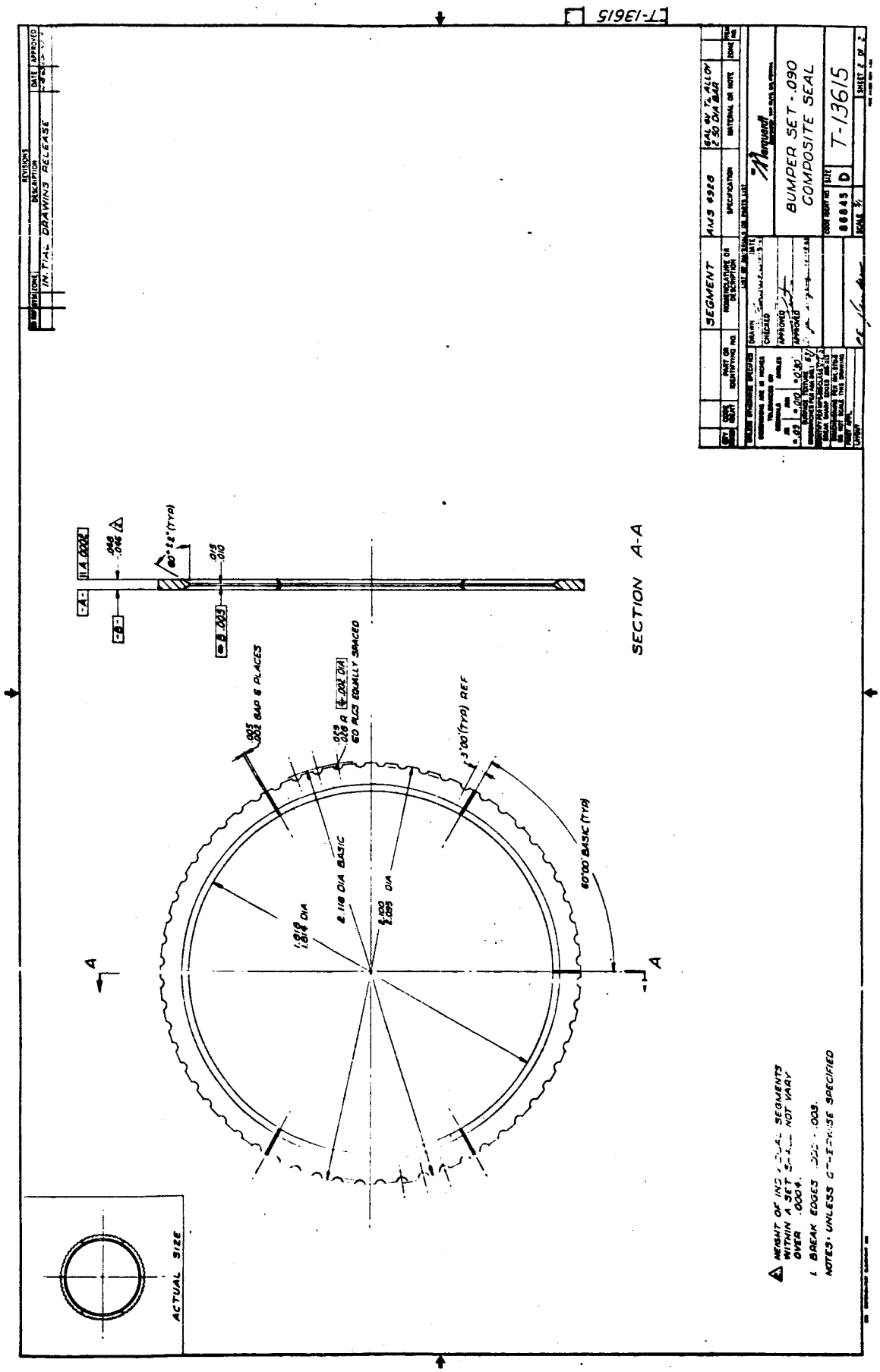

T-13615
SECTION A-A
BUMPER SET - .090
COMPOSITE SEAL
T-13615
ACTUAL SIZE
NOTES: UNLESS OTHERWISE SPECIFIED

FIGURE 12

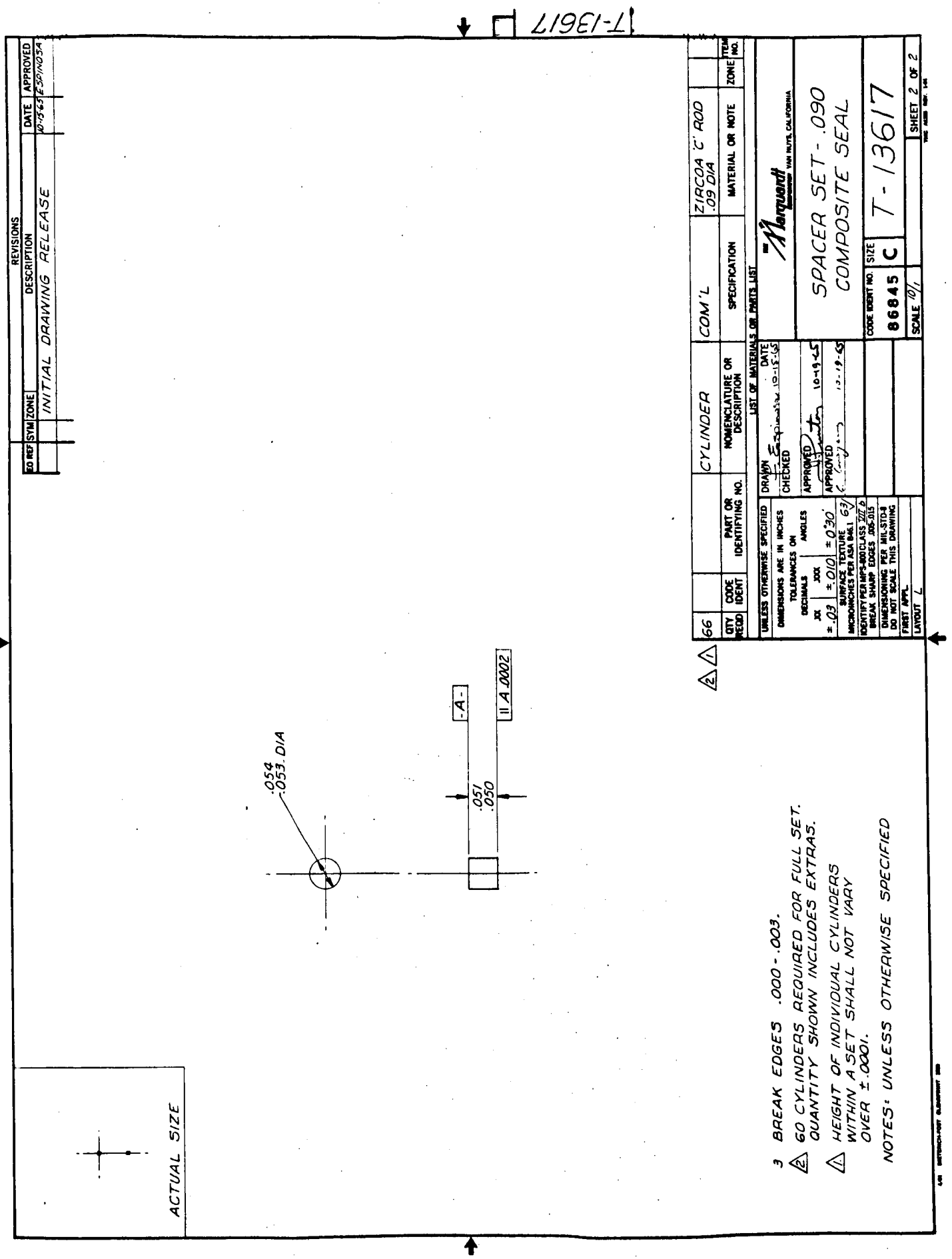

T-13617
REVISIONS
ED REF | SYM | ZONE | DESCRIPTION | DATE | APPROVED
INITIAL DRAWING RELEASE
10-15-65 E.S.P./N.D.S.A.
CYLINDER
COM'L
ZIRCOA 'C' ROD .09 DIA
66
PART OR IDENTIFYING NO.
NOMENCLATURE OR DESCRIPTION
SPECIFICATION
MATERIAL OR NOTE
ITEM NO.
QTY REQD
CODE IDENT
LIST OF MATERIALS OR PARTS LIST
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON DECIMALS XX ±.03 XXX ±.010 ANGLES ±.030'
SURFACE TEXTURE MICROINCHES PER ASA B46.1 63
IDENTIFY PER MPP-200 CLASS ZnT b
BREAK SHARP EDGES .005-.015
DIMENSIONING PER MIL-STD-8
DO NOT SCALE THIS DRAWING
FIRST APPL
LAYOUT L
DRAWN
CHECKED
APPROVED
APPROVED
10-19-65
Marquardt
VAN NUYS, CALIFORNIA
SPACER SET - .090
COMPOSITE SEAL
CODE IDENT NO. 86845
SIZE C
T-13617
SCALE 10/1
SHEET 2 OF 2
.054
.053 DIA
-A-
.051
.050
11 A .0002
ACTUAL SIZE
3 BREAK EDGES .000 - .003.
2 60 CYLINDERS REQUIRED FOR FULL SET. QUANTITY SHOWN INCLUDES EXTRAS.
1 HEIGHT OF INDIVIDUAL CYLINDERS WITHIN A SET SHALL NOT VARY OVER ±.0001.
NOTES: UNLESS OTHERWISE SPECIFIED

FIGURE 13

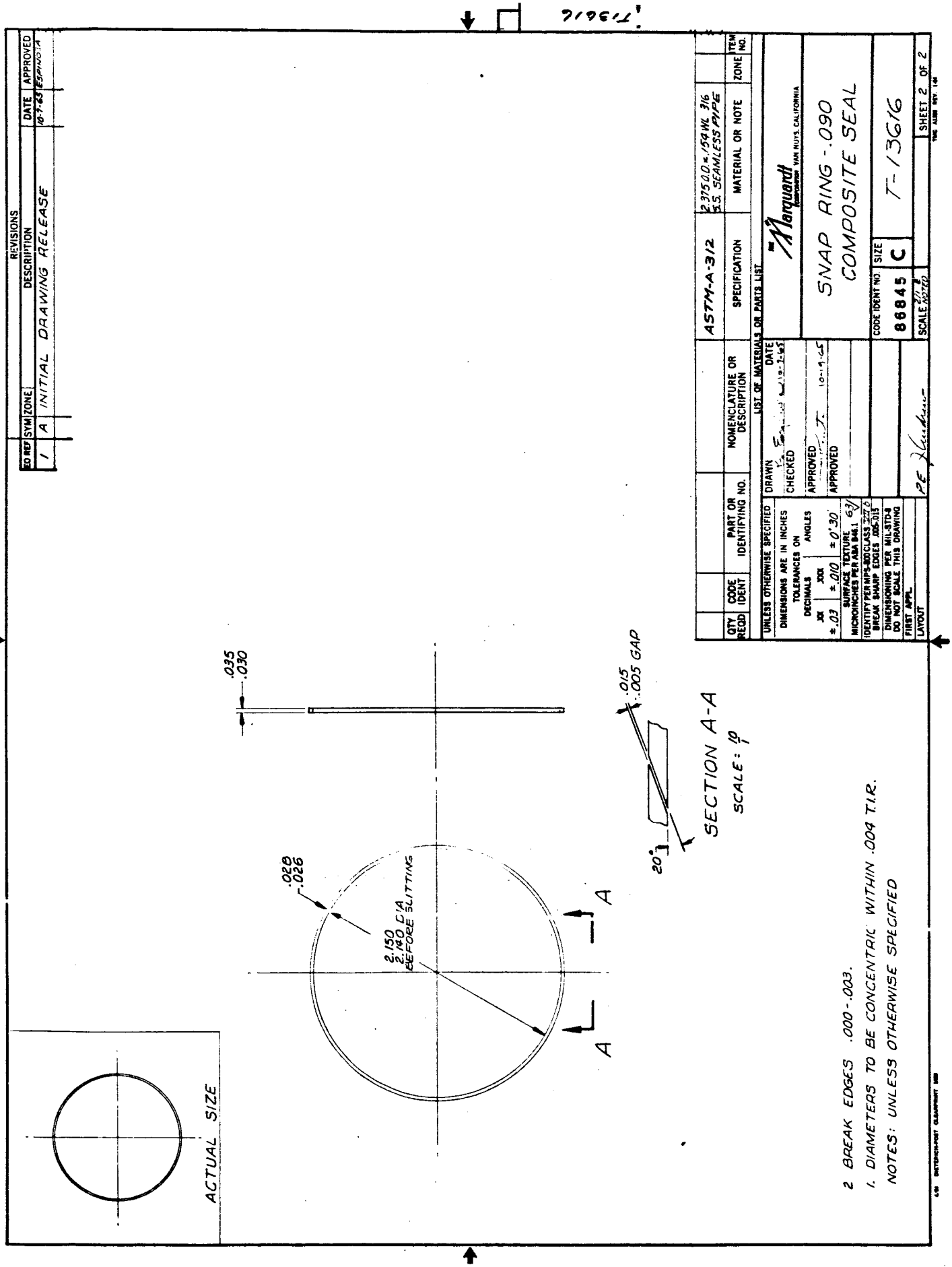

REVISIONS
ED REQ | SYM | ZONE | DESCRIPTION | DATE | APPROVED
1 | A | | INITIAL DRAWING RELEASE | 10-7-63 | ESPINOSA
ASTM-A-312
2.375 O.D. x .154 WL 316 S.S. SEAMLESS PIPE
QTY REQD | CODE IDENT | PART OR IDENTIFYING NO. | NOMENCLATURE OR DESCRIPTION | SPECIFICATION | MATERIAL OR NOTE | ZONE | ITEM NO.
LIST OF MATERIALS OR PARTS LIST
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON DECIMALS .XX ±.03 .XXX ±.010 ANGLES ±0°30'
SURFACE TEXTURE MICROINCHES PER ASA B46.1
IDENTIFY PER MPS-BDCLASS
BREAK SHARP EDGES .005-.015
DO NOT SCALE THIS DRAWING
DIMENSIONING PER MIL-STD-8
FIRST APPL.
LAYOUT
DRAWN
CHECKED
APPROVED
APPROVED
DATE
Marquardt
VAN NUYS, CALIFORNIA
SNAP RING - .090
COMPOSITE SEAL
CODE IDENT NO. 86845
SIZE C
T-13616
SCALE
SHEET 2 OF 2
.035
.030
.028
.026
2.150
2.140 DIA
BEFORE SLITTING
A
A
.015
.005 GAP
20°
SECTION A-A
SCALE: 10/1
ACTUAL SIZE
2 BREAK EDGES .000-.003.
1. DIAMETERS TO BE CONCENTRIC WITHIN .004 T.I.R.
NOTES: UNLESS OTHERWISE SPECIFIED

FIGURE 14

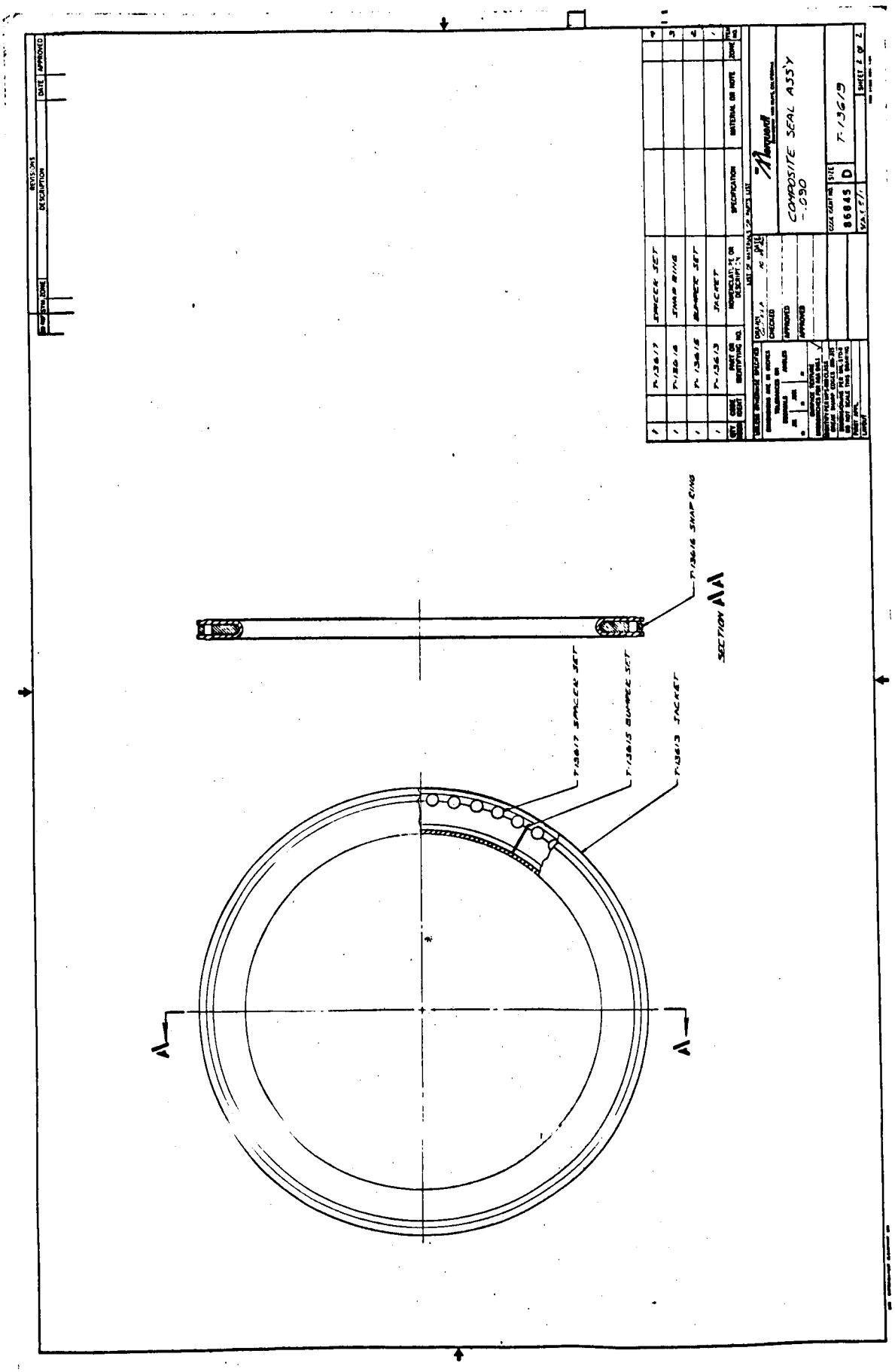

P-1361 SPACER SET
P-1361 SNAP RING
P-1361 BUMPER SET
P-1361 JACKET
SECTION A-A
COMPOSITE SEAL ASSY
-090
P-1361
86845
D

FIGURE 15

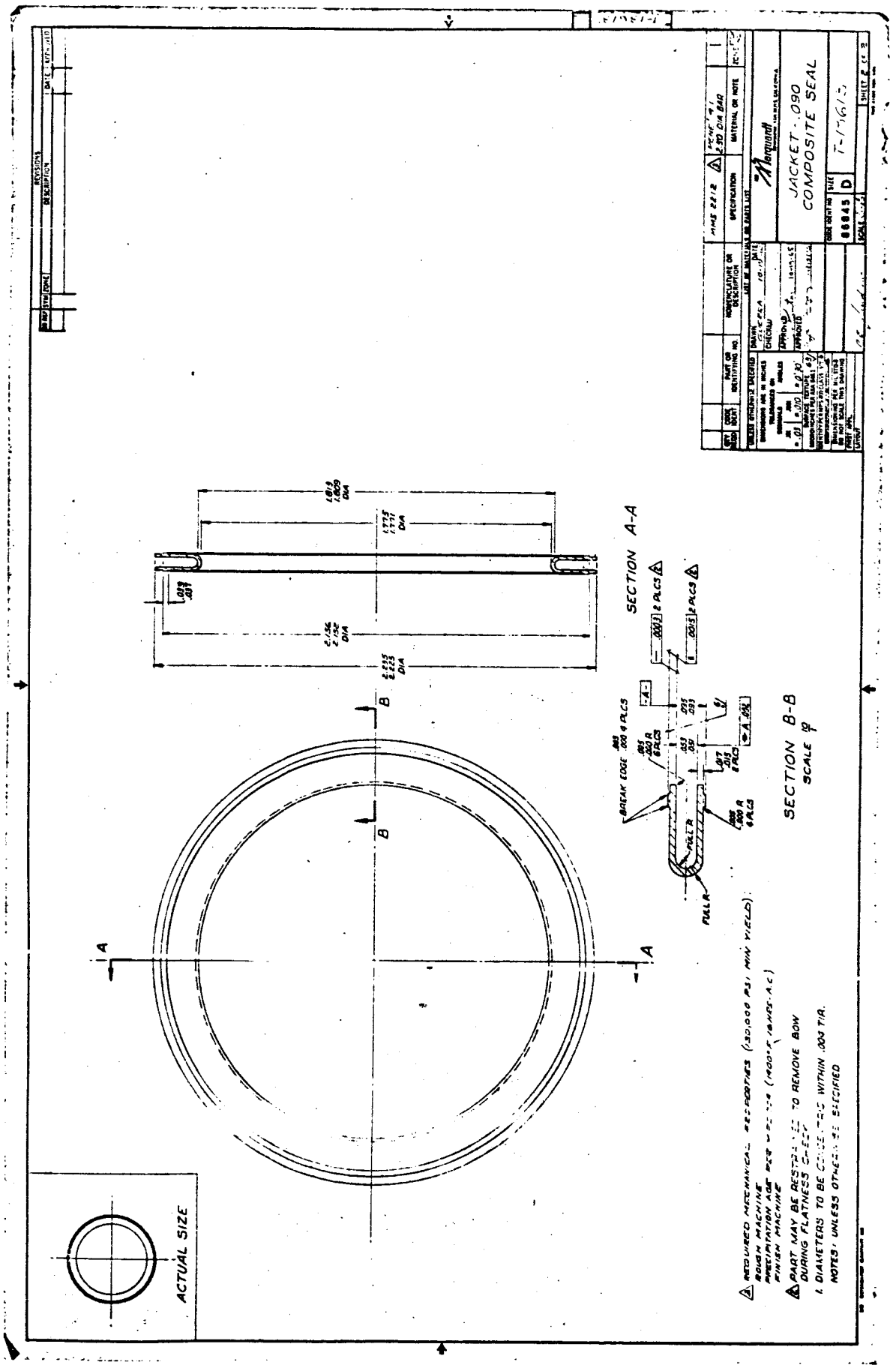

SECTION A-A
SECTION B-B
SCALE 1/1
ACTUAL SIZE
JACKET - .090
COMPOSITE SEAL
T-17613
88845
D
AMS 2212
.250 DIA BAR
Marquardt

FIGURE 16

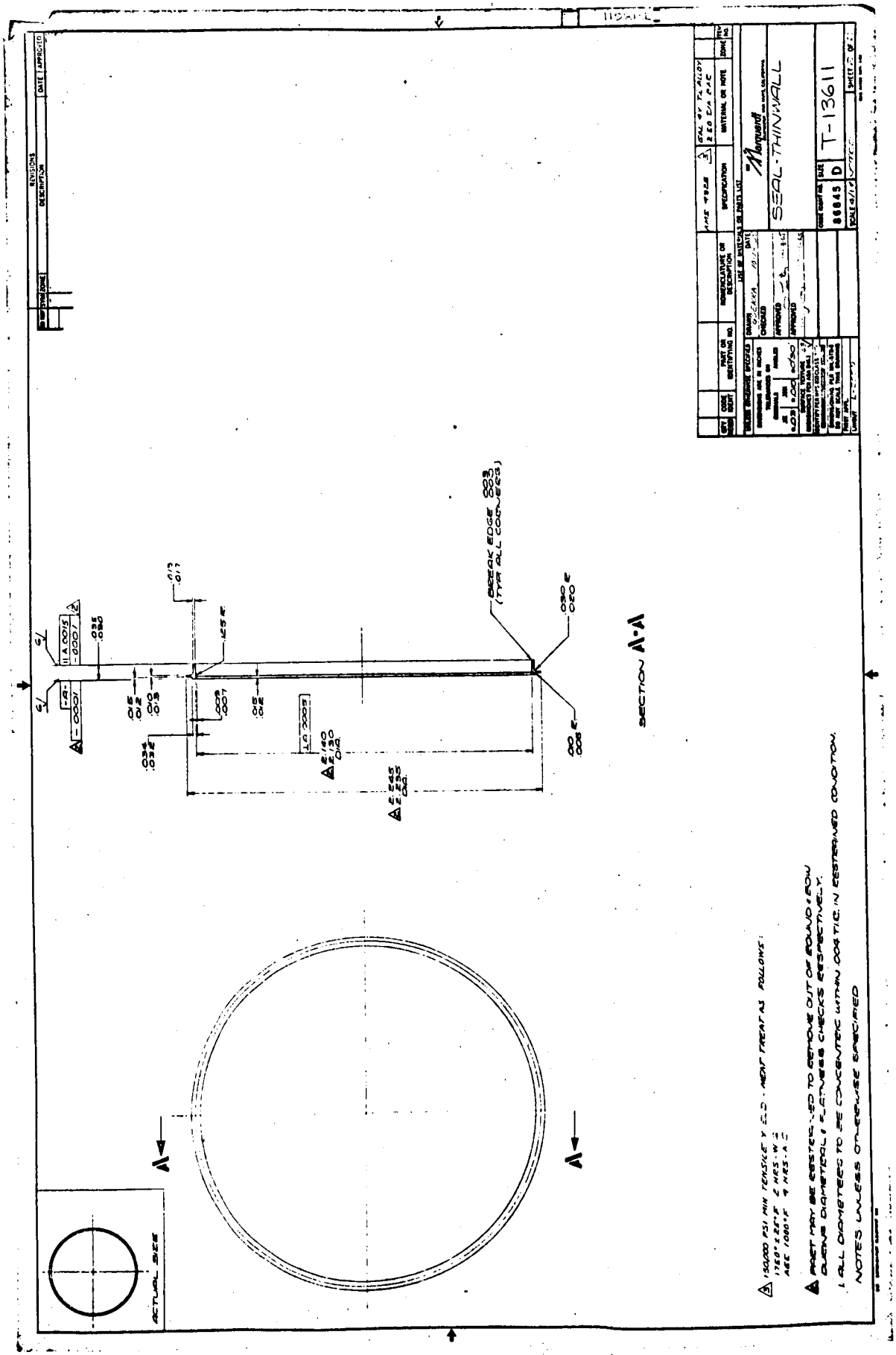

SECTION A-A
BREAK EDGE (TYP ALL CORNERS)
ACTUAL SIZE
SEAL-THINWALL
T-13611

FIGURE 17

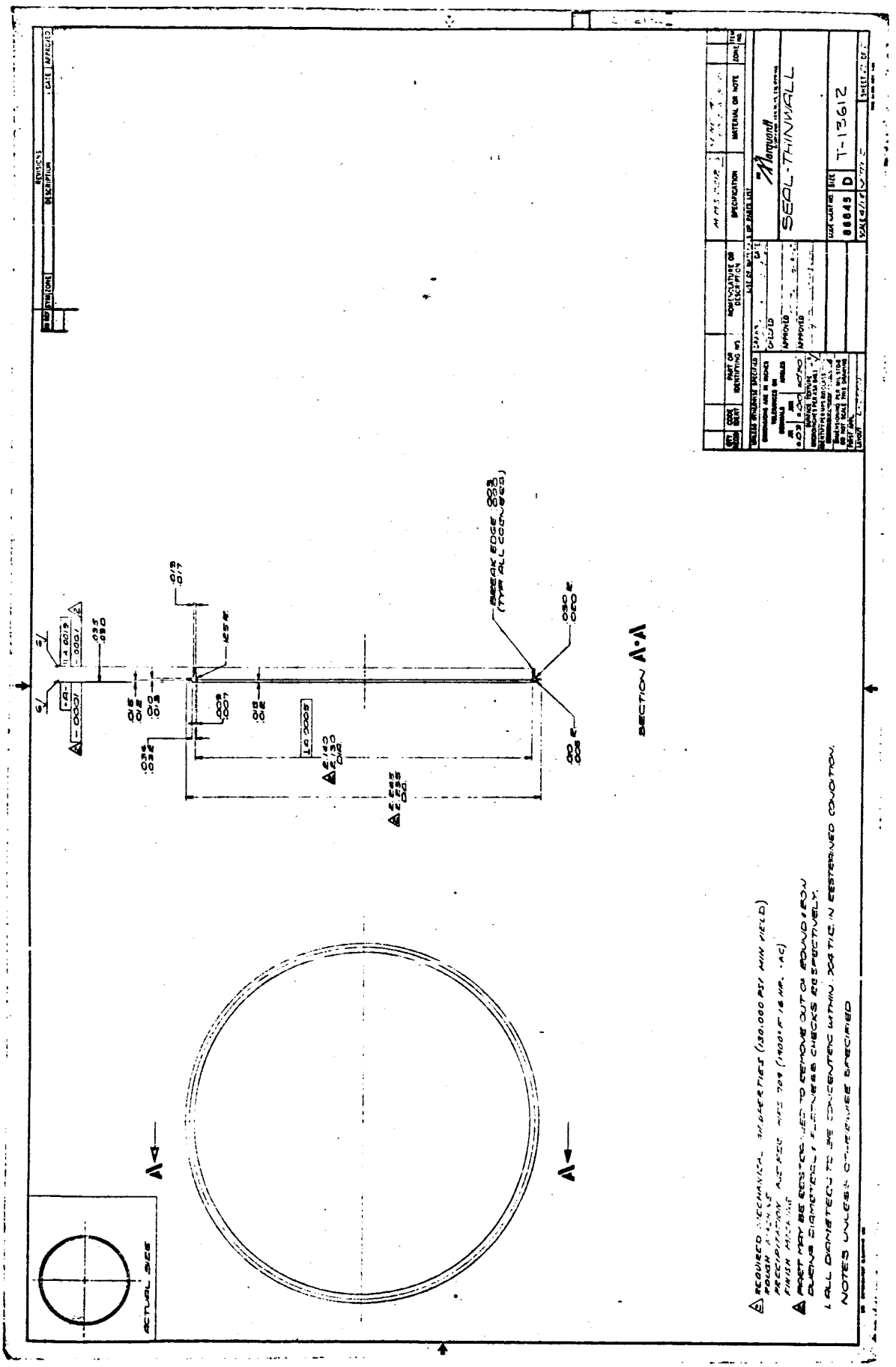

SEAL-THINWALL
T-13612
SECTION A-A
ACTUAL SIZE
BREAK EDGE .033 .020
(TYP ALL CORNERS)
NOTES UNLESS OTHERWISE SPECIFIED

FIGURE 18

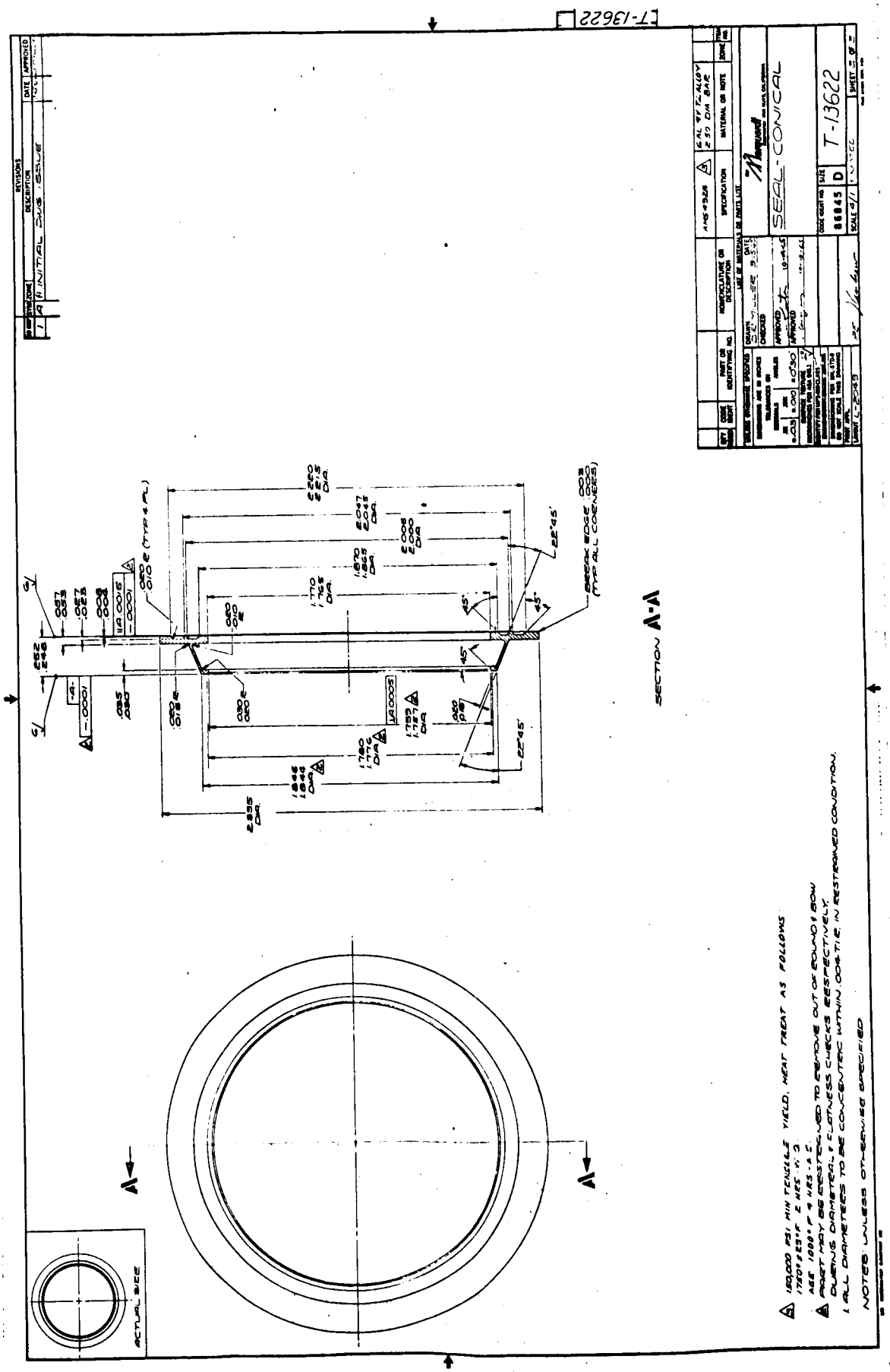

T-13622
SEAL - CONICAL
T-13622
SECTION A-A
ACTUAL SIZE
NOTES: UNLESS OTHERWISE SPECIFIED

FIGURE 19

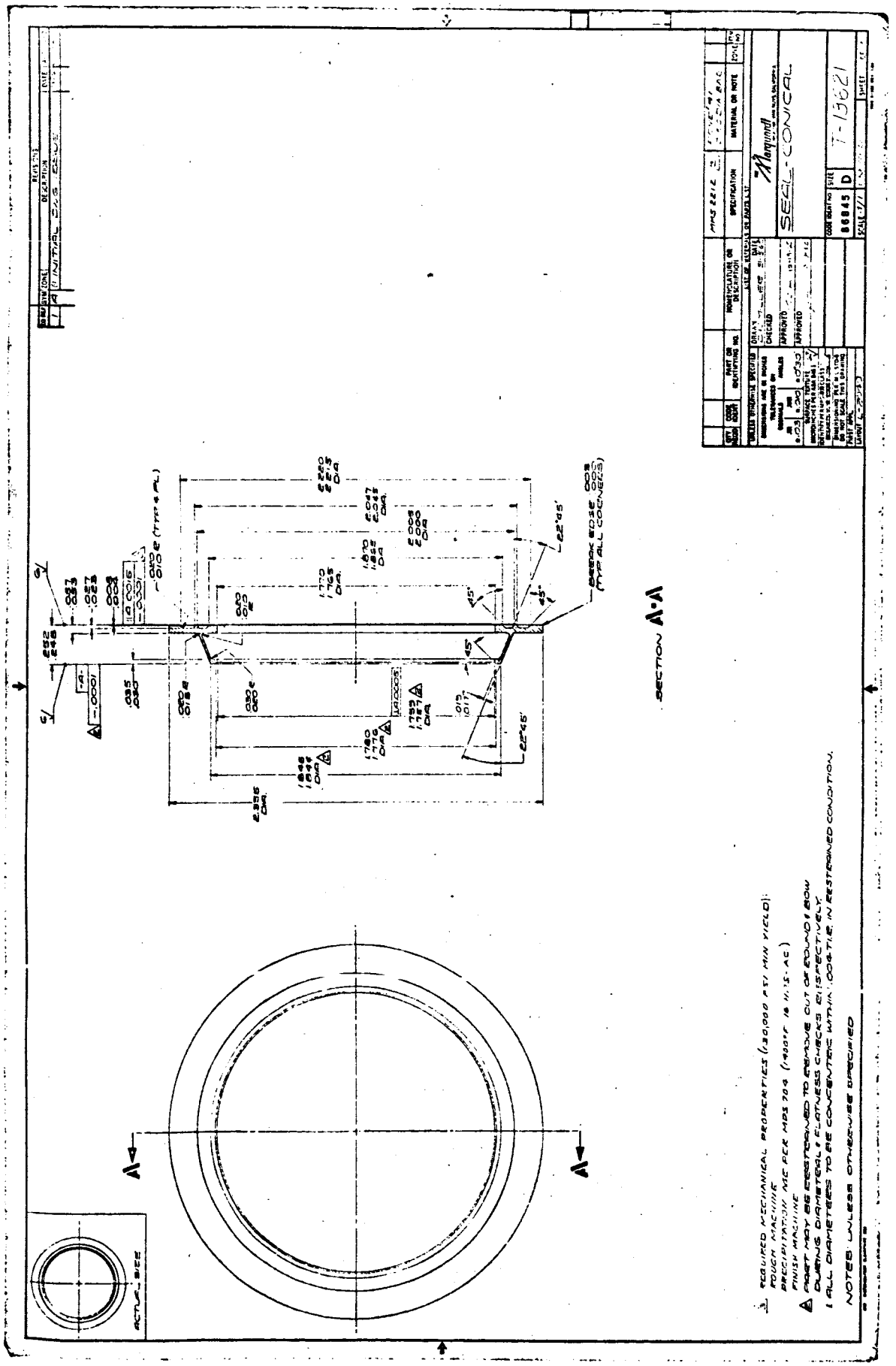

SEAL - CONICAL
T-13621
88845
SECTION A-A
ACTUAL SIZE
NOTES UNLESS OTHERWISE SPECIFIED

FIGURE 20



FULL SCALE HIGH THERMAL RESISTANCE SEALS--CHAMBER SEAL STUDY
TEST 11267 12 JAN 66

NEG. T11267-9

FIGURE 21

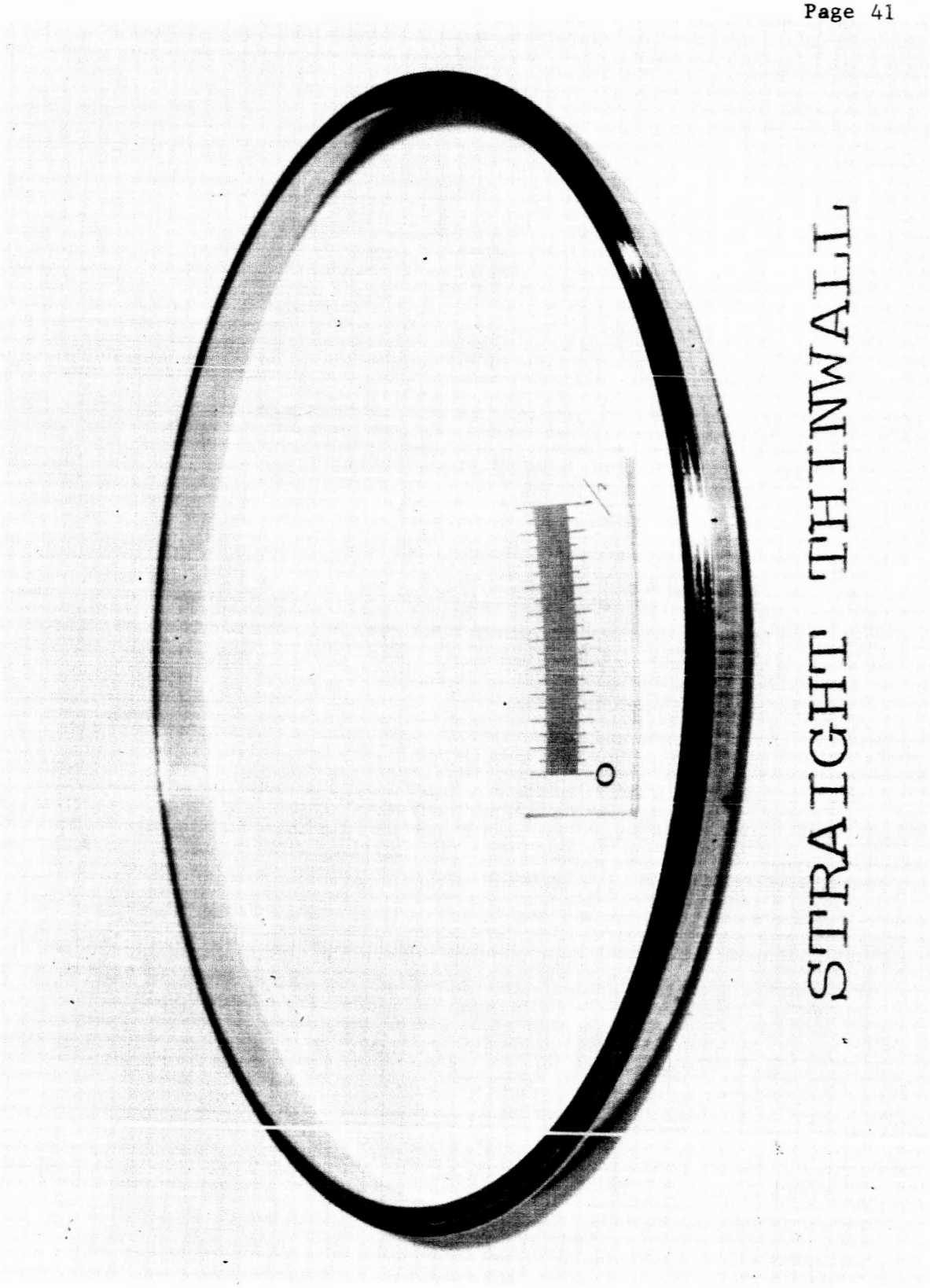

STRAIGHT THINWALL
NEG. 111267-7
FULL SCALE HIGH THERMAL RESISTANCE SEALS--CHAMBER SEAL STUDY
TEST 11267
12 JAN 66

FIGURE 22

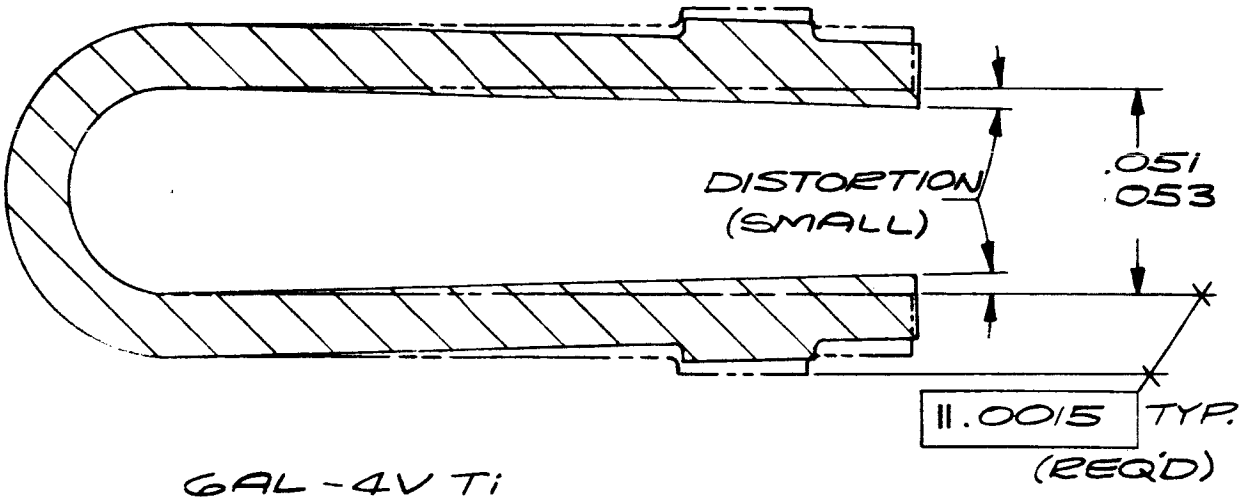
NEG. T11267-8



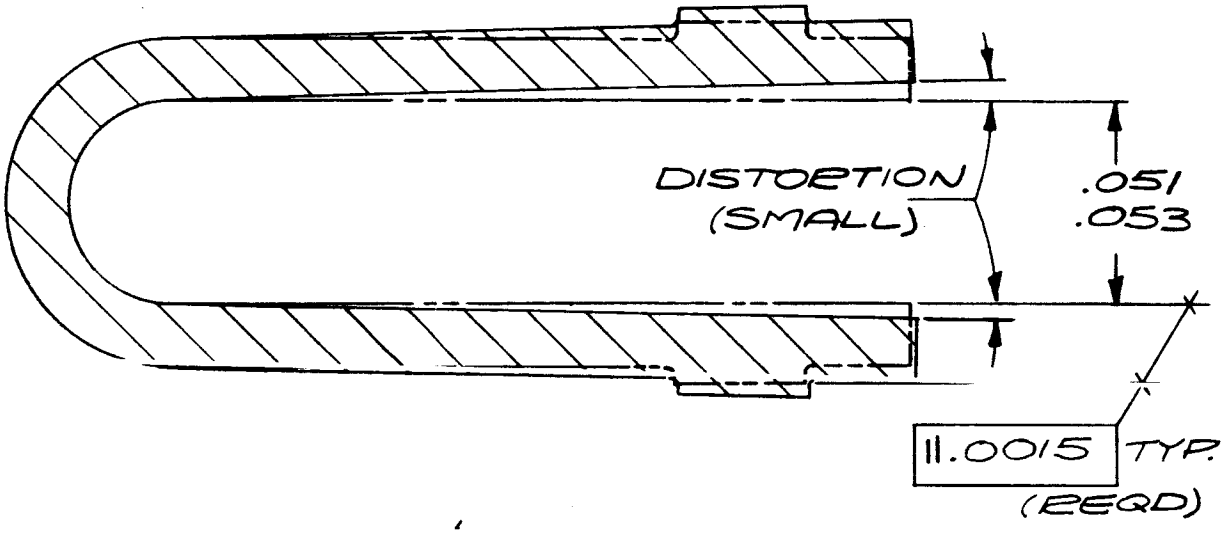
FIGURE 23

FULL SCALE HIGH THERMAL RESISTANCE SEALS--CHAMBER SEAL STUDY
TEST 11267 12 JAN 66

JACKET DISTORTION DUE TO RESIDUAL MACHINING STRESS (NO SCALE)



6AL-4V Ti
FREE STATE DISTORTION VS. REQ'D



RENE' 41
FREE STATE DISTORTION VS. REQD

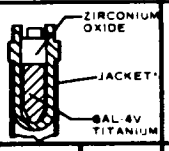
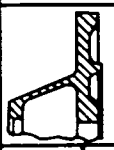
FIGURE 24

SEAL EVALUATION TEST MATRIX-APOLLO SM-RCS ENGINE, CHAMBER/SEAL STUDY

MTP 0041 TEST PLAN, EVALUATION OF EXPERIMENTAL HIGH THERMAL RESISTANCE SEALS FOR THE APOLLO SMRCS ENGINE

SPECIMEN DESCRIPTION - FULL SCALE SEALS

CATEGORY	TEST PLAN APPENDIX	TYPE OF TEST AND TEST NUMBER	TEST DESCRIPTION (OBJECTIVES, TEST CONDITIONS, VARIABLES, ETC.)
STRUCTURAL	A	SIMULATED ENGINE HEAT SOAKBACK A-3.1	OBJECTIVE - EVALUATE BUCKLING, COMPRESSION AND OR BEARING CHARACTERISTICS UNDER REPEATED SOAKBACK CONDITIONS. TEST CONDITIONS - COMBUSTOR FLANGE, 750°F; INJECTOR HEAD, 190° F, TAILOFF TO 350° F AND 230° F IN 600 SEC. - 6 CYCLES.
STRUCTURAL	A	CREEP (SHORT TERM HI TEMP), A-3.4	OBJECTIVE - EVALUATE CREEP CHARACTERISTICS AT HIGH TEMPERATURE UNDER EXTENDED HEAT SOAKBACK CONDITIONS. TEST CONDITIONS - COMBUSTOR FLANGE, 750° F, INJECTOR HEAD, 190° F; DWELL FOR 1 2 HR.
STRUCTURAL	A	SIMULATED CHAMBER PRESSURE SPIKE (STATIC), A-3.2	OBJECTIVE - EVALUATE STRUCTURAL CHARACTERISTICS, HOOP LOAD CAPACITY AND SEALING CAPABILITY UNDER CHAMBER SPIKE CONDITIONS. TEST CONDITIONS - HEAD, SEAL, COMBUSTOR AND ATTACH HARDWARE, 0° F, PRESSURIZE SEAL CAVITY TO 1200 PSI IN 200 PSI STEPS HYDROSTATICALLY - ISOLATE PRESSURE AND CHECK LEAKAGE AT EACH STEP - 1 CYCLE
STRUCTURAL	A	SIMULATED SEAL CAVITY EXPLOSION (STATIC) A-3.3	OBJECTIVE - EVALUATE STRUCTURAL CHARACTERISTICS, HOOP LOAD CAPACITY AND SEALING CAPABILITY UNDER SEAL CAVITY EXPLOSION CONDITIONS. TEST CONDITIONS - SAME AS A-3.2 EXCEPT PRESSURIZE TO APPARENT FAILURE AT R.T.
STRUCTURAL	A	CREEP (LONG TERM) SIMULATED STORAGE, STORAGE, A-3.5	OBJECTIVE - EVALUATE CREEP AND SEALING CHARACTERISTICS UNDER SIMULATED STORAGE ENVIRONMENT. TEST CONDITIONS - STABILIZE AT 120° F AND MAINTAIN FOR 30 DAYS.
THERMAL	B	SEAL THERMAL RESISTANCE - SIMULATED ENGINE, TEST NO. N/A	OBJECTIVE - MEASURE SEAL THERMAL RESISTANCE AT 0°F IN SIMULATED ENGINE. TEST CONDITIONS - TEST CHAMBER PRESSURE, 10^{-4} mm Hg ABSOLUTE - TEST CHAMBER COLDWALL, -320°F INJECTOR HEAD TEMPERATURE = 20°F.
VIBRATION	C	VIBRATION - NON-FIREABLE ENGINE, TEST NO. N/A	OBJECTIVE - EVALUATE STRUCTURAL AND SEALING CAPABILITY AFTER EXPOSURE TO RANDOM VIBRATORY LOADINGS. TEST CONDITIONS - APOLLO SMRCS ENGINE BOOST VIBRATION SPECTRUM (RANDOM ONLY) 3 AXES, 5 MINUTES EACH.
CORROSION	D	CORROSION - SIMULATED ENGINE, TEST NO. N/A	OBJECTIVE - EVALUATE STRUCTURAL AND SEALING CAPABILITY AFTER EXPOSURE TO CORROSION INDUCING ENVIRONMENT. TEST CONDITIONS - SALT FOG ATMOSPHERE PER MIL-STD-810 FOR 48 HOURS.
THERMAL	E	SEAL THERMAL RESISTANCE - FIREABLE ENGINE, TEST NO. N/A	OBJECTIVE - MEASURE SEAL THERMAL RESISTANCE AT 0° F AND DETERMINE ENGINE HEAT FLOW CHARACTERISTICS WITH NON-OPERATING, FIREABLE ENGINE IN SPACE ENVIRONMENT. TEST CONDITIONS - SAME AS APPENDIX B
FIRING	F	FIRING - FIREABLE ENGINE, TEST NO. /4	OBJECTIVE - EVALUATE STRUCTURAL, THERMAL AND SEALING CAPABILITY DURING AND AFTER ACTUAL ENGINE FIRING AT ALTITUDE (P = 0.08 PSIA) MJL PAD "9". TEST VARIABLES - THREE O/F = 2.0 TRIM RUNS, STEADY STATE AT O/F = 2.0 FOR 100 SEC. STEADY STATE AT O/F = 1.8 AND 2.2 FOR 80 SEC. ⚠ DUTY CYCLE FOR MAXIMUM HEAT SOAKBACK (INJECTOR HEAD & COMB. FLANGE) 5500 PULSES (STRUCTURAL CAPACITY)
—	—	— — —	NO PLANNED TEST - SEALS ARE TEST SPARES

	COMPOSITE (0.090 0.095 LONG)				STRAIGHT THINWALL (0.090 0.095 LONG)				CONICAL THINWALL (0.248 0.252 LONG)				TYPE
CROSS SECTION OF SEAL													
PART NUMBER	T-13618		T-13619		T-13611		T-13612		T-13622		T-13621		
MATERIALS	*6AL-4V TITANIUM		*RENE* 41		6AL-4V TITANIUM		RENE* 41		6AL-4V TITANIUM		RENE* 41		
THERMAL RESISTANCE ⚠	4.87/5.26		3.77/4.30		1.82/2.21		1.21/1.48		5.30/6.20		3.68/4.33		
SPECIMEN IDENT. (1 EA. REQ'D.)	A	B C D	A	B C D	A	B C D	A	B C D	A	B C D	A	B C D	
PROJECTED SPECIMEN USAGE AND TEST STATUS	●1/17		●1/31		●12/30		●1/5		●1/23		●1/28		
	●1/25		○		●1/11		●1/13		●1/31		○		
	●3/17		●3/1		●3/18		●3/17		●3/3		●3/7		
	●3/18		●3/16		●3/18		●3/18		●3/4		●3/15		
	●4/1		●4/4		●4/1		●3/26		●3/6		●3/45		
	●1/14		●1/14		●12/21		●12/35		●12/21		●12/33		
	●3/9		○		●3/15		○		●3/24		○		
	●3/18		●3/38		○		○		○		○		
	○		○		○		○		●3/11		○		
	●3/24		○		○		○		●3/21		○		
	S		S		S		S		S		S		

LEGEND

- ○ – PROJECTED USAGE
- ● – TEST COMPLETE (DATE NOTED)
- ●● – DENOTES TESTS ARE COMBINED (NO DISASSEMBLY)
- S – DENOTES SPARE
- ⚠ – SEAL SELECTION DEPENDENT ON NASA TMC APPROVAL
- ⚠ – PREDICTED THERMAL RESISTANCE = $\frac{HR - °F}{BTU}$ (NEGLECTS CONTACT R)
- ⚠ – DEPENDENT ON NASA APPROVAL
- \ ELIMINATED (DESIGN SIMILITUDE)
- / ELIMINATED (2 SEALS SELECTED AS SHOWN)

FIGURE 25

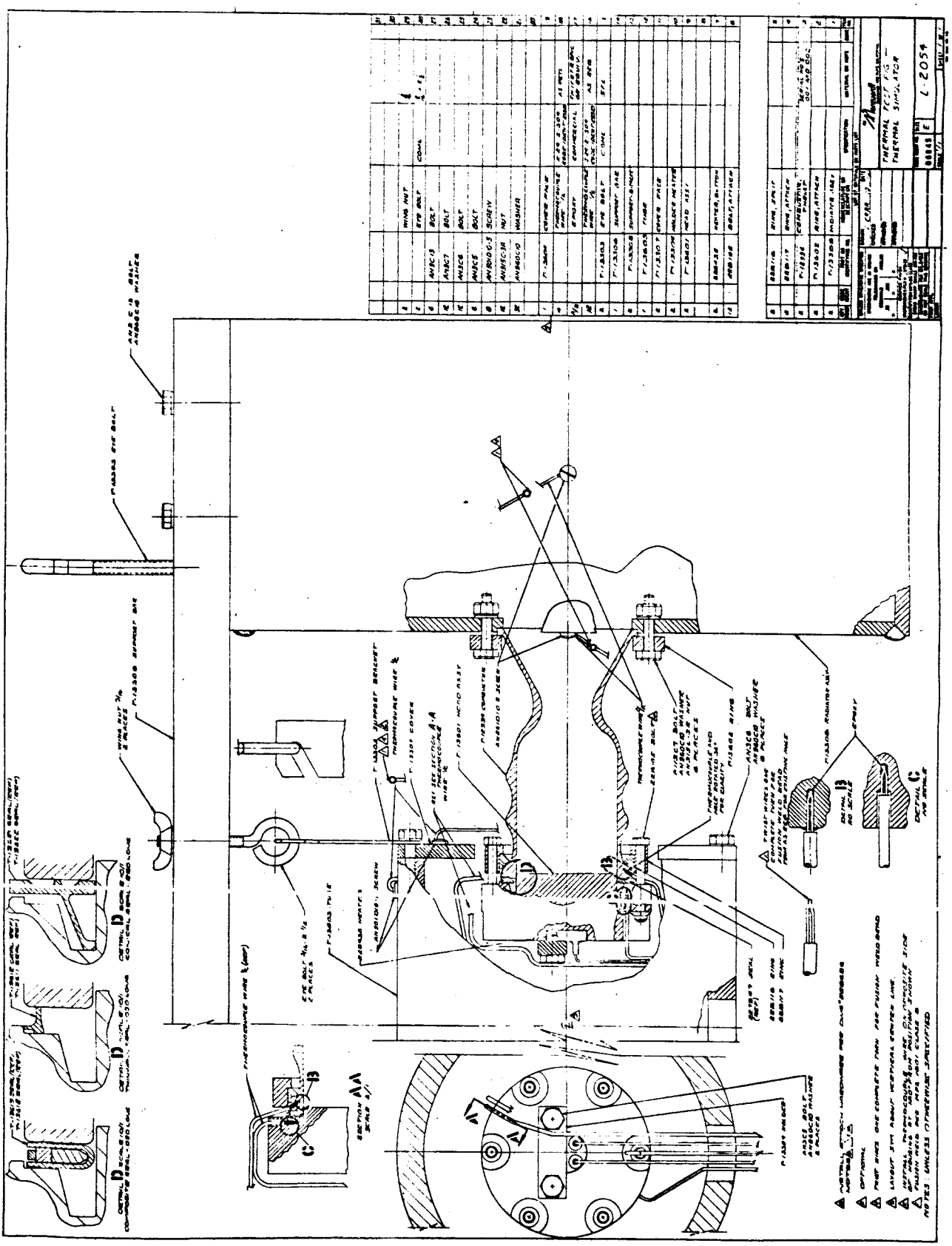


FIGURE 26

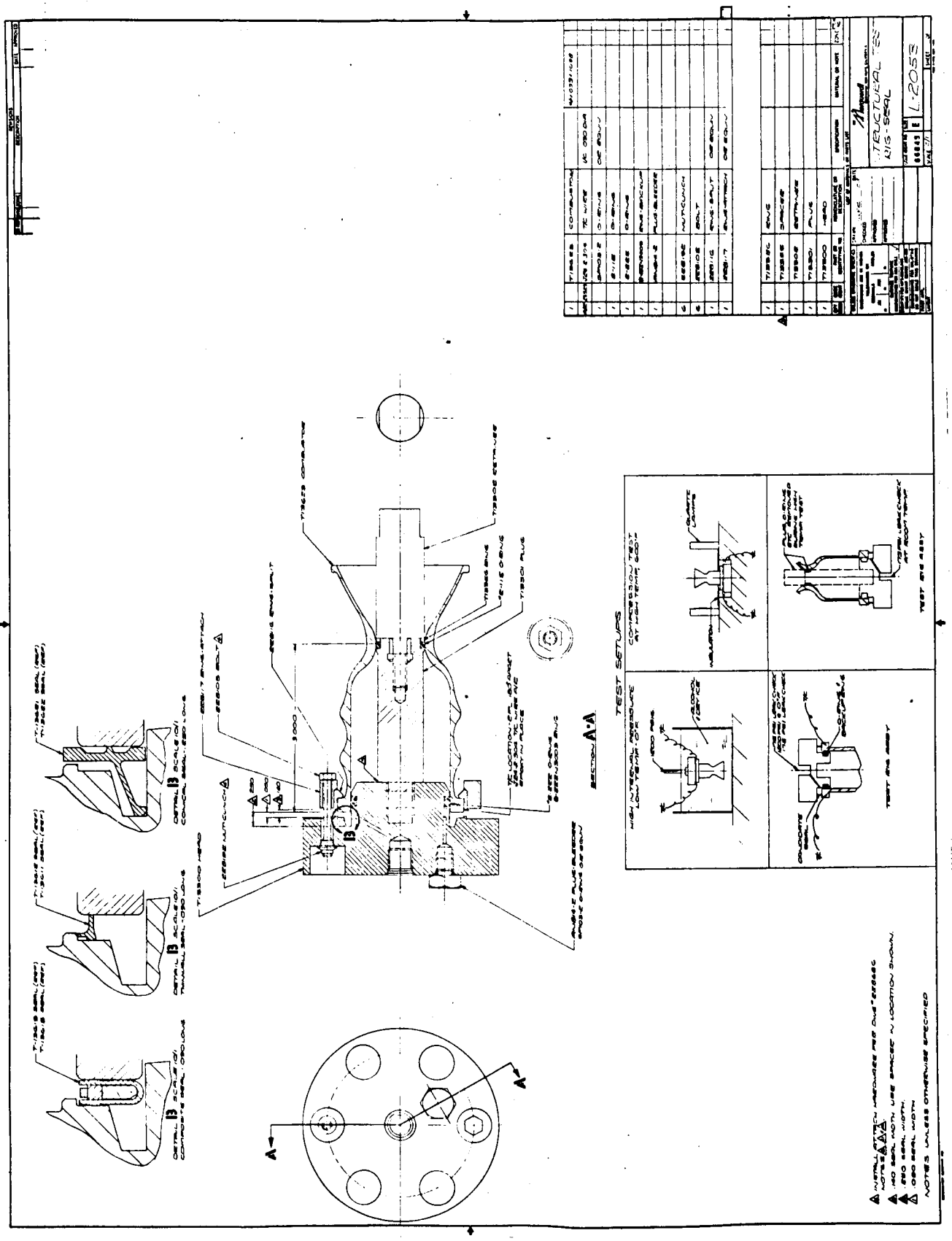


FIGURE 27

ATTACHMENT 1

THE Marquardt CORPORATION VAN NUYS, CALIFORNIA

TEST REPORT

THERMAL RESISTANCE MEASUREMENT OF FULL SCALE SEALS

FOR

APOLLO SERVICE MODULE

REACTION CONTROL SYSTEM ENGINE

CHAMBER SEAL STUDY

PREPARED UNDER CONTRACT NAS 9-4775

TMC 3008

Prepared By C. S. Hill
C. S. Hill
Analysis Engineer

Approved By
de Funbar
Principal Investigator
Design Engineering

Approved By E. P. Perlman
E. P. Perlman
Program Manager

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CONCLUSIONS AND RECOMMENDATIONS	4

LIST OF ILLUSTRATIONS

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2	Chamber Pressure Spike	6

REFERENCE

1. "The Effect of Rapid Liquid Phase Reactions on Injector Design and Combustion in Rocket Motors", - G. Elverum and P. Staudhammer, JPL, 25 August 1959, Progress Report 30-4.

INTRODUCTION

This report describes the dynamic analysis performed in support of development of high thermal resistance injector/chamber seals for the Apollo SM RCS engine under Contract NAS 9-4775. Analytical estimates and calculations for chamber/head seal cavity peak gas pressures are presented herein.

SUMMARY

For typical seal cavities associated with high thermal resistance injector/chamber seals, the estimated peak seal cavity pressures are 1200 psi and 10,000 psi respectfully for engine ignition overpressure (chamber pressure spike) and seal cavity propellant reactions.

DISCUSSION

The magnitude and characteristics of seal cavity peak pressures were analytically estimated based on a typical seal cavity volume and restrictive passages separating the cavity from the main combustion chamber.

It is important to note that two separately distinct phenomena can be responsible for generating high seal cavity pressures. The first, a pressure originating in the combustion chamber due to engine ignition overpressure, can be transmitted to the seal cavity. The second phenomenon is attributed to a pressure generated in the seal cavity resulting from reaction of accumulated propellants within the cavity. A discussion on each phenomena follows.

Combustion Chamber Pressure Spike

Seal cavity pressure caused by engine ignition overpressure (chamber pressure spike) can rise almost as high as the peak spike pressure if the restrictive gap between the seal cavity and the combustion chamber is .0125 inches (current maximum radial gap width on the Apollo engine).

For choked flow into an initially evacuated volume (seal cavity), the pressure is given by

$$\frac{P}{P_e} = k\left(\frac{2}{k+1}\right)^{\frac{1}{k-1}} \left(\frac{k}{k+1}\right)^{\frac{1}{2}} \sqrt{2RT_e} \quad \frac{A}{V} t$$

For combustion gases with k = 1.25, R = 2250 $ft^2/sec^2 \cdot {}^oR$

$Te = 5{,}000^oR$

$$\frac{P}{P_e} = 2770 \quad \frac{A}{V} t$$

The ratio $\frac{A}{V}$ is approximately the ratio of the restrictive gap to the cross sectional area of the sealcavity. For a gap of .0125 inches and an area of .0172 $in.^2$

$$\frac{P}{P_e} = 24{,}000\ t$$

If the non-ideal nature of the flow through the gap causes a discharge coefficient of .7, this becomes

$$\frac{P}{P_e} = 17{,}000\ t$$

The critical pressure ratio is given by

$$\left(\frac{P}{P_e}\right)_{crit} = \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}} = .56$$

For a constant P_e, the pressure will rise to the choked value in

$$t = \frac{.56}{17{,}000} = 33 \times 10^{-6} \text{ seconds}$$

During an actual spike, the pressure transient in the chamber might be considered to be an exponential pulse of the form

$$P_e = P_{e_o}\ e^{-t/.4 \times 10^{-3}}$$

The pressure in the seal cavity will never reach the full value of the spike because of the decay of chamber pressure while the cavity is filling.

Figure 1 shows the estimated cavity pressure time history for different values of restrictive gaps. The usual spikes measured in engines have a series of shock wave phenomena superimposed. The peak spike pressure is usually taken as the maximum pressure which occurs as one of the shock waves reaches the pressure transducer. Figure 2 shows a typical pressure transient during a spike. The sharp shock-wave transients are narrow enough so that the seal cavity will tend to respond to the underlying exponential chamber pressure transient rather than to the fine structure of the shock wave pressures. The peak value of the exponential chamber pressure will be less than the peak instantaneous pressure by a factor of 2 or more in a typical case.

For a spike with a maximum measured instantaneous chamber pressure of 1500 psi, the exponential pressure might be 750 psi and the seal cavity, with a restrictive gap of .0125 inches, would have a maximum internal pressure of .8 X 750 = 600 psi. However, chamber wall strain gage measurements obtained during chamber spike tests indicate that the chamber wall responds to a pressure greater than that recorded by the pressure transducer. The ratio of strain gage to pressure transducer measurements in the range of 1500 psi is approximately 2. Therefore, a conservative design limit pressure for the seal cavity is estimated to be .8 X 1500 psi or 1200 psi for a maximum restrictive gap of .0125 in.

PRESSURE DUE TO REACTION OF ACCUMULATED PROPELLANTS IN SEAL CAVITY

Reference (1) gives an experimentally determined value for the pressure produced by the combination of Hydrazine and Nitrogen Tetroxide in an enclosed volume. This pressure was 50,000 psi and lies between the values of 260,000 psi and 16,000 psi estimated for an O/F of 2 and 13 respectively. It is felt that the 50,000 psi is a reasonable estimate of the maximum local pressure that might be produced in the seal cavity due to the explosion of propellant accumulated within the cavity, presuming that it is filled with propellant.

The present Apollo chamber seal, fabricated from annealed L-605 is calculated to yield at approximately 10,000 psi internal pressure. This pressure corresponds to a pressure generated by a 20% propellant fill of the seal cavity. There have been no failures of the present Apollo chamber seals attributed to high internal pressures. Further, there is no evidence to indicate that seal cavity explosions have, in fact, occurred. However, due to the lack of evidence leading to the conclusion that seal cavity explosions cannot occur, it is assumed that this phenomena may occur under certain environmental conditions and engine attitudes.

On this basis, it is reasonable to consider a maximum cavity pressure which will not exceed the capabilities of the present L-605 seal. For design purposes, a 10,000 psi maximum pressure was established.

CONCLUSIONS AND RECOMMENDATIONS

Of the two pressure phenomena investigated, the low pressure (1200 psi) should be selected for design criteria because the Apollo SM RCS engine combustion chamber is designed for (10σ = 1500 psia). The high pressure criteria (10,000 psi) corresponding to the maximum pressure capability (yield) of the present Apollo SM RCS engine seal, should be used for follow on designs.

ESTIMATED SEAL CAVITY PRESSURE FOR EXPONENTIAL SPIKE

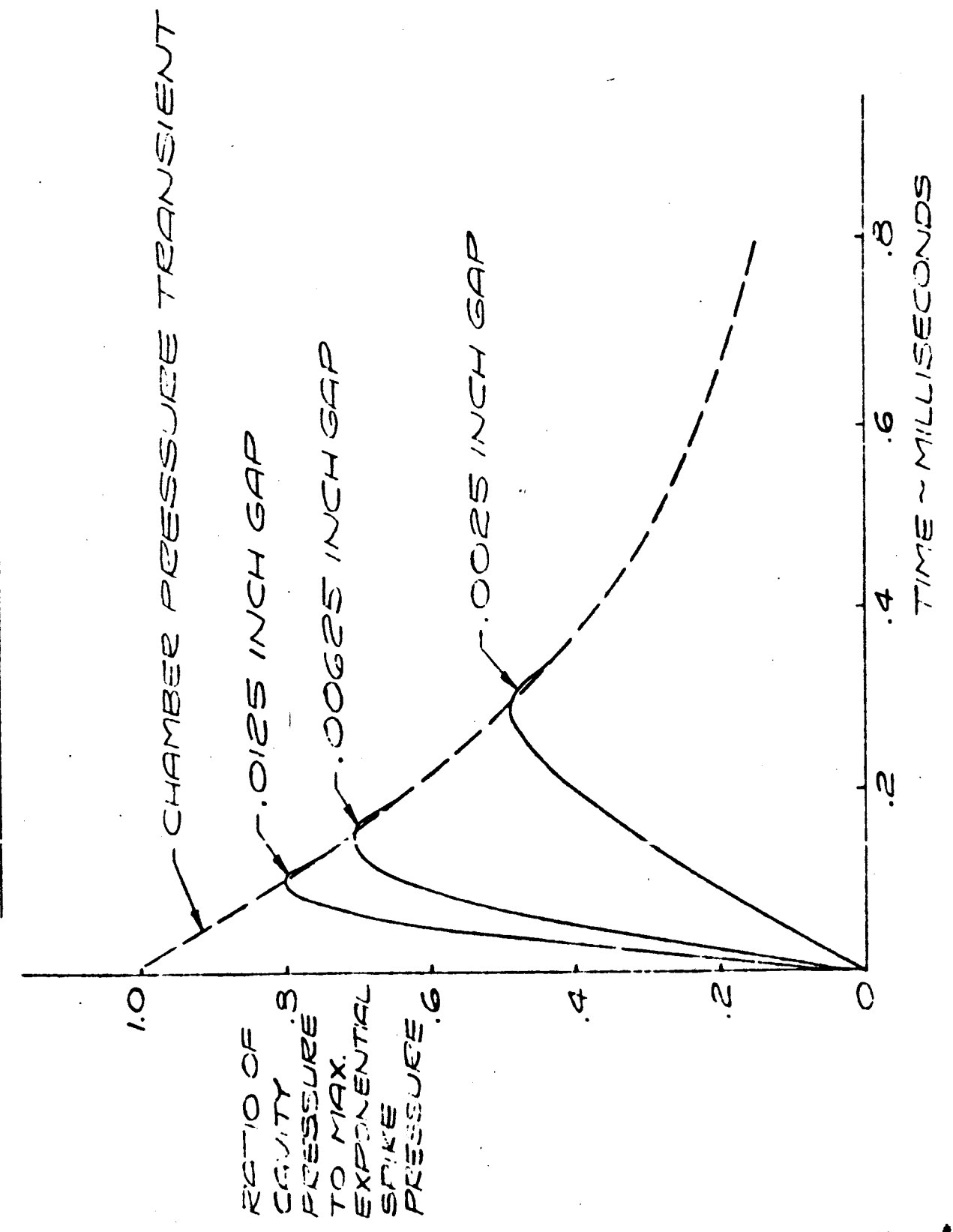


FIGURE 1

CHAMBER PRESSURE SPIKE

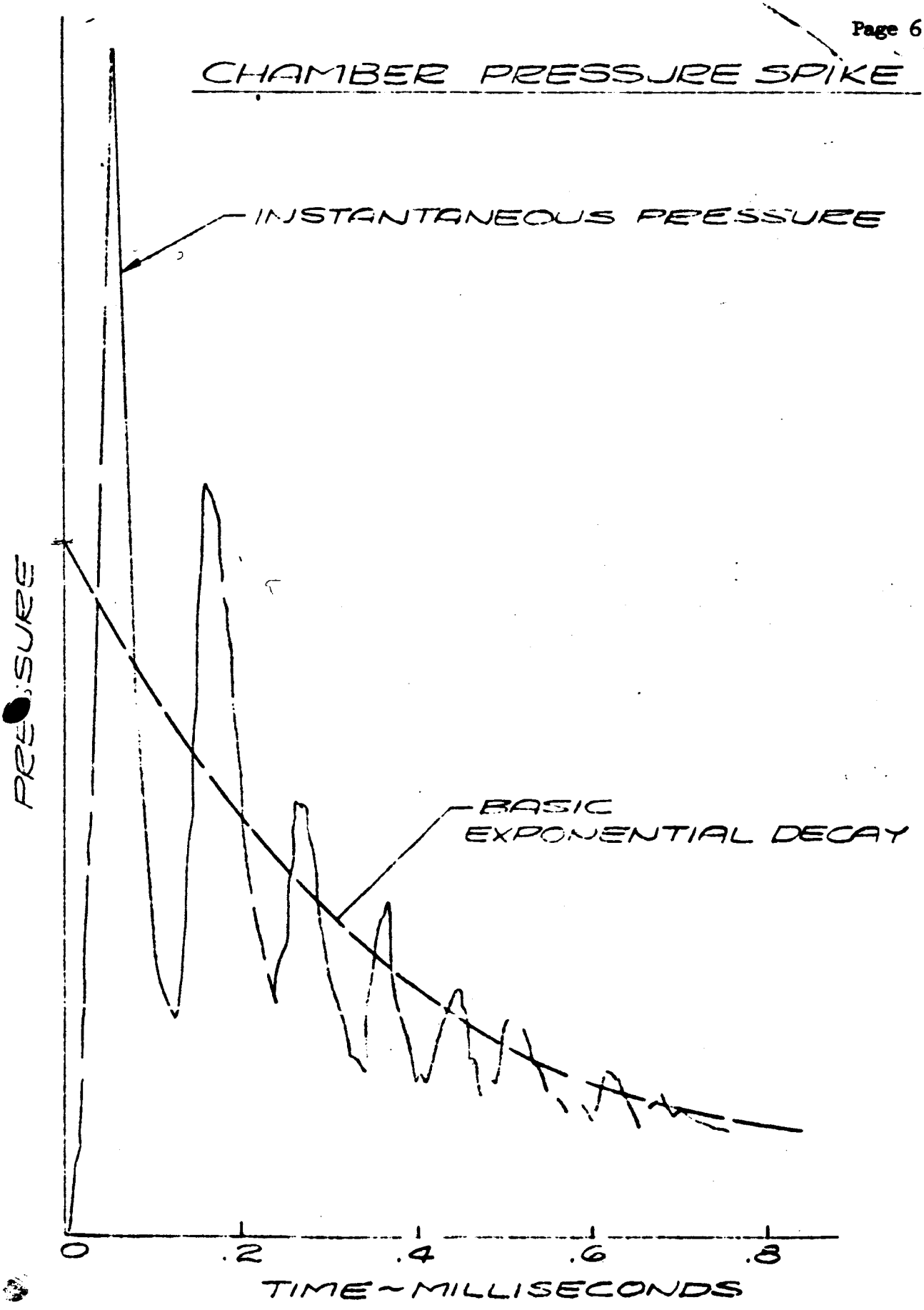


FIGURE 2

ATTACHMENT 2

THE Marquardt CORPORATION VAN NUYS, CALIFORNIA

THERMAL MODEL ANALYSIS

OF TRANSIENT INJECTOR/COMBUSTOR

JOINT TEMPERATURES DURING ENGINE HEAT SOAKBACK

FOR

APOLLO SERVICE MODULE

REACTION CONTROL SYSTEM ENGINE INJECTOR

CHAMBER SEAL STUDY

PREPARED UNDER CONTRACT NAS9-4775

TMC 3008

Prepared By: C. S. Hill
C. S. Hill

Approved By: J. Puntar
J. Puntar
Principal Investigator
Design Engineering

Approved By: E. P. Perlman
E. P. Perlman
Program Manager

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2	TEMPERATURE VS. TIME, CALCULATED HEAT SOAKBACK TRANSIENTS, SEAL RESISTANCE = .5 HR-^{o}F/BTU	4
3	TEMPERATURE VS. TIME, CALCULATED HEAT SOAKBACK TRANSIENTS, SEAL RESISTANCE - 2.75 HR-^{o}F/BTU	5
4	TEMPERATURE VS. TIME, CALCULATED HEAT SOAKBACK TRANSIENTS, SEAL RESISTANCE = 5.0 HR-^{o}F/BTU	6
5	100 LBS. ENGINE THERMAL CIRCUIT	7

INTRODUCTION

This report describes the thermal analysis performed on a computer model of the Apollo SM RCS Engine in support of the development of high thermal resistance injector/chamber seals under Contract NAS9-4775.

SUMMARY

A computer model of the TMC 100# Engine was made using various seal resistances in order to estimate the temperature effect of high resistance seals upon the design.

The calculated results are compared with a typical engine firing on Figure I. The calculated temperature transients are slightly higher than measured but are within 10% during heat up and the maximum soakback temperature.

The temperature transients have been plotted at four different locations in the engine to show the effects of increasing the seal resistance. Figures 2 through 4 show computed transient temperatures for seal resistances of 0.5, 2.75, and 5.0 $\frac{HR\text{-}^{o}F}{BTU}$.

Figure 5 is a schematic of the engine showing the location of the node points in the analysis.

DISCUSSION

The computer model shown in Figure 5 was made using the standard technique of lumping the mass at node points and connecting the nodes with resistances using the engine geometry to calculate the thermal resistances.

The temperature transients were calculated on the 7040 computer using the Marquardt thermal analyser program. The temperature distribution from a steady state engine firing was specified as the initial temperature and a soakback transient calculated. The engine was assumed thermally isolated and radiating to deep space -460°F.

The calculated injector head rise rate is slower than actual indicating that the injector head does not act as one node during the initial soakback. The temperature gradients in the actual engine will also effect the initial rise rate. The maximum soakback temperature calculated is at 330°F at 350 seconds where the actual is 325°F at 200 seconds. However, the calculated value is within 15°F of the actual at 200 seconds. The

cooldown transient of the computer model is slower than the measured transient reflecting either too high computed thermal capacity in the model and/or heat losses from the engine to the facility which are not accounted for in the analysis.

The computer model is within 10% of the actual temperatures of the engine and can be used with a high degree of confidence for structural design evaluation.

The computer tabulated output lists the temperature at each node point every five seconds for six hundred seconds of real time. This output should be used for detailed structural analysis. The transient soakback temperatures of four significant points, i.e., the moly flange, the injector head, the chamber bolts head and the mid-point of the bolt are plotted on Figures 2 through 4 for seal resistances of 0.5, 2.75, and 5.0 $\frac{HR-^{o}F}{BTU}$ respectively.

These plots show that the peak moly flange temperature will increase from 600°F to approximately 750°F as the seal resistance is increased from 0.5 to 5.0 $\frac{HR-^{o}F}{BTU}$. The relatively small amount of change indicates that increasing the seal resistance will not take the flange temperature above 775°F even if the seal thermal resistance were to increase to ≈ 8 $\frac{HR-^{o}F}{BTU}$.

The computer model tends to be conservative as the injector is assumed to have the same steady state temperature distribution as the present engine. Actually, the injector temperature will decrease by some amount due to a smaller amount of heat conducted into the injector from the chamber.

The computer model is reasonably accurate and can be used to generate data for design evaluation. Further refinement of the model is recommended to determine the temperature transients through the valves and the effects of design changes upon the design.

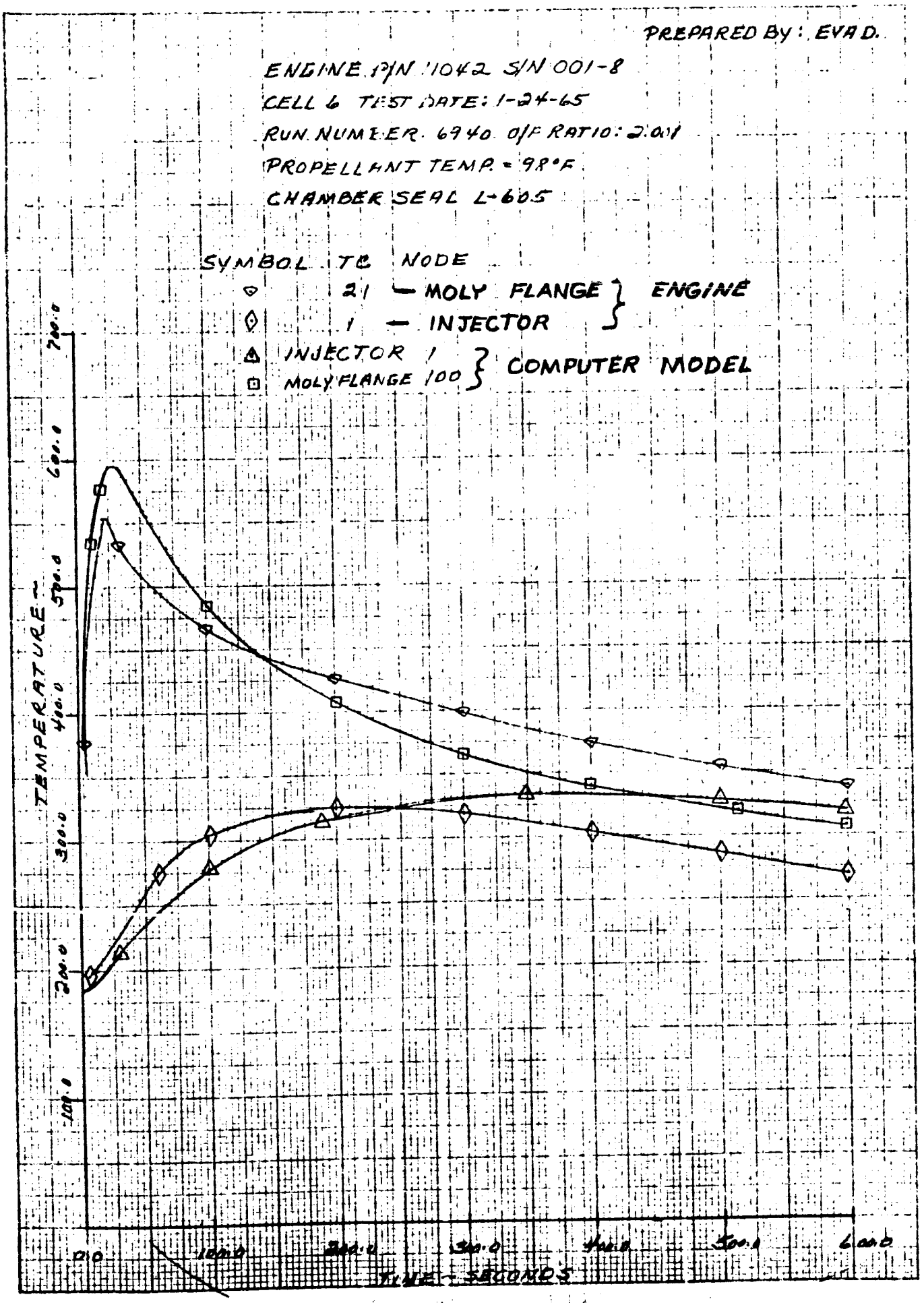

PREPARED By: EVA D.
ENGINE P/N 1042 S/N 001-8
CELL 6 TEST DATE: 1-24-65
RUN NUMBER 6940 O/F RATIO: 2.01
PROPELLANT TEMP. = 98°F
CHAMBER SEAL L-605
SYMBOL TC NODE
21 — MOLY FLANGE } ENGINE
1 — INJECTOR }
INJECTOR 1
MOLY FLANGE 100 } COMPUTER MODEL
TEMPERATURE
TIME - SECONDS

FIG 1.

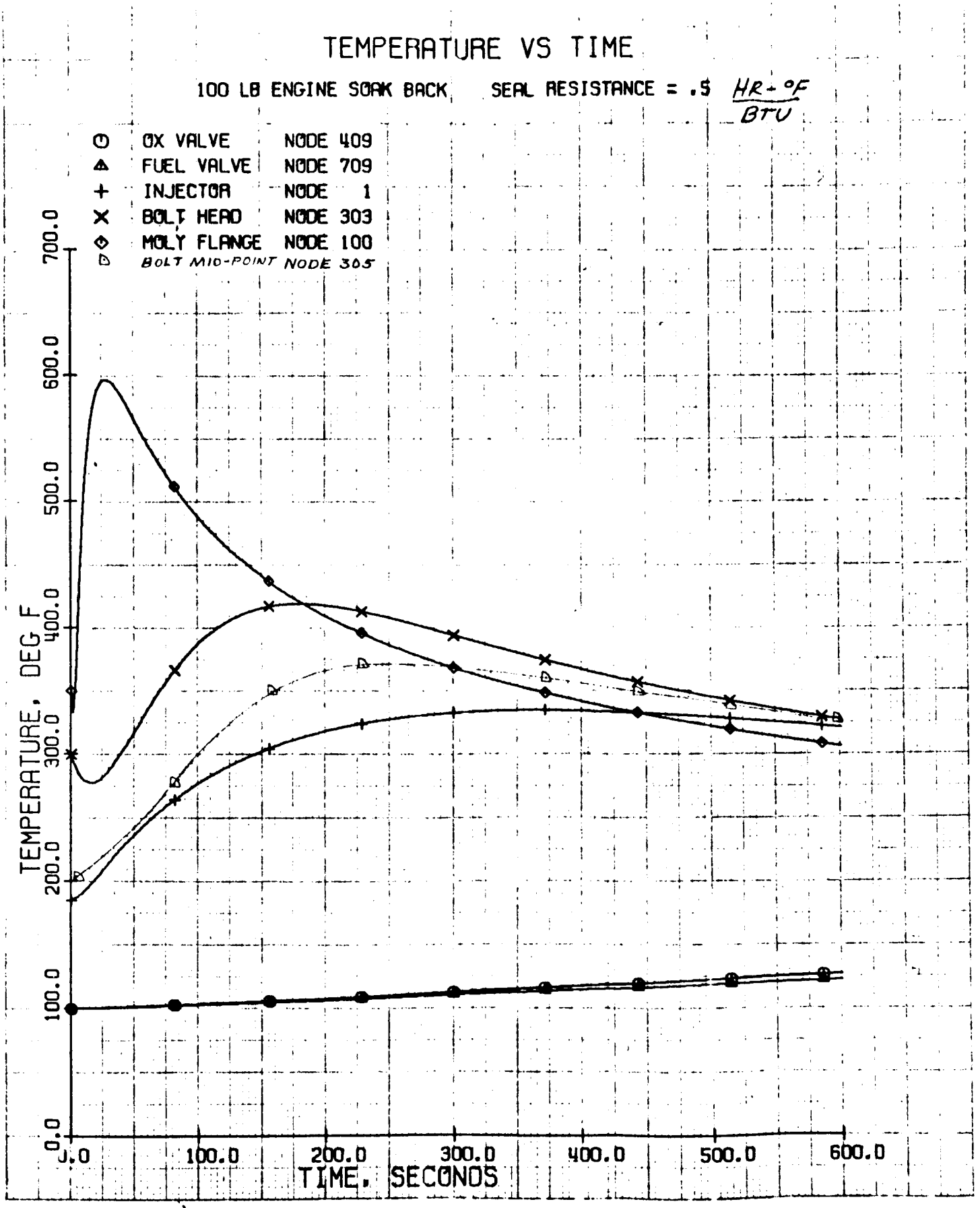

TEMPERATURE VS TIME
100 LB ENGINE SOAK BACK SEAL RESISTANCE = .5 HR-°F/BTU
OX VALVE NODE 409
FUEL VALVE NODE 709
INJECTOR NODE 1
BOLT HEAD NODE 303
MOLY FLANGE NODE 100
BOLT MID-POINT NODE 305
TEMPERATURE, DEG F
0.0
100.0
200.0
300.0
400.0
500.0
600.0
700.0
0.0
100.0
200.0
300.0
400.0
500.0
600.0
TIME, SECONDS

FIGURE 2

TEMPERATURE VS TIME

100 LB ENGINE SOAK BACK SEAL RESISTANCE= 2.75 HR-°F/BTU

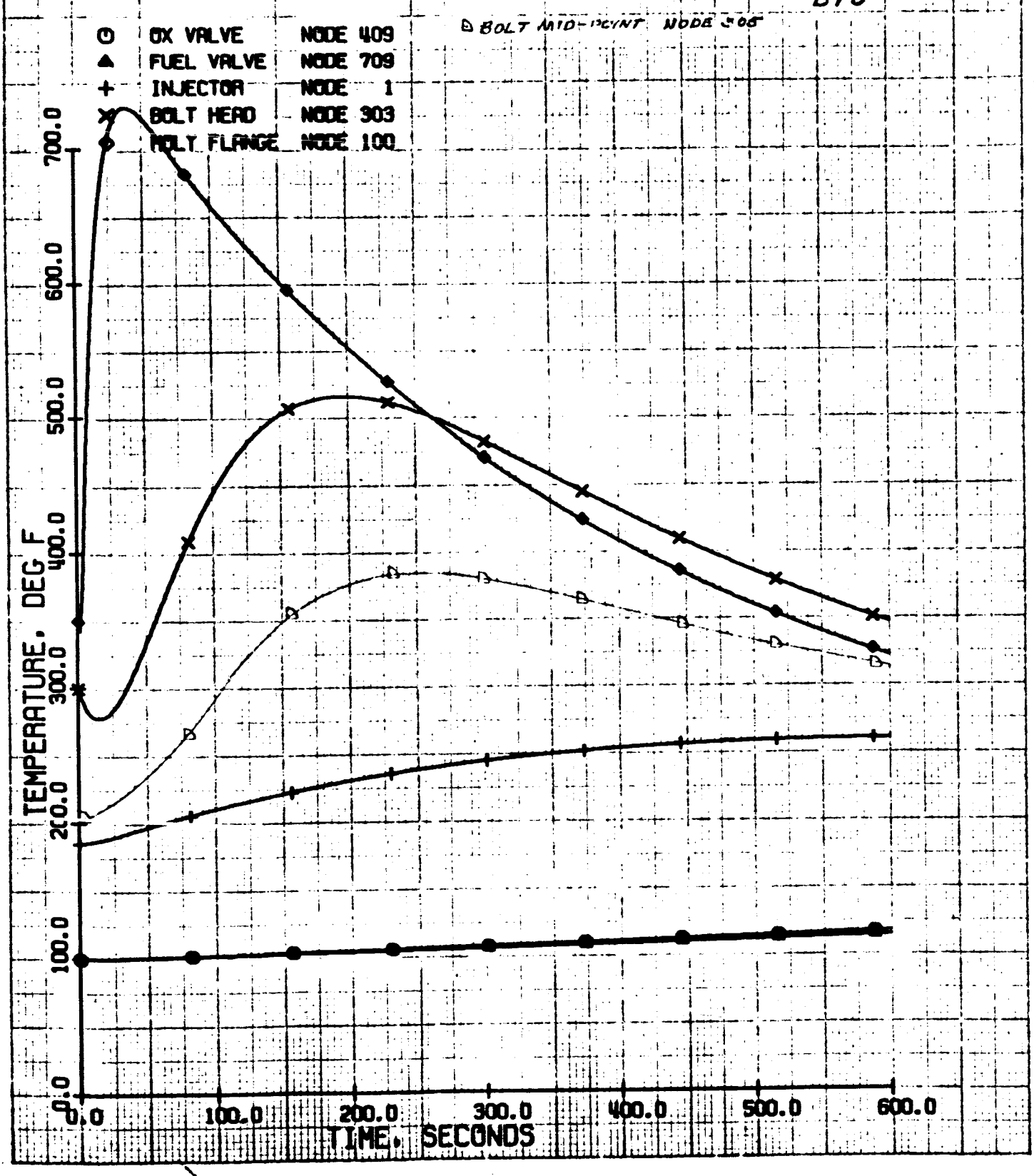


FIGURE 3

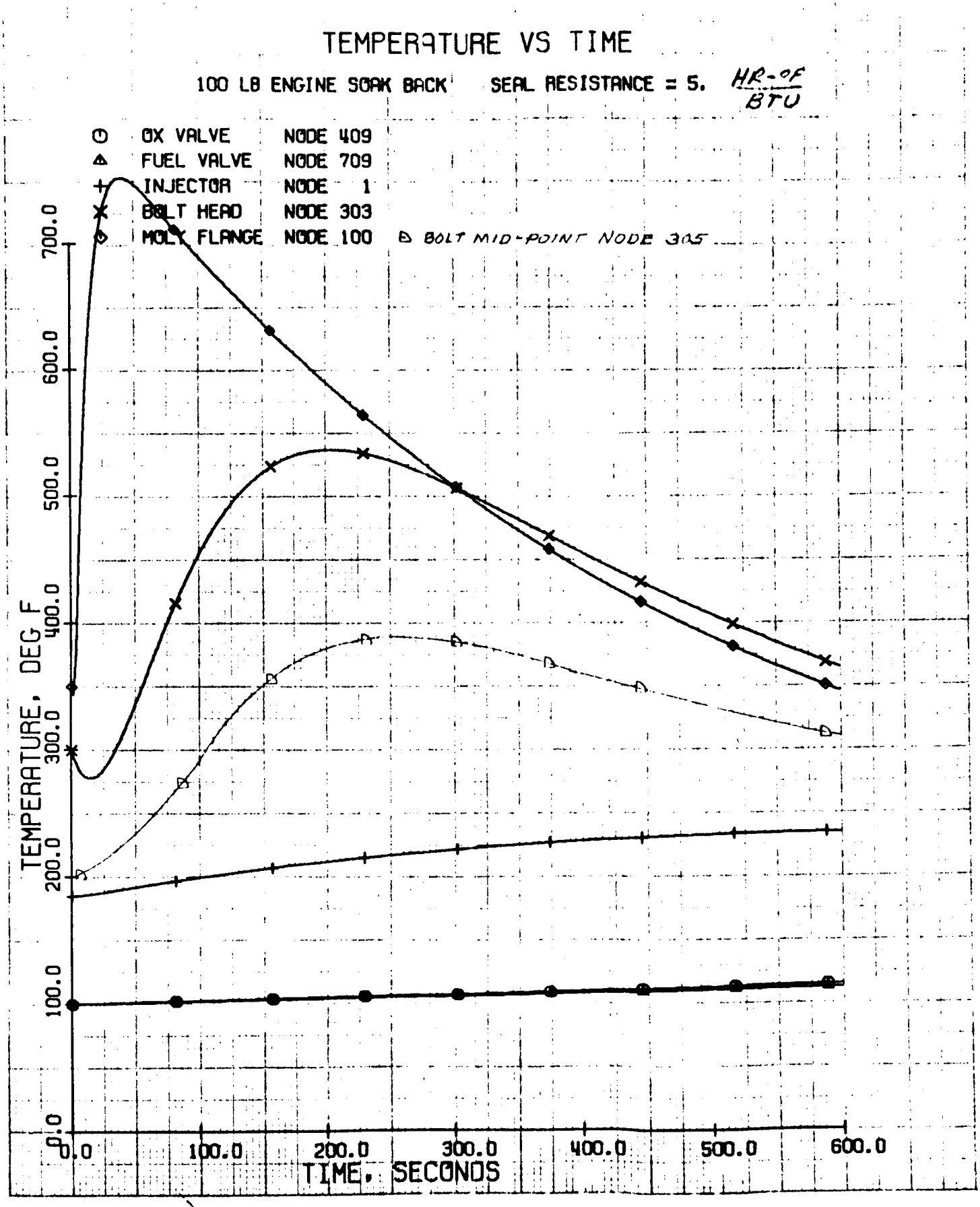

TEMPERATURE VS TIME
100 LB ENGINE SOAK BACK SEAL RESISTANCE = 5. HR-°F/BTU
OX VALVE NODE 409
FUEL VALVE NODE 709
INJECTOR NODE 1
BOLT HEAD NODE 303
MOLY FLANGE NODE 100
BOLT MID-POINT NODE 305
TEMPERATURE, DEG F
0.0
100.0
200.0
300.0
400.0
500.0
600.0
700.0
TIME, SECONDS
0.0
100.0
200.0
300.0
400.0
500.0
600.0

FIGURE 4

100 # ENGINE THERMAL CIRCUIT

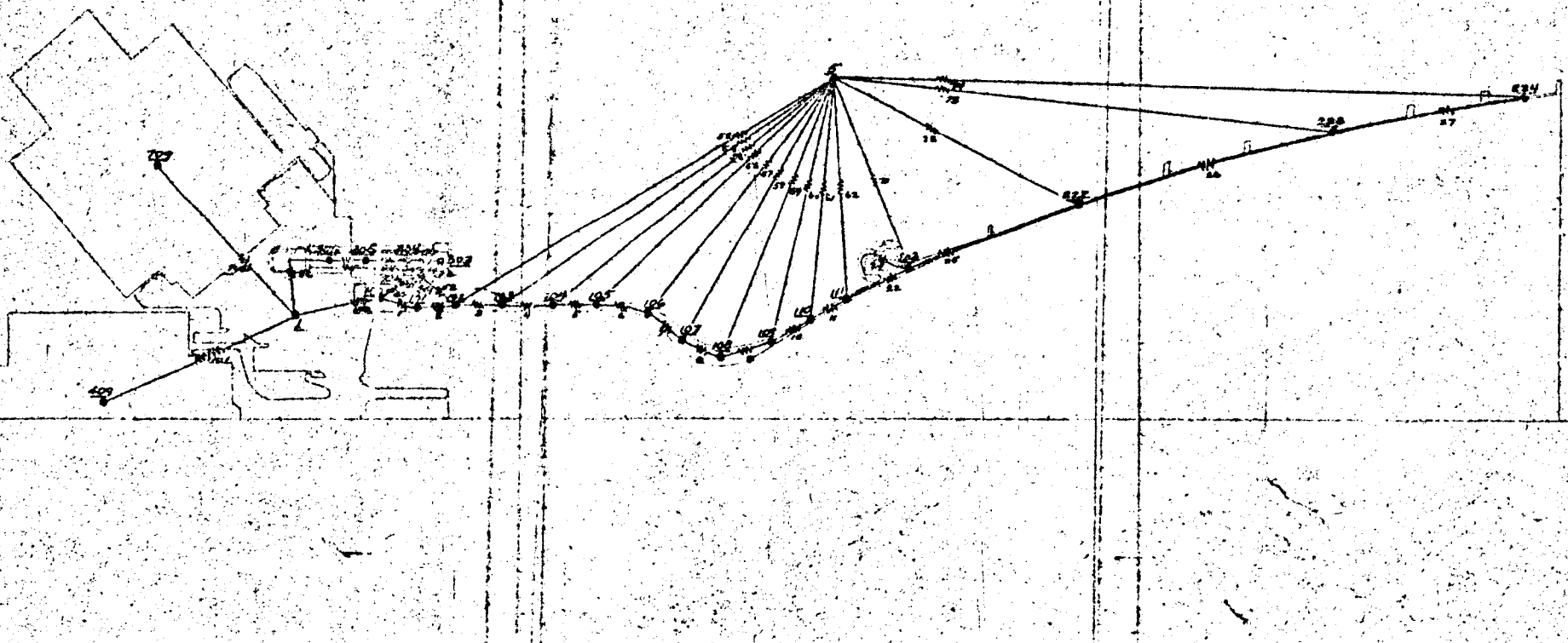


FIGURE 5

ATTACHMENT 3

THE Marquardt CORPORATION VAN NUYS, CALIFORNIA

STRESS ANALYSIS

FOR

APOLLO SERVICE MODULE

REACTION CONTROL SYSTEM ENGINE INJECTOR

CHAMBER SEAL STUDY

PREPARED UNDER CONTRACT NAS9-4775

TMC 3008

Prepared By G. Carayanis

Approved By J. Puntar
Principal Investigator
Design Engineering

Approved By E. P. Perlman
Program Manager

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Title	Page
Introduction	1
Summary	1
Conclusions	2
Attachment - Stress Memo, S.M. #153	

INTRODUCTION

This report describes the Stress Analysis performed in support of development of high thermal resistance injector/chamber seals for the Apollo SM RCS Engine under Contract NAS9-4775. Stress analysis calculations for candidate seal designs are presented herein.

SUMMARY

This report is based on the development of a seal to replace the present Apollo head to chamber seal with a seal of higher thermal resistance and contains the stress analysis for the three basic seal configurations which are:

1. The conical seals (T-13621 and T-13622 made of Rene'41 and 6AL-4V Ti, respectively).

2. The thinwall seals (T-13611 and T-13612 made of 6AL-4V Ti, and Rene' 41, respectively).

3. Composite seal-jacket (T-13618 made of 6AL-4V Ti jacket, and bumper and Zircoa C spacer).

The bearing stresses between seals and chamber flange as well as the injector head are calculated for the design loads and are included in this report.

The load conditions used for the stress analysis are:

1. Estimated maximum spike pressure on the seal cavity - p = 1,200 psi limit and p = 1,800 psi ult. Ref. Progress Report, PR 3008-2. (Only the jacket design was checked for this pressure; the other two were not critical).

2. Preload and thermal load: P = 1,285 #1 bolt limit and P = 1,920 #1 bolt ult. (Based on the Apollo Engine loads, Ref. S.M. #101-5, Page 2).

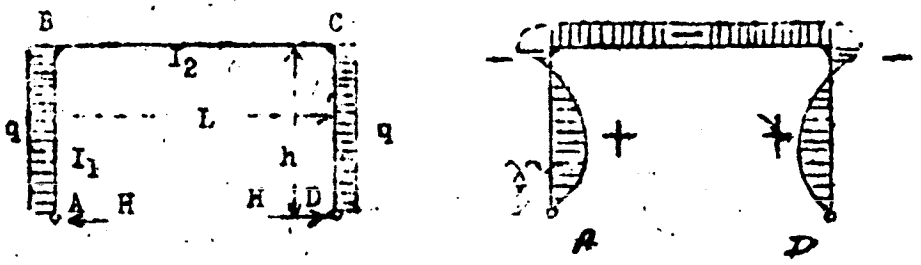
3. Boost load: P = 1,500 #/in limit, and P = 2,250 #/in ult. These loads are also based on the Apollo Engine loads (Ref. S.M. #101-5, Page 4).

Loads (2) and (3) are used for checking the seals as columns for finding the tension stress on the flange of the conical seal, for getting the bearing stresses on the aluminum injector head and the moly flange, and for obtaining the bending stresses on the jacket-seal. The temperatures corresponding to the three loading conditions are shown on Page 1, Attachment S.M. #153.

The stresses and minimum margins are summarized on Page A, Attachment S.M. #153. Method of analysis is detailed in the body of the report.

CONCLUSIONS

Designs as shown in attached Table of Margins are satisfactory for the conditions analyzed. Margins of safety areshown on Page A, Attachment S.M. #153, and in the Stress Analysis.



(

$$V = 0 \qquad K = \frac{I_2}{I_1} \cdot \frac{h}{L}$$

$$H = \frac{3}{4} qh \cdot \frac{k+2}{2k+3}$$

Moment in any section of the column at a distance x from A or from D:

$$M_x = + H \cdot x - \frac{q \cdot x^2}{2}$$

$$M_A = M_C = - \frac{qh^2}{4} \cdot \frac{k}{2k+3}$$

Constant moment at any point of the beam:

$$M_x = M_B = M_C = - \frac{qh^2}{4} \cdot \frac{k}{2k+3}$$

Greatest positive moment in the column at:

$$x_m = \frac{3}{4} \cdot h \cdot \frac{k+2}{2k+3} \quad (x_m \text{ measured from A})$$

Zero moment in the column at:

$$x_o = \frac{3}{2} \cdot h \cdot \frac{k+2}{2k+3}$$

$$+M_{max} = + H \cdot x_m - \frac{q x_m^2}{2}$$

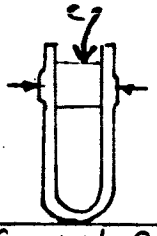
TABLE OF CONTENTS

CHAMBER SEAL STUDY

ITEM	DESCRIPTION	PAGE
1	Table of Margins of Safety	A
2	Design Loads	1
3	Jacket Seal Stress Analysis	2-7
4	Spacers Corresponding to the Jacket Design	8
5	Conical Seals Analysis	9-16
6	Thinwall (Straight) Seals Analysis	17-18
7	Bearing Between Seals and Chamber Flange	19
8	Bearing Between Seals and Injector Head	20

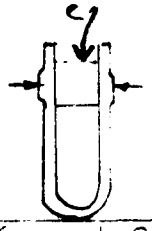
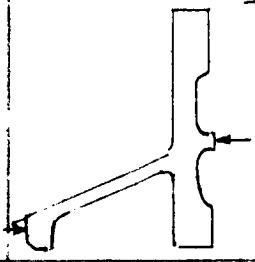
Chamber Seal Study

Table of Minimum Margins of Safety

Item	Part	Material	Temp.	Stress (KSI)	Allow.	M.S.	Page
1a	Jacket Seal  T-13614 Jacket	GAL 4VT4	0 °F	143 ult	160 ult	+.12	6
1b	T-13613 Jacket	Rene 41	0 °F	104 limit	110.5 (.85 F_{TY})	+.06	7
1c	T-13617 Spacer	Zircoac	150°F	113 ult.	303 ult	+1.68	8
2a	Conical Seal T-13622	GAL-4VT4	600°F	114 ult	114 ult	.0	12
2b	T-13621	Rene 41	150°F	121 ult	135.5 ult	+.12	14
3a	Thin (straight) Seal T-13611	GAL-4VT4	600°F	100 ult	120 ult	+.20	17
3b	T-13612	Rene 41	150°F	132 ult	146 ult	+.11	18
4	Moly chamber Flange bearing	Moly	650°F	66.9 limit	78.5 (.85 F_{TY})	+.18	19
5	Injector Head bearing	6061-T6 Alum.	350°F	63.3 ult	63.4 ult	+.002	20

Chamber Seal Study

Table of Minimum Margins of Safety

Item	Part	Material	Temp.	Stress (KSI)	Allow.	M.S.	Page
1a	Jacket Seal  T-13614 Jacket	6AL 4VT4	0 °F	143 ult	160 ult	+.12	6
1b	T-13613 Jacket	Rene 41	0 °F	104 limit	110.5 (.85 FTY)	+.06	7
1c	T-13617 Spacer	Zircoac	150°F	113 ult.	303 ult	+1.68	8
2a	Conical Seal  T-13622	6AL-4VT4	600°F	114 ult	114 ult	.00	12
2b	T-13621	Rene 41	150°F	121 ult	135.5 ult	+.12	14
3a	Thin (Straight) Seal  T-13611	6AL-4VT4	600°F	100 ult	120 ult	+.20	17
3b	T-13612	Rene 41	150°F	132 ult	146 ult	+.11	18
4	Moly chamber Flange bearing	Moly	650°F	66.9 limit	78.5 (.85 FTY)	+.18	19
5	Injector Head bearing	6061-T6 Alum.	350°F	63.3 ult	63.4 ult	+.002	20

Design Loads

1) Spike Pressure On the Seal Cavity [a]

P = 1200 psi Limit At 0 °F
= 1,800 psi ult. " "

2) Boost Load (From Air Load & Vibration

q = 1,500 #/in Limit at 150°F
q = 2,250 #/in ult " "

Refere to SM # 101-5, page 4 ($q = 16{,}700 \times .09 = 1{,}500$ #/in Limit [b]

3) Preload & Thermal

P = 1,285 # /bolt Limit (Chamber Face at 650°F
= 1,920 # /bolt ult. Injector end at 350 °F)

P = 7,710 # Limit (6 Bolts)
= 11,565 # ult

Refere to SM # 101-5 page 2

[a] This is an estimated pressure and is based on the Progress Report PR 3008-2

[b] This load is based On the Apollo Seal bearing stress of σ = 16,700 psi & the Apollo seal thickness of t = .09

T-13614 JACKET -.090 COMPOSITE SEAL (ALSO T-13613)
METHOD OF ANALYSIS

TO FIND STRESSES IN THE CROSS-SECTION OF THIS PIECE, USE IS MADE OF A RECTANGULAR "BENT", THIS BENT IS SHOWN ON PAGE 1 SUPERPOSED ON THE CROSS-SECTION.

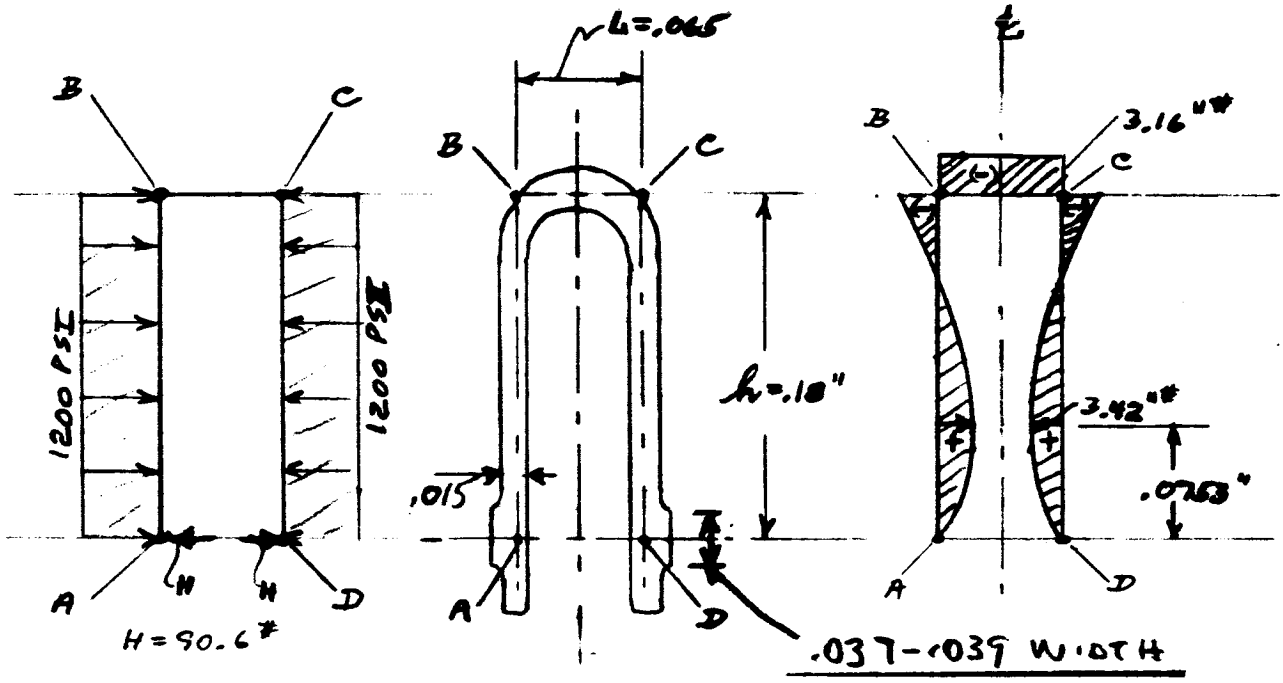
TWO BASIC LOADINGS ARE CONSIDERED. ONE IS TO REPRESENT PRESSURE ATTEMPTING TO DISTORT THE SEAL CROSS SECTION. THE PRESSURES APPLIED FOR THIS ANALYSIS ARE SHOWN BY THE LOADING DIAGRAM ON PAGE 3 THE SEMI-CIRCULAR ARCH BETWEEN B AND C WILL BE EFFECTIVE IN CARRYING PRESSURE IN THAT REGION WITHOUT INDUCING INTERNAL MOMENTS AT B & C SO THE PRESSURE IS NOT INCLUDED FOR LOADING ON THE SUBSTITUTE STRAIGHT MEMBER B-C. REFERENCE CAN BE MADE TO BENT FORMULAE IN THE BOOK "RIGID FRAME FORMULAS" by PROF. DR-ING. A. KLEINLOGEL, FRAME 39. PUBL. BY FREDERICK UNGAR PUBLISHING CO, N.Y. A SIMPLIFIED FORM FOR APPLICATION TO THIS PROBLEM IS SHOWN ON APPENDIX PAGE A OF THIS REPORT.

THE OTHER BASIC LOADING IS THE INITIAL LOADING WHICH RESULTS FROM INSTALLATION. THE PRESSURE PADS A AND D ARE MOVED TOWARD EACH OTHER WHICH INDUCES BENDING AT EDGES B AND C. THIS LOADING IS SHOWN ON PAGE 4 SKETCHES

AFTER STRESSES ARE FOUND FOR EACH OF THE BASIC LOADINGS THEY ARE ADDED TO FIND TOTALS. THIS IS DONE ON PAGE 6 FOR THE TITANIUM PIECE.

PART T-13613 IS SIMILAR TO T-13614 EXCEPT THAT IT IS MADE OF STEEL. THE INSTALLATION STRESS WILL BE GREATER BECAUSE OF THE HIGHER MODULUS OF ELASTICITY. COMBINED STRESSES ARE FOUND ON PAGE 7 FOR THE STEEL PIECE.

T-13614 JACKET - .090 COMPOSITE SEAL



LOADING DIAGRAM

SHOWING IDEALIZED BENT SUPER-POSED ON CROSS-SECTION OF JACKET

BENDING-MOMENT DIAGRAM

$V = 0 \qquad k = \frac{1}{1} \times \frac{.18}{.065} = 2.77$

$H = \frac{3}{4} \times 1200 \times .18 \times \frac{2.77+2}{(2\times 2.77)+3} = 900 \times .18 \times \frac{4.77}{8.54} = 90.6\#$

GREATEST + MOM ON A-B OR D-C IS AT $X_M = \frac{3}{4} \times .18 \times \frac{4.77}{8.54} = .0753$

MAX MOM IN A-B OR B-C $= (90.6 \times .0753) - \frac{1200 \times .0753^2}{2}$

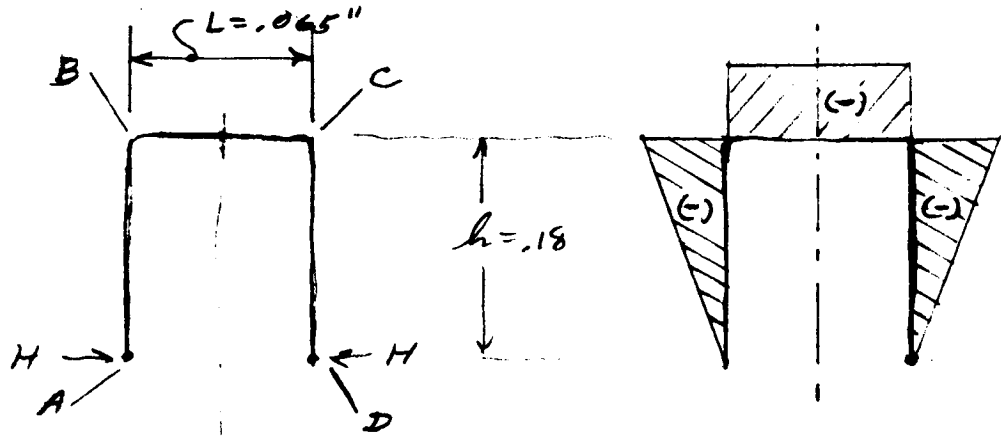
$= 6.82 - 3.40 = 3.42"\#$

$f_b = \frac{MC}{I \times t^2} = \frac{3.42 \times 6}{1 \times .065^2} = 9.120 \times 10^4 = 91{,}200 \text{ PSI}$

CONSTANT MOM. ALONG B-C $= \frac{-1200 \times .18^2}{4} \times \frac{2.77}{8.54} =$

$= -9.74 \times .324 = -3.16"\#$

T-13614 JACKET (CONT'D)



TO FIND DEFL OF POINT A REL TO ℄ OR PLANE OF SYMMETRY DUE TO H

MOM ON CROSS-BEAM IS $H \times .18$

TAKE I CROSS BEAM ℄ OF LEGS AS FOR 1" STRIP .065" THICK (MIN) OR 16.4×10^6 TAKE E_c AS E OF T_A AT RT

ROTATION OF "B", $\theta_1 = \frac{Ml}{EI} = \frac{(.18H)\cdot\frac{.065}{2}}{EI}$

$= \frac{1}{EI}(.18H \times .0325) = \frac{H}{EI} \times .00585$ RADIANS

DEFL. OF A DUE TO BNDG DEFL OF (A - B) LEG IS

$y = -\frac{1}{3}\frac{Wl^3}{EI} = -\frac{1}{3}\frac{H \times .18^3}{EI} = .001945 \times \frac{H}{EI}$ INCHES

TOTAL DEFL AT "A" REL TO ℄ PLANE IS

$\left[\frac{H}{EI} \times .00585\right].18 + \left[\frac{H}{EI} \times .001945\right] = \frac{H}{EI} \times .002998$ IN'S

FROM DWG T13345, WHEN ASSEMBLED AT RT MAX GAP AVAILABLE FOR CYL PC'S IS .053"

FROM DWG T13351 MIN LNGTH OF CYLINDERS IS .050
∴ TOTAL GAP TO BE CLOSED BY DRAWING POINTS A & D TOWARDS EACH OTHER BY TIGHTENING BOLTS IS .003" OR FROM STR PLANE .0015" PER SIDE

T-13614 JACKET (CONT'D)

TO FIND H REQ'D TO CLOSE .0015"/SIDE TAKE I AS I OF 1.0" WIDE STRIP AT A MINI t OF .015" TAKE E AS R.T. E OF 16.4×10^6

$$I = \frac{1 \times .015^3}{12} = \frac{3.38 \times 10^{-6}}{12} = .282 \times 10^{-6}$$

$$.0015 = \frac{H}{EI} \times .002998$$

$$H = \frac{.0015 \times 16.4 \times 10^6 \times .282 \times 10^{-6}}{.002998} = 232^{\#}$$

THE MOM'S AT B & C DUE TO ABOVE ARE

$-2.32 \times .18 = -.42$ IN#

$$f_b = \frac{.42 \times 6}{1 \times .015^2} = 1.113 \times 10^4 = 11{,}130 \text{ PSI}$$

2.25×10^{-4}

AT POINT .0753" UP FROM A TO FIND MOM FROM INITIAL INSTALLATION.

$$M = -2.32 \times .0753 = -.18 \text{ IN}^{\#}$$

T-1361H (CONT'D)
COMBINED MOMENTS

THE TOTAL MOMENT AT THE CORNERS B AND C PLACING TENSION ON THE OUTSIDE IS:
$M = -3.16 - .42 = -3.58$ #"
THE TOTAL MOMENT AT A POINT .0753" FROM "A" IS: $M = +3.42 - .18 = +3.24$ #"

$$f_b = \frac{M_{in}}{bt^2} = \frac{3.58 \times 6}{1.0 \times .045^2} = 95,500 \text{ PSI}$$

6AL-4V AGED Ti PROPERTIES FROM MIL-HNDBK 5, TABLE 5.4.6.1 (a), MAY 1, 1964

$F_{TU} = 160$ KSI — F_{CU} = NOT AVAILABLE

$F_{TY} = 150$ KSI — $F_{CY} = 154$ KSI

$E = 16 \times 10^6$ psi — $E_c = 16.4 \times 10^6$ psi

TITANIUM 6AL-4V AGED:
AT 70°F, WITH NORMAL STRAIN RATES ALLOWABLES ARE FROM ABOVE — USING .85 F_{TY} TO INSURE LINEARITY.

MS AT 1200 PSI "LIMIT" is $\frac{.85 \times 150,000}{95,500} - 1 = +\underline{.33}$

MS AT 1800 PSI "ULT" is $\frac{160,000}{95500 \times 1.5} - 1 = +\underline{.12}$

T-13613 JACKET

EFFECT OF CHANGING TO ST'L

USING E 29.5×10^6 FOR RENÉ OR L-605, THE NEW LOAD, H, OF PAGE 3 BECOMES

$$.0015 = \frac{H}{EI} \times .002998$$

$$H = \frac{.0015 \times 29.5 \times 10^6 \times .282 \times 10^{-6}}{.002998} = 4.17\#$$

THE MOMENT AT B OR C DUE TO ABOVE IS $-4.17 \times .18 = -.75$ "#

AT POINT .0753" FROM A TO FIND MOM FROM INITIAL INSTALLATION

$$M = -4.17 \times .0753 = -.31"\#$$

TOTAL MOMENT AT B : $-3.16 - .75 = -3.91"\#$
" " .0753" FROM A: $+3.42 - .31 = +3.11"\#$

$$f_b = \frac{3.91 \times 6}{1 \times .015^2} = 104{,}000 \text{ PSI "LIMIT"}$$

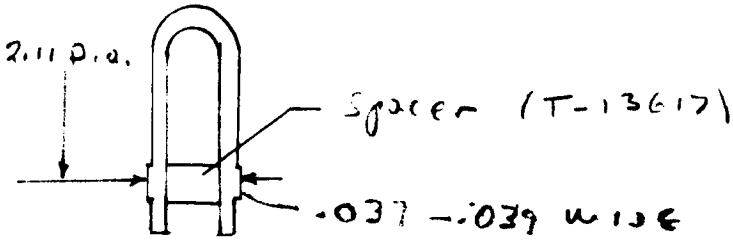
USE .85 F_{TY} AS LINEARITY ALLOWABLE

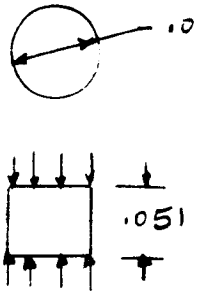
RENÉ 41 MS AT 1200PSI LIMIT IS $\frac{.85 \times 130{,}000}{104{,}000} - 1 = \underline{+.06}$

M.S. AT 1800 PSI "ULT" IS $\frac{170{,}000}{104{,}000 \times 1.5} - 1 = \underline{+.09}$

Chamber Seal Study

Spacers corresponding to the Jacket Design





Material

Zircoa C

$F_{cu} = 303$ at RT
$F_{cu} = 303$ at 150°F Assumed

60 Cylinders to a full Set

Boost Load

P = 2,250 #/in ULT (R-f pg 1.)

$P_{total} = \pi \times 2.11 \times 2,250 = 14,900$ # ult

Total Area = 60 A $= 60 \times \frac{\pi}{4}(.053)^2 = .132\ in^2$

$\sigma = \frac{P_{total}}{A_{total}} = \frac{14,900}{.132} = 113,000$ psi ult

ult, $M.S. = \frac{303}{113} - 1 = +1.68$

BEARING ON MOLY

.037 MINIMUM NOT CRITICAL IN COMPARISON WITH T-13611, T-13612, pg 19, 20

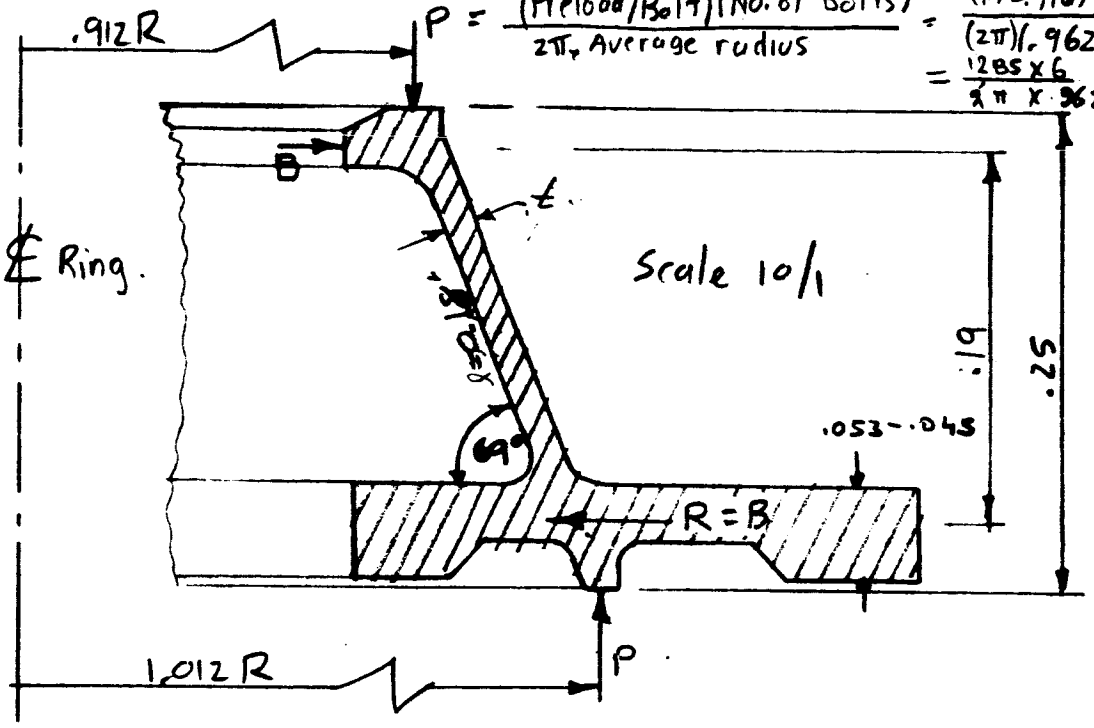
Chamber Seal Study

Seal Analysis (Conical Seal, T-13622)

$$P = \frac{(\text{Preload/Bolt})(\text{No. of Bolts})}{2\pi, \text{ Average radius}} = \frac{(P.L.)(6)}{(2\pi)(.962)} = \frac{1285 \times 6}{2\pi \times .962} = 1{,}275\#/\text{in}$$

preload & thermal

Ref p, 1



Discussion

The cross section above is that of a ring whose ℄ is shown. The ring is loaded by force P/in. The ensuing couple (P)(1.012 − .912) is reacted by a couple 0.19 B. "B" arises from the fact that the ring is in contact with the injector head at B, and as the ring tends to twist, "B" results. The reaction to "B", "R", arises from the internal ring-restraint of the lower flange. See also pg 15

P = 1275 #/inch limit, = 1980 #/in ult at 650°F } G Carayani's
℄ preload & thermal see above
P = 1500 #/inch limit, = 2250 #/in ult at 150°F
boost

Chamber Seal Study

Seal Analysis (cont'd) (Conical Seal T-13622)

Web Stresses

Assume $t = .014$

Checking first as a column of unit width,

use Ramberg-Osgood equations as modified by Cozzone & Melron & illustrated in Brohn, Article C 2.5 & Fig C 2.17

$B = \left(\frac{1}{\pi}\right)\left(\frac{L'}{e}\right)\sqrt{\frac{F_{0.7}}{E_c}}$ ✓ , $n = 1 + \ln\frac{17}{7} \Big/ \ln\frac{F_{0.7}}{F_{0.85}}$ ✓ (Brohn, Article B2.12)

For Ti 6 Al 4V, Heat treated & Aged, at 600°F. (Preload & thermal) the stress-strain curve, from which E, $F_{0.7}$ & $F_{0.85}$ can be obtained, is found in TIMET Bulletin #1, Fig. 39.

$E_c = \frac{85000}{.006} = \frac{F}{\epsilon} = 14.15 \times 10^6$ ✓

$(.85)(14.15)(10)^6 = (12.05)(10)^6$

$\therefore F_{0.85}: 112000\ \#/in^2$ (scaled)

$(.7)(14.15)(10)^6 = 9.9 \times 10^6$

$F_{0.7} = 125000\ \#/in^2$ (scaled)

$F_{0.7}/F_{0.85} = 125/112 = 1.117$ ✓

$\therefore n = 1 + \ln 2.43 / \ln 1.117 = 1 + .889/.1109 = 9.03$ ✓

$\rho = \sqrt{I/A} = \sqrt{\frac{bh^3}{12bh(1-\mu^2)}} = \frac{h}{\sqrt{12.9}} = .303h = (0.303)(.014) = .00424$

Assume one end is pinned & one end is fixed, $\therefore C = 2.05$ page C2.2 of Brohn

$L'/\rho = L/\rho\sqrt{C} = (.18)/(.00424)\sqrt{2.05} = 29.5$ ✓

$\therefore B = \left(\frac{1}{\pi}\right)(29.5)\sqrt{\frac{125000}{14.15 \times 10^6}} = .90$

Chamber Seal Study (Conical Seal T-13622)
(Web Stresses Cont'd)

From Bruhn Fig C2.17 For B = .90 & m = 9.03

$F_c/F_{.7} = .785$, $F_c = 125000$ psi

$F_c = .785 \times 125{,}000 = 98{,}200$ psi At approx. 600°F

Since P = 1,920 #/in ult see page 9

& $P/\cos 21^\circ = \frac{1{,}920}{.934} = 2{,}055$ #/in ult

$f_c = \frac{2{,}055}{.014} = 147{,}000$ psi. > $F_c = 98{,}200$ psi.

use t > .014 See pages that follow

Chamber Seal Study

Seal Analysis (cont'd) (Conical Seal T-13622)

Web Stresses (cont'd)

Try $t = 0.018"$

$\rho = (0.303)(.018) = .0055$ See page 12

$L'/\rho = (.14)/.0055\sqrt{2.05} = 22.8$

$\therefore B = \left(\frac{1}{\pi}\right)(22.8)\sqrt{125000/14.15\times10^6} = .68$

$\therefore F_c/F_{0.7} = .91$ ✓

$F_c = (.91)(125000) = 114000$ ✓ $\#/in^2 = F_{ty}$ ∴ elastic range

$f_c = 2055/.018 = 114000\ \#/in^2$ Ult.

$MS = \frac{114000}{114000} - 1 = +0.00$ ✓ ✓

Ult. compression during 1920 #/in Ult. Preload ~~& thermal~~ using .018 HT & Aged Ti6Al4V at 600°F

Now check the 2250 #/in Ult. Load at 150°F. for $t = .018"$ (pg 9)

$E_c = 16.8\times10^6$

$(85)(16.8)(10)^6 = 14.3\times10^6$, ∴ $F_{0.85} = 160000$ psi.

$(.7)(16.8)(10)^6 = 11.76\times10^6$, ∴ $F_{0.7} = 175000$ psi.

$F_{0.7}/F_{0.85} = 175/160 = 1.092$

$n = 1 + \ln 2.43/\ln 1.092 = 1 + .889/.088 = 11.1$

$B = (1/\pi)(22.8)\sqrt{175000/16.8\times10^6} = 0.74$ (Bruhn Fig C2.1)

$(F_c) = (175000)(.875) = 153000\ \#/in^2$

$f_c = P/A = 2250/.018\cos 21 = 134000\ \#/in^2$ Ult.

$MS = \frac{153000}{134000} - 1 = +0.14$

Ult compr. during 2250 #/in Ultimate only, for .018" Ti6Al4V HT, Aged, at 150°F

Chamber Seal Study (T-13621)

Seal Analysis (cont'd)

Web Stresses (cont'd)

Investigate Rene 41 as a column, for P=2250 #/in c/t. at 150°F (pg. 1)

Ref: TMC DH Vol II for Rene 41 Material Properties (See below)

Comparing Fig 20 with Fig 25, and Fig 38 with Fig 26, it can be seen that tensile & compressive properties are approximately equal. ∴ the tensile stress-strain diagram can be used instead of the desired compressive stress-strain diagram. (The σ-ε Diagram for compr. is not available) Use Fig 47 (Mat'l is HT ~~at~~ 1975°F, WQ, Aged at 1400°F for 16 Hrs, & this corresponds to an $F_{Ty} \cong 150000$ #/in² at 150°F which is a mat'l. property already used by TMC)

$E_c = \frac{120000}{.004} = 30 \times 10^6$

$.85\,E_c = 25.5 \times 10^6$

$F_{.85} = 140000$ psi (scaled)

$\therefore E_t = 21 \times 10^6$

$F_{.7} = 149000$ psi (scaled)

$F_{.7}/F_{.85} = 149/140 = 1.06$

$n = 1 + \ln 2.43 / \ln 1.06 = 1 + .889/.0583 = 16.2$

Try t=.017, $L'/\rho = .18/(.303)(.017)\sqrt{2.05} = 24.4$

$B = (1/\pi)(24.4)\sqrt{149000/30\times10^6} = .545$, $\therefore F_c = (149000)(.95) = 141500$

$f_c = \frac{2250}{\cos 21}/.017 = 141500$

$MS = \frac{141500}{141500} - 1 = 0.00$

.017" Rene 41, HT, WQ, Aged at 150°F

Chamber Seal Study (T-13621)

Seal Analysis (cont'd)

Web Stresses (cont'd)

Now check this Rene 41 for P = 1920 #/in ult at 600°F, t = .017" Ref #9

By inspection of Stress-Strain Diagram (Fig 47) this is less critical than for P = 2250 #/in ult at 150°F. (pg 13)

$E_c = \frac{55000}{.002} = 27.5 \times 10^6$

$.85\,E_c = 23.4 \times 10^6$

$F_{.85} = 135000\ \#/in^2$ (scaled)

$\therefore E_c = 16.4 \times 10^6$

$F_{.7} = 145000\ \#/in^2$ (scaled)

$F_{.7}/F_{.85} = 145/135 = 1.07$

$n = 1 + \ln 2.43 / \ln 1.07 = 1 + .889/.0677 = 14.1$ ✓

$B = (1/\pi)(24.4)\sqrt{145000/27.5 \times 10^6} = 564$

$\therefore F_c = (145000)(.935) = 135500\ \#/in^2$

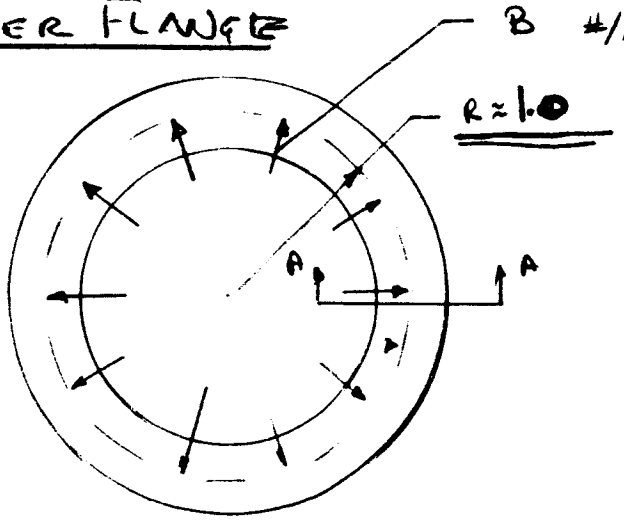
$f_c = 1920/.017 \cos 21 = 121000\ \#/in^2$ ult

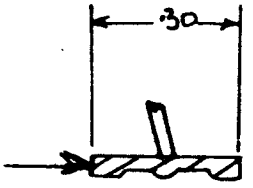
$MS = \frac{135500}{121000} - 1 = +0.12$ ✓

ult compr at 600°F
.017" Rene 41

Chamber Seal Study (Conical Seal T-13691, T-13622)
Seal Analysis Cont'd

LOWER FLANGE





A-A

Area = .0122 IN²

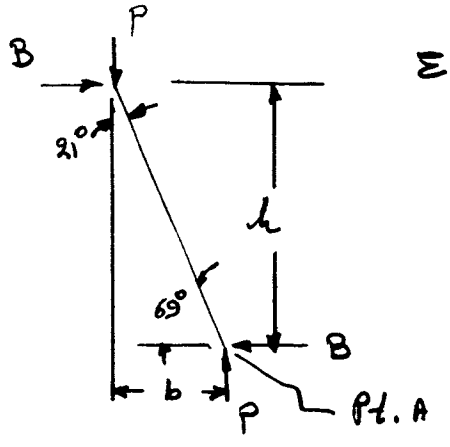
Preload & Thermal

$B = P \tan 21° = 1920 \tan 21 = 738$ #/IN ult at 650°F (p 9)
$= 738/1.5 = 492$ #/IN limit " "

Boost

$B = P \tan 21° = 2{,}250 \tan 21° = 864$ #/IN ult at 150°F (p. 9)
$= 864/1.5 = 576$ #/IN limit " "

Derivation of Load B (Also see page 9)



$\Sigma M_A = 0 \qquad Bh = Pb$

$B = P\left(\frac{b}{h}\right) = P \tan 21°$

Chamber Seal Study (Conical Seal T-13621, T-13622)

Seal Analysis (cont'd)

Lower Flange Stresses (cont'd)
From "B" Load

The entire lower flange will be used. The Area = 0.0122 in^2 (scaled)

∴ At 150°, $f = P/A = 864/.0122 = 70800\ \#/in^2$ ult, $f = 47{,}200$ psi, Limit

At 650°, $f = P/A = 738/.0122 = 60500\ \#/in^2$ ult, $f = 40{,}300$ psi, Limit

Material	Temp.	F_{tu}	f_{tu}	M.S.	f_t Limit	$.85F_{ty}$	M.S.	
Ti 6Al 4V	150	155,000	70800	+ 1.19 ult	47,200	119,000	+1.52	y. old
Ti 6Al 4V	650	122,000	60500	+ 1.02 ult	40,300	80,700	+1.00	"
Rene 41	150	170,000	70800	+1.40	47,200	110,000	+1.33	"
Rene 41	650	168,000	60500	+1.80	40,300	108,000	+1.68	"

Bearing Stress Between the alum. Head and the Seal due to the load B.

At 150°F, Boost Load

B = 576 #/in Limit See page 15

6061-T6 Allom. Allowables $F_{BRY} = 53{,}800$ psi, $F_{BRU} = 84{,}500$ psi

$\sigma = 576/.019 = 30{,}300$ psi, Limit

$\sigma = 1.5 \times 30{,}300 = 45{,}500$ psi, ult

$M.S. = \frac{.85 \times 53{,}800}{39300} - 1 = +.51$ yield

$M.S. = \frac{84{,}500}{45{,}500} - 1 = +.86$ ult

At Book Bolt ∧ 6061-T6 Alum. At 350°F, $F_{BRY} = 43.7$ KSI, $F_{BRU} = 63.4$ KSI

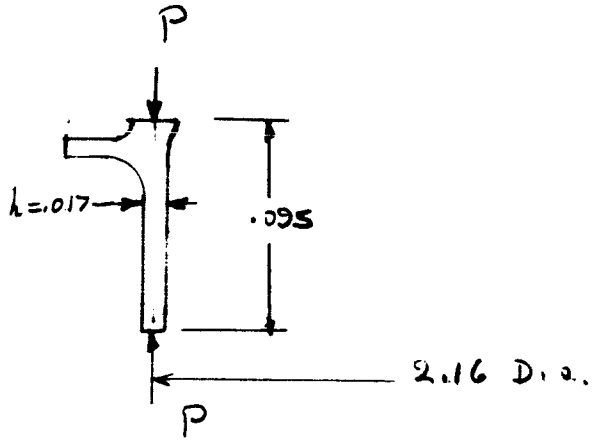
B = 492 #/in limit see page 15

$\sigma = 492/.019 = 25.9$ KSI, Limit
$= 38.9$ KSI, ult

ult: $M.S. = \frac{63.4}{38.9} - 1 = +.63$

A665

Chamber Seal Study (T-13611)



$B = \frac{1}{\pi}\left(\frac{e}{f}\right)\sqrt{\frac{F_{.70}}{E_c}}$ & $m = 1 + \frac{\ln \frac{17}{7}}{\ln \frac{F_{.70}}{F_{BS}}}$ (see page 10)

$\rho = \sqrt{\frac{I}{A}} = \sqrt{\frac{bh^3}{12(1-\nu^2)bh}} = \frac{h}{\sqrt{10.9}} = .303h = .303 \times .017 = .00515$

For 6Al 4V Ti at 600°F (Soak Back) Refer to page 10

$E_c = 14.15 \times 10^6$ psi, $F_{BS} = 112{,}000$ psi, $F_{.70} = 125{,}000$ psi

$m = 9.03$, $B = \frac{1}{\pi}\frac{.095}{.00515}\sqrt{\frac{125{,}000}{14.15 \times 10^6}} = .552$

From Bruhn F.f. C2.17 $F_c/F_{.7} = .96$

$F_c = .96 \times 125{,}000 = 120{,}000$ psi

P = 11,565 # ult see page

$\sigma = \frac{11{,}565}{\pi \times 2.16 \times .017} = 100{,}000$ psi ult

M.S. $= \frac{120}{100} - 1 = +.20$

For 6Al 4V Ti at 150°F (Preload & thermal)

By inspection Not critical

Chamber Seal Study (T-13612)

For Kemc 41 at 150°F Boost See page 13

$E_c = 30 \times 10^6$, $F_{.85} = 140$ KSI, $F_{.70} = 149$ KSI, $n = 16.2$

$f = .00515$, $\epsilon = .095$ see page 17

$$B = \frac{1}{2} \frac{\epsilon}{f} \sqrt{\frac{F_{.70}}{E_c}} = \frac{1}{\pi} \frac{.095}{.00515} \sqrt{\frac{149{,}000}{30 \times 10^6}} = .413$$

From Brohn Fig. C2.17 $F_c/F_{.70} = .98$

$F_c = .98 \times 149{,}000 = 146{,}000$ psi

$P = 4{,}250$ #/IN ult. see page

$$T = \frac{4{,}250}{.017} = 132{,}000 \text{ psi ult} \qquad M.S. = \frac{146}{132} - 1 = +.11$$

Chamber Seal Study

Bearing between the seal and the Moly Flange.

Moly Allowables

At R.T. $F_{TY} = 56$ KSI $F_{TU} = 62$ KSI Ref: TMC MPM 14.154

At 150°F $F_{TY} = 54$ KSI $F_{TU} = 61$ KSI

At 650°F $F_{TY} = 31$ KSI $F_{TU} = 43$ KSI

Also At RT $F_{BRY} = 1.6 F_{CY} = 1.6 \times 104 = 166.4$ KSI *
(It was assumed F_{BRY} same at RT & -100°F)
Therefore At 150°F $F_{BRY} = 166.4 \times \frac{54}{56} = 162.1$ KSI

Assume " " $F_{BRU} = 162,100 \times \frac{61}{54} = 183.7$ KSI

At 650°F $F_{BRY} = 166.4 \times \frac{31}{56} = 92.4$ KSI

$F_{BRU} = 92.4 \times \frac{43}{31} = 128.2$ KSI

1) Preload & Thermal (650°F)

The smallest bearing area corresponds to the seals (T-13611, & T-13612)

Bearing width = .017 min. at D = 2.16

P = 7,710 # limit (6 bolts)

$\sigma = \frac{7,710}{\pi \times 2.16 \times .017} = 66,900$ psi limit — yield — $M.S. = \frac{.85 \times 92.4}{66.9} - 1 = +.18$

$= 100,000$ psi ult — ult. — $M.S. = \frac{128.2}{100.0} - 1 = +.28$

2) Boost Load

By inspection this condition is not critical

* Ltr From J.C. Reeves to I.C. Dickens & I.E. Rosman Dated July 26, 1965 RT & -100°F Compression Stress on Coated and Uncoated Moly

Chamber Seal Study

Bearing between the seal and the Aluminum Head

1) Preload & Thermal load

The smallest bearing width and bearing area correspond to the conical seals (T-13621, T-13622)

Bearing width = .032 min. at 1.81 dia.

P = 7,710 # Limit (6 Bolts) (Ref page 11)

$= \frac{P}{A} = \frac{7,710}{\pi \times 1.81 \times .032} = 42,200$ psi Limit

$= 63,300$ psi Ult

[illegible] Alum. 6061-T6 at 350°F

$F_{BRY} = 43,700$ psi Ref.

$F_{BRU} = 63,400$ psi

$M.S. = \frac{63.4}{63.3} - 1 = +.002$

Note: A .85 factor is not considered important for bearing yield.

2) Seal Load (at 150°F)

By Inspection this condition is not critical

ATTACHMENT 4

THE Marquardt CORPORATION VAN NUYS, CALIFORNIA

STRESS ANALYSIS (FINAL)

For

APOLLO SERVICE MODULE

REACTION CONTROL SYSTEM ENGINE INJECTOR

CHAMBER SEAL STUDY

PREPARED UNDER CONTRACT NAS 9-4775

TMC 3008

Prepared By George Carayanis
I. Stoughton & G. Carayanis

Approved By
J. Puntar
Principal Investigator
Design Engineering

Approved By E P Perlman
E. P. Perlman
Program Manager

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REFERENCES

1. Thermal Model Analysis of Transient Injector/Combustor Joint Temperatures during Engine Heat Soakback for the Apollo SM RCS Engine Injector Chamber Seal Study - C. S. Hill.

2. Stress Memo, S. M. #153, The Stress Analysis of High Resistance Chamber to Head Seals - G. Carayanis

3. Stress Memo, S. M. #101-5, Stress Analysis of Apollo Engine Combustion Chamber Hardware - G. Carayanis

INTRODUCTION

This report describes the additional stress analysis performed in support of development of high thermal resistance injector/chamber seals for the Apollo SM RCS engine under Contract NAS 9-4775. This analysis considers revised temperature criteria for candidate seal designs and injector head/combustor joint attachment hardware. Calculations are presented herein.

SUMMARY

In support of the Chamber Seal Study Program, a Stress Analysis was made of the affect on the Attach Hardware of using high resistance head to chamber seals.

The affect of transient temperatures during soakback, as defined in Reference (1), on the loads and the stresses, was calculated for seal thermal resistances of .5, 2.75, and 5 hours/BTU/°F.

A comparison of the margins of safety of the attach hardware components for the various seal resistances and the present Apollo Seal is shown in Table I.

The seals were re-evaluated and were found to have equal or higher margin of safety than those of S. M. #153, The Stress Analysis of High Resistance Chamber to Head Seals, Reference (2).

The loads resulting for all three resistances, .50, 2.75, and 5.0 hours/BTU/°F are somewhat higher than the loads used in Reference (3) but after correcting for the brinneling affect on the flange and split ring bearing areas, the load was only a few percent higher than the load used in Reference (3). The brinneling correction factor was used only for the critical areas, which are the chamber flange bearing, the attach bolt, and the injector head bearing.

The Table of Margins shows slight negative margin on the bolts and chamber flange. The negative margin on the bearing of the chamber corresponds only to the more severe criteria used in Reference (2) (Yield allowable = F_{ty} instead of yield allowable = F_{ty} as used in the Qual Engine Analysis, $\frac{}{1.18}$ Reference (3).

In order to show a positive margin on the bolts, some redesign is required of the bolt, i.e., increase slightly the bolt diameter or increase the bolt length to decrease the thermal load.

SM158 A

EFFECTS OF HIGH RESISTANCE SEAL UPON ATTACHMENT HARDWARE

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10	Curves of Results found in Pages 1-9
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12	Bending Stress in Split Ring (228116) of Rene 41 Material
13	"Brinnelling" Depth in Chamber Flange 228128 of Moly Material
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15	Bearing Stress Under Bolt Head
16	Computation of Bolt Load Change As a Result of Temperature Change Accounting for "Brinelling" of Chamber Flange and the Split-Ring
17	Clinch Nut
18-20	Revision of the Stress Analysis of the High Thermal Resistance Chamber to Head Seals (SM #153)

APPENDIX

1. Modulus of Elasticity of Rene' 41 material versus temperature.
2. Ultimate and yield strengths of Rene' 41 Material versus temperature.

TABLE I

COMPARISON OF COMPONENT MARGINS OF SAFETY FOR VARIOUS SEAL RESISTANCES AND PRESENT APOLLO SEAL

Seal Resistance	Component	Material	Condition	Page Ref.	M.S.	Present Apollo M.S.*
.5 hrs/Btu/°F 2.75 hrs/Btu/°F 5.00 hrs/Btu/°F	Attach Ring 228117	Rene' 41	Combined bending & tension, also bearing from initial bolt tension after temp. increase	11 14	.95 .90 .85 .00	1.00 Bending 1.00 Bending 1.00 Bending .00 Bearing
.5 hrs/Btu/°F 2.75 hrs/Btu/°F 5.00 hrs/Btu/°F	Split Ring 228116	Rene' 41	Local bending, also bearing from initial bolt tension after temp. increase	12 14	2.40 2.32 2.26 .00	2.5 Bending 2.5 Bending 2.5 Bending .00 Bearing
.5 hrs/Btu/°F 2.75 hrs/Btu/°F 5.00 hrs/Btu/°F	Attach Bolts 228105	Rene' 41	Bolt bending tension & related effects	16	- .01** .03 - .05	.01 Bend. & Tension .01 Bend. & Tension .01 Bend. & Tension
.5 hrs/Btu/°F 2.75 hrs/Btu/°F 5.0 hrs/Btu/°F	Injector Hd. 228168	6061-T6	Bearing of clinch nut on the injector head	17	.81** .77 .65	.40 .40 .40 Bearing
.5 hrs/Btu/°F 2.75 hrs/Btu/°F 5.00 hrs/Btu/°F	Clinch Nut 228192	A-286	Flange Bending	17	.06** .04 .02	.03 .03 .03 Bending
.5 hrs/Btu/°F 2.75 hrs/Btu/°F 5.00 hrs/Btu/°F	Chamber Flange 228128	Moly	Bearing of the chamber flange on seal	19	+ .48*** (+ .50ult)** + .28 (+ .25ult) - .05 (+ .12limit)	2.0 Bearing 2.0 Bearing 2.0 Bearing
.5 hrs/Btu/°F 2.75 hrs/Btu/°F 5.00/hrs/Btu/°F	Injector Hd. 228168	6061-T6	Bearing of seal on injector head	20	+ .04** .02 + .002	Large Large Large

*Ref: S.M. #101-5

**Considering Reduction due to Brinneling

***This contains an additional safety factor of 1.18 over the corresponding values shown in the parenthesis. This is consistent with the S.M. #153 criteria. 1.18 factor applies to yield only.

NOTE: The margins of safety for the .5 and 2.75/hrs/Btu/°F are estimated by comparison, and are not shown in the text.

PREPARED BY J.R.S.
CHECKED BY G. Carayannis
CLASSIFICATION

THE MARQUARDT CORPORATION

PAGE 1
REPORT SM158
DATE 12-29-65

EFFECTS OF HIGH RESISTANCE SEAL UPON ATTACHMENT HARDWARE

SEE S.M. #101-5 PAGE 17 FOR SKETCH SHOWING LOCATION OF ITEMS IN THE ASSEMBLY AND FOR METHOD WHICH IS FOLLOWED HERE WITH REVISED TEMPERATURES. TEMPERATURES ARE FROM [O M S. Hill to J. Punter, 3008/153-32/836

$.5 \frac{HR.-°F}{BTU}$ AT 25 SECOND INSTANT

ITEM NO.	DESCRIPTION	MATERIAL	TEMP.	COEFF. OF THERM. EXPANSION	EFFECTIVE LENGTH	THERMAL EXPANSION (INCHES)	SYMBOL ON TEMP. CURVES.
1	CHAMBER FLANGE	MOLY	600	2.9×10^{-6}	.25	[illegible] $\times 10^{-6}$	#100 ◇
2	SPLIT RING	RENÉ 41	475	6.9×10^{-6}	.15	420×10^{-6}	#301 ⊙ (RED)
3	ATTACHMENT RING	RENÉ 41	370	6.9×10^{-6}	.17	352×10^{-6}	#302 X (RED)
4	SPACER	RENÉ 41	405 ①	6.9×10^{-6}	.095	220.8×10^{-6}	SEE NOTE ①
5	HEAD	AL. ALLOY 6061-T6	210	13.3×10^{-6}	.510	952.0×10^{-6}	#1 +
6	BOLT	RENÉ 41	220	6.8×10^{-6}	1.180	2328.0×10^{-6} / 1202×10^{-6}	#305 ⊡

$$\sigma\,(\text{BOLT TENS.}) = \frac{e}{l} \times E = \frac{(2328-1202)10^{-6}}{1.18} \times 30.9\times10^{+6} = 29{,}500 \text{ PSI}$$

$$P\,(\text{BOLT TENS}) = \sigma \times A_{BOLT} = (29{,}500 \times .785 \times .12^2) = 333 \text{ \#/BOLT (LIMIT)}$$

NOTES :-

① BY AVERAGING ITEMS 5 AND 1 (I.E. NODES #1 AND #100)

EFFECTS OF HIGH RESISTANCE SEAL UPON ATTACHMENT HARDWARE

SEE S.M. #101-5 PAGE 17 FOR SKETCH SHOWING LOCATION OF ITEMS IN THE ASSEMBLY

$.5 \frac{HR - {}^\circ F}{BTU}$ AT 25 SECOND INSTANT

ITEM NO.	DESCRIPTION	MATERIAL	TEMP.	COEFF. OF THERM. EXPANSION	EFFECTIVE LENGTH	THERMAL EXPANSION (INCHES)	SYMBOL ON TEMP. CURVES
1	CHAMBER	MOLY	525	2.9×10^{-6}	.25	330×10^{-6}	#100 ◇
2	SPLIT RING	RENÉ 41	600	6.9×10^{-6}	.16	445×10^{-6}	#301 ⊙ (RED)
3	ATTACHMENT RING	RENÉ 41	475	6.9×10^{-6}	.17	476×10^{-6}	#302 X (RED)
4	SPACER	RENÉ 41	392	6.9×10^{-6}	.095	211×10^{-6}	SEE NOTE ①
5	HEAD	AL ALLOY 6061-T6	260	13.3×10^{-6}	.510	1290×10^{-6}	#1 +
						-225×10^{-6}	
6	BOLT	RENÉ 41	270	6.8×10^{-6}	1.180	1605×10^{-6}	#305 □

$$\sigma_{(BOLT\ TENS)} = \frac{e}{l} \times E = \frac{(2751 - 1605)10^{-6}}{1.18} \times 30.7 \times 10^{+6} = 29{,}800\ PSI$$

$$P_{(BOLT\ TENS)} = \sigma \times A_{BOLT} = (29800 \times .785 \times .12^2) = 337\ \#/BOLT\ (\text{"LIMIT"})$$

NOTES:

① BY AVERAGING ITEMS 5 AND 1 OR NODES #1 AND #100

EFFECTS OF HIGH RESISTANCE SEAL UPON ATTACHMENT HARDWARE

SEE S.M. #101-5 PAGE 17 FOR SKETCH SHOWING LOCATION OF ITEMS IN THE ASSEMBLY

$.5 \frac{HR - {}^\circ F}{BTU}$ AT 1.25 SEC INSTANT

ITEM NO.	DESCRIPTION	MATERIAL	TEMP.	COEFF. OF THERM. EXPANSION	EFFECTIVE LENGTH	THERMAL EXPANSION (INCHES)	SYMBOL ON TEMP. CURVES
1	CHAMBER	MOLY	460	2.9×10^{-6}	.25	282.0×10^{-6}	#100 ◇
2	SPLIT RING	RENÉ 41	470	6.9×10^{-6}	.15	414.0×10^{-6}	#301 ⊙ (RED)
3	ATTACHMENT RING	RENÉ 41	475	6.9×10^{-6}	.17	475.0×10^{-6}	#302 × (RED)
4	SPACER	RENÉ 41	375	6.9×10^{-6}	.096	$200. \times 10^{-6}$	SEE NOTE ①
5	HEAD	AL ALLOY 6061-T6	290	13.3×10^{-6}	.510	1490.0×10^{-6}	#1 +
						2861.7×10^{-6}	
6	BOLT	RENÉ 41	325	6.8×10^{-6}	1.18	2040.0×10^{-6}	#305 ⊟

$$\sigma_{(BOLT\ TENS.)} = \frac{e}{\ell} \times E = \frac{(2861 - 2040)10^{-6}}{1.18} \times 30.4 \times 10^{6} = 21,150$$

$$P_{(BOLT\ TENS)} = \sigma \times A_{BOLT} \quad 21,150 \times .785 \times .12^2) = 239\ \#/BOLT\ (\text{"LIMIT"})$$

NOTES:

① BY AVERAGING ITEMS 5 AND 1 OR NODES #1 AND #100

EFFECTS OF HIGH RESISTANCE SEAL UPON ATTACHMENT HARDWARE

$2.75 \frac{HR-°F}{BTU}$ AT 25 SECOND INSTANT

ITEM NO.	DESCRIPTION	MATERIAL	TEMP.	COEFF. OF THERM. EXPONSION	EFFECTIVE LENGTH	THERMAL EXPONSION (INCHES)	SYMBOL ON TEMP CURVES
1	CHAMBER FLANGE	MOLY	705	2.9×10^{-6}	.25	460×10^{-6}	#100 ◇
2	SPLIT RING	RENÉ 41	550	6.9×10^{-6}	.15	496×10^{-6}	#301 ◇ (RD4
3	ATTACHMENT RING	RENÉ 41	380	6.9×10^{-6}	.17	364×10^{-6}	#302 × (RD0)
4	SPACER	RENÉ 41	448 (1)	6.9×10^{-6}	.095	248×10^{-6}	SEE NOTE (1)
5	HEAD	AL. ALLOY 6061-T6	190	13.3×10^{-6}	.510	816×10^{-6}	# 1 +
						2384×10^{-6}	
6	BOLT	RENÉ 41	215	6.8×10^{-6}	1.180	1162.0×10^{-6}	#305 △

$$\sigma(\text{BOLT TENS}) = \frac{e}{l} \times E = \frac{(2384-1162)10^{-6}}{1.18} \times 31.0\times10^{+6} = 32{,}100 \text{ PSI}$$

$$P(\text{BOLT TENS}) = \sigma \times A_{BOLT} = 32{,}100 \times .785 \times .12^2 = 363 \text{ \#/BOLT (LIMIT)}$$

NOTES:

(1) BY AVERAGING TEMPERATURES OF ITEMS 5 AND 1

EFFECTS OF HIGH RESISTANCE SEAL UPON ATTACHMENT HARDWARE

$2.75 \frac{HR-°F}{BTU}$ AT 75 SECOND INSTANT

ITEM NO.	DESCRIPTION	MATERIAL	TEMP.	COEFF. OF THERMAL EXPANSION	EFFECTIVE LENGTH	THERMAL EXPANSION (INCHES)	SYMBOL ON TEMP. CURVES
1	CHAMBER FLANGE	MOLY.	690	2.9×10^{-6}	.25	450×10^{-6}	#100 ⊖
2	SPLIT RING	RENÉ41	635	6.9×10^{-6}	.16	585×10^{-6}	#301 ⊙ (RED)
3	ATTACHMENT RING	RENÉ41	575	6.9×10^{-6}	.17	592×10^{-6}	#302 × (RED)
4	SPACER	RENÉ41	448	6.9×10^{-6}	.095	248×10^{-6}	SEE NOTE ①
5	HEAD	AL ALLOY 6061-T6	205	13.3×10^{-6}	.510	916.0×10^{-6}	#1 +
						$2791.\times10^{-6}$	
6	BOLT	RENÉ41	260	6.8×10^{-6}	1.180	1522×10^{-6}	#305 ⊡

$$\sigma(\text{BOLT TENS.}) = \frac{e}{l} \times E = \frac{(2791-1522)10^{-6}}{1.18} \times 30.75\times10^{+6} = 33{,}000.\text{PSI}$$

$$P(\text{BOLT TENS.}) = \sigma \times A_{BOLT} = 33{,}000\times.785\times.12^2 = 373\ ^{\#}/\text{BOLT (LIMIT)}$$

.0113

NOTES:

① BY AVERAGING TEMPERATURES OF ITEMS 5 AND 1

EFFECTS OF HIGH RESISTANCE SEAL UPON ATTACHMENT HARDWARE

$2.75 \frac{HR-°F}{BTU}$ AT 125 SECOND INSTANT

ITEM NO.	DESCRIPTION	MATERIAL	TEMP °F	COEFF. OF THERMAL EXPANSION	EFFECTIVE LENGTH	THERMAL EXPANSION (INCHES)	SYMBOL ON TEMP. CURVES
1	CHAMBER FLANGE	MOLY	630	2.9×10^{-6}	.25	405×10^{-6}	#100 ⊙
2	SPLIT RING	RENÉ 41	625	6.9×10^{-6}	.85	575×10^{-6}	#300 ⊙ (RED)
3	ATTACHMENT RING	RENÉ 41	620	6.9×10^{-6}	.17	645×10^{-6}	#302 X (RED)
4	SPACER	RENÉ 41	423 (1)	6.90×10^{-6}	.095	231×10^{-6}	SEE NOTE (1)
5	HEAD	AL ALLOY 6061-T6	215	13.3×10^{-6}	.570	985.0×10^{-6}	#1 +
						2841×10^{-6}	
6	BOLT	RENÉ 41	325	6.8×10^{-6}	1.180	2042×10^{-6}	#305 ⊡

799

$$\sigma\,(\text{BOLT TENS.}) = \frac{e}{l} \times E = \frac{(2841-2042)10^{-6}}{1.18} \times 30.4 \times 10^{+6} = 20{,}600 \text{ PSI}$$

$$P(\text{BOLT TENS.}) = \sigma \times A_{BOLT} = 20{,}600 \times .785 \times .12^2 = 233 \text{ \#/BOLT (LIMIT)}$$

NOTES:

(1) BY AVERAGING TEMPERATURES OF ITEMS 5 AND 1

EFFECTS OF HIGH RESISTANCE SEAL UPON ATTACHMENT HARDWARE

SEE S.M. #101-5 PAGE 17 FOR SKETCH SHOWING LOCATION OF ITEMS IN THE ASSEMBLY

$5.0 \frac{HR-°F}{BTU}$ AT 25 SECOND INSTANT

ITEM NO.	DESCRIPTION	MATERIAL	TEMP.	COEFF. OF THERM. EXPANSION	EFFECTIVE LENGTH	THERMAL EXPANSION (INCHES)	SYMBOL ON TEMP. CURVES
1	CHAMBER FLANGE	MOLY	725'	2.9×10^{-6}	.25	$475^{J} \times 10^{-6}$	#100 ◇
2	SPLIT RING	RENÉ 41	560'	6.9×10^{-6}	.15	$506^{J} \times 10^{-6}$	#301 ⊙ (RED)
3	ATTACHMENT RING	RENÉ 41	385'	6.9×10^{-6}	.17	$370^{J} \times 10^{-6}$	#302 X (RED)
4	SPACER	RENÉ 41	458' (1)	6.9×10^{-6}	.095	$254^{J} \times 10^{-6}$	SEE NOTE (1)
5	HEAD	AL ALLOY 6061-T6	190'	13.3×10^{-6}	.510	$815.0^{J} \times 10^{-6}$	#1 +
6	BOLT	RENÉ 41	215'	6.8×10^{-6}	1.180	$2420^{J} \times 10^{-6}$ / $1163.0^{J} \times 10^{-6}$	#305 ⊙

$$\sigma(\text{BOLT TENS.}) = \frac{e}{l} \times E = \frac{(2420-1163)10^{-6}}{1.18} \times 30.95 \times 10^{6} = 33{,}000^{J} \text{ PSI}$$

$$P(\text{BOLT TENS}) = \sigma \times A_{\text{BOLT}} = (33000 \times .785 \times .12^{2}) = 373^{J} \#/\text{BOLT (LIMIT)}$$

NOTES:
(1) BY AVERAGING TEMPERATURES OF ITEMS 5 AND 1

EFFECTS OF HIGH RESISTANCE SEAL UPON ATTACHMENT HARDWARE

SEE S.M. #101-5 PAGE 17 FOR SKETCH SHOWING LOCATION OF ITEMS IN THE ASSEMBLY

5.0 $\frac{HR-°F}{BTU}$ AT 50 SECOND INSTANT

ITEM NO.	DESCRIPTION	MATERIAL	TEMP.	COEFF. OF THERM. EXPANSION	EFFECTIVE LENGTH	THERMAL EXPANSION (INCHES)	SYMBOL ON TEMP. CURVES
1	CHAMBER FLANGE	MOLY	260	2.9×10^{-6}	.255	492×10^{-6}	#100 ⊕
2	SPLIT RING	RENÉ 41	640	6.9×10^{-6}	.15	590×10^{-6}	#301 ⊕ (RED)
3	ATTACHMENT RING	RENÉ 41	515	6.9×10^{-6}	.17	522×10^{-6}	#302 X (REV)
4	SPACER	RENÉ 41	470 ①	6.9×10^{-6}	.095	262×10^{-6}	SEE NOTE ①
5	HEAD	AL ALLOY 6061-T6	190	13.3×10^{-6}	.510	8.15×10^{-6}	#1 +
						2681×10^{-6}	
6	BOLT	RENÉ 41	235	6.6×10^{-6}	1.180	1322×10^{-6}	#305 ⊖

$$\sigma(\text{BOLT TENS}) = \frac{\varepsilon}{\ell} \times E = \frac{(2681-1322)10^{-6}}{1.18} \times 30.92\times10^{+6} = 35{,}500\text{PSI}$$

$$P(\text{BOLT TENS}) = \sigma \times A_{BOLT} = 35{,}500 \times .786 \times .12^2 = 401\ \#/\text{BOLT (LIMIT)}$$

NOTES:
① BY AVERAGING TEMPERATURES OF ITEMS 5 AND 1

EFFECTS OF HIGH RESISTANCE SEAL UPON ATTACHMENT HARDWARE

SEE S.M. #101-6 PAGE 17 FOR SKETCH SHOWING LOCATION OF ITEMS IN THE ASSEMBLY

$5.0 \frac{HR-°F}{BTU}$ AT 100 SECOND INSTANT

ITEM NO.	DESCRIPTION	MATERIAL	TEMP.	COEFF. OF THERM. EXPANSION	EFFECTIVE LENGTH	THERMAL EXPANSION (INCHES)	SYMBOL ON TEMP. CURVES
1	CHAMBER FLANGE	MOLY	690	2.9×10^{-6}	.255	450×10^{-6}	#100 Δ
2	SPLIT RING	RENÉ 41	660	6.9×10^{-6}	.15	610×10^{-6}	#301 ⊙ (RED)
3	ATTACHMENT RING	RENÉ 41	630	6.9×10^{-6}	.17	656×10^{-6}	#302 X (RED)
4	SPACER	RENÉ 41	445 ①	$6.9\times10^{+6}$	.095	246×10^{-6}	SEE NOTE ①
5	HEAD	AL ALLOY 6061-T6	200	13.3×10^{-6}	.510	882×10^{-6}	#1 +
						2844×10^{-6}	
6	BOLT	RENÉ 41	290	6.8×10^{-6}	1.180	$1770.\times10^{-6}$	#305 ⊡

$$\sigma(\text{BOLT TENS}) = \frac{e}{\ell} \times E = \frac{(2844-1770)10^{-6}}{1.18} \times 30.6\times10^{+6} = 27,900 \text{ PSI}$$

$$P(\text{BOLT TENS}) = \sigma \times A_{Bolt} = (27,900 \times .785 \times .12^2) = 315\#/\text{BOLT (LIMIT.)}$$

NOTES:
① BY AVERAGING TEMPERATURES OF ITEMS 5 AND 1

Effects of High Resistance Seal Upon Attach Hardware

See SM # 101-5 page 17 for sketch showing location of items in the assembly

5.0 $\frac{Hr - °F}{BTU}$ at 25 sec Instant corresponding to the .25 in length Rene 41 Seal (T-13622)

Item No.	Description	Material	Temp (°F)	Coeff. of Thermal Exp. IN/IN/°F	Effect Length (IN)	Thermal Expansion (IN)
1	Chamber Flange	Moly	725	2.9×10^{-6}	.25	475×10^{-6}
2	Split Ring	Rene 41	560	6.9×10^{-6}	.15	506×10^{-6}
3	Attachment Ring	Rene 41	385	6.9×10^{-6}	.17	370×10^{-6}
4	Spacer	Rene 41	458	6.9×10^{-6}	.25	669×10^{-6}
5	Head	Alum. Alloy 6061-T6	190	13.0×10^{-6}	.355	553×10^{-6} / $2,573 \times 10^{-6}$
6	Bolt	Rene 41	215	6.8×10^{-6}	1.18	$1,163.0 \times 10^{-6}$

$$\sigma(\text{Bolt Tens}) = \frac{\varepsilon}{\ell} \times E = \frac{(2,573 \times 10^{-6} - 1,163 \times 10^{-6}) \times 30.9 \times 10^{6}}{1.18} = 36,900 \text{ psi}$$

$$P(\text{Bolt Tens}) = \sigma A_{Bolt} = (36,900 \times .785 \times .12^2) = 417 \text{ \# / bolt Limit}$$

Effects of High Resistance Seal Upon Attach Hardware

See SM # 101-5 page 17 for sketch showing location of items in the assembly.

5.0 $\frac{HR-{}^{o}F}{BTU}$ at 50 sec. instant corresponding to the .25 IN length Rene 41 Seal (T-13622)

Item No.	Description	Material	Temp (°F)	Coeff. of Thermal Exp. IN/IN/°F	Effect Length (IN)	Thermal Expansion (IN)
1	Chamber Flange	Moly	750	2.9×10^{-6}	.25	492×10^{-6}
2	Split Ring	Rene 41	640	6.9×10^{-6}	.15	590×10^{-6}
3	Attachment Ring	Rene 41	515	6.9×10^{-6}	.17	522×10^{-6}
4	Spacer	Rene 41	470	6.9×10^{-6}	.25	690×10^{-6}
5	Head	Alum. Alloy 6061-T6	190	13.0×10^{-6}	.355	553×10^{-6}
6	Bolt	Rene 41	235	6.8×10^{-6}	1.18	$2,847 \times 10^{-6}$ / $1,324 \times 10^{-6}$

$$\sigma(\text{Bolt Tens.}) = \frac{\epsilon}{\ell} E = \frac{(2,847 \times 10^{-6} - 1,324 \times 10^{-6})}{1.18} \times 30.8 \times 10^{6} = 39,700 \text{ psi}$$

$$P(\text{Bolt Tens.}) = \sigma A_{Bolt} = 139,700 \times .785 \times .12^{2} = 1,580 \text{ lb} * \quad 11.1 \text{ L.M.I.}$$

* This load is conservative and can be reduced as follows.

$$\Delta(\text{Temp. Expansion}) = \delta(\text{Bolt Elong.}) + \delta(\text{Seal Comp.})$$

Conical Seal T-13622 Rene 41

$$\delta_{bolt} = \frac{P_{total}\,\ell}{6 A_{bolt} E} = \frac{P_{total} \times 1.18}{6 \times .0113 \times 30.8 \times 10^{6}} = .565 \times 10^{-6} P_{total}$$

$$\delta_{seal} = \frac{(P_{total})(\text{height})}{\cos 21^{\circ}\, A\, E} = \frac{P_{total} \times .163}{.934 \times 2\pi \times .36 \times .019 \times 30 \times 10^{6}} = .050 \times 10^{-6} P_{total}$$

Effects of High Resistance Seal Upon Attach Hardware

$\frac{5.0\ HR-{}^{o}F}{BTU}$ at 50 sec. Instant Corresponding to the .25 IN length Conical Rene 41 Seal (T-13622)

Δ(Temp Expansion) = δ(bolt elong) + δ(seal comp)

$(2,847-1,324)\times10^{-6} = .565\times10^{-6} P_{total} + .050\times10^{-6} P_{total}$

$P_{total} = \frac{1523}{.615} = 2476\ \#$ Limit

$P = \frac{2,476}{6} = 412\ \#/bolt$ Limit *

* Taking into account that the actual resistance is $\frac{4.0\ HR-{}^{o}F}{BUT}$ Ave. Instead of $\frac{5.0\ HR-{}^{o}F}{BTU}$ and using the results of pages 5 and 8 we get:

$\%\ \frac{\text{Load Reduction}}{\frac{HR-{}^{o}F}{BTU}} = \frac{401-373}{401} \times \frac{1}{5.0-2.75} \times 100 = 3.10\%$

Final Load $P = 412 \times .969 = 399\ \#/bolt$ Limit $< 401\ \#/bolt$ Limit

O.K.

See page 8

Effects of High Resistance Seal Upon Attach Hardware

See SM # 101-5 page 17 for sketch showing location of Items in the assembly.

5.0 $\frac{HR-^{\circ}F}{BTU}$ at 100 sec. Instant Corresponding to the .25 IN length Rene 41 Seal (T-13622

Item No.	Description	Material	Temp (°F)	Coeff. of Thermal Exp. IN/IN/°F	Effect Length (IN)	Thermal Expansion (IN)
1	Chamber Flange	Moly	590	2.9×10^{-6}	.25	450×10^{-6}
2	Split Ring	Rene 41	660	6.9×10^{-6}	.15	610×10^{-6}
3	Attachment Ring	Rene 41	530	6.9×10^{-6}	.17	656×10^{-6}
4	Spacer	Rene 41	445	6.9×10^{-6}	.25	647×10^{-6}
5	Head	Alum. Alloy 6061-T6	200	13.0×10^{-6}	.355	600×10^{-6}
6	Bolt	Rene 41	230	6.8×10^{-6}	1.18	$2,963 \times 10^{-6}$ / $1,765 \times 10^{-6}$

$$P_{(Bolt\ Tens.)} = \frac{e}{\ell} E = \frac{(2,963 - 1,765) \times 10^{-6}}{1.18} \times 30.6 = 31,000\ psi$$

$$P_{(Bolt\ Tens.)} = \sigma A = (31,000 \times .785 \times .142) = 3500\ \#/160\ \#\ L \rightarrow L$$

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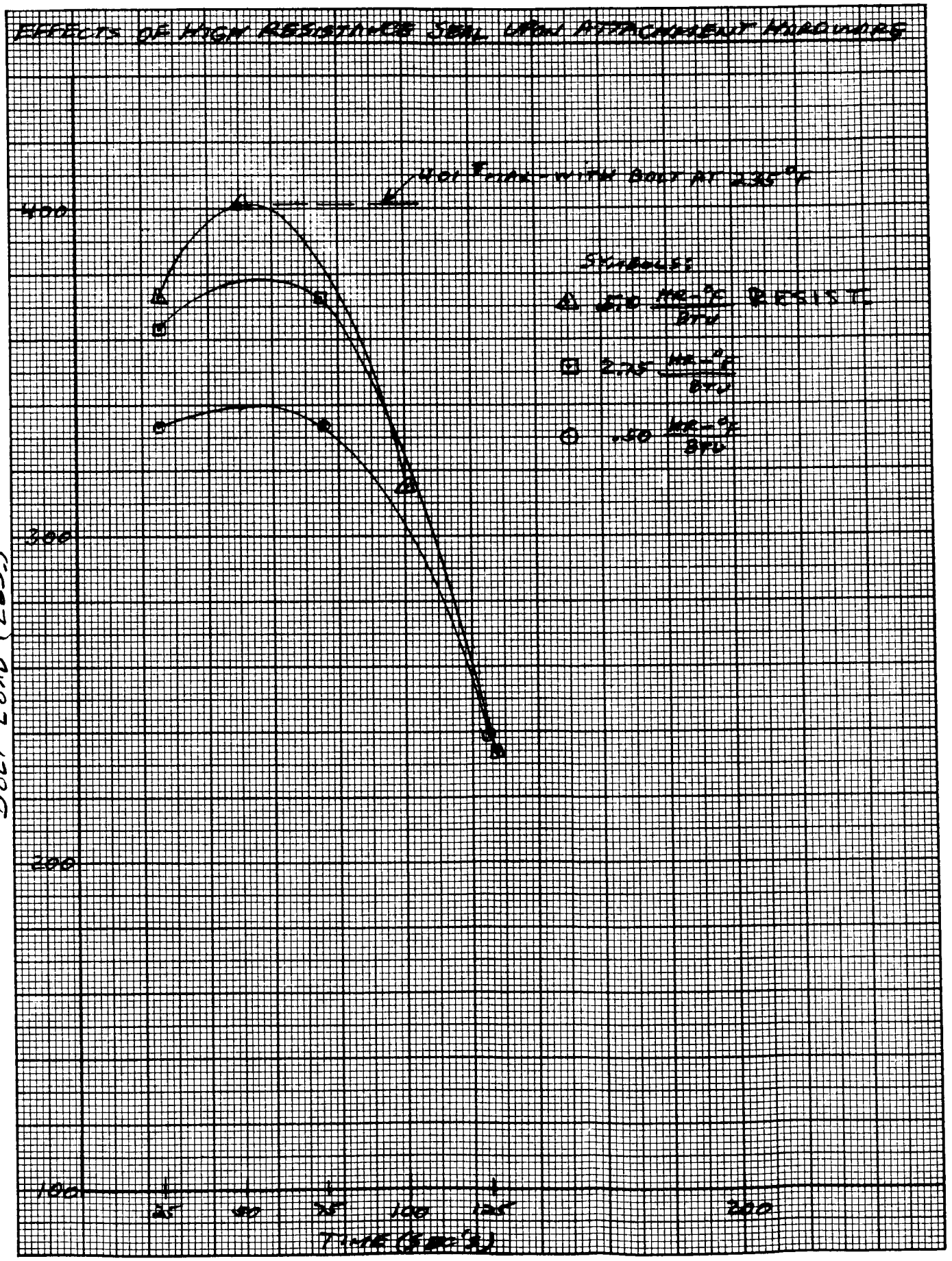
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DATE 12-29-65

EFFECTS OF HIGH RESISTANCE SEAL ON ATTACHMENT HARDWARE



EFFECTS OF HIGH RESISTANCE SEAL UPON ATTACHMENT HARDWARE

REVISION TO S.M. 101-5, P22 (ATTACH RING 228117)

MATERIAL RENÉ 41 AMS 5713 AT 575°F (P8)
MECHANICAL PROPERTIES FROM AMS 5713 & ASMH*

$F_{TY} = 130 \times \frac{150}{155} = 126$ KSI, $F_{TU} = 170 \times \frac{204}{206.7} = 167.5$ KSI

TOTAL LOAD = 6 (1381) = 8286 #' (LIMIT) P12

$P_{AVE} = \frac{8286}{2\pi(1.282)} = 1030$ #/" (LIMIT)

$V_{AVE} = 364$ #/" (LIMIT) P11

MOM = .155 (1030) + .045 (364) = 176.4 "#/" (approx)

ROTATION OF RING:

$$\theta = \frac{MR^2}{EI} = \frac{(176.4)1.282^2}{30 \times 10^6 (.00096)} = .0102 \text{ RADIANS}$$

BENDING & TENSION STRESSES:

$$\sigma_{c_1} = \frac{MRC_1}{I} + \frac{VR}{A} = \frac{(176.4)(1.282).21}{(.00096)} + \frac{364 \times 1.282}{.044 6}$$

$$= 50000 + 10460 = 60,460 \text{ PSI (LIMIT) OR } 90,600 \text{ PSI (ULT)}$$

$$\sigma_{c_2} = \frac{(176.4)1.282(.280)}{.00096} + \frac{364 \times 1.282}{.044 6}$$

$$= -66800 + 10,460 = -56,340 \text{ PSI (LIMIT) OR } -84,500 \text{ PSI (ULT)}$$

$$MS = \frac{167,500}{1.5(60460)} - 1 = +.85$$

* AEROSPACE STRUCTURAL METALS HANDBOOK.

EFFECTS OF HIGH RESISTANCE SEAL UPON ATTACHMENT HARDWARE

REVISIONS TO S.M. 101-5, P23 (SPLIT RING 228116, RENÉ 41)

TOTAL LOAD ON 6 BOLTS $6(970 + 401) = 8286^{\#}$ (LIMIT) ← PAGE 8 OF THIS REPORT

$P_{AVG} = \frac{8286}{7710} \times 1107 = 1188$ #/in (LIMIT)

$V_{AVG} = \frac{8286}{7710} \times 339 = 364$ LB/in (LIMIT)

SHEAR STRESS AT A

$T = \frac{V}{A} = \frac{364}{.0607} = 6000$ PSI (LIMIT) MS – HIGH

BENDING STRESS AT "A":

$\sigma_b = \frac{6M}{t^2} = \frac{6 \times 364 \times .04 \times 1.45}{.0607^2} = 34300$ PSI (Limit)

OR 51,500 PSI (ULT.)

FROM PAGE 8 SPLIT-RING IS AT 640°F SPLIT-RING MAT'L IS RENÉ 41 REFER TO SM101-5, P22 FOR METHOD OF FINDING ALLOWABLES AT ELEVATED TEMPERATURE, AND USING THE 640°F

$F_{TY} = 130 \times \frac{150}{155} = 126$ KSI $\quad F_{TU} = 170 \times \frac{204}{206.7} = 167.8$ KSI

$MS = \frac{167.8}{51.5} - 1 = \underline{\underline{2.26}}$

EFFECTS OF HIGH RESISTANCE SEAL UPON ATTACHMENT HARDWARE

REVISIONS TO S.M. 101-5, P26 CHAMBER FLANGE 228128 (BOLT)

PRELOAD + THERMAL LOAD FROM P 12 is 8286* TOTAL

$$\sigma = \frac{8286}{6.28 \times 1.09 \times A} = 40{,}800^{*} \text{ PSI (LIMIT)}$$

$$A = \frac{8286}{6.28 \times 1.09 \times 40800} = .0297 \text{ SQ. INS.}$$

THIS INCREASED AREA TO BALANCE THE ALLOWABLES WILL RESULT IN A NEW "BRINELING" DEPTH AS FOLLOWS:-

$$\frac{.0297}{.0243} \times .00025 = .000916 \text{ INCHES}$$

* FROM MPM 14.154, FIG 1 FOR 750°F

$F_{TU} = 40{,}000$ PSI $F_{TY} = 25{,}500$ PSI

EST. $F_{BRY} = 1.6 \times 25{,}500 = 40{,}800$ PSI

EFFECTS OF HIGH RESISTANCE SEAL UPON ATTACHMENT HARDWARE

REVISIONS TO S.M. 101-5, P27 (SPLIT RING 229116, RENÉ 41)

PRELOAD + THERMAL LOAD $980 + 401 = 1381$ #/BOLT (LIMIT)

A) FOR NON-ROTATING SPLIT-RING

$$q = \frac{6 \times 1381}{3.14 \times 2.292} = 1152 \text{ #/in (LIMIT)}$$

$$\sigma = \frac{1152}{.042} = 27500 \text{ PSI (LIMIT)}$$

OR 41300 PSI (ULT)

M.S. WILL BE LARGE AS BEFORE

B) FOR CASE OF ROTATING SPLIT-RING (Rene 41 at 560°F)

$$\sigma = \frac{P}{\pi D t} = F_{BRU}, \qquad t = \frac{P}{\pi D F_{BRU}}$$

$$t = \frac{6 \times 1381 \times 1.5}{3.14 \times 2.292 \times (1.6 \times 167{,}800)} = .00644''$$

← F_{TU} AT 640°F - FROM P11

FROM SM 101-5, P26 .00075 DEPTH CORRESPONDS TO A BEARING WIDTH OF .0243"

APPROX BRINNELING = $\frac{.00644}{.0243} \times .00075 = .000199$ DEPTH

Split Ring M.S. = $\frac{269}{269} - 1 = \underline{.00}$ (ULT)

Attach Ring (Rene 41 at 385°F) M.S. = $\frac{269}{269} - 1 = .006$ H

Since the split ring bears on the attach ring the stress of the attach ring is identical to the stress of the split ring and since the allowables are practically the same, (the attach ring has slightly higher allowable), will be conservatively assumed

EFFECTS OF HIGH RESISTANCE SEAL UPON ATTACHMENT HARDWARE

REVISIONS TO SM 101-5 P 30, (BEARING STRESS UNDER BOLT HEAD)

228117 ATTACH RING OF RENÉ 41 AMS 5713 AT 575°F

FROM APPENDIX PAGE 2, $F_{TY} = 127$ KSI, $F_{TU} = 168$ KSI

$F_{BRY} = 1.6 \times 127000 = 203,000$ $\quad F_{BRU} = 1.6 \times 168000 = 269\,000$

PRE-LOAD + THERMAL LOAD = 1381 # (P 11)

$$\sigma = \frac{1381}{.0237} = 58300 \text{ PSI (LIMIT)}$$

OR 87500 PSI (ULT.)

$$\text{BRG. ULT. M.S.} = \frac{269000}{87500} - 1 = \underline{2.08}$$

EFFECTS OF HIGH RESISTANCE SEAL UPON ATTACHMENT HARDWARE

REVISIONS TO S.M. 101-5 P 31 (ATTACH HARDWARE BRINELLING)

PRE-LOAD & THERMAL LOAD = 1381# (P12)

BRINELLING DEPTH IN CHAMBER FLANGE = .000916 P13
SPLIT-RING = .000199 P14
TOTAL BRINELLING = .001115 INCH DEPTH

$\Delta_{BOLT} + \Delta_{BRINNELING} = \Delta_{DIFF\ EXPANSION}$ [SEE TABLE OF TEMPS. ON PAGE 8]

$$\frac{Pl}{AE} + \frac{.001115P}{1381} = (2681 - 1322)10^{-6}$$

$$\frac{P \times 1.18}{.785 \times .125^2 \times 30.6 \times 10^6} + \frac{P \times .001115}{1381} = 1359 \times 10^{-6}$$

$$3.42 \times 10^{-6} P + .808 \times 10^{-6} P = 1359 \times 10^{-6}$$

$$P = 321\#/\text{BOLT (LIMIT)}$$

[AV. TEMP. OF BOLT IS 225° FROM P 8]

THE NEW TOTAL LOAD IN ONE BOLT AFTER TAKING INTO ACCOUNT THE BRINELING BECOMES

$P = 980 + 321 = 1301\#/\text{BOLT}$ (LIMIT) OR $1952\#$ (ULT)

THE PERCENT REDUCTION $= \frac{1381 - 1301}{1381} \times 100 = 5.79\%$

PER-CENT LOAD $= 100 - 5.79 = 94.21\%$

BOLT ITSELF:

THE FINAL LOAD OF $1301\#/\text{BOLT}$, LIMIT, IS HIGHER THAN THE LOAD OF $1230\#/\text{BOLT}$ (SEE SM 101-5, PAGE 31

SINCE THE M.S. VALUE IN SM 101-5, P 20.2 WAS +.01 (ULT) NEW M.S. VALUE WILL BE:

$$(\text{ULT})\ M.S. = \frac{1.01 \times 1840}{1.5 \times 1301} - 1 = \frac{1860}{1950} - 1 = \underline{-.05}$$

CLINCH NUT (228192) AND INJECTOR HEAD (228168)

REFER TO S.M. 101-5, PAGE 24 AND PAGE 25

THE CONDITION OF PAGE 8, WHICH PRODUCES LARGEST BOLT TENSION, IS EXAMINED.

1) NUT: A-286 AMS 5737 AT SAME TEMP AS HEAD, 190°F

$F_{TU} = 140$ KSI, $F_{TY} = 95$ KSI AT R.T.

$F_{TU} = .98 \times 140 = 137$ KSI, $F_{TY} = .98 \times 95 = 93$ KSI AT 190°F SEE MIL HDBK-5 AUG 1962, PAGE 6.2.1.0.(b)

2) HEAD: 6061-T6 AT 190°F SEE MIL HDBK-5, AUG 1962, PAGES 3.2.6.0(b) AND 3.2.6.2.1(d),

$F_{BRU} = (.92)\,88000 = 81\,000$ PSI

$F_{BRY} = (.93)(F_{BRY_{70°}}) = .93(58000) = 54000$ PSI

TOTAL LOAD ON NUT FROM PAGE 16 1301 # AT ELEV. TEMP.

$\sigma_{bu} = \frac{1301}{.0399} = 32{,}700$ PSI (LIMIT) $= 49{,}000$ PSI (ULT.) } BEARING PRESSURES.

THREAD SHEAR, $\tau = \frac{1301}{.0438} = 29{,}800$ PSI (LIMIT) $44{,}800$ PSI (ULT.)

From SM 101-5, P24

M.S., ULT BRG ON HEAD, $= \frac{81000}{49{,}000} - 1 = +.65$

TAKING $F_{SU} = .60\, F_{TU}$

M.S. THREAD SHEAR $= \frac{.60 \times 137000}{44800} - 1 = +.84$

BENDING STRESS ACROSS SECTION (nn-nn) OF NUT FLANGE:-

$\sigma_b = \frac{1301}{1285} \times 116{,}600 = 118{,}000$ PSI (LIMIT) $= 177{,}000$ PSI (ULT)

FROM SM # 101-5, P25

WITH SAME BENDING MODULI AS ON P25 OF SM 101-5

$\sigma_b = \frac{118000}{1.3} = 91{,}000$ PSI (LIMIT)

$\sigma_b = \frac{177000}{1.5} = 118{,}000$ PSI (ULT.)

YIELD M.S. $= \frac{93000}{91000} - 1 = +.02$

Revision to the Stress Analysis of the High Thermal Resistance Chamber to Head Seals (S.M. # 153).

The PreLoad & Thermal load is increased from P = 1,285 #/bolt limit (Ref. SM # 153, page 1) to P = 1,301 #/bolt limit (see page 16).

Load Increment = 16 # limit

% Load Increase = $\frac{16 \times 100}{1,285}$ = 1.2 %

This load increase effects the seals as follows:

1) Jacket Seal (Ref. S.M. # 153)

The critical load is the boost load. Therefore the above 1.2% load increase does not effect this part.

2) Conical Seal (Ref. S.M. # 153)

a) Material: 6AL-4V Ti (T-13622)

The temperature drops from 600°F to 470°F (See pg. 8) and therefore the allowable increases more than the load increases and the new M.S. is larger.

b) Material: Rene 41 (T-13621)

The boost load is critical and therefore this part is not effected by the above load change.

3) Thin Seal (Ref. SM. # 153)

a) Material: 6AL-4V Ti (T-13611)

Since the temperature drops from 600°F to 470°F (See page 8) the allowable increases more than the load, and the M.S. is larger.

Revision to the Stress Analysis of the High Thermal Resistance Chamber to Head Seals (S.M. # 153)

3) Thin Seal (Ref. S.M. # 153) Continued

6) Material Rene 41 (T-13612)

The boost load is critical and therefore this part is not effected by the above load change.

4) Moly Chamber Flange Bearing to the Seal

Temperature = 750°F (see page 9.2)

Moly Allowables

Refere to S.M. # 153 and Marquardt Library Curve 2BA1963

$F_{BRY} = 166.4 \times \frac{25.5}{56} = 75.8$ psi

$F_{BRU} = 75.8 \times \frac{40.0}{25.5} = 119.0$ psi

P = 1301 #/bolt Limit see page 16

$\sigma = \frac{6 \times 1,301}{\pi \times 2.16 \times .017} = 67,700$ psi Limit

Limit M.S. $= \frac{.85 \times 75.8}{67.7}^{*} - 1 = -.05$

This contains an extra safety factor at yield allowable. This factor is $\frac{1}{.85} = 1.18$. Without this factor the M.S. becomes

Limit $M.S. = \frac{75.8}{67.7} - 1 = +.12$

Revision to the Stress Analysis of the High Thermal Resistance Chamber to Head Seals (SM #153)

5) Injector Head Bearing to the Seals

(Ref. SM #153)

Since the temperature drops from 350°F to 190°F (See page 9.2) the increase of the allowable is higher than the load increase and the new M.S. is larger.

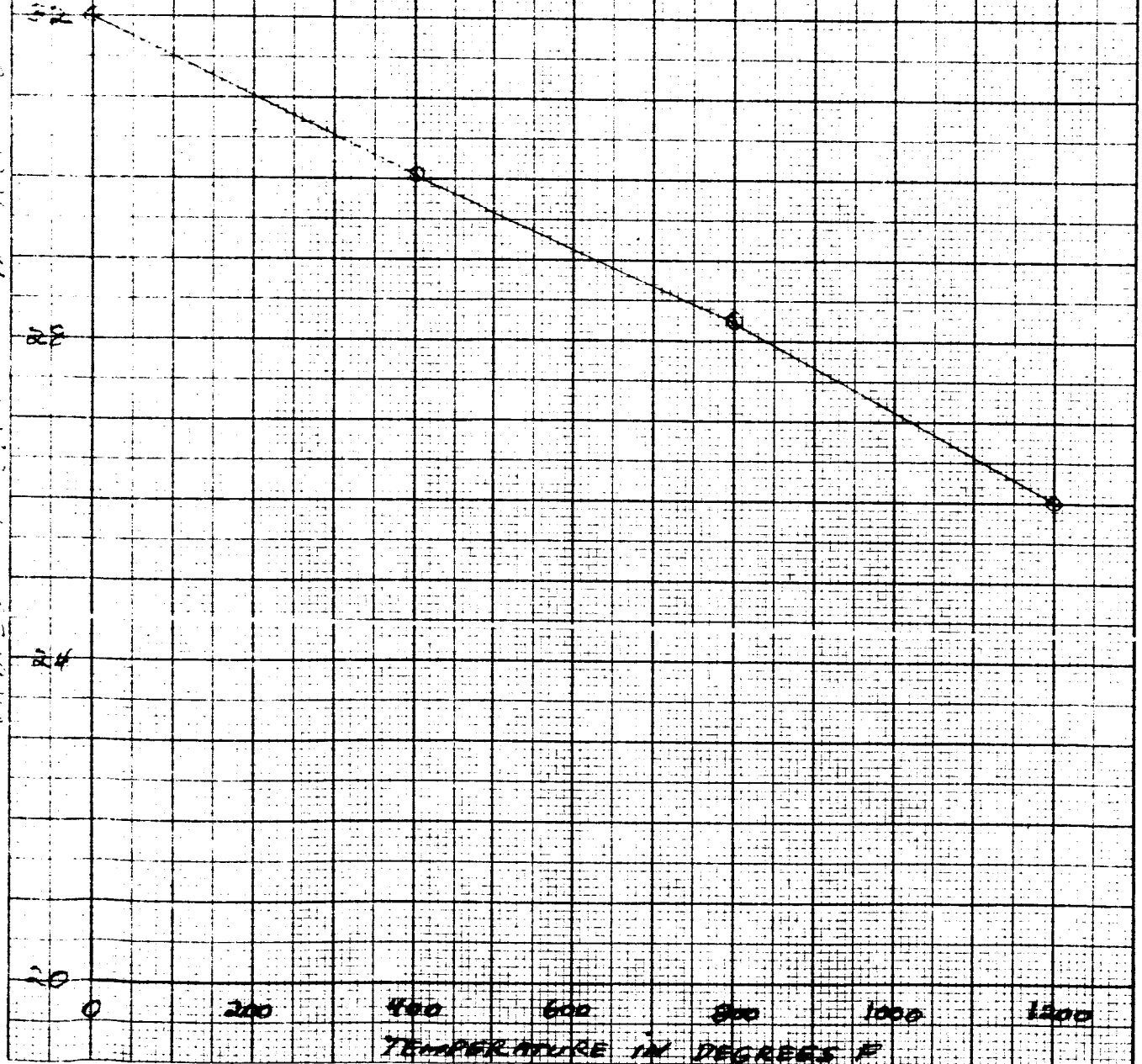
$$MS = +.002^{*}$$

* See SM #153 (This MS. is conservative for the case of the bearing of the head on the high resistance seals.

EFFECTS OF HIGH RESISTANCE SEAL UPON ATTACHMENT HARDWARE

MODULUS OF ELASTICITY OF RENÉ 41 MATERIAL VERSUS TEMPERATURE.

REFERENCE: MMH Vol. II FIG. 3.061



PREPARED BY R.K.S.

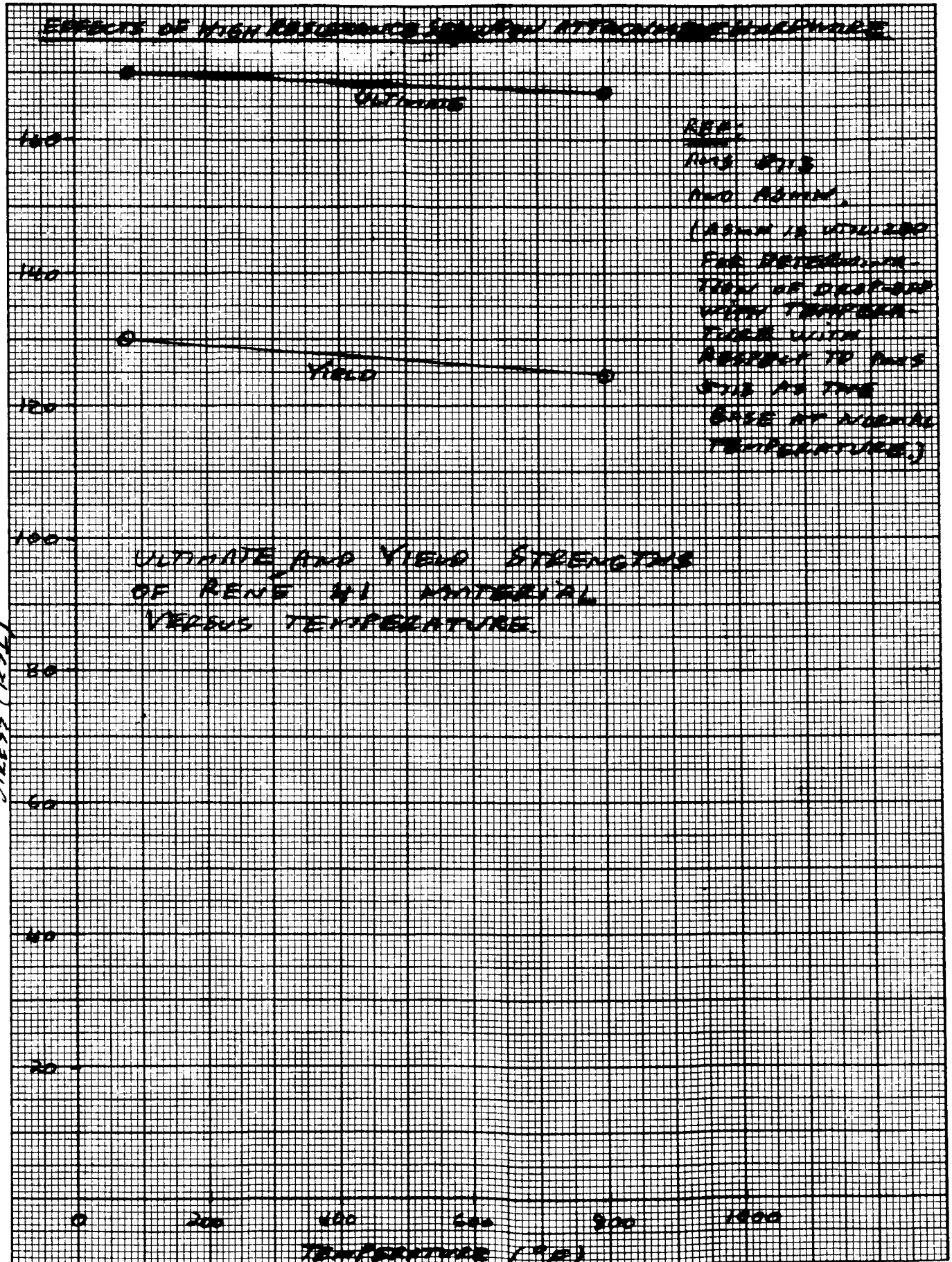
CHECKED BY G. Gogan

THE Marquardt CORPORATION

PAGE

DATE 1-4-66

EFFECTS OF HIGH RESISTANCE [illegible] ATTACHMENT HARDWARE



ATTACHMENT 5

THERMAL ANALYSIS

FOR

APOLLO SERVICE MODULE

REACTION CONTROL SYSTEM ENGINE INJECTOR

CHAMBER SEAL STUDY

PREPARED UNDER CONTRACT NAS9-4775

TMC 3008

Prepared By C. S. Hill
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J. Puntar
Principal Investigator
Design Engineering

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ATTACHMENT #3 - CONICAL SEAL	

INTRODUCTION

This report describes the Thermal Analysis performed in support of development of high thermal resistance injector/chamber seals for the Apollo SM RCS Engine under Contract NAS9-4775. Thermal resistance calculations for candidate seal designs are presented herein.

SUMMARY

The thermal resistances of three candidate seal configurations employing various material combinations were calculated using the released detail drawing dimensions. The results are as shown in Table I.

TABLE I

DESCRIPTION	THICKNESS	P/N	MATERIAL	*THERMAL RESISTANCE HR-°F/BTU	
				MINIMUM	MAXIMUM
Composite Seal	.090-.095	T-13618 T-13619	Titanium and Zirconium Rene'41 Zirconium	4.67 3.77	5.26 4.30
Straight Thinwall	.090-.095	T-13611 T-13612	Titanium Rene' 41	1.82 1.21	2.21 1.48
Conical Thinwall	.248-.252	T-13622 T-13621	Titanium Rene' 41	5.30 3.68	6.20 4.33

* Neglects contact resistance

Rene' 41 6.0 BTU/HR-°F-Ft Titanium 6AL-4V - 4.0 $\frac{BTU}{HR-°F-Ft}$ Zirconium Oxide - .54 $\frac{BTU}{HR-°F-Ft}$

Copies of the detail analysis are available upon request.

Attachment #1 - Composite Seal .090-.095 - T-13618 - T-13619
#2 - Thinwall .090-.095 - T-13612 - T-13611
#3 - Conical Seal .248-.252 - T-13621 - T-13622

DISCUSSION

The resistance to heat transfer between two points is determined by the geometry of the connecting structure and the material properties. This thermal resistance is defined by

$$R_t = \frac{L}{KA}$$

R_t = Thermal Resistance HR-^oF/BTU

K = Thermal Conductivity $\frac{\text{BTU-Ft}}{\text{HR-}^oF\text{-Ft}^2}$

L = Length of Heat Path - Ft

A = Cross Sectional Area of Heat Path - Ft^2

The total thermal resistance between two points of the complex seal configuration was obtained by calculating the thermal resistance of small sections and combining these into an equivalent series and parallel network. This network was then reduced to an equivalent overall thermal resistance.

Contact resistances were assumed zero for all designs. Two dimensional effects at sudden changes of section were approximated by using simple geometric shapes. The thermal conductivity at room temperature was used, taken from Table I - Progress Report PR 3008-1, August 1965. Radiation heat transfer was neglected due to low temperature. Convective heat transfer was neglected due to vacuum in space.

The differences between the final analysis and the preliminary values shown on the layout drawings were caused by dimensional differences between the detail drawing and those used in the preliminary analysis. The following table compares the results.

TABLE II

PART NO.	FINAL *MINIMUM	FINAL *MAXIMUM	PRELIMINARY *MINIMUM	REASON FOR DIFFERENCE
T-13618 T-13919	4.67 3.77	5.26 4.30	5.1 4.2	- Dimensional error on preliminary analysis
T-13611 T-13612	1.82 1.21	2.21 1.48	2.0 1.3	Thickness increased from .015 - .017 to .017 - .019
T-13621 T-13622	3.68 5.30	4.33 6.20	3.81 5.48	Good agreement - Tolerance variations and slide error

* Neglects contact resistance

The analysis is conservative and, therefore, the actual test should show thermal resistances of from .1 to .5 $\frac{HR-^{o}F}{HR}$ higher than the minimum due to contact resistance and tolerance stackups which may average closer to the nominal instead of the maximum. The thermal resistance of both the composite seal and conical thinwall should be higher than 5.0 HR-^{o}F/BTU.

ATTACHMENT #1

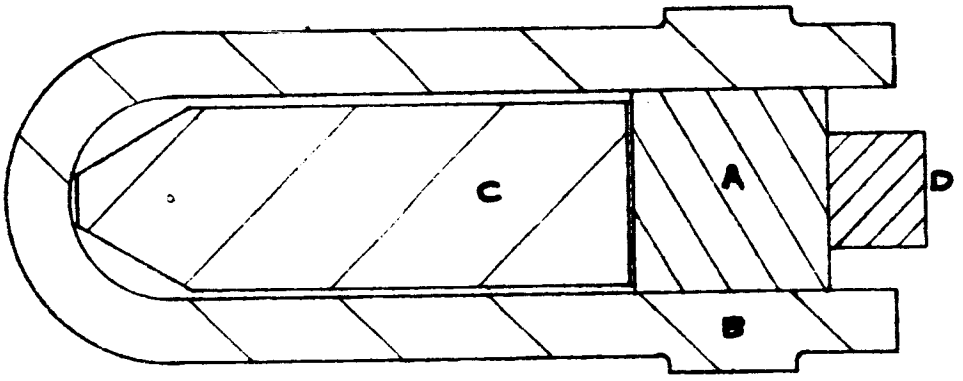
COMPOSITE SEAL

An approximation of the composite seal thermal resistance was made using simplified geometry shown on Figure 2. Figure 1 shows an enlarged cross-section of the composite seal.

The following conditions were analyzed:

1. Thermal conductivities at room temperature were used.
   a. Rene' 41 - 6.0 $\frac{BTU\text{-}FT}{HR^{\circ}F\text{-}Ft^{2}}$
   b. Titanium 6AL-4V - 4.0
   c. Zirconium Oxide - 0.54
2. Contact resistances assumed = 0.0.
3. Conductive heat transfer was the only method of heat transfer.
4. No heat transfer through the snap ring and bumper.

FIGURE 1

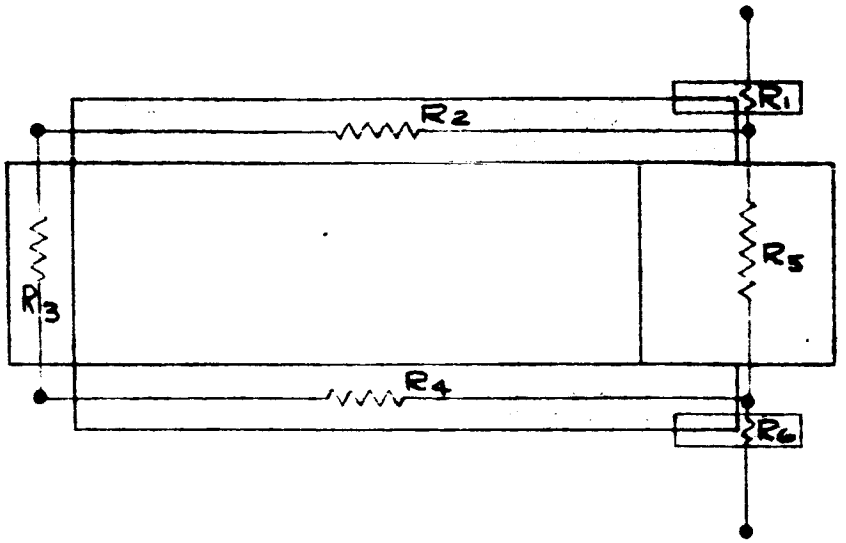


COMPOSITE SEAL CROSS SECTION
T-13618 - T-13619

	DESCRIPTION	DRAWING NO.	MATERIAL
A	Spacer Set	T-13617	Zirconium
B	Jacket	T-13613 T-13614	Rene Titanium
C	Bumper Set	T-13615	Titanium
D	Snap Ring	T-13616	316 Cres

FIGURE 2

SIMPLIFIED THERMAL EQUIVALENT



RESISTANCE $\frac{HR-^{o}F}{BTU}$	T-13618 TITANIUM ZIRCONIUM		T-13619 RENE' ZIRCONIUM	
	MINIMUM	MAXIMUM	MINIMUM	MAXIMUM
R_1	0.13	0.16	0.088	0.108
R_2	4.20	5.01	2.80	3.34
R_3	1.29	1.66	0.86	1.10
R_4	4.20	5.01	2.80	3.34
R_5	8.08	8.56	8.08	8.56
R_6	0.13	0.16	.088	0.108

The resistances were combined as follows:

$$R_T = R_1 + \frac{(R_2 + R_3 + R_4)R_5}{(R_2 + R_3 + R_4) + R_5} + R6$$

R_{Total} = 4.67 $\frac{HR-^oF}{BTU}$ Minimum

T-13618 Titanium

5.26 $\frac{HR-^oF}{BTU}$ Maximum

R_{Total} = 3.77 $\frac{HR-^oF}{BTU}$ Minimum

T-13619 Rene' 41

4.30 $\frac{HR-^oF}{BTU}$ Maximum

NOTE: Neglects all contact resistances.

ATTACHMENT #2

STRAIGHT THIN WALL SEAL

.090 - .095

T-13612 - T-13611

The thin wall seal, Figure 1, was approximated by thermal circuit shown, Figure 2. Maximum and minimum tolerance combinations were used to calculate the minimum and maximum overall thermal reiistance.

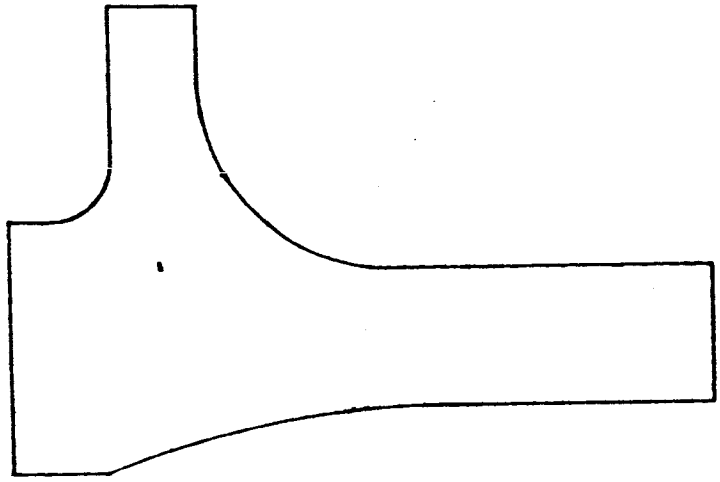
Thermal conductivities at room temperature

Rene' 41 - 6.0 $\frac{BTU\text{-}Ft}{HR\text{-}^{o}F\text{-}Ft^{2}}$

Titanium - 4.0 6AL 4V $\frac{BTU\text{-}Ft}{HR\text{-}^{o}F\text{-}Ft^{2}}$

Contact resistances were neglected.

FIGURE 1



THIN WALL SEAL

.090 -.095 LONG

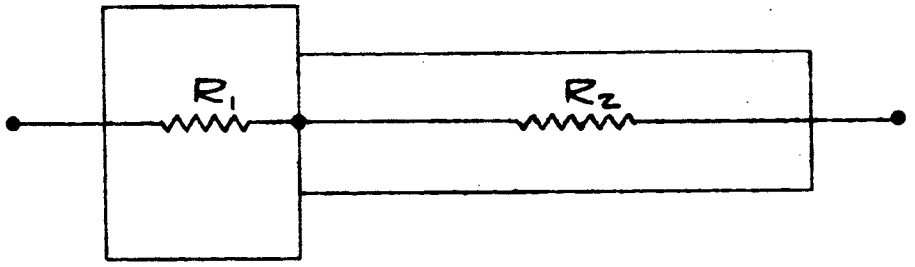
T-13611
6AL-4V TITANIUM

T-13612
RENE' 41

FIGURE 2

THERMAL EQUIVALENT

$$R_{Total} = R_1 + R_2$$



THE THERMAL RESISTANCES CALCULATED

THERMAL RESISTANCE HR-°F/BTU	T-13611 TITANIUM		T-13612 RENE' 41	
	MINIMUM	MAXIMUM	MINIMUM	MAXIMUM
R_1	.366	.306	.244	.204
R_2	1.449	1.908	.966	1.272
R_{Total}	1.82	2.21	1.21	1.48

ATTACHMENT #3

CONICAL SEAL

T-13621	T-13622
Rene' 41	6AL-4V

An overall thermal resistance was calculated.

Figure 1 shows the thinwall seal. Figure 2 shows the equivalent thermal configuration.

Contact resistances were neglected.

The flanges near the base of the seal do not touch, therefore, no heat is transferred out the "flanges."

FIGURE 1

CONICAL SEAL

T-13621 T-13622

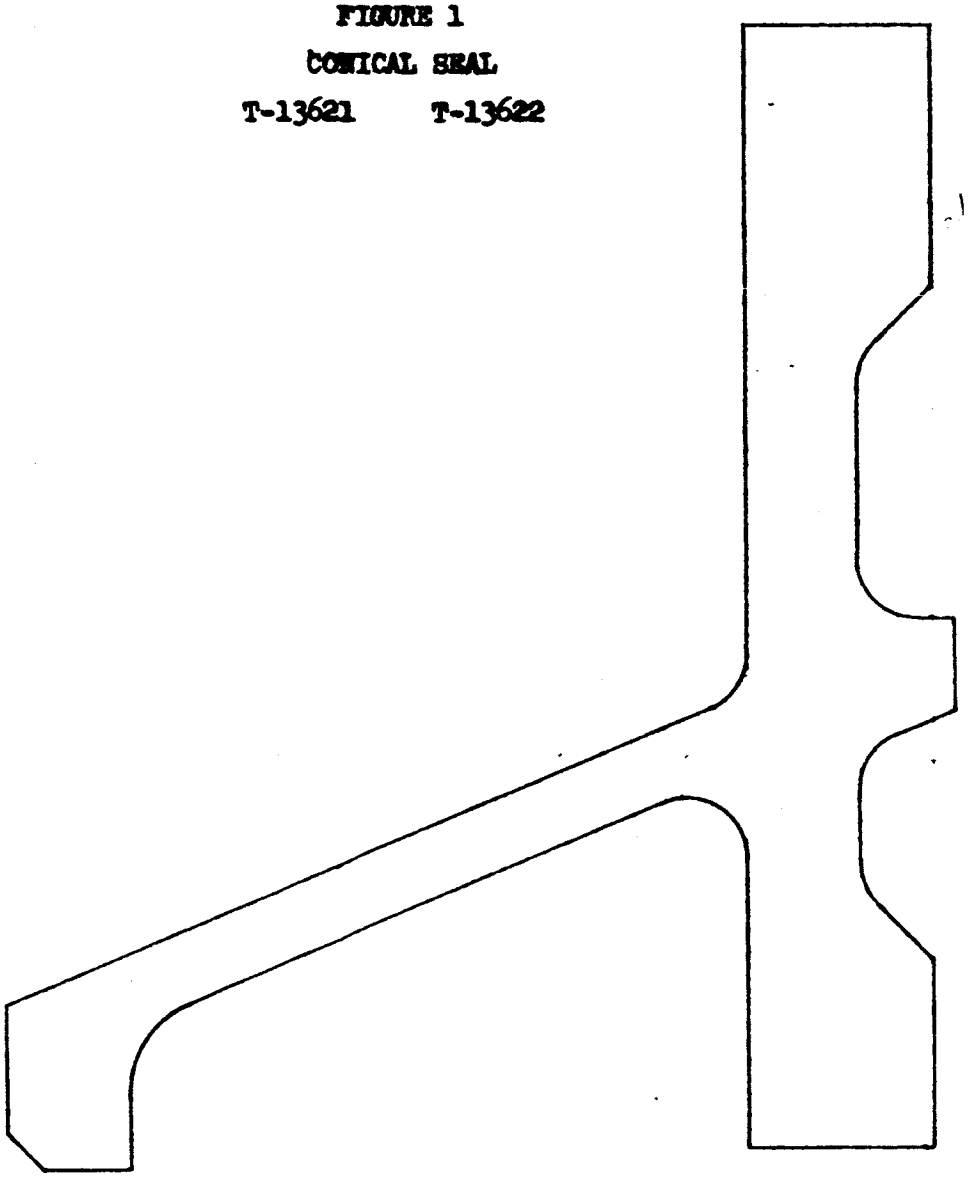
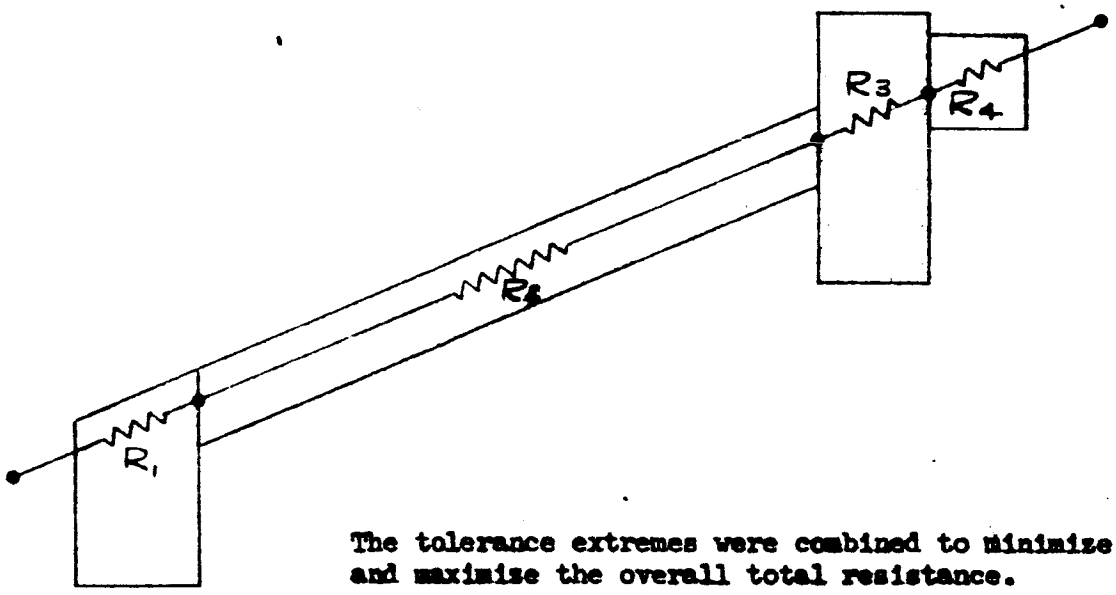


FIGURE 2

EQUIVALENT THERMAL SKETCH



The tolerance extremes were combined to minimize and maximize the overall total resistance.

$R_{Total} = R_1 + R_2 + R_3 + R_4$

RESISTANCE HR-°F/BTU	T-13622 TITANIUM		T-13621 REMI 41	
	MINIMUM	MAXIMUM	MINIMUM	MAXIMUM
R_1	0.441	0.357	0.294	0.238
R_2	4.2	5.052	2.946	3.568
R_3	0.195	0.152	0.13	0.104
R_4	0.462	0.636	0.308	0.424
R_{Total}	5.30	6.20	3.68	4.33

ATTACHMENT 6

THE Marquardt CORPORATION VAN NUYS, CALIFORNIA

TEST REPORT (FINAL)

SMALL SCALE MATERIAL SPECIMENS

FOR

APOLLO SERVICE MODULE

REACTION CONTROL SYSTEM ENGINE INJECTOR

CHAMBER SEAL STUDY

PREPARED UNDER CONTRACT NAS 9-4775

TMC 3008

Prepared By J. Puntar
Design Engineering

Approved By E. P. Perlman
Program Manager

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I. INTRODUCTION

This test report covers the results in testing candidate seal materials in support of development of high thermal resistance injector head/combustor seals for the Apollo Service Module Reaction Control System Engine under Contract NAS 9-4775. Metallic and non-metallic small scale specimens fabricated from candidate seal materials were tested to determine specific structural properties and failure modes as applied to seals developed in this program.

II. CONCLUSIONS AND RECOMMENDATIONS

Analysis of test data obtained from small scale metallic specimen structural tests indicated that sufficient safety margins were attained with these materials in combination with the disilicide coated molybdenum combustion chamber material. The materials tested, 6AL-4V Titanium Rene' 41 and L-605, were proven to be suitable engineering materials for high thermal resistance seals.

Non-metallic specimens, fabricated from two (2) different types of Zirconium Oxide, demonstrated compressive strengths commensurate with requirements for composite type seals. Structural safety margins in excess of maximum ultimate stress (Apollo specifications define this as "maximum limit stress" x 1.5) were documented. A third type of Zirconium Oxide demonstrated compressive strength equivalent to 78% of the required value.

On the basis of static compression tests, Zirconium Oxide material is suitable for application to composite type high thermal resistance seals.

III. SUMMARY

Small scale bearing tests of specimens fabricated from candidate seal metals were conducted. Test data indicated that sufficient safety margins in bearing were attained with these materials in combination with the disilicide coated molybdenum combustor flange. A summary of the test results follows:

RESULTS OF SMALL SCALE BEARING TESTS - SUMMARY

Small scale specimens fabricated from 6AL-4V Titanium, Rene' 41 and 20% cold worked L-605 cobalt base alloy, in combination with a disilicide coated and lapped molybdenum combustor flange used in the Apollo SM RCS Engine

were subjected to bearing loads induced by the Baldwin Universal Compression Test Machine. Each specimen contained a contact bearing width of .017/.019 inch corresponding to the bearing width on the straight thinwall seal at the seal/combustor interface. Load steps were applied serially at room temperature to individual specimens to establish the bearing strength of the coated flange.

A yield criteria at bearing stresses corresponding to moly flange deformations of .0001 to .0002 was chosen. For these deformations, which correspond to an average 270 lbs. loss of seal preload, the minimum bearing stress was 154,000 psi and the maximum was 200,000 psi. The yield allowable of 166,000 psi used in SM 153, Stress Analysis of Seal Configurations (Ref. 1), would seem to be justified.

The ultimate criteria was taken to be that stress corresponding to the maximum observed permanent deformations, .0006 and .0015 inch. For these deformations, which correspond to an average loss of 1800 lbs. seal preload, the minimum bearing stress was 215,000 psi and the maximum 222,000 psi. These values are higher than those used in the seal stress analysis which was 183,700 psi at 150°F.

Failure mode of the specimens and the molybdenum disilicide coated and lapped molybdenum combustor flange was manifested by clean perceptable local yielding at the highly stressed areas.

Tests verifying the compressive strength of three (3) different types of Zirconium Oxide in combination with candidate seal metals were conducted. Problems were experienced initially in obtaining consistent test data.

A summary of test results follows:

RESULTS OF SMALL SCALE ZIRCONIUM OXIDE COMPRESSION TESTS - SUMMARY

Small scale specimens, .050/.051 diameter x .053/.054" long, full dense, hard fired Zirconium Oxide (Zircoa "C") in combination with

candidate seal metals were subjected to oompressive loads generated by the Baldwin Universal Compression Test Machine. Loading was applied at a low strain rate at room temperature to individual specimens aimed at establishing the compressive strength of the Zirconium Oxide.

Favorable test results were obtained on five (5) specimens load tested to levels exceeding the required minimum without failure. Stresses ranging between 112.5 to 140 ksi were demonstrated. The required ultimate compressive strength is 112.95 ksi.

Additional specimens of the same material were also fabricated and tested using .080 inch and .250 inch diameters with a length to diameter ratio of unity. These tests were aimed at establishing compressive strength corresponding to failure.

Two (2) specimens of each size were individually load tested to apparent failure using the same test method. Erratic test results were obtained. Failure stresses ranging from 33 to 95.2 ksi were recorded. It was concluded that uneven specimen loading resulting in deviation from ideal test conditions was caused by minute, unobservable shifts within the test setup. No further attempts were made to obtain F_{cu} values for this material using the singular specimen test method.

Another test, however, was designed and implemented which was very successful in attaining consistent compression test data of a more practical nature. The test method employed three (3) .050/.051 x .053/.054" long specimens nested equidistantly within a composite seal jacket. In this case, it was predicted that one of the three specimens would fail upon reaching it's discrete critical stress. In practice, the failure point was realized by an instantaneous collapse of the weakest specimen.

Three (3) different types of Zirconium Oxide materials were tested on the Baldwin Compression Test Machine using this method, Zircoa "C" (full dense), Zircoa "C" (modified) and Zircoa #1027 (modified) were fabricated into test specimens. The first material previously discussed, was selected early in the program while the latter two were specially developed later in the program. The modified materials were aimed at obtaining lower thermal conductivity (K) consistent with high compressive strength.

Uniform test results were obtained from three (3) "triplet" sets (consisting of three cylinders/set) for each material. Failure stresses ranging from 130 to 148 ksi were recorded for the Zircoa "C" (full dense) material, 110 to 115 ksi for the Zircoa #1027 (modified) material and 83.5 to 97.5 ksi for the Zircoa "C" (modified) material.

Compression load tests were also performed on "ganged" Zirconium Oxide cylinders. This testing was facilitated by assembling sixty (60) cylinders into composite seal jackets. Four (4) assemblies conforming to full scale composite seal assemblies P/N T-13618 (Titanium jacket seal) and P/N T-13619 Rene' 41 jacket seal) were load tested. No failures or indications of structural degradation were observed after application of 5880 lbs. compressive load was applied by the Baldwin Universal Compression Test Machine. (5880 lbs. load corresponds to the maximum preload applied to seals during Apollo engine assembly).

IV. TECHNICAL DISCUSSION AND TEST RESULTS

Small scale specimen testing of candidate seal materials was performed at the Marquardt Materials and Process Laboratory. Informal test outlines were used in lieu of formal test plans in order to facilitate the flexibility in changes to test setups and test procedures.

Early in this program, four (4) candidate materials were chosen as best suited for high thermal resistance seals. They are:

1. 6AL-4V, Titanium alloy
2. Rene' 41
3. L-605, cobalt base alloy (20% cold worked)
4. Zirconium Oxide (Zircoa "C")

Small scale specimens were fabricated from the metallic materials and subjected to compression tests on the Baldwin Universal Compression Test Machine. The metallic specimens:

1. 6AL-4V
2. Rene' 41
3. L-605

were designed to contain a contact bearing width of .017/.019 inch. Corresponding to that reflected by the straight thinwall seal designs (P/N's T-13611 and T-13612) at the seal/combustor interface. Bearing widths on conical thinwall and composite seals are larger and less critical, therefore, were not tested in small scale.

An Apollo production combustor fabricated from un-alloyed molybdenum was obtained from the Apollo project. The combustor was disilicide coated and the flange face (adjacent to the seal) was lapped per Apollo specifications.

Objectives of the tests were to verify contact bearing width requirements analytically estimated for the thinwall seal at the combustor interface. Additionally, the bearing strength of the combustor flange was to be determined as well as identification of the compressive/bearing failure modes of the candidate metals in combination with the combustor flange.

Early tests were conducted on specimens with small contact bearing widths (.015/.017 inch). A design change to the thinwall seals (contact bearing width was increased to .017/.019), coupled with test setup instability problems, terminated testing of these specimens. A description of the specimens and test setup is shown in Figure 1.

Figure 2 describes the revised specimens and test setup. The test procedure consisted of applying load steps, at room temperature, to individual specimens. Load steps are tabulated in Figure 3. After each load step, the loading was removed and a visual inspection was made of the specimen and combustor flange surface for indications of changes (brinelling and/or deformations). Succeeding load steps were made at new locations on the flange. At the conclusion of load step application, all positions were measured to record minimum and maximum depths of impressions on the flange surface. An indicator with .00005 inch accuracy was used. Each specimen was also measured to obtain bearing areas at the specimen/combustor flange interface and the stresses corresponding to each load step were calculated.

Figure 4 tabulates the deformation measurements, bearing areas and stresses for all specimens at each load step.

Figure 5 is a cross plot of the moly flange bearing stress vs. indentation taken from Figure 4.

Analysis of these data resulted in choosing yield criteria at bearing stresses corresponding to moly flange deformations of .0001 to .0002. The plot (Figure 5) shows one data point at 154 ksi at .00015 inch indentation with all others at an average of 200 ksi. The yield allowable of 166,000 psi used in (Ref. 1), SM 153, Stress Analysis of Seal Configurations, would seem to be justified.

For ultimate criteria, permanent deformations of .0006 to .0015 inch were chosen. The plot (Figure 5) shows bearing stresses ranging from 215 ksi to 222 ksi. These values are higher than 183,700 psi used in Ref. 1.

Compression testing of non-metallic specimens was completed for three (3) different types of Zirconium Oxide. The primary variable for the three (3) types of materials is bulk density (lbs/ft^3). The materials and bulk densities are:

1. Zircoa "C" (full dense) - 347 lbs/ft^3
2. Zircoa "C" (modified) - 269 lbs/ft^3
3. Zircoa #1027 (modified) - 275 lbs/ft^3

Chemically, materials 1 and 2 are identical. The third material consists primarily of Zirconia. The other constituants in this material are considered proprietary by the manufacturer, Zirconium Corporation of America, thus, could not be obtained.

Initially, small scale specimens were fabricated from Zircoa "C" rod. This material was chosen early in the program for it's high compressive strength and low thermal conductivity. It is described as dense, hardfired, lime stabilized Zirconium Oxide.

The specimens used in the first test series conformed to dimensional requirements of Drawing T-13617 (.050/.051 diameter x .053/.054 inch long).

Objectives of the tests were to verify the compressive strength of the material and evaluate its' behavior under load in combination with candidate seal metals.

Initial tests produced erratic test results. The variance in test results was primarily due to uneven specimen loading manifested by the test setup and test procedures used. The test setup is illustrated in Figure 6. The test procedure consisted of applying load steps at room temperature similar to the procedure used for metallic specimens.

Reasons for the erratic performance is explained as follows:

> Zirconium Oxide, having a crystalline structure consistent with a relatively high modulus of elasticity (ϵ = 21.5 x 10 psi @ R.T.), is a brittle material with reportedly very high compressive strength (F_{cu} = 303,000 psi @ R.T. under ideal loading conditions). The ultimate

tensile strength, however, is relatively low (F_{tu} = 20,000 psi). To obtain absolute F_{cu} values, even specimen loading, applied at a low strain rate is essential to maintain a compressive mode uniformly within the material. Should uneven loading be applied across the specimen, a shear mode can be generated in the material resulting in a tensile failure at the shear plane.

The test setup was modified, as shown in Figure 7. The modification consisted of providing a "centering nest" for the specimens to obviate articulation of the test setup elements under load. The nest was designed to accommodate a single specimen or three specimens arranged in a circular pattern, evenly spaced about the load axis.

The revised test procedure consisted of applying a continuously increasing load at a low strain rate instead of interrupted load steps.

Five (5) specimens were tested individually in accordance with the above. Favorable results were obtained on all specimens. Results are compared with required performance as follows:

Specimen No. (.050/.051 Dia. x .053/.054 In. Lg.)	Applied Load-Lbs. (2-3 Lbs/Sec.)	Demonstrated Equiv. Compressive Stress-Psi x 10^3	Required Ult. Comp. Strength -Psi x 10^3
#1	270*	135	↑
#3	280*	140	
#4	260*	130	112.95**
#5	275*	137.5	
#6	225*	112.5	↓

*Load applied at constant rate to value shown - no failure.

**Maximum Apollo launch boost limit σ x M.S. (1.5) = Maximum Ult. σ = (75.3 x 1.5) x 10^3 for individual cylinder.

Photographs taken of each end of the tested specimens, Figure 8, indicate that minor degradation of the edges is evident. This was expected due to edge loading effects. However, the resultant loss of cross sectional area at the specimen faces combined with the ability of the remaining material to sustain the applied load, indicates that the material was capable, in each case, of bearing additional load. Loading, however, was purposely stopped at the values shown to permit inspection of the specimens prior to failure.

Additional tests were conducted on specimens made from the same material to establish compressive strength corresponding to failure.

Cylindrical specimens, .080 inch and .250 inch diameter with a length to diameter ratio of unity were tried. The outside diameters of these specimens were "unground", i.e., in the "as fired" condition to preserve the fired skin and obviate the presence of grinding cracks which might contribute to premature failure. Presence of these cracks, if they in fact exist, has never been detected on any parts fabricated from zirconia in this program. Faces of the specimens were ground flat and parallel. The test setup, shown in Figure 9, employed a RTV rubber cast to nest a single specimen properly between the metallic slugs. A continuously increasing load at a low rate was applied by the Baldwin Universal compression test machine. At approximately fifty (50) lbs. load, the RTV nest, which was previously slitted, was removed (to permit viewing the specimen) while the load was continuously increased (without interruption) until failure was detected. Failure detection was facilitated by simultaneous observation of the specimen and the Baldwin load gauge. Load application was terminated when either the specimen showed signs of failing or the load gauge showed erratic load rate steps. Two (2) specimens of each size (.080 inch diameter and .250 inch diameter) were tested with erratic test results. Figure 10 summarizes these results. Figure 11 documents the pre and post test condition of the .080 inch diameter specimens. Figure 12 shows the pre and post test condition of the .250 inch diameter specimens. Although the photographs do not indicate total failure of all the cylinders, it is believed that visually undetectable cracks within the material were responsible for the erratic load rate steps observed on the Baldwin load gauge. It was concluded that minute, unobservable shifts within the test set-up caused uneven specimen loading and deviation from ideal test conditions. No further attempts were made to obtain, the hoped for, absolute F_{cu} values for this material.

Another test, however, was designed and implemented which was very successful in attaining consistent test data of a more practical nature. This test employed three (3) standard size zirconia cylinders, fabricated per Drawing T-13617, and the titanium jacket and bumperset, P/N's T-13614 and T-13615, previously used in a thermal test. The three (3) cylinders were

nested equidistantly within the jacket by the bumper set. The snapring was purposely not used in order to permit visual access to the cylinders. The setup, shown in Figure 13, also used the simulated injector head (from thermal tests), moly combustor ring (from small scale metallic specimen tests) and a molybdenum simulated combustor. Compressive loads were applied at a low rate by the Baldwin compression test machine. The accurate geometry of the test setup elements and small L/D ratio described by the test setup extremities assured equal load distribution to each cylinder consistent with excellent stability. Further, the setup provided accurate simulation of uneven loading conditions which prevail at the cylinder/jacket interfaces in the composite seal.

The test procedure employed the same failure detection methods used in the single specimen tests, i.e., simultaneous observation of the specimens and the Baldwin load gauge. In this case, it was predicted that one of the three specimens would fail upon reaching it's discrete critical stress. In practice, the failure point was realized by an instantaneous collapse of the weakest specimen which was recorded accurately by the Baldwin load gage.

All three (3) different types of Zirconium Oxide materials were successfully tested on the Baldwin compression test machine using this test method to determine the ultimate compressive strengths corresponding to failure.

Uniform test results were obtained from all three (3) "triplet sets" (consisting of 3 cylinders/set) for each material. A comparison of the test results is shown in Figure 14. The data is considered to be reliable as well as practical in that it was generated under typical loading conditions as found normally in composite seals.

Figures 15 through 23 document the pre and post-test condition of each triplet set. The post-test photographs show the characteristic minor edge degradation (on each of the unfailed specimens) which prevails due to edge loading effects. This type of edge degradation does not occur at stresses corresponding to limit loads.

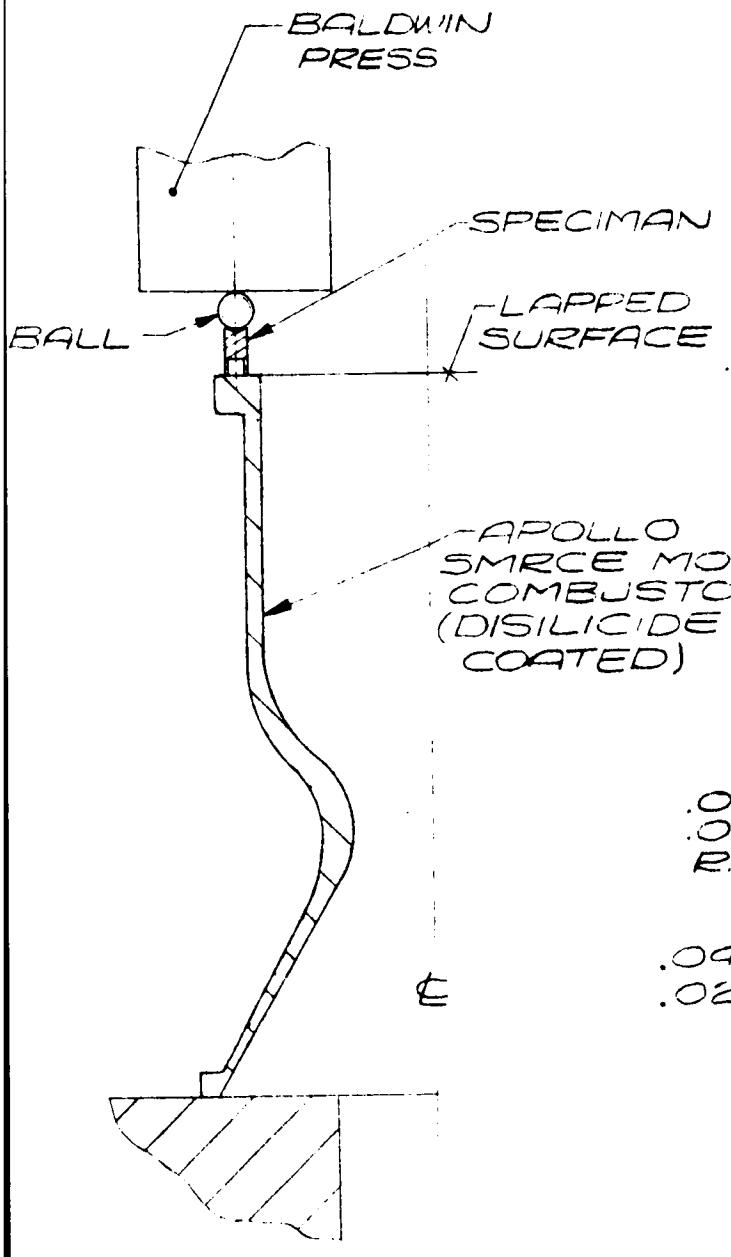
Load tests were also performed on completely assembled composite seals. Both composite configurations, P/N's T-13618 (Titanium) and T-13619 (Rene' 41) were subjected to approximately three (3) ton (5880 lbs.) loads in the Baldwin Universal Compression Test Machine. No failures or indications of structural degradation occurred. The 5880 lbs. load is equivalent to the maximum preload applied during Apollo engine assembly. These tests (regarded as acceptance tests for composite seals) confirmed the suitability of composite seal jackets which contained minor distortions. These seals were subsequently reloaded successfully by the standard Apollo assembly techniques (with combustor attach bolts) in the structural and thermal test rigs.

The test setup for the assembled composite seals is shown in Figure 24.

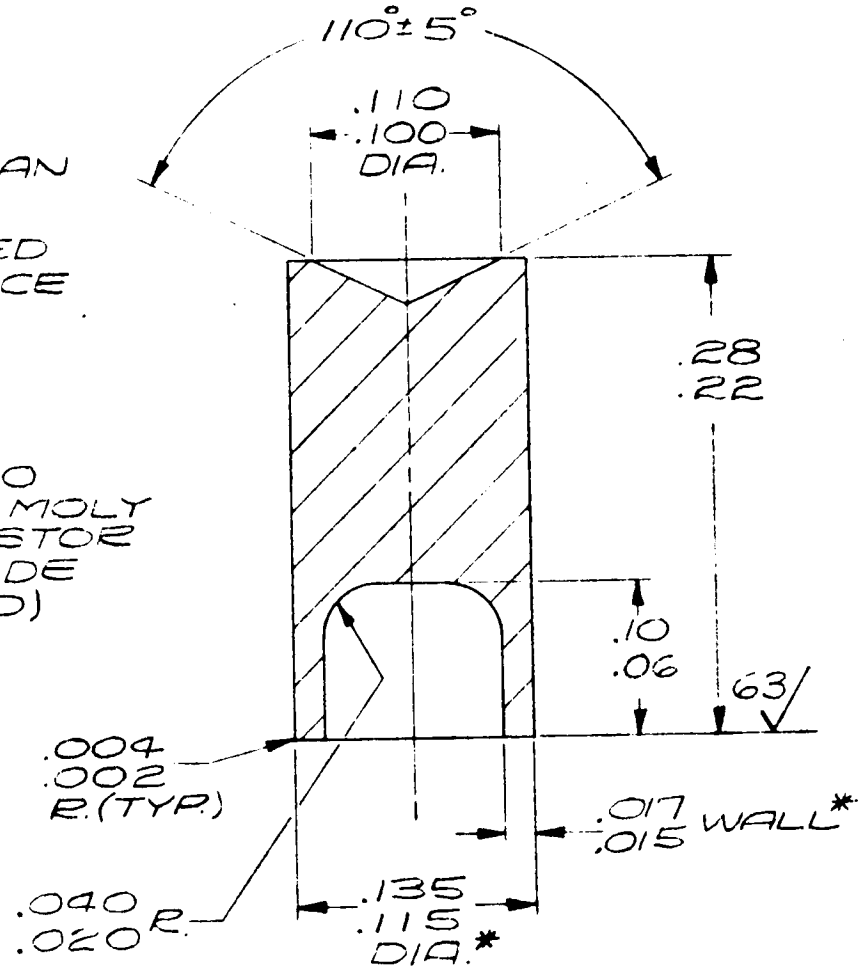
REFERENCES:

1. Stress Memo - SM 153, Stress Analysis of Seal Configurations - G. Carayanis

BEARING TEST SETUP & SPECIMENS



TEST SETUP



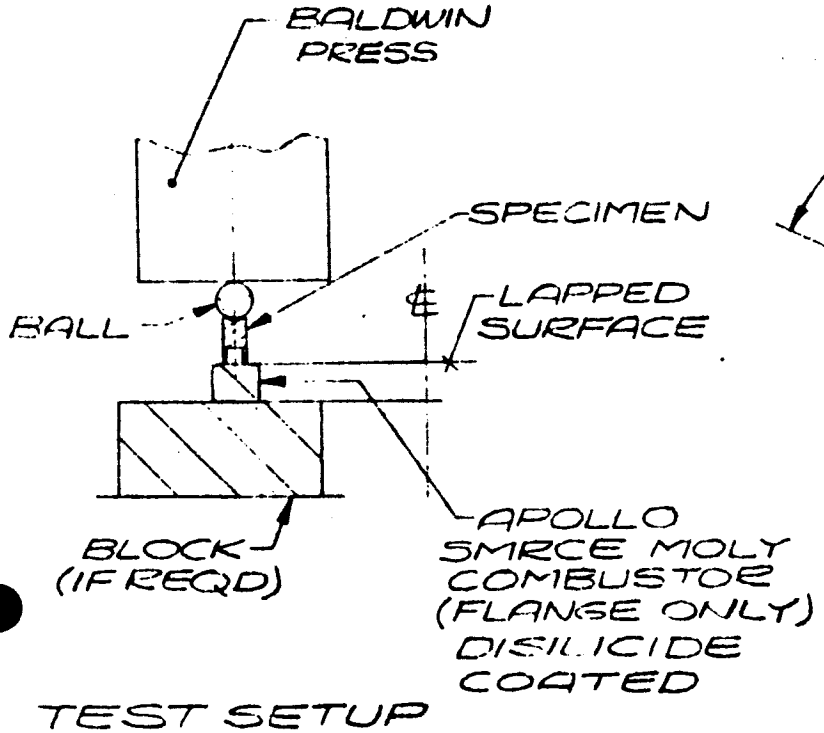
SPECIMEN DETAIL

MAT'LS: WASPALOY
RENE' 41
6AL4V Ti
L-605

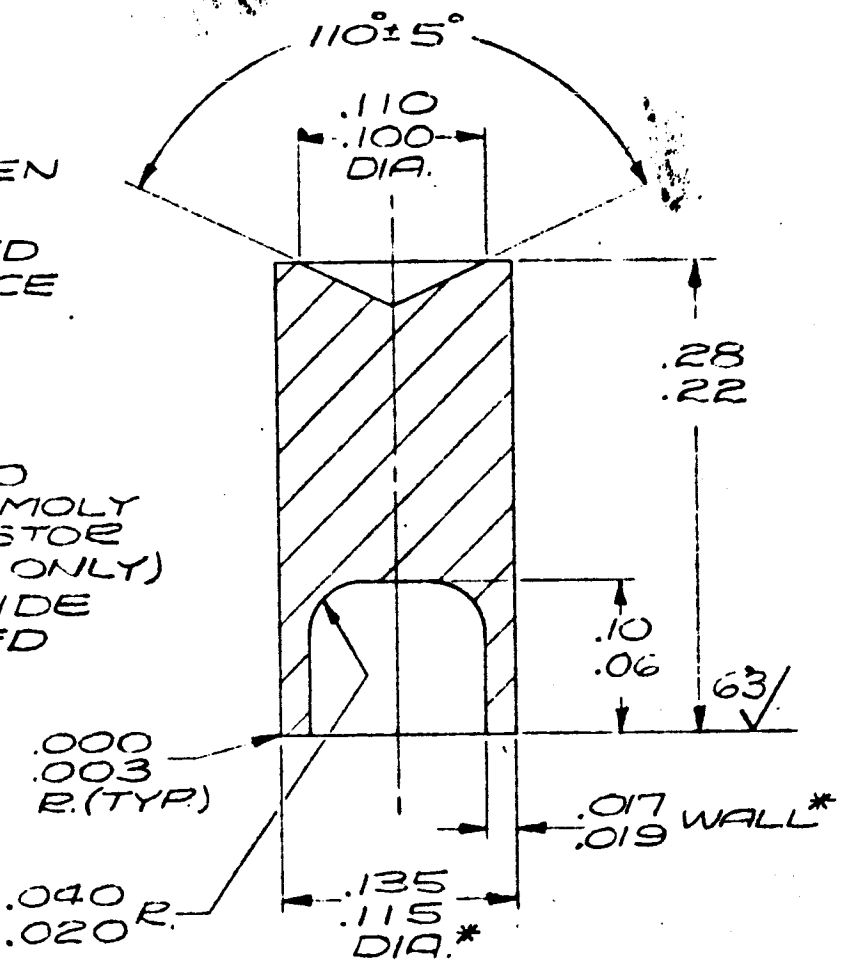
* DIM. TO BE RECORDED

FIGURE 1

BEARING TEST SETUP & SPECIMENS



TEST SETUP



SPECIMEN DETAIL

MAT'LS: L-605
RENE' 41
6AL4V Ti

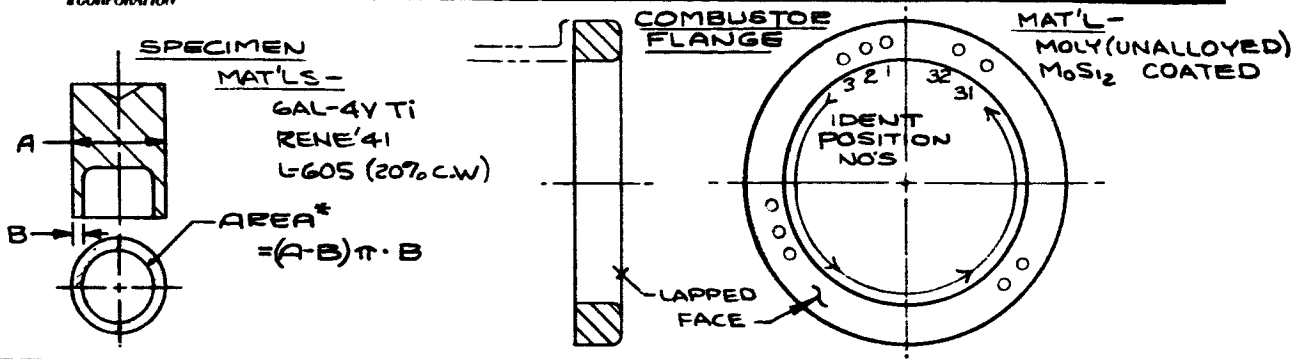
* DIM. TO BE RECORDED

FIGURE 2

LOAD STEPS - SMALL SCALE SPECIMENS,
CANDIDATE SEAL METALS

Load Steps	L-605	Rene' 41	6AL-4V Ti
1	370#	830#	860#
2	460#	1040#	1080#
3	560#	1250#	1300#
4	650#	1460#	1510#
5	740#	1660#	1720#

FIGURE 3



	POS. NO.	INDENTATION ($IN \times 10^{-4}$) MIN.	MAX.	LOAD (LBS.)	A-B (IN.)	B (IN.)	AREA* ($IN^2 \times 10^{-3}$)	σ (KSI)	IDENT. AVG ($IN \times 10^{-4}$)
L-605	1	0	0	560	.1064	.017	5.68	98.6	0
	2	0	0	650	NOT RECORDED		/	/	/
	3	0	0	740	NOT RECORDED		/	/	/
	4	0	0.6	1,100	.1058	.018	5.98	183.9	0.3
	5	6.0	15.0	1,500	.1170	.019	6.98	214.8	10.5
RENE 41	6	1.0	2.0	840	.1083	.016	5.44	154.4	1.5
	7	2.0	3.0	1,040	NOT RECORDED		/	/	/
	8	1.0	5.0	1,250	.1088	.017	5.81	215.1	3.0
	9	4.0	7.0	1,400	.1114	.018	6.30	222.2	5.5
Ti	10	0	1.0	1,080	.1051	.019	6.27	172.2	0.5
	11	2.0	4.0	1,300	.1057	.0195	6.47	200.9	3.0
	12	1.0	1.0	1,400	.112	.020	7.04	198.9	1.0
L-605	13	1.0	3.0	1,100	.1052	.018	5.95	184.8	2.0
	14	3.0	4.0	1,250	.1054	.018	5.96	209.7	3.5
	15	2.0	3.0	1,400	.1061	.0185	6.16	227.3	2.5
	16	1.0	4.0	1,500	.1098	.0195	6.72	223.2	2.5
RENE41	17	0	0	1,040	.1077	.017	5.75	180.8	0
	18	1.0	2.0	1,250	.1080	.018	6.11	204.8	1.5
	19	1.5	2.0	1,400	.1142	.018	6.46	216.7	1.75
Ti	20	0	1.0	1,080	.1082	.0175	5.95	181.5	0.5
	21	0	5.0	1,300	.1090	.018	6.16	211.0	2.5
	22	1.0	4.0	1,460	.1170	.020	7.35	198.6	2.5
L-605	23	0.5	1.0	1,100	.1066	.019	6.36	173.0	0.75
	24	0	1.0	1,250	.1063	.019	6.34	197.2	0.5
	25	1.0	1.5	1,400	.1076	.019	6.42	218.1	1.25
	26	0	1.0	1,500	.1118	.019	6.67	224.9	0.5
RENE41	27	1.0	2.0	1,040	.1087	.017	5.80	179.3	1.5
	28	1.0	3.0	1,250	.1097	.017	5.86	213.3	2.0
	29	1.5	3.0	1,430	.1115	.0175	6.13	233.3	2.25
Ti	30	0	0	1,080	.1073	.018	6.07	177.9	0
	31	0	1.5	1,300	.1078	.018	6.09	213.5	0.75
	32	1.0	2.0	1,410	.1110	.019	6.62	213.0	1.5

TABULATION - LOAD & STRESS DATA

FIGURE 4

MOLYBDENUM CHAMBER BEARING STRESS VS. INDENTATION

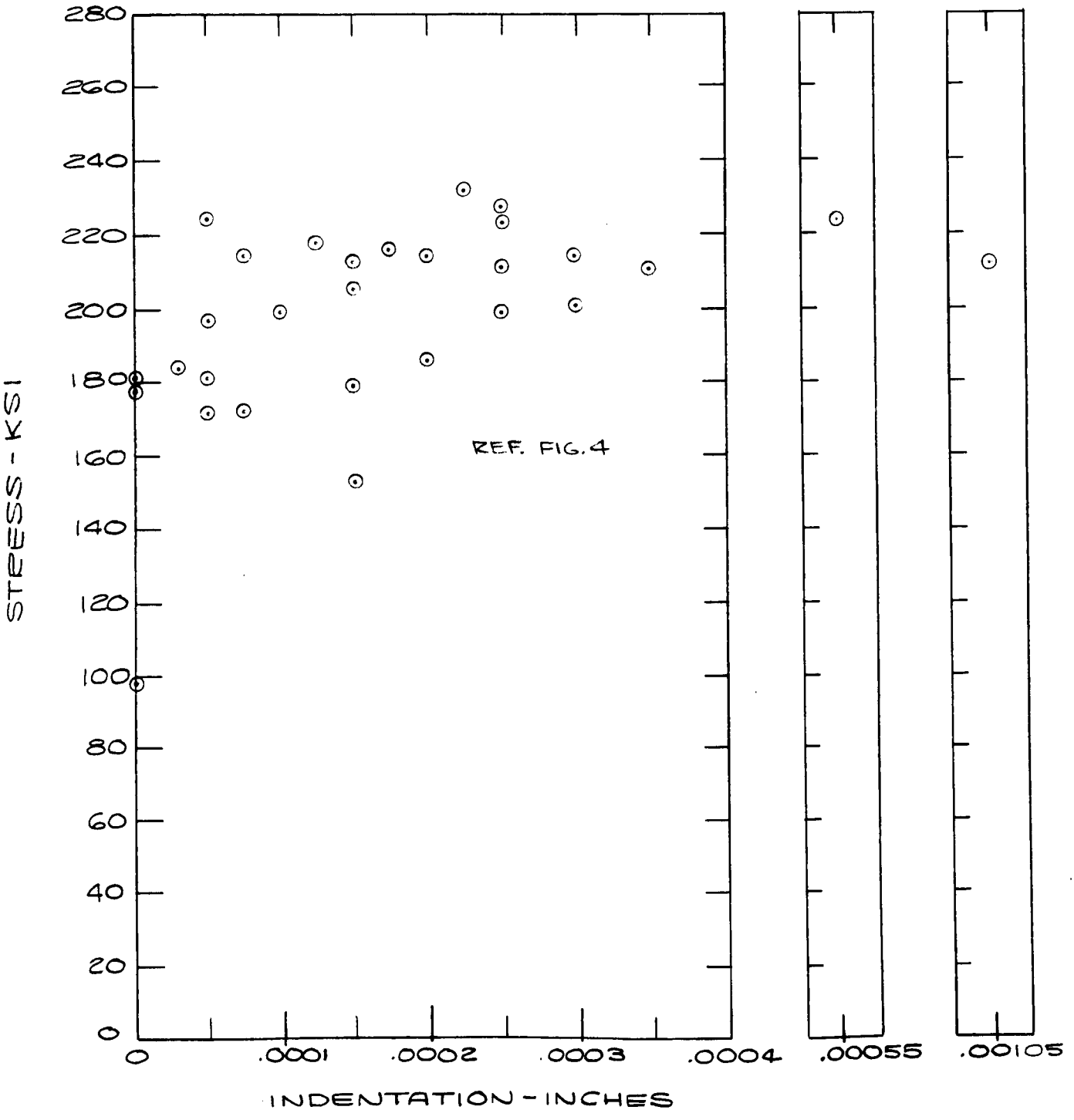
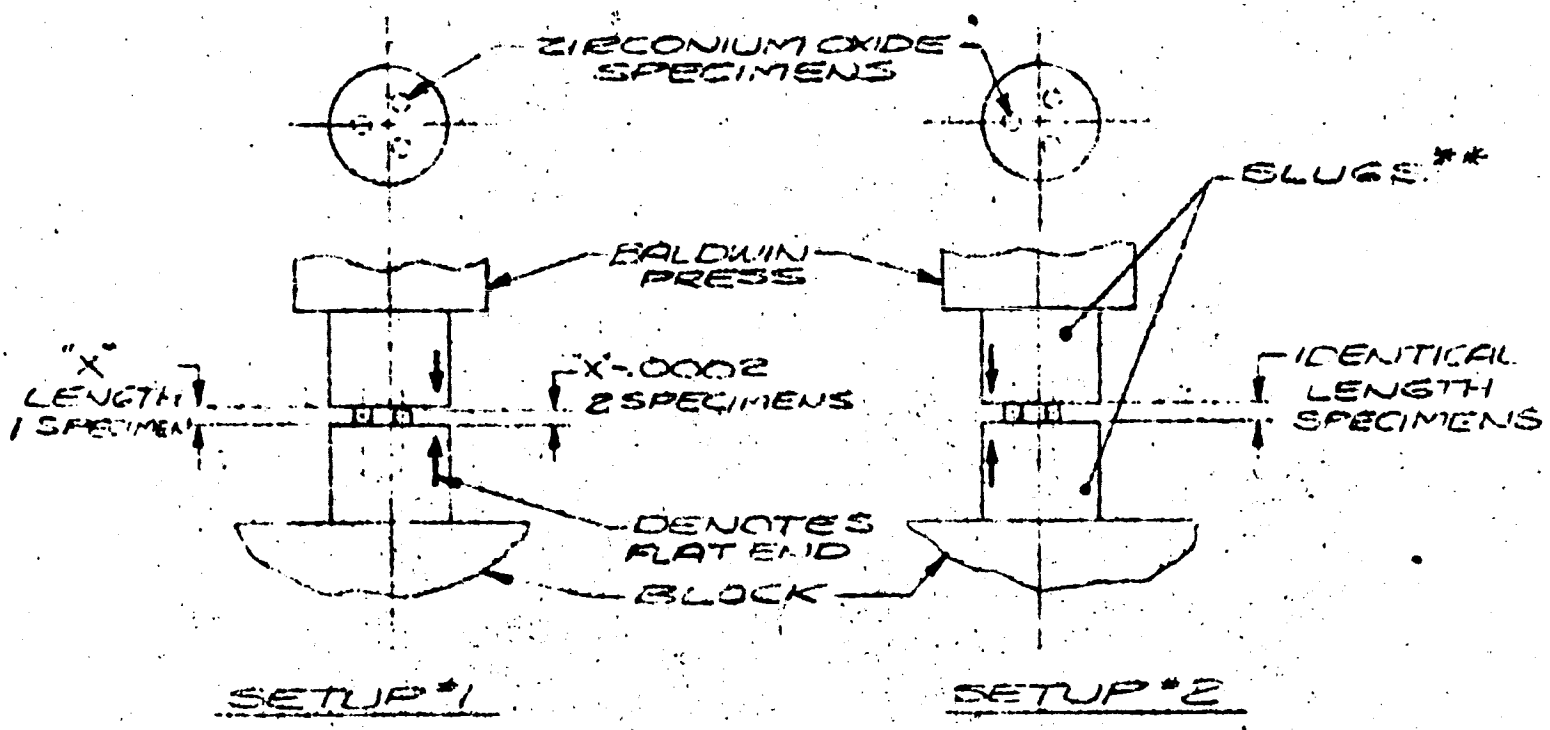


FIGURE 5

TEST SETUP

COMPRESSION TEST- ZIRCOA "C" VS. CANDIDATE METALS



** MAT'L
1. L-605
2. RENE 41
3. GAL-4VT

TEST PROCEDURE

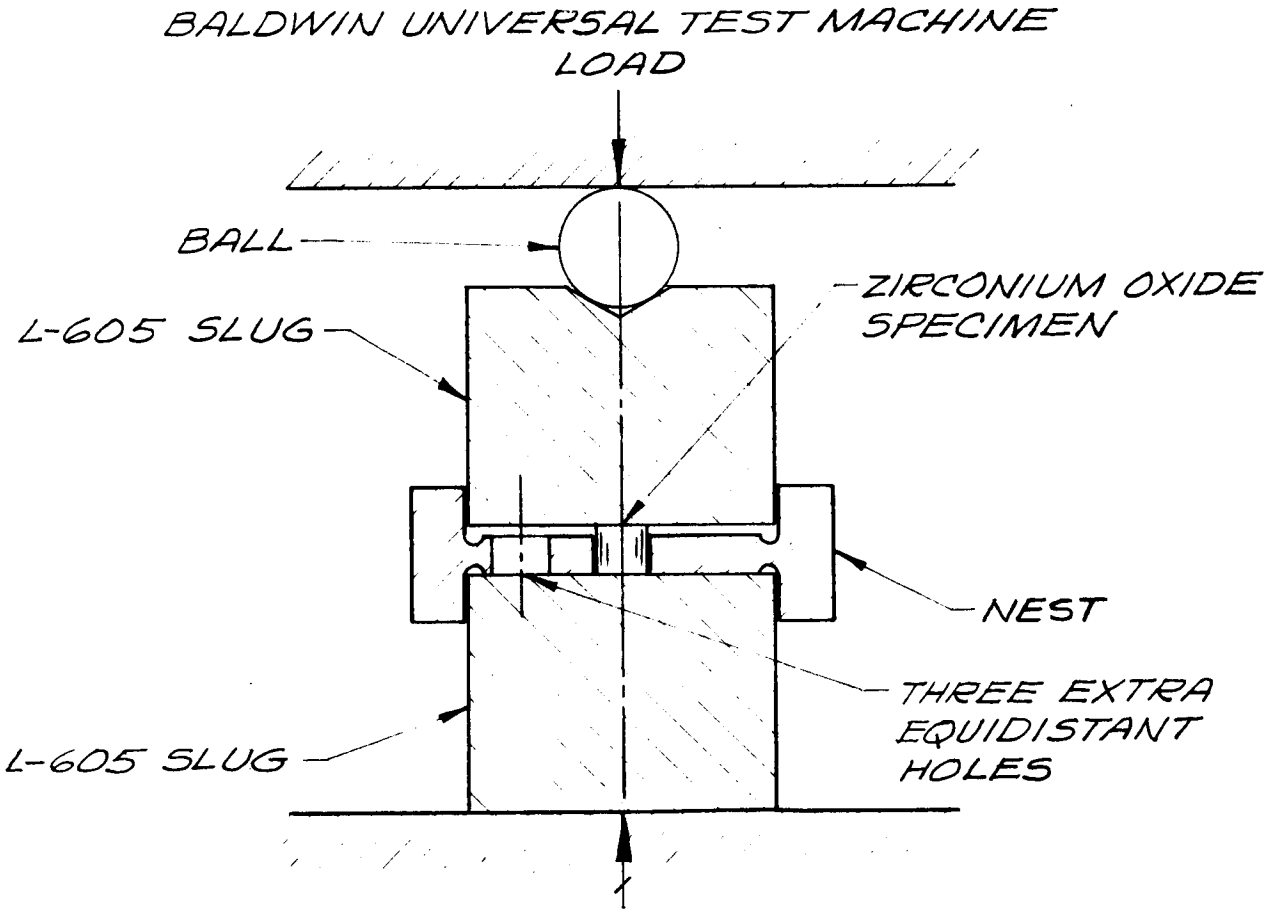
1. USING L-605 SLUGS IN SETUP #1 APPLY LOADS PER TABLE I. INSPECT PARTS BETWEEN LOAD STEPS.
2. REPEAT STEP 1 WITH SLUGS OF RENE 41, GAL-4VT & NEW ZIRCONIUM OXIDE SPECIMENS.
3. USING TEST SETUP #2, USE PROCEDURE PER STEPS 1 & 2.

TABLE I

LOAD STEPS	1	2	3	4	5	6	7	8	9	10
LOAD (LBS)	200	300	400	600	800	1000	1200	1400	1600	1800

FIGURE 6

TEST SETUP
COMPRESSION TEST - ZIRCOA "C" VS. CANDIDATE METALS



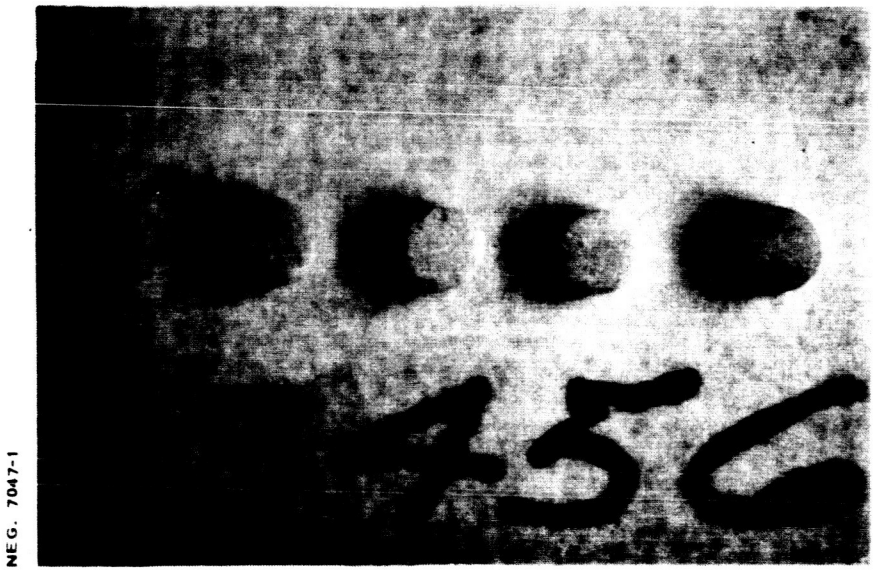
5/1 SCALE

FIGURE 7

ZIRCOA 'C' (ZIRCONIUM OXIDE) COMPRESSION TEST SPECIMENS

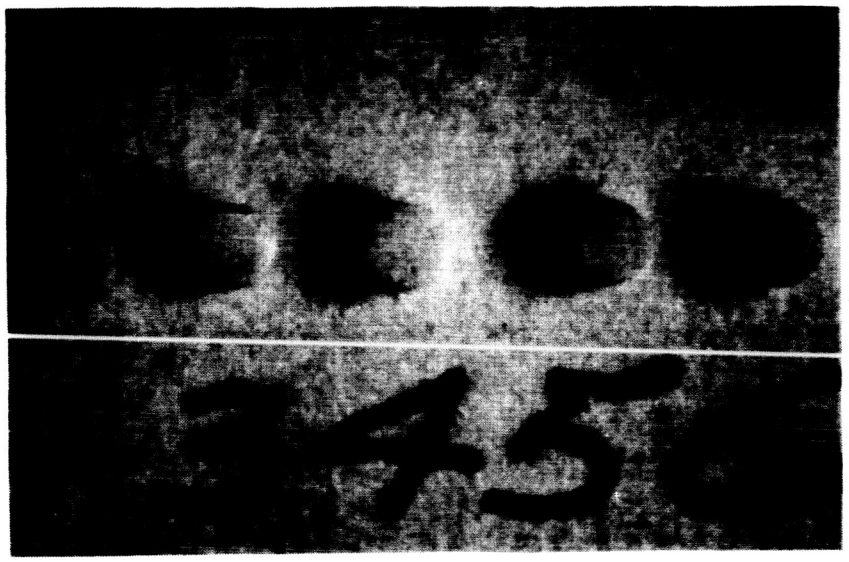
.053/.054 DIA. X .050/.051 IN. LONG AFTER TEST

SCALE 9/1



NEG. 7047-1

SIDE 1

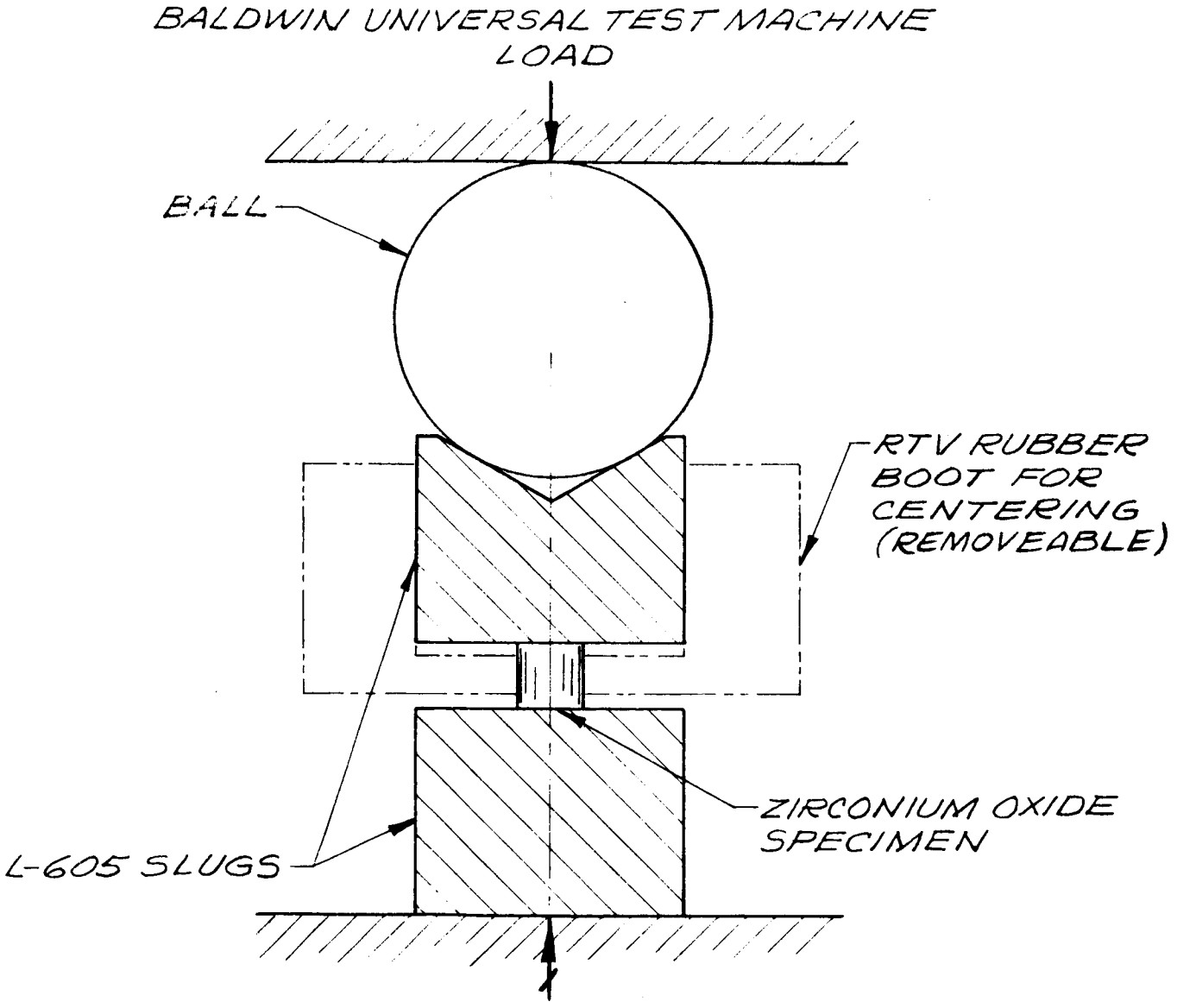


NEG. 7047-2

OPPOSITE SIDE

FIGURE 8

COMPRESSION TEST - ZIRCOA "C", .080 & .250 IN. DIA. SPECIMENS



5/1 SCALE

FIGURE 9

TEST RESULTS

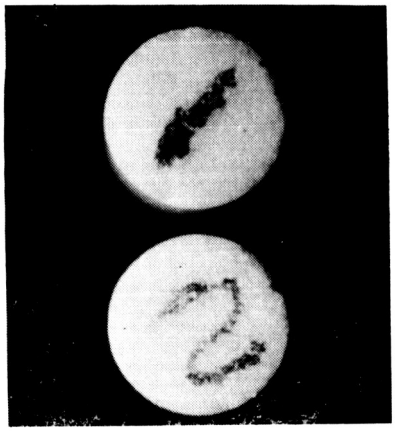
ZIRCOA "C", 0.080 IN. DIA. & 0.250 IN. DIA. SPECIMENS

Specimen P/N & Ident.	Applied Load-lbs	Demonstrated Equiv. Compressive Stress - psi x 10^3	Remarks
T-13627 #1	285/290	57	Load applied at 2 lbs/sec, specimen started to powder at 285/290 lbs with simultaneous load rate decrease ($\leq$ 2 lbs/sec) - stopped loading.
T-13627 #2	165	33	Load applied at 2 lbs/sec, specimen started to powder at 165 lbs.- stopped loading - faces of slugs did not appear to be parallel during loading.
T-13626 #1	4,665	95.2	Load applied at 5 lbs/sec, specimen started to powder at 4,665 lbs load - stopped loading - specimen was removed - one side was crumbled.
T-13626 #2	3,365	68.67	Used 2 layers 0.001 thick silverfoil on each end of specimen. Load applied at 3 lbs/sec, erratic load rate at 1,220 lbs (dropped to 150 lbs). Load increased to 3,000 lbs, cracks appeared slowly - load rate nil - many cracks at 3,300 lbs - stopped load at 3,365 lbs.

FIGURE 10

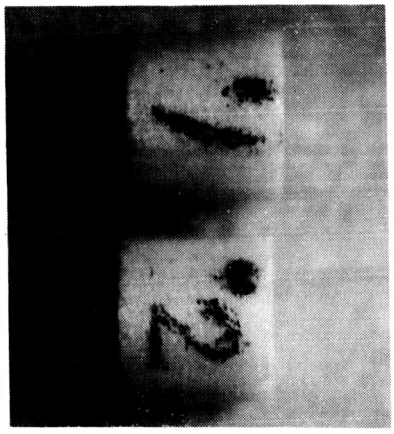
COMPRESSION TEST OF ZIRCOA "C" CYLINDERS
.080 DIAMETER × .080 HIGH

END NO. 2



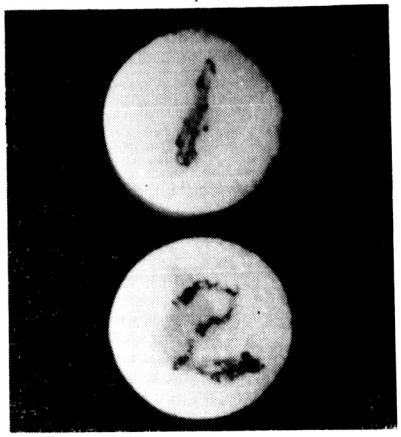
NEG. 7093-18

SIDE



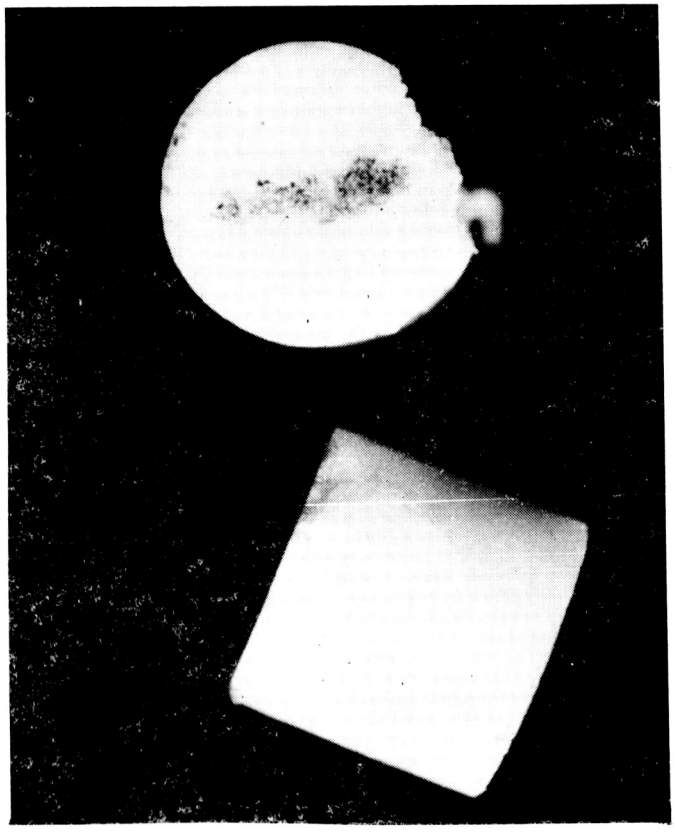
NEG. 7093-19

END NO. 1



NEG. 7093-20

T13627 CYLINDERS, NO'S. 1 & 2, BEFORE TEST
SCALE APPROX. 10/1



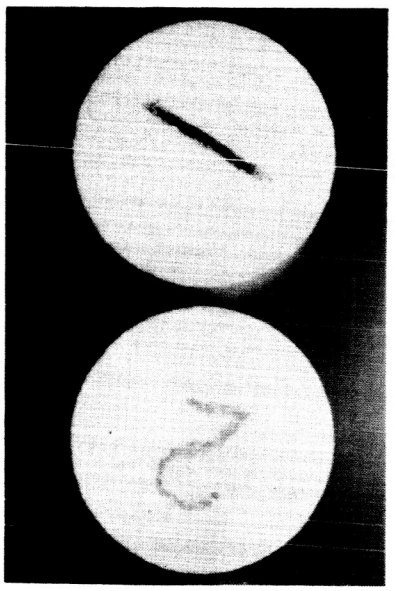
NEG. 7093-21

T13627 CYLINDERS, NO'S. 1 & 2, AFTER TEST
SCALE APPROX. 20/1

FIGURE 11

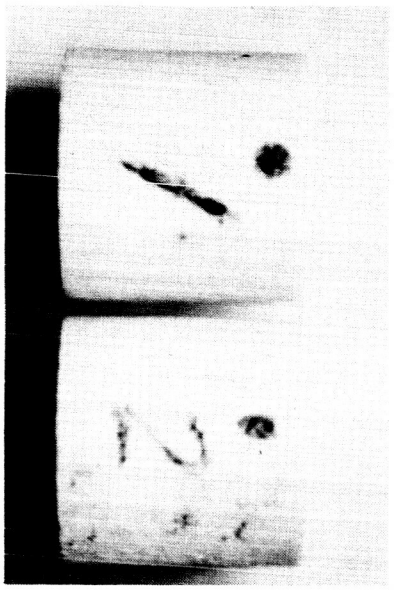
COMPRESSION TEST OF ZIRCOA "C" CYLINDERS
.250 DIAMETER × .250 HIGH

END NO. 2



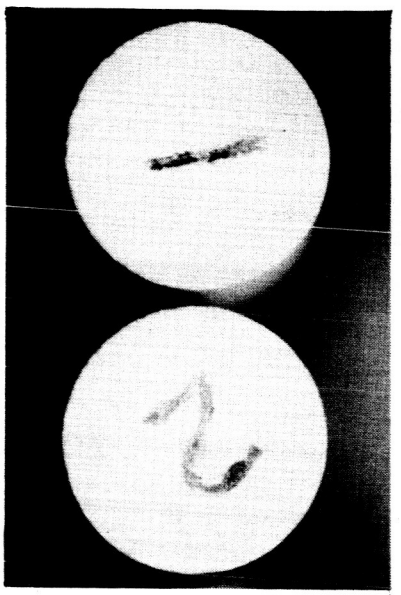
NEG. 7093-22

SIDE



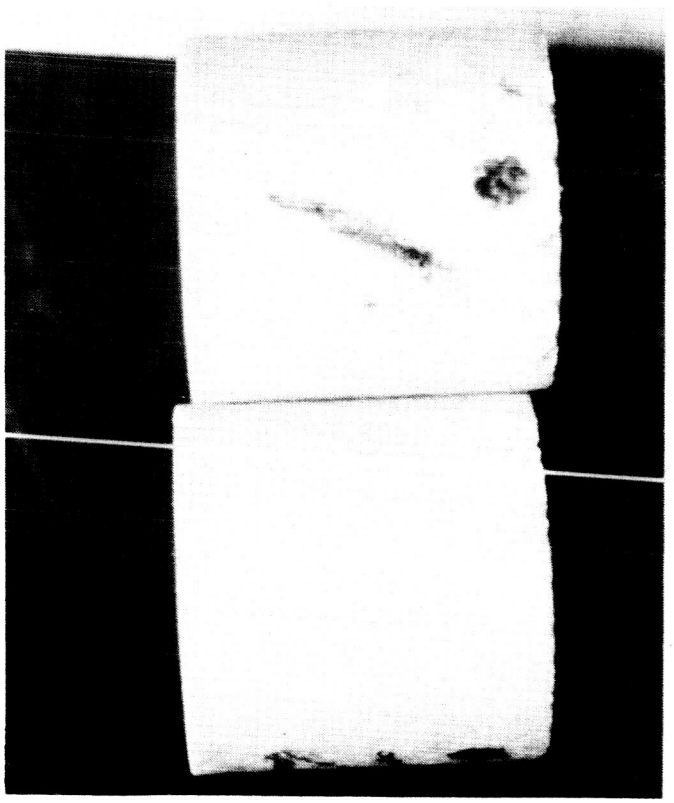
NEG. 7093-23

END NO. 1



NEG. 7093-24

T13626 CYLINDERS, NO'S. 1 & 2, BEFORE TEST
SCALE APPROX. 5/1

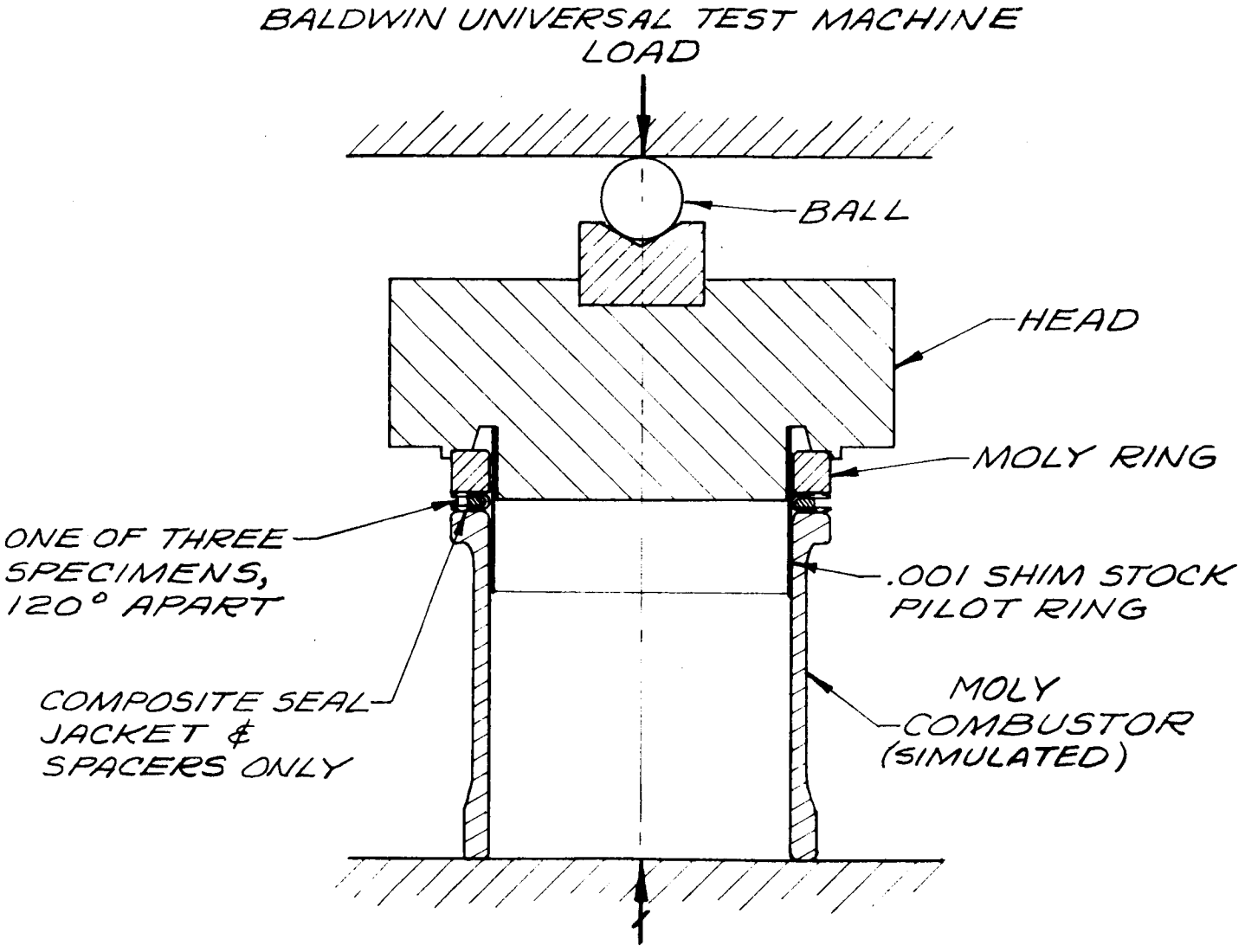


NEG. 7093-25

T13626 CYLINDERS, NO'S. 1 & 2, AFTER TEST
SCALE 8/1

FIGURE 12

COMPRESSION TEST- ZIRCOA "C", TRIPLET SPECIMENS



FULL SCALE

FIGURE 13

ZIRCONIUM OXIDE COMPRESSION TEST RESULTS

.053/.054 DIAMETER X .050/.051 IN. LONG TRIPLET SPECIMENS

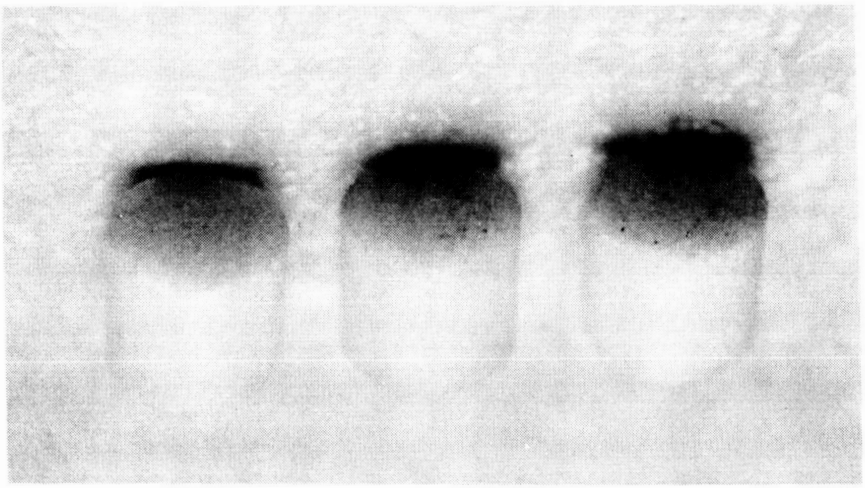
Material	Triplet Set No.	Applied Load-Lbs. ($\frac{P\ total}{3} = P_{cyl}$)	Demonstrated Equiv. Compressive Stress - psi x 10^3	Required Ult. Comp. Strength -psi x 10^3
Zircoa "C" (Full Dense)	1	260*	130	
	2	296*	148	
	3	270*	135	
Zircoa #1027 (Modified)	1	220*	110	
	2	223*	111.5	112.95**
	3	230*	115	
Zircoa "C" (Modified)	1	195*	97.5	
	2	167*	83.5	
	3	175*	87.5	

* Failure load applied at 0.5 - 1 lb/sec.

** Maximum Apollo launch boost limit σ x M.S. (1.5) = Maximum Ult. σ = (75.3 x 1.5) x 10^3 for individual cylinder.

FIGURE 14

COMPRESSION TEST OF T13617 ZIRCOA "C" CYLINDERS .053 DIAMETER × .050 HIGH



NEG. 7093-12

TRIPLET SET NO. 1 BEFORE TEST
SCALE APPROX. 18/1



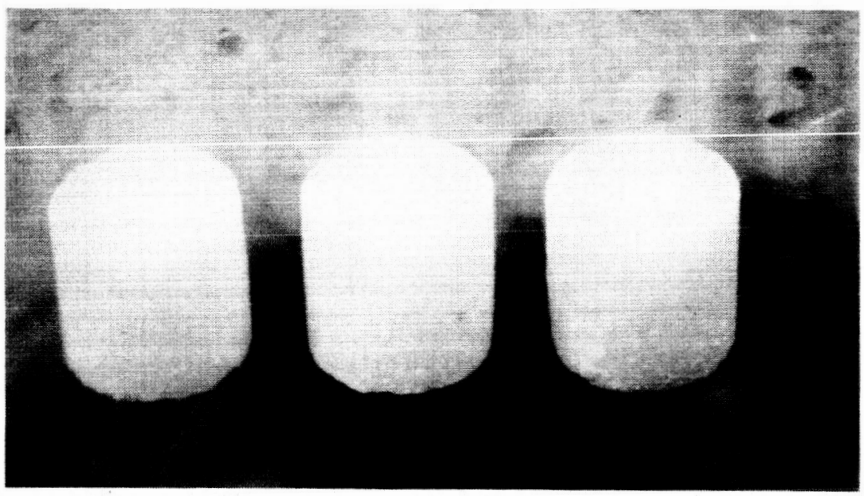
NEG. 7093-13

0° 120° 240°

TRIPLET SET NO. 1 AFTER TEST
SCALE APPROX. 20/1

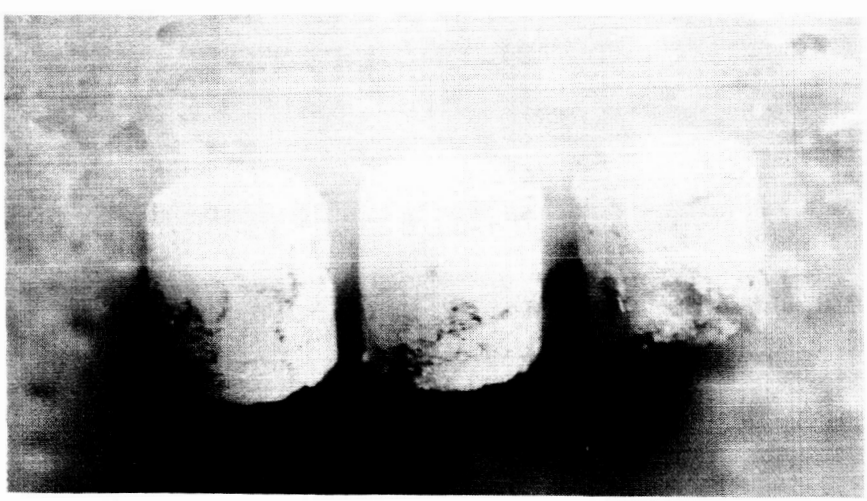
FIGURE 15

COMPRESSION TEST OF T13617 ZIRCOA "C" CYLINDERS .053 DIAMETER × .050 HIGH



NEG. 7093-14

TRIPLET SET NO. 2 BEFORE TEST
SCALE APPROX. 20/1



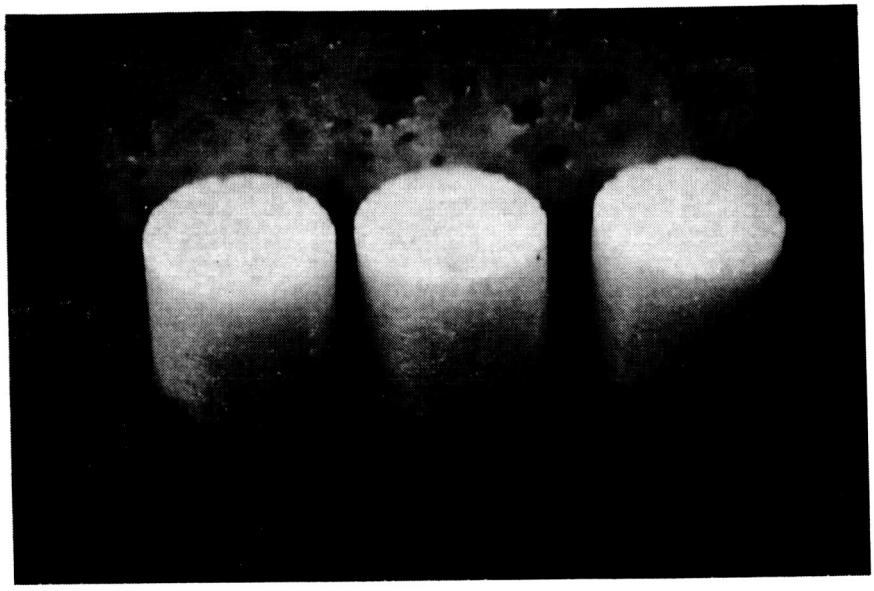
NEG. 7093-15

6° 126° 246°

TRIPLET SET NO. 2 AFTER TEST
SCALE APPROX. 19/1

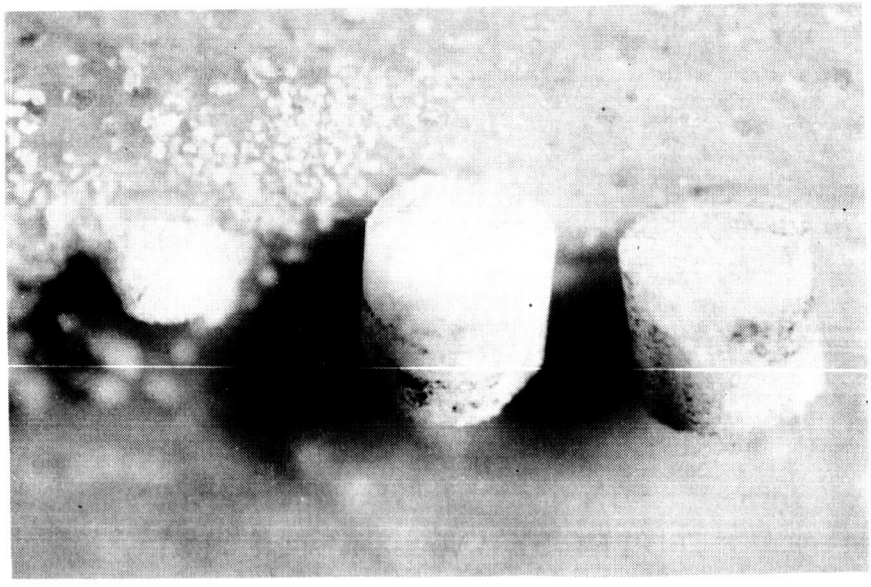
FIGURE 16

COMPRESSION TEST OF T13617 ZIRCOA "C" CYLINDERS .053 DIAMETER × .050 HIGH



NEG. 7093-16

TRIPLET SET NO. 3 BEFORE TEST
SCALE APPROX. 20/1



NEG. 7093-17

354° 114° 236°

TRIPLET SET NO. 3 AFTER TEST
SCALE APPROX. 20/1

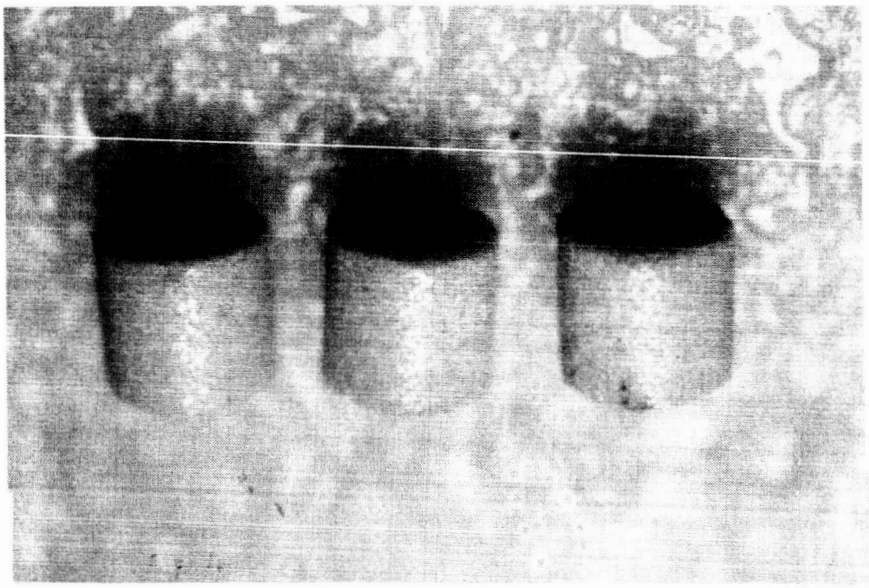
FIGURE 26

COMPRESSION TEST OF T-13899 CYLINDERS

ZIRCOA "C" (MODIFIED), 0.053 DIAMETER X 0.050 HIGH

TRIPLET SET NO. 1

SCALE APPROX. 17/1



NEG. 8065-1

BEFORE TEST



NEG. 8065-2

AFTER TEST

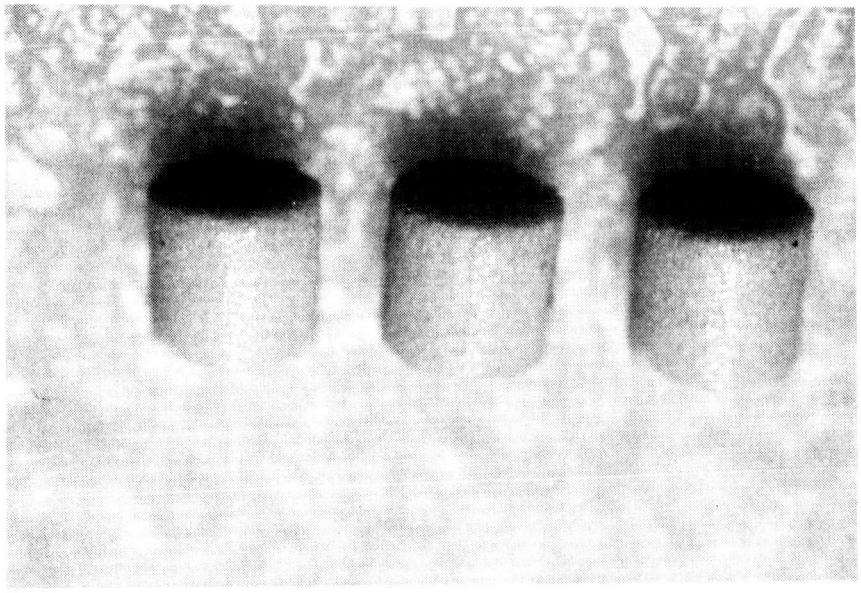
FIGURE 18

COMPRESSION TEST OF T-13899 CYLINDERS

ZIRCOA "C" (MODIFIED), 0.053 DIAMETER X 0.050 HIGH

TRIPLET SET NO. 2

SCALE APPROX. 17/1



NEG. 8065-7

BEFORE TEST



NEG. 8065-8

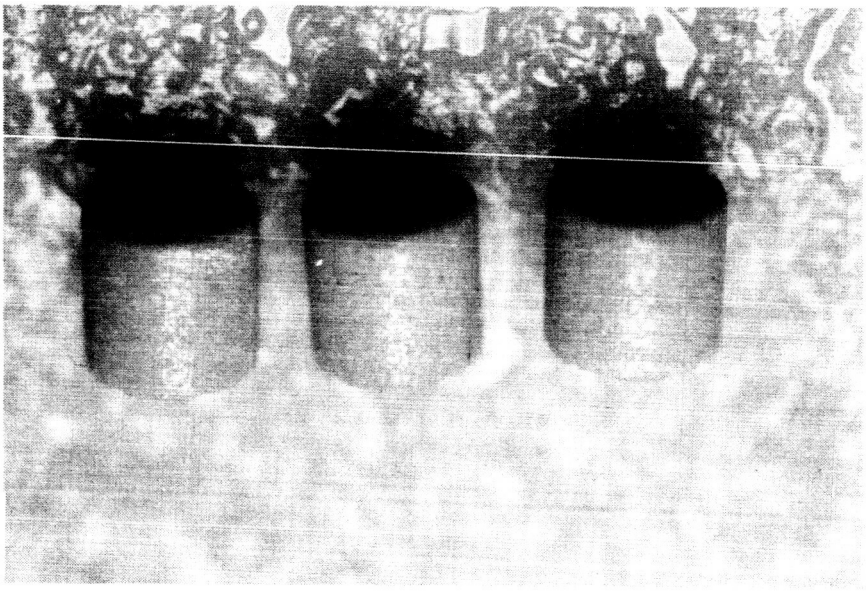
AFTER TEST

FIGURE 19

COMPRESSION TEST OF T-13899 CYLINDERS

ZIRCOA "C" (MODIFIED), 0.053 DIAMETER X 0.050 HIGH

TRIPLET SET NO. 3
SCALE APPROX. 17/1



NEG. 8065-11

BEFORE TEST



NEG. 8065-12

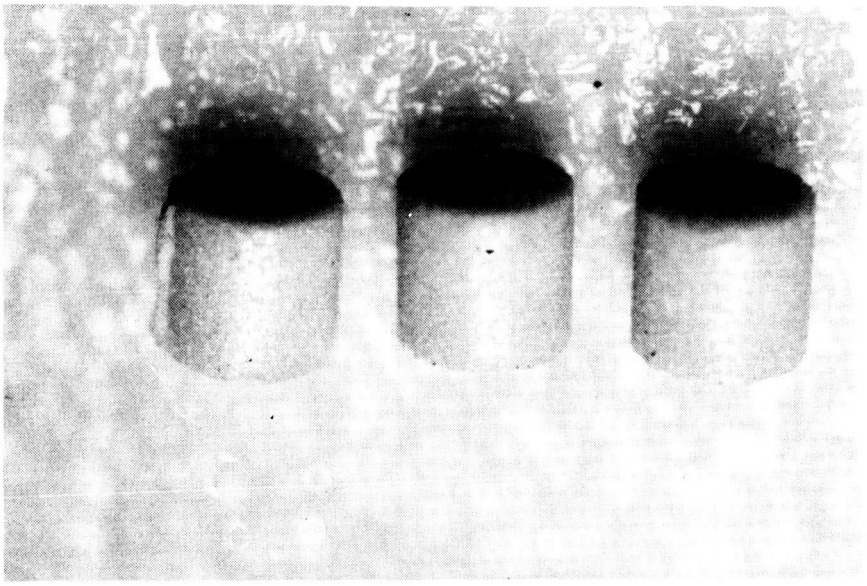
AFTER TEST

FIGURE 20

COMPRESSION TEST OF T-13900 CYLINDERS

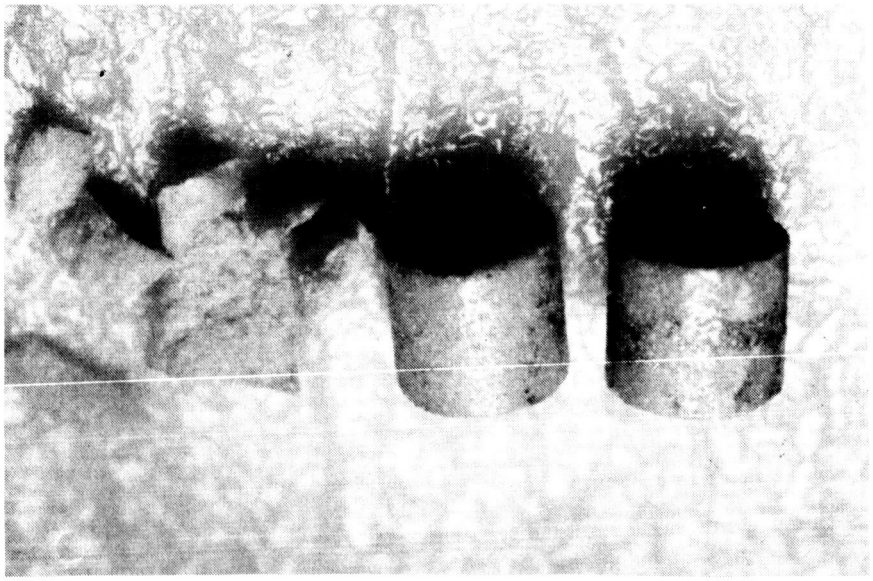
ZIRCOA NO. 1027 (MODIFIED), 0.053 DIAMETER X 0.050 HIGH

TRIPLET SET NO. 1
SCALE APPROX. 17/1



NEG. 8065-3

* BEFORE TEST



NEG. 8065-4

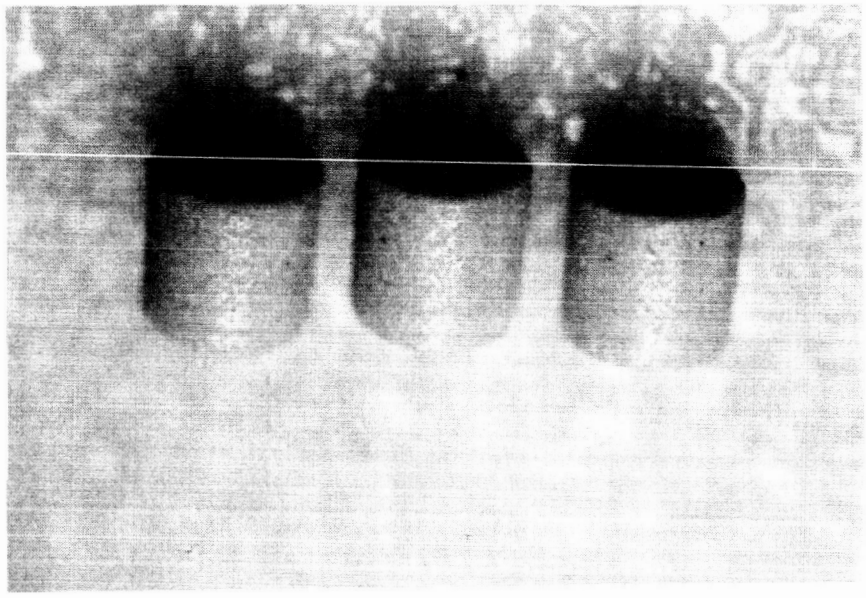
AFTER TEST

FIGURE 21

COMPRESSION TEST OF T-13900 CYLINDERS

ZIRCOA NO. 1027 (MODIFIED), 0.053 DIAMETER X 0.050 HIGH

TRIPLET SET NO. 2
SCALE APPROX. 17/1



NEG. 8065-5

BEFORE TEST



NEG. 8065-6

AFTER TEST

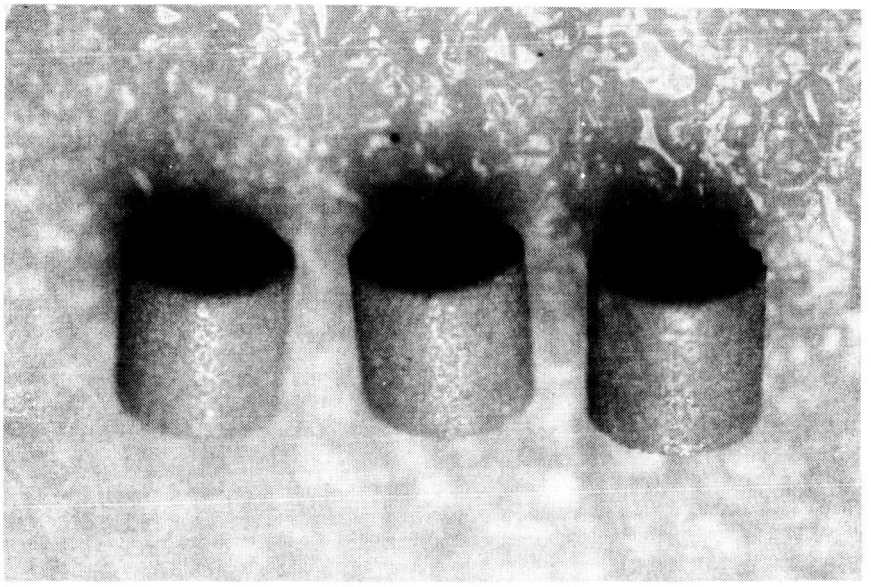
FIGURE 22

COMPRESSION TEST OF T-13900 CYLINDERS

ZIRCOA NO. 1027 (MODIFIED), 0.053 DIAMETER X 0.050 HIGH

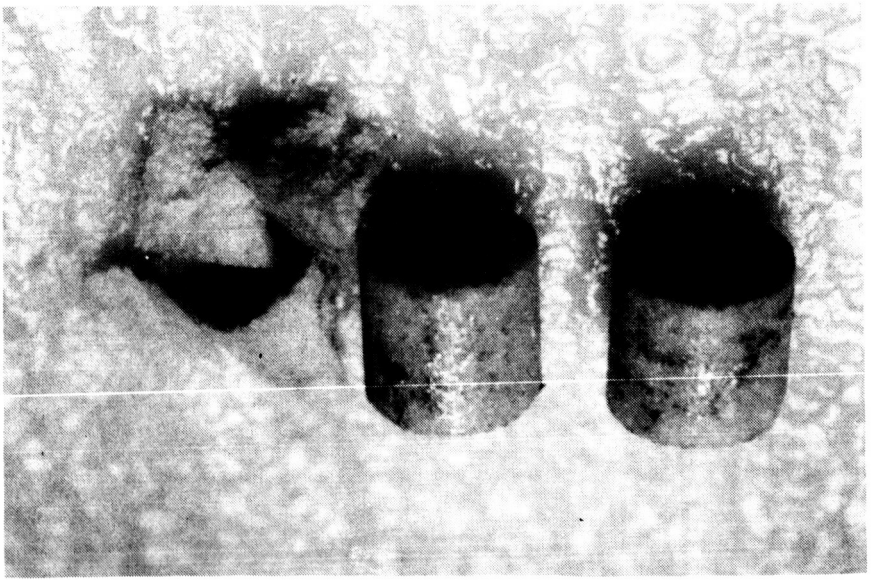
TRIPLET SET NO. 3

SCALE APPROX. 17/1



NEG. 8065-9

BEFORE TEST

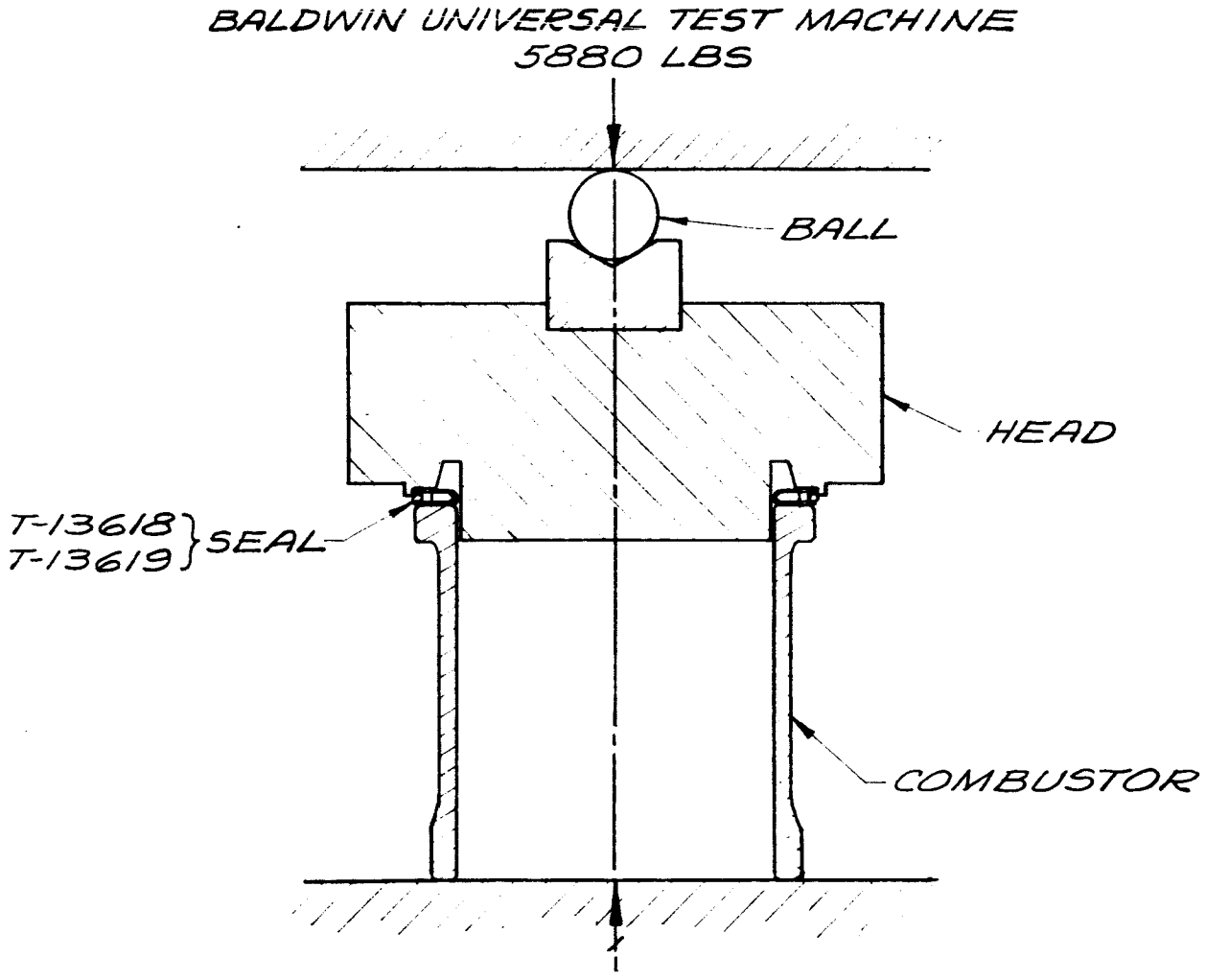


NEG. 8065-10

AFTER TEST

FIGURE 23

LOAD TEST-FULL SCALE COMPOSITE SEALS



FULL SCALE

FIGURE 14

ATTACHMENT 7

THE Marquardt CORPORATION VAN NUYS, CALIFORNIA

TEST REPORT

THERMAL RESISTANCE MEASUREMENT OF FULL SCALE SEALS

FOR

APOLLO SERVICE MODULE

REACTION CONTROL SYSTEM ENGINE

CHAMBER SEAL STUDY

PREPARED UNDER CONTRACT NAS 9-4775

TMC 3008

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J. Puntar
Principal Investigator
Design Engineering

Approved By E. P. Perlman
E. P. Perlman
Program Manager

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SECTION	TITLE	PAGE
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II	CONCLUSIONS AND RECOMMENDATIONS	1
III	SUMMARY	1-2
IV	TEST PROCEDURE	3
V	SEAL RESISTANCE CALCULATION PROCEDURE	4
VI	DISCUSSION OF TEST RESULTS	5

APPENDIX A

FIGURE 1 - PHOTOGRAPH OF TEST RIG

2 - TEST HISTORY

3 - SEAL SPECIMEN DESCRIPTION

4 - DETAILED SUMMARY OF THERMAL RESISTANCE TEST RESULTS

5 - PHOTOGRAPH OF FACILITY

APPENDIX B

TEST DATA SUMMARY SHEETS

I INTRODUCTION

The thermal resistance of six seal configurations was measured in the Marquardt cold soak facility. The seals tested were made of 6AL-4V Titanium or Rene' 41 and the configurations were as follows:

a. Conical Thinwall
b. Straight Thinwall
c. Composite - With Zirconium Oxide Spacers

II CONCLUSIONS AND RECOMMENDATIONS

Both conical thinwall seals demonstrate thermal resistances higher than 5.0 HR-^{o}F/BTU required to satisfy the program objectives. The composite seals require a design change to obtain a thermal resistance $\geq$ 5.0 $\frac{\text{HR-}^{o}\text{F}}{\text{BTU}}$. The length/area ratio of the Zirconia cylinders must be approximately doubled. A material with lower thermal conductivity could be substituted if structural criteria could be met.

A problem area associated with high thermal resistance seals was identified. The high thermal expansion coefficient of the aluminum head can cause a thermal short to the chamber at high head temperatures if the chamber is not centered during assembly. The present Apollo assembly procedure does not have a positive center line alignment of the chamber to the injector head. This problem should be eliminated by an assembly procedure change when the high resistance seal is incorporated into the design.

This method of testing has been proven satisfactory for measurement of the thermal resistance of chamber seals. The analytical approach has been verified and can be used for seal design evaluation with a high degree of confidence. The thermal properties of non-standard materials should be verified by test data in future programs during the preliminary design phase before substantial design and development effort has been expended.

III SUMMARY

The composite seal, as designed, does not have a thermal resistance of 5.0 HR-^{o}F/BTU. The actual seal resistance was about 50% lower than theoretical due to a materials property survey error. The measured thermal conductivity of Zirconia was 1.2 BTU/HR-^{o}F-Ft instead of the design value of 0.54 BTU/HR-^{o}F-Ft.

Test results for the thinwall seals showed excellent agreement with theoretical predicted values. The following Table I is a summary of all test results.

TABLE I

SEAL THERMAL RESISTANCE TEST RESULTS

Seal Configuration	P/N	Material	Thermal Resistance			
			Predicted (Neglects Contact Resistance)		Demonstrated	
			Minimum	Maximum	Seal	Joint*
			$\frac{Hr-^{o}F}{BTU}$	$\frac{Hr-^{o}F}{BTU}$	$\frac{Hr-^{o}F}{BTU}$	$\frac{Hr-^{o}F}{BTU}$
Conical Thinwall	T-13622	Titanium	5.3	6.2	6.6	5.7
	T-13621	Rene' 41	3.7	4.3	5.2	4.6
Straight Thinwall	T-13611	Titanium	1.8	2.2	2.1	2.0
	T-13612	Rene' 41	1.2	1.5	1.3	1.2
Composite	T-13618	Titanium	4.7	5.3	3.0	2.8
	T-13619	Rene' 41	3.8	4.3	2.8	2.6
Zirconia Cylinder	T-13617	Zirconia	8.1	8.3	3.5	3.2

*Overall thermal resistance of head/seal chamber

IV TEST PROCEDURE

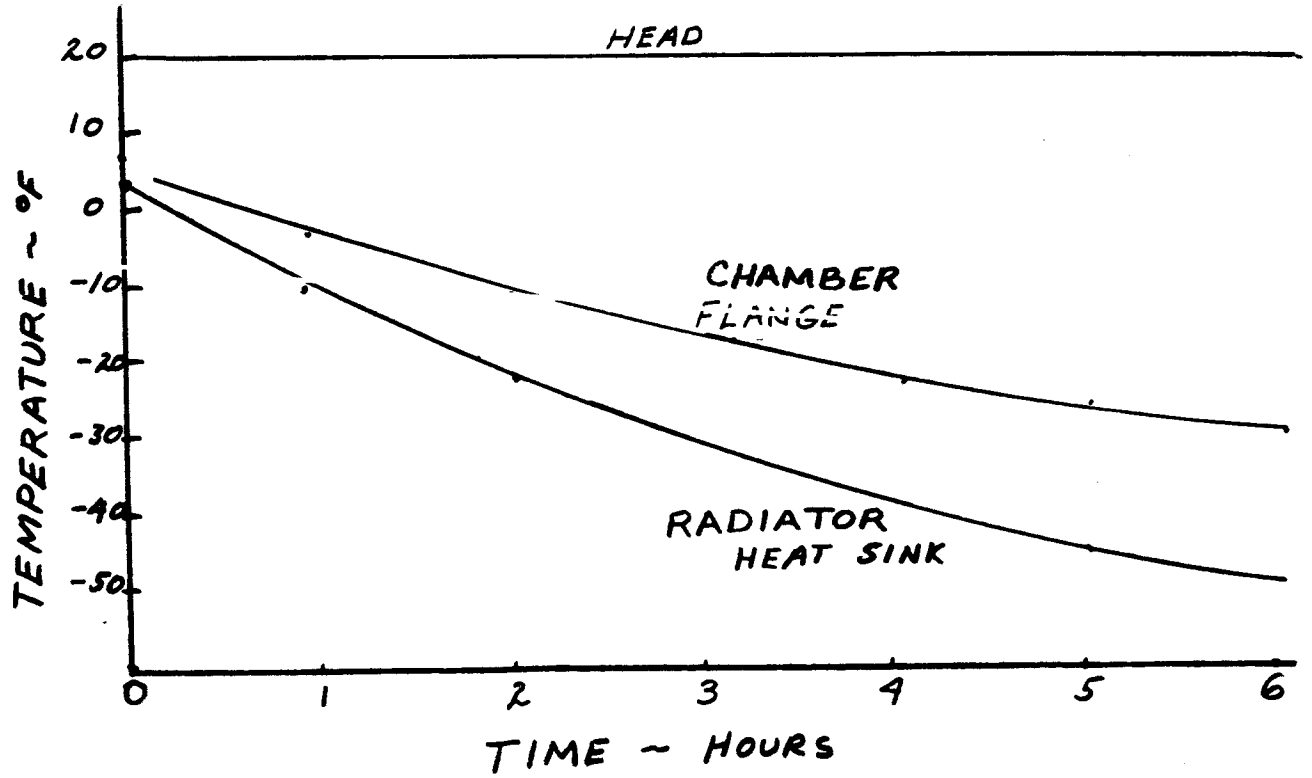
Each seal was assembled into the thermal test rig and tested in the cold soak test facility. Figure 1 is a photograph of assembled test hardware. A chronological test history is shown in Appendix A, Figure 2. The seal configurations tested are shown in Figure 3. Figure 4 is a detail summary of the measured thermal resistances. A photograph of the facility is shown in Figure 5, Appendix A.

Thermal resistance was measured using the general procedures outlined in MTP 0041, Appendix B which contains a schematic of the test setup, the instrumentation, and the detailed test procedure used.

A modification of the test procedure was made because the large heat capacity of the thermal radiator and the low rate of radiation heat transfer required excessive test time to reach complete thermal equilibrium. The low heat capacity of the simulated injector head allowed the test head to reach steady state temperatures at a constant heat input while the radiator did not change temperature significantly. Therefore, measurements were made prior to reaching complete thermal equilibrium of the radiator. Several measurements of the heat flow and the resulting temperature difference were taken and used to calculate the joint thermal resistance.

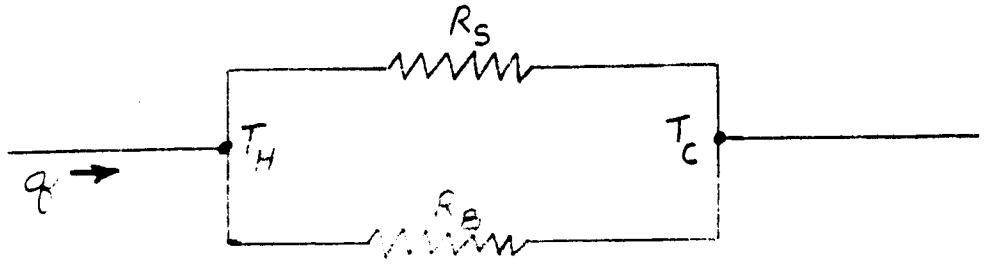
A typical time-temperature history of a test item during a data period is shown below:

TEST ITEM - TIME HISTORY



V SEAL RESISTANCE CALCULATION PROCEDURE

The heat paths across the head-seal-chamber joint are shown below:



where;

R_J = Total Joint Thermal Resistance

R_B = Attach Hardware Thermal Resistance $\frac{HR-^oF}{BTU}$

R_S = Seal Thermal Resistance $\frac{HR-^oF}{BTU}$

T_H = Temperature of Simulated Head

T_C = Chamber Flange Temperature

q = Heat Flow Rate - $\frac{BTU}{HR}$

The joint overall thermal resistance (R_J) was calculated by dividing the temperature difference (T_H - T_C) between the injector head and the chamber flange by the heat flow rate (q), $R_J = \frac{T_H - T_C}{q} \frac{^oF}{(BTU/Hr)}$. The joint resistance is equal to

$$R_{joint} = \frac{R_S \; R_B}{R_S + R_B}$$

and therefore

$$R_S = \frac{R_B \; R_J}{(R_B - R_J)}$$

Seal resistance was calculated from $R = \frac{R_B \ R_J}{(R_B - R_J)}$ where bolt thermal resistance (R_B) was calculated to be 42.3 $\frac{HR-^\circ F}{BTU}$ from the nominal dimensions of the attach hardware. Heat losses by convection were negligible at high vacuum, $< 10^{-5}$ mm Hg. Radiation heat losses from the simulated injector to the guard boundary were made $\approx$ zero by heating the boundary to the same temperature as the simulated injector head.

Several heat flow rates were measured and the joint thermal resistance averaged to calculate the seal thermal resistance. Appendix B contains a summary of the data used to calculate joint resistance for seal resistance tests 1 through 4.

VI DISCUSSION OF TEST RESULTS

Thermal resistance testing of the thinwall seals was very successful. Measured results were close to the predicted thermal resistances. Test thermal resistance values were repeatable within 15% from high temperature to low temperature and within 10% or less during the run.

Conical seal thermal resistances were slightly higher than the predicted maximum indicating the analysis to be conservative. This agreement is excellent considering contact resistance was neglected in the analysis and conservative simplifying assumptions were made with the complicated shaped areas.

Thermal shorting between injector head and chamber occurred during high temperature testing of titanium straight thinwall seal. Additional tests were made to verify the temperature dependency of the thermal short. Cause of the short was determined to be off center assembly of the chamber to the test item. The high thermal expansion coefficient of the aluminum head caused the register diameter of the injector to contact the chamber inside diameter. This lowered the joint thermal resistance to 0.75 $\frac{HR-^\circ F}{BTU}$.

Present Apollo assembly procedures have no centering requirement of chamber with injector. A change in engine chamber-injector assembly procedure will be required when any high resistance seal is incorporated into the engine.

COMPOSITE SEAL

The thermal resistances of the composite seals were about 50% less than the calculated minimum. Analysis indicated the most probable cause to be low thermal resistance through the Zirconia cylinders. An additional test (#4), was run to verify this conclusion. Only the Zirconia

cylinders from the Titanium composite seal were assembled into the test item to isolate that heat path. The measured thermal resistance was 3.5 HR-^{o}F/BTU.

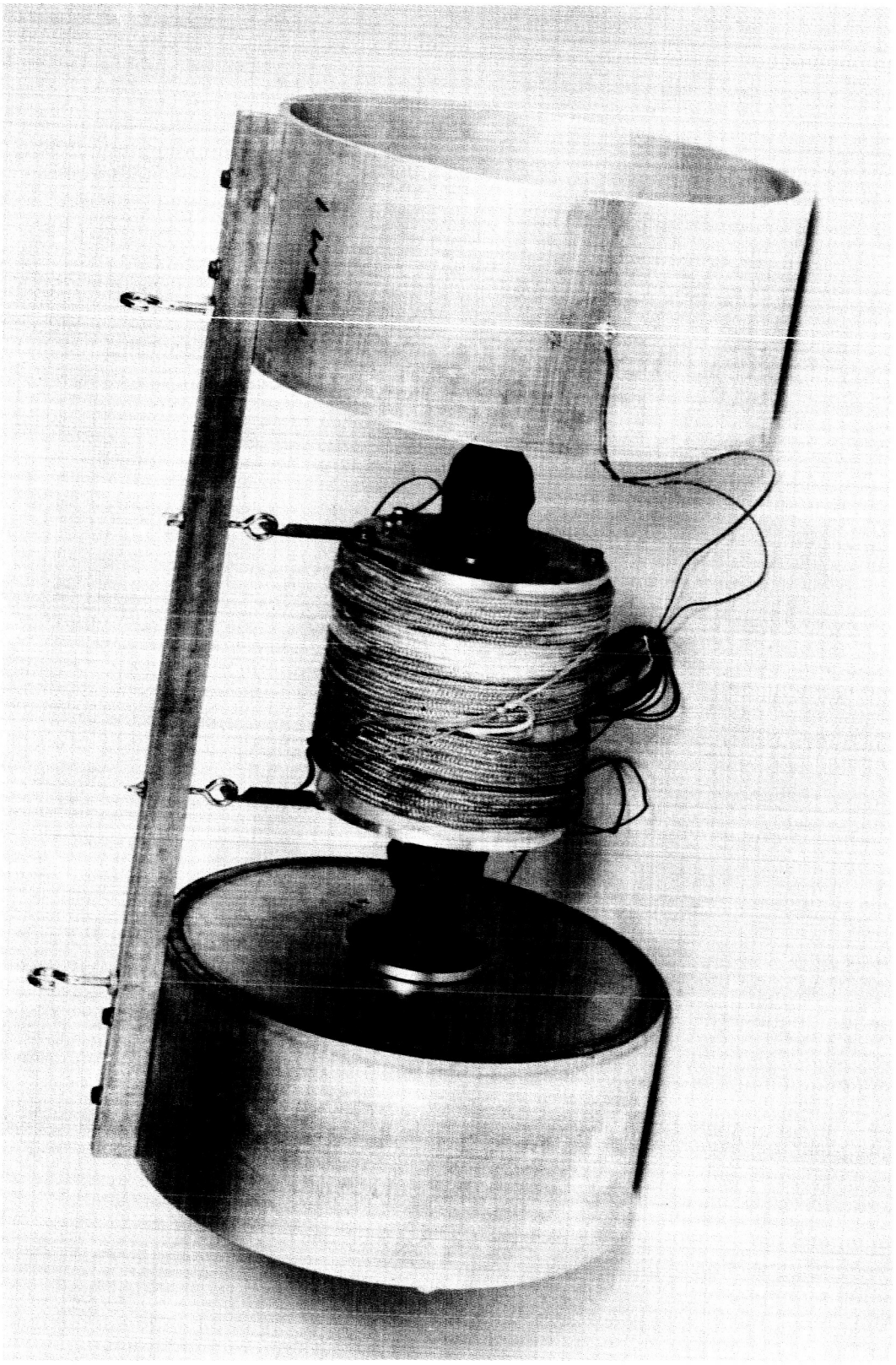
The theoretical resistance of the cylinders is 8.0 HR-^{o}F/BTU. Dimensions of the cylinders were identical to those used in the analysis, therefore, thermal conductivity of the Zirconia was $\approx$ 1.2 BTU/HR-^{o}F-Ft rather than 0.54 BTU/HR-^{o}F-Ft which was used as design criteria.

The composite seal design requires a Zirconia segment thermal resistance of $\geq$ 8.0 HR-^{o}F/BTU to achieve an overall minimum resistance of $\geq$ 5.0 HR-^{o}F/BTU. Therefore, the ratio of length to heat transfer area of the Zirconia cylinders must be $\approx$ doubled or a lower conductivity material substituted to satisfy the program objectives.

A P P E N D I X A

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FIGURE 1	PHOTOGRAPH OF ASSEMBLED TEST RIG
FIGURE 2	TEST HISTORY
FIGURE 3	SEAL SPECIMEN DESCRIPTION
FIGURE 4	SUMMARY OF THERMAL RESISTANCE TEST RESULTS
FIGURE 5	PHOTOGRAPH OF COLD SOAK FACILITY



TEST 11267 SEAL THERMAL RESISTANCE TEST HARDWARE (U)
BLDG. 32
11 JAN 66

NEG. T11267-3

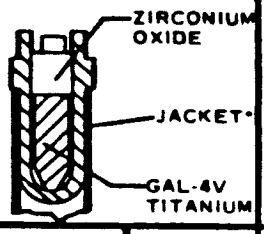
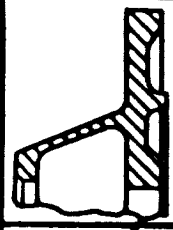
FIGURE 1

The following table summarizes the thermal testing:

FIGURE 2

TEST HISTORY

THERMAL RESISTANCE TEST #	RUN #	HEAD TEMPERATURE °F	PURPOSE
Test #1 - Dec. 18-21, 1965			
Titanium Seals	1	20	Measure thermal resistance (R_S) @ 0°F
Item 1 - T-13622	2	130	Increase heat flow across seal for greater accuracy
Item 2 - T-13611	3	20	Verify Run 1
	4	130	Verify Run 2
	5	60	Verify thermal short dependency on assembly temperature
Test #2 - Dec. 30, 1965			
Rene' 41 Conical T-13621	1	20	Measure R_S at 0°F
Rene' 41 Thinwall T-13612	2	160	Increase heat flow across seal for greater accuracy
Test #3 - Jan. 13-14, 1966			
Composite Seals	1	20	Measure R_S at 0°F
Titanium T-13618 Rene' 41 T-13619	2	160	Increase heat flow across seal for greater accuracy
Test #4 - Jan. 21, 1966			
Unplanned test to define problem with composite seal low resistance	1	20	Measure thermal conductivity of the Zirconia cylinders and effect of bumper segments
	2	160	

SPECIMEN DESCRIPTION - FULL SCALE SEALS						
COMPOSITE (0.090 0.095 LONG)		STRAIGHT THINWALL (0.090 0.095 LONG)		CONICAL THINWALL (0.248 0.252 LONG)		TYPE
						CROSS SECTION OF SEAL
T-13618	T-13619	T-13611	T-13612	T-13622	T-13621	PART NUMBER
*6AL-4V TITANIUM	*RENE' 41	6AL-4V TITANIUM	RENE' 41	6AL-4V TITANIUM	RENE' 41	MATERIALS
4.87/5.26	3.77 4.30	1.82 2.21	1.21 1.48	5.30 6.20	3.68 4.33	THERMAL RESISTANCE ⚠

⚠ Predicted thermal resistance $= \frac{HR\text{-}^{o}F}{BTU}$
Neglects contact resistance

FIGURE 3

TMC A685

PREPARED BY C.S. HILL
CHECKED BY
CLASSIFICATION

THE MARQUARDT CORPORATION

PAGE
REPORT
DATE FEB 6, 1966

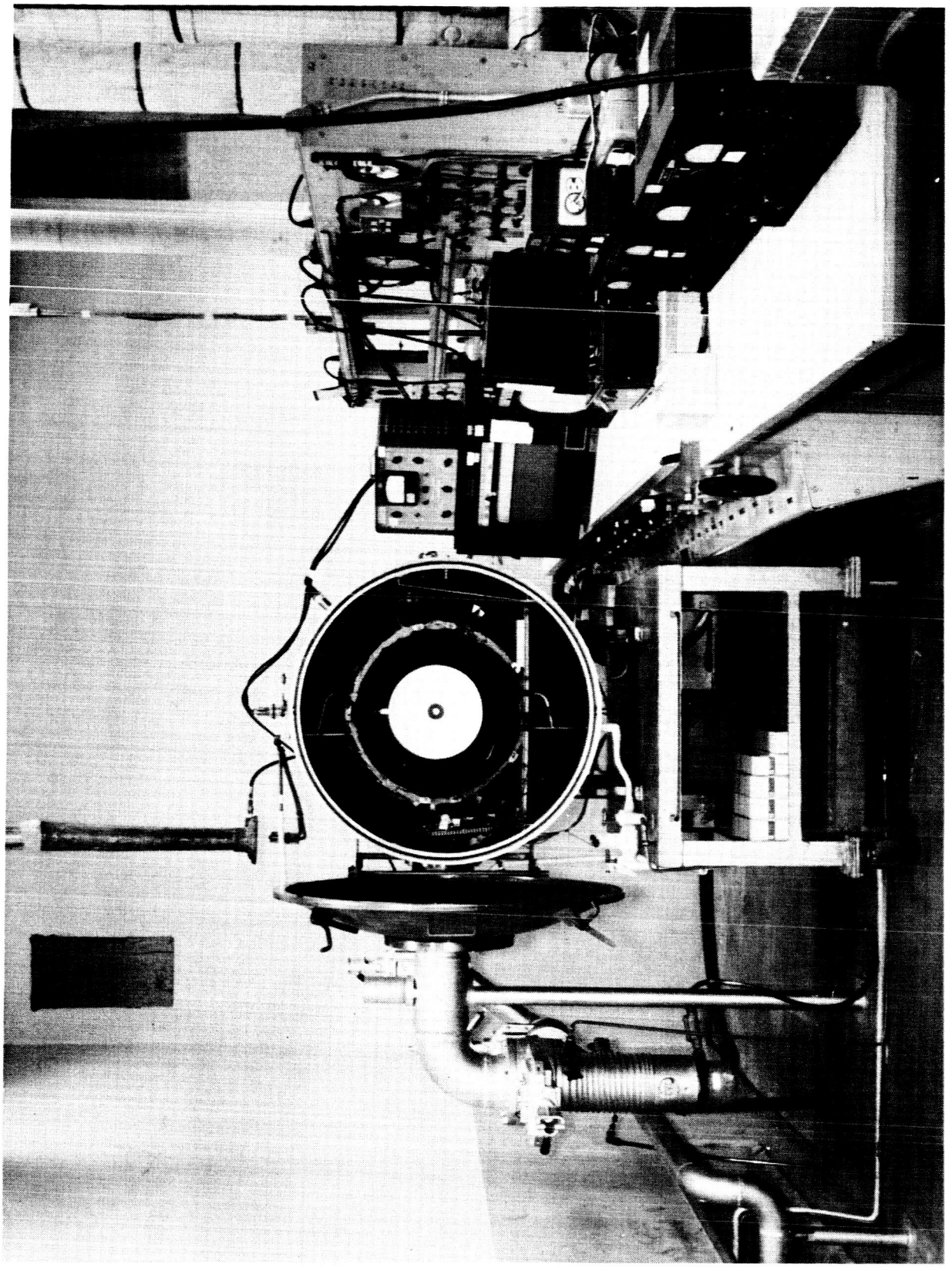
SEAL THERMAL RESISTANCE TEST RESULTS

DESIGN CONFIGURATION	PART NUMBER	MAT'L	THERMAL RESISTANCE HR-°F/BTU				
			TEST JOINT		TEST SEAL		PREDICTED MINIMUM SEAL
			20 °F	150 °F	20 °F	150 °F	
CONICAL THINWALL	T-13622	6AL-4V	6.0	5.7	7.0	6.6	5.30
	T-13621	RENE'41	4.8	4.6	5.4	5.2	3.68
STRAIGHT THINWALL	T-13611	6AL-4V	2.0	.75	2.1	—	1.82
	T-13612	RENE'41	1.4	1.2	1.5	1.3	1.21
COMPOSITE SEAL ASSEMBLY	T-13618	6-AL-4V ZIRCONIA	2.7	2.8	2.9	3.0	4.67
	T-13619	RENE'41 ZIRCONIA	2.2	2.6	2.3	2.8	3.77
ZIRCONIA CYLINDERS	T-13617	ZIRCONIA	3.8*	3.2	4.2*	3.5	8.08
COMPOSITE WITHOUT SEGMENT SET-OR SNAP RING	T-13613 T-13617	RENE'41 ZIRCONIA	3.2*	2.3	3.6*	2.5	3.77

* NOT ACCURATE DUE TO SMALL TEMPERATURE DIFFERENCE

FIGURE 4

FIGURE 4



TEST 11267 3008 SEAL THERMAL RESISTANCE TEST SETUP (U)
BLDG. 32
21 DEC 65

NEG. T11267-2

FIGURE 5

APPENDIX B

TEST DATA SUMMARY SHEETS

TMC A-88

PREPARED BY _____ CHECKED BY _____ CLASSIFICATION _____

THE MARQUARDT CORPORATION

DATE _____ REPORT _____ PAGE _____

SEAL TEST # 1 DATE DEC 18-21 1965

RUN / DATA POINT	CONICAL TITANIUM T_{HEAD} °F	T_{FLANGE} °F	ΔT °F	HEAT BTU/HR	JOINT R_{TH} HR-°F/BTU	SEAL R_{TH}	SEAL TEMP °F	THINWALL TITANIUM T_H °F	T_F °F	ΔT °F	Q BTU/HR	R_J HR-°F/BTU	R_S HR-°F/BTU	T_S °F
1 / 1830	+20	-29	49	8.54	5.73	6.63	-4.5	+20	-7	27	12.53	2.16	2.28	6.5
1 / 1900	+20	-30	50	8.59	5.82	6.75	-5.0	+20	-8	28	13.88	2.02	2.12	6.0
1 / 1930	+20	-30	50	7.95	6.29	7.39	-5.0	+20	-8	28	13.00	2.15	2.27	6.0
1 / 2000	+20	-34	54	8.58	6.29	7.39	-7.	+20	-10	30	13.60	2.21	2.3	5.0
2 / 0230	+131	+17	114	19.78	5.76	6.81	111.0	131	100	31	41.56	0.75	0.75	115.5
2 / 0300	130	17	113	19.78	5.71	6.7	73.5	131	100	31	41.56	0.75	0.75	113.5
2 / 0330	130	17	113	20.11	5.62	6.48	73.5	131	100	31	41.56	0.75	0.75	115.5
3 / 1230	+20	-47	67	10.7	6.27	7.34	-13.	+20	-15	35	16.4	2.13	2.24	2.5
3 / 1300	+20	-48	68	10.9	6.24	7.32	-14.0	+20	-15	35	16.8	2.08	2.19	2.5
3 / 1315	+20	-48	68	11.3	6.02	7.12	-14.0	+20	-15	35	16.8	2.08	2.1	2.5
4 / 1730	129	+7	122	23.0	5.30	6.06	64.0	129	+95	34	47.2	0.72	0.73	112.0
5 / 2115	60	-15	75	12.47	6.01	7.21	22.5	61	20	41	22.0	1.81	1.91	40.5
5 / 2145	60	-15	75	12.66	5.92	6.88	22.5	60	20	40	20.13	1.79	2.01	40.0
5 / 2200	60	-15	75	12.66	5.92	6.88	22.5	60	20	40	20.21	1.80	1.93	40.0
5 / 2245	60	-16	75	12.64	5.92	6.84	22.5	59	19	40	20.21	1.80	1.88	39.0

SEAL TEST # 2 DATE DEC 30, 1965

RUN / DATA POINT	CONICAL RENE T_H °F	T_F °F	ΔT °F	Q BTU/HR	R_J HR-°F/BTU	R_S HR-°F/BTU	T_S °F	THIN WALL RENE T_H °F	T_F °F	ΔT °F	Q BTU/HR	R_J HR-°F/BTU	R_S HR-°F/BTU	T_S °F
1/1515	20.5	-34	54.5	11.3	4.74	5.34	-6.75	20	-6	26	17.6	1.48	1.53	7.0
1/1520	20	-38	58	11.5	5.04	5.72	-1	18	-8	26	17.5	1.49	1.54	5.[illegible]
1/1530	20	-40	60	12.5	4.80	5.41	[illegible]	19	-8	27	20.2	1.34	1.38	[illegible]
1/1540	20.5	-40	60.5	12.5	4.84	5.47	-11	20	-8	28	19.3	1.45	1.50	[illegible]
				AVER	4.82					AVER		1.44		
2/1050	160	18	142	32.3	4.40	4.91	[illegible]	160	90	70	58.8	1.19	1.22	12[illegible]
2/1040	160	20	140	30.2	4.64	5.21	10.2	160	92	68	56.0	1.21	1.25	12[illegible]
2/1030	161	22	139	28.2	4.93	5.58	7[illegible]	161	93	68	53.8	1.26	1.30	127.0
2/1020	160	22	138	29.7	4.65	5.22	9[illegible]	161	95	66	53.8	1.23	1.27	1.29
2/1015	160	23	137	29.7	4.61	5.17	9[illegible]	162	96	66	53.4	1.24	1.27	1.29
				AVER	4.65					AVER		1.23		

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SEAL TEST # 3 DATE JAN 13-14, 1966

RUN / DATA POINT	T_H °F	T_F °F	ΔT °F	Q BTU/HR	R_J HR-°F/BTU	R_S HR-°F/BTU	T_S °F	T_H °F	T_F °F	ΔT °F	Q BTU/HR	R_J HR-°F/BTU	R_S HR-°F/BTU	T_S °F
	COMPOSITE - TITANIUM							COMPOSITE - RENE						
1/1410	159	69	90	31.6	2.85	3.06	114.0	157	80	77	35.8	2.15	2.27	118.5
1/1430	160	69	91	35.2	2.59	2.76	114.5	161	82	79	34.2	2.15	2.27	121.5
1/1445	162	70	92	34.1	2.71	2.90	116	162	82	80	34.1	2.31	2.44	122.0
1/1500	161	71	90	32.8	2.74	2.93	116	161	82	79	34.1	2.28	2.41	122.0
1/1510	160	70	90	32.8	2.74	2.93	115.0	160	82	78	34.6	2.25	2.38	121.0
			AVER		2.73						AVER 34.3			
2/1330	21	-19	40	13.7	2.92	3.14	4.0	21	-10	31	11.8	2.63	2.80	5.5
2/1352	20	-19	39	13.7	2.85	3.06	.5	19	-11	30	11.8	2.54	2.77	4.0
2/1425	19	-20	39	13.8	2.83	3.03	-.5	20	-11	31	12.1	2.56	2.73	4.5
2/1435	19	-21	40	13.6	2.90	3.11	-1.0	20	-12	32	12.3	2.60	2.77	4.0
2/1500	21	-21	42	16.1	2.61	2.72	0	21	-12	33	13.9	2.37	2.51	4.5
			AVER		2.82						AVER	2.54		

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SEAL TEST # 4 DATE JAN 21, 1966

ZIRCONIA - ONLY

RUN / DATA POINT	T_H °F	T_F °F	ΔT °F	Q BTU/Hr	R_J Hr-°F/BTU	R_S Hr-°F/BTU	T_S °F
1 / 1300	19.5	0	19.5	5.32	3.67	4.01	9.75
2 / 1315	19.1	+1	20	5.44	3.77	4.14	9.2
3 / 1330	18	-3	21	5.72	3.95	4.31	7.5
4 / 1345	17	-4	21	5.52	3.95	4.36	6.5
				AVG	3.84		
2 / 1430	153	42	111	35.8	3.10	3.35	97.5
2 / 1515	167	52	115	35.5	3.24	3.51	109.5
2 / 1600	169	53	116	35.6	3.26	3.53	111.0
			AVERAGE		3.20		

NO BUMPERS - RENE

RUN / DATA POINT	T_N °F	T_F °F	ΔT °F	Q BTU/Hr	R_J Hr-°F/BTU	R_S Hr-°F/BTU	T_S °F
1 / 1300	18	8	10	3.48	2.79	2.99	13.0
2 / 1315	18	7	11	3.67	3.00	3.23	12.5
3 / 1330	17	5	12	3.82	3.29	3.57	11.5
4 / 1345	16	4	12	3.72	3.32	3.63	10.0
				AVG.	3.20		
2 / 1430	154	63	91	42.7	2.13	2.24	108.5
2 / 1515	169	75	94	40.3	2.33	2.47	84.5
2 / 1600	170	76	94	40.3	2.32	2.47	123.0
				AVG.	2.26		

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ATTACHMENT 8

THE Marquardt CORPORATION VAN NUYS, CALIFORNIA

TEST REPORT (FINAL)

STRUCTURAL EVALUATION

of

FULL SCALE SEALS

For

APOLLO SERVICE MODULE

REACTION CONTROL SYSTEM ENGINE INJECTOR

CHAMBER SEAL STUDY

PREPARED UNDER CONTRACT NAS 9-4775

TMC 3008

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I. INTRODUCTION

This test report covers the final results in static structural testing full scale seals in support of the development of high thermal resistance injector head/combustor seals for the Apollo Service Module Reaction Control System (S/M RCS) Engine under Contract NAS 9-4775. Seals were evaluated for structural and leakage performance before and after exposure to environmental conditions simulating:

A. Engine Heat Soakback

B. Creep (short term/high temperature)

C. Chamber Pressure Spike (static)

D. Seal Cavity Propellant Explosion (static)

E. Storage (long term creep)

Leakage versus compressive preload data evaluation is also presented for seals exposed to cold soak (sub-zero), high vacuum environments experienced in thermal tests (seal thermal resistance measurement).

Three (3) different seal design types (composite, straight thinwall, and conical thinwall) were evaluated. Each type was fabricated from two (2) materials and/or material systems. One each of the six (6) design/material combinations was tested.

II. CONCLUSIONS

All six (6) seal design/material combinations, representing the three (3) basically different seal designs (composite, straight thinwall, and conical thinwall) were evaluated for structural and leakage performance on the basis of test results. In evaluating the seal performance, consideration was simultaneously given to the behavior of the adjacent test rig hardware comprising the head/combustor joint.

All seals tested met design objectives by demonstrating structural performance within elastic limits under combinations of compressive and tensile loadings and temperatures corresponding to ultimate design factors.

Positive safety margins were demonstrated for all seals after exposure to combined compressive and tensile loadings in excess of ultimate design conditions. Although these tests were considered destructive in a structural sense, post-test seal preload and leakage performance was not necessarily adversely affected.

Seals which demonstrated the greatest apparent structural safety margins also exhibited the largest permanent deformations when exposed to destructive test conditions. Conical thinwall designs exhibited the largest deformations consistent with low leakage rates. The highest leakage rates consistent with low permanent deformations (practically unmeasurable) were exhibited by the composite seal fabricated from Titanium. The conical thinwall seals demonstrated the highest hoop load capacity

consistent with the ability to contain high seal cavity pressures. Composite seals were next and straight thinwall seals demonstrated the lowest capacity.

For the thirty-four (34) individual tests performed, thirty-one (31) exhibited leakage performance within acceptable Apollo S/M RCS engine requirements. Three (3) of the thirty-four (34) (these tests used the same type of composite Titanium seal) demonstrated leakage slightly in excess of the allowed maximum during post-test checkout.

Pre and post-test seal preload and leakage test data for seals exposed to sub-zero, high vacuum conditions experienced in seal thermal resistance measurement tests indicated that performance was generally the same as that obtained in the structural static test series.

A comparison of all test data indicated that the best overall performance, for these test series, was demonstrated by the conical thinwall seal fabricated from Titanium. The six (6) seals are rated in descending order as follows:

1. Conical Thinwall (Titanium)
2. Conical Thinwall (René 41)
3. Composite (René 41 + Zirconium Oxide + 6AL-4V Ti)
4. Straight Thinwall (René 41)
5. Straight Thinwall (Titanium)
6. Composite (Titanium + Zirconium Oxide)

III. RECOMMENDATIONS

A modification to the composite seal design, which has the advantage of fitting the existing seal cavity, is recommended. Since structural safety margins are high for this design, consideration should be given to improving the leakage performance.

The comparatively higher leakage rates demonstrated by the composite (Titanium) seal were attributed to excessive deflections in the jacket wall adjacent and between the Zirconia compression members. These deflections can be minimized by decreasing the unsupported distance between cylinders by increasing their number.

For seals which require engine component modifications to achieve an extended seal cavity, the conical thinwall seals, which have demonstrated superior overall performance in these tests, should also be considered further for engine retrofit studies.

IV. SUMMARY

Structural evaluation tests for all six (6) design/material combinations were performed in accordance with the test plan (MTP 0041 - Appendix A). Specimen seals were contained in special test rigs and environmental conditions were artificially simulated in bench test setups. Existing facilities, located at Marquardt's Structural Test Laboratory, were utlized for all tests.

One specimen of each of the following seals was structurally static tested per Appendix A, Paragraphs (tests) A-3.1, A-3.2, A-3.3 and A-3.5*:

P/N, Type, and S/N	Materials
T-13618, Composite, B	6AL-4V + Zirconium Oxide
T-13619, Composite, B	René 41 + Zirconium Oxide + 6AL-4V Ti
T-13611, Straight Thinwall, B	6AL-4V Ti
T-13612, Straight Thinwall, B	René 41
T-13622, Conical Thinwall, B	6AL-4V Ti
T-13621, Conical Thinwall, B	René 41

*S/N A seals, from Appendix B tests, were re-used for this test only.

Leakage versus seal preload data were evaluated for seals exposed to cold soak (sub-zero), high vacuum environments experienced in MTP 0041, Appendix B, Thermal Tests (seal thermal resistance measurement) and are presented for one (1) each of the following seals:

P/N, Type, and S/N	Materials
T-13618, Composite, A	6AL-4V + Zirconium Oxide
T-13619, Composite, A	René 41 + Zirconium Oxide + 6AL-4V Ti
T-13611, Straight Thinwall, A	6AL-4V Ti
T-13612, Straight Thinwall, A	René 41
T-13622, Conical Thinwall, A	6AL-4V Ti
T-13621, Conical Thinwall, A	René 41

Success/Failure criteria was not established prior to conduct of the structural test series due to the exploratory nature of the test program. Some of the tests were considered "off limit" or destructive. However, since all specimen seals were contained in reasonably uniform test rigs and tested in accordance with uniform procedures and environmental conditions, a sufficient quantity of meaningful inspection and test data was attained from which performance could be evaluated.

The most significant types of data, which served as common denominators in evaluating all seals, were pre and post-test seal preload and leakage. These data, summarized in Figures 1 and 2, combined with pre-test physical conditions and post-test determination of damage, was the basis on which evaluations were largely made. Additionally, consideration was given to the behavior of the test rig hardware adjacent to the seals which comprised the head/combustor joint.

Recognition was given to design/material similarities and dissimilarities represented by each of the three (3) basically different designs which in turn accounted for, in part, specific behaviors of various seals during tests.

Observation of dynamic behavior of the test seals was not within the scope of this test series. However, pre and post-test inspections of the seals and test rig hardware provided sufficient evidence from which some conclusions for dynamic performance could be postulated.

Summarily, no indications of rupture, creep, bearing failure or permanent deformations were exhibited by any of the test seals after exposure to combinations of compressive and tensile loadings and temperatures corresponding to ultimate design conditions.

After exposure to test conditions in excess of ultimate design factors, all seals demonstrated positive structural safety margins. Quantitative values for these safety margins, however, were not established in this test program because universally practical failure criteria (other than rupture) could not be determined for all of the various seals tested. Loadings required to initiate and/or propagate rupture were unattainable due to the test rig hardware structural limitations.

V. TECHNICAL DISCUSSION

Initial steps taken to implement test plan MTP 0041, Appendix A, consisted of design and fabrication of special test rigs and preparation of test facilities.

A total of six (6) test rigs were used to contain the six (6) various specimen seals chosen for the series of structural static tests. Two (2) of these test rigs are photographed in Figures 3 and 4. These test rigs, generically identified as "Structural Test Rigs #1 and #2", were used exclusively for Appendix A Tests A-3.1 through A-3.4.

After completion of Appendix B Thermal Resistance Measurement Tests (not covered by this test report), portions of the "Thermal Test Rig, L-2054" were used to accommodate two of the six seals for Appendix A, Test A-3.5 (thirty day creep test). Another two seals, for Test A-3.5, were again contained in "Structural Test Rigs #1 and #2". The last two of the six seals, for Test A-3.5, were installed in partial subassemblies of the Apollo S/M RCS engine sufficient to accommodate simulation of the injector head/seal/combustor joint. All of these six test rigs are shown in Figure 5.

Structural static tests were performed in accordance with MTP 0041, Appendix A, which specified various combinations of pressure and temperature environments. Additional pressure and temperature conditions, not within the scope of Appendix A, were also experienced by full scale seals during seal thermal resistance measurement tests specified by MTP 0041, Appendix B. Since Appendix B objectives were primarily aimed at determining seal thermal resistances, little regard was given to evaluating structural and leakage performance. However, data pertinent to structural and leakage performance of seals exposed to sub-zero, high vacuum conditions were accumulated during these tests which this report now considers.

Chronologically, Appendix B Thermal Tests were initiated prior to Appendix A Structural Tests. For clarity, the discussion on all testing will be in the order that the tests were performed.

A. Documentation of Structural & Leakage Performance for Seals Subjected to Seal Thermal Resistance Measurement Tests per MTP 0041, Appendix B

Evaluation of structural and leakage test data prior to and after exposure to cold soak environments, per Appendix B, is reported for the following seals:

P/N, Type, and S/N	Materials
T-13618, Composite, A	6AL-4V + Zirconium Oxide
T-13619, Composite, A	René 41 + Zirconium Oxide + 6AL-4V
T-13611, Straight Thinwall, A	6AL-4V Ti
T-13612, Straight Thinwall, A	René 41
T-13622, Conical Thinwall, A	6AL-4V Ti
T-13621, Conical Thinwall, A	René 41

During these tests, injector head/combustor joint hardware temperatures and test chamber pressures less than -20°F and 10^{-5} mmHg, respectively, were recorded.

A tabulation of seal preload and leakage before and after exposure to these conditions is summarized in Figure 2. As shown, leakage rates for all seals except P/N T-13618 decreased. A fine scratch on the sealing surface of this seal accounted for the relatively high pre and post-test leakage rates. Losses in apparent preload were attributed to the seating of clinch nuts in the injector head. This phenomenon occurred only during initial usage of the thermal test rig hardware and was progressively lessened during later tests. This is routinely experienced during Apollo S/M RCS engine assembly in production.

A detailed discussion on the above seals follows:

(1) Candidate seals were tested in pairs. The first test rig buildup for thermal testing consisted of a T-13622 conical thinwall (Titanium) seal and a T-13611 straight thinwall (Titanium) seal. The T-13611 seal was assembled in Rig #1 with .102 OD attach bolts. Calculated clamping load was 5,900 pounds and leakage was 4.5 psi in 5 minutes. After testing, the clamping load had dropped to 4,675 pounds and leakage was 3.0 psi in 5 minutes. Pre-test seal clamping load is calculated from bolt elongation. Post-test clamping load is calculated from loss in bolt elongation. Some pre-load loss is normal due to the seating action of the seal and associated clamping hardware.

(2) The T-13622 seal was assembled in Rig #2 with .112 OD bolts. Calculated clamping load was 5,580 pounds and leakage was 2.5 psi in 5 minutes. After testing, the clamping load was 2,250 pounds and leakage was 0.5 psi in 5 minutes.

The major loss in clamping load was attributed to setting of the clinch nuts in the aluminum housing. This is normal even on Apollo S/M RCS engines in production.

Disassembly of both test rigs showed no structural degradation of the test rig hardware or seals. A loss of .0009 inch in the length of the T-13622 seal, which was reported in Attachment 8 of Reference No. 1 was found to be in error.

(3) The second test rig buildup for thermal testing consisted of a T-13621 conical thinwall seal (René 41) and a T-13612 straight thinwall (René 41) seal. The T-13621 seal was assembled in Test Rig #2. Clamping load was 4,750 pounds and leakage was 3.0 psi in 5 minutes. After testing, the clamping load was 3,960 pounds and leakage, 2.5 psi in 5 minutes.

Disassembly of both test rigs showed no visible evidence of failure to the seals or test hardware. What had been suspected as an .0008 inch deep indentation in the sealing surface of the injector head of Test Rig #2 was only a change in surface texture due to seal bearing stresses. It was determined that an improper inspection setup detected a general slope of .0008 inch across the entire sealing surface instead of a local indentation. The actual depth of the bearing area in question was not measurable, but estimated to be less than .00005 inch. Figure 7 shows the contrast in surface texture to the adjacent area. Certain light reflections tend to amplify this contrast which deceive the viewer.

The third test rig buildup for thermal testing consisted of a T-13618 composite seal (6AL-4V Titanium Jacket) and a T-13619 composite seal (René 41 Jacket).

(4) The T-13618 was assembled in Test Rig #1. A slight scratch across the sealing surface on one side of the seal was placed toward the head side. In an attempt to stop leakage across this scratch, bolt set #1 (.102 diameter attach bolts) was over-torqued resulting in a deformation of the bolts. Leakage was 15.0 psi in 5 minutes with a clampimg load of 8,157 pounds. After testing, leakage was 17.0 psi in 5 minutes and clamping load, 7,940 pounds.

(5) The T-13619 seal was assembled in Rig #2. Leakage was 4.5 psi in 5 minutes with 5,680 pounds clamping load. After testing, leakage remained at 4.5 psi with a 5,380 pound clamping load.

Disassembly of both units disclosed no visible signs of failure to seals or test hardware except for the aforementioned bolts. The deformation of the bolts, however, did not truly constitute a failure even though maximum preload values were exceeded. A comparison of pre and post-test preloads, shown in Figure 2, indicate that even though excessive preload prevailed, relatively no change occurred as a result of test exposure.

B. Documentation of Structural and Leakage Performance for Seals Subjected to Simulated Engine Heat Soakback Cycling and Short Term/High Temperature Creep Tests per MTP 0041, Appendix A, Paragraphs (Tests) A-3.1 and A-3.4

Evaluation of structural and leakage test data prior to and after exposure to simulated engine heat soakback cycling and cumulative heat soakback conditions is reported for the following seals:

P/N, Type, and S/N	Materials
T-13618, Composite, B	6AL-4V + Zirconium Oxide
T-13619, Composite, B	René 41 + Zirconium Oxide + 6AL-4V Ti
T-13611, Straight Thinwall, B	6AL-4V Ti
T-13612, Straight Thinwall, B	René 41
T-13622, Conical Thinwall, B	6AL-4V Ti
T-13621, Conical Thinwall, B	René 41

Test A-3.1 subjected the seals to cyclic structural loads and temperatures corresponding to normal limits anticipated for engine heat soakback after a steady state run. Test A-3.4 exposed seals to the same conditions except that peak temperature differentials between the combustor flange and injector head were maintained constant for approximately one half-hour. This condition was considered "off-limit" and possibly destructive to seals.

A tabulation of seal preload and leakage before and after exposure to these conditions are summarized in Figure 1. The tabulation shows that leakage for all seals remained well within acceptable Apollo S/M RCS engine requirements for Test A-3.1. After exposure to A-3.4 test conditions, all seals continued to exhibit leakage rates within acceptable limits. The relatively large losses in seal preload for P/Ns T-13611 and T-13612 were attributed to the seating of clinch nuts in the injector head. These seals utilized the structural test Rigs #1 and #2 for the first time. As can be seen, this phenomenon was apparently eliminated in later usage of these test rigs.

The following is a discussion of the detail findings:

The two (2) structural test rigs (Figures 3 and 4) for these tests were identical except for combustor attach bolt diameters. Standard Apollo S/M RCS Qualification-type engine bolts with full size diameters were unavailable. Test Rig #1 used .112 diameter bolts and Test Rig #2 used .121 diameter bolts. Tests utilized a special radiant heat oven and controls shown in Figures 8, 9 and 10.

(1) The T-13611 straight thinwall (6AL-4V Ti) was assembled in Rig #2. Clamping load was 6,570 pounds with 11.0 psi leakage in 5 minutes. After being subjected to heat cycling, documented in Figure 11, clamping load was 4,020 pounds with 9.5 psi leakage. The major portion of loss in bolt elongation was attributed to seating of the clinch nuts in the aluminum head. The unit was disassembled. No visible failure was evident. The unit was reassembled with a clamping load of 5,550 pounds resulting in a leakage of 12.0 psi. The seal was then subjected to the creep test conditions documented in Figure 17. Leakage after test was 2.5 psi with no change in clamping load. Disassembly of the unit disclosed no visible failures to the seal or test hardware. Dimensional inspection of the seal showed no dimensional change after testing.

(2) The T-13612 straight thinwall (René 41) seal was assembled in Test Rig #1. Clamping load was 6,695 pounds with leakage of 2.5 psi. After being subjected to heat cycling, documented in Figure 12, clamping load was 4,050 pounds with leakage of 4.0 psi. Based on the excellent test results of the T-13611 seal and high creep resistance properties of René 41 material, the decision was made not to disassemble between the tests. The creep test was run as documented in Figure 17. Clamping load was 3,900 pounds with a leakage of 3.0 psi. Disassembly of the unit showed no visible signs of structural failure. No change in dimensions of the seal was found.

(3) The T-13618 composite seal (6AL-4V Titanium Jacket) was assembled in Test Rig #2. Clamping load was 5,250 pounds with a leakage of 8.0 psi. The unit was subjected to heat cycles documented in Figure 13. After test, clamping load was 4,900 pounds with a leakage of 14.0 psi. Disassembly of the unit showed only heat stains on combustor side of the seal (Figure 18). The unit was reassembled with 5,180 pounds clamping load and a leakage ot 4.0 psi. After the creep test, documented in Figure 17, the clamping load was unchanged but leakage was 12.5 psi. Disassembly of the hardware showed no visible signs of structural failure of the seal or associated hardware.

(4) The T-13619 composite seal (René 41 Jacket) was assembled in Test Rig #1. Clamping load was 4,950 pounds and leakage was 6.0 psi. After the heat cycling test, documented in Figure 14, the clamping load remained unchanged and leakage was 3.75 psi. Disassembly of the test rig disclosed markings on the combustor sealing surface. They appeared to be indentations but were unmeasurable ($<$ .0005 inch deep). There were heat stains on the jacket on the combustor side of the seal. No signs of failure were detected on the associated test hardware or the seal. Dimensional inspection was waived. Based on the very good results in T-13618 Titanium seal testing, the decision was made not to run the creep test as no useful test data could be attained.

(5) The T-13622 conical thinwall seal (6AL-4V Titanium) was assembled in Test Rig #1. Clamping load was 4,240 pounds with leakage of 2.0 psi. The unit was heat cycled as shown in Figure 15. After testing, the clamping load was unchanged and leakage was 1.0 psi. Disassembly disclosed only heat stains on the seal face toward the combustor side. The unit was reassembled with a clamping load of 4,975 pounds with a leakage of 1.75 psi. After the creep test (Figure 17) the clamping load was still 4,975 pounds and leakage was now 1.50 psi. Disassembly disclosed no visible signs of structural degradation. Dimensional inspection of the seal showed no change. The interim test report disclosure in Attachment 8 of Reference 1 stated that a .0009 inch change in seal length was evident. Further investigation found this statement to be in error.

(6) The T-13621 conical thinwall seal (René 41) was assembled in Test Rig #2. Clamping load was 6,060 pounds and leakage 4.75 psi. After heat cycling (Figure 16), clamping load was 5,570 pounds and leakage 8.5 psi. Disassembly disclosed only heat staining of the seal. Dimensional inspection of the seal showed no change. A decision was made not to run the creep test on this specimen for the same reasons as given for P/N T-13619.

C. Documentation of Structural and Leakage Performance for Seals Subjected to Hydrostatically Simulated Chamber Pressure Spikes and Seal Cavity Explosion Tests per MTP 0041, Appendix A, Para. (Tests) A-3.2 and A-3.3

Evaluation of structural and leakage test data prior to, during and after exposure to hydrostatically simulated chamber pressure spikes and seal cavity explosion conditions is reported for the same seals as used in Tests A-3.1 and A-3.4.

Test A-3.2 subjected seals to a maximum seal cavity pressure of 1200 psi in steps of 200 psi each. At each step, the cavity was isolated and seal leakage was recorded. The test rigs were entirely stabilized to $\cong$ 0°F during the tests. The 1200 psi pressure and 0°F temperature conditions correspond to known limits which prevail during engine ignition overpressure (chamber pressure spike).

Test A-3.3 exposed the seals to seal cavity pressures in excess of 1200 psi at room temperature. Pressurization was increased until loss of pressure containment, indicated by gross leakage, was apparent. This condition was considered "off limit" and possibly destructive to seals. This test was designed to evaluate structural characteristics, hoop load capacity and sealing capability of seals at steady state pressure and temperatures simulating a hypothetical seal cavity pressure spike generated by propellant reactions within the seal cavity.

Seal preload and leakage before and after exposure to these conditions are tabulated in Figure 1. Leakages recorded during the A-3.2 pressurization steps are tabulated in Figure 19. Pressure levels at which gross leakage occurred during A-3.3 tests are also tabulated in Figure 19. Figure 1 shows that post-test leakage performance for all seals, except P/N T-13618, improved or remained virtually unchanged after exposure to test conditions. Surprisingly, seal preload levels remained relatively constant even though various degrees of permanent deformations were exhibited by the seals after disassembly.

A detailed discussion follows for each of the seals tested:

The same two structural test rigs as used in the previous Appendix A tests were utilized for these tests. Testing was performed with the hydraulic test bench shown in Figures 20 and 21.

(1) The T-13622 conical thinwall (6AL-4V Ti) was assembled in Test Rig #1. Clamping load was 5,890 pounds and leakage was 1.0 psi in 5 minutes. After exposure to A-3.2 test conditions, clamping load was 5,810 pounds and leakage was 0.75 psi in 5 minutes. Disassembly disclosed no signs of structural degradation. The unit was reassembled with 5,150 pounds clamping load. Leakage was 1.0 psi in 5 minutes. During the A-3.3 test, a pressure of 4600 psig was attained before seal leakage occurred. The pressurant used during this test, as in Test A-3.2, was alcohol. Seal preload after testing remained at 5,150 pounds and leakage was 0.5 psi in 5 minutes. After disassembly, the seal exhibited significant permanent deformation in the conical thinwall section. The outward bulge of this thinwall section, shown in Figure 22, caused a slight rotation of the seal end faces which apparently enhanced

sealing capability while high alcohol pressures prevailed during the test. The post-test nitrogen leakage rate was also slightly improved. The mating surfaces of the injector head and combustor exhibited only minor changes in surface roughness and lay. Figures 23 and 24 show the burnished areas on these sealing surfaces which deceptively appear to be indented grooves. Dimensional inspection of the seal disclosed no change in overall length despite the presence of the thinwall bulge. The inside diameter at the injector end of the seal, however, was reduced an average .002 inch which was apparently caused by the aforementioned rotation.

(2) The T-13621 conical thinwall (René 41) seal was assembled in Test Rig #2. Clamping load was 5,860 pounds and leakage was 11.75 psi in 5 minutes. After exposure to A-3.2 test conditions, clamping load remained unchanged and leakage was reduced to 1.75 psi in 5 minutes. Disassembly and examination showed no changes in the seal or the test rig hardware. The unit was reassembled with 5,570 pounds preload and the leakage rate was 9.5 psi in 5 minutes. During Test A-3.3, gross seal leakage occurred at 4,600 psig. After this test, clamping load was reduced to 5,220 pounds and leakage was also reduced to 3.5 psi in 5 minutes. Examination of the seal and test rig hardware, after disassembly, disclosed that damage was very similar to that found in the T-13622 seal. Figure 25 shows the characteristic conical thinwall section bulge in the seal. Dimensional inspection showed a .0005 inch decrease in overall length which may account for the loss in seal preload. The inside diameter at the injector end of the seal decreased an average .003 inch, which again (as in the T-13622 seal), was caused by the seal end rotation. Figure 26 shows the burnished condition of the sealing surface on the injector head.

(3) The T-13619 composite seal (René 41) Jacket) was assembled in Test Rig #1. The seal preload was 5,125 pounds and leakage was 3.75 psi in 5 minutes. After the A-3.2 test, the preload was 5,080 pounds and leakage reduced to 3.0 psi in 5 minutes. After disassembly, inspection of the seal disclosed a slight permanent deformation of the jacket which was characterized by an average decrease of .0028 inch at the inside diameter of the seal. The seal length was unaffected. The unit was reassembled with a 6,420 pound seal preload. The attendant leakage was 4.25 psi in 5 minutes. During the A-3.3 hydrostatic test, the seal leaked grossly at 3,650 psig. After testing the seal preload and leakage remained unchanged at 6,420 pounds and 4.25 psi, respectively. Post-test inspection disclosed no deformations of the test rig hardware. The inside diameter of the seal was reduced an additional .001 inch. This deformation displayed by the jacket membrane in this seal is considered insignificant and for practical purposes should be ignored.

(4) The T-13618 composite seal (6AL-4V Titanium Jacket), was assembled in Test Rig #1. Seal preload was 4,925 pounds and pre-test leakage was 13.0 psi in 5 minutes. After A-3.2 testing, the preload dropped to 4,800 pounds and leakage increased to 19.0 psi. Dimensional inspection after disassembly disclosed that the only measurable change to the seal occurred at the inside diameter. This diameter was increased over pre-test measurements an average .001 inch. No measurable permanent deformations of the jacket wall at the sealing surfaces could be detected although the visual appearance of the jacket in the sealing areas showed suspicious characteristics similar to those shown in Figure 18. To eliminate the possibility that the head and combustor were responsible for the high leakage rate, the seal was reassembled in a different test rig. In Test Rig #2, the relatively high leakage rate (14 psi in 5 min.)

persisted even though the seal preload level was increased to 5,220 pounds. It was concluded that very small deflections in the jacket walls adjacent and between the Zirconia compression members were responsible for the leakage. "Snoop" leak detecting fluid indicated that the leak paths were confined to the combustor side of the seal. It was further deduced that this phenomenon may be associated with the fact that a large difference in material ductility exists between the aluminum head and coated molybdenum combustor flange. The low ductility permits the aluminum to conform to the very small jacket deflections and thereby effect a better seal on that face.

Testing was continued with exposure of this test rig assembly to the A-3.3 conditions. During this test, gross seal leakage (with alcohol) occurred @ 2,400 psig. After this test, seal preload was 5,040 pounds and leakage had risen to 26.0 psi in 5 minutes. Permanent deformation of the jacket walls adjacent to the sealing surfaces seemed to be certain. However, after disassembly, no measurable deformation could be detected with the equipment used. Inspection disclosed that the inside diameter of the seal increased an average .001 inch. The head and combustor sealing surfaces were void of any signs of deterioration.

(5) The T-13612 straight thinwall (René 41) seal was assembled in Test Rig #2. Clamping load was 5,250 pounds and leakage was 5.25 psi. After A-3.2 testing, the preload was 5,160 pounds and leakage decreased to 4.75 psi in 5 minutes. No disassembly was conducted after this test. Instead, Test A-3.3 was performed during which gross seal leakage was detected at 4,000 psig. After this test, preload was 5,070 pounds and leakage was reduced to 0.75 psi in 5 minutes. Examination after disassembly disclosed a circular line on the combustor face corresponding to the sealing diameter of the seal. Subsequent dimensional inspection indicated that the depth of this mark, (shown in Figure 27) was too small to be measured. Dimensional inspection of the seal showed only an average increase of .001 inch for the inside diameter.

(6) The T-13611 straight thinwall (6AL-4V Titanium) seal was assembled in Test Rig #1. Seal preload was 4,720 pounds and leakage was 7.5 psi in 5 minutes. After A-3.2 testing, seal preload remained at 4,720 pounds and leakage decreased to 1.25 psi. Based on the good results obtained for the T-13612 seal, no disassembly and inspection was conducted. During the next test (A-3.3) a seal cavity pressure of 4,000 psig was reached before gross leakage occurred (same as the T-13612 seal). Post-test preload remained at 4,720 pounds but leakage increased to 2.25 psi in 5 minutes. Disassembly disclosed the same type of circular line as was exhibited by the combustor used with the T-13612 seal. The depth of the outer ring on the combustor face, shown in Figure 24, was so shallow that inspection equipment could not accurately measure it. The seal inside diameter increased insignificantly (an average .0015 inch).

D. Documentation of Structural and Leakage Performance for Seals Subjected to Long Term (30 Days) Creep Tests per MTP 0041, Appendix A, Paragraph (Test) A-3.5

Evaluation of structural and leakage test data prior to and after exposure to simulated storage for approximately 30 days is reported for the same seals as used in MTP 0041, Appendix B, Heat Transfer Tests.

Test A-3.5, photographed in Figures 5 and 6, exposed preloaded seals to loadings and temperatures corresponding to normal limits anticipated during storage at tropical temperatures. Creep characteristics and seal leakage data were evaluated.

Seal preload and leakage before and after exposure to these conditions are summarized in Figure 1. The tabulation shows that the majority of the seals exhibited leakage performance improvement after storage. Leakage rates for all seals were well within acceptable Apollo S/M RCS engine leakage requirements. Seal preload values remained constant for all seals as indicated by pre and post-test data.

A detailed discussion for each seal follows:

(1) The T-13612 straight thinwall (René 41) was assembled in thermal test rig #1. Clamping load was 4,680 pounds and leakage was 10.25 psi in 5 minutes. After storage for 21 days at 117°-134°F, the clamping load remained the same and leakage was 9.5 psi in 5 minutes. Disassembly disclosed no structural deterioration of the hardware. Dimensional inspection of the hardware also showed no change.

(2) The T-13611 straight thinwall (6AL-4V Titanium) seal was assembled in a test rig which utilized a pre-Qualification-type Apollo S/M RCS engine injector head. Clamping load was 5,160 pounds and leakage was 14.0 psi in 5 minutes. After a 29 day storage period at temperatures ranging from 117° to 134°F, the preload remained unchanged at 5,160 pounds. But the leakage rate reduced to 10 psi in 5 minutes. Examination and dimensional inspection of the seal and other components disclosed that no changes took place during this test.

(3) The T-13621 conical thinwall (René 41) seal was assembled in thermal test rig #2. Clamping load was 5,110 pounds and leakage was 2.25 psi in 5 minutes. After storage for 21 days at 117°-134°F the clamping load remained unchanged and leakage increased to 3.25 psi. Disassembly disclosed only slight burnishing of the injector head sealing surface. Dimensional inspection of the seal disclosed no change to dimensions.

(4) The T-13622 conical thinwall (6AL-4V Titanium) seal was assembled in structural test rig #2 with 4,900 pounds clamping load and 0.25 psi leakage in 5 minutes. After storage for 30 days at 117°-134°F, clamping load remained at 4,900 pounds and leakage was 0.50 psi in 5 minutes. Disassembly disclosed slight burnishing of both the head and combustor. Dimensionally, the seal remained constant.

(5) The T-13618 composite seal (6AL-4V Ti Jacket) was assembled in structural test rig #1 with 5,350 pounds clamping load and a leakage rate of 8.5 psi in 5 minutes. Storage was for 30 days at 117°-134°F. After testing, clamping load was still 5,350 pounds and leakage was reduced to 5.25 psi in 5 minutes. Disassembly disclosed no changes to the hardware or the seal.

(6) The T-13619 composite seal (René 41 Jacket) was assembled in a test rig which utilized a pre-Qualification-type Apollo S/M RCS engine injector head. This rig was similar to the one used for P/N T-13611 seal. Seal preload was 5,130 pounds and leakage was 4.25 psi in 5 minutes. Following a storage period of

29 days at 117° to 134°F, the preload remained the same at 5,130 pounds and the leakage rate was reduced to 2.0 psi in 5 minutes. No physical deterioration or dimensional changes were detected upon disassembly.

VI. TEST PLAN AND PROCEDURES

All testing was conducted in accordance with MTP 0041. Minor deviations from the test plan were made in order to facilitate testing. These deviations are described below:

A. Engine Heat Soakback, MTP 0041, Appendix A, Paragraph A-3.1

One heat soakback cycle was omitted for seal P/N T-13612 because of schedule loading.

B. Creep (Short Term/High Temperature), MTP 0041, Appendix A, Para. A-3.4

Cycling time was changed from 30 minutes to 25 minutes. Preliminary tests showed that some of the quartz lamps in the test setup were shorting out after about 27 minutes of continuous operation which resulted in power control difficulties. Creep tests for seals P/N T-13619 and T-13621 (René 41) were eliminated. This deviation from the test plan was made because creep test data from the T-13612 (René 41) seal and good test results obtained for Titanium versions (T-13618 and T-13622) of these seals indicated that no useful data could be attained.

C. Simulated Chamber Pressure Spike (Static), MTP 0041, Appendix A, Paragraph A-3.2

Continuous temperature recordings were not made because preliminary spot checks of the alcohol dry ice bath assured stable temperature control within acceptable limits.

D. Storage (Long Term), MTP 0041, Appendix A, Paragraph A-3.5

The 30 day storage time for seals P/N T-13612 and T-13621 was arbitrarily cut to 21 days. Both seals were fabricated from René 41 material which exhibited excellant creep resistance for the 21 days exposure and earlier tests of seals made from this material. The additional 9 days exposure was not justified as seals of identical design but fabricated from Titanium provided 30 day creep data on material (Titanium) substantially more sensitive to creep than René 41.

VII. TEST HARDWARE, INSTRUMENTATION AND FACILITY

A. Test Hardware

The aluminum simulated injector heads for Appendix B Thermal Tests (seal thermal resistance measurement) and Appendix A Structural Tests were mechanically identical and differed only in the plumbing and sealing features incorporated therein to facilitate pressurizing and heating operations. Storage Tests also used these, in addition to two (2) Apollo preQualification type heads.

Combustors used for thermal tests (Appendix B) were fabricated from TZM material while those used for structural (Appendix A) tests were unalloyed Molybdenum. Storage tests utilized both types. Coating for all combustors was Molybdenum Discilicide.

Split rings and attach rings were identical to current Apollo hardware.

Some of the combustor bolt sets varied from the present Apollo Qualification design only by having undersize shank diameters. Standard Apollo Qualification type bolts were unavailable in time for these tests. During the first few usages of these bolts, some sets were mistakenly over-tightened during assembly and took a permanent set (overall length increased and shank diameter reduced). The methods used to calculate bolt preloads are shown in Figure 28. A typical stress/strain diagram for Apollo Qualification type René 41 bolts is shown in Figure 29. Values for bolt preloads, where yielding occurred, were corrected as required.

B. Instrumentation and Facilities

This report does not cover the instrumentation and test facilities used to conduct (Appendix B) seal thermal resistance measurement tests. Tools and equipment used for pre and post-test seal leakage tests, however, were the same as those used for (Appendix A) structural tests. Current Apollo production tooling and practices were utilized. These pressure tests were performed in the Marquardt Precision Assembly Department in Building No. 3.

All structural static tests (except storage tests) were conducted in the MJL Structures Laboratory, Building No. 31.

Heat soakback and high temperature creep tests utilized the radiant heat oven and power control panel shown in Figures 8, 9 and 10. Head and combustor temperatures were monitored through C/A thermocouples and recorded on Brown Internal Reference Point Recorders.

Chamber pressure spike and seal cavity propellant explosion hydrostatic simulation tests were conducted in Building No. 31 and utilized the hydraulic test bench and equipment shown in Figures 20 and 21. Alcohol was used as the pressurant. An alcohol and dry ice bath was used to obtain a temperature of 0°F for the chamber pressure spike test. Temperature was monitored intermittently with I/C thermocouples.

The 30-day storage test was conducted in a thermostatically controlled electric oven (Figures 5 and 6) in Building No. 16 of the MJL.

REFERENCES:

1. Second Quarter Report, PR 3008-2Q, Apollo Service Module Reaction Control System Engine Injector/Chamber Seal Study, dated February 1966.

TABULATION - LEAKAGE VS. PRELOAD, STRUCTURAL STATIC TESTS

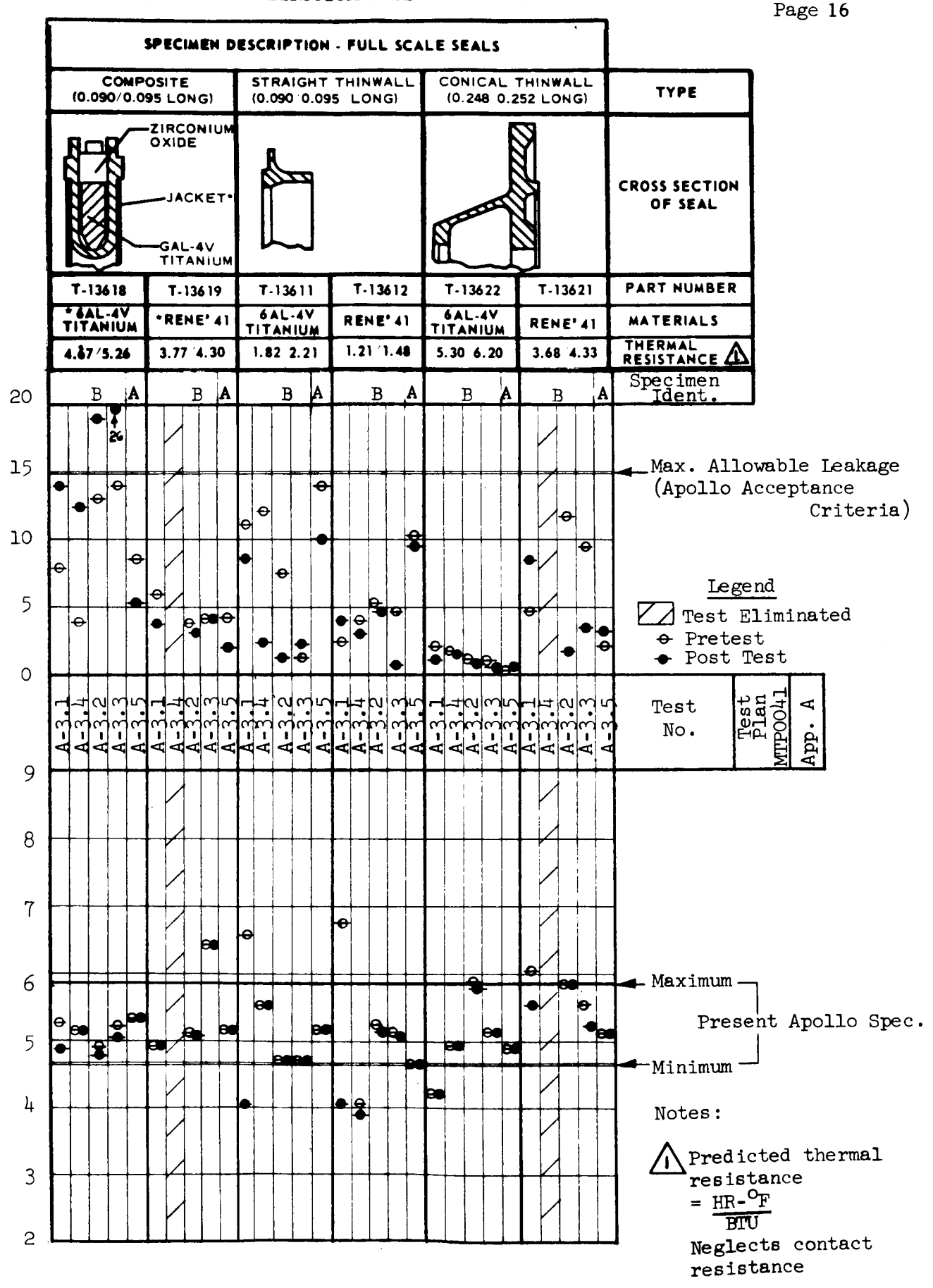


FIGURE 1

TABULATION - LEAKAGE VS. PRELOAD, THERMAL TESTS

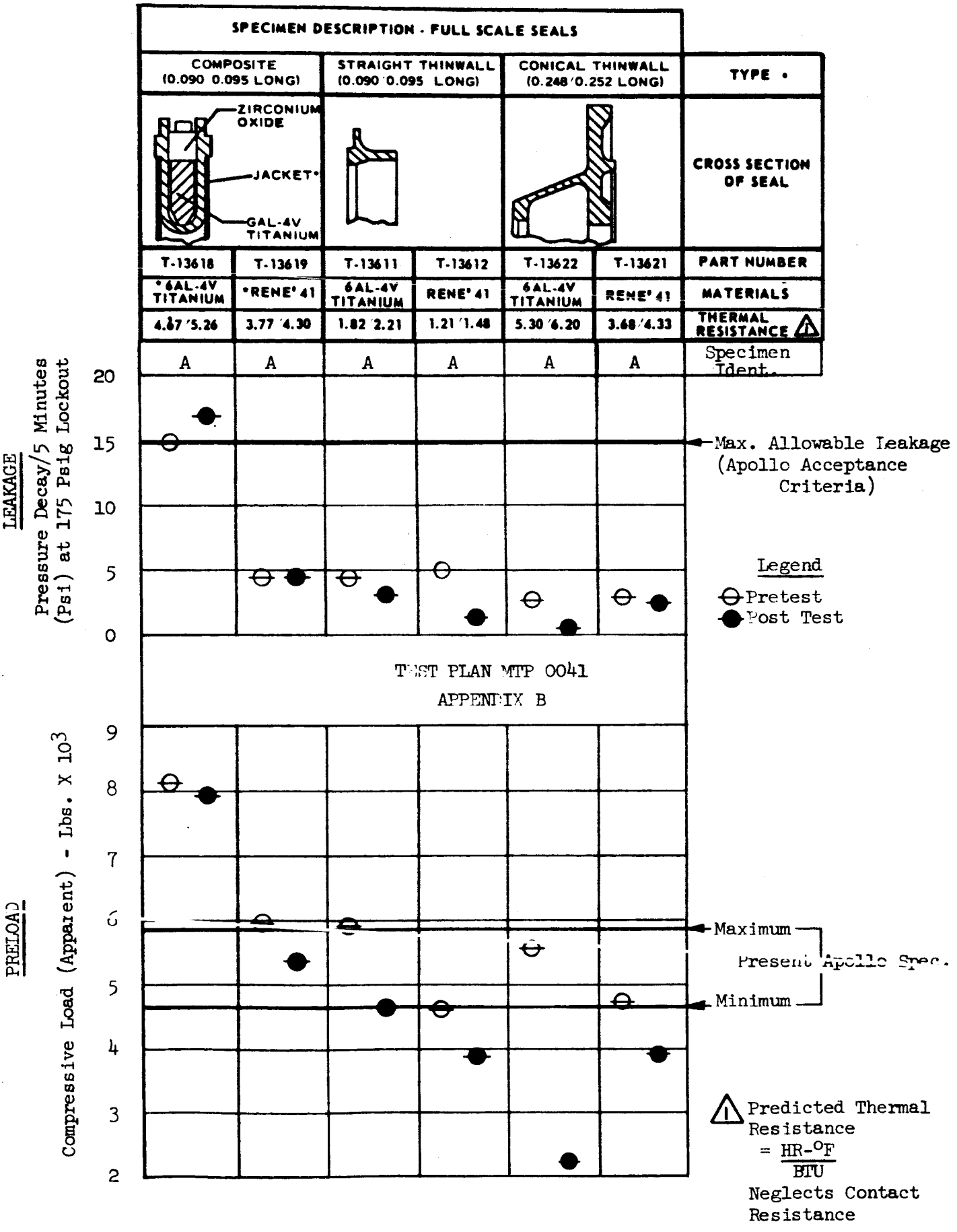
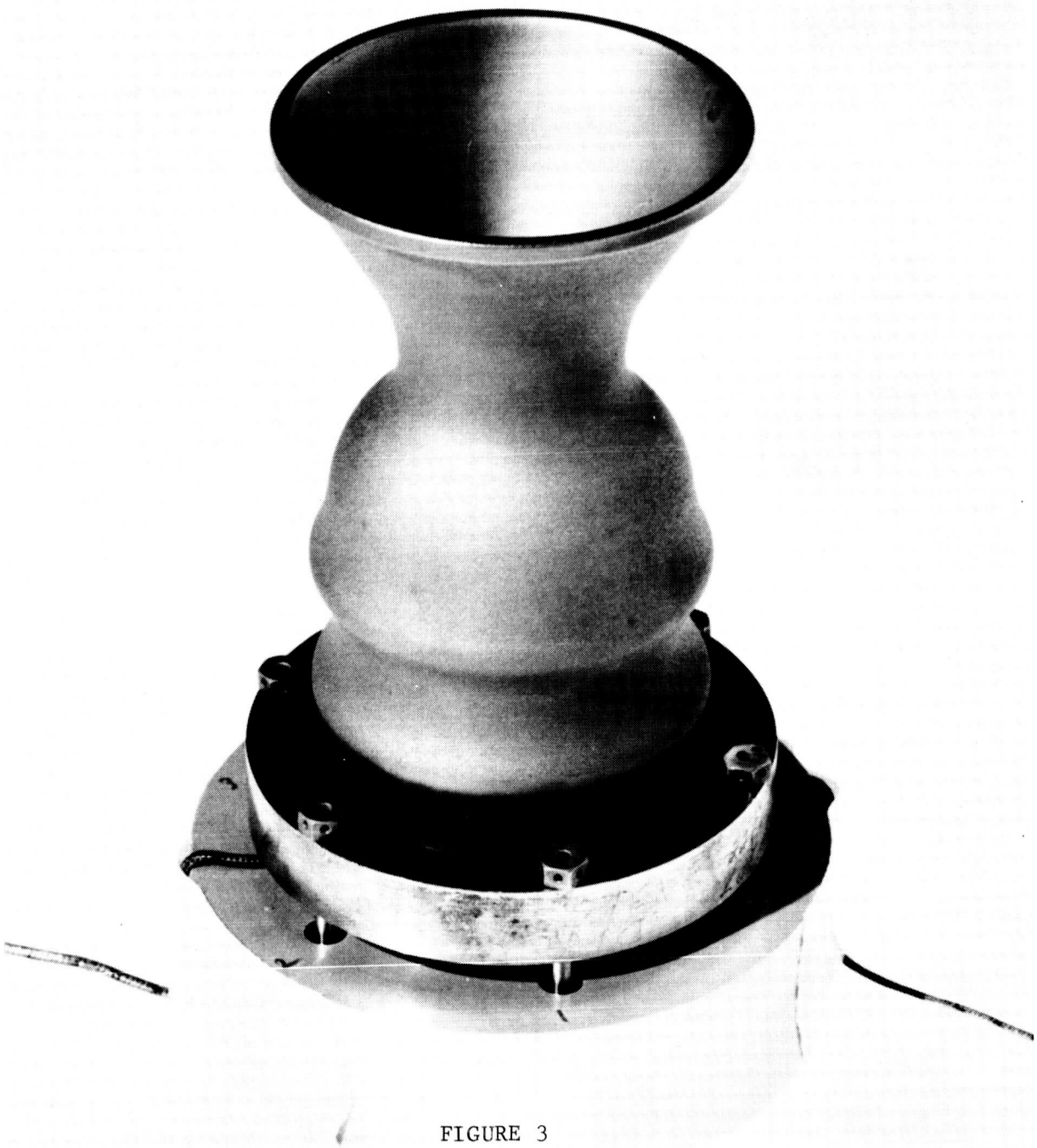


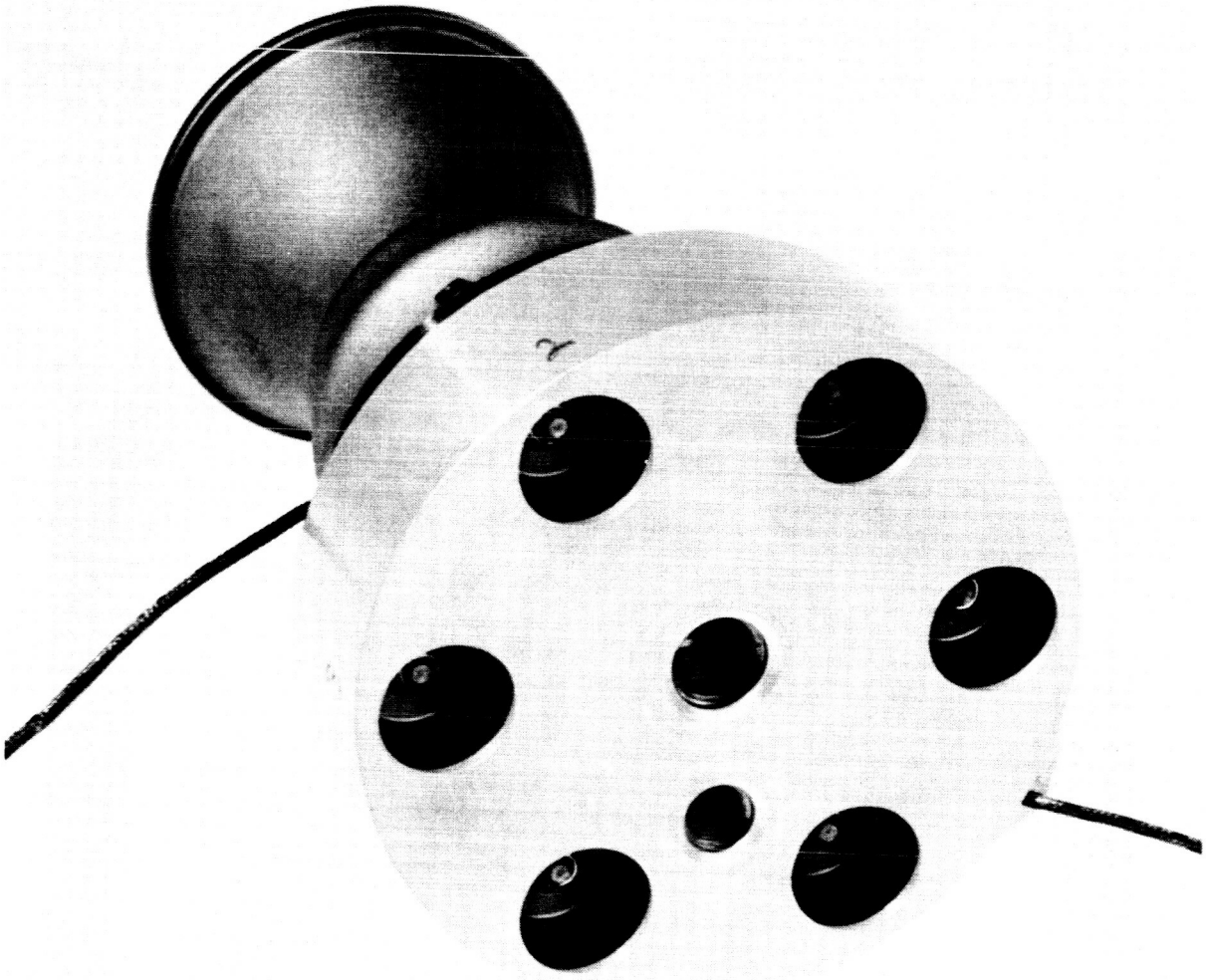
FIGURE 2



STRUCTURAL TEST RIG-- CHAMBER SEAL STUDY

NEG. 7008-2

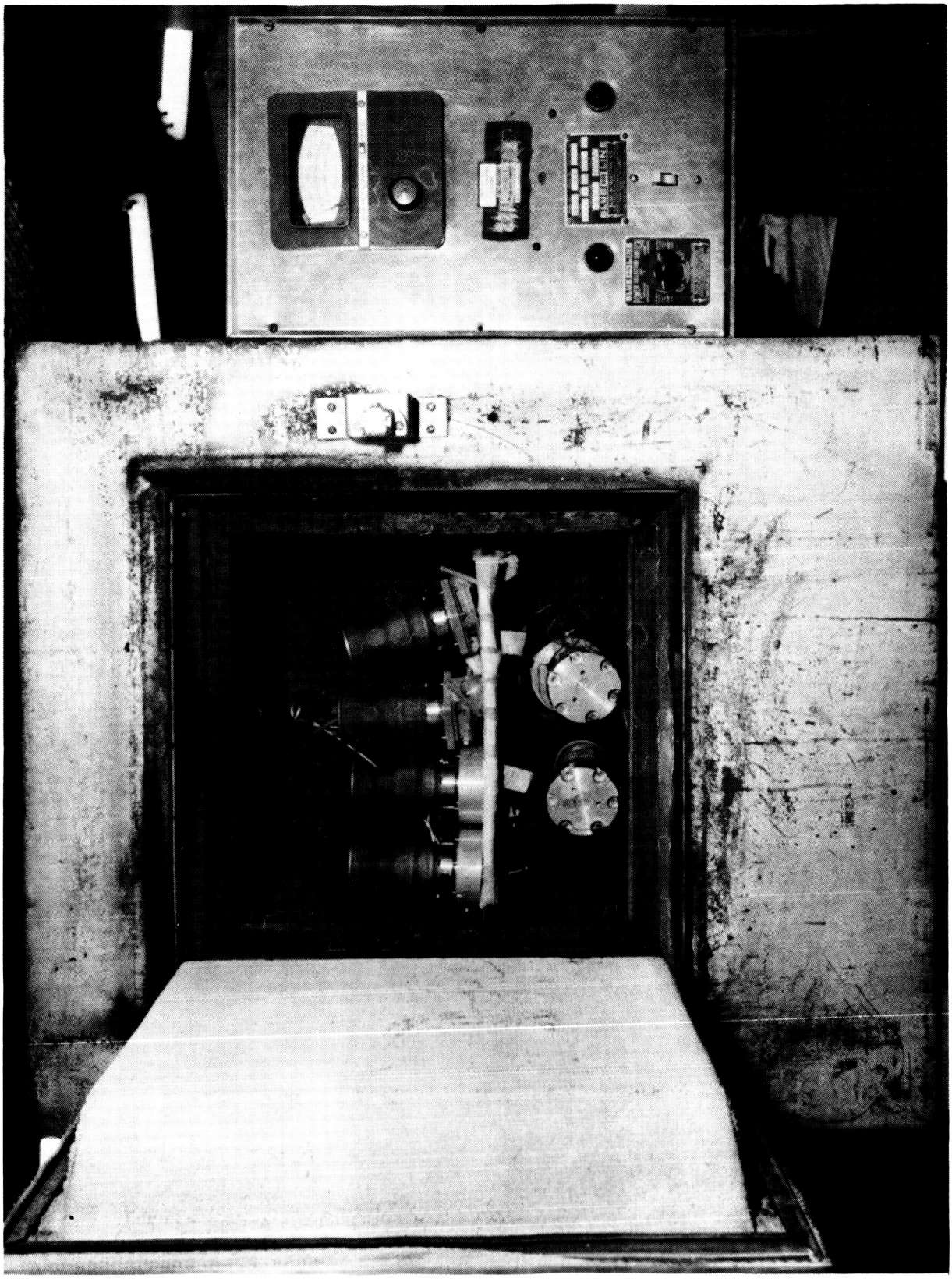
FIGURE 3



NEG. 7008-1

STRUCTURAL TEST RIG--CHAMBER SEAL STUDY

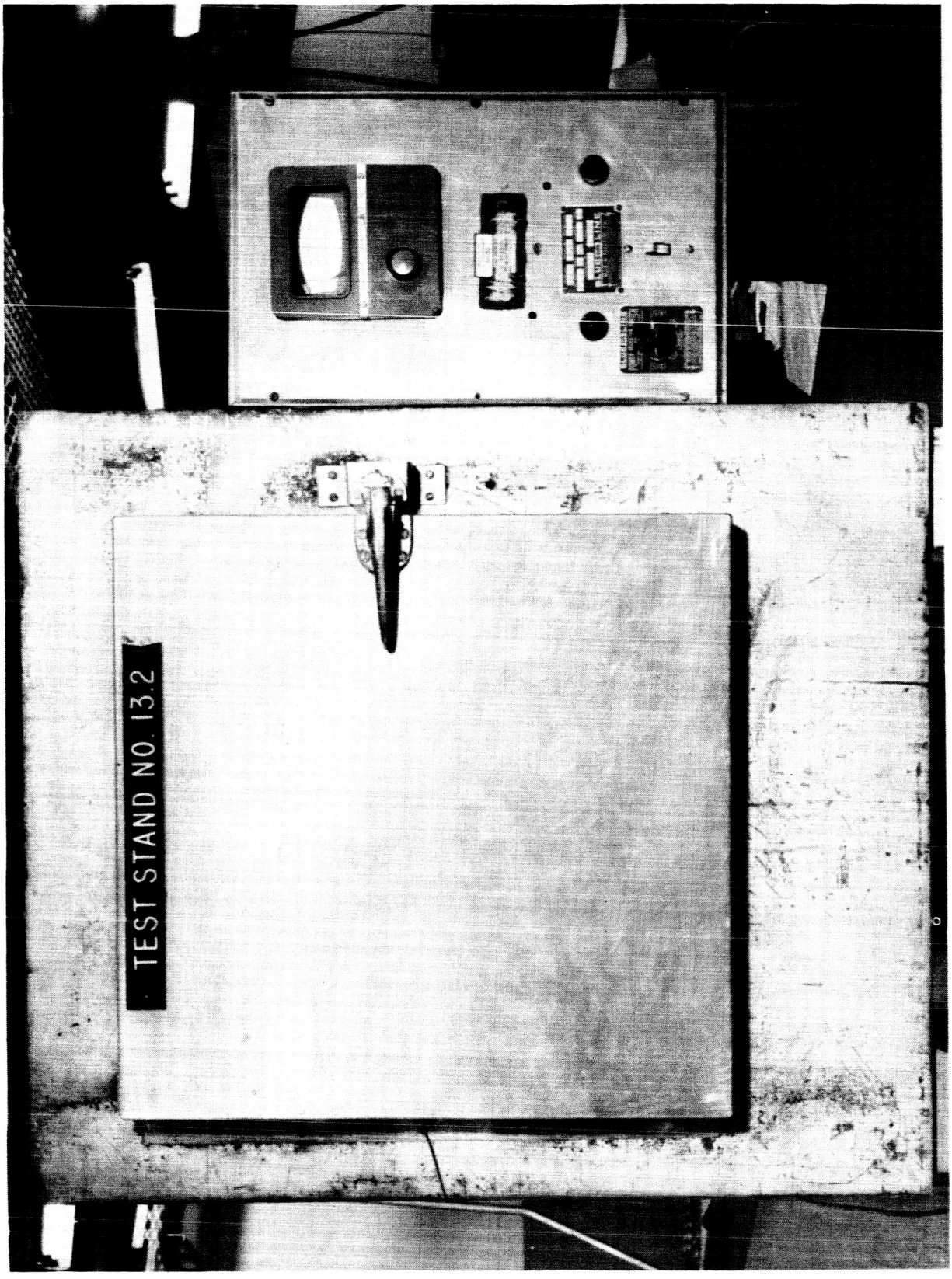
FIGURE 4



NEG. T11267-22

STORAGE TEST OVEN (OPEN) - 30 DAY CREEP

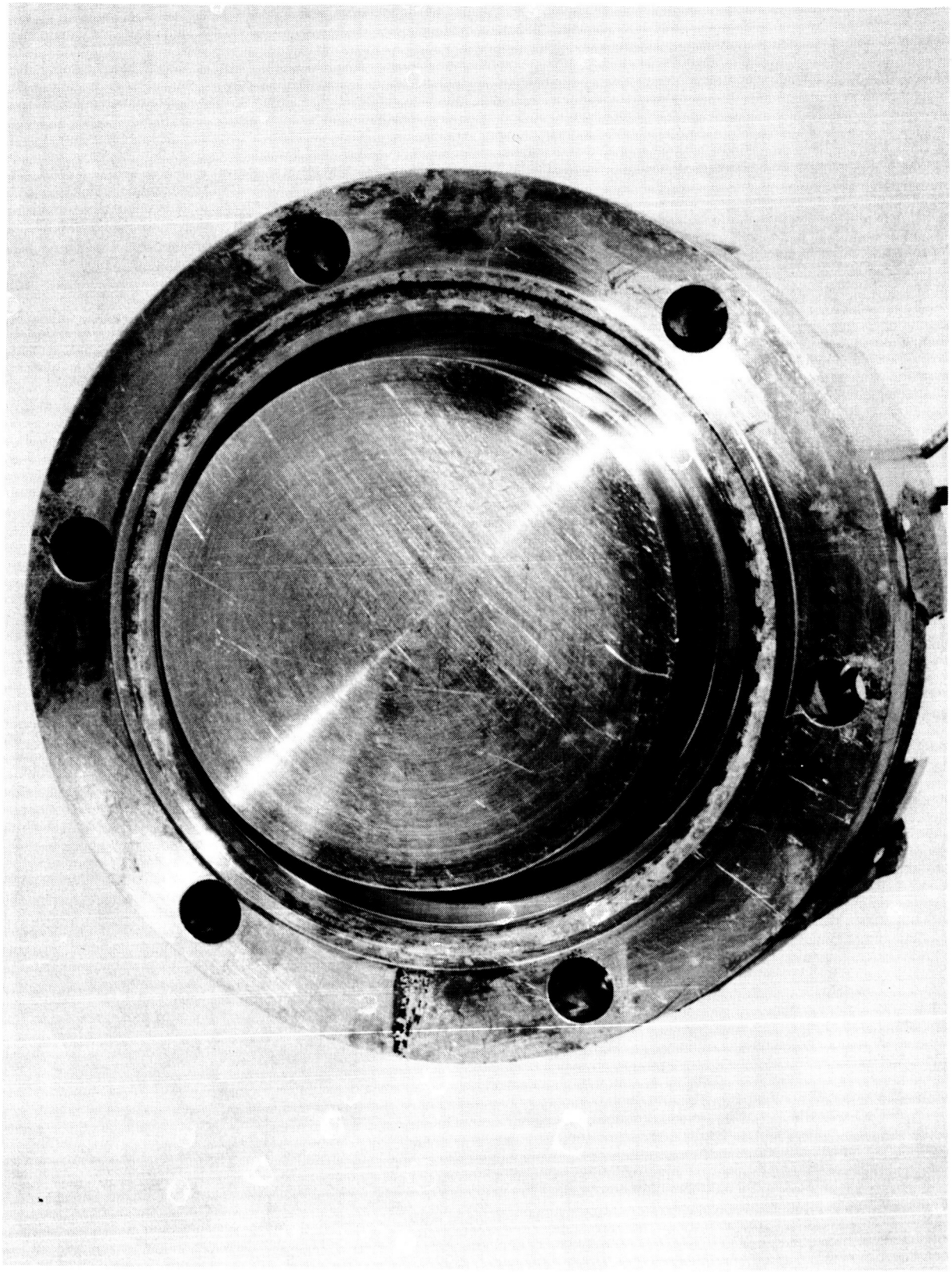
FIGURE 5



NEG. T11267-21

STORAGE TEST OVEN (CLOSED) - 30 DAY CREEP

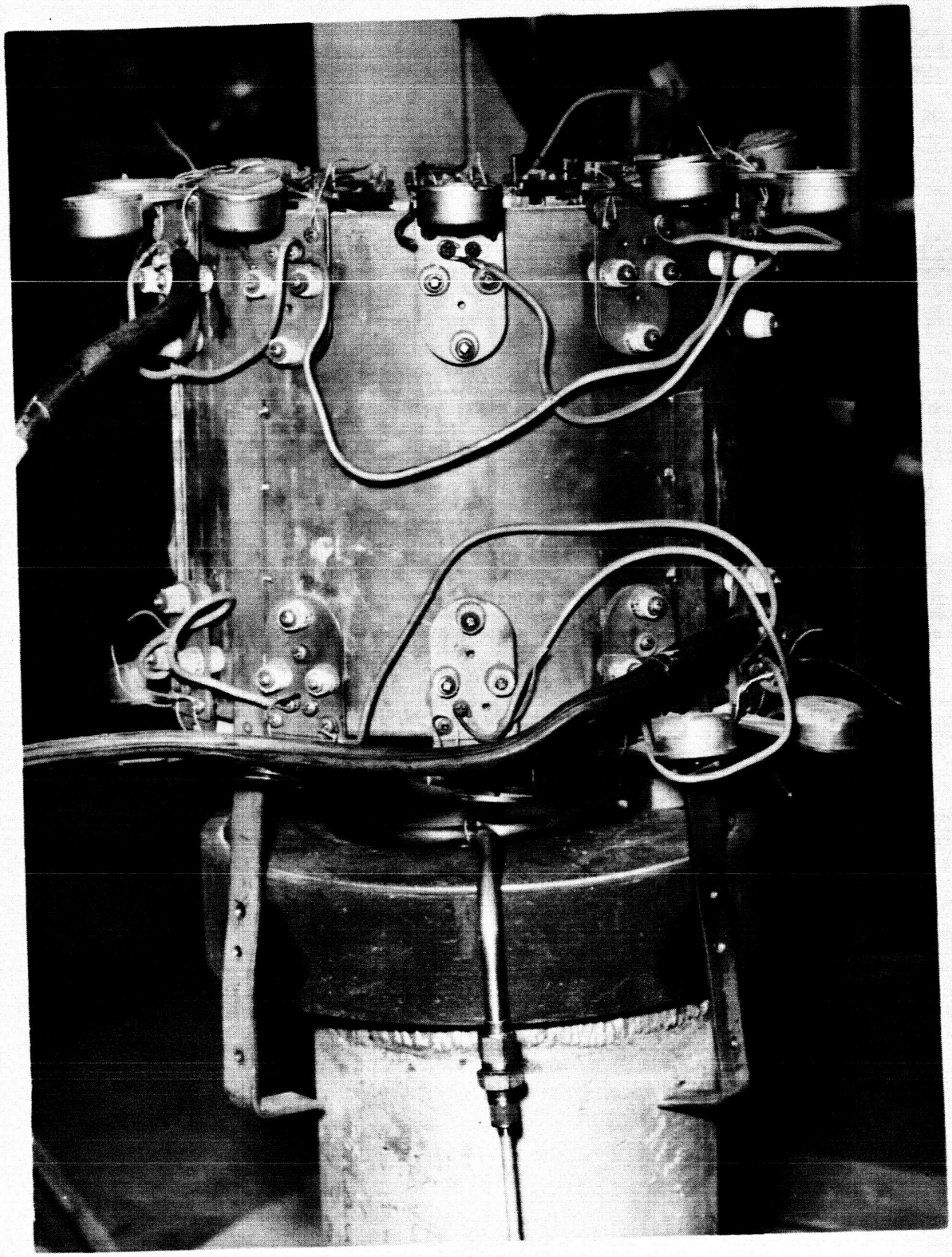
FIGURE 6



NEG. T11267-18

BURNISHED BEARING AREA - THERMAL TEST RIG HEAD #2
(Appendix B, T-13621, S/N A)

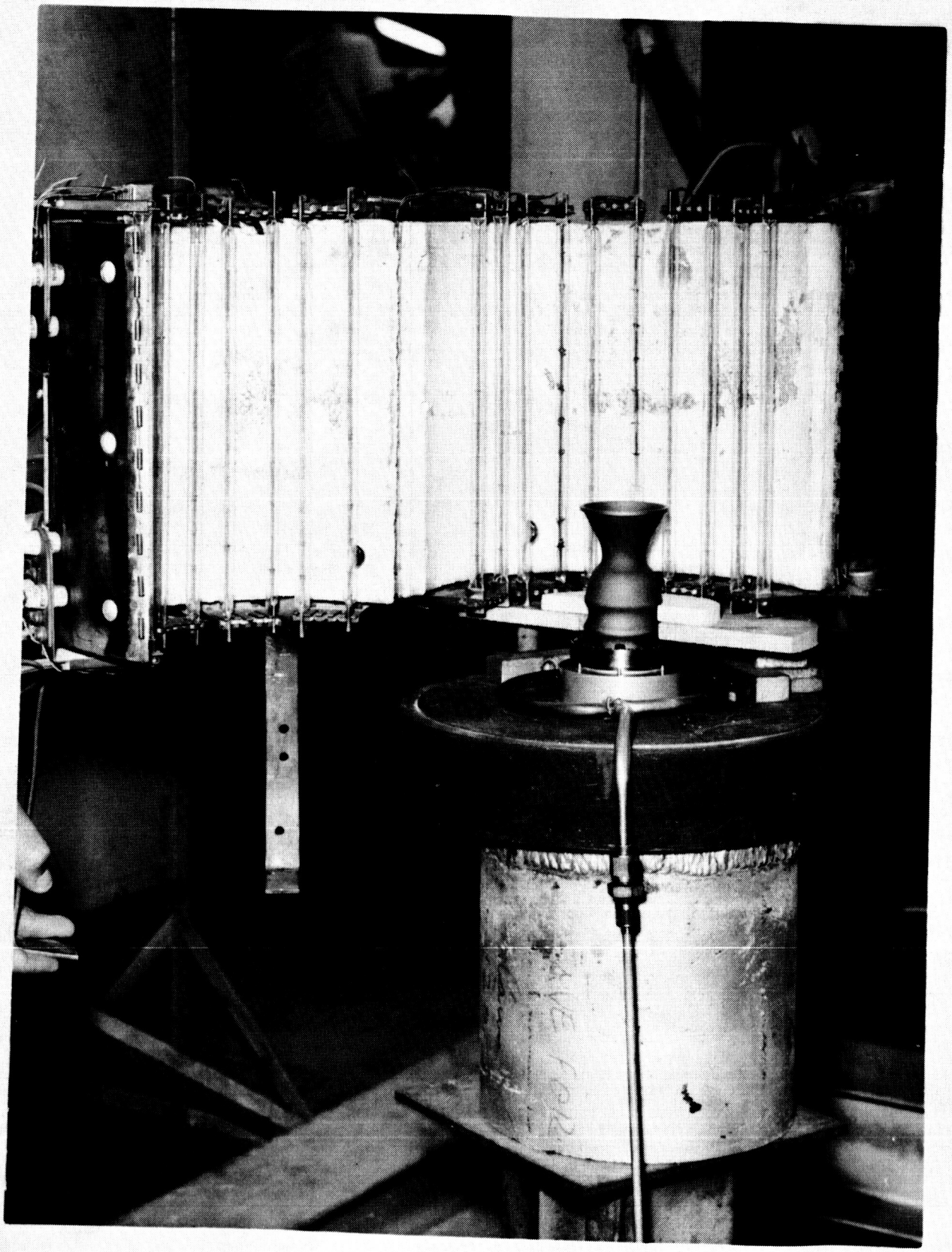
FIGURE 7



NEG. T11267-5

TEST 11267 3008 SEAL PROGRAM - RADIANT OVEN
BLDG. 31 STRUCTURAL THERMAL TEST SETUP (U)
12 JAN 66

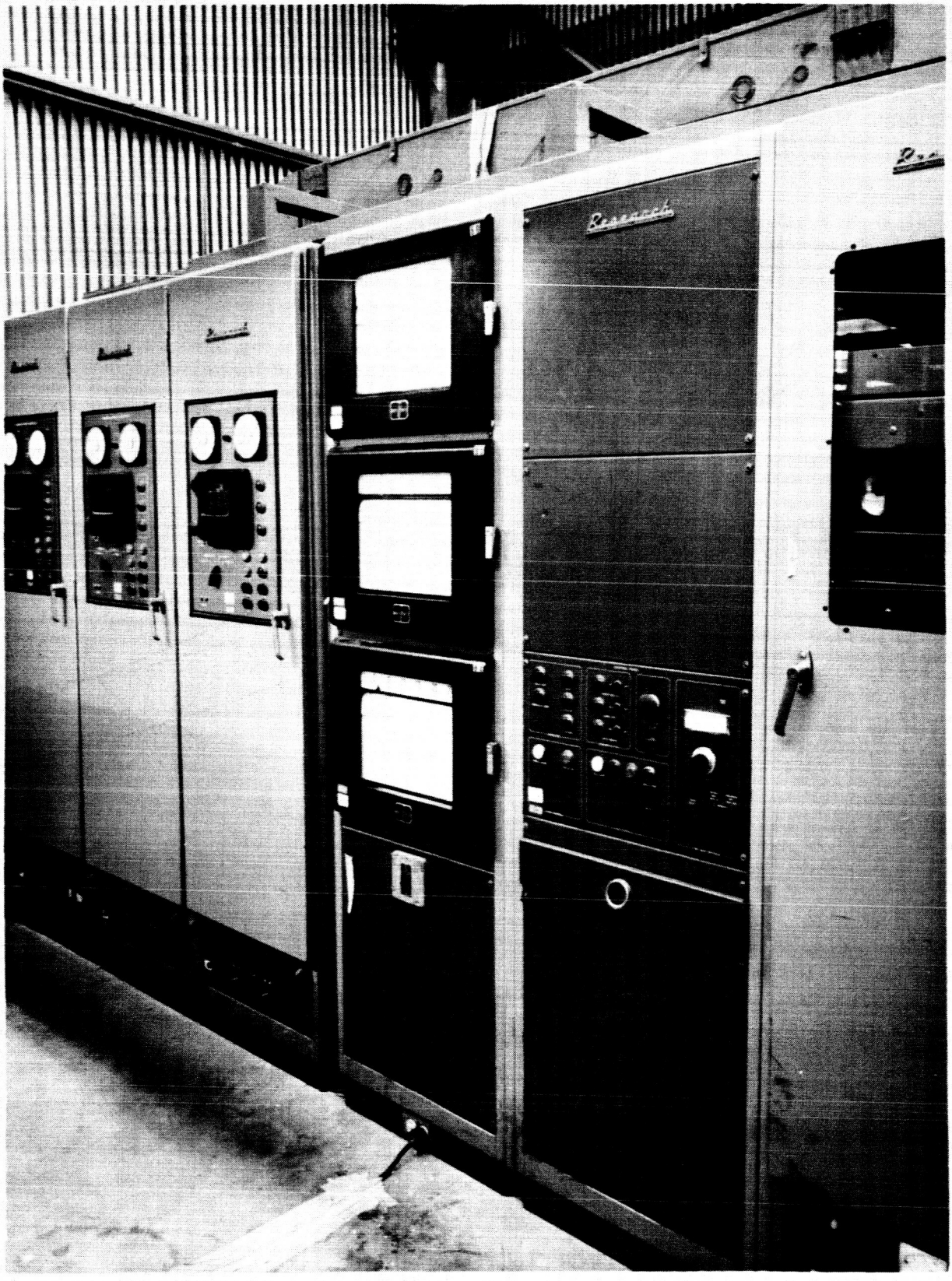
FIGURE 8



TEST 11267 3008 SEAL PROGRAM - RADIANT OVEN
BLDG. 31 STRUCTURAL THERMAL TEST SETUP
12 JAN 66 (U)

NEG. T11267-6

FIGURE 9



TEST 11267
BLDG. 31
12 JAN 66

3008 SEAL PROGRAM
RADIANT HEAT POWER CONTROL PANEL
(U)

NEG. T11267-4

FIGURE 10

SIMULATED ENGINE HEAT SOAKBACK - TEST A-3.1

COMPARISON OF ACTUAL TEST DATA & TEST PLAN REQUIREMENTS - TEMPERATURE VS. TIME

Seal Specimen	
Part No.	T-13611
S/N	B

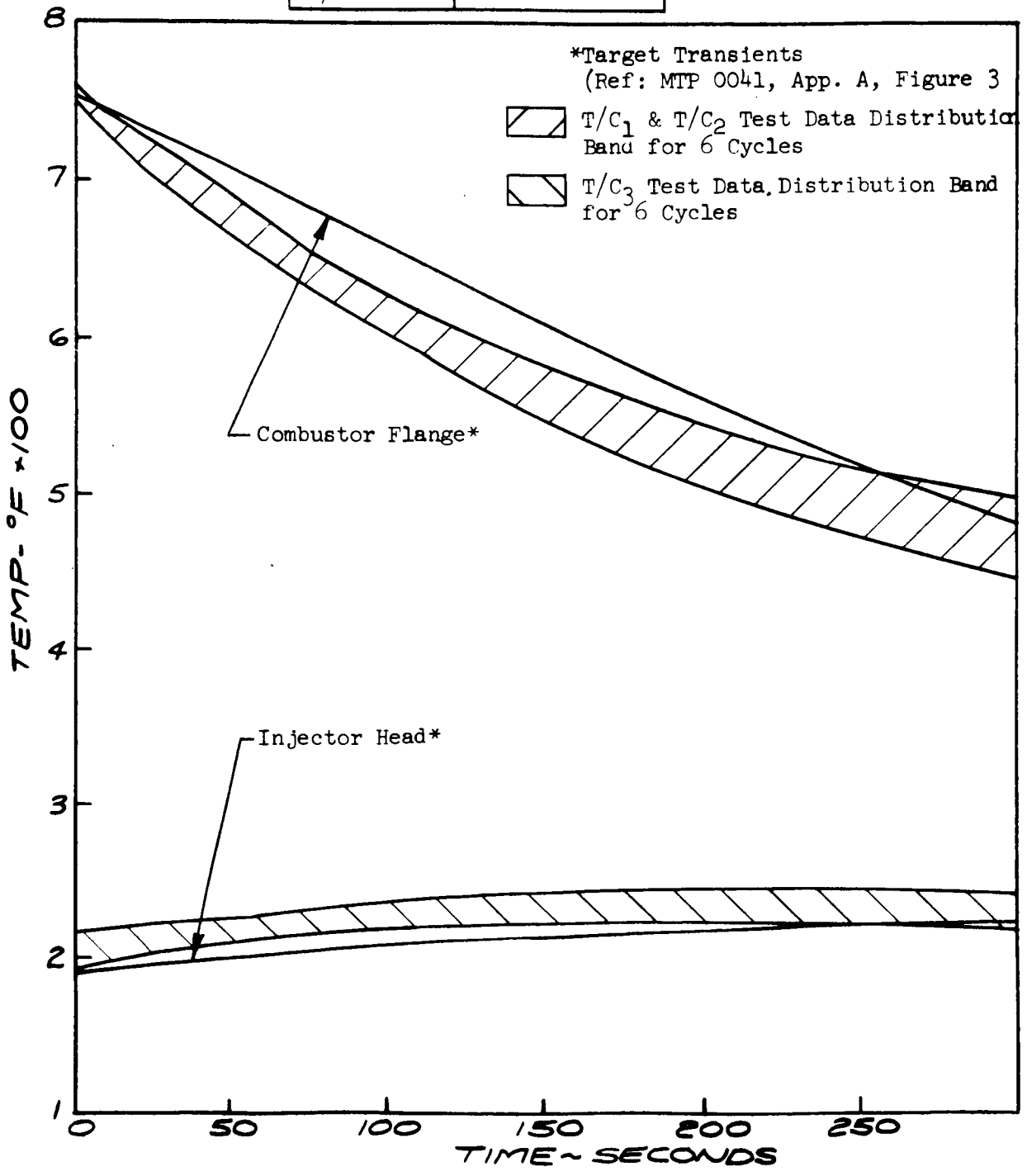


FIGURE 11

SIMULATED ENGINE HEAT SOAKBACK - TEST A-3.1

COMPARISON OF ACTUAL TEST DATA & TEST PLAN REQUIREMENTS - TEMPERATURE VS. TIME

Seal Specimen	
Part No.	T-13612
S/N	B

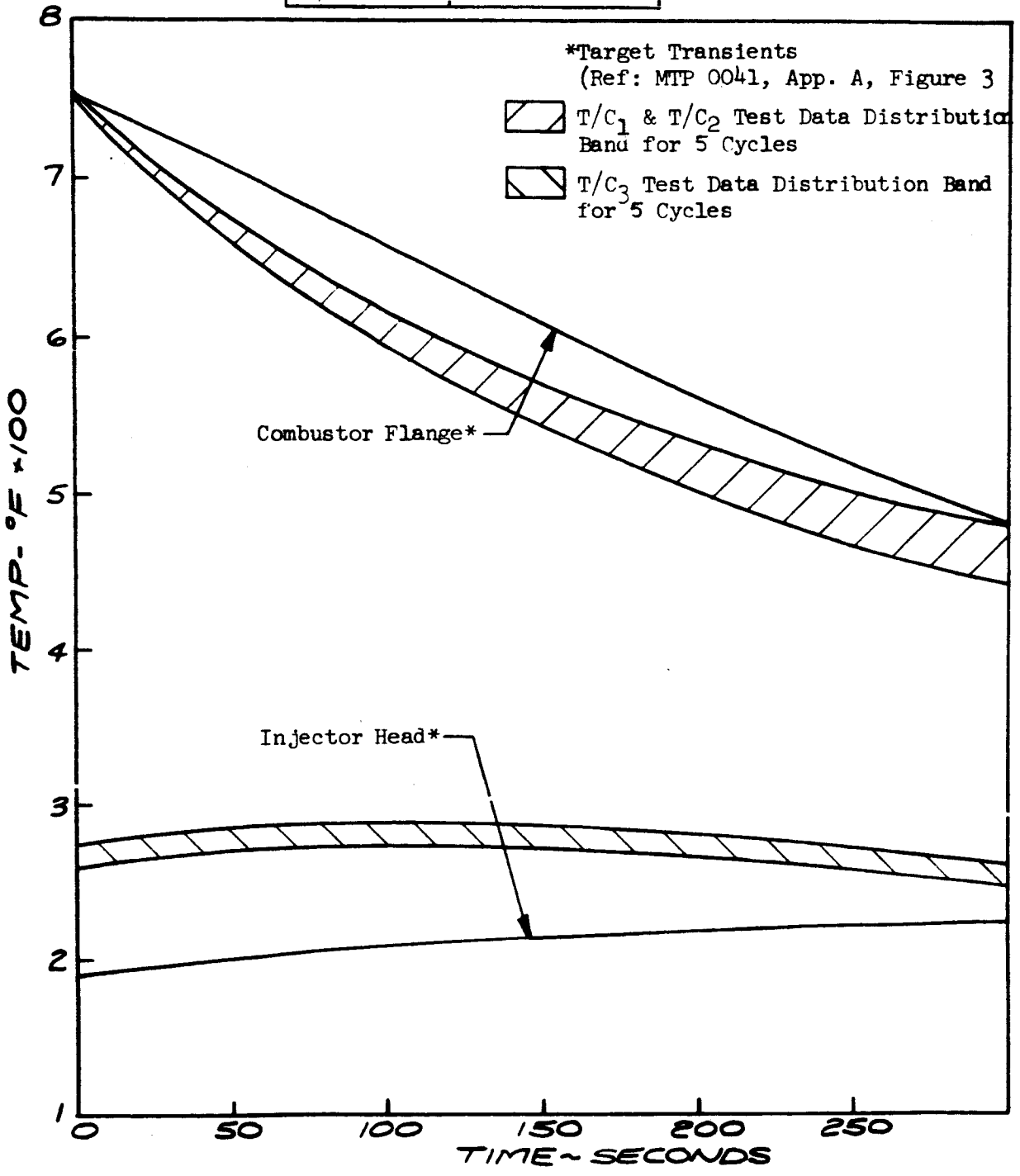


FIGURE 12

SIMULATED ENGINE HEAT SOAKBACK - TEST A-3.1

COMPARISON OF ACTUAL TEST DATA & TEST PLAN REQUIREMENTS - TEMPERATURE VS. TIME

Seal Specimen	
Part No.	T-13618
S/N	B

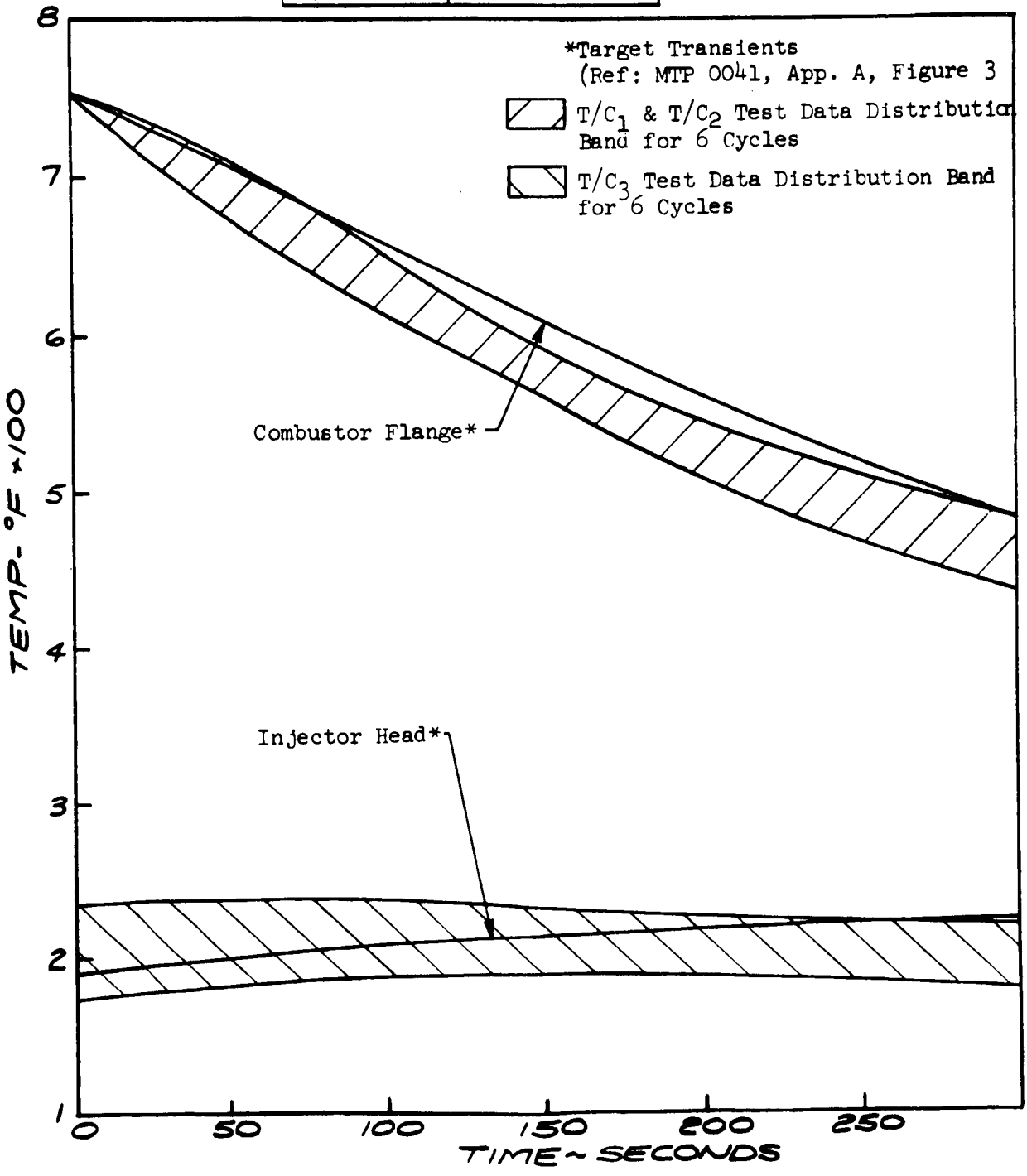


FIGURE 13

SIMULATED ENGINE HEAT SOAKBACK - TEST A-3.1

COMPARISON OF ACTUAL TEST DATA & TEST PLAN REQUIREMENTS - TEMPERATURE VS. TIME

Seal Specimen	
Part No.	T-13619
S/N	B

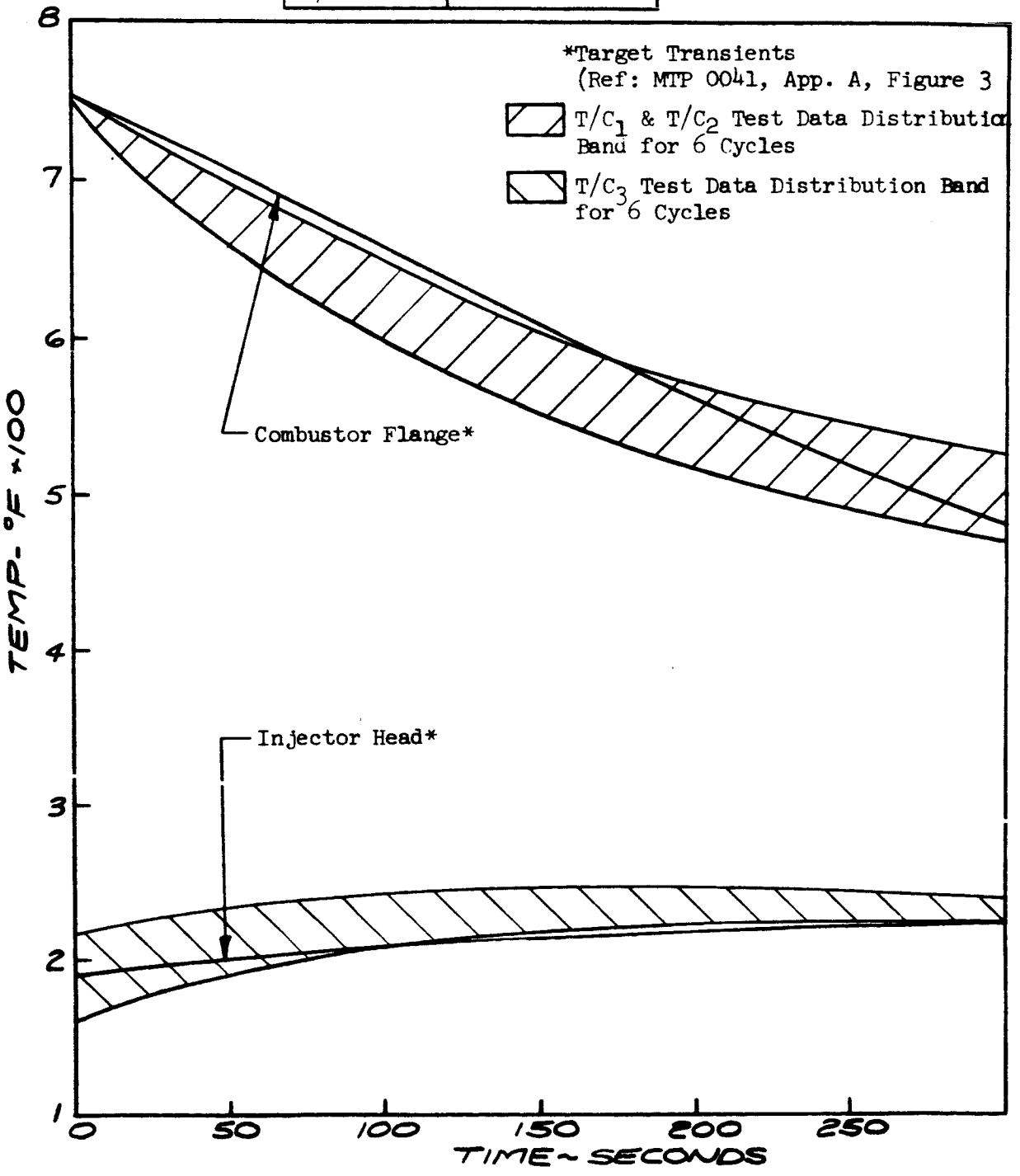


FIGURE 14

SIMULATED ENGINE HEAT SOAKBACK - TEST A-3.1

COMPARISON OF ACTUAL TEST DATA & TEST PLAN REQUIREMENTS - TEMPERATURE VS. TIME

Seal Specimen	
Part No.	T-13622
S/N	B

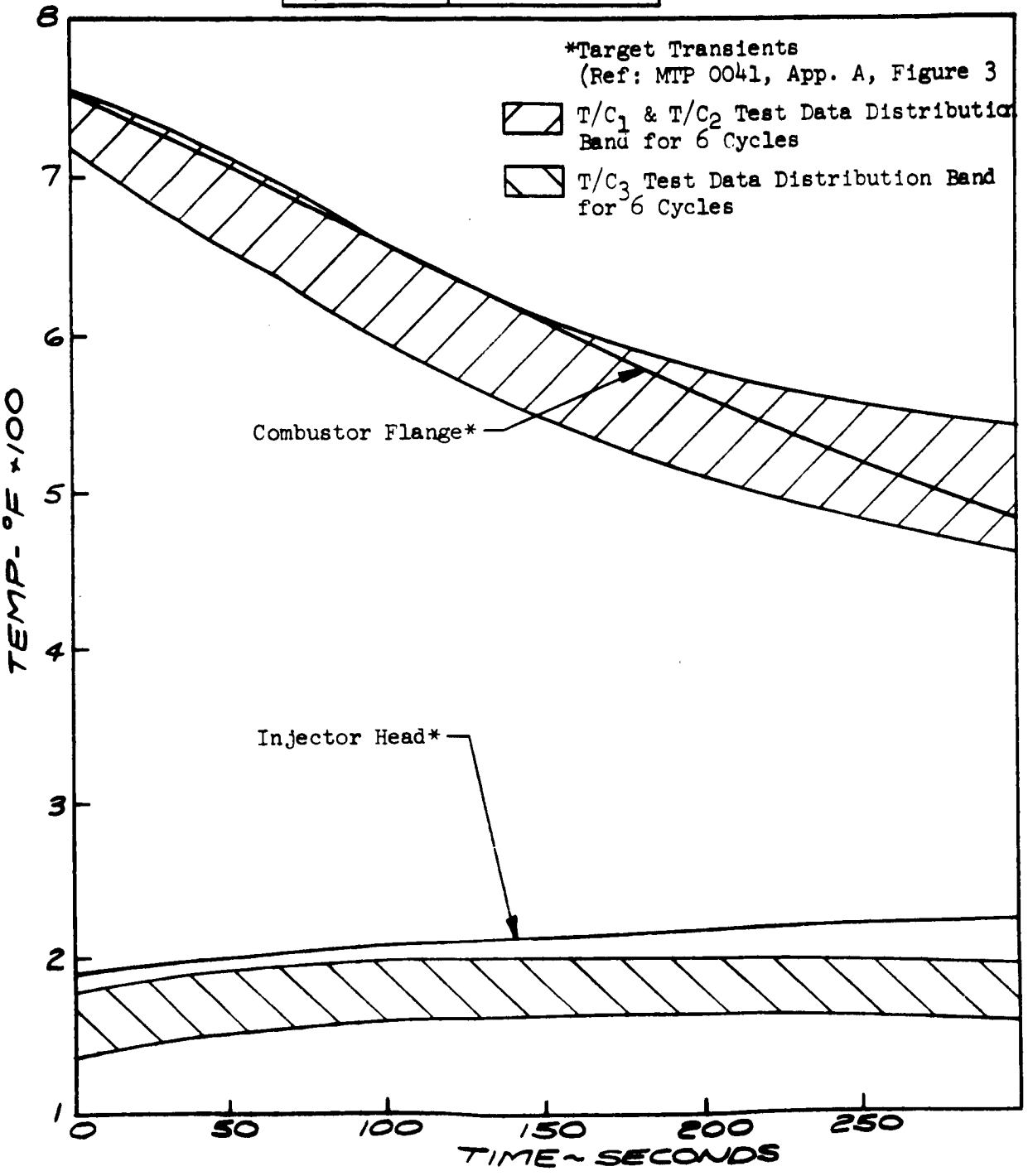


FIGURE 15

SIMULATED ENGINE HEAT SOAKBACK - TEST A-3.1

COMPARISON OF ACTUAL TEST DATA & TEST PLAN REQUIREMENTS - TEMPERATURE VS. TIME

Seal Specimen	
Part No.	T-13621
S/N	B

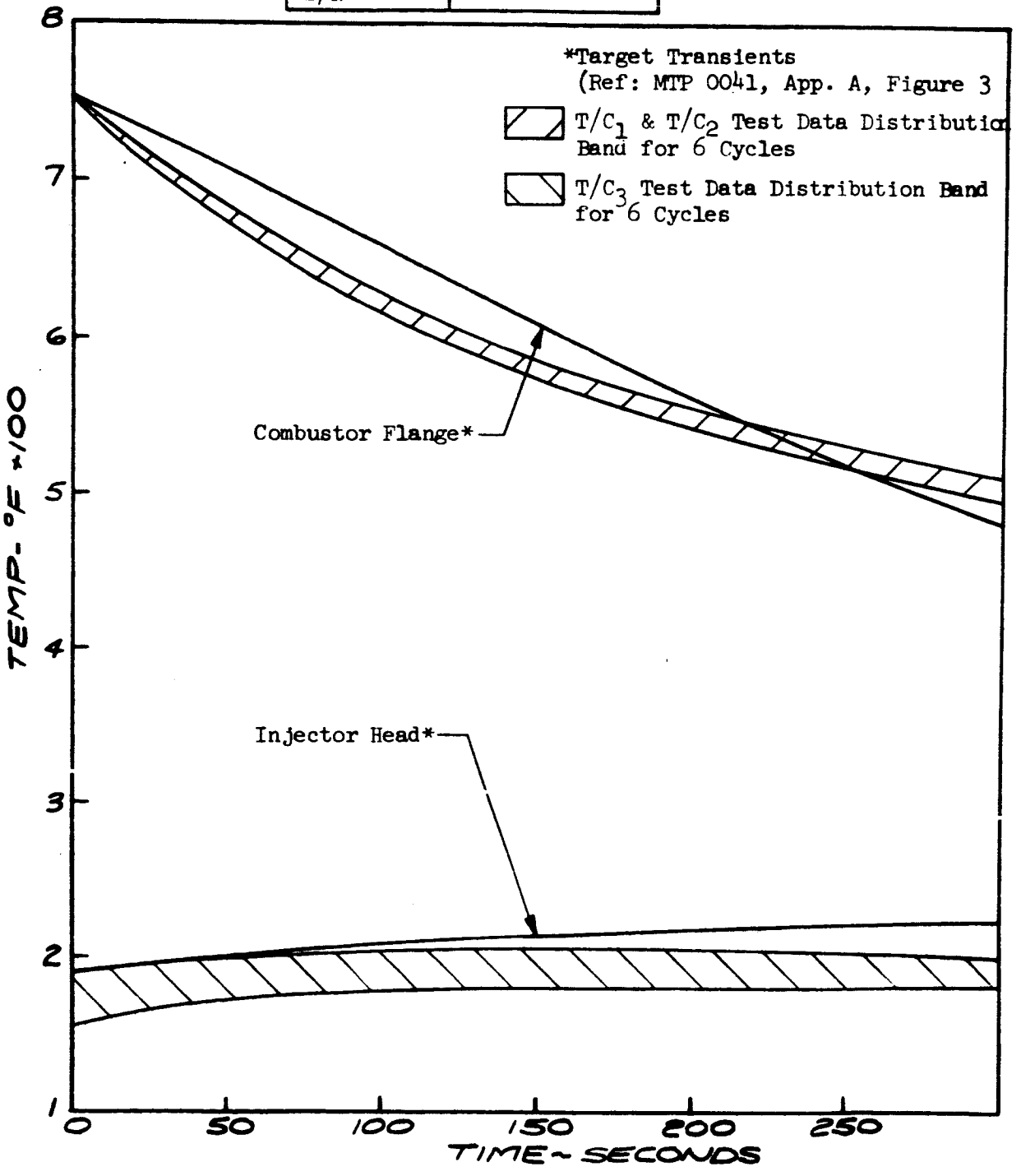


FIGURE 16

SIMULATED CREEP (SHORT TERM/HI TEMPERATURE) - TEST A-3.4

COMPARISON OF ACTUAL TEST DATA & TEST PLAN
REQUIREMENTS - TEMPERATURE VS. TIME (1 CYCLE)

SEAL SPECIMENS				
Part No. S/N	T-13611 B	T-13612 B	T-13618 B	T-13622 B

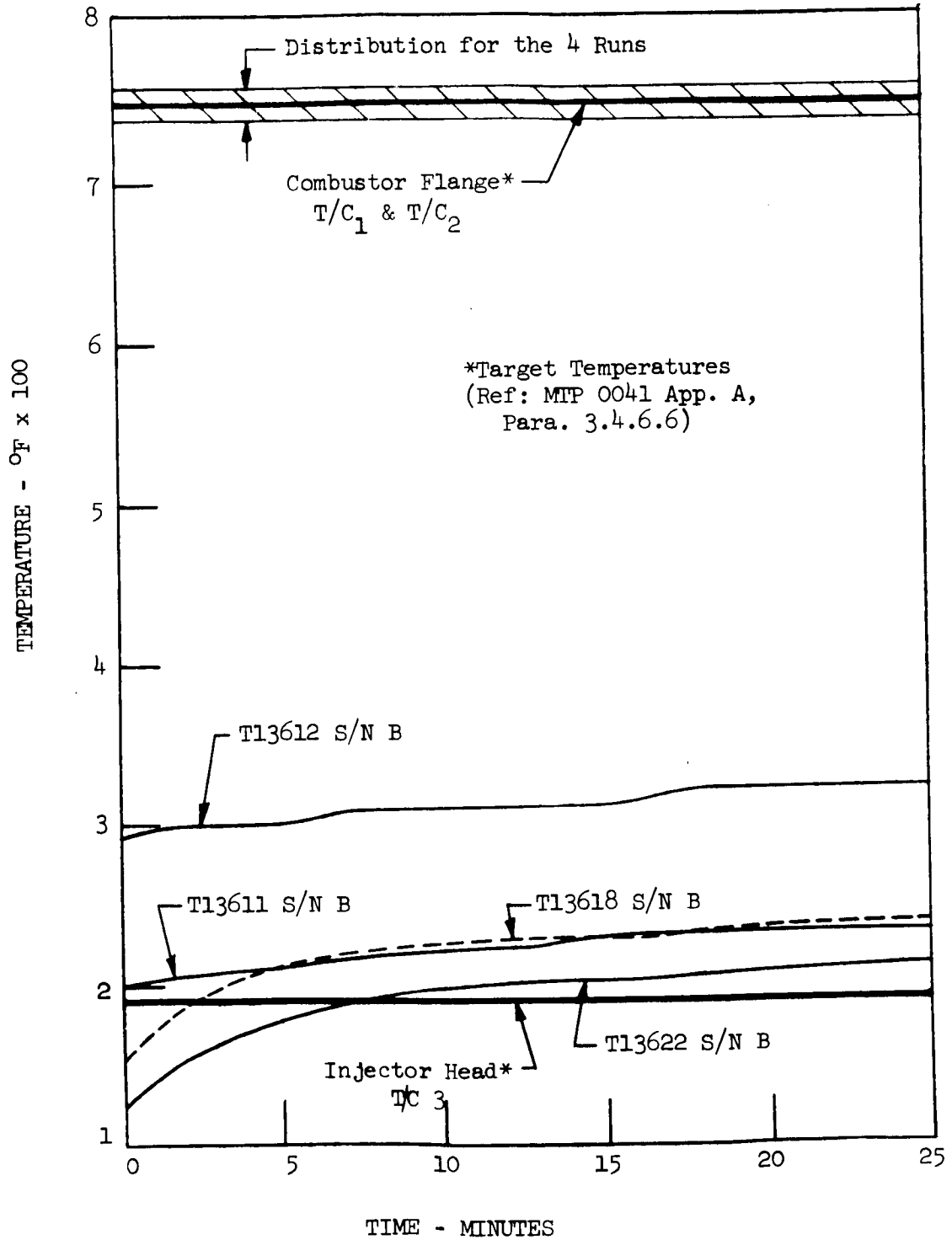
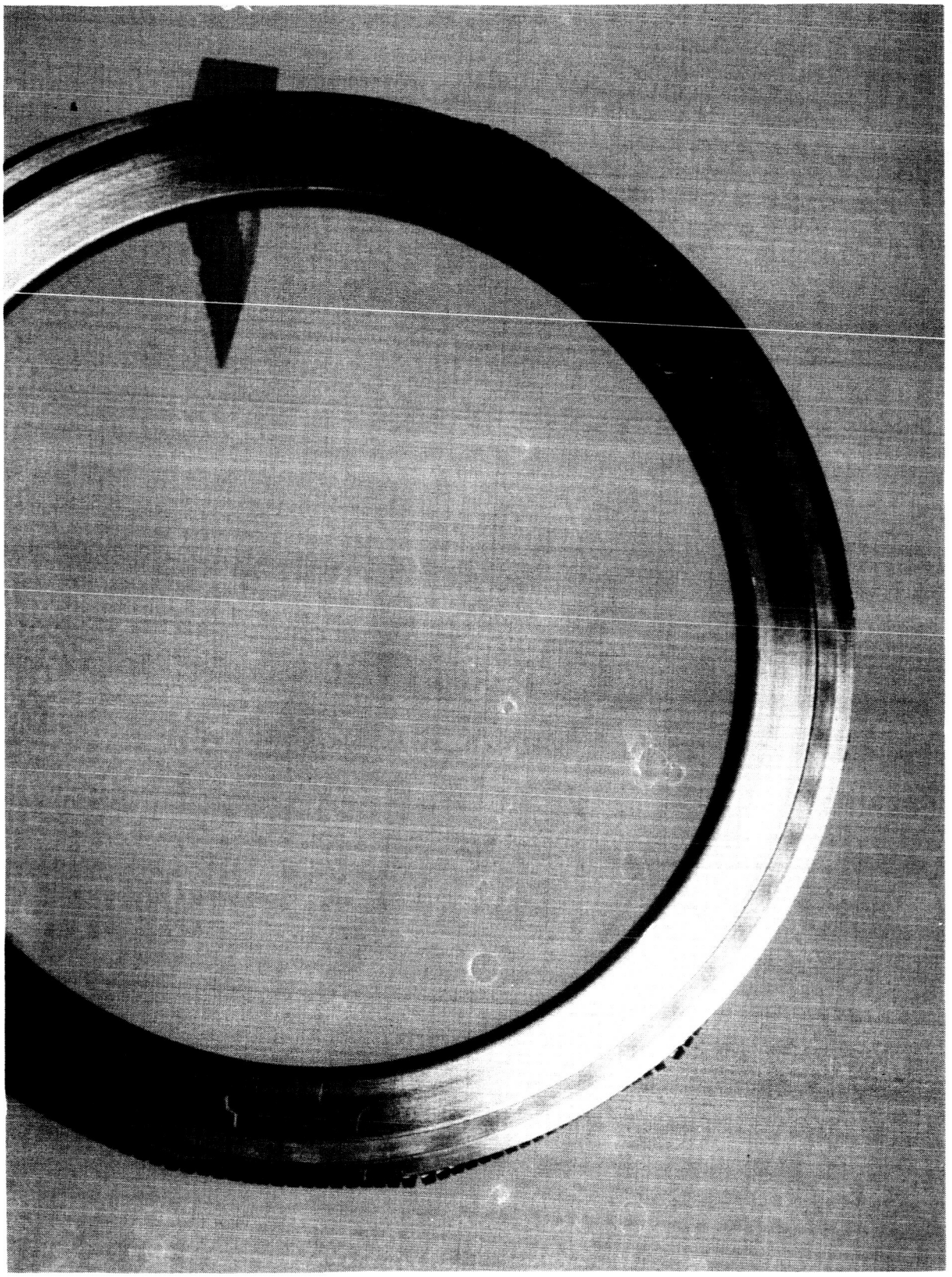


FIGURE 17



NEG. T11267-13

HEAT STAINS, COMBUSTOR SIDE - P/N T 13618, S/N B
(Appendix A, A-3.1)

FIGURE 18

TEST RESULTS

TEST A-3.2 SIMULATED CHAMBER PRESSURE SPIKE

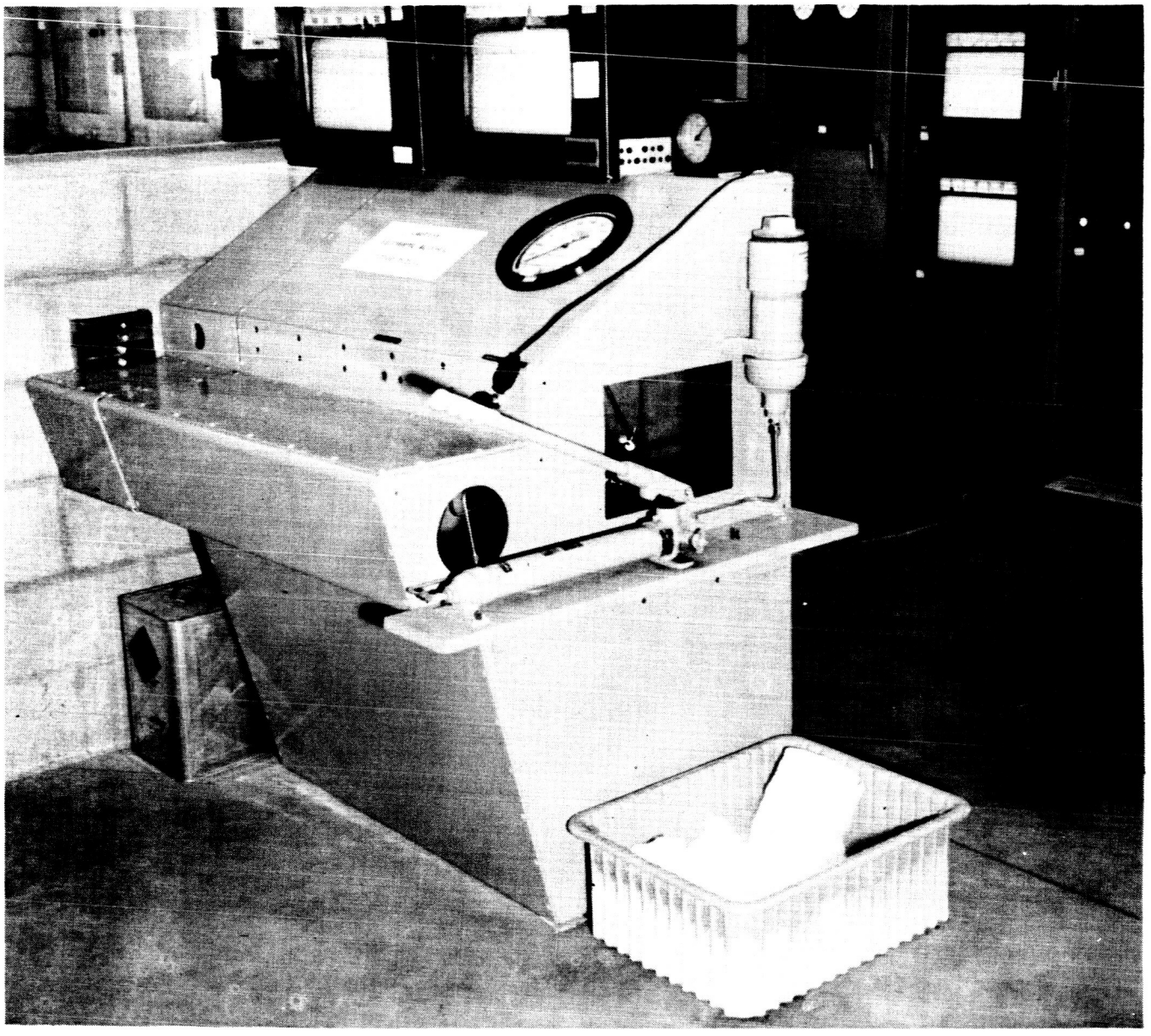
P/N	LEAKAGE IN 1 MIN (PSIG) AT						TEMP. RANGE °F
	200	400	600	800	1000	1200	
T-13622	1	59	66	170	180	132	0 TO +3
T-13621	9	45	30	75	100	110	+1 TO +3
T-13619	10	30	65	95	105	120	-4 TO 0
T-13618	20	40	90	100	120	150	0 TO +1
T-13611	5	10	60	100	100	120	+1 TO +4
T13612	10	45	100	100	120	105	+1 TO +2

TEST A-3.3 CAVITY EXPLOSION

P/N	SEALING * FAILURE (PSIG)
T-13622	4,600
T-13621	4,600
T-13619	3,650
T-13618	2,400
T-13611	4,000
T-13612	4,000

* DEFINED AS GROSS LEAKAGE FROM SEAL (LEAKAGE RATES NOT RECORDED)

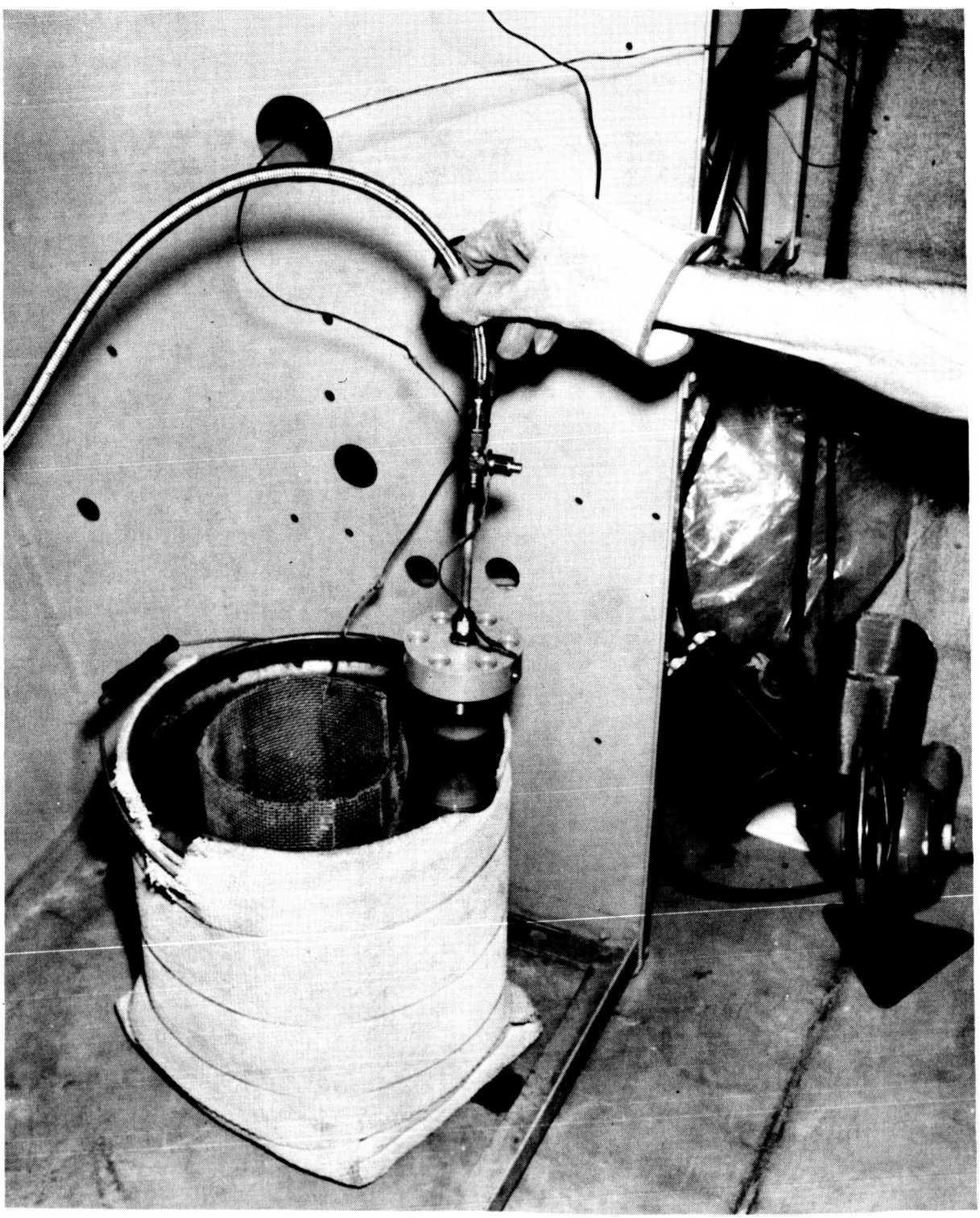
FIGURE 19



NEG. T11267-12

HYDRAULIC TEST BENCH - (Appendix A, A-3.2 and A-3.3)

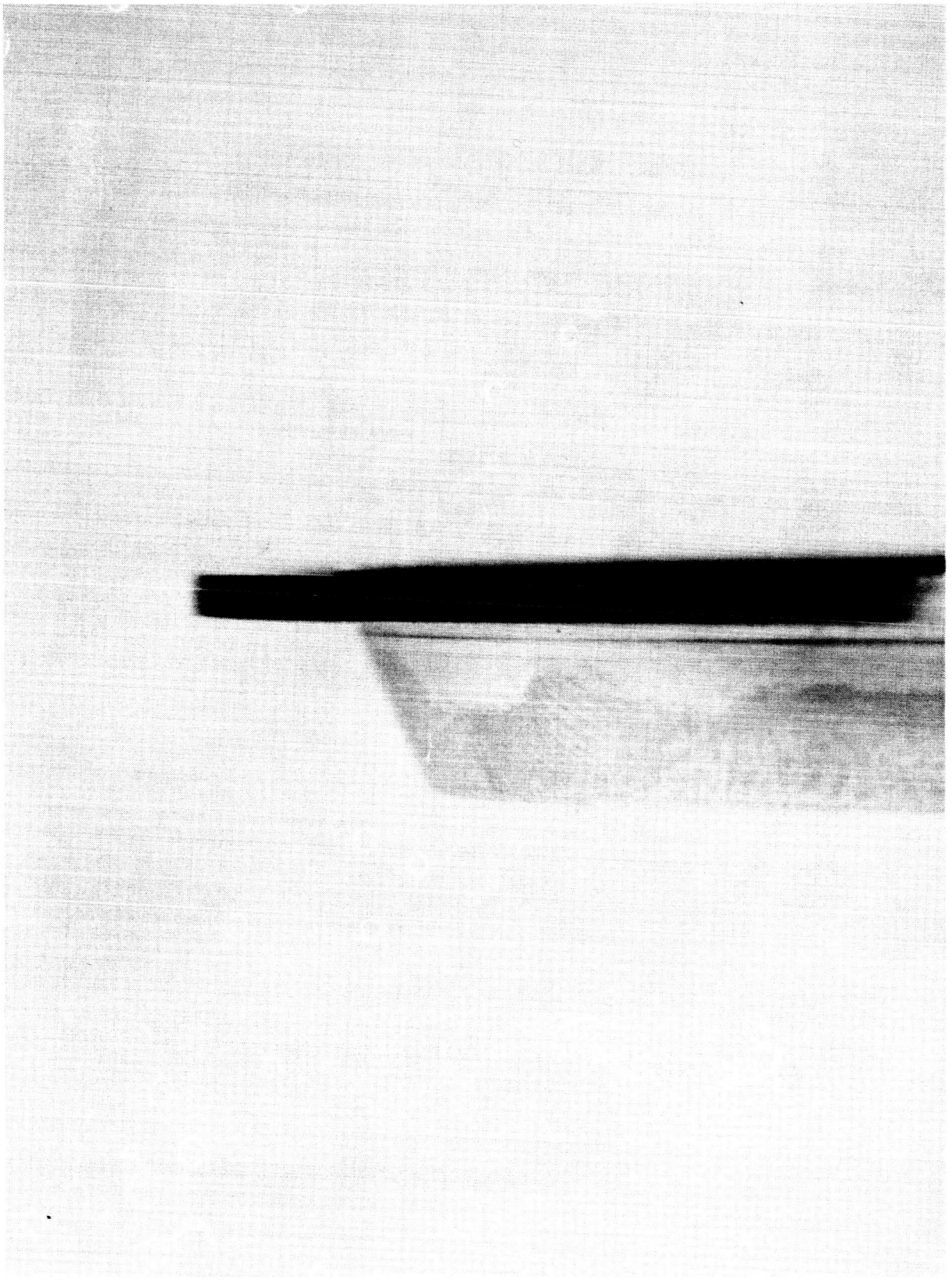
FIGURE 20



NEG. T11267-11

HYDROSTATIC TEST SETUP (Appendix A, A-3.2 and A-3.3)

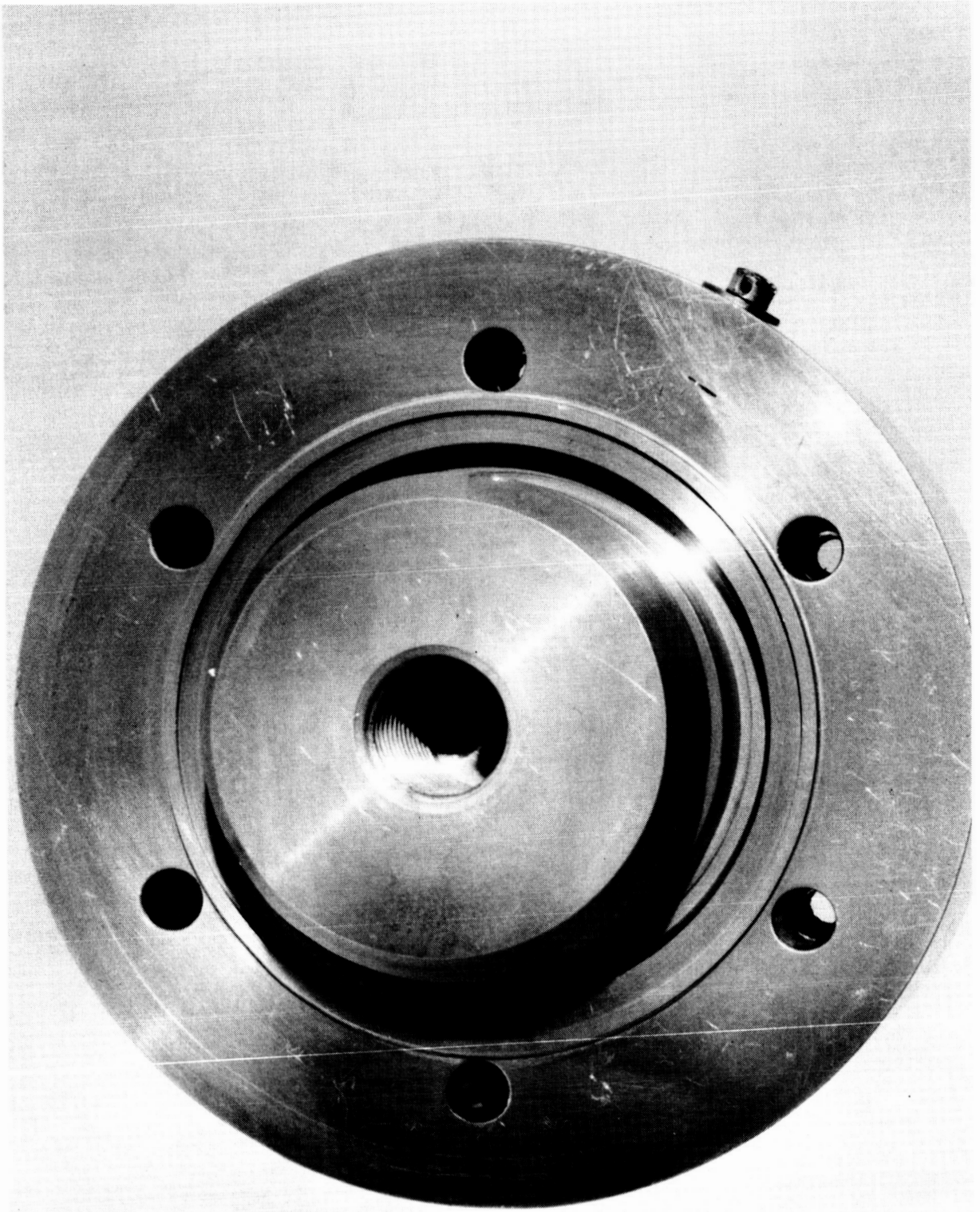
FIGURE 21



NEG. T11267-20

THINWALL SECTION DEFORMATION - P/N T-13622, S/N B
(Appendix A, A-3.3)

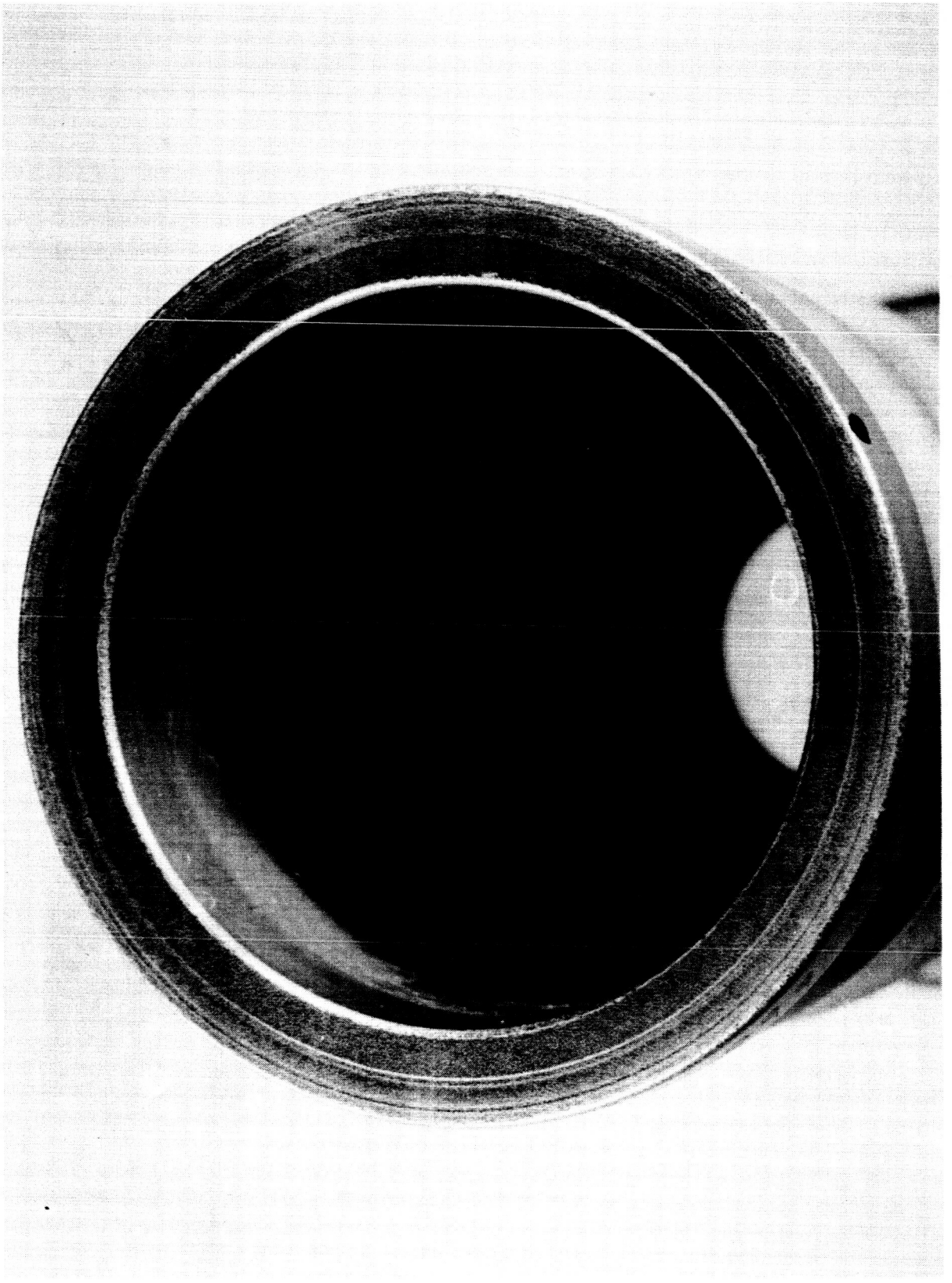
FIGURE 22



BURNISHED BEARING AREA, STRUCTURAL TEST RIG HEAD #1
(Appendix A, A-3.3) P/N T-13622, S/N B

NEG. T11267-16

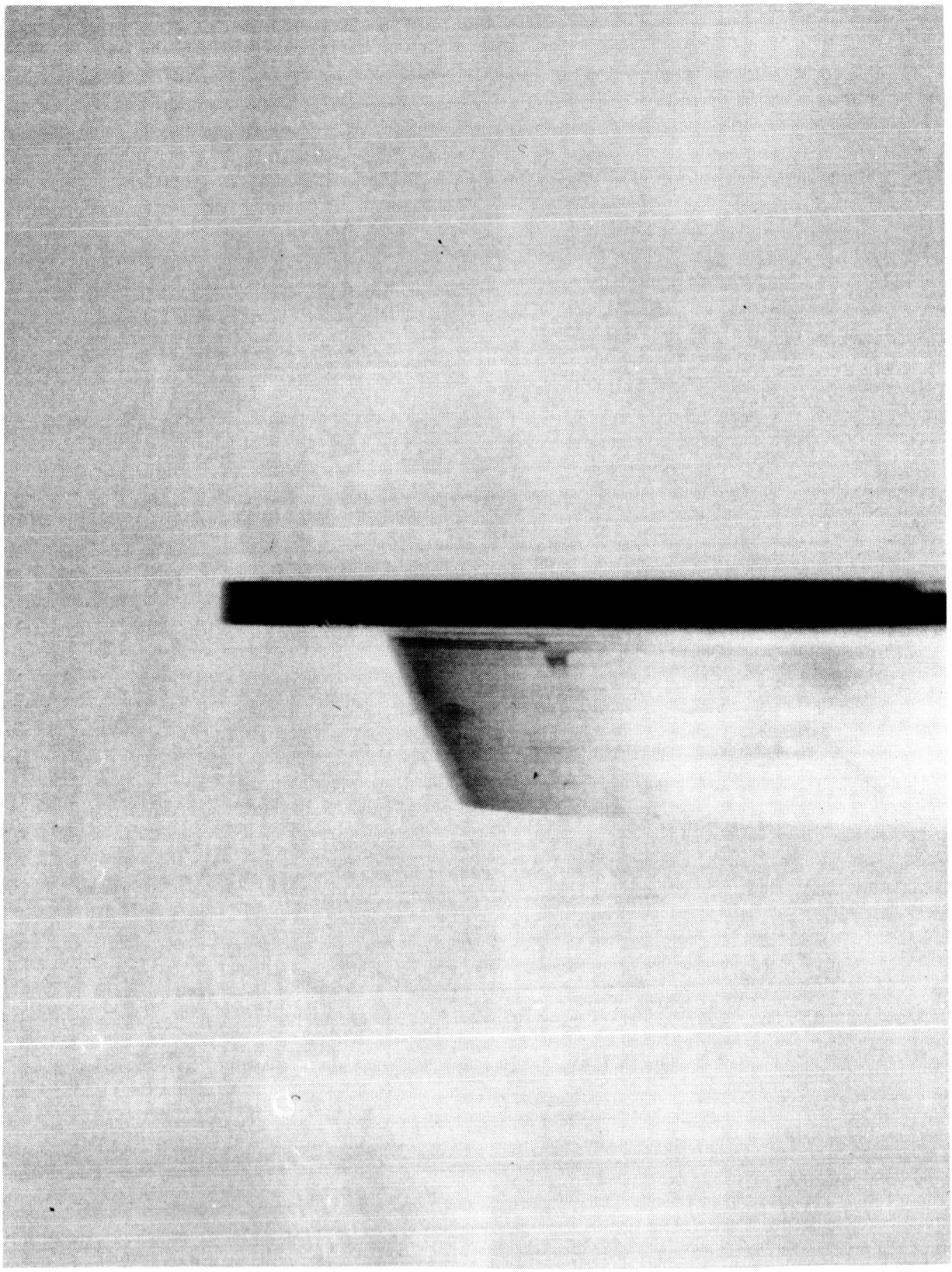
FIGURE 23



NEG. T11267-14

BURNISHED BEARING AREAS, STRUCTURAL TEST RIG #1 COMBUSTOR
(Appendix A, A-3.3 - P/N T-13622, S/N B)
(Appendix A, A-3.3 - P/N T-13611, S/N B)

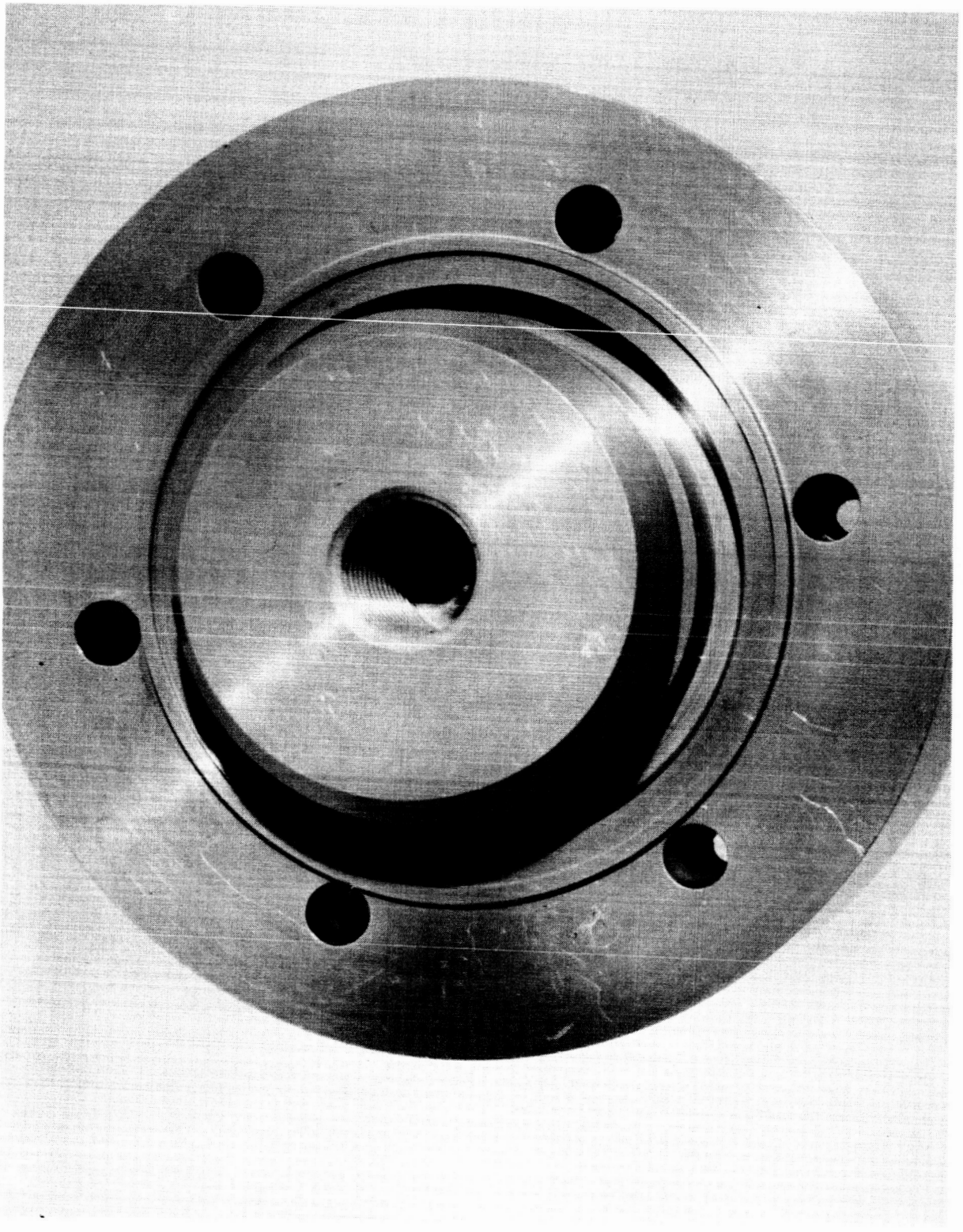
FIGURE 24



NEG. T11267-19

THINWALL SECTION DEFORMATION - P/N T-13621, S/N B
(Appendix A, A-3.3)

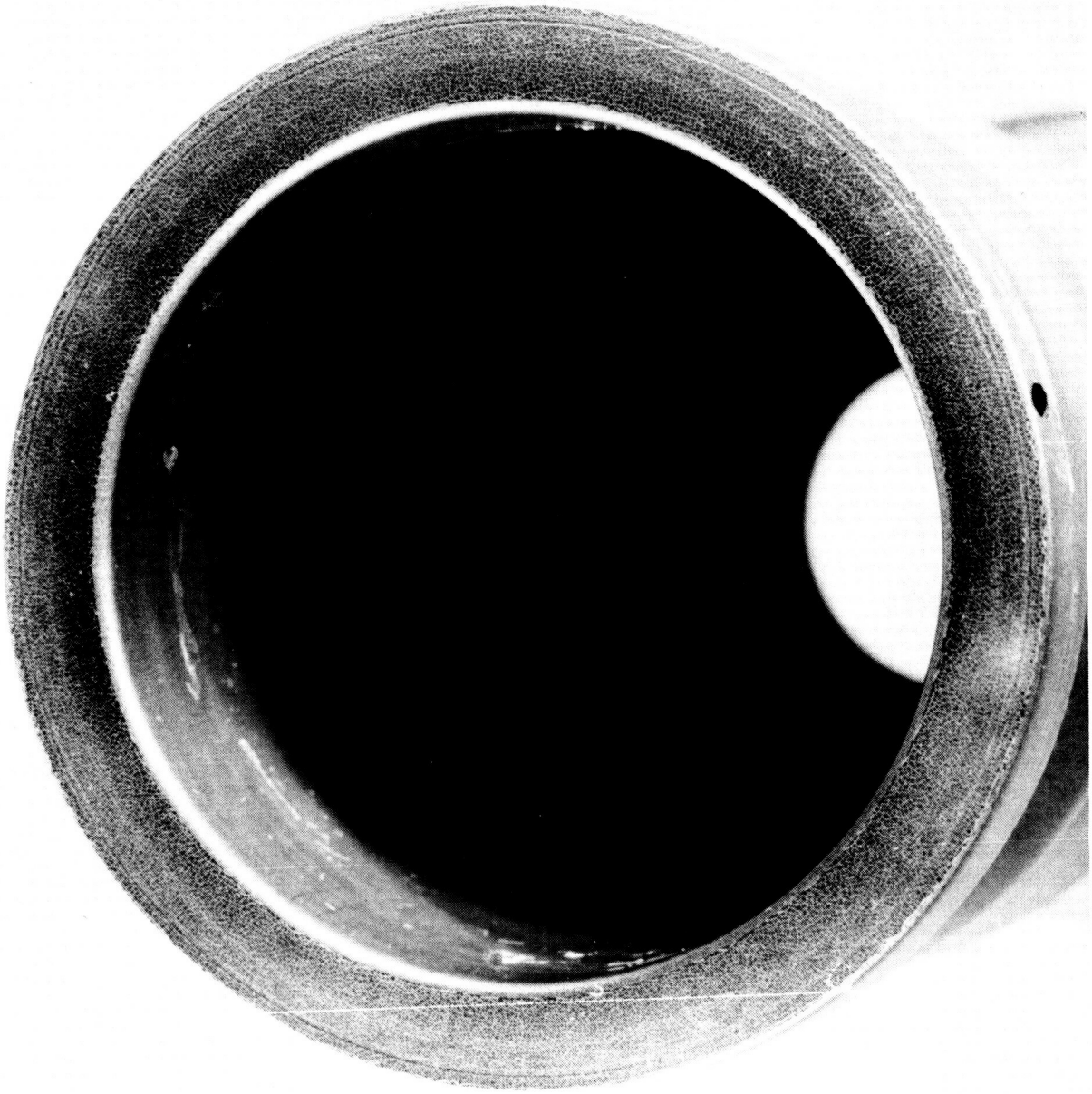
FIGURE 25



NEG. T11267-17

BURNISHED BEARING AREA, STRUCTURAL TEST RIG HEAD #2
(Appendix A, A-3.3 - P/N T-13621, S/N B)

FIGURE 26



BURNISHED BEARING AREA, STRUCTURAL TEST RIG #2 COMBUSTOR
(Appendix A, A-3.3 - P/N T-13612, S/N B)

NEG. T11267-15

FIGURE 27

BOLT CLAMPING LOAD CALCULATION METHODS

1. For Bolts with no Permanent Deformation

P = Clamping Load per Bolt

A = Cross Sectional Area of Shank Diameter

E = Bolt Modulus of Elasticity = 30,000,000 psi

L = Nominal Effective Length of Bolt = 1.18 inch

ΔL = Bolt Elongation

$$P = E\left(\frac{\Delta L}{L}\right) A$$

2. For Bolts with Permanent Deformation

P = A x Actual Stress

FIGURE 28

TYPICAL STRESS/STRAIN DIAGRAM

FOR APOLLO S/M RCS ENGINE, RENÉ 41 ATTACH BOLTS

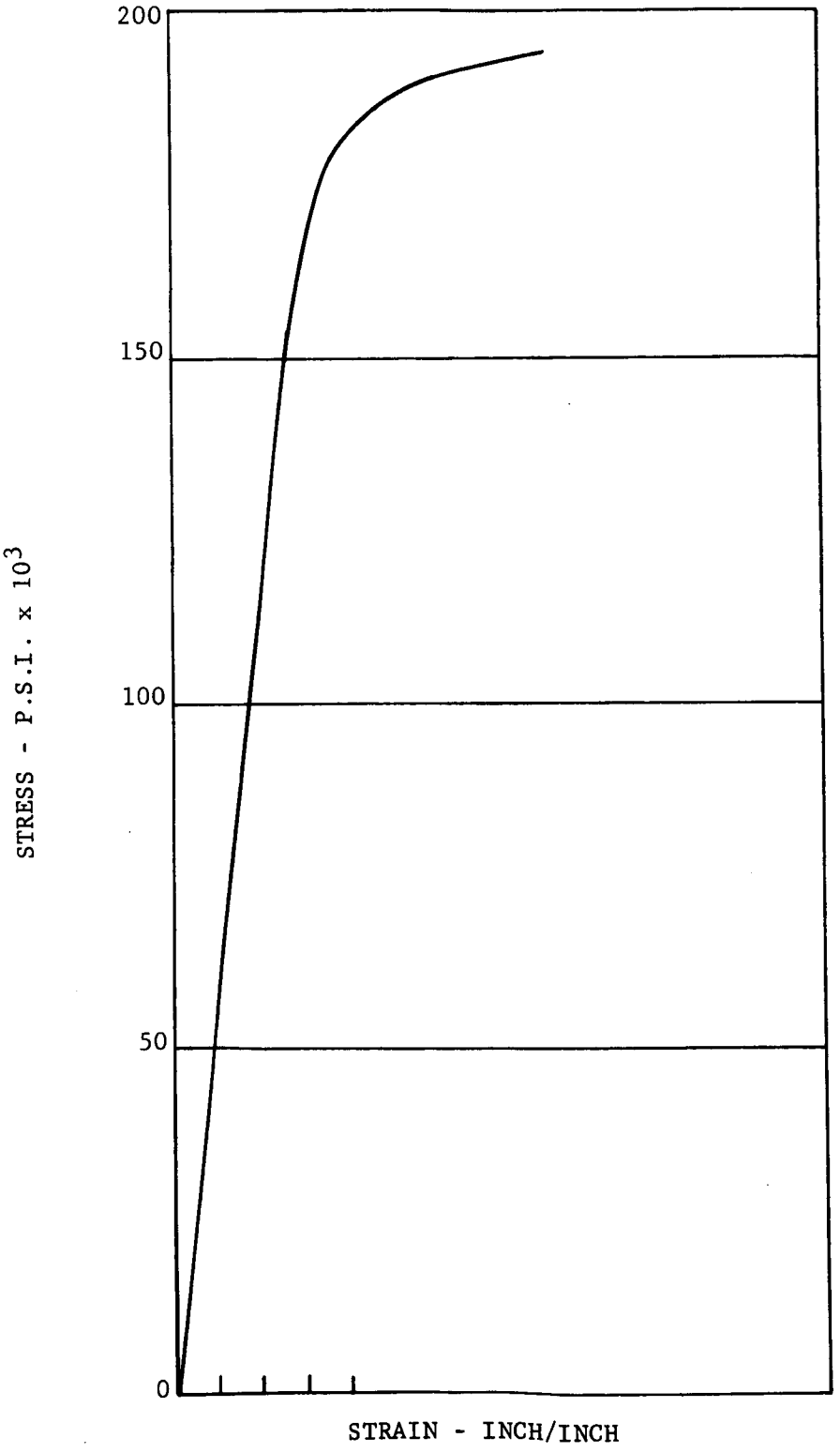


FIGURE 29

ATTACHMENT 9

THE Marquardt CORPORATION VAN NUYS, CALIFORNIA

TEST REPORT

VIBRATION TEST

FOR

APOLLO SERVICE MODULE

REACTION CONTROL SYSTEM ENGINE

CHAMBER SEAL STUDY

PREPARED UNDER CONTRACT NAS 9-4775

TMC 3008

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Design Engineering

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E. Perlman
Program Manager

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I. INTRODUCTION

The test objective was to evaluate candidate high thermal resistance seals with regards to vibration. Leakage and structural performance were evaluated after exposure to the Apollo SM RCS engine specification random boost vibration. Test results are reported herein.

II. CONCLUSIONS AND RECOMMENDATIONS

It is concluded that all of the candidate high thermal resistance seals, and the materials used in their construction, are satisfactory for their intended use with regards to vibration. Therefore, it is recommended that selection of seals for the final evaluation test phases, for seals developed in this program, be based upon considerations other than vibration performance.

III. SUMMARY

Vibration evaluation tests were performed in accordance with Test Plan MTP 0041, Appendix C. Vibration tests were limited to the titanium version of each of the three (3) candidate seal types. This was because of design similitude between seals fabricated from 6AL-4V Titanium and those made from Rene' 41. A composite seal, a straight thinwall seal and a conical thinwall seal were vibration tested.

All tests were performed with the test specimen seals installed in non-fireable Apollo SM RCS engines which simulated the qualified engine design. Each seal was preloaded in accordance with established Apollo engine assembly procedures. The head/seal/combustor interfaces were visually examined before and after assembly and test. Leakage rates were noted before and after exposure to the Apollo SM RCS engine specification random boost vibration loadings.

Results indicated that the test engines adequately simulated the qualified Apollo engine design, that the vibration tests were conducted essentially in accordance with specifications, and that no degradation could be found in any of the test seals. The vibration test is considered to be the most critical of the non-firing structural evaluation test series for the composite seal. A close examination of the zirconium oxide cylinders after testing disclosed no macroscopically apparent structural degradation. All candidate seals were found to be satisfactory for their intended use, with regards to random boost vibration.

IV. TEST SPECIMENS

One specimen of each of the following seals was vibration tested:

A. T-13618 S/N B Seal Assembly - Composite
(Materials = 6AL-4V + Zirconium Oxide)

B. T-13611 S/N B Seal - Straight Thinwall
(Material = 6AL-4V Titanium)

C. T-13622 S/N A Seal - Conical Thinwall
(Material = 6AL-4V Titanium)

Vibration tests were limited to the titanium version of each seal type. Titanium mechanical properties are generally similar although somewhat lower than the properties for Rene' 41. The titanium fatigue strength (endurance) is comparatively higher at the test temperature (70°F). Notch sensitivity for titanium is high and other physical properties (lower K) are better than for Rene' 41. Vibration tests on Rene' 41 seals were therefore eliminated, based on design similitude.

V. TEST HARDWARE

The first two seals, T-13618 and T-13611, were tested assembled in the T-11044 Engine Assembly. The conical seal, T-13622, was tested assembled in the T-13768 Engine Assembly. Both test engines used the same identical parts except for the test specimen seals, and the injector heads (the T-13768 Engine contained a head modified to extend the seal cavity length for the conical seal). Both engines adequately simulated the qualified Apollo engine for this test, although they were non-fireable.

VI. FACILITIES AND INSTRUMENTATION

The Precision Assembly Department (Bldg. 3) was used for inspection and examination of test specimens and hardware. Assembly, disassembly and pressure test operations were also conducted in this area, using available Apollo engine tools and equipment. Ambient temperature was controlled at 73°± 3°F.

Actual vibration tests were performed in the MJL Vibration Laboratory (Bldg. 44). Tests simulating aerodynamic turbulance (random vibrations) utilized a shaker, amplifier and controls in this facility.

Each test engine was mounted to either the 705323 Test Fixture for the longitudinal axis or the 705322 Test Fixture for the pitch and yaw axes. Setup for vibration in the longitudinal axis is shown in Figure 13. Setup for the yaw axis is shown in Figure 14. Pitch axis was set up by utilizing the same fixture as for the yaw axis but the engine was rotated 90 degrees. These are the same fixtures which were used in the Apollo PFRT and qualification engine tests.

VI. FACILITIES AND INSTRUMENTATION (Continued)

A control accelerometer, rated at 10 MV/G, was located in each fixture for each run, as can be seen in Figures 13 and 14. Each accelerometer recorded input in the axis of vibration only, and in a range of interest from zero to 100 g's rms. Accelerometer readout was by magnetic tape with an accuracy within ± 11.5%, as required by specification. Both accelerometers used were facility calibrated prior to vibration, as required by specification.

Engine and fixture were mounted to an MB Shaker with a rating of 1500 force pounds, (Model C 10 VB, Type A, Serial 107). The controls and power equipment utilized for the shaker were a Ling Amplifier and Console.

Spectral analysis equipment, in Building 32, was utilized for magnetic tape data reduction. One loop for spectral analysis was cut from each magnetic tape recording. Each loop was taken from the first one and one-half (1 1/2) minutes of each five (5) minute test run, as required by specification.

These loops were analyzed with equipment consisting of an Ampex Recorder and a Technical Products Analyzer. The analyzer time constant used was four (4) seconds minimum, as required by specification. This equipment had the following normal analyzer filter band width ratings:

Frequency (cps)	Band Width (cps)	
	Rated	Actual
10-100	5.0	6.0
100-200	10.0	14.8
200-500	20.0	21.0
500-2000	50.0	65.5

Required random vibration levels for these tests are shown in Figure 2, (Boost Vibration Spectrum). These required vibration levels were essentially met. Figures 3 through 11 are recordings made by the spectrum analyzer taken from the actual magnetic tape loops. "Power Spectral Density" was converted to "G_{rms}" by the following formula:

$$G_{rms} = \sqrt{(G^2/cps)\ (BW\ eff.)}$$

Where:

G^2/cps = Power Spectral (or Acceleration) Density
BW eff. = Effective (or Actual) Filter Bandwidth in cps

Example: Assume Acceleration Density = .5 G^2/cps
Checking 6.0 cps BW eff.

$$G_{rms} = \sqrt{(.5)\ (6)} = \underline{1.732}$$

VII. TEST

Each test specimen seal was preloaded prior to test in accordance with established Apollo engine assembly procedures. All combustor attach bolt data (pre and post test) from which seal preload is calculated, is shown in Figure 1. The method of calculation is also presented.

Each of the three (3) test specimen seals was tested for random vibration. Each test engine was vibrated first along the longitudinal, then pitch, and then yaw axis, as specified in MTP 0041, Paragraph C-3.1.6.6.1. Required duration for each test run is 300 $^{+10}_{-0}$ seconds. All nine (9) test runs met this time specification. Loads were applied to the engine mounting surface for all test runs as specified in the test plan.

Allowable Apollo frequency tolerance for the required random vibration levels is ±5%. All nine (9) test runs were within this tolerance (see Figures 3 through 11). Allowable Apollo amplitude tolerance for the required random vibration levels is ±3.0 decibels. All test runs were essentially within this tolerance. See Figures 4, 7, 9, 10 and 11 for test runs that slightly exceeded this tolerance. These test runs were considered satisfactory because amplitude was out-of-tolerance for only eleven (11) cycles at the most in the low frequency range, and amplitude exceeded G_{rms} requirements slightly at higher frequencies.

A. T-13618 S/N B Composite Seal - This seal had been previously subjected to a heat soak-back test per MTP 0041, Paragraph A-3.1, and to a creep test per MTP 0041, Paragraph A-3.4 (high temperature environment).

The original yellow color of the zirconium oxide cylinders was dulled by these previous tests. The cylinders were also colored grey where the garter spring touched them. Some solid particle contaminants picked up during previous tests were present. The seal jacket was heat-stained on the combustor side. Both sealing surfaces of the jacket had a bright appearance at local positions corresponding to the locations of all zirconia cylinders inside the jacket (see Figure 12). A careful dimensional check of the sealing surface flatness indicated that the surface undulated (waved) between each bright spot less than .00005 inch. Otherwise, there was no visual indication of seal anomalies prior to the vibration test.

Sealing surfaces were wiped clean with MEK then freon, and the test specimen seal was assembled in the T-11044 S/N 0001-9 Engine. A dry nitrogen pressure test was conducted on the assembled seal at 175 psig. There was 31.5 decay in five (5) minutes where Apollo procedures allow 15.0 psi decay maximum. Calculated seal preload was 5,350 pounds. The excess leakage was attributed to leak paths caused by the very slightly undulating surface of the seal, as shown in Figure 12, minor imperfections on the head sealing

VII. TEST (Continued)

A. T-13618 S/N B Composite Seal (Continued)

surface and out of specification flatness of the combustor sealing surface. Although this condition was less than ideal, meaningful evaluation could still be attained. Therefore, refurbishment of the hardware was held in abeyance until after the vibration test was performed.

The engine was subjected to vibration per MTP 0041, Appendix C. No seal or engine degradation could be discerned during vibration. The pressure test was repeated after completion of vibration. Leakage was reduced to 26.5 psi decay in five (5) minutes. Calculated seal preload was 5,380 pounds.

A macroscopic examination of the test specimen seal and its zirconium oxide cylinders after vibration testing disclosed no apparent structural degradation.

B. T-13611 S/N B Straight Thinwall Seal - This seal had been previously subjected to a heat soak-back test per MTP 0041, Paragraph A-3.1, and to a creep test per MTP 0041, Paragraph A-3.4 (high temperature environment).

The head and combustor sealing surfaces of the T-11044 Engine were relapped because of the high leakage encountered prior to the previous vibration test. The combustor sealing surface was found to be out of specification flatness. All sealing surfaces were wiped clean with MEK then freon, and the test specimen seal was assembled in the T-11044 S/N 0001-10 Engine. A dry nitrogen pressure test was conducted on the assembled seal at 175 psig. There was 11.5 psi decay in five (5) minutes. Calculated seal preload was 5,263 pounds.

The engine was subjected to vibration per MTP 0041, Appendix C. No seal or engine degradation could be discerned during vibration. The pressure test was repeated after vibration, and leakage was 12.5 psi decay in five (5) minutes of pressure application. No seal structural degradation could be found after disassembly. Calculated seal preload was 5,233 pounds.

C. T-13622 S/N A Conical Thinwall Seal - This seal had been previously subjected to a thermal test per MTP 0041, Appendix D (sub-zero environment).

Head, combustor, and seal sealing surfaces were wiped clean with MEK then freon, and the seal was assembled in the T-13768 S/N 0001-1 Engine. A dry nitrogen pressure test was conducted on the assembled seal at 175 psig. There was 2.5 psi decay in five (5) minutes. Calculated seal preload was 5,818 pounds.

The engine was subjected to vibration per MTP 0041, Appendix C. No seal or engine degradation could be discerned during vibration. The pressure test was repeated after vibration, and leakage was 5.0 psi decay in five (5) minutes of pressure application. No seal structural degradation could be found after disassembly. Calculated seal preload was 4,590 pounds.

COMBUSTOR ATTACH BOLT DATA FROM WHICH SEAL PRELOAD IS CALCULATED

TEST SPECIMEN SEAL	BOLT NO.	PRE-VIBRATION BOLT DATA INCHES			POST-VIBRATION BOLT DATA. INCHES		
		FREE LENGTH	ASSEMBLED LENGTH	ELONG-ATION	ASSEMBLED LENGTH	FREE LENGTH	ELONG-ATION
T-13618 S/N B COMPOSITE	1	1.4708	1.4741	.0033	1.4739	1.4709	.0030
	2	1.4707	1.4738	.0031	1.4738	1.4706	.0032
	3	1.4710	1.4742	.0032	1.4744	1.4711	.0033
	4	1.4709	1.4738	.0029	1.4742	1.4710	.0032
	5	1.4708	1.4736	.0028	1.4737	1.4710	.0027
	6	1.4709	1.4739	.0030	1.4740	1.4710	.0030
T-13611 S/N B STRAIGHT THINWALL	1	1.4711	1.4745	.0034	1.4745	1.4710	.0035
	2	1.4709	1.4738	.0029	1.4736	1.4708	.0028
	3	1.4715	1.4742	.0027	1.4741	1.4711	.0030
	4	1.4712	1.4741	.0029	1.4739	1.4710	.0029
	5	1.4710	1.4741	.0031	1.4741	1.4709	.0032
	6	1.4711	1.4741	.0030	1.4737	1.4712	.0025
T-13622 S/N A CONICAL THINWALL	1	1.4708	1.4742	.0034	1.4737	1.4711	.0026
	2	1.4706	1.4740	.0034	1.4737	1.4712	.0025
	3	1.4712	1.4745	.0033	1.4742	1.4714	.0028
	4	1.4708	1.4741	.0033	1.4740	1.4713	.0027
	5	1.4712	1.4744	.0032	1.4740	1.4715	.0025
	6	1.4709	1.4742	.0033	1.4738	1.4712	.0026

Method of Calculating Seal Preload (Apollo seal assembly preload requirements are 4,680 to 5,880 pounds):

$$P = E\left(\frac{\Delta l_1 + \Delta l_2 + \Delta l_3 + \Delta l_4 + \Delta l_5 + \Delta l_6}{l}\right) A$$

where: P = Seal preload (pounds)
E = Bolt modulus of elasticity = 30,000,000 psi
Δl = Bolt elongation (inches)
l = Nominal effective length of each bolt = 1.18 inches
A = Average bolt shank cross-sectional area = .0115 inch^2

FIGURE 1

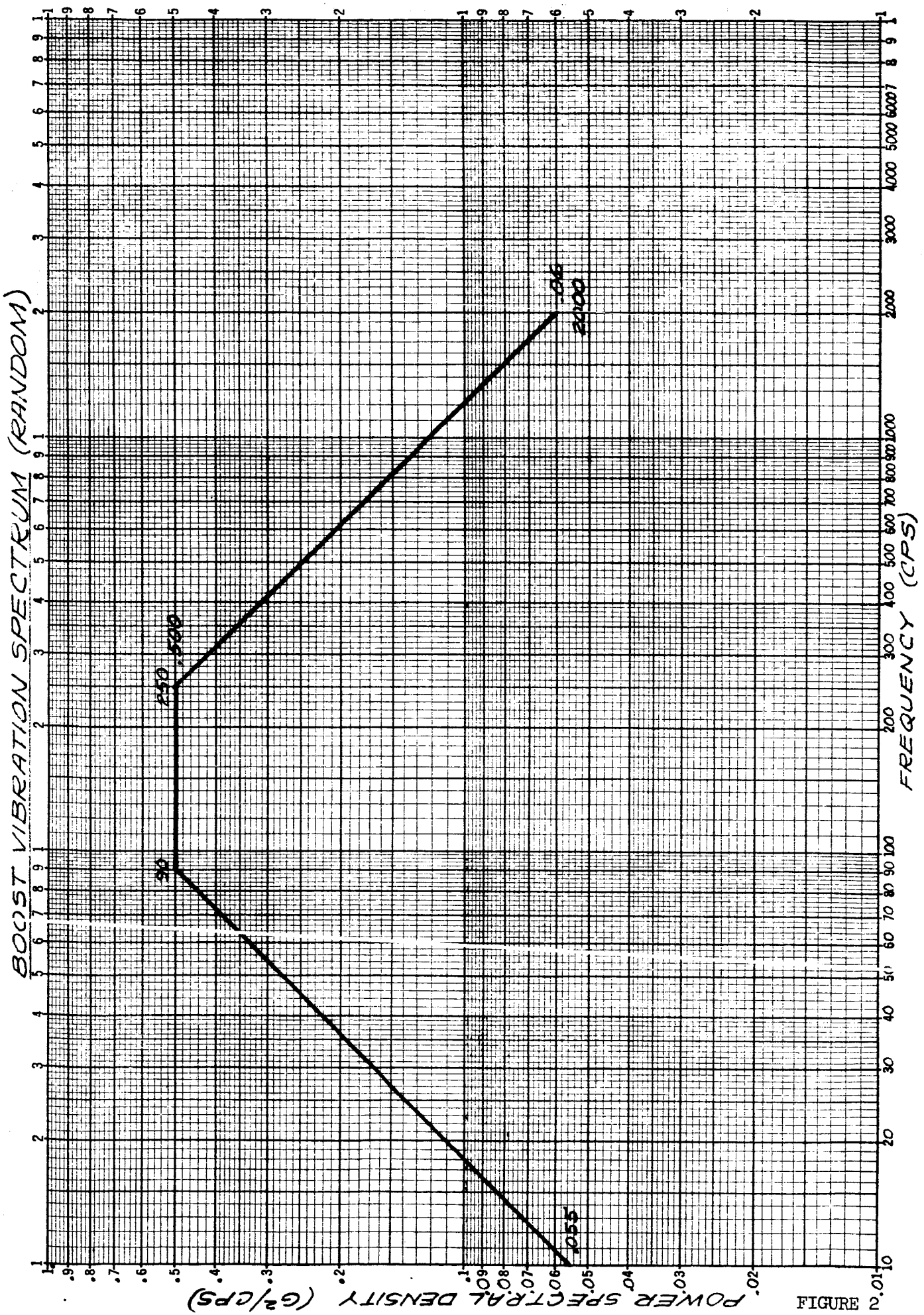
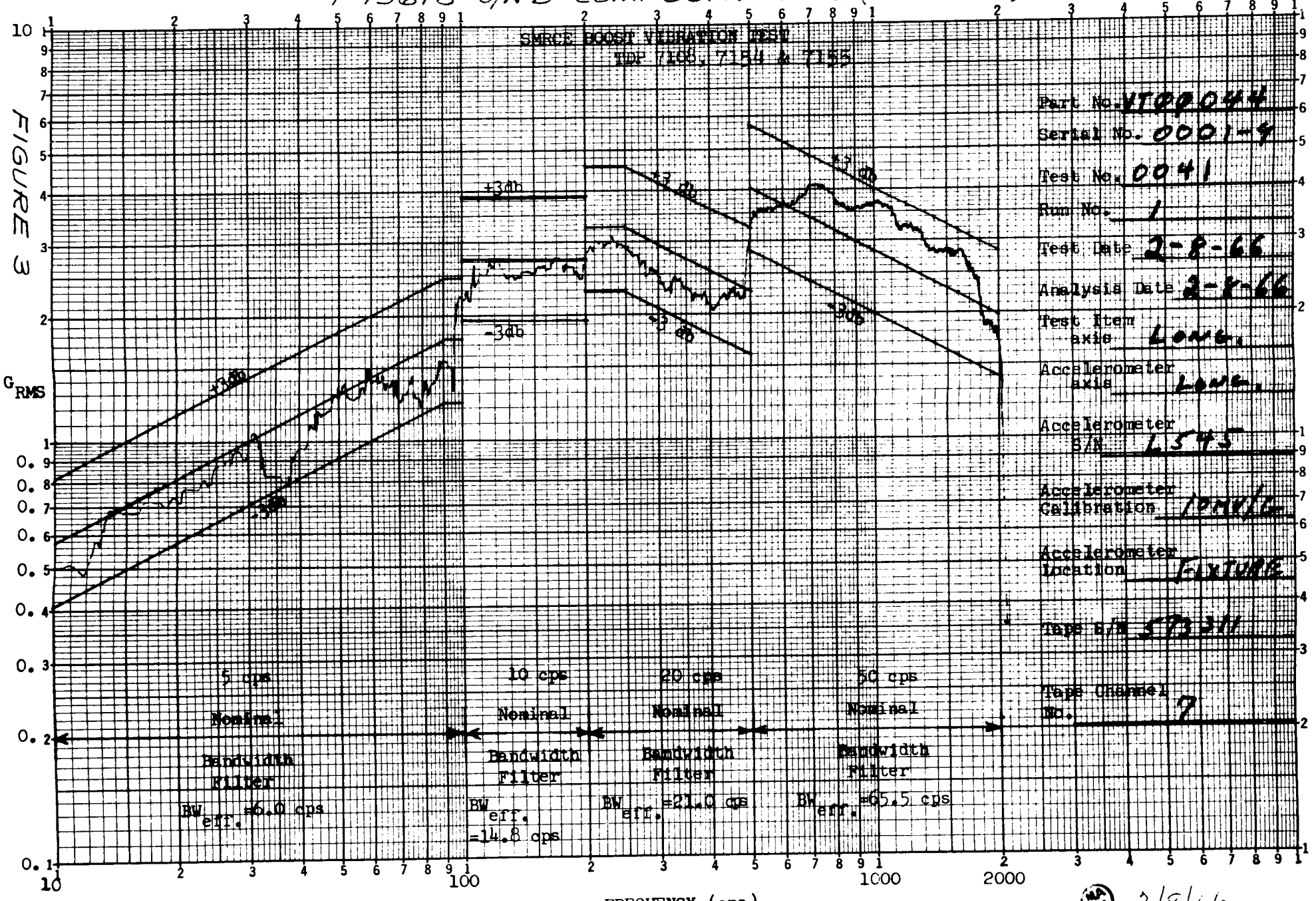

BOOST VIBRATION SPECTRUM (RANDOM)
POWER SPECTRAL DENSITY (G²/CPS)
FREQUENCY (CPS)
.04
2000
250
.500
20
.055
LOGARITHMIC
2 X 3 CYCLES
KEUFFEL & ESSER CO
46 7323
MADE IN U.S.A.

FIGURE 2.

K&E LOGARITHMIC 2 X 3 CYCLES KEUFFEL & ESSER CO. 46 7323 MADE IN U.S.A.

T-13618 S/N B COMPOSITE SEAL (TITANIUM)

FIGURE 3



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K&E LOGARITHMIC 2 X 3 CYCLES 46 7323 MADE IN U.S.A.
KEUFFEL & ESSER CO.

T-13618 S/N B COMPOSITE SEAL (TITANIUM)

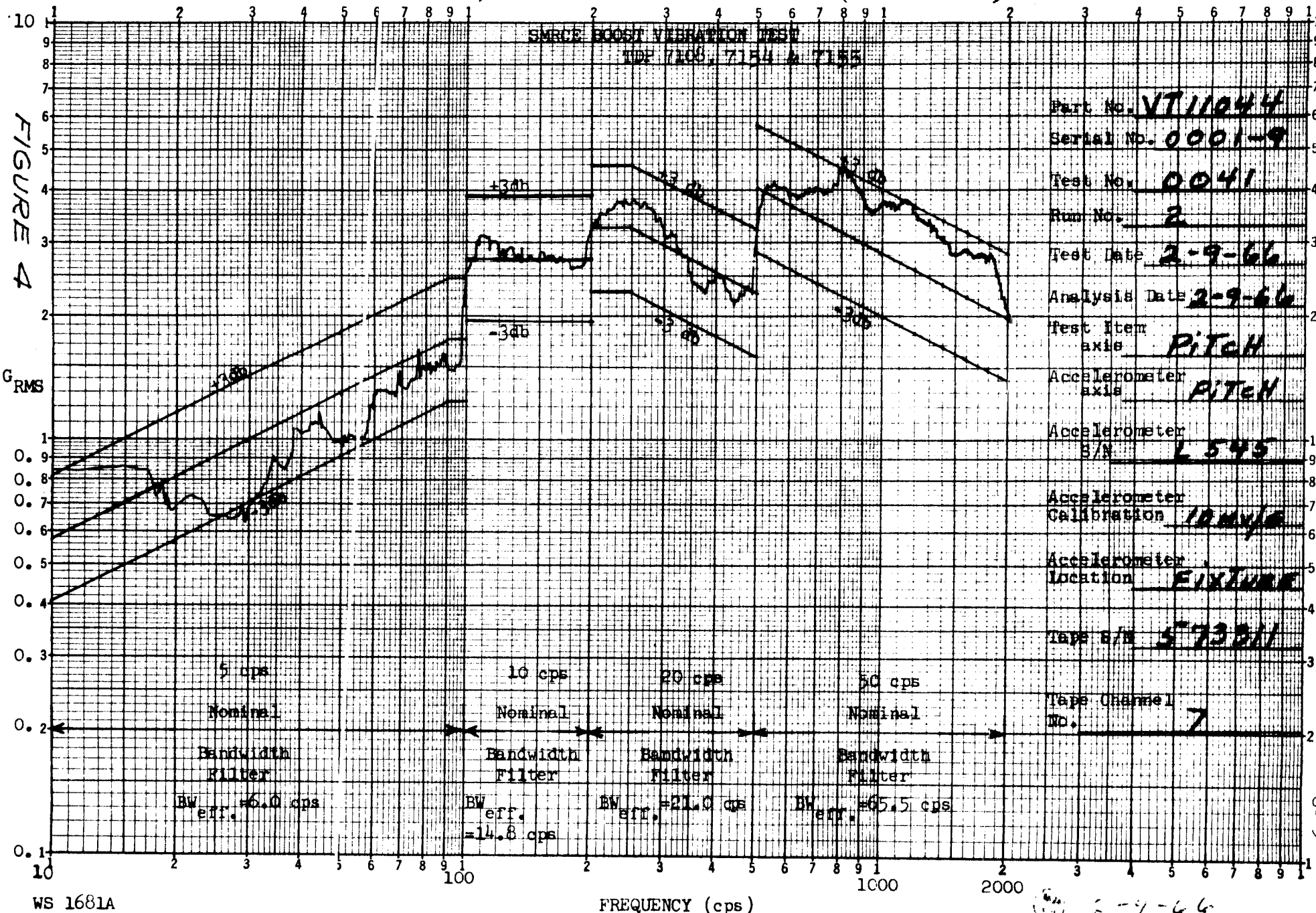


FIGURE 4

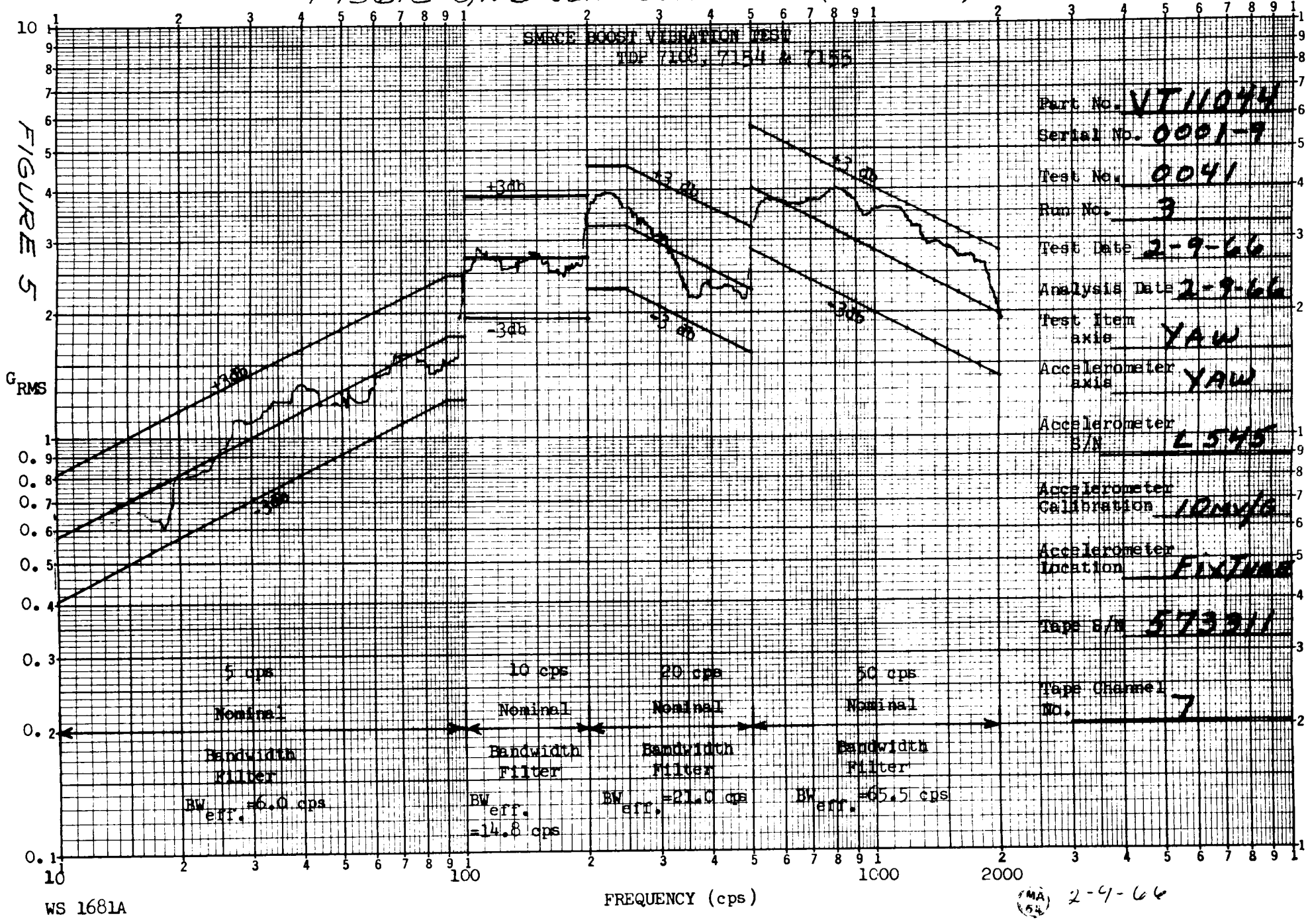
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K&E LOGARITHMIC 2 X 3 CYCLES KEUFFEL & ESSER CO. 46 7323 MADE IN U.S.A.

T-13618 S/N B COMPOSITE SEAL (TITANIUM)



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(MA 54) 2-9-66

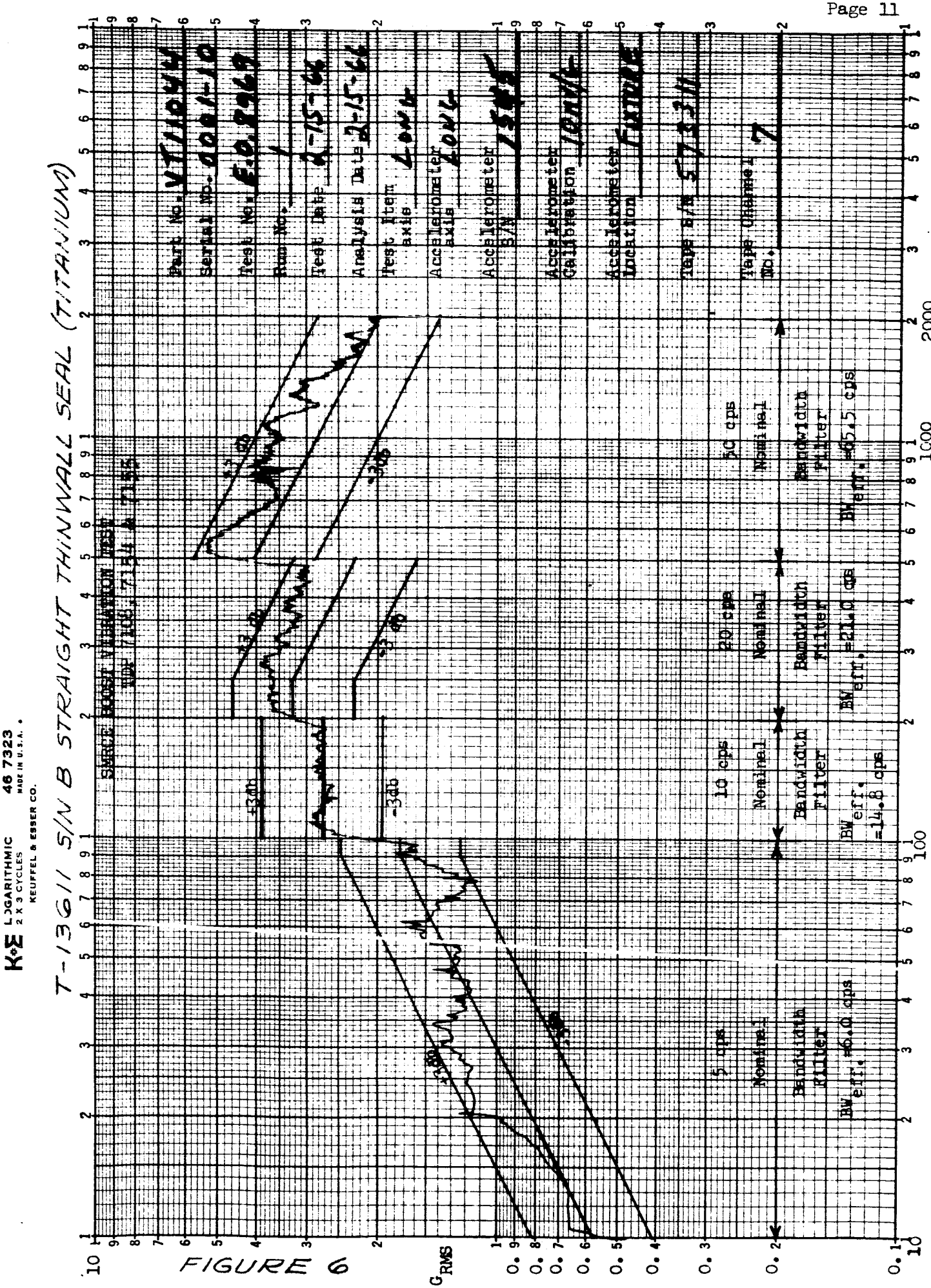


FIGURE 6

K+E LOGARITHMIC 46 7323
2 X 3 CYCLES MADE IN U.S.A.
KEUFFEL & ESSER CO.

2-15-66

WS 1681A

K&E LOGARITHMIC 2 X 3 CYCLES KEUFFEL & ESSER CO. 46 7323 MADE IN U.S.A.

T-13611 S/N B STRAIGHT THINWALL SEAL (TITANIUM)

FIGURE 7

SMRCE BOOST VIBRATION TEST
TDP 7108, 7154 & 7155

Part No. VT 11044
Serial No. 0001-10
Test No. E.O. #7 #7
Run No. 2
Test Date 2-15-66
Analysis Date 2-15-66
Test Item axis PITCH
Accelerometer axis P, T, C, H
Accelerometer S/N L 5345
Accelerometer Calibration 100 g/G
Accelerometer location FIXTURE
Tape S/N 5733 H
Tape Channel No. 7

±3db
-3db
+3 db
-3 db
+3 db
-3 db

5 cps Nominal Bandwidth Filter BW eff. =6.0 cps
10 cps Nominal Bandwidth Filter BW eff. =14.8 cps
20 cps Nominal Bandwidth Filter BW eff. =21.0 cps
50 cps Nominal Bandwidth Filter BW eff. =65.5 cps

G_{RMS}

FREQUENCY (cps)

WS 1681A

2-15-66

K&E LOGARITHMIC 2 X 3 CYCLES 46 7323 MADE IN U.S.A.
KEUFFEL & ESSER CO.

T-13611 S/N B STRAIGHT THINWALL SEAL (TITANIUM)

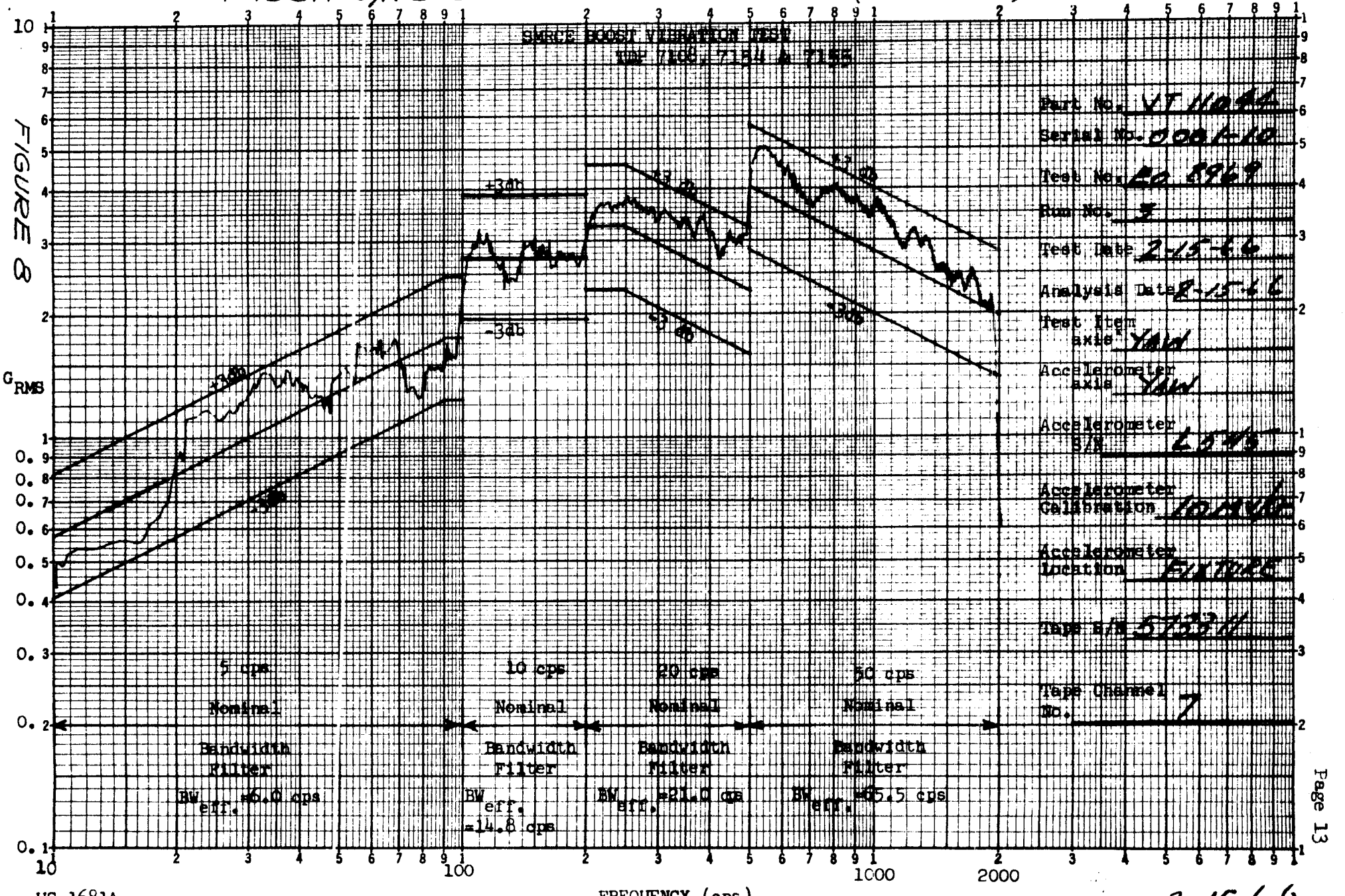


FIGURE 8

WS 1681A

2-15-66

K&E LOGARITHMIC 2 X 3 CYCLES KEUFFEL & ESSER CO. 46 7323 MADE IN U.S.A.

T-13622 S/N A CONICAL THINWALL SEAL (TITANIUM)

FIGURE 9

SMRCE BOOST VIBRATION TEST
TDP 7103, 7154 & 7155

Part No. T13768
Serial No. 0001
Test No. 11285
Run No. 1
Test Date 3-4-66
Analysis Date 3-4-66
Test Item axis LONG
Accelerometer axis LONG
Accelerometer S/N 5892
Accelerometer Calibration 10mv/G
Accelerometer Location Fixture
Tape S/N 5071406
Tape Channel No. 7

+3db
-3db
+3 db
-3 db
+3db
-3db

G_{RMS}

5 cps Nominal Bandwidth Filter $BW_{eff.}$ =6.0 cps

10 cps Nominal Bandwidth Filter $BW_{eff.}$ =14.8 cps

20 cps Nominal Bandwidth Filter $BW_{eff.}$ =21.0 cps

50 cps Nominal Bandwidth Filter $BW_{eff.}$ =65.5 cps

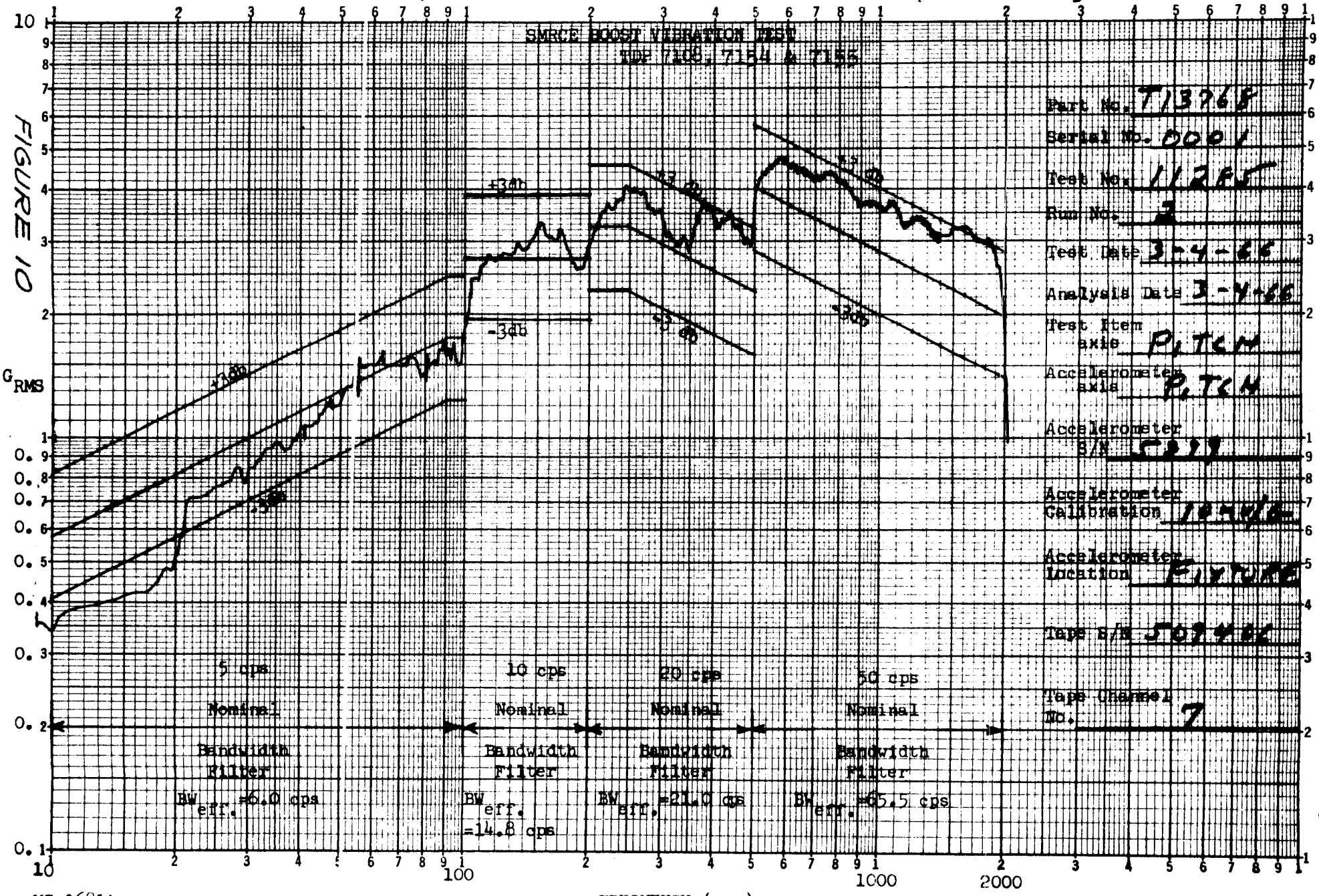
10 100 1000 2000

FREQUENCY (cps)

WS 1681A

K&E LOGARITHMIC 2 X 3 CYCLES 46 7323 MADE IN U.S.A.
KEUFFEL & ESSER CO.

T-13622 S/N A CONICAL THINWALL SEAL (TITANIUM)



WS 1681A

K&E LOGARITHMIC 2 X 3 CYCLES 46 7323 MADE IN U.S.A.
KEUFFEL & ESSER CO.

T-13622 S/N A CONICAL THINWALL SEAL (TITANIUM)

FIGURE 11

SMRCE BOOST VIBRATION TEST
TDP 7108, 7154 & 7155

Part No. T13768
Serial No. 0001
Test No. 11285
Run No. 3
Test Date 3-4-66
Analysis Date 3-4-66
Test Item axis YAW
Accelerometer axis YAW
Accelerometer S/N 5899
Accelerometer Calibration 19 mv/G
Accelerometer Location FIXTURE
Tape S/N 5699406
Tape Channel No. 7

+3db
-3db
+3 db
-3 db
+3db
-3db

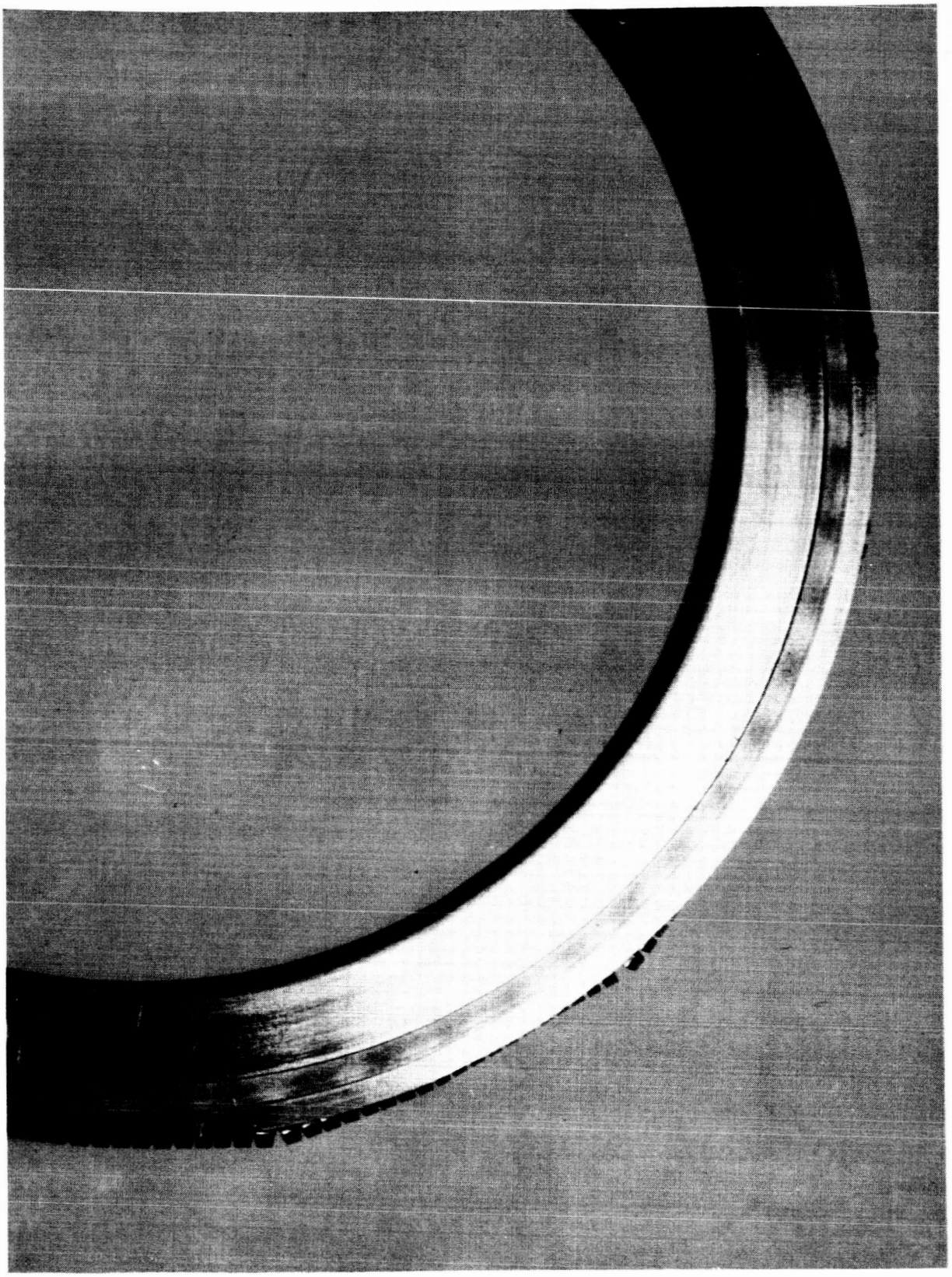
5 cps Nominal Bandwidth Filter BW eff. =6.0 cps
10 cps Nominal Bandwidth Filter BW eff. =14.8 cps
20 cps Nominal Bandwidth Filter BW eff. =21.0 cps
50 cps Nominal Bandwidth Filter BW eff. =65.5 cps

G_{RMS}

10 100 1000 2000

FREQUENCY (cps)

WS 1681A



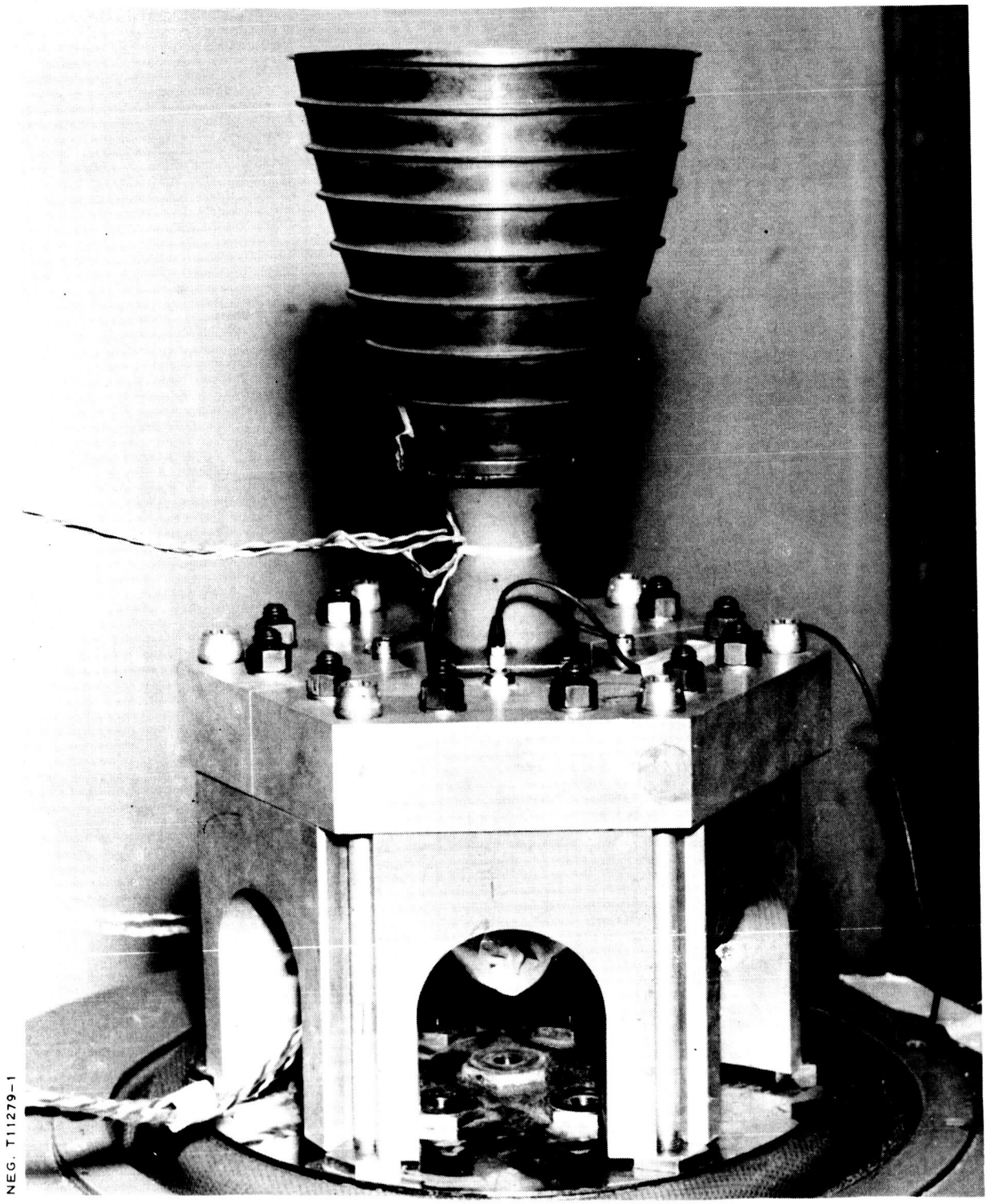
TEST 11267 INDICATIONS OF ZIRCOA CYLINDER LOCATIONS THROUGH JACKET
3 FEB 66 T13618 S/N B SEAL ASSEMBLY (T_1) AFTER CREEP TEST (U)

NEG. T11267-13

FIGURE 12

COMPOSITE SEAL VIBRATION TEST SETUP

LONGITUDINAL AXIS

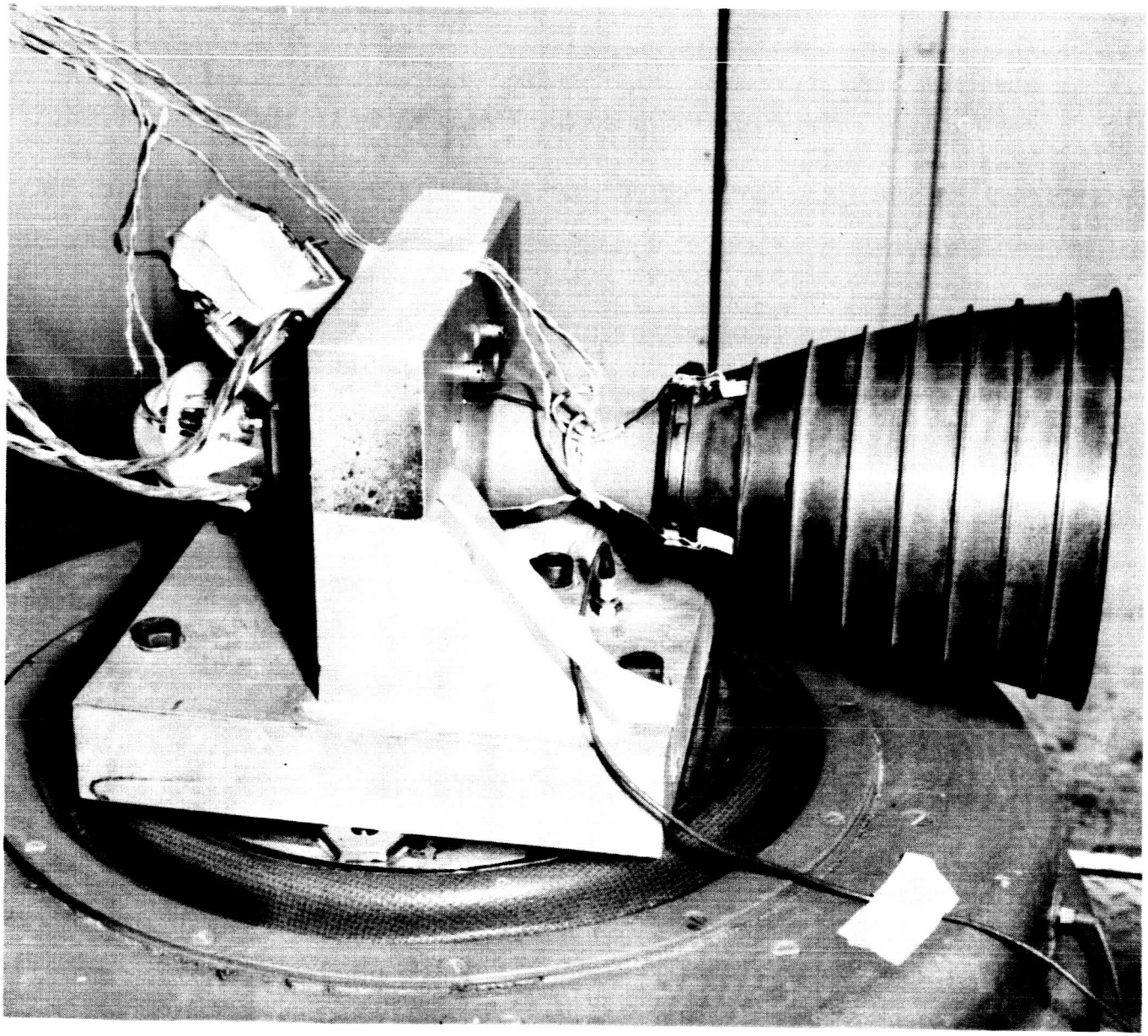


NEG. T11279-1

FIGURE 13

COMPOSITE SEAL VIBRATION TEST SETUP

YAW AXIS



NEG. T11279-2

FIGURE 14

ATTACHMENT 10

THE Marquardt CORPORATION VAN NUYS, CALIFORNIA

TEST REPORT

CORROSION TEST

FOR

APOLLO SERVICE MODULE

REACTION CONTROL SYSTEM ENGINE

CHAMBER SEAL STUDY

PREPARED UNDER CONTRACT NAS 9-4775

TMC 3008

Prepared by T. L. Nelson
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Design Engineering

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J. Puntar
Principal Investigator
Design Engineering

Approved By E. P. Perlman
E. P. Perlman
Program Manager

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I. INTRODUCTION

The test objective was to evaluate candidate high thermal resistance seals with regards to corrosion. Leakage performance and material resistance to degradation were evaluated after exposure to a salt-fog environment. Corrosion test results for the head/seal/combustor interface are reported herein.

II. CONCLUSIONS & RECOMMENDATIONS

It is concluded that all of the candidate high thermal resistance seals and the materials used in their construction are satisfactory for their intended use with regards to corrosion. Seals tested exhibited improved leakage performance and no signs of corrosive attack after exposure to the Apollo SM RCS salt-fog environment. Therefore, it is recommended that selection of seals for the final evaluation test phases on this program be based upon considerations other than corrosion resistance.

III. SUMMARY

A corrosion evaluation test was performed in accordance with Test Plan MTP 0041, Appendix D. Two composite seals, one with a Rene' 41 jacket and one with a titanium jacket, were selected for testing. These composite seals embodied all the various material combinations and galvanic couples represented by all six (6) design/material variations in the candidate seals. Tests, therefore, were not performed on straight thinwall and conical thinwall seals.

These composite seals were installed in special test rigs* simulating the Apollo SM RCS engine injector head/combustor joint. The seals were preloaded essentially in accordance with established Apollo engine assembly procedures. The head/seal/combustor interfaces were visually examined before and after assembly and test. Bolt lengths, torques and preloads were noted before and after testing. Leakage rates were noted before and after exposure to the Apollo SM RCS engine specification salt-fog environment.

Results indicated that the seal test rigs simulated the Apollo SM RCS engine installation adequately, that the salt fog test was conducted in accordance with specifications, and that no seal deleterious effects could be found. With both units, leakage had been reduced approximately 75%, apparently clogged by the salt deposits. After the test, no corrosion or any other deficiency could be found on any sealing surface by macroscopic examination. The only corrosion found was on the entire exposed surface of one of the heads which had not been anodized. Therefore, these seals were found to be satisfactory for their intended use, with regards to corrosion.

*Test rigs were used previously to conduct seal heat transfer tests (Ref. MTP 0041, Appendix B).

IV. TEST SPECIMENS

Two (2) composite seals were tested for corrosion. They were T-13618 S/N A Seal Assembly (Ti Jacket) and T-13619 S/N A Seal Assembly (Rene' Jacket).

V. TEST HARDWARE

The T-13618 Seal was tested using T-13601 Head Assembly S/N 002 and T-12334 Combustor S/N 001. The T-13619 Seal was tested using T-13601 Head Assembly S/N 001 and T-12334 Combustor S/N 002. These heads simulated the Apollo SM RCS engine injector. The head for the T-13619 Seal was anodized, while the head for the T-13618 Seal was bare. The bare head was considered satisfactory because the electrolytic couple between the head and seal would be more severe than that which prevails in the engine. Both combustors were fabricated from TZM material (rather than unalloyed molybdenum as for Apollo). These combustors were considered satisfactory for use in this test because their coating was molybdenum disilicide, the same as for Apollo. The attach hardware used was similar to current Apollo hardware. Both attach rings were similar to 228117. Both split rings were similar to 228116. All bolts were similar to 228105 except for the shank diameters which were undersize. Bolts with full size shank diameters were unavailable.

Apollo seal assembly preload requirements are 4,680 to 5,880 pounds. Seal preload was calculated as follows:

$$P = E\left(\frac{\Delta\ell_1 + \Delta\ell_2 + \Delta\ell_3 + \Delta\ell_4 + \Delta\ell_5 + \Delta\ell_6}{\ell}\right) A$$

where:

P = Seal preload (lbs.)
E = Bolt modulus of elasticity = 30,000,000 psi
$\Delta\ell$ = Bolt elongation (inches)
ℓ = Nominal effective length of each bolt = 1.18 in.
A = Average bolt shank cross-sectional area
(A = .00825 in.^{2} for bolts loading T-13618 Seal)
(A = .00996 in.^{2} for bolts loading T-13619 Seal)

VI. FACILITIES

The Precision Assembly Department (Bldg. 3) was used for inspection and examination of test specimens and hardware. Assembly, disassembly and pressure test operations were also conducted in this area, using available Apollo engine tools and equipment. Ambient temperature was controlled at 73°± 3°F.

The actual test was performed in the MJL Hydraulic Lab (Bldg. 16). A salt fog corrosion test cabinet was utilized. This was the Model CA-1 Test Cabinet shown in Figures 4 and 5.

VII. TEST

A. Hardware Assembly - T-13618 S/N A Seal - (This seal had been previously subjected to a thermal test, MTP 0041, Appendix B, and to several informally planned load tests).

The titanium jacket and titanium spacers were vapor degreased then ultrasonic cleaned prior to this assembly. T-13617 Zircoa "C" cylinder set was reused. A new garter spring was used.

The seal jacket zero degree index mark was installed against the head sealing surface, because there was a prominent scratch across the seal jacket sealing surface at this mark. This was done to accurately locate an anticipated leak path caused by the scratch. The mark was installed radially in line with a blue mark on the head. The head sealing surface contained slight indentations from a previous thermal test in which the cylinders (only) were assembled without a jacket. The combustor sealing surface was satisfactory.

The attach bolt free lengths, assembly torque and assembled lengths are noted in Figure 1. Seal preload was 3,901 pounds (calculated), which was below minimum Apollo requirements. This was purposely low to prevent bolt deformation (bolt shank diameters were undersize).

Dry nitrogen was applied to the assembled seal at 175 psig. There was 16.0 psi decay in five minutes (where 15.0 psi is maximum allowable for Apollo assemblies). The main source of leakage was observed to be from the area of the scratch as anticipated. A portion of the leakage was attributed to the low seal preload.

B. Hardware Assembly - T-13619 S/N A Seal - (This seal had been previously subjected to an informally planned load test and to two thermal tests per MTP 0041, Appendix B).

The Rene' 41 jacket and titanium spacers were vapor degreased then ultrasonic cleaned prior to this assembly. A new T-13617 Zircoa "C" cylinder set and a new garter spring was used.

The seal jacket zero degree index mark was installed against the combustor face and radially in line with the number one bolt. The combustor and head sealing surfaces were satisfactory.

The attach bolt free lengths, assembly torque and assembled lengths are noted in Figure 2. Seal preload was 4,735 pounds (calculated), which was near the Apollo minimum requirements.

Dry nitrogen was applied to the assembled seal at 175 psig. There was 6.75 psi decay in five minutes (within allowable limits). Leakage appeared to be evenly dispersed around the seal periphery and mostly from the combustor side of the seal.

VII. TEST (Continued)

C. Corrosion Test Operation - See Figures 6 and 8 for condition of specimens and their test rigs prior to immersion in salt fog.

Both test rigs were ganged at one time in the Model CA-1 corrosion test cabinet. They were installed vertically with thrust chambers pointed down, hanging from nylon cords as shown in Figure 5. Schematic for the test cabinet is shown in Figure 4.

The specimens were subjected to salt fog for 48 hours per MIL-STD-810, Procedure 509, as required by MTP 0041, Appendix D, Paragraph D-3.1.6.6.1. See Figure 3 for data and parameters.

D. Hardware Disassembly and Examination

Both test rigs were removed from the corrosion test cabinet immediately after shutdown. They were photographed (see Figures 7 and 9), then washed with tap water and dried.

Dry nitrogen pressure test was conducted on each assembled seal at 175 psig. There was 3.75 psi decay in five minutes for the T-13618 Seal, and 1.50 psi decay in five minutes for the T-13619 Seal.

The attach bolt assembled lengths, breakaway torque and free lengths were recorded. See Figure 1 for T-13618 Seal data; see Figure 2 for T-13619 Seal data. Seal preload for T-13618 Seal was 3,733 pounds (calculated). Seal preload for T-13619 Seal was 4,457 pounds (calculated).

Both individual seals were photographed together prior to washing. See Figure 10. Seal jackets were stained; no corrosive attack (pitting) was exhibited.

T-13618 TEST RIG ATTACH BOLT DATA

BEFORE AND AFTER CORROSION TEST

BOLT NUMBER	PRIOR TO SALT FOG EXPOSURE			AFTER SALT FOG EXPOSURE		
	FREE LENGTH- INCHES	ASSEMBLY TORQUE (TOTAL)- INCH LBS	ASSEMBLED LENGTH- INCHES	ASSEMBLED LENGTH- INCHES	BREAKAWAY TORQUE- INCH LBS	FREE LENGTH- INCHES
1	1.4717	23.0	1.4748	1.4748	14.5	1.4717
2	1.4657	20.0	1.4688	1.4686	14.0	1.4655
3	1.4647	23.0	1.4677	1.4676	14.5	1.4643
4	1.4638	20.0	—*	1.4662	11.5	1.4638
5	1.4652	25.0	1.4682	1.4682	13.0	1.4652
6	1.4662	23.0	1.4692	1.4691	13.5	1.4662

*Length is presumed to have been erroneously read as 1.4672.

FIGURE 1

T-13619 TEST RIG ATTACH BOLT DATA

BEFORE AND AFTER CORROSION TEST

BOLT NUMBER	PRIOR TO SALT FOG EXPOSURE			AFTER SALT FOG EXPOSURE		
	FREE LENGTH- INCHES	ASSEMBLY TORQUE (TOTAL)- INCH LBS	ASSEMBLED LENGTH- INCHES	ASSEMBLED LENGTH- INCHES	BREAKAWAY TORQUE- INCH LBS	FREE LENGTH- INCHES
1	1.4608	18.0	1.4640	1.4639	13.0	1.4603
2	1.4606	23.0	1.4635	1.4635	14.5	1.4606
3	1.4607	18.0	1.4639	1.4639	12.0	1.4610
4	1.4605	21.0	1.4633	1.4633	12.0	1.4605
5	1.4605	21.0	1.4637	1.4635	12.5	1.4605
6	1.4606	25.0	1.4640	1.4636	9.0	1.4606

FIGURE 2

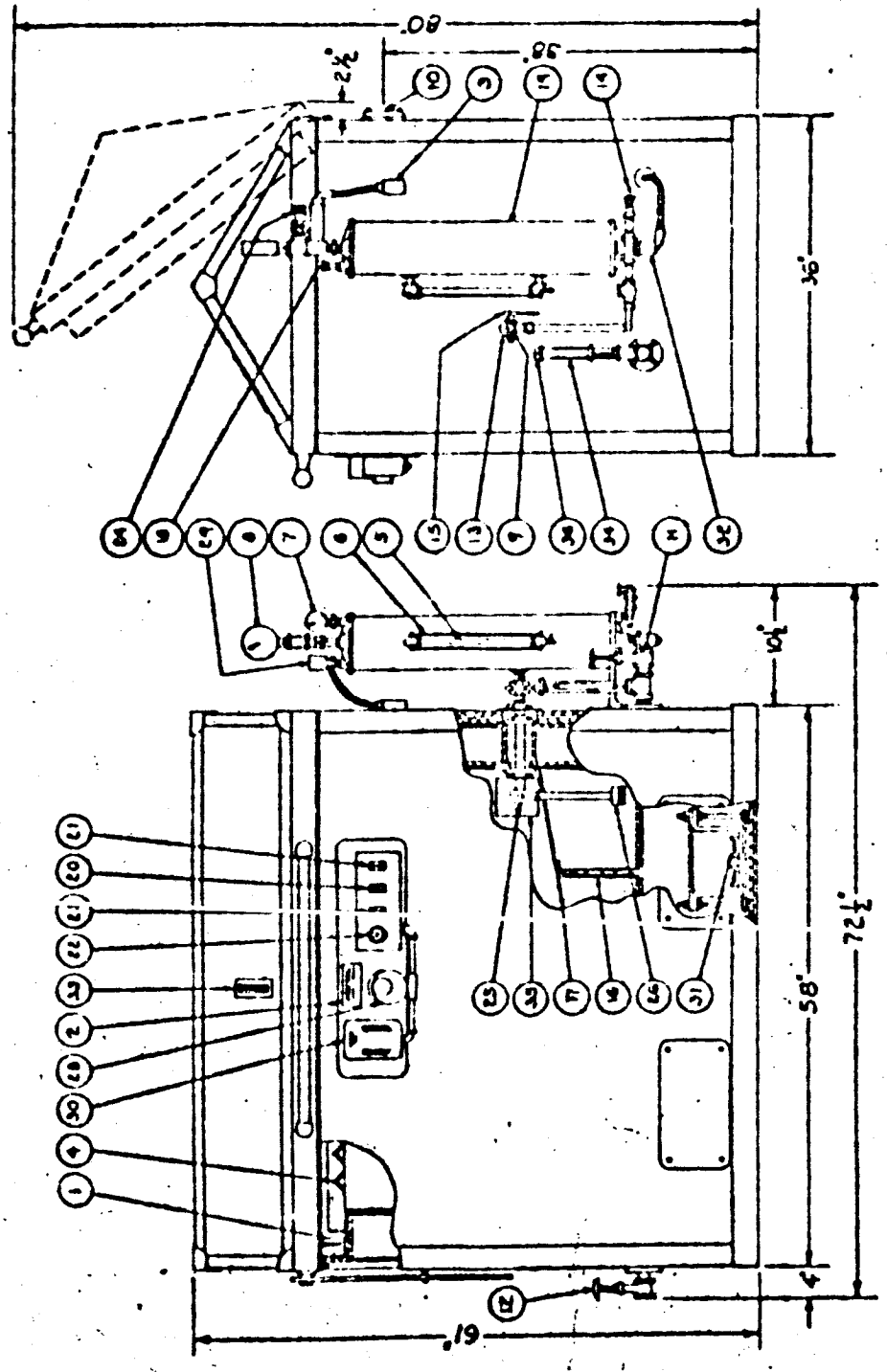
DATA & PARAMETERS - CORROSION TEST OPERATION

DATE	TIME	CABINET DRY BULB TEMP. - °F		SATURATING TOWER TEMP. - °F		SATURATING TOWER PRESSURE - PSIG		PH SALT SOLUTION		SPECIFIC GRAVITY OF SOLUTION		COMMENTS
		REQ'D	ACTUAL	REQ'D	ACTUAL	REQ'D	ACTUAL	REQ'D	ACTUAL	REQ'D	ACTUAL	
2-16-66	1330	95^{+2}_{-3}	—	100-110	—	12.0-18.0	—	6.5-7.2	6.5	1.023-1.037	1.0365	STARTED HEATERS
2-16-66	1405		—		102		13.0					STARTED SALT FOG
2-16-66	1507		93		108		13.0					"ON" CONDITION
2-17-66	0815		93		107		13.2					
2-17-66	1500		94		104		13.5					
2-17-66	1915		93		112*		13.3					
2-18-66	0800		93		104		13.3					
2-18-66	1115		94		110		13.3					
2-18-66	1435		94		104		13.3					
2-18-66	1507	95^{+2}_{-3}	94	100-110	108	12.0-18.0	13.3	6.5-7.2	6.5	1.023-1.037	1.0365	COMPLETED TEST

*Test is considered satisfactory because 2°F higher temperature increased the salt vapor concentration.

FIGURE 3

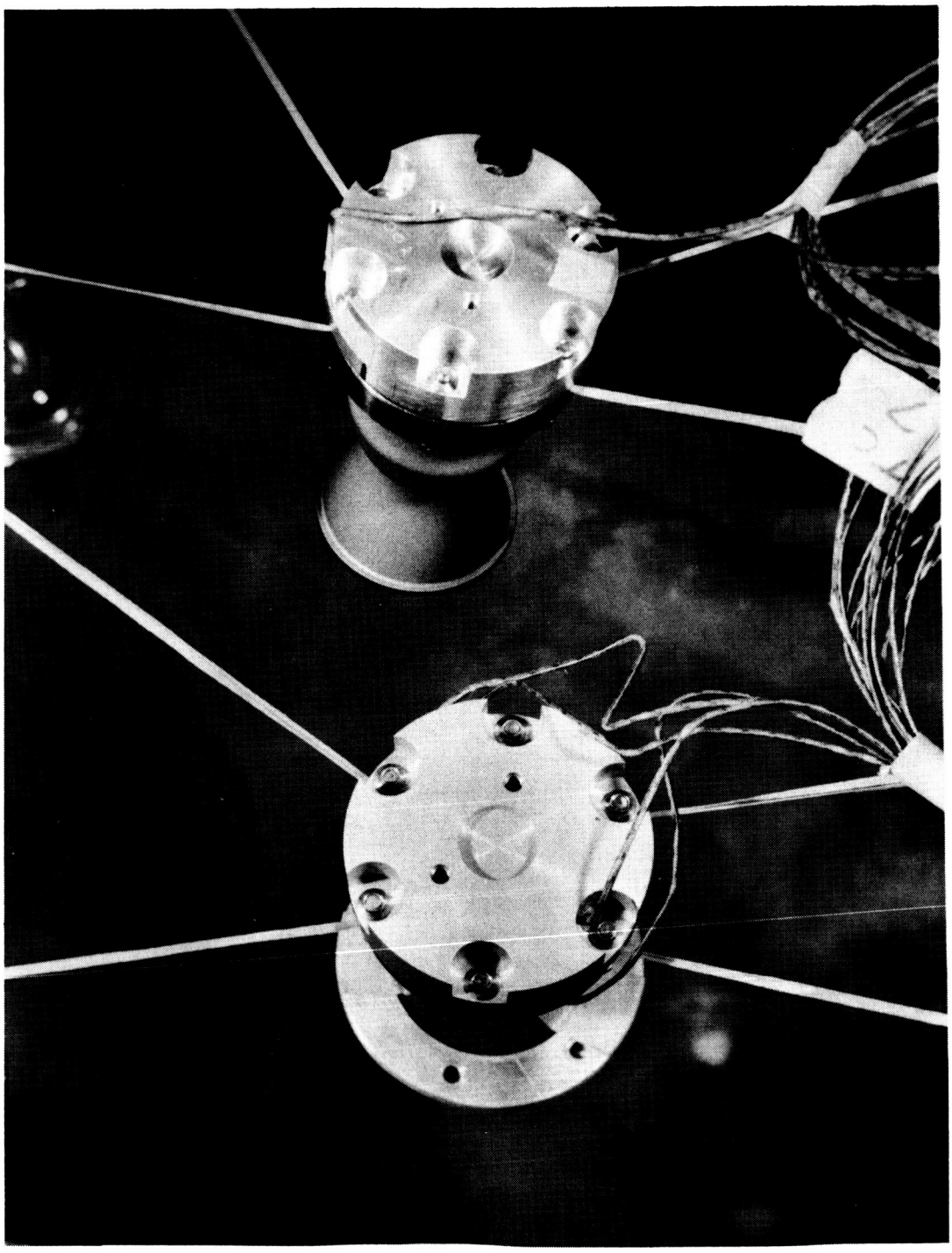
NO	REFERENCE LIST:
1	WATER SEAL
2	NAME PLATE
3	CONDUIT BOX-POWER INLET
4	SPECIMEN SUPPORT BARS
5	SIGHT GLASS
6	GUARD RODS
7	THERMOMETER SATURATOR TOWER
8	PRESSURE GAGE
9	AIR INLET
10	EXHAUST VENT
11	DRAIN VALVE SALT SOLUTION
12	DRAIN VALVE CABINET
13	FOG PURGE INLET
14	DRAIN SOCK-SATURATOR
15	AIR INLET COCK (THREE-WAY)
16	SALT SOLUTION COMPARTMENT
17	COVER FOR 16
18	WATER CAP
19	SATURATOR TOWER
20	MAIN SWITCH
21	PILOT LIGHT FOR 32
22	THREE HEAT SWITCH
23	PILOT LIGHT FOR 31
24	AIR RELIEF VALVE
25	ATOMIZER
26	FILTER SOCK FOR ATOMIZER
27	
28	THERMOSWITCH FOR CABINET
29	CONDUIT BOX THERMOSWITCH FOR 28
30	RELAY SWITCH
31	HEATING ELEMENTS FOR CABINET
32	IMMERSION HEATER FOR 16
33	THERMOMETER FOR CABINET
34	SIGHT GLASS & FILLER TUBE
35	SPRAY BAFFLE
36	SALT SOLUTION CAP



SALT FOG TEST SETUP

FIGURE 4

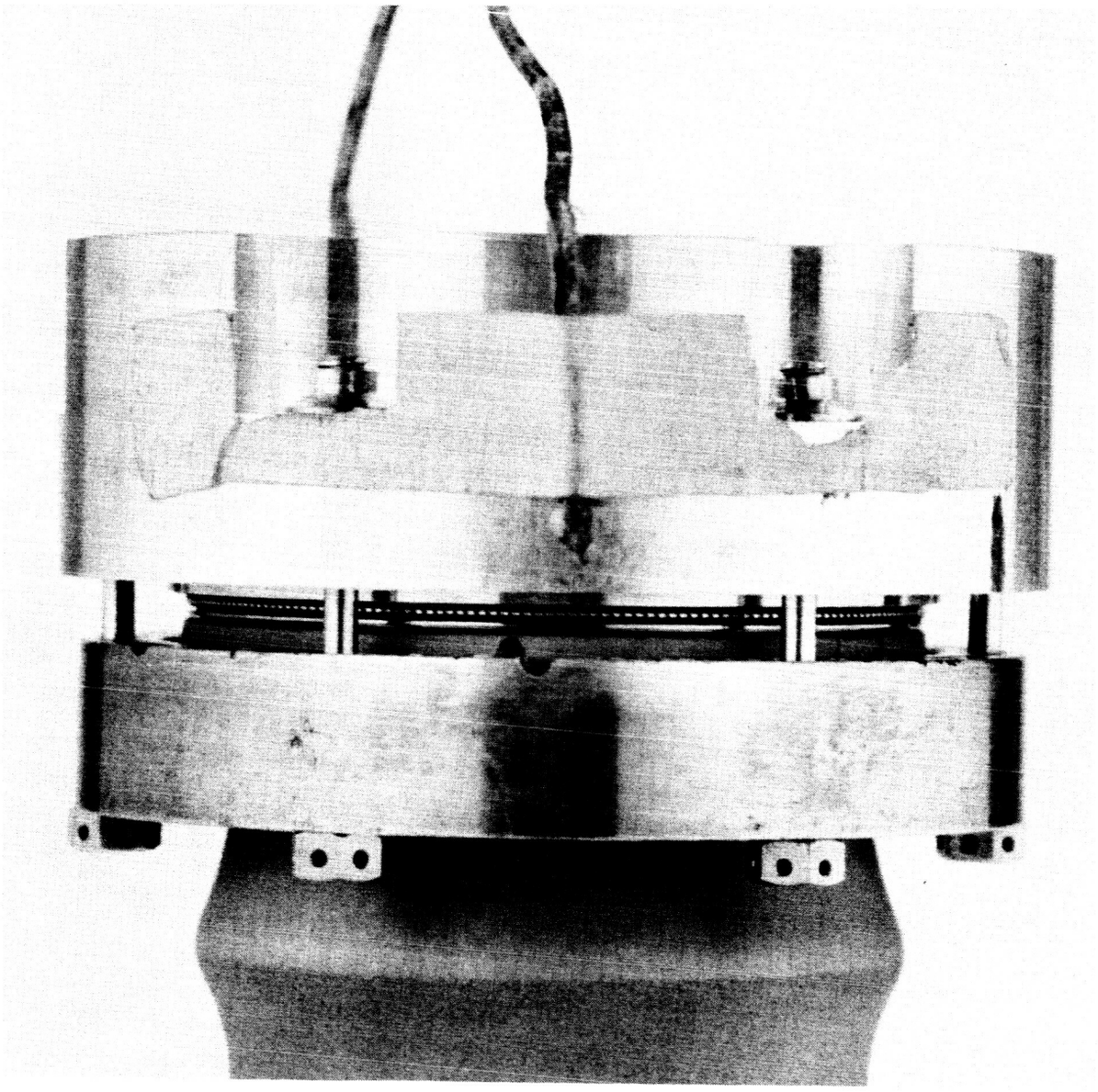
TEST SETUP, CORROSION TEST



NEG. T11282-7

Figure 5

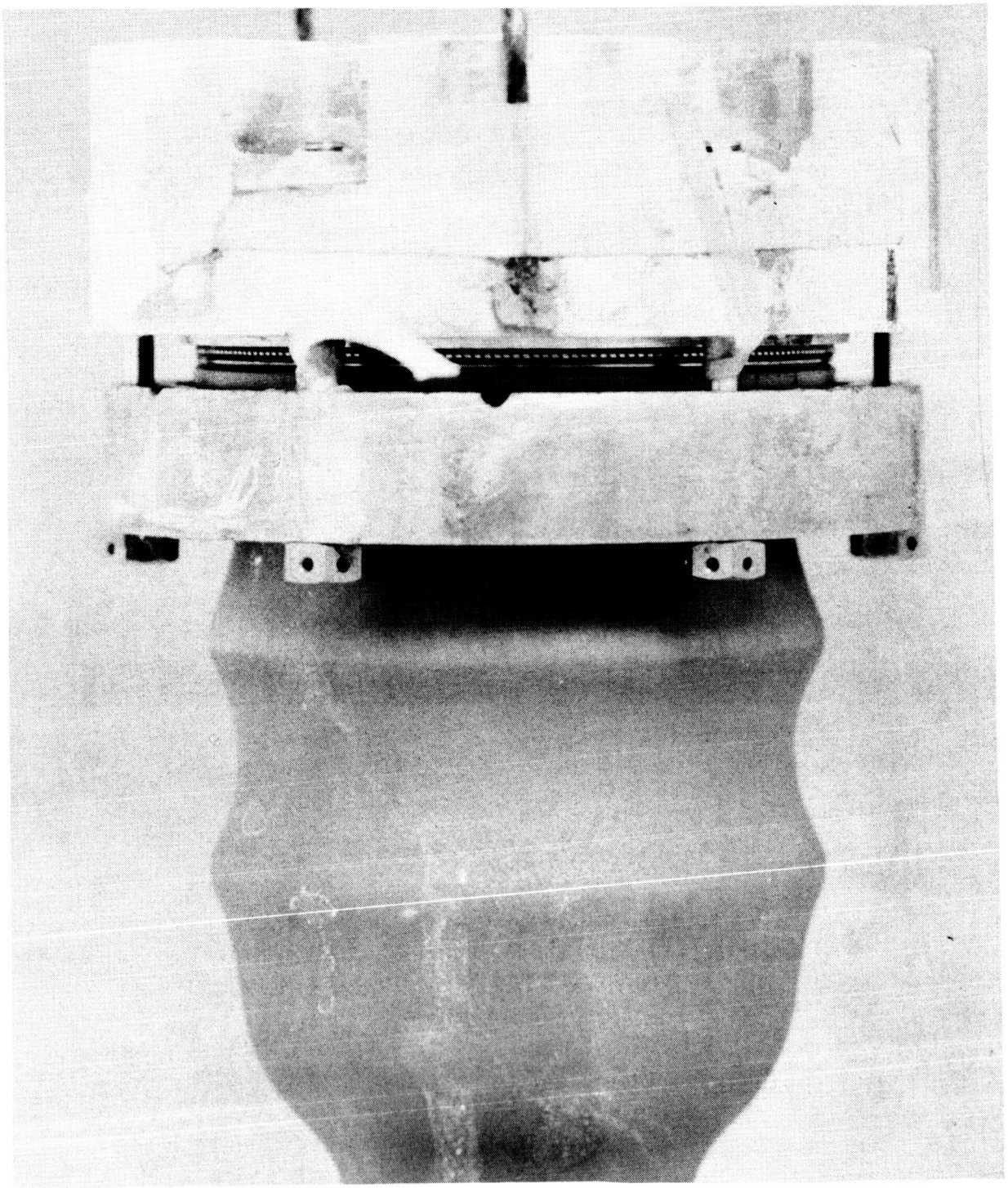
COMPOSITE SEAL ASSEMBLY (TITANIUM)
T-13618 S/N A INSTALLED IN TEST RIG, PRIOR TO CORROSION TEST



NEG. T11282-5

Figure 6

COMPOSITE SEAL ASSEMBLY (TITANIUM)
T-13618 S/N A INSTALLED IN TEST RIG, AFTER CORROSION TEST

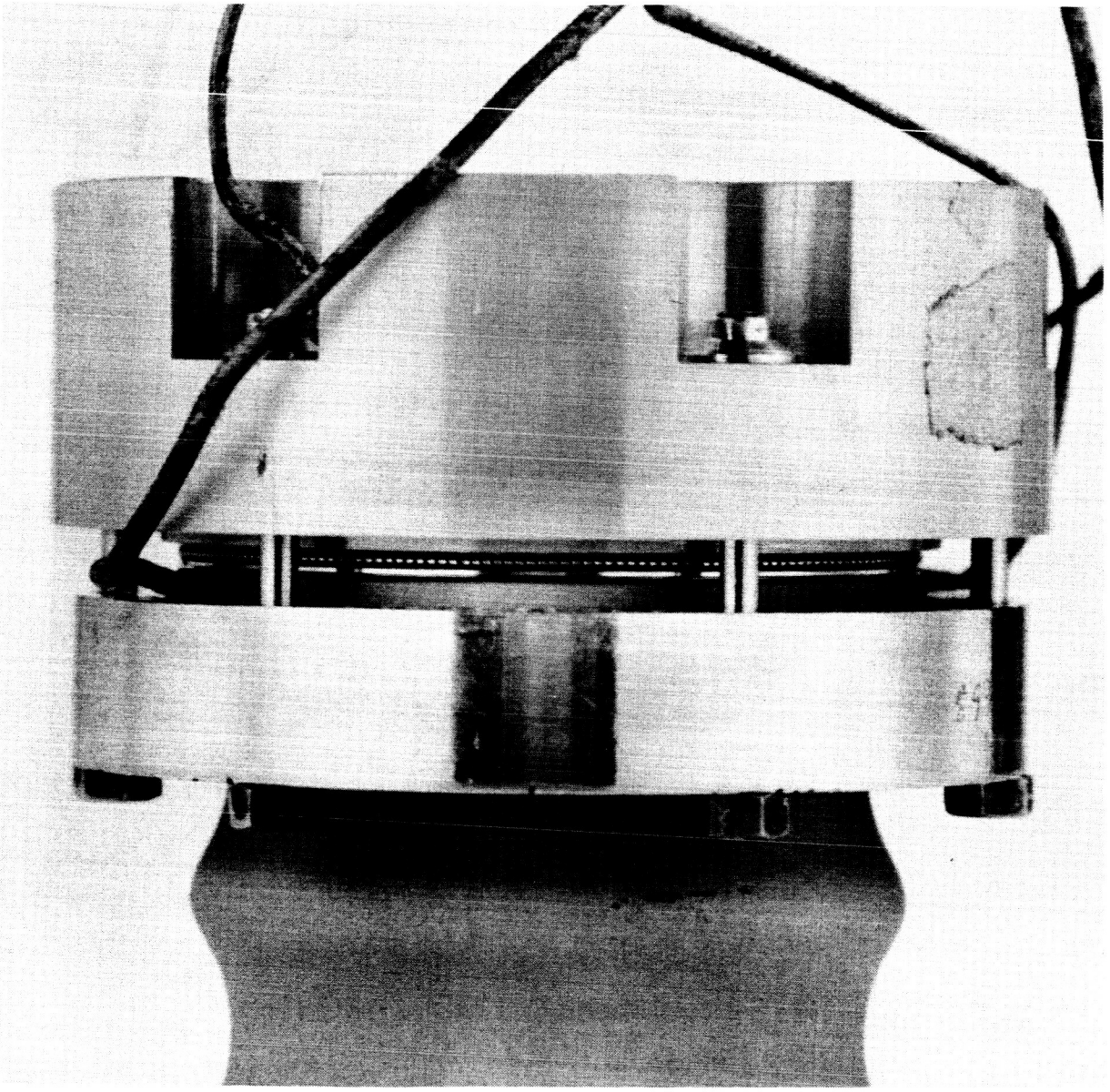


NEG. T11282-9

Figure 7

COMPOSITE SEAL ASSEMBLY (RENE)

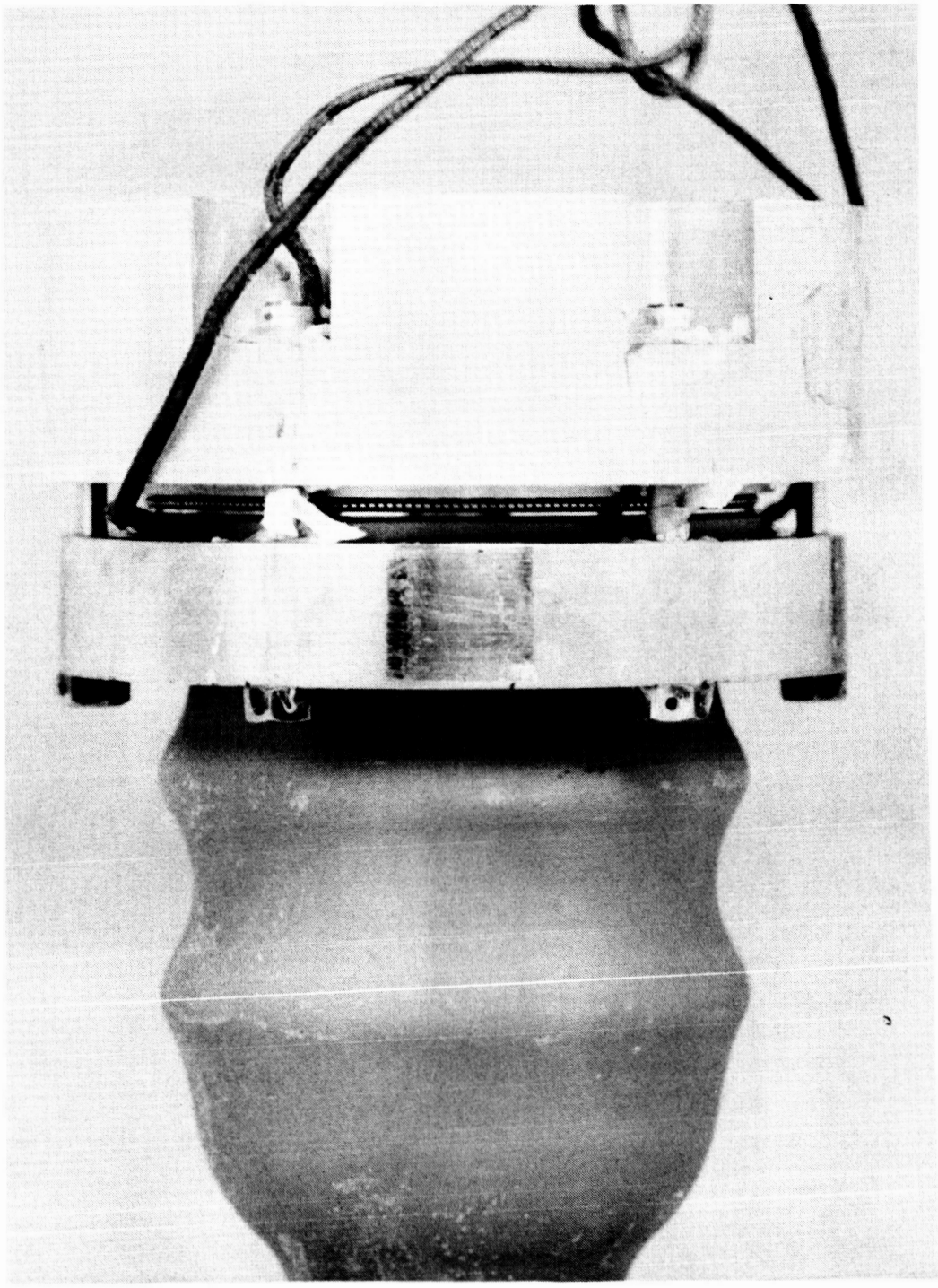
T-13619 S/N A INSTALLED IN TEST RIG, PRIOR TO CORROSION TEST



NEG. T11282-3

Figure 8

COMPOSITE SEAL ASSEMBLY (RENE)
T-13619 S/N A INSTALLED IN TEST RIG, AFTER CORROSION TEST



NEG. T11282-12

Figure 9

COMPOSITE SEALS AFTER CORROSION TEST BUT PRIOR TO CLEANING



NEG. T11282-20

Figure 10

ATTACHMENT 11

TEST REPORT

SUPPLEMENTAL THERMAL EVALUATION

OF

EXPERIMENTAL ZIRCONIUM OXIDE MATERIALS

FOR

APOLLO SERVICE MODULE

REACTION CONTROL SYSTEM ENGINE

CHAMBER SEAL STUDY

PREPARED UNDER CONTRACT NAS 9-4775

TMC 3008

Prepared by J C Paladin
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E. Perlman
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3	SCHEMATIC OF INSTRUMENTATION	7

I. INTRODUCTION

Initial full scale seal thermal resistance tests of composite seals with full density Zircoa "C" cylinder spacers indicated that seal resistance was about 3.0 Hr-°F/Btu and not the expected 5.0 Hr-°F/Btu. Subsequent tests were conducted to measure thermal conductivity of the full density Zircoa "C" (347 lb/ft^3). It was discovered that the conductivity was 1.2 Btu/Hr-Ft°F rather than the assumed 0.54 Btu/Hr-Ft°F.

A literature survey was made and it was found that thermal conductivity of zirconium oxide could be controlled by varying it's bulk density. (Figure 15a of Reference 1)

The supplier of the Zircoa "C" was contacted and he verified that porosity (and thus density) of Zircoa "C" could be controlled. By the information shown on the above referenced Figure, it appeared that modified Zircoa "C" with bulk density of 270 lbs/ft^3 might have a thermal conductivity approaching the required 0.54 Btu/Hr-Ft°F. The compressive strength, however, of modified Zircoa "C" was anticipated to be marginal. The vendor suggested that another grade of zirconium oxide, Zircoa 1027, which possesses compressive strength approximately 30% greater than Zircoa "C", also be evaluated at the same bulk density.

A set of 60 cylinders of each of the above, modified Zircoa "C" and modified Zircoa 1027, were manufactured and tested for thermal conductivity in accordance with the test method previously employed in evaluating the full dense Zircoa "C".

II. CONCLUSIONS AND RECOMMENDATIONS

Neither of the two types of experimental Zirconium Oxide tested, Zircoa No. 1027 (Modified) or Zircoa "C" (Modified), exhibited sufficiently high thermal resistance to meet the program objective.

Minimum acceptable resistance of the heat path through the cylinders is 8.0 Hr-°F/Btu. The Zircoa "C" (Modified) had an average resistance of 5.0 Hr-°F/Btu and Zircoa 1027 (Modified) had an average resistance of 3.5 Hr-°F/Btu.

The relationship of porosity (bulk density) of Zircoa "C" and its thermal conductivity is not as reported in Figure 15a of Reference 1. Based on results of this test, a higher degree of porosity of the Zirconium Oxide is required for the necessary high thermal resistance. For this high porosity, the compressive strength of the cylinders would be less than adequate.

It is recommended that the alternate methods of obtaining high resistance of the composite seal be reconsidered. The most feasible method would be to double the ratio of the existing Zirconium Oxide cylinder length to heat transfer area.

III. SUMMARY

One set of cylinders from each of the two types of experimental Zirconium Oxide which were selected for further study were tested for their thermal resistance in test rigs which were made to simulate Apollo SM/RCS engines.

Testing was performed in Marquardt's high altitude, cold wall, space simulator chamber. The materials which were tested and the measured thermal resistances of 60 cylinders (required quantity per composite seal) are shown below:

Material	Bulk Density lbs/ft^3	Thermal Resistance Hr-°F/Btu
Zircoa "C" (Modified	269	5.0
Zircoa 1027 (Modified)	275	3.5

IV. TEST HARDWARE

Both sets of Zirconium Oxide cylinders were assembled into simulated Apollo SM/RCS engines consisting of flight-type Apollo combustion chambers, attach rings and bolts and machined aluminum blocks to simulate engine injector heads. A detail of cylinder assemblies is shown in Figure 1. The composite seal jacket, which provides the second heat path in the composite seal, was not used in order to facilitate direct measurement of the cylinder heat path resistance only.

The two simulated engines were then suspended from a bar, with the simulated engine injector heads encased in an aluminum thermal boundary. A photograph of a similar test rig prior to installation into the cold wall vacuum chamber is shown in Figure 2.

Figure 3 schematically shows the locations of engine and facility thermocouples.

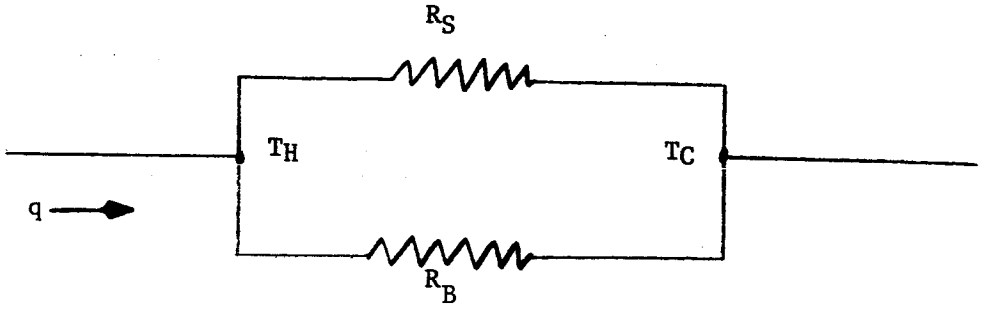
V. TEST PROCEDURE

Testing was conducted per Appendix B of MTP 0041. Throughout testing, the facility chamber pressure was maintained at 9×10^{-6} mm Hg or less. Chamber walls were cooled by liquid nitrogen to about -320°F. Simulated engine injector heads and the thermal boundary were then heated to the same desired run temperature to prevent radiation heat loss from the simulated injector heads. Run temperatures were maintained constant for one hour during which time data were recorded.

Two record runs were made during this test. One was at a nominal simulated injector head temperature of +20°F (cylinder temperature $\cong$ 0°F) and one at +160°F.

VI. SEAL RESISTANCE CALCULATION PROCEDURE

The heat paths across the head-seal-chamber joint are shown below:



where:

R_J = Total Joint Thermal Resistance

R_B = Attach Hardware Thermal Resistance $\frac{Hr\text{-}^\circ F}{BTU}$

R_S = Seal Thermal Resistance $\frac{Hr\text{-}^\circ F}{BTU}$

T_H = Temperature of Simulated Head

T_C = Chamber Flange Temperature

q = Heat Flow Rate - $\frac{BTU}{Hr.}$

The joint overall thermal resistance (R_J) was calculated by dividing the temperature difference ($T_H - T_C$) between the injector head and the chamber flange by the heat flow rate (q),

$$R_J = \frac{T_H - T_C}{q} \quad \frac{^\circ F}{(BTU/Hr)} .$$

The joint resistance is equal to

$$R_{joint} = \frac{R_S \; R_B}{R_S + R_B}$$

and therefore

$$R_S = \frac{R_B \; R_J}{(R_B - R_J)}$$

Seal resistance was calculated from $R = \frac{R_B \; R_J}{(R_B - R_J)}$ where bolt thermal resistance (R_B) was calculated to be 42.3 Hr-°F/BTU from the nominal dimensions of the attach hardware. Heat losses by convection were negligible at high vacuum, $< 10^{-5}$ mm Hg. Radiation heat losses from the simulated injector heads to the thermal boundary were made approximately zero by heating the thermal boundary to the same temperature as the simulated injector heads.

VII. DISCUSSION OF TEST RESULTS

Thermal resistances which were obtained for the two types of Zirconium Oxide cylinders tested are:

Material	Thermal Resistance Hr-°F/BTU
Zircoa "C" (Modified)	5.0
Zircoa 1027 (Modified)	3.5

Both of the above resistances are average values calculated from results of two separate heat flow rates (engine simulated injector head temperatures of +20°F and +160°F).

Neither of the materials are suitable for use as spacers in the current composite seal design. Zircoa "C" (Modified) spacers would result in seal thermal resistance of about 3.6 Hr-°F/BTU. Zircoa 1027 (Modified) spacers would yield a seal resistance of about 2.8 Hr-°F/BTU.

Appendix A presents the raw test data and Appendix B contains the thermal resistance calculations which were made.

Reference:

1. Second Quarter Report, Apollo Service Module Reaction Control System Engine Injector Chamber Seal Study - PR3008-2Q, dated February 1966.

CYLINDER INSTALLATION SKETCH

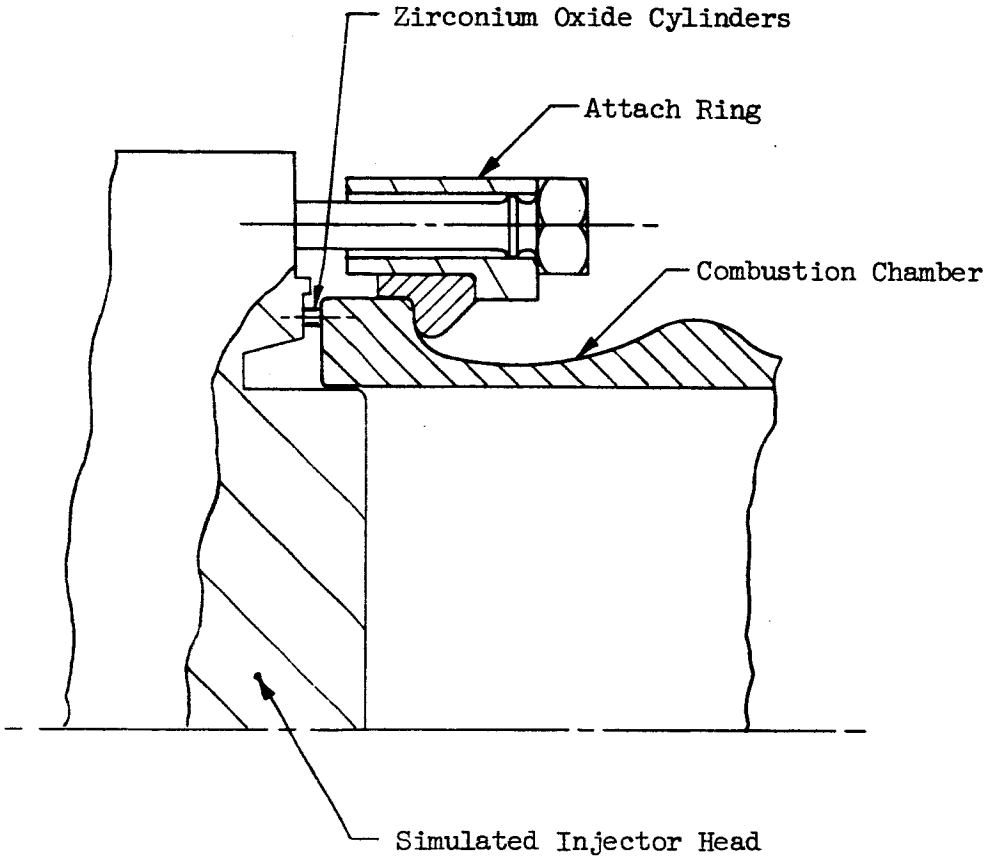
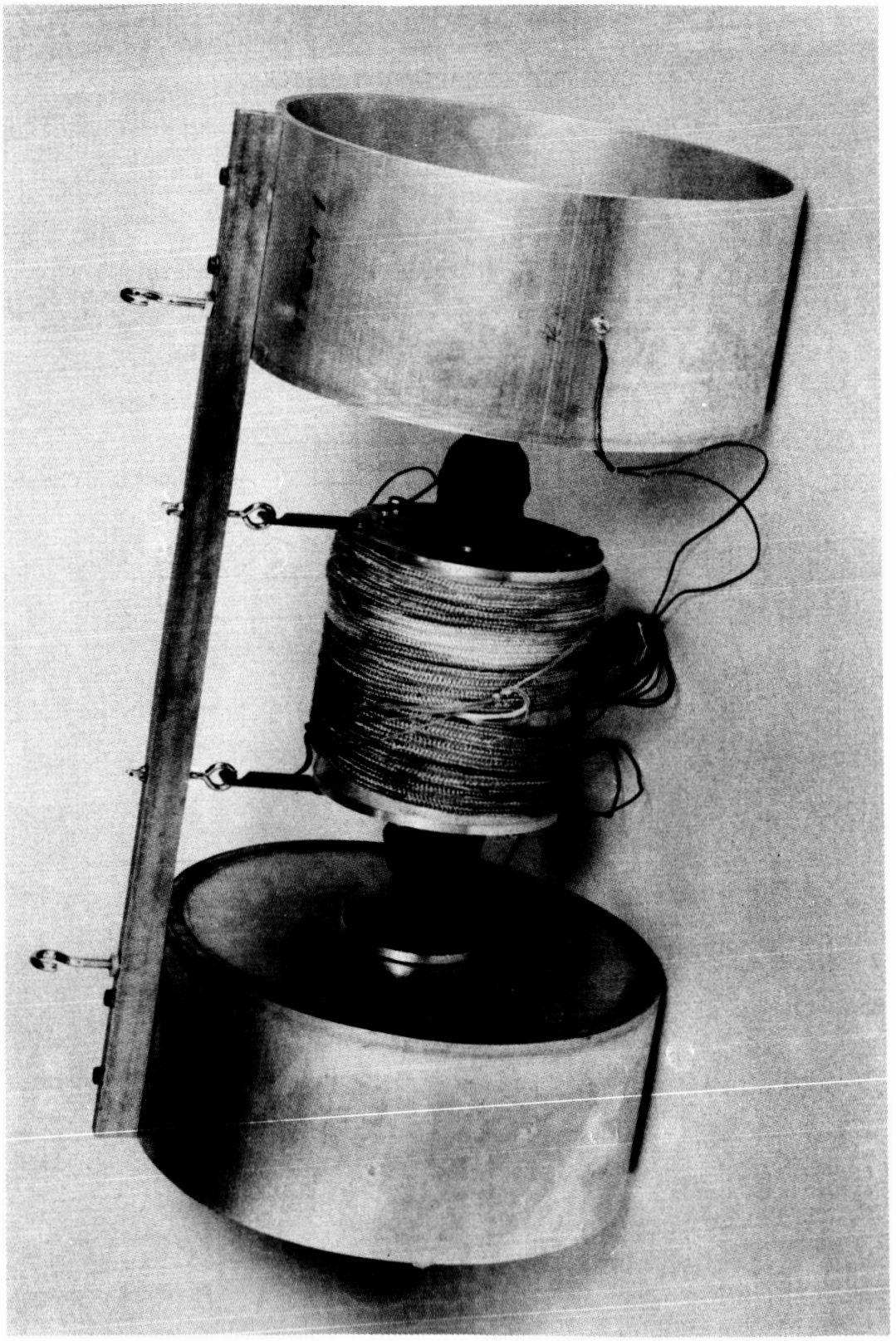


FIGURE 1

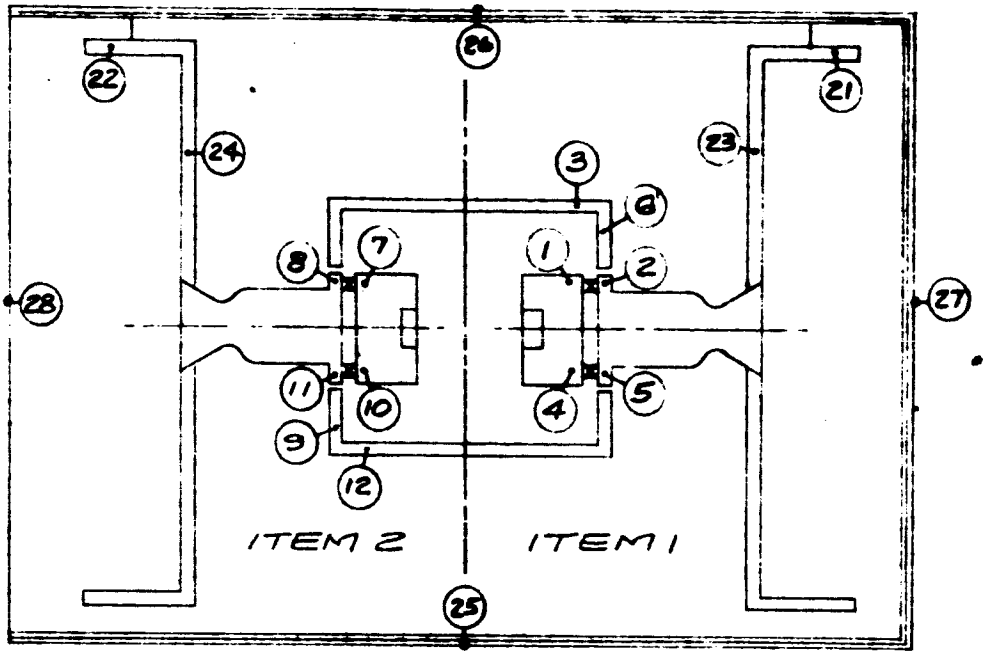


TEST 11267 SEAL THERMAL RESISTANCE TEST HARDWARE (U)
BLDG. 32
11 JAN 66

NEG. T11267-3

FIGURE 2

SCHEMATIC OF INSTRUMENTATION



T/C NO.	LOCATION	ITEM	TYPE
1	INJ. HD. ADJACENT TO SEAL	1	I/C
2	COMBUSTOR FLANGE OPPOSITE T/C 1	1	I/C
3	TOP OF BOUNDARY FIXTURE	1	I/C
4	INJ. HD ADJACENT TO SEAL (180° OPP. T/C 1)	1	I/C
5	COMBUSTOR FLANGE OPPOSITE T/C 4	1	I/C
6	END OF BOUNDARY FIXTURE OPP. T/C 3	1	I/C
7	INJ. HD. ADJACENT TO SEAL	2	I/C
8	COMBUSTOR FLANGE OPPOSITE T/C 7	2	I/C
9	END OF BOUNDARY FIXTURE	2	I/C
10	INJ. HD. ADJACENT TO SEAL (180° OPP. T/C 7)	2	I/C
11	COMBUSTOR FLANGE OPPOSITE T/C 10	2	I/C
12	BOTTOM OF BOUNDARY FIXTURE OPP. T/C 9	2	I/C
13			
14			
15			
16			
17			
18			
19			
20			
21	TOP OF RADIATOR	1	C/A
22	TOP OF RADIATOR	2	C/A
23	WALL OF RADIATOR	1	C/A
24	WALL OF RADIATOR	2	C/A
25	BOTTOM OF LN_2 COOLED WALL	-	C/A
26	TOP " " " "	-	C/A
27	END " " " "	-	C/A
28	UNCOOLED WALL	-	C/A

FIGURE 3

APPENDIX A

TEST DATA

SEAL THERMAL RESISTANCE TEST
SIMULATED ENGINE
PER MTP 0041 APPENDIX B
TEST #5 DATE 3-31-60
4-1-60

ENG #1
SEAL TYPE ZIRCOA #1027
MODIFIED
60 EA CYLINDERS ONLY

ENG #2
SEAL TYPE ZIRCOA "C"
MODIFIED
60 EA CYLINDERS ONLY

DATA PT. No.	TIME	V.B.S. VOLTS	V.B.S. AMPS	VACUUM PRESS MM Hg	FACILITY TEMP T25	FACILITY TEMP T26	FACILITY TEMP T27	FACILITY TEMP T28	HEAD HTR VOLTS	HEAD HTR M.A	ENGINE TEMP T1	ENGINE TEMP T2	ENGINE TEMP T3	ENGINE TEMP T4	ENGINE TEMP T5	ENGINE TEMP T6	ENGINE TEMP T21	ENGINE TEMP T23	HEAD HTR VOLTS	HEAD HTR M.A	ENGINE TEMP T7	ENGINE TEMP T8	ENGINE TEMP T9	ENGINE TEMP T10	ENGINE TEMP T11	ENGINE TEMP T12	ENGINE TEMP T22	ENGINE TEMP T24
1	22:00	16.0	1.3	.04x10⁻⁴	-350	-350	-320	-75	20.0	212.0	+19	-28	+21	+20	-27	—	-63	-62	18.0	195.0	+20	-35	+22	+20	-35	+20	-60	-60
2	22:15	0	0	.04x10⁻⁴	-350	-350	-330	-96	20.0	212.0	+20	-28	+24	+20	-27	—	-63	-61	18.0	195.0	+20	-34	+23	+20	-35	+21	-60	-60
3	22:30	0	0	.04x10⁻⁴	-350	-350	-335	-96	20.0	212.0	+20	-28	+22	+20	-27	—	-63	-62	18.0	195.0	+20	-35	+21	+20	-34	+19	-60	-60
4	22:45	30.0	2.3	.04x10⁻⁴	-350	-350	-336	-96	20.0	212.0	+20	-28	+20	+20	-27	—	-63	-62	18.0	195.0	+20	-35	+19	+19	-35	+18	-61	-60
5	23:00	0	0	.04x10⁻⁴	-350	-350	-330	-96	20.0	212.0	+20	-27	+22	+20	-27	—	-63	-62	18.0	195.0	+20	-34	+22	+20	-35	+20	-61	-60
6	23:15	0	0	.05x10⁻⁴	-350	-350	-335	-96	20.0	212.0	+20	-27	+21	+21	-27	—	-63	-62	18.0	195.0	+20	-35	+20	+20	-34	+18	-61	-60
7	03:30	15.0	1.5	.05x10⁻⁴	-325	-325	-315	-90	31.5	300	+162	+55	+164	+162	+59	—	-24	-22	28.5	285	+160	+36	+163	+160	+35	+160	-25	-23
8	03:45	17.5	1.95	.05x10⁻⁴	-325	-325	-320	-90	31.5	305	+160	—	+163	+160	+59	—	-22	-20	28.5	285	+159	+36	+159	+159	+36	+156	-24	-22
9	04:00	30.0	2.2	.05x10⁻⁴	-325	-325	-305	-90	31.5	305	+160	—	+160	+160	+60	—	-20	-18	28.5	285	+158	+37	+159	+158	+37	+157	-22	-18
10	04:15	11.0	1.0	.05x10⁻⁴	-325	-325	-310	-89	31.5	305	+160	—	+161	+160	+60	—	-18	-16	28.5	285	+158	+38	+160	+158	+38	+157	-20	-17
11	04:30	39.0	2.9	.07x10⁻⁴	-325	-325	-305	-88	31.5	305	+160	—	+157	+160	+61	—	-17	-15	28.5	285	+158	+38	+156	+157	+39	+154	-19	-16
12	04:45	0.0	0.0	.09x10⁻⁴	-325	-325	-300	-88	31.5	305	+161	—	+154	+162	+62	—	-15	-13	28.5	285	+158	+40	+162	+158	+40	+160	-17	-15

APPENDIX B

CALCULATIONS

SEAL TEST #5

ENG #1

ZIRCOA #1027

MODIFIED

60 EA CYL ONLY

4-1-66

ENG #2

ZIRCOA "C" MODIFIED

60 EA CYL ONLY

Run Hr	Run Min	T_H °F	T_C °F	ΔT °F	G BTU/HR	R_J HR-°F/BTU	R_S HR-°F/BTU	T_S °F	T_H °F	T_C °F	ΔT °F	Q BTU/HR	R_J HR-°F/BTU	R_S HR-°F/2.20	T_S °F
2	0330	+162	+59	103	32.76	3.15	3.39		+160	+35	125	27.8	4.5	5.03	
8	0345	+160	+59	101	32.76	3.09	3.34		+159	+36	123	27.8	4.43	4.94	
9	0400	+160	+60	100	32.76	3.06	3.30		+158	+37	121	27.8	4.35	4.86	
10	0415	+160	+60	100	32.76	3.06	3.30		+158	+38	120	27.8	4.32	4.83	
11	0430	+160	+61	99	32.76	3.02	3.25		+157	+39	116	27.8	4.17	4.75	
12	0445	+162	+62	100	32.76	3.06	3.30		+158	+40	118	27.8	4.25	4.72	

SEAL TEST TEST #5

ENG #1

ZIRCCA #1027 MODIFIED

60 FA CYL. ONLY

RUN / DATA PT	T_H T_4 °F	T_C T_5 °F	ΔT °F	Q BTU/HR	R_J HR-°F/BTU	R_S HR-°F/BTU	T_S °F
1 2200	+20	-27	47	14.45	3.24	3.6	
2 2215	+20	-27	47	14.45	3.24	3.6	
3 2230	+20	-27	47	14.45	3.24	3.6	
4 2245	+20	-27	47	14.45	3.24	3.6	
5 2300	+20	-27	47	14.45	3.24	3.6	
6 2315	+21	-27	47	14.45	3.33	3.61	

3-31-66 4-1-66

ENG #2

ZIRCCA "C" MODIFIED

60 CYL. ONLY

T_H T_{10} °F	T_C T_{11} °F	ΔT °F	Q BTU/HR	R_J HR-°F/BTU	R_S HR-°F/BTU	T_S °F
20	-35	55	12.1	4.55	5.1	
20	-35	55	12.1	4.55	5.1	
20	-34	54	12.1	4.47	5.0	
19	-35	54	12.1	4.47	5.0	
20	-35	55	12.1	4.55	5.1	
20	-34	54	12.1	4.47	5.0	

ATTACHMENT 12

THE Marquardt CORPORATION VAN NUYS, CALIFORNIA

TEST REPORT

SEAL THERMAL RESISTANCE MEASUREMENT IN FIREABLE ENGINES

FOR

APOLLO SERVICE MODULE

REACTION CONTROL SYSTEM ENGINE

CHAMBER SEAL STUDY

PREPARED UNDER CONTRACT NAS 9-4775

TMC 3008

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Principal Investigator
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E. P. Perlman
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IV	TEST HARDWARE	2
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B	CALCULATIONS	B/1-4

I. INTRODUCTION

This report presents results of thermal resistance measurement testing of two selected high thermal resistance injector head-to-combustor seals for the Apollo Service Module Reaction Control System Engine, performed under Contract NAS 9-4775.

Of the original six high thermal resistance chamber seal designs, two were selected for combustion testing based upon the results of previous tests. The two selected designs were:

A. Conical Thinwall Titanium

B. Composite Titanium

The seals were built up in separate engine assemblies and, prior to combustion testing, were simultaneously tested for their thermal resistance in Marquardt's high-vacuum, cold wall, space simulator chamber.

II. SUMMARY AND CONCLUSIONS

Two high thermal resistance chamber seal designs were selected for combustion testing in Apollo S/M RCS Qualification type engines. The seal designs selected were (1) conical thinwall and (2) composite, both made of titanium 6Al-4V. The composite had "Zircoa C" spacers. Cross sections of these seals are shown in Figure 1. Basic reasons for selecting the two designs are:

(1) Conical: Exceeded program objectives (Resistance = 5.0 hr-°F/Btu) during simulated engine tests with a thermal resistance of 6.6 hr-°F/Btu. However, minor modification to the engine injector head is necessary to lengthen the seal cavity so that it can accommodate this seal.

(2) Composite: Although this seal exhibited a thermal resistance of 3.0 hr-°F/Btu, 2.0 hr-°F/Btu short of the program objective, this resistance is six times the R = 0.5 hr-°F/Btu of the current S/M RCS engine seal. This seal concept also shows promise of achieving the program objective by appropriate design modification. Further, it fits into the existing seal cavity in the Apollo S/M RCS engine injector head.

Prior to combustion testing of these two engine assemblies, seal resistances previously obtained were verified by cold soak testing of the engines.

A summary of the results obtained, together with seal resistance obtained during the previous cold soak tests (per MTP 0041, Appendix B) with simulated engines is presented in the following table:

SEAL CONFIGURATION	MATERIAL	SEAL THERMAL RESISTANCE Hr-°F/Btu	
		Fireable Engine	Simulated Engine
Conical Thinwall	Titanium	6.7	6.6
Composite	Titanium	2.9	3.0

III. RECOMMENDATIONS

Because the seal thermal resistances closely agreed with the predicted values, it is recommended that the engines be combustion tested, as originally planned.

IV. TEST HARDWARE

Each of the two seals were assembled into Apollo S/M RCS Qualification-type engines intended for eventual combustion testing per Appendix F of MTP 0041. Upon assembly, each engine was pressure checked to determine the seal leakage rate at 175 psig chamber pressure. Leakage rates are presented in Table I of this report.

Conical thinwall seal P/N T-13622, S/N C, made of 6Al-4V Titanium became a part of engine assembly P/N T-13768, S/N 0001-1. Composite seal, P/N T-13618, S/N C, also made of 6Al-4V Titanium with zirconium oxide cylindrical spacers was assembled into engine P/N T-12340, S/N 0001-7. Engine T-12340 had a new unfired chamber and bell. Engine T-13768 had a previously-fired chamber and bell. A cross-sectional view of the two seals is presented in Figure 1. Photographs of the two engines (after firing) are shown in Figures 2 and 3.

The two engines were assembled onto a suspension bar, as shown schematically in Figure 4, with the engine injector heads encased in an aluminum thermal boundary. Photographs of the test rig, prior to installation in the cold wall vacuum chamber are shown in Figures 5 and 6. Figure 7 is a photograph of the test rig installed in the cold wall chamber.

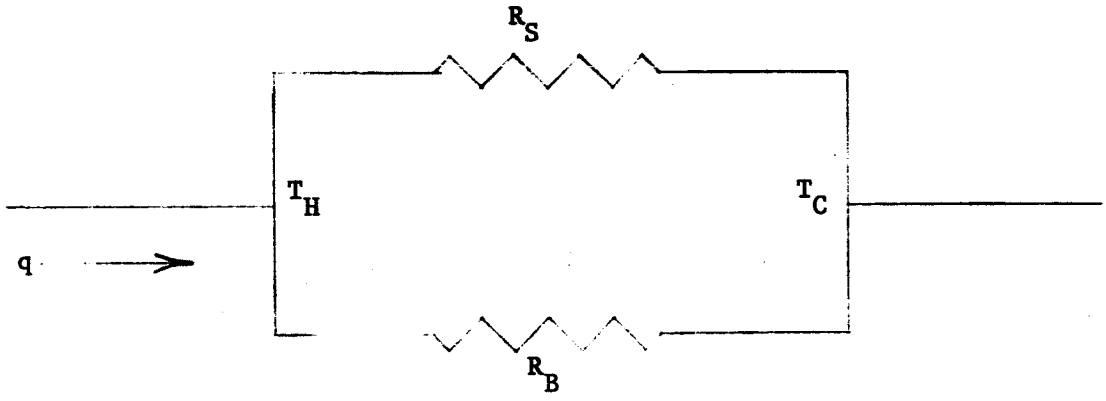
V. TEST PROCEDURE

Testing was conducted per Appendix E of MTP 0041. Throughout testing the facility chamber was maintained at a pressure of 10×10^{-5} mm Hg or lower with liquid nitrogen-cooled walls at about -320°F. Engine injector heads and the thermal boundary were then heated to the same target run temperature in order to prevent radiation heat loss from the injector heads. Target temperatures were maintained, plus or minus one degree F, for one hour during which time data were recorded.

For this test series, data were taken at three target engine head temperatures: 20°F, 50°F, and 130°F.

VI. SEAL RESISTANCE CALCULATION PROCEDURE

The heat paths across the head-seal-chamber joint are shown below:



where:

R_J = Total Joint Thermal Resistance

R_B = Attach Hardware Thermal Resistance hr-°F/Btu

R_S = Seal Thermal Resistance hr-°F/Btu

T_H = Temperature of Injector Head

T_C = Chamber Flange Temperature

q = Heat Flow Rate - Btu/hr

The joint overall thermal resistance (R_J) was calculated by dividing the temperature difference ($T_H - T_C$) between the injector head and the chamber flange by the heat flow rate (q):

$$R_J = \frac{T_H - T_C}{q} \quad \frac{°F}{(Btu/hr)}$$

The joint resistance is equal to:

$$R_{joint} = \frac{R_S \; R_B}{R_S + R_B}$$

and therefore

$$R_S = \frac{R_B \; R_J}{(R_B - R_J)}$$

Seal resistance was calculated from

$$R = \frac{R_B \; R_J}{(R_B - R_J)}$$

where bolt thermal resistance (R_B) was calculated to be 42.3 hr-°F/Btu from the nominal dimensions of the attach hardware. Heat losses by convection were negligible at high vacuum, 10^{-5} mm Hg. Radiation heat losses from the injector to the thermal boundary were made approximately zero by heating the thermal boundary to the same temperature as the injector heads.

Three heat flow rates were administered to each engine and the joint thermal resistances averaged to calculate the seal thermal resistances.

VII. DISCUSSION OF TEST RESULTS

Results which were obtained during this test closely agree with results previously obtained with simulated engines. The table below presents the thermal resistance of this and the previous test for comparison:

SEAL CONFIGURATION	MATERIAL	THERMAL RESISTANCE Hr-°F/Btu			
		Simulated Engines		Fireable Engines	
		Seal	Joint	Seal	Joint
Conical Thinwall	Titanium	6.6	5.7	6.7	5.7
Composite	Titanium	3.0	2.8	2.9	2.7

The results presented above are average values obtained during three separate heat flow rates (engine head temperatures). For the conical seal the resistance varied from 7.9 hr-°F/Btu at 20°F head temperature to 5.5 hr-°F/Btu at 130°F head temperature. This apparent drop in seal resistance at the higher heat flux can only be attributed to radiation loss from the attach ring, which was facing the cold wall (-300°F) and that portion of the injector face which could see the cold wall through the engine throat. The reason these losses were of a smaller magnitude for the composite seal, where the seal resistance dropped from 3.0 to 2.8 for head temperatures of 20°F and 130°F respectively, is that the facility chamber wall which faced engine T-12349 was much warmer, at -100°F.

Figures 8 through 13 present the heat flow rates, seal resistances, and temperature distributions for both engines at each of the three conditions tested.

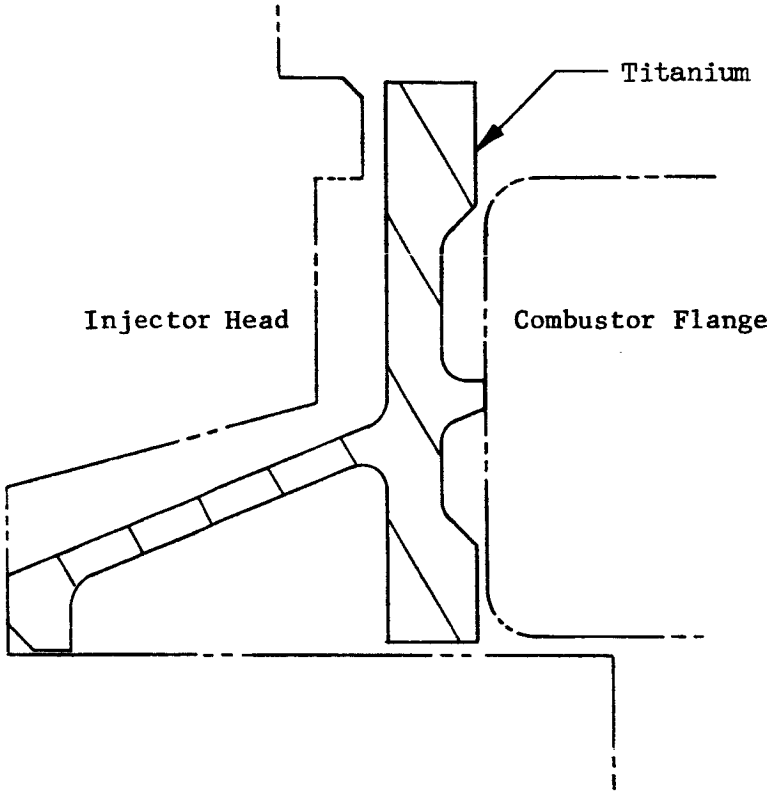
Appendix A presents the raw test data and Appendix B contains the seal resistance, joint resistance, and heat flux calculations which were made.

TABLE I

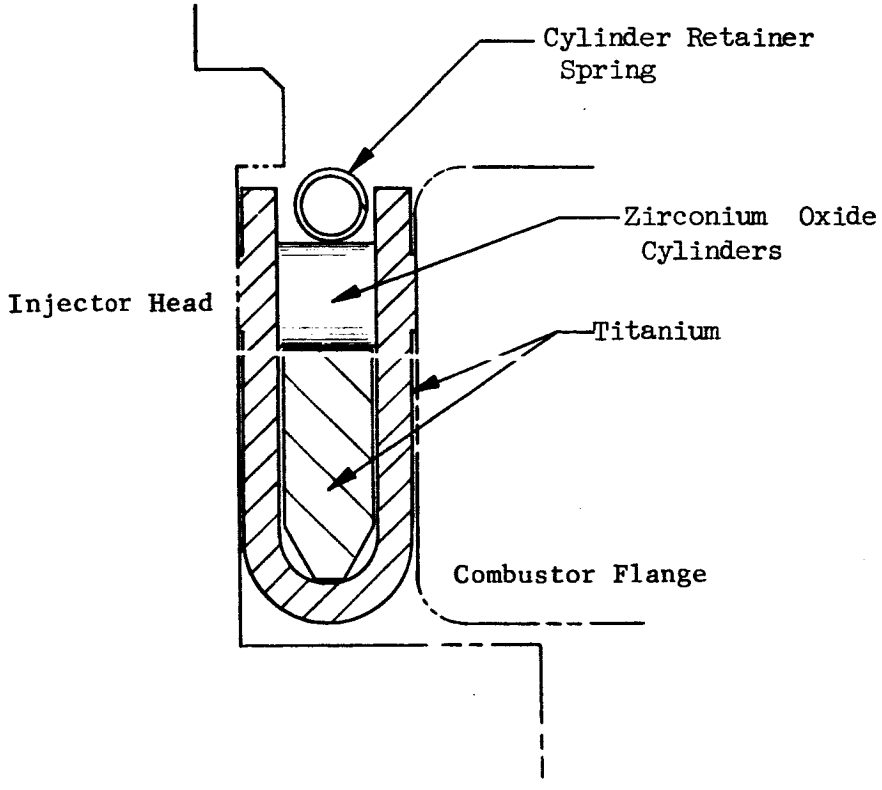
SEAL LEAKAGE RATES BEFORE AND AFTER COLD SOAK TEST

SEAL CONFIGURATION	ENGINE P/N	LEAKAGE RATES (psi/5 min. @ 175 psig)	
		Before Cold Soak	After Cold Soak
Conical Thinwall	T-13768	0.5	0.5
Composite	T-12340	5.0	3.75

HIGH THERMAL RESISTANCE SEALS
SELECTED FOR COMBUSTION TESTING

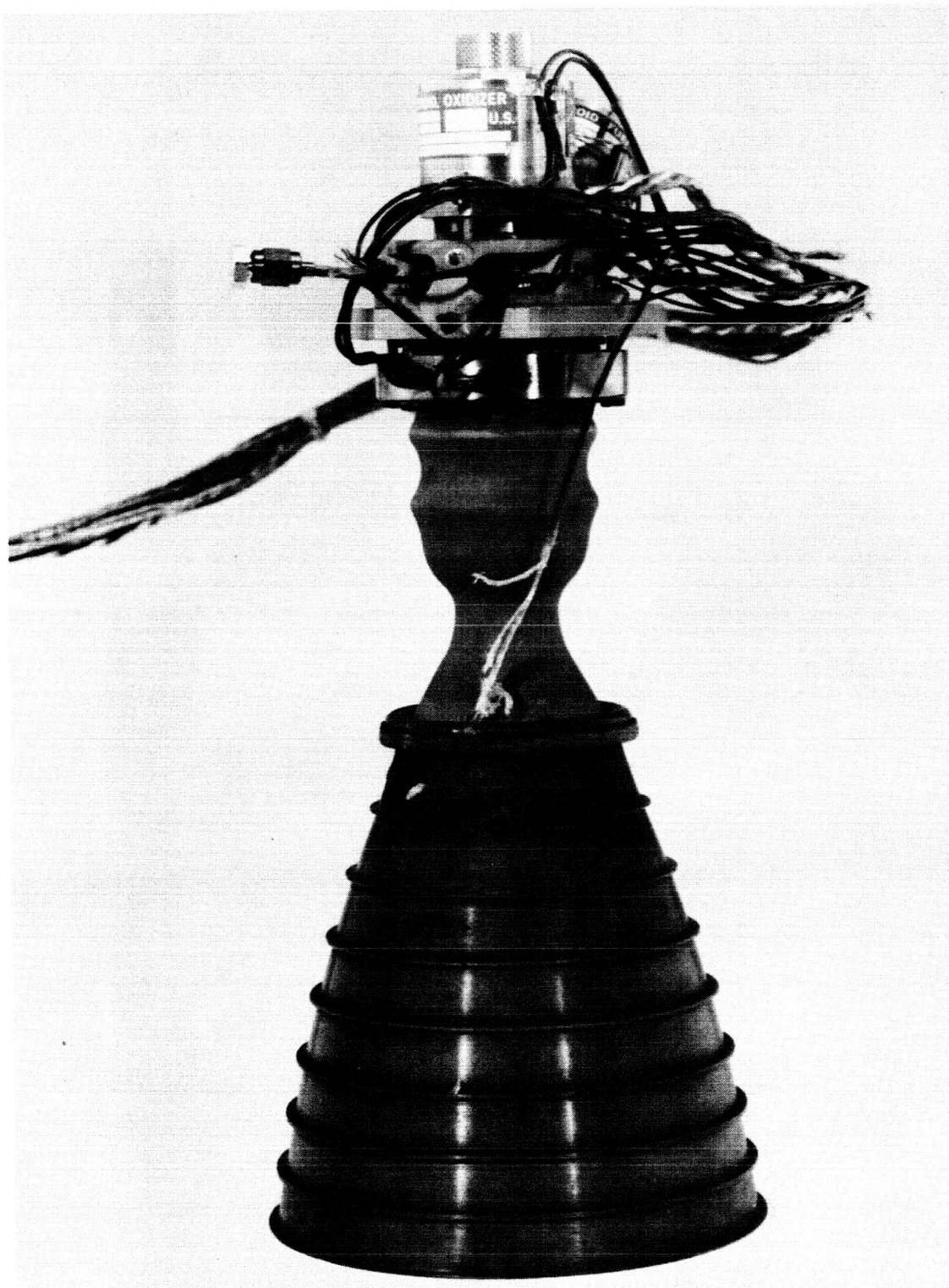


CONICAL THINWALL SEAL



COMPOSITE SEAL

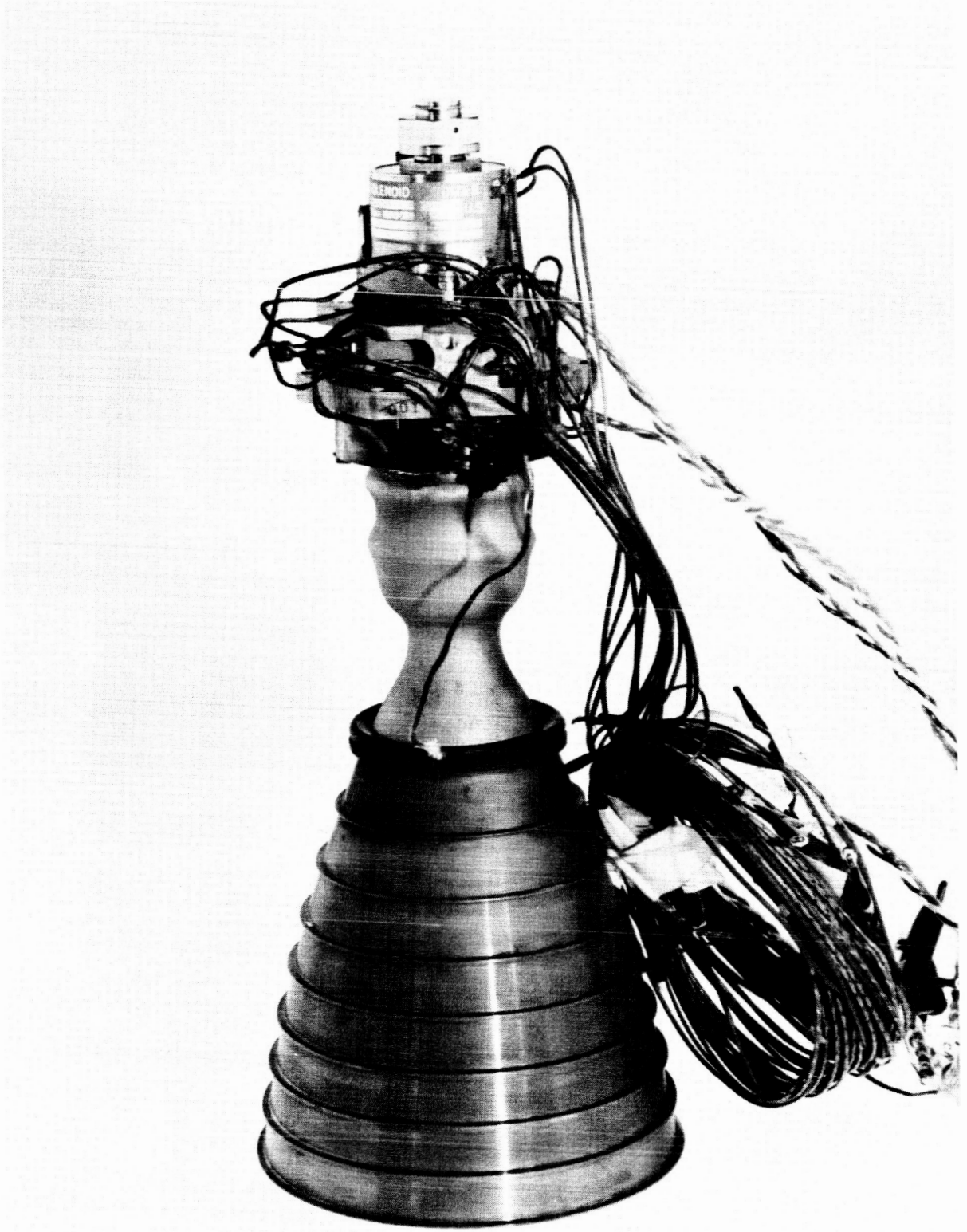
FIGURE 1



SEAL TEST
ENGINE T-13768 AFTER COMBUSTION TESTING (U)
TEST 3403
ATL-PAD D
23 MAR 66

NEG. T3403-5

FIGURE 2



SEAL TEST
ENGINE T12340 AFTER COMBUSTION TESTING
(U)

TEST 3403
RRL-PAD D
28 MAR 66

NEG. T3403-6

FIGURE 3

SEAL THERMAL RESISTANCE TEST RIG

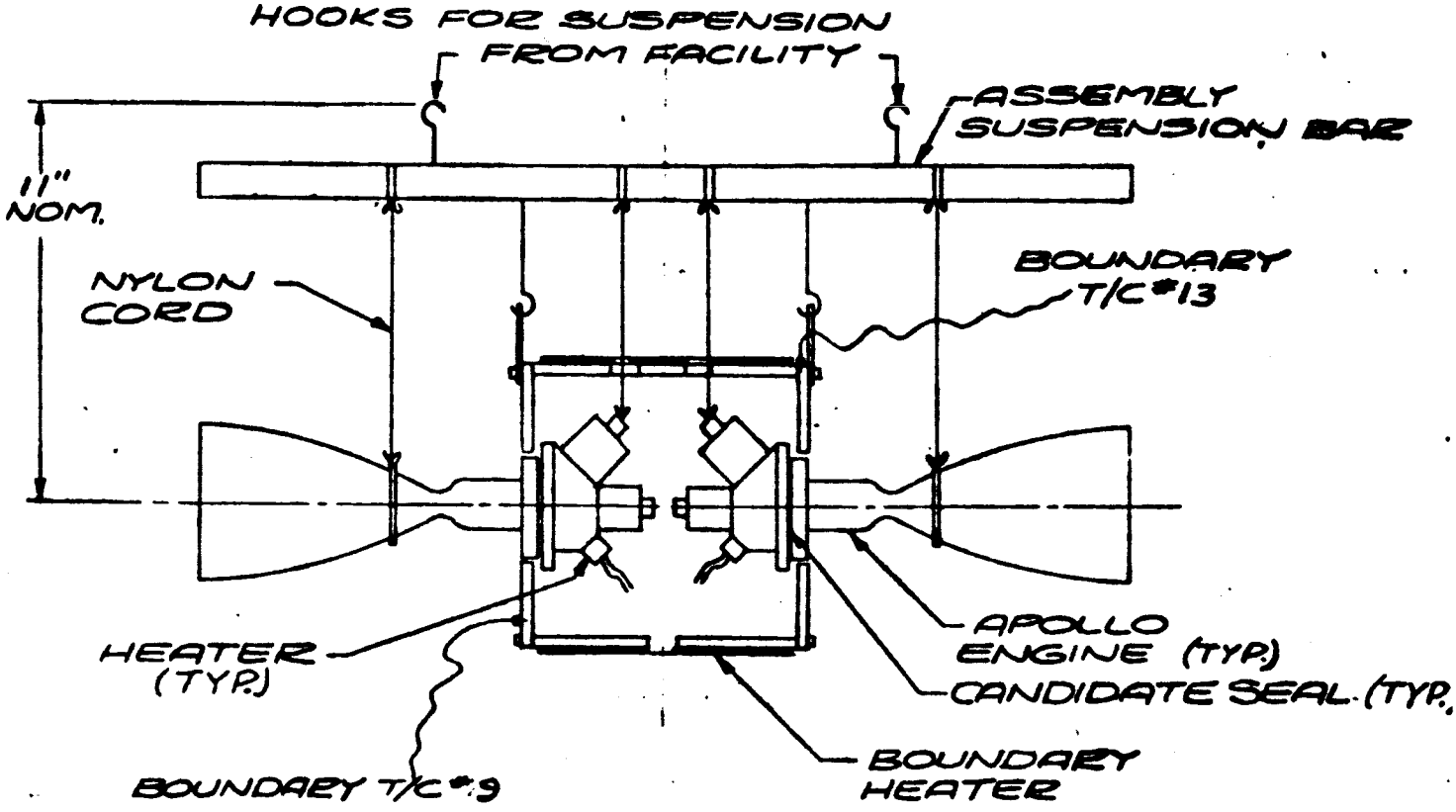
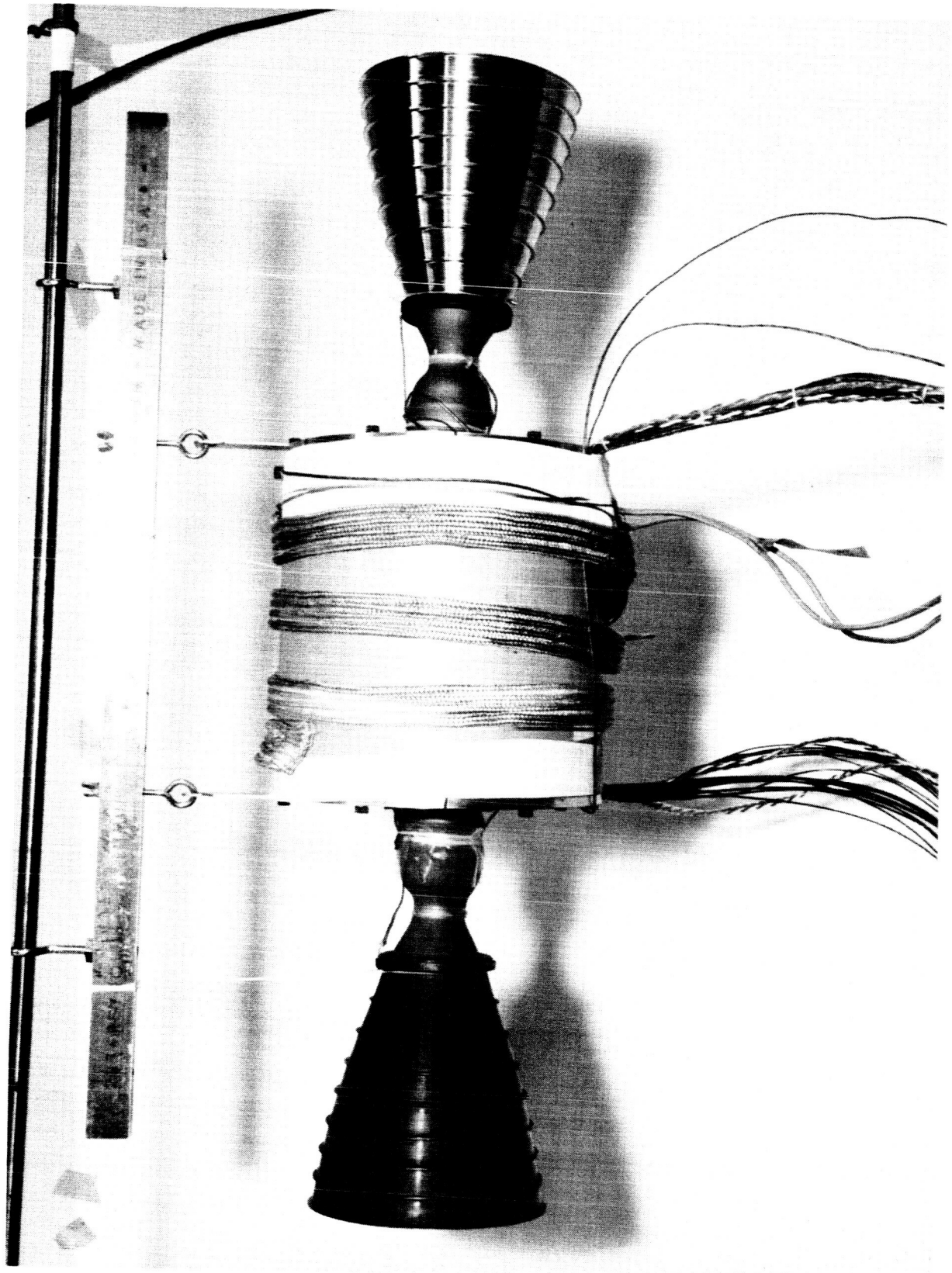


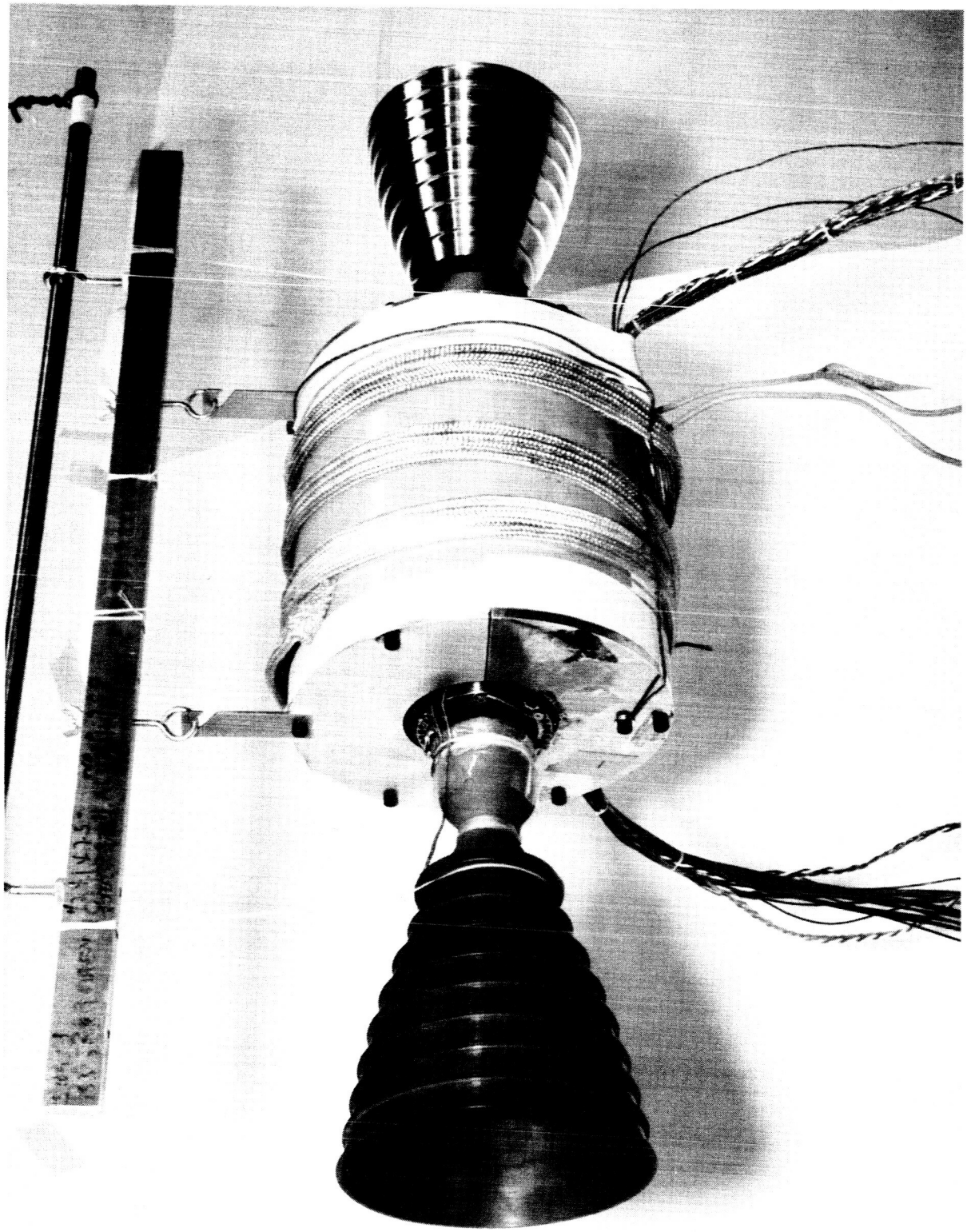
FIGURE 1



TEST 11284 TEST HARDWARE FOR SEAL THERMAL TEST
BLDG. 32 WITH FIREABLE ENGINE
10 MAR 66 (U)

NEG. T11284-1

FIGURE 5

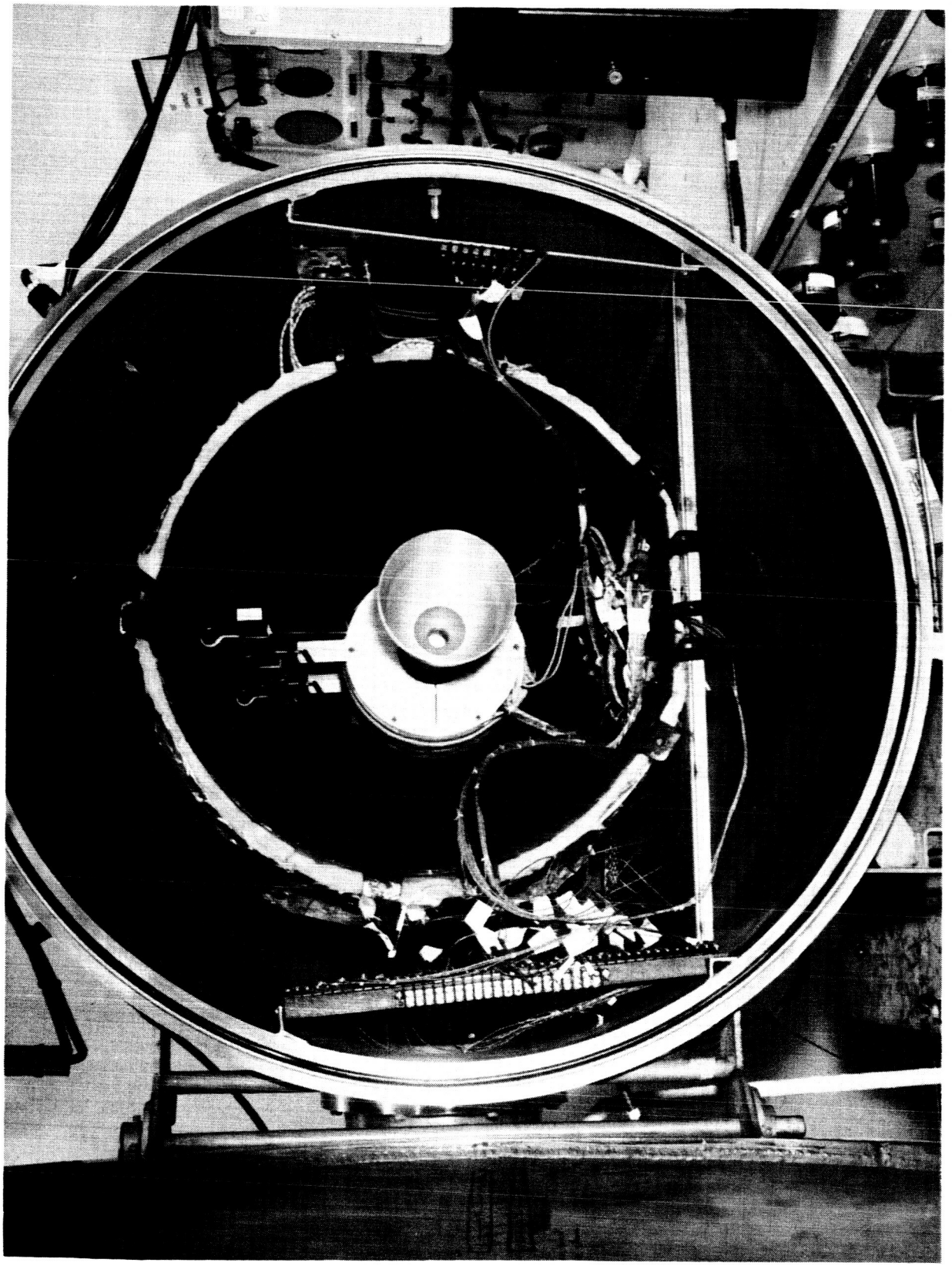


TEST HARDWARE FOR SEAL THERMAL TEST
WITH FIREABLE ENGINE
(U)

TEST 11284
BLDG. 32
10 MAR 66

NEG. T11284-2

FIGURE 6

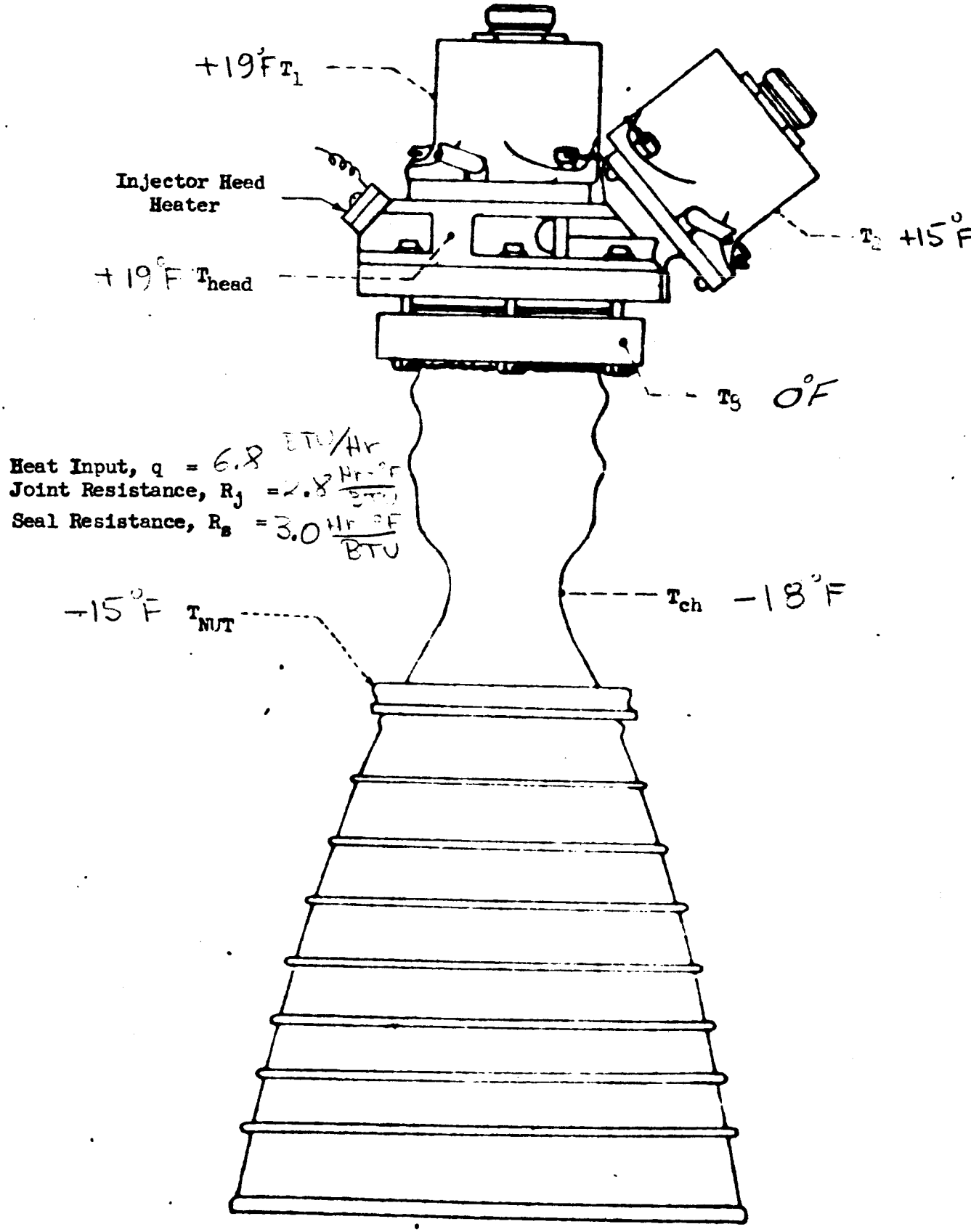


TEST 11284 TEST SETUP FOR SEAL THERMAL TEST WITH FIREABLE ENGINE (U)
BLDG. 32
14 MAR 66

NEG. T11284-3

FIGURE 7

TEMPERATURE DISTRIBUTION
COLD SOAK TEST WITH FIREABLE ENGINES



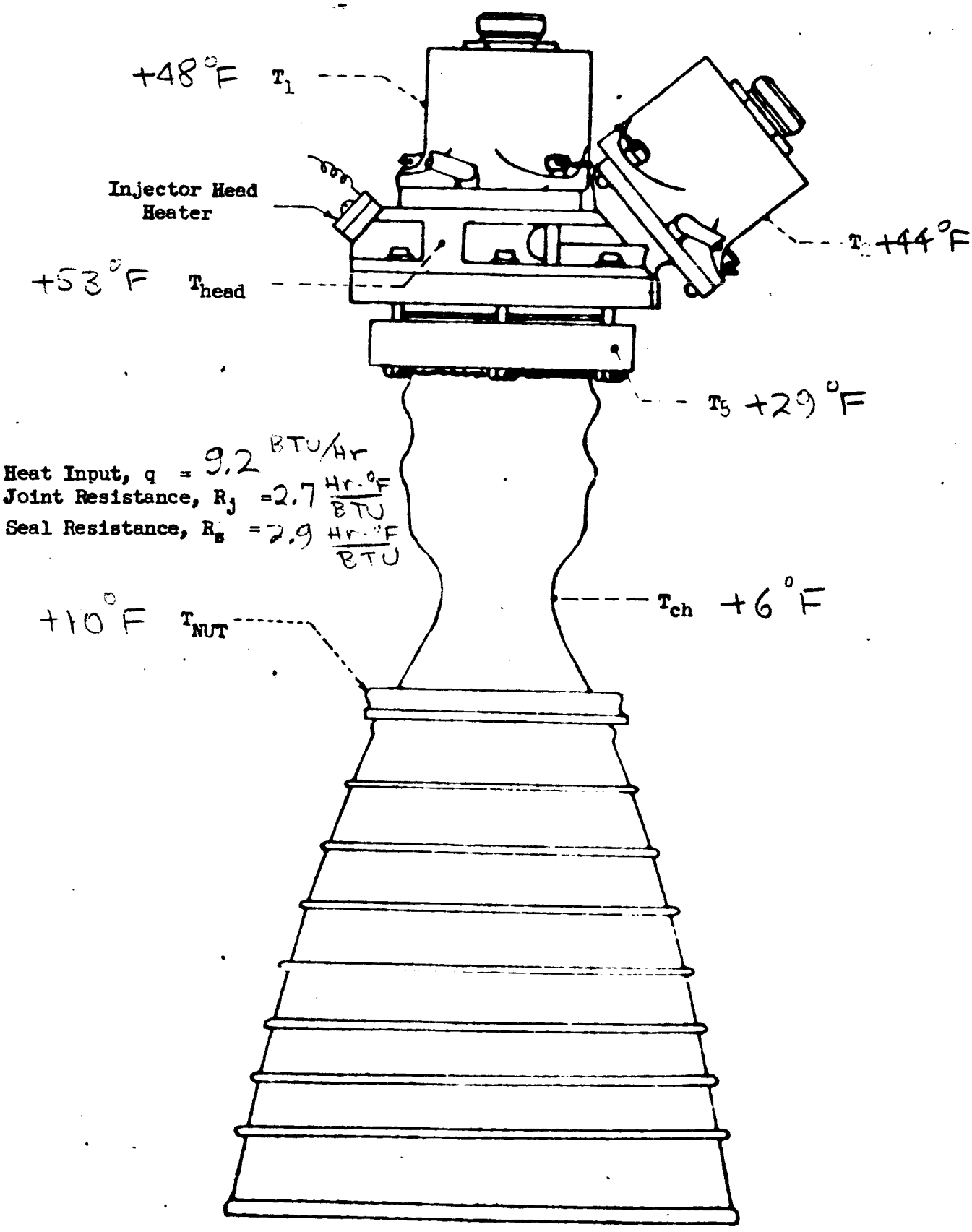
SEAL TYPE COMPOSITE, TITANIUM ENGINE P/N T 12340 S/N 0001-7

TEST NO. 11284

RUN NO. 2

- FIGURE NO. 8 -

TEMPERATURE DISTRIBUTION
COLD SOAK TEST WITH FIREABLE ENGINES



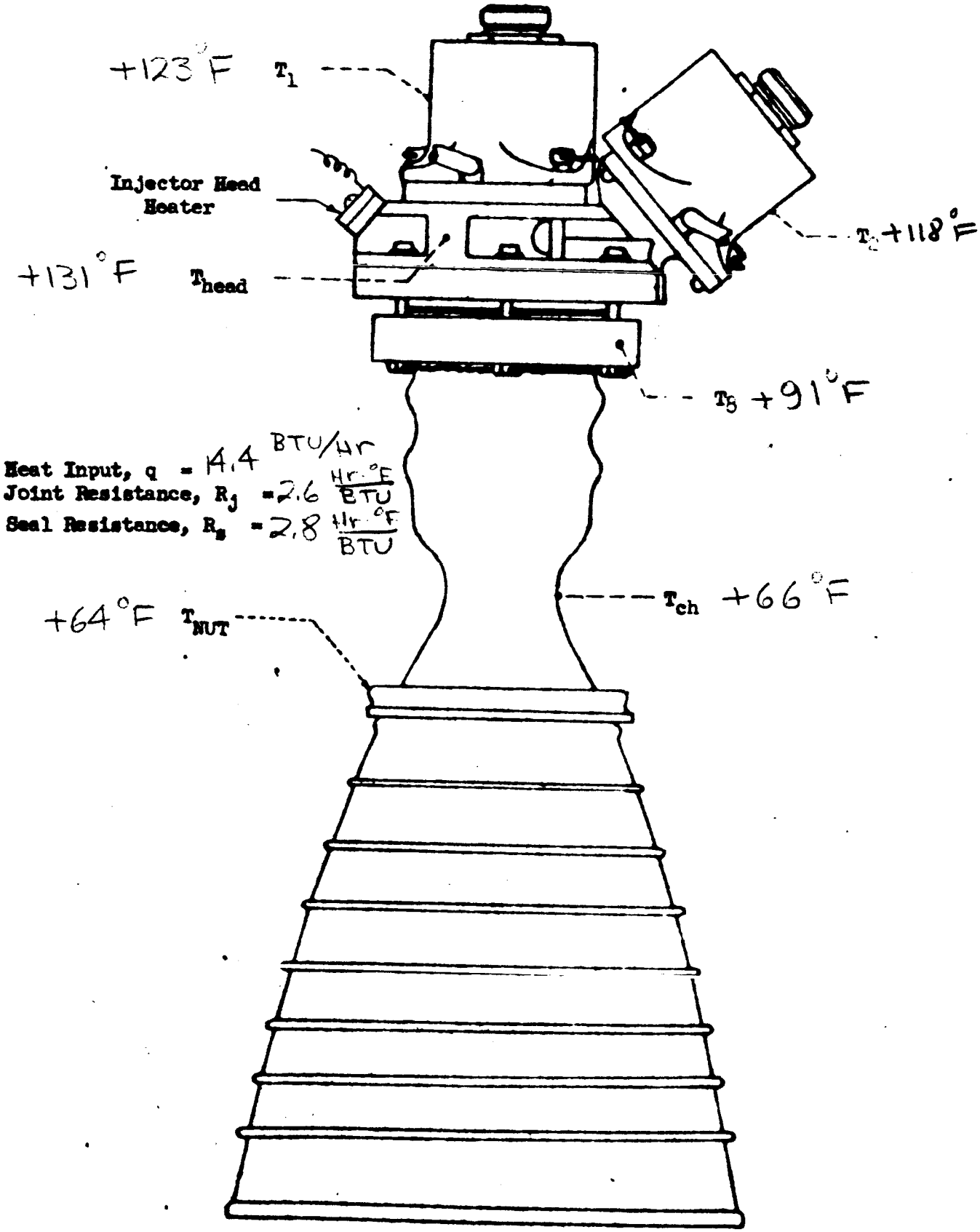
SEAL TYPE COMPOSITE, TITANIUM ENGINE P/N T12340 S/N 0001-7

TEST NO. 11284

RUN NO. 3

- FIGURE NO. 9 -

TEMPERATURE DISTRIBUTION
COLD SOAK TEST WITH FIREABLE ENGINES



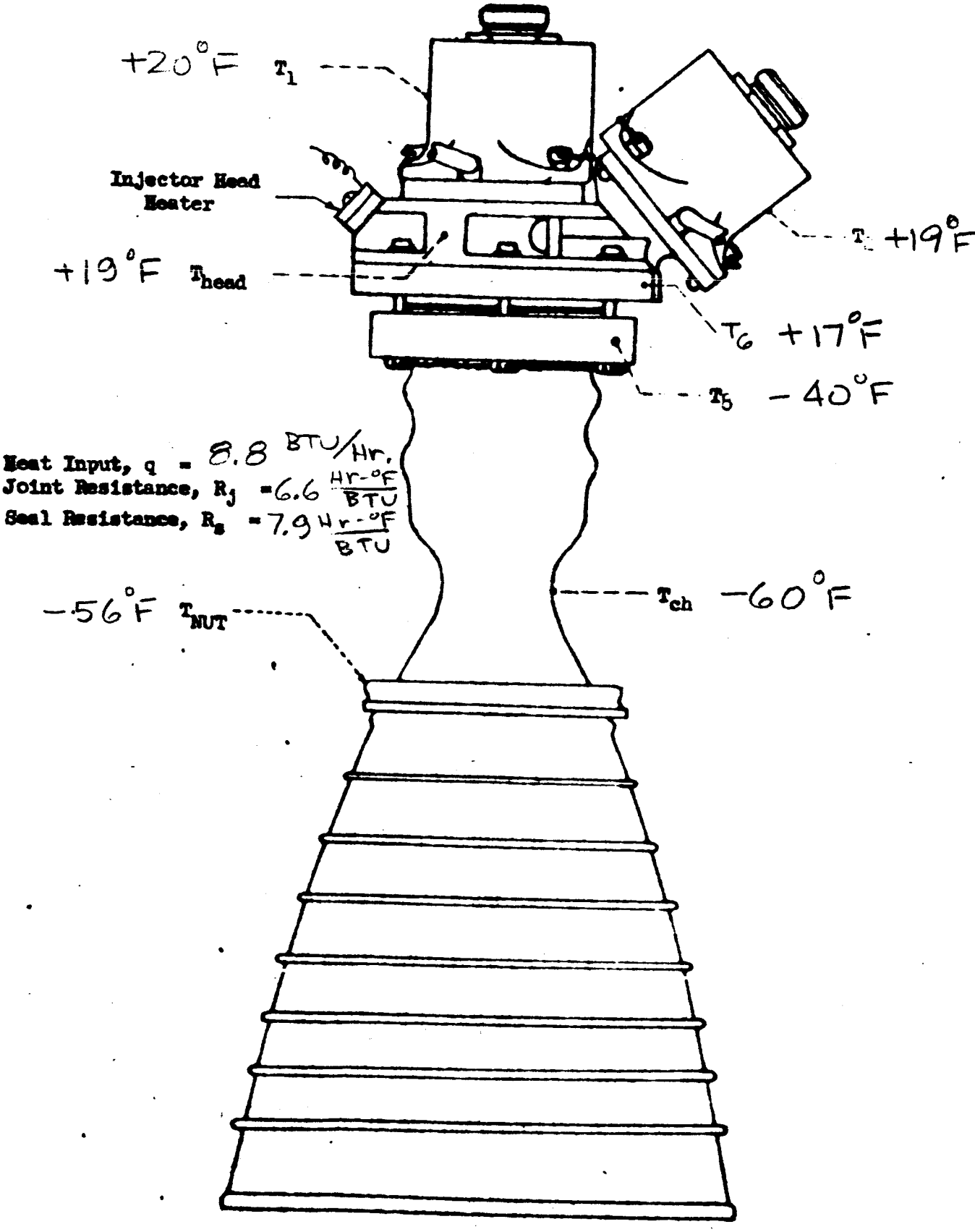
SEAL TYPE COMPOSITE, TITANIUM ENGINE P/N T12340 S/N 0001-7

TEST NO. 11284

RUN NO. 4

- FIGURE NO. 10 -

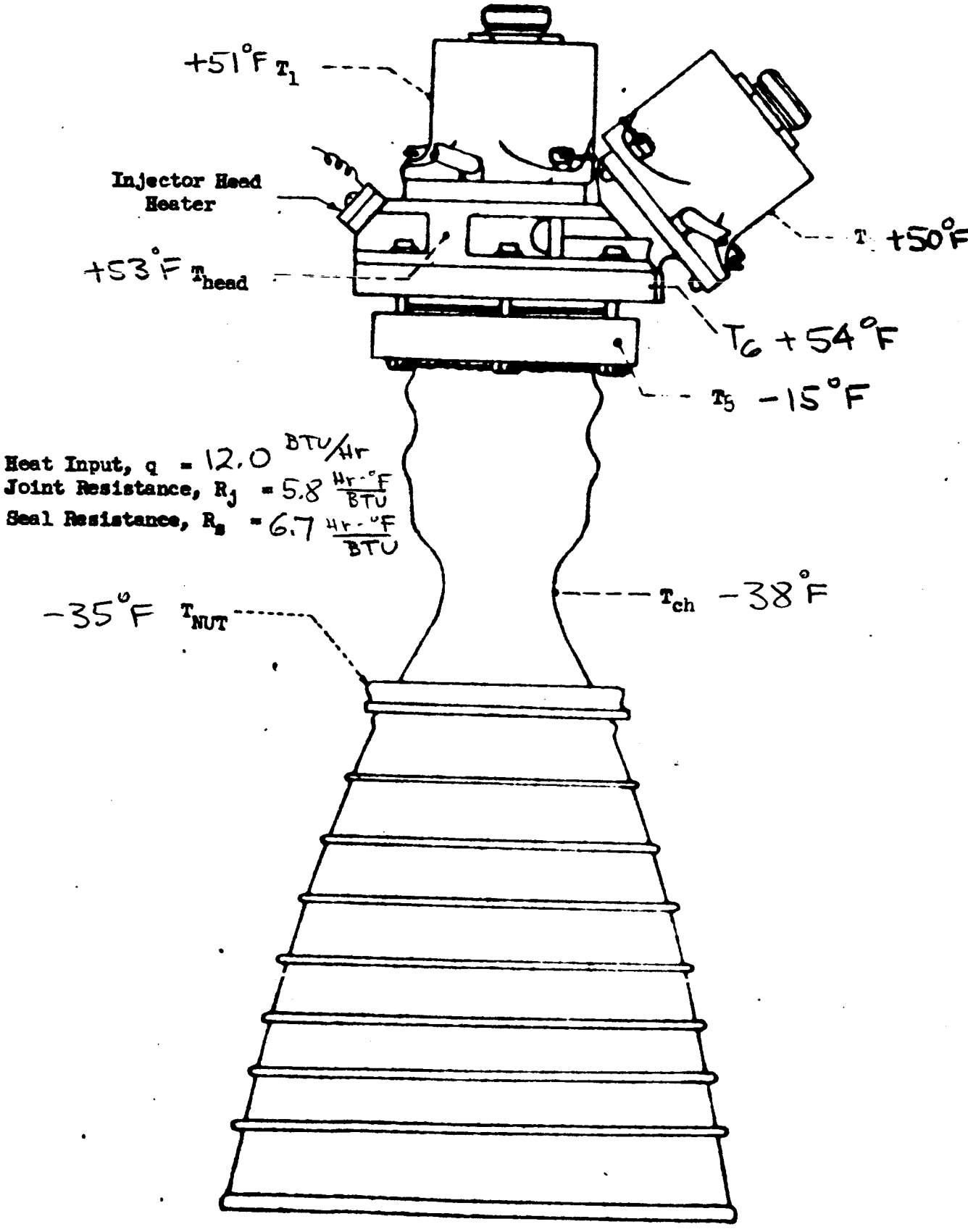
TEMPERATURE DISTRIBUTION
COLD SOAK TEST WITH FIREABLE ENGINES



SEAL TYPE CONICAL, TITANIUM ENGINE P/N T13768 S/N 0001-1
TEST NO. 11284
RUN NO. 2

- FIGURE NO. 11 -

TEMPERATURE DISTRIBUTION
COLD SOAK TEST WITH FIREABLE ENGINES



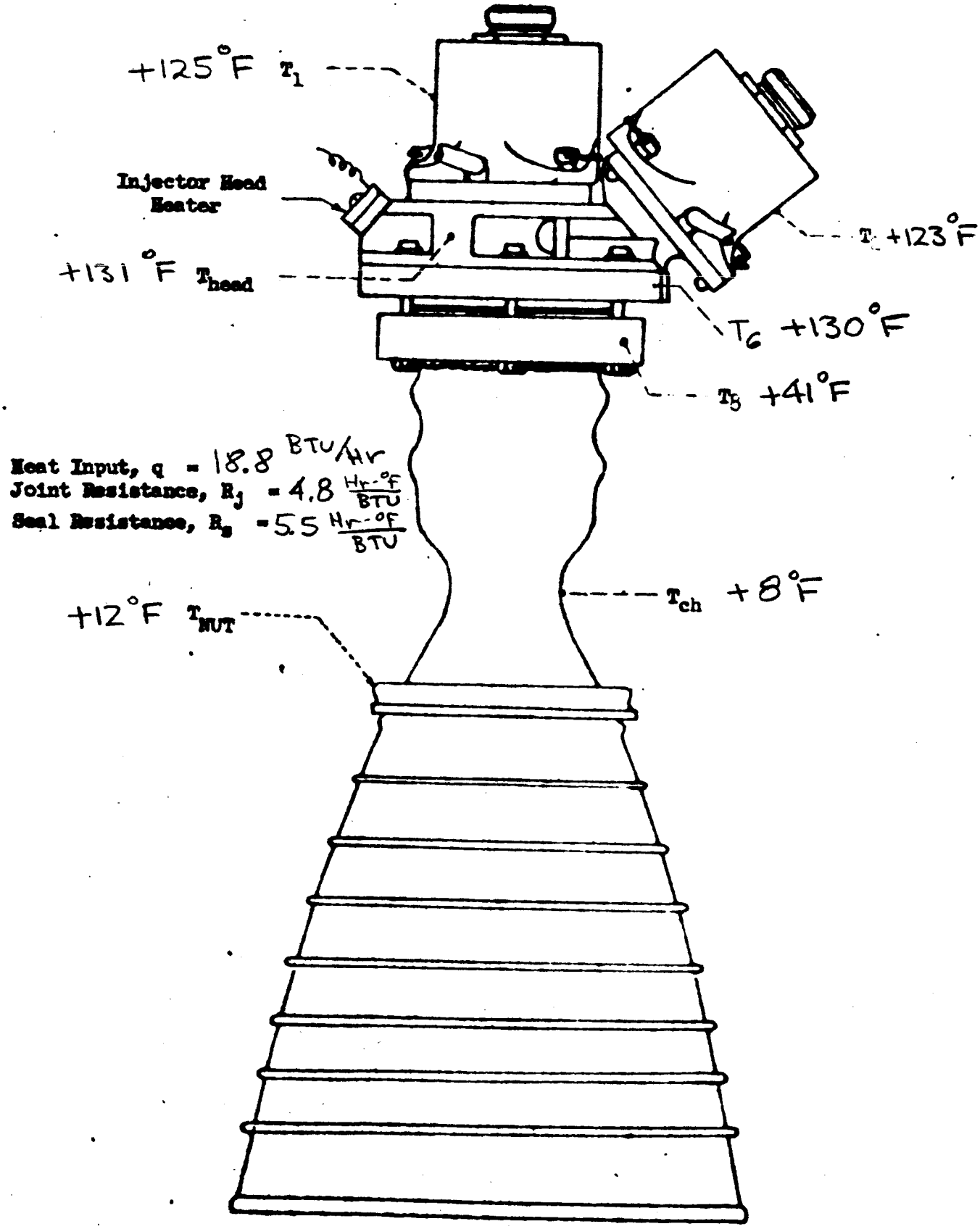
SEAL TYPE CONICAL, TITANIUM ENGINE P/N T 13768 S/N 0001-1

TEST NO. 11284

RUN NO. 3

- FIGURE NO. 12 -

TEMPERATURE DISTRIBUTION
COLD SOAK TEST WITH FIREABLE ENGINES



SEAL TYPE CONICAL, TITANIUM ENGINE P/N T 13768 S/N 0001-1

TEST NO. 11284

RUN NO. 4

- FIGURE NO. 13 -

APPENDIX A

T E S T D A T A

SEAL RESISTANCE TEST
WITH FEMALE ENDING
PER MTP 0041, APPENDIX E

ENGINE P/N T12340 ENG #1
S/N 0001-7
DATE 3-11-66

SEAL TYPE COMPOSITE
P/N T 13618
S/N C

Data Point No.	Time	Voltage, VDC		Temperatures, °F												
		Engine	Boundary	Engine							Boundary		Facility			
				T_1	T_2	T_6	T_8	T_{bend}	T_{21} T_{nb}	T_{23} T_{mnt}	T_9	T_{13}	T_{25}	T_{26}	T_{27}	T_{28}
RUN #1 1	04:00	13.3	35	+19	+16	—	+1	+20	-17	-14	+20	+22	-330	-330	-300	-100
2	04:15	13.0	32	+19	+16	—	+1	+21	-18	-14	+23	+25	-330	-330	-300	-100
			SCRUB RUN — TEMPS CHANGE													
3	05:30	13.2	27	+19	+16	—	+1	+20	-18	-13	+18	+19	-330	-330	-305	-105
RUN #2 4	05:45	13.0	27	+19	+15	—	+1	+20	-18	-13	+17	+19	-330	-330	-305	-105
5	06:00	13.2	30	+19	+15	—	+1	+20	-18	-14	+17	+19	-330	-330	-305	-105
6	06:15	13.2	30	+19	+15	—	0	+19	-18	-15	+19	+20	-330	-330	-305	-105
7	06:30	13.1	25	+19	+15	—	0	+19	-18	-15	+19	+20	"	"	"	"
8	06:45	13.3	26	+19	+15	—	0	+19	-18	-15	+18	+19	"	"	"	"
RUN #3 9	10:15	16.8	45	+39	+35	—	+28	+53	+6	+9	+54	+55	-330	-330	-300	-100
10	10:30	17.0	0	+43	+38	—	+29	+54	+6	+10	+55	+55	-330	-330	-225	-100
11	10:45	15.2	57	+44	+39	—	+29	+54	+7	+10	+50	+50	-330	-330	-294	-102
12	11:00	15.2	28	+45	+40	—	+29	+53	+7	+10	+54	+57	-330	-330	-287	-102
13	11:15	15.2	0	+47	+43	—	+29	+53	+6	+10	+56	+56	-330	-330	-305	-102
14	11:30	15.2	40	+48	+44	—	+29	+53	+6	+10	+54	+54	-330	-330	-307	-102

SEAL RESISTANCE TEST
WITH FIREABLE ENGINES

PER MTP 0041, APPENDIX E

ENGINE P/N T-12340
S/N 0001-7
DATE 3-11-66

ENG #1

SEAL TYPE COMPOSITE
P/N T-13618
S/N C

Data Point No.	Time	Voltage, VDC		Temperatures, °F												
				Engine							Boundary		Facility			
		Engine	Boundary	T_1	T_2	T_6	T_8	T_{head}	T_{ch}	T_{nut}	T_9	T_{13}	T_{25}	T_{26}	T_{27}	T_{28}
15	13:15	27	32	+95	+91	—	+86	+130	+59	+57	+130	+130	-320	-320	-290	-90
16	13:50	20	32	+109	+103	—	+94	+133	+58	+56	+130	+133	-320	-320	-277	-90
RUN #4 17	14:05	20	30	+114	+108	—	+94	+130	+67	+66	+130	+132	-320	-320	-288	-90
18	14:20	20	60	+117	+111	—	+93	+130	+67	+65	+126	+128	-320	-320	-288	-88
19	14:35	18	30	+120	+115	—	+92	+130	+67	+65	+132	+133	-320	-320	-282	-88
20	14:50	202	58	+122	+117	—	+91	+129	+66	+64	+126	+127	-320	-320	-290	-88
21	15:05	20	58	+123	+118	—	+91	+131	+66	+64	+130	+132	-320	-320	-280	-88

SEAL MEDIA ACK TEST
WITH FIBERALL BEARINGS
PER MTP 0041, APPENDIX E

ENGINE P/N T 13768 ENG. #2
S/N 0001-1
DATE 3-11-66

SEAL TYPE CONICAL
P/N T 13622
S/N C

Data Point No.	Time	Voltage, VDC Engine	Voltage, VDC Boundary	Engine Temperatures °F T_1	T_2	T_5	T_6	$T_{bearing}$	T_{oil}	T_{duct}	Engine Heater Current Amperes T-12340	T-13768	Chamber Vacuum mm Hg
RUN #1 1	04:00	16.7	35	+19	+19	+21	-39	+22	-58	-55	0.150	0.190	9×10^{-6}
2	04:15	16.7	32	+20	+19	+23	-38	+23	-58	-55	0.150	0.190	9×10^{-6}
			SCRUB		RUN								
3	05:30	14.6	27	+21	+20	+21	-37	+22	-57	-54	0.150	0.174	9×10^{-6}
RUN #2 4	05:45	15.0	27	+21	+20	+20	-38	+20	-57	-54	0.150	0.174	9×10^{-6}
5	06:00	14.2	30	+20	+20	+19	-38	+20	-57	-55	0.152	0.173	9×10^{-6}
6	06:15	14.6	30	+20	+20	+18	-39	+19	-59	-56	0.152	0.173	9×10^{-6}
7	06:30	14.8	25	+20	+20	+17	-40	+19	-60	-57	0.152	0.172	9×10^{-6}
8	06:45	15.0	26	+20	+19	+17	-40	+19	-60	-56	0.152	0.174	9×10^{-6}
9	10:15	18.7	45	+45	+43	+53	-16	+53	-40	-37	0.185	0.210	8×10^{-6}
RUN #3 10	10:30	18.7	0	+47	+46	+55	-15	+55	-35	-39	0.187	0.210	11×10^{-6}
11	10:45	12.4	37	+48	+46	+54	-14	+54	-39	-35	0.170	0.198	10×10^{-6}
12	11:00	12.4	28	+48	+47	+53	-15	+54	-39	-35	0.170	0.198	9×10^{-6}
13	11:15	12.2	0	+50	+50	+53	-15	+53	-38	-35	0.170	0.198	8×10^{-6}
14	11:30	12.2	40	+51	+50	+54	-15	+53	-38	-35	0.170	0.198	8×10^{-6}

SEAL RESISTANCE TEST
WITH FIREABLE ENGINES

PER MTP 0041, APPENDIX E

ENGINE P/N T-13768

S/N 0001-1

DATE 3-11-66

ENG #2

SEAL TYPE CONICAL

P/N T-13622

S/N C

Data Point No.	Time	Voltage, VDC		Engine Temperature °F							Engine Heater Current Amperes		Chamber Vacuum
		Engine	Boundary	T_1	T_2	T_6	T_8	T_{head}	T_{ch}	T_{nut}	T-12340	T-13768	mm Hg
15	13:15	30	32	+96	+95	+128	+30	+130	-5	0	0.280	0.310	8×10^{-6}
16	13:50	23	32	+110	+107	+128	+38	+130	+5	+9	0.218	0.252	8×10^{-6}
17	14:05	23	30	+115	+113	+130	+40	+132	+6	+11	0.218	0.252	8×10^{-6}
18	14:20	23.2	60	+117	+115	+131	+40	+132	+8	+12	0.218	0.252	8×10^{-6}
19	14:35	22	30	+120	+119	+131	+41	+131	+8	+12	0.205	0.240	8×10^{-6}
20	14:50	22	58	+123	+122	+130	+41	+131	+8	+12	0.218	0.240	8×10^{-6}
21	15:05	22	58	+125	+123	+130	+41	+131	+8	+12	0.214	0.240	8×10^{-6}

RUN #4

APPENDIX B

C A L C U L A T I O N S

GENERAL CALCULATION SHEET

MAC 8030 REV. 4-57

q = Heat input = (Volts)(Amps)(3.413)

$R = \frac{T_{hot} - T_B}{q}$

$R_s = \frac{R_B R_J}{R_B - R_J}$ $R_B = 42.3$

ENGINE T 12340 WITH COMPOSITE TITANIUM SEAL

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RUN NO.	DATA POINT	V	A	(V)(A)	q	T_{hd}	T_B	$T_{hd}-T_B$	R_J	R_{av_J}	$\overline{R_{jav.}}$	$R_B R_J$	$R_B - R_J$	$R_{S_{AV}}$
2	4	13.0	.150	1.950	6.655	+20	+1	19	2.855					
	5	13.2	.152	2.006	6.846	20	+1	19	2.775					
	6	13.2	"	2.006	6.846	19	0	19	2.775					
	7	13.1	"	1.991	6.795	19	0	19	2.796					
	8	13.3	"	2.022	6.901	19	0	19	2.753	2.791		118.1	39.5	2.99
3	10	17.0	.187	3.179	10.850	+54	+28	26	2.396					
	11	15.2	.170	2.584	8.819	54	29	25	2835					
	12	15.2	"	"	"	53	29	24	2.721					
	13	15.2	"	"	"	53	29	24	2.721					
	14	15.2	"	"	"	53	29	24	2.721	2.679		113.3	39.6	2.86
4	17	20	.218	4.360	14.881	+130	+94	36	2.419					
	18	20	.218	4.360	14.881	+130	93	37	2.486					
	19	18	.205	3.690	12.594	+130	92	38	3.017					
	20	20.2	.218	4.404	15.031	+129	91	38	2.528					
	21	20	.214	4.280	14.608	+131	91	40	2.738	2.638	2.703	111.6	39.7	2.81
												$R_{S_{AV}} = 2.89$		

GENERAL CALCULATION SHEET

MAC 8830 REV. 4-57

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RUN NO.	P_{ch}	T_{ch}	T_{chau}	R_j	R_s									
		°F	°R											
	6.81	-18	443	2.8	3.0									
3	9.23	+6	467	2.7	2.7									
4	14.40	+67	528	2.6	2.8									
AVERAGE				2.7	2.9									

GENERAL CALCULATION SHEET

MAC B830 REV. 4-57

q = Heat input = (volts)(Amps)(3.413)

$R = \frac{T_{hrmd} - T_8}{q}$

$R_s = \frac{R_B R_J}{R_B - R_J}$ $R_B = 42.3$

ENG. T 13768 WITH CONICAL TITANIUM SEAL

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RUN No.	DATA POINT	V	A	(V)(A)	q	T_{hrmd}	T_8	$T_{hrmd}-T_8$	K_J	$R_{J\,av.}$	$\overline{R_{J\,av.}}$	$R_B R_J$	$R_B - R_J$	$R_{S\,AV}$
2	4	15.0	.174	2.610	8.908	+20	-38	58	6.511					
	5	14.9	.173	2.578	8.799	20	-38	58	6.592					
	6	14.9	.173	2.578	8.799	19	-39	58	6.592					
	7	14.8	.172	2.546	8.689	19	-40	59	6.790					
	8	15.0	.174	2.610	8.908	19	-40	59	6.623	6.642		281.0	35.7	7.87
3	10	18.5	.210	3.885	13.260	+55	-15	70	5.279					
	11	17.2	.198	3.406	11.625	54	-14	68	5.849					
	12	17.2	.198	"	"	54	-15	69	5.935					
	13	17.2	.198	"	"	53	-15	68	5.849					
	14	17.2	.198	"	"	53	-15	68	5.849	5.752		243.3	36.5	6.67
4	17	23.0	.252	5.796	19.782	+132	+40	92	4.651					
	18	23.2	.252	5.846	19.952	132	40	92	4.611					
	19	22.0	.240	5.280	18.021	131	41	90	4.994					
	20	22.0	.240	"	"	131	41	90	"					
	21	22.0	.240	"	"	131	41	90	"	4849	5.748	205.1	37.5	5.47
														↑
												$R_{S_{AV}} = 6.67$		

GENERAL CALCULATION SHEET

MAC 8830 REV. 4-57

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RUN NO.	q_{av}	$T_{ch_{av}}$	$T_{ch_{av}}$	R_j	R_s									
		°F	°R											
2	8.82	-58	403	6.6	7.9									
3	11.95	-38	423	5.8	6.7									
4	18.76	+8	469	4.8	5.5									
AVERAGE				5.7	6.7									

ATTACHMENT 13

TEST REPORT

COMBUSTION TESTING

OF

TWO HIGH THERMAL RESISTANCE HEAD-TO-CHAMBER SEALS

IN

APOLLO S/M RCS QUALIFICATION-TYPE ENGINES

TESTED UNDER CONTRACT NAS 9-4775

TMC 3008

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I. INTRODUCTION

This report presents results of combustion testing of two high thermal resistance injector head-to-combustor seals intended for the Apollo Service Module Reaction Control System Engine (S/M RCS). One seal was a conical thinwall type and the other a composite type. Tests were performed under Contract NAS 9-4775.

The two seals, which were selected from six seal designs previously tested under non-firing conditions, were assembled into two fireable SM/RCS qualification type engines, and combustion tested per Appendix F of MTP 0041 to determine:

1. Effects of increased seal thermal resistances on engine temperature distribution.

2. Capability of the seals to structurally withstand steady state engine operating and soakback temperatures.

3. Capability of the seals to structurally withstand loadings resulting from more than 5500 engine starts.

Prior to combustion testing, the two engines were tested in Marquardt's cold wall space simulator chamber to measure thermal resistance of the seals. The measured resistances were 6.7 hr-^{o}F/Btu for the conical thinwall seal and 2.9 hr-^{o}F/Btu for the composite seal; the comparable resistance for the seal now used in the qualified SM/RCS engine is approximately 0.5 hr-^{o}F/Btu.

II. SUMMARY AND CONCLUSIONS

The two seal designs tested were assembled into Apollo S/M RCS qualification type engines and combustion tested per Appendix F of MTP 0041 to determine their effect on engine temperature distributions and to ascertain their structural integrity. One of the seals was a composite and the other a conical thinwall type. Cross sectional views of these two seals are shown in Figure 1. It is noted that the composite seal fits directly into the existing seal cavity and that minor injector head modifications were necessary to accommodate the conical design.

These seals were selected for combustion testing because previous non-firing tests had demonstrated adequate structural capability and thermal resistances much higher than the present S/M RCS engine seal. The composite seal had

demonstrated a resistance of 2.9 hr-°F/Btu and the conical thinwall seal had demonstrated a resistance of 6.7 hr-°F/Btu, as compared with the present S/M RCS seal resistance of R = 0.5 hr-°F/Btu.

Each engine was combustion tested for a total of approximately 900 seconds at O/F ratios ranging from 1.8 to 2.2, and was started more than 5500 times.

The thin wall seal exhibited a higher thermal resistance than did the composite seal, consistent with non-firing test data. Test results also agreed reasonably well with the analytically predicted engine soakback temperature transients following steady state runs at O/F = 1.8.

Engine temperatures during steady state, and what was originally assumed maximum heat soakback conditions, were all within acceptable limits. However, the 50 ms on - 50 ms off duty cycle, chosen to generate the 5500 engine starts, proved to be sensitive to the magnitude of the seal resistance. The seal resistance of R = 2.9 hr-°F/Btu did not establish restrictions to this duty cycle, but the higher resistance, R = 6.7 hr-°F/Btu conical thinwall seal affected thermal conduction between combustor and injector head such that after 980 pulses the combustor flange temperatures were still increasing.

III. RECOMMENDATIONS

It is recommended that additional analysis and test evaluation of engines containing these high resistance seals be made to further demonstrate their potential for meeting S/M RCS qualification test firing requirements. These tests would include:

1. Mission duty cycle, including off limit O/F and thrust
2. Propellant temperatures ranging from 40° to 100°F
3. Pulse widths ranging from 10 milliseconds to 5 seconds.

It is recommended that further tests and analysis be conducted to determine the extent to which seal resistance may limit duty cycles. Test results would form a matrix of duty cycle description, maximum number of pulses allowable, and seal resistance.

The current IBM analytical model should be checked out to determine if predicted soakback temperatures agree with test results when test end-of-run engine temperatures are used as inputs for the program. If agreement does not exist the program should be modified to eliminate any anomalies. The analytical model should further be improved to enable the use of firing heat inputs for predicting temperature rise transients during engine steady state and pulse firings.

IV. TEST HARDWARE AND FACILITY

Two Apollo S/M RCS Qualification-type engines were used for testing of the high thermal resistance seals. Conical seal (P/N T-13622, S/N C) was assembled into engine P/N T-13768, S/N 0001-1. The injector head of this engine had been modified by the removal of 0.140 inch of material in front of the seal contact point to provide the longer seal cavity necessary to accommodate this seal design. Composite seal (P/N T-13618, S/N C) was assembled into engine P/N T-12340, S/N 0001-7. Apollo assembly procedures were used for assembly of both engines. Photographs of the two engine assemblies, after testing, are shown in Figures 2 and 3.

Cross-sectional views of the two seals are presented in Figure 1. The conical seal is made from 6Al-4V Titanium and the composite seal from 6Al-4V Titanium with Zirconium Oxide spacers. These seals were selected for firing tests because earlier non-firing evaluation tests in the program had indicated them to be the most suitable for incorporation into the Apollo SM/RCS engine design. Criteria for this selection was that both seals had demonstrated the required structural adequacy plus thermal resistance far in excess of the R = 0.5 hr-^{o}F/Btu characteristic of the current Apollo S/M RCS seals. The cold soak testing conducted just prior to the firing tests had shown the composite and thinwall conical seals to have resistances of 2.9 and 6.7 hrs-^{o}F/Btu, respectively.

After the engines completed their cold soak testing (Appendix E of MTP 0041) they were assembled into thrust stands, as shown in Figure 4, in preparation for installation into the altitude test cell. Figure 5 is a photograph of Engine T-12340 (composite seal) installed in Rocket Research Laboratory, Pad D, prior to closing the chamber for altitude testing.

Both of the engines were extensively instrumented for temperature measurement. Locations of the 15 engine thermocouples are schematically shown in Figure 6, with a description of nomenclature given in Table I.

V. TEST PROCEDURE

Testing was conducted per procedures of Appendix F of MTP 0041. Summarily, testing of both engines consisted of the following:

1. Steady state runs of 100 seconds duration each at O/F = 1.8, 2.0, and 2.2

2. Maximum soakback duty cycle at O/F = 1.8. The duty cycle consisted of:

   a. 90 seconds ON

   b. maximum soakback on T_{head}

c. 90 seconds ON

d. maximum soakback on T_{head}

e. 90 seconds ON

f. 10 minutes soakback

3. Several series of 50 milliseconds ON, 50 milliseconds OFF pulses totaling 5500.

All of the steady state runs were followed by a 10 minute heat soakback where the thermal energy which is stored in combustor flows through the chamber seal and chamber attach bolts into the injector head. The altitude chamber pressure was maintained at less than 0.1 psia throughout the testing in order to permit full nozzle flow during firing and to more closely simulate space thermal characteristics by minimizing convective heat transfer during engine firing and soakback.

All steady state runs of both the 90 second and the 100 second duration were made from the main facility storage tanks. Pulses were conducted from the pulse tanks in order to avoid undesirable pressure surges which result from longer line lengths between storage tanks and the engine.

All testing was done with ambient temperature propellants. Five-second trim runs were made to establish required tank set pressures to yield the correct oxidizer and fuel flows.

VI. DISCUSSION OF TEST RESULTS

The high thermal resistance seals caused engine temperatures to behave approximately as predicted, except for the temperature increases encountered after hundreds of 50 ms ON/50 ms OFF pulses. Injector head temperatures at O/F of approximately 2.0 were comparable to a typical Apollo S/M RCS Qualification-type engine, about 160°F. (Typical Apollo engines contain seals with a thermal resistance $\cong$ 0.5 hr-°F/Btu.) Maximum soakback temperature, however, was about 50°F below Apollo, about 225°F. The conical seal, in engine P/N T-13768, demonstrated higher thermal resistance than the composite seal, in engine P/N T-12340, evidenced by lower head soakback temperatures and higher combustor flange soakback temperatures.

The Apollo S/M RCS engine selected for comparison with the subject engine data was T-11606, hereafter referred to as "Apollo". This engine was of the current Qualification-type design and was selected because it had demonstrated typical temperature gradients consistent with production engines. Thermocouple instrumentation, comparable to the two engines tested was present on this engine. For clarity of presentation, the two seal designs tested shall be discussed separately.

A. Conical Seal

Engine T-13768 had a conical thinwall titanium seal with a thermal resistance of 6.7 hr-°F/Btu. Figure 7 shows running and soakback injector head temperature as a function of oxidizer-to-fuel ratio. As shown, the running temperature ranged from 168°F at O/F = 1.8 to 159°F at O/F = 2.2. Soakback temperatures are significantly lower than Apollo, ranging from 228°F at O/F 1.8 to 219°F at O/F of approximately 1.9.

Figure 8 shows combustor throat temperatures as a function of O/F. At O/F = 1.8 the temperature is the same as Apollo, about 2400°F. At O/F = 2.2, however, the throat was about 750°F hotter than Apollo at 2250°F. Combustor flange running temperatures, Figure 9, were 270°F at O/F = 1.8 which is about 70°F hotter than Apollo. Flange soakback temperature was 670°F, considerably warmer than the 350°F soakback for current Apollo engines.

The 5500 pulses had no apparent adverse effect on the seal structural or sealing capability. Leakage integrity well within S/M RCS allowables was maintained throughout the entire test; however, the 50 ms ON - 50 ms OFF, arbitrarily selected to generate these 5500 pulses, resulted in engine temperature increases which eventually caused termination of each run. At 980 pulses, the head and combustor flange temperatures were approximately 200°F and 1100°F respectively, both within structural limits; however, what was probably extreme caution was exercised, and the run terminated prematurely. Additional runs of 600 pulses were then conducted until a total of 5500 had been accumulated.

The variation of injector head and combustor flange temperatures with the number of uninterrupted pulses is shown in Figure 14.

B. Composite Seal

Engine T-13240 had a composite seal with a thermal resistance of 2.9 Hr-°F/Btu. Injector head running temperatures, as shown in Figure 7, range from 175°F at O/F = 1.8 to 150°F at O/F = 2.2. Soakback head temperatures were 255°F at O/F = 1.8 and 217°F at O/F = 2.2. Chamber throat temperatures, Figure 8, were very close to the Apollo engine, being only about 100°F higher. Throat temperature at O/F = 2.2 was below 1800°F, which is the lower limit of the recorder which was used and thus is not shown.

Combustor flange running temperatures, as shown in Figure 9, were comparable to engine T-13768, being only about 15°F colder over the entire O/F traverse.

The 50 ms ON - 50 ms OFF duty cycle used to generate the 5500 starts, did not cause unacceptable engine temperatures. As shown in Figure 14, the head and flange temperatures had risen to only 220°F and 330°F, respsectively, after 1400 pulses. This was the very maximum number of pulses possible with the propellant supply tanks used. The flange temperature was still increasing at a modest rate. The point to which it would have risen with further pulses is not known.

Comparison of the R = 2.9 hr-°F/Btu temperatures with the R = 6.7 hr-°F/Btu temperatures at the same duty cycle clearly indicates a variance of duty cycle limitation with seal resistance. The extent to which this limit on the number of pulses will vary with different duty cycles, O/F ratio, and seal resistance was not determined in these tests, but is recommended for later evaluation.

C. General

Figures 10 and 11 show a comparison of a typical soakback with the analytically derived predictions. As shown, the two agree quite closely. Figures 12 and 13 show the temperature gradients which existed across the seals. The gradients were computed by subtracting engine head temperature from the combustor flange temperature. In all cases except one (Figure 12) the ΔTs fell well below the predicted maximum.

Plots of all temperatures as a function of time during runs and soakback are included in Appendix A.

Appendix B contains all reduced data, listing propellant flow rates, oxidizer-to-fuel ratios, chamber pressures, and characteristic velocities. Appendix C contains a copy of the original "quick look" data.

D. Preloads and Seal Leakages

Chamber attach bolt lengths and seal leakage rates at 175 psig chamber pressure were recorded...

1. following engine assembly
2. following the cold soak testing
3. following combustion testing.

Preloads, particularly on the composite seal, dropped after testing, however, there was no appreciable increase in seal leakage rates. Table II lists the preloads and seal leakage rates, and Appendix D contains the preload calculations.

TABLE I

DESCRIPTION OF ENGINE THERMOCOUPLES

PARAMETER	DESCRIPTION
T_{head}	Head Temperature
T_{nut}	Bell Nut Temperature
T_1	Oxidizer Valve Case Temperature
T_2	Fuel Valve Case Temperature
T_3	Oxidizer Valve Flange Temperature
T_4	Fuel Valve Flange Temperature
T_5	Aluminum Flange, Oxidizer Side
T_6	Aluminum Flange, Fuel Side
T_7	Moly Flange, Oxidizer Side
T_8	Moly Flange, Fuel Side
T_{ch}	Chamber Throat Temp. (Thermoscope)
T_{b1}	Bolt Nut
T_{b2}	Bolt Middle
T_{b3}	Bolt Head
$T_{s.r.}$	Split Ring
$T_{a.r.}$	Attach Ring

TABLE II

SEAL PRELOADS AND LEAKAGE RATES

SEAL	TIME OF MEASUREMENT	PRELOAD LBS (1) & (2)	LEAKAGE RATE (3) psi/5 min @ 175 psig
Conical	After engine assembly	4,700	0.5
	After cold soak test	4,725	0.5
	After Combustion Test	4,320	1.5
Composite	After engine assembly	5,060	5.0
	After cold soak test	4,600	3.7
	After combustion test	3,130	3.0

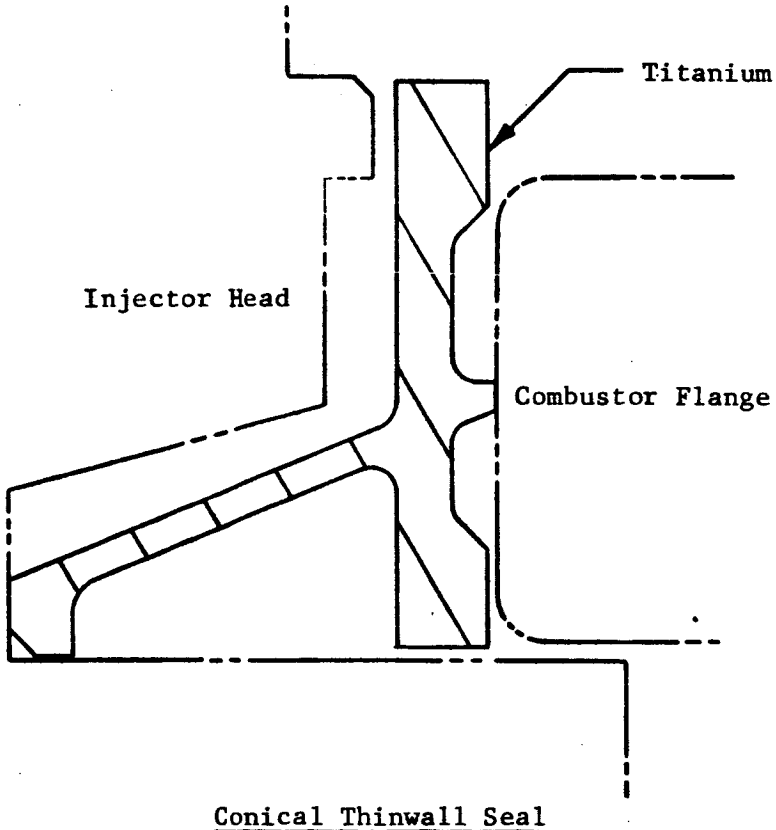
NOTE: (1) All preloads are calculated values based on chamber attach bolt measurements.

(2) Apollo Specification Apparent Compressive Load Limits are:

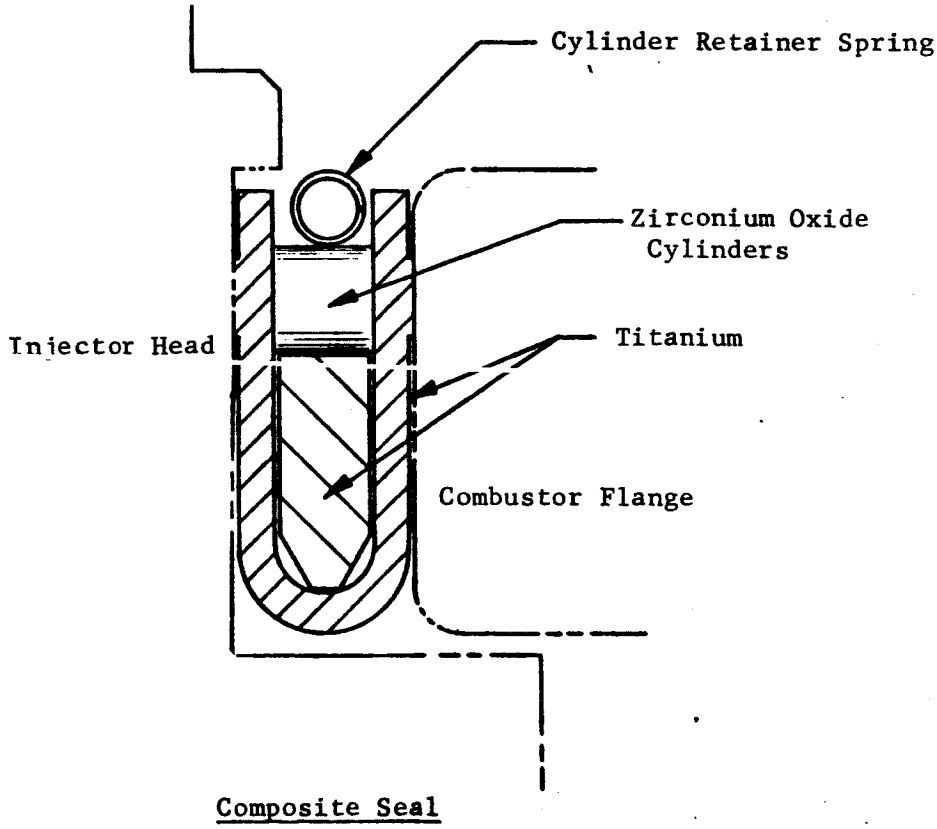
Maximum - 5880 pounds
Minimum - 4680 pounds

(3) Apollo S/M RCS Engine maximum allowable leakage rate is 15.0 psi/5 minutes @ 175 psig.

HIGH THERMAL RESISTANCE SEALS
SELECTED FOR COMBUSTION TESTING

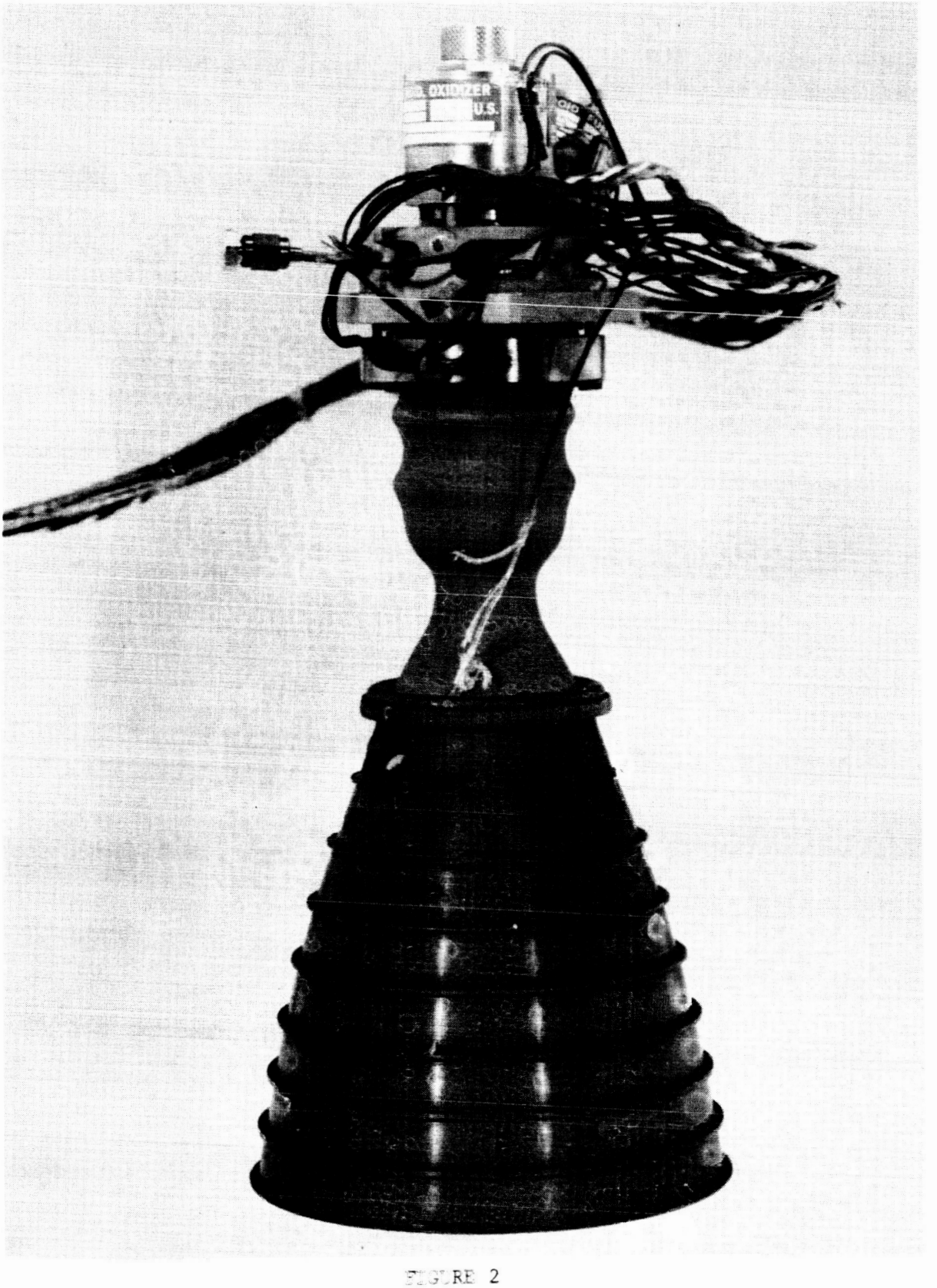


Conical Thinwall Seal



Composite Seal

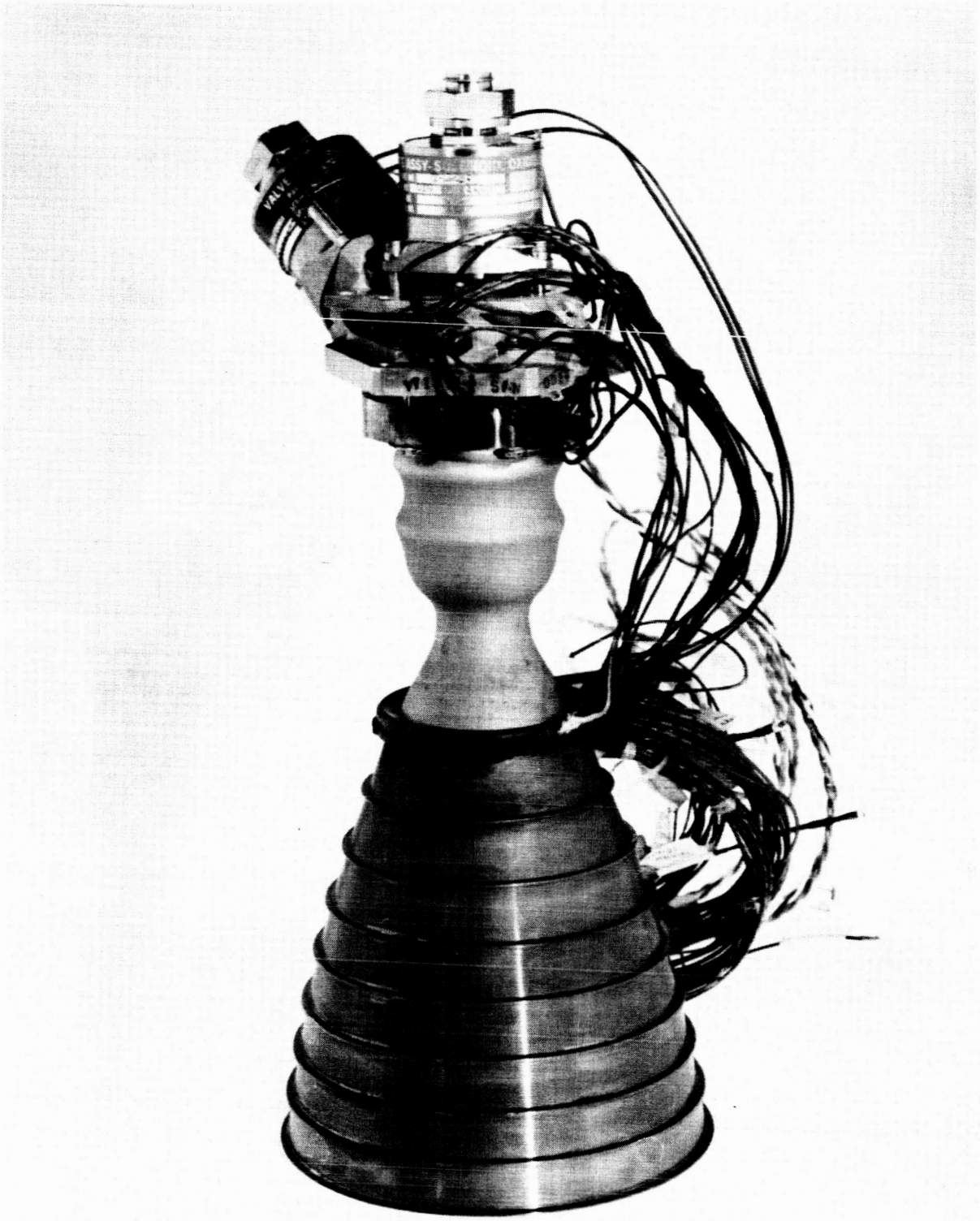
FIGURE 1



SEAL TEST
ENGINE T-13768 AFTER COMBUSTION TESTING (U)
TEST 3403
ATL-PAD D
23 MAR 66

NEG. T3403-5

FIGURE 2



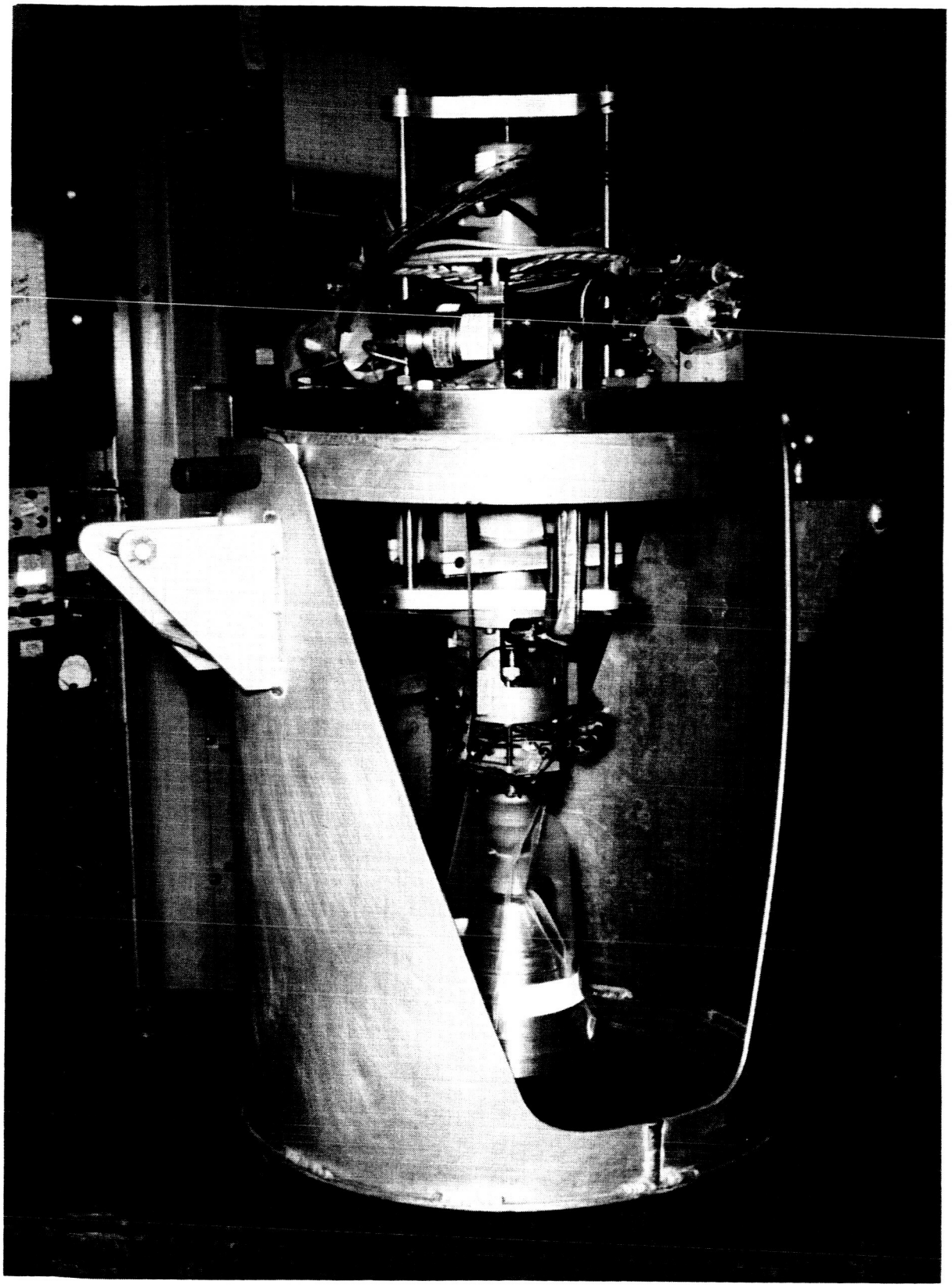
TEST 3403
RRL-PAD D
28 MAR 66

ENGINE T12340 AFTER COMBUSTION TESTING (U)

SEAL TEST

NEG. T3403-7

FIGURE 3

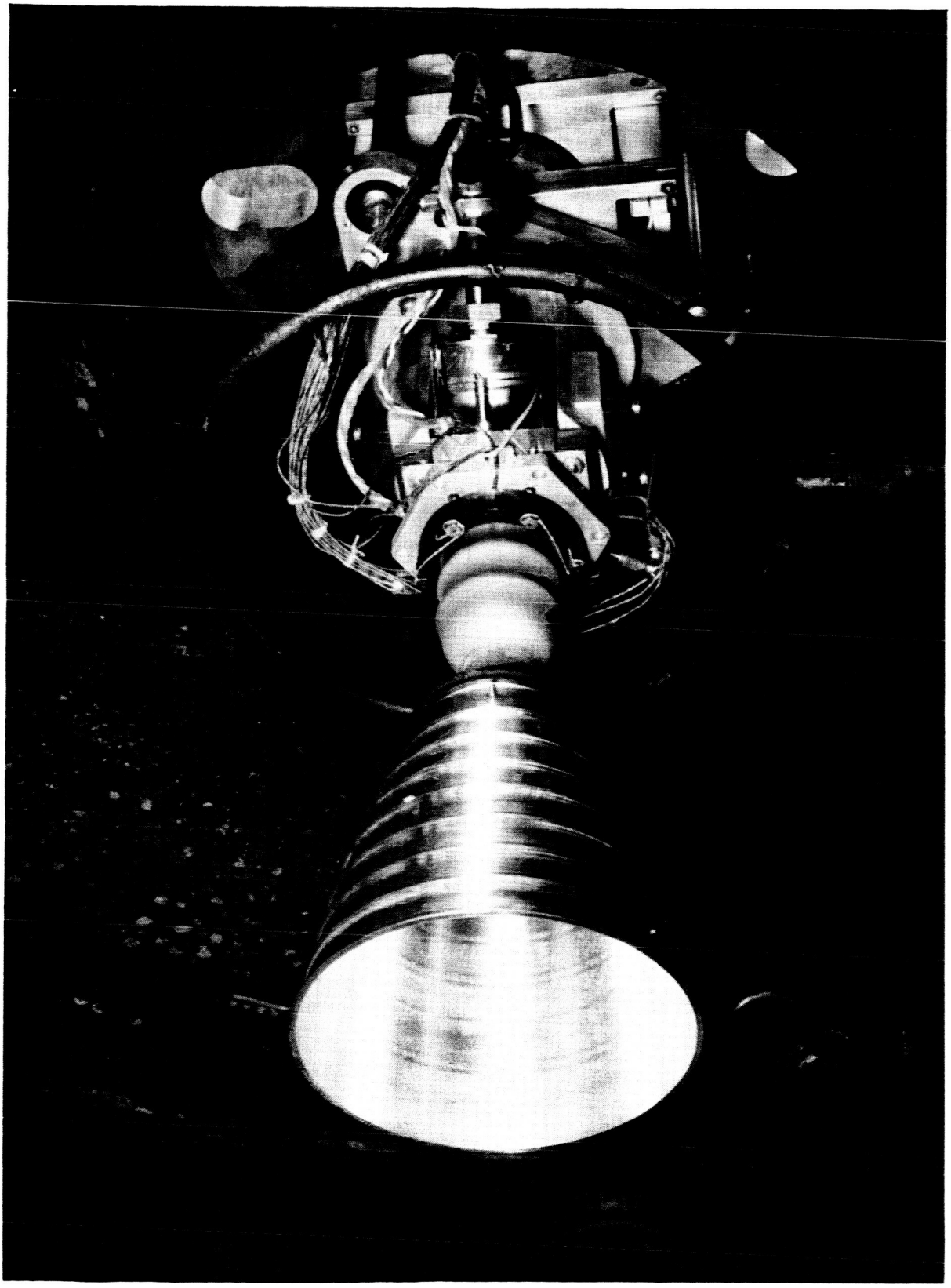


TEST 3403
ATL-PAD D
22 MAR 66

SEAL TEST
ENGINE AND THRUST STAND
(U)

NEG. T3403-1

FIGURE 4



SEAL TEST
ENGINE INSTALLATION IN ALTITUDE CHAMBER
(U)

TEST 3403
ATL-PAD D
22 MAR 66

NEG. T3403-2

FIGURE 5

TEMPERATURE INSTRUMENTATION SCHEMATIC

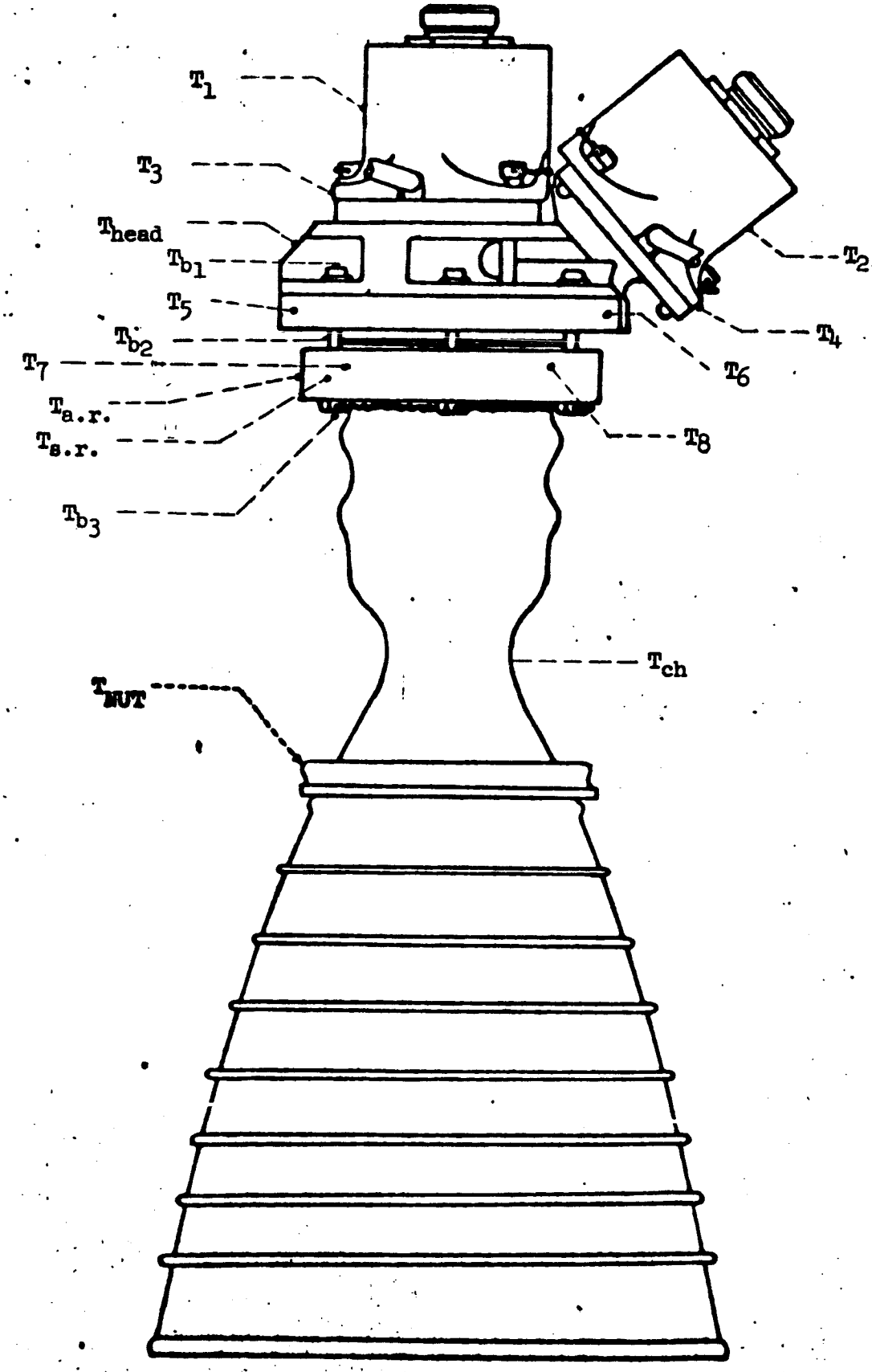


FIGURE 6

PREPARED BY [illegible]

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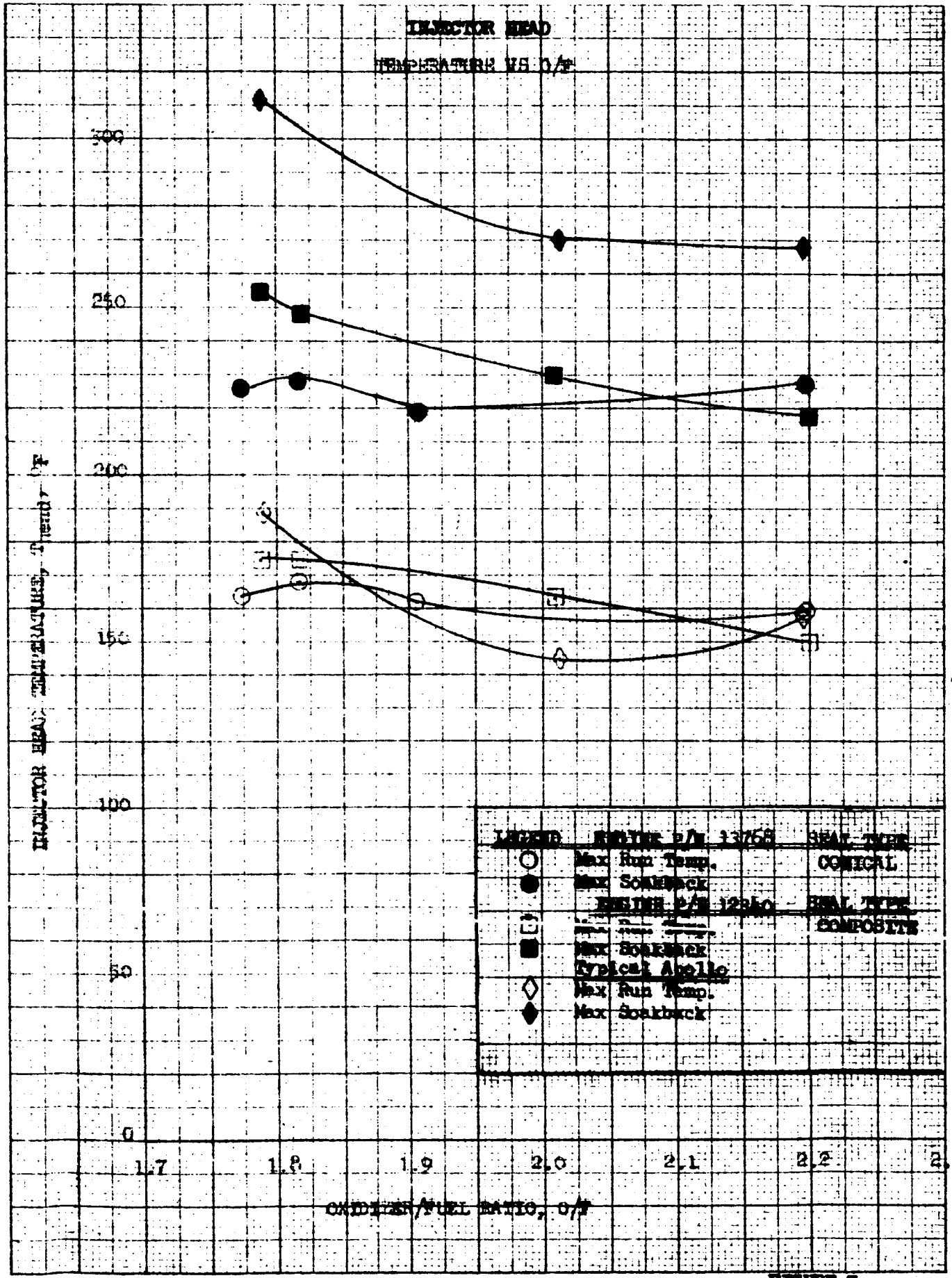


FIGURE 7

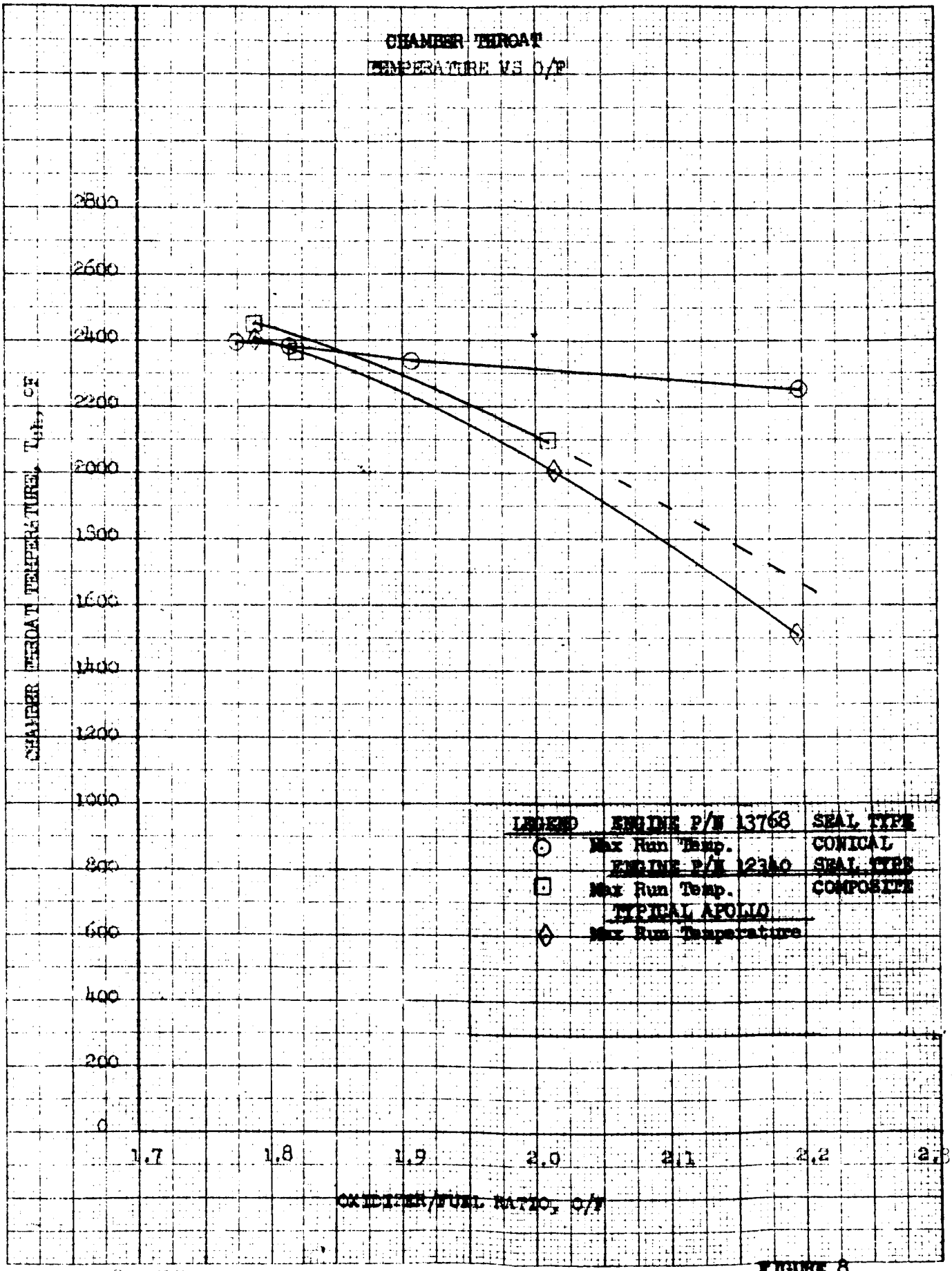

CHAMBER THROAT
TEMPERATURE VS O/F
CHAMBER THROAT TEMPERATURE, T_{th}, °F
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1.7
1.8
1.9
2.0
2.1
2.2
2.3
OXIDIZER/FUEL RATIO, O/F
LEGEND
ENGINE P/N 13768 SEAL TYPE
Max Run Temp. CONICAL
ENGINE P/N 12340 SEAL TYPE
Max Run Temp. COMPOSITE
TYPICAL APOLLO
Max Run Temperature

FIGURE 8

PREPARED BY Eve Dawson

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DATE 4-11-66

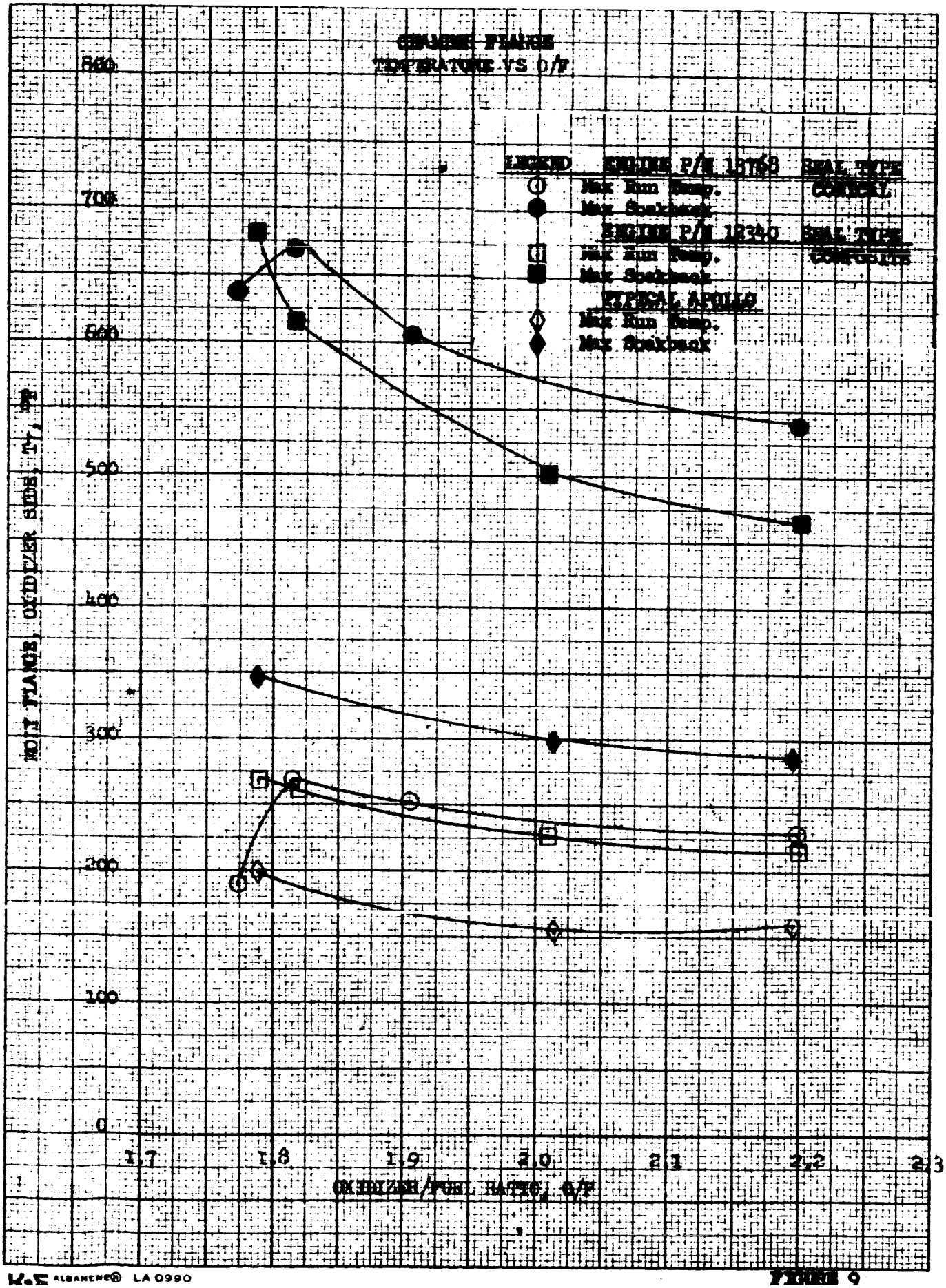


FIGURE 9

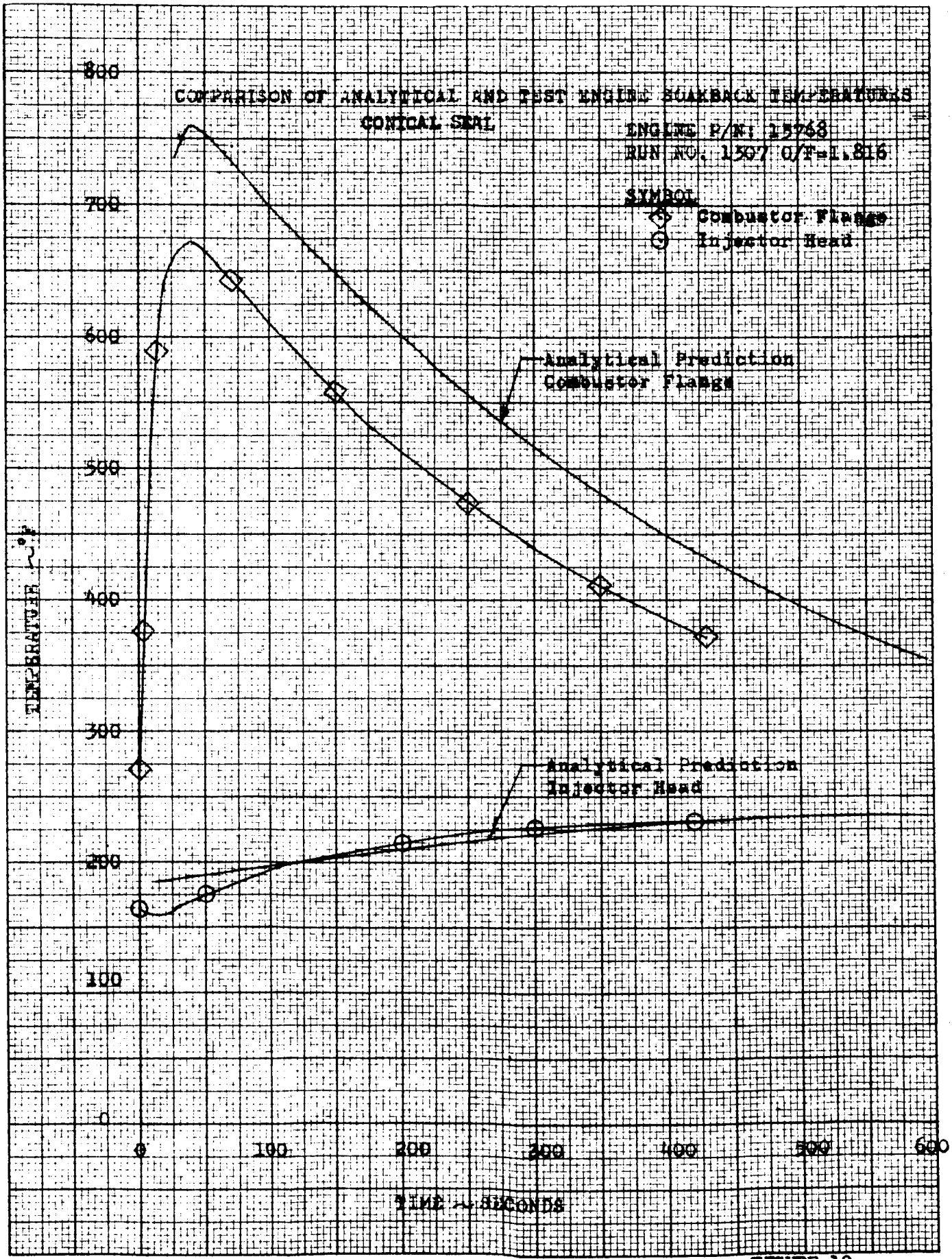


FIGURE 10

K+E ALBANENE® LA 0990 TRACING PAPER

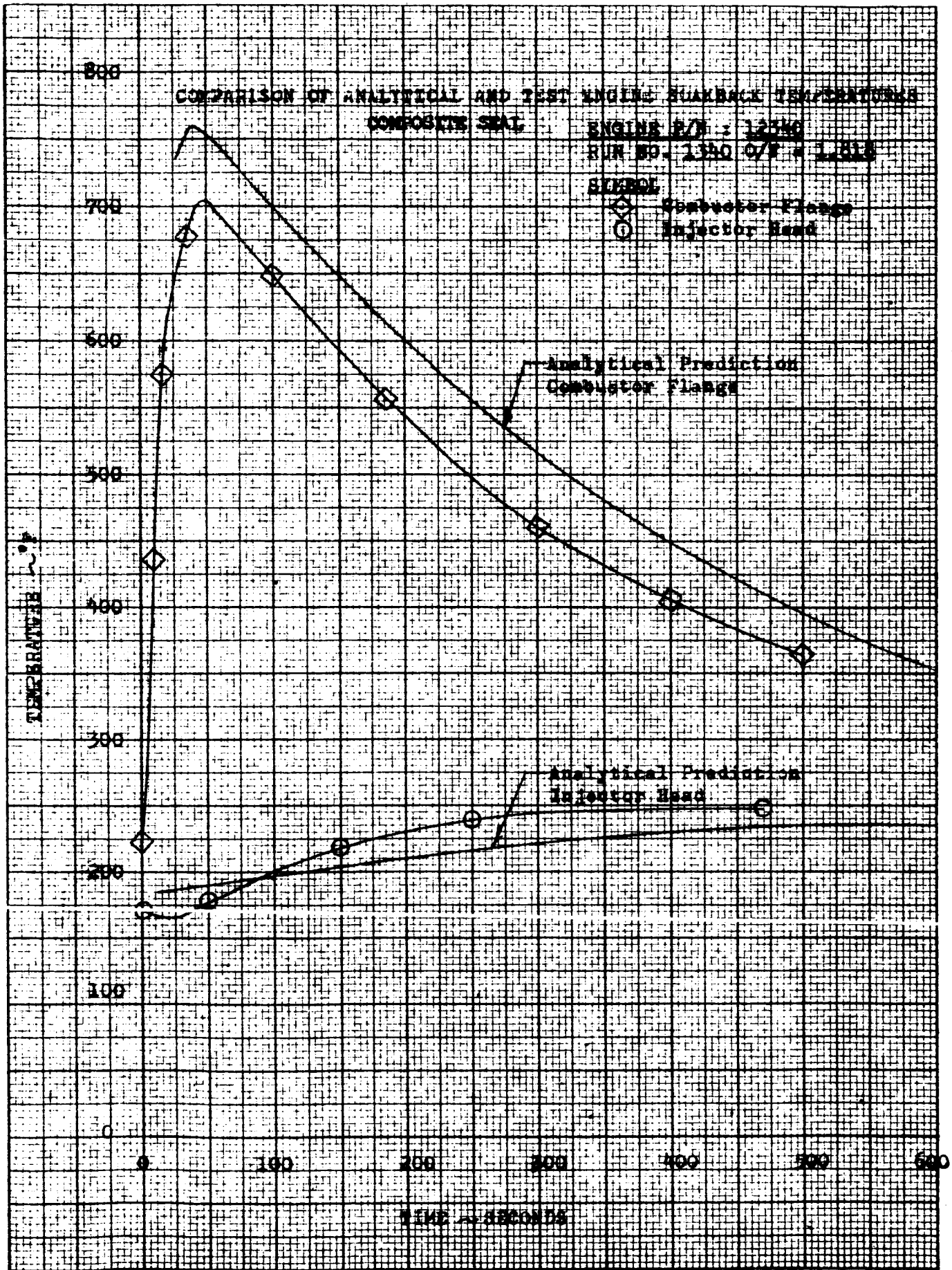

COMPARISON OF ANALYTICAL AND TEST ENGINE HOOKBACK TEMPERATURES
COMPOSITE SEAL
ENGINE O/F = 1.615
RUN 89, 2350 O/F = 1.615
SYMBOL
Combustor Flange
Injector Head
Analytical Prediction
Combustor Flange
Analytical Prediction
Injector Head
TEMPERATURE °F
TIME - SECONDS
800
700
600
500
400
300
200
100
0
0
100
200
300
400
500
600

FIGURE 11

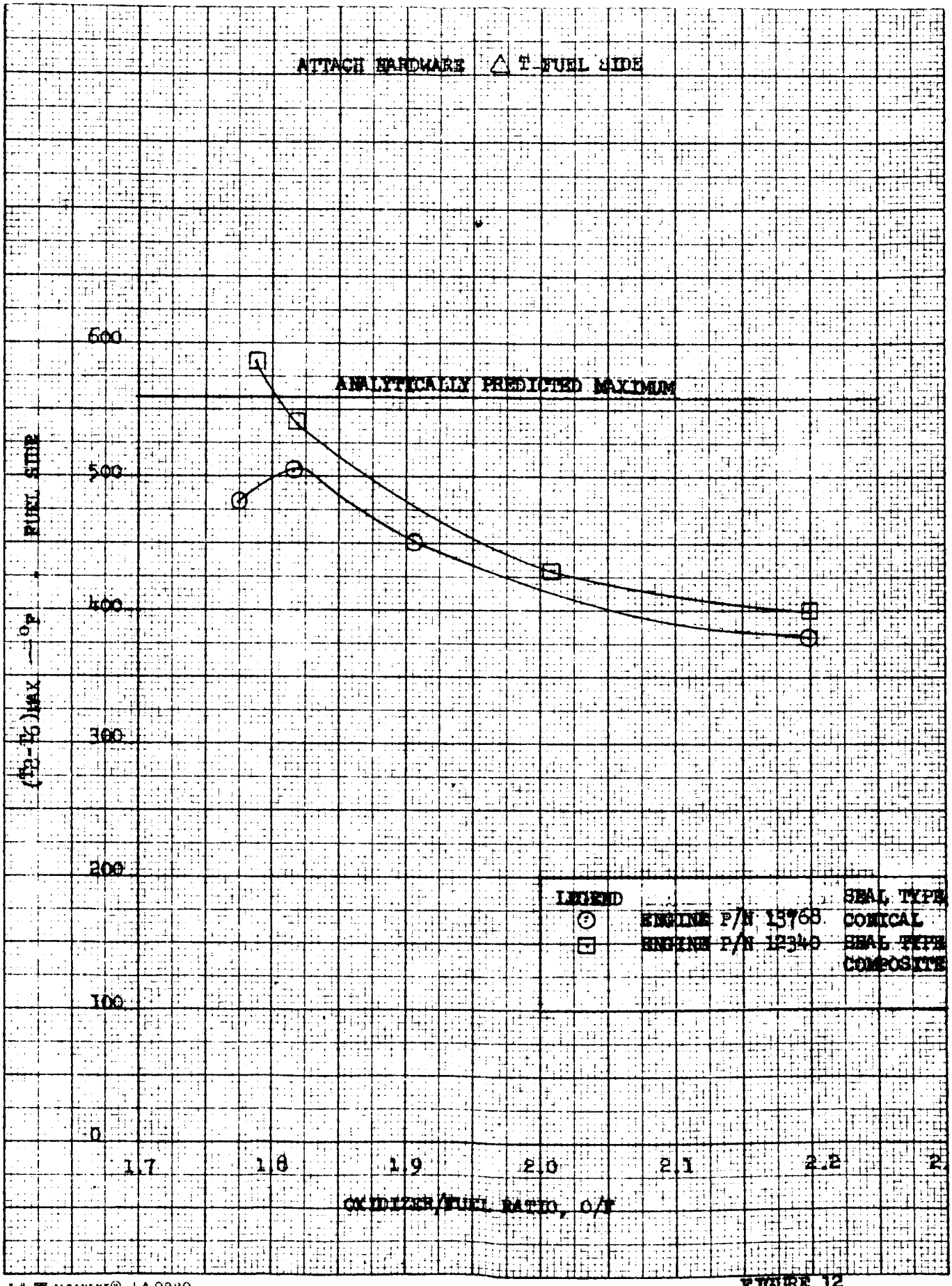


FIGURE 12

K&E ALBANENE® LA 0990

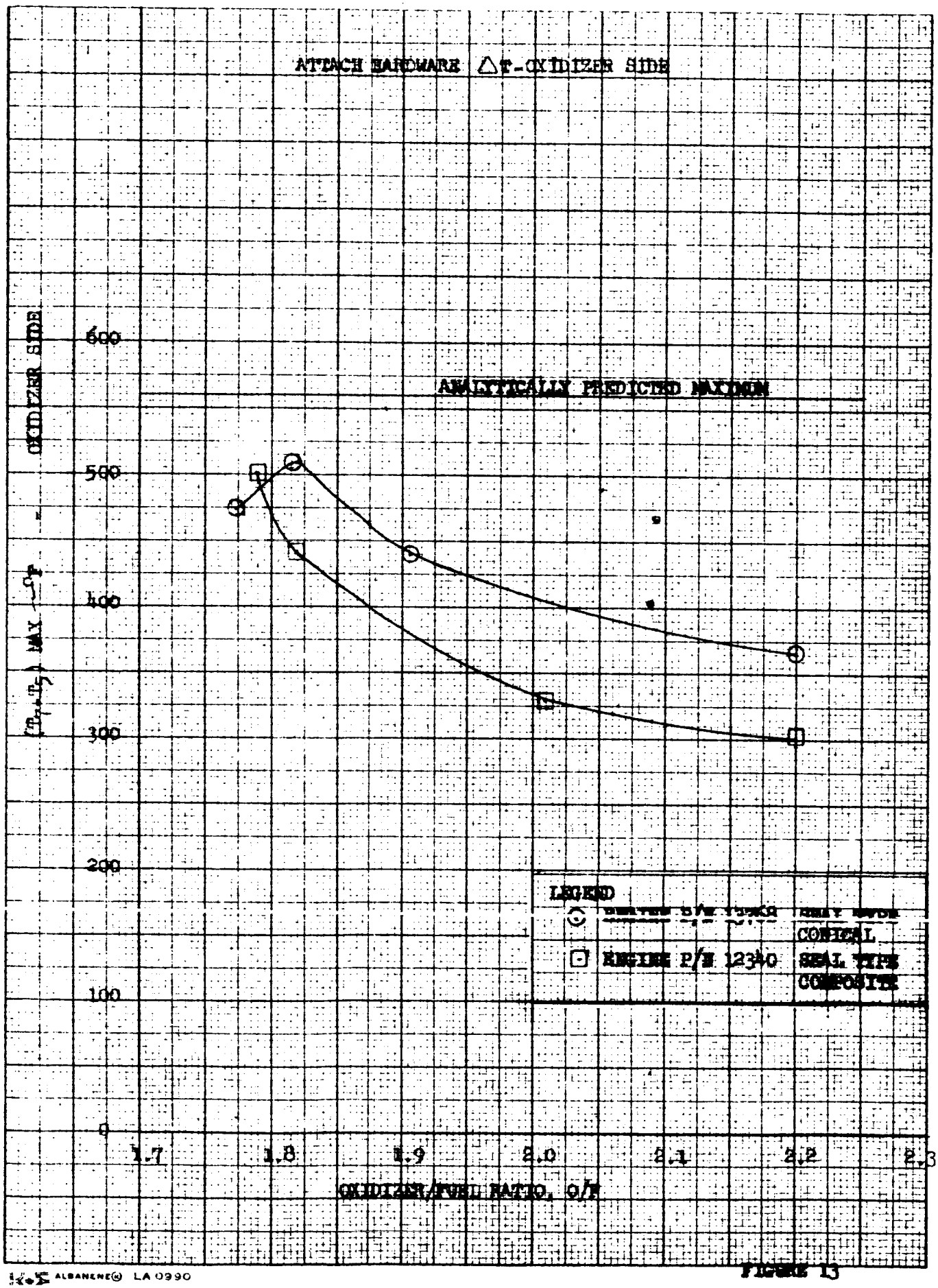

ATTACH HARDWARE ΔT-OXIDIZER SIDE
ANALYTICALLY PREDICTED MAXIMUM
OXIDIZER SIDE
$(T_{w_1} - T_c)$ MAX - °F
600
500
400
300
200
100
0
LEGEND
ENGINE P/N 12340 SEAL TIPS COMPOSITE
1.7
1.8
1.9
2.0
2.1
2.2
2.3
OXIDIZER/FUEL RATIO, O/F

FIGURE 13

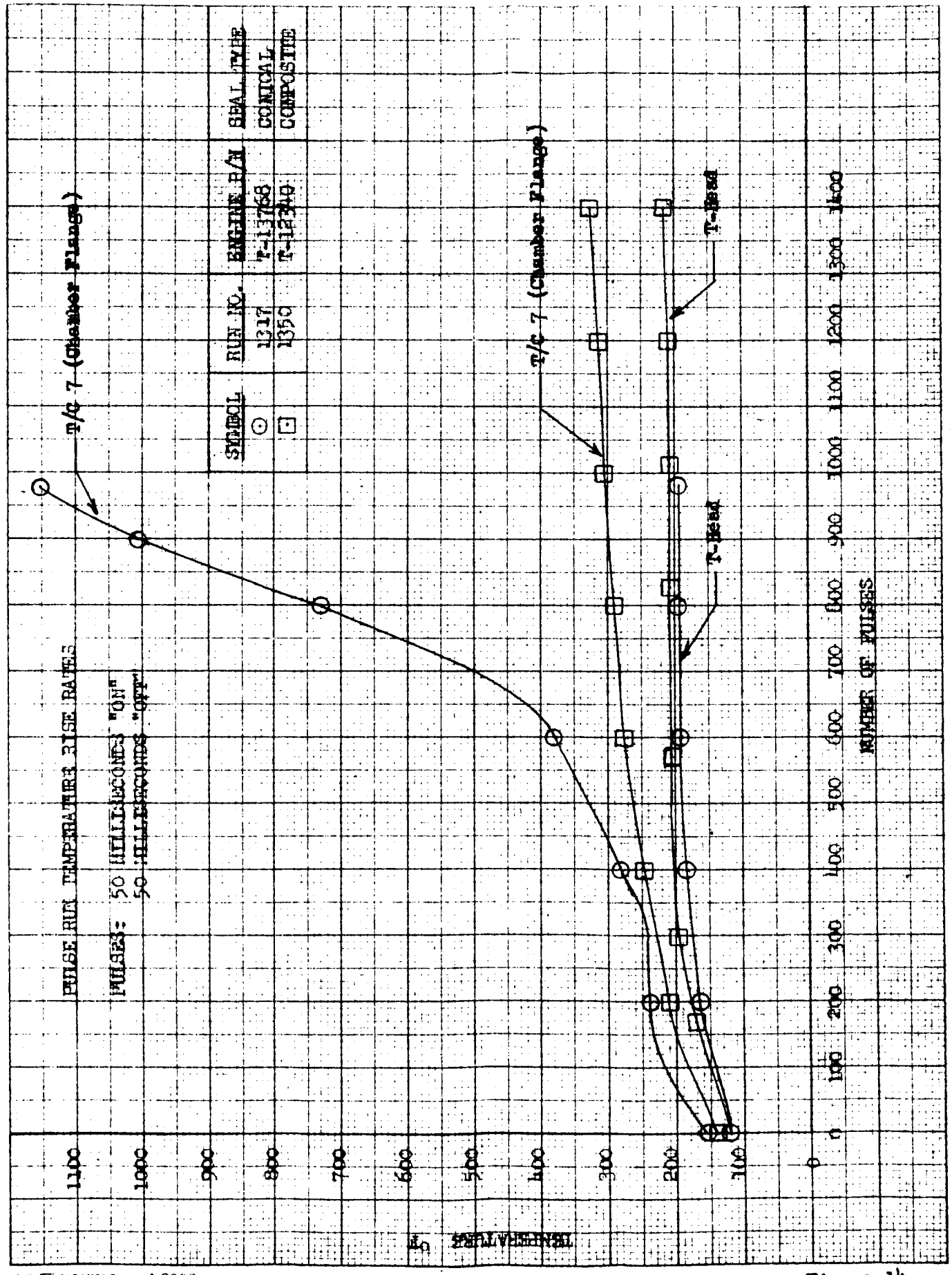

PULSE RUN TEMPERATURE RISE RATES
PULSES: 50 MILLISECONDS "ON"
50 MILLISECONDS "OFF"
SYMBOL
RUN NO.
ENGINE P/N
SEAL TYPE
1317
T-13768
CONICAL
1350
T-12310
COMPOSITE
T/C 7 (Chamber Flange)
T/C 7 (Chamber Flange)
T-Head
T-Head
TEMPERATURE °F
NUMBER OF PULSES
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400

Figure 14

APPENDIX A

Curves of Temperature Transients

PREPARED BY EVA DAWSON

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PAGE A-1

DATE 4-4-66

SYMBOL T/C

⊙ NUT

◇ 7 SCOPE (CHROMEL ALUMEL)

ENGINE P/N 19768 S/N0001-1

TEST NO. 3403 DATE 3-18-66

CELL NO. ATL. "D" RUN No. 130.5

CONICAL THINWALL SEAL

DATA @ 30 SEC.

WF = .1088

WOX = .2393

WP = .3481

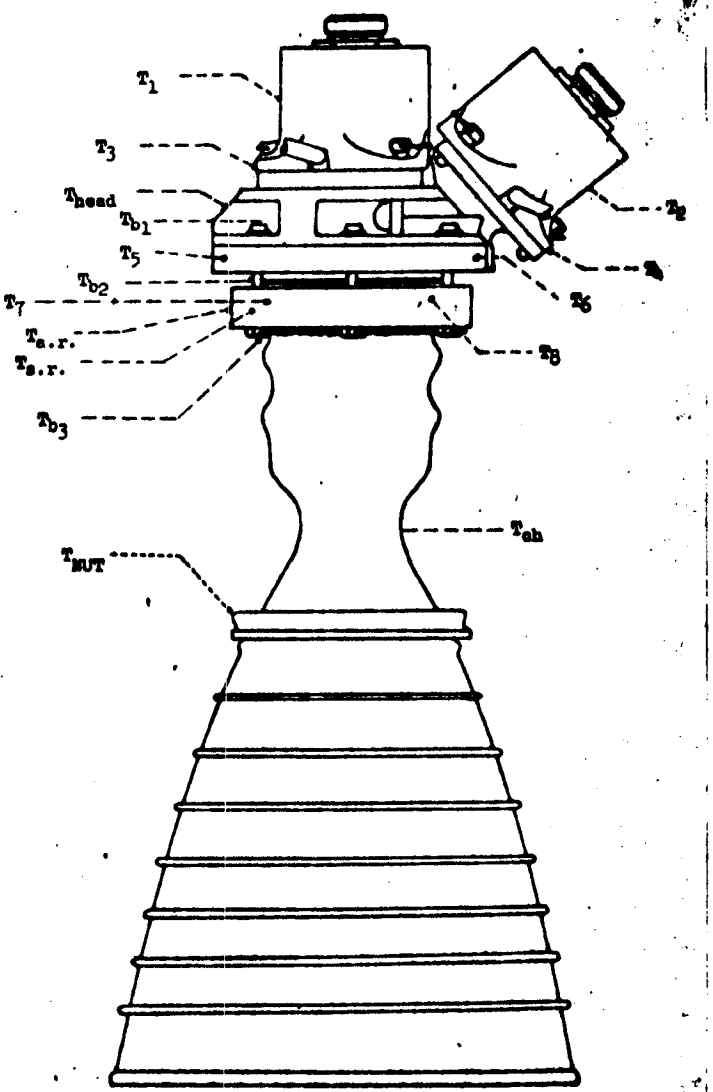
O/F = 2.199

PCH = 89.1

TEMPERATURE ~ °F

RUN TIME ~ SECONDS

SOAKBACK TIME ~ MINUTES



TMCA-327

The Marquardt Corporation

PREPARED BY EVA DAWSON

CHECKED BY

PAGE A-2

DATE 4-4-66

SYMBOL T/C
T-NUT
T-SCOBE
(CHAMBER THROAT)

ENGINE P/N: 19768 S/N 0001-1
TEST NO. 3401 DATE 3-17-66
CELL NO. ETL-"D" DURATION 130#
CONICAL THINWALL SEAL

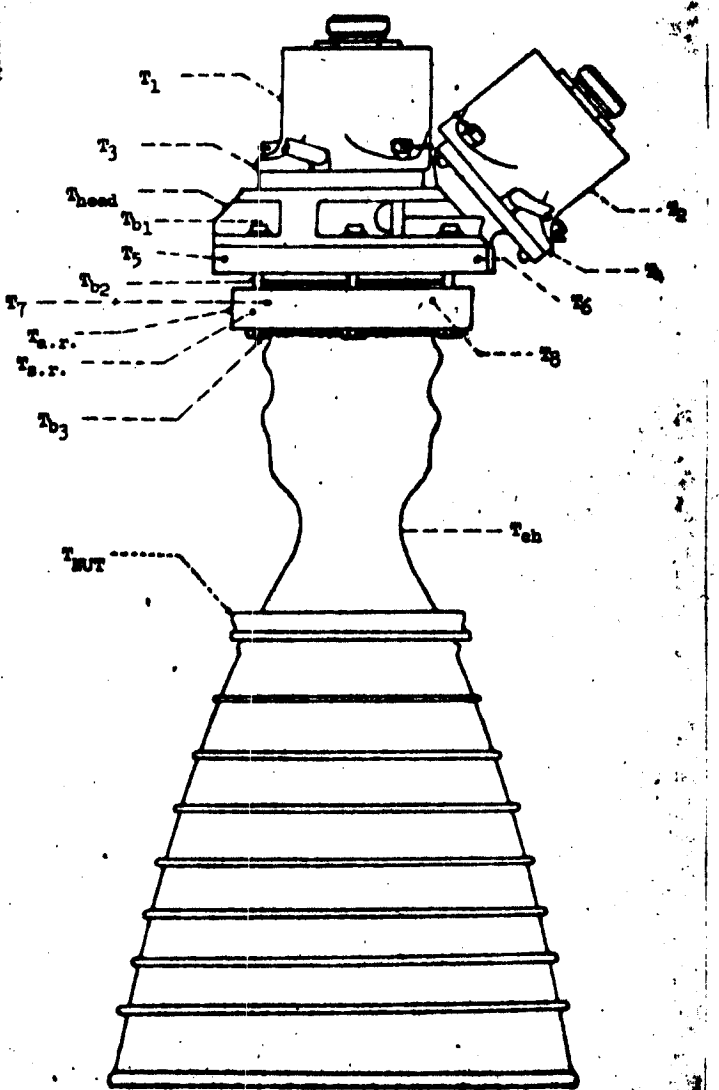
DATA @ 30 SEC.
W/F = .1206
Wox = .2301
W.P = 1.3507
O/F = 1.907
PCH = 93.6

TEMPERATURE ~ °F

2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0

0 10 20 30 40 50 60 70 80 90 100 0 1 2 3 4 5 6 7 8 9 10

RUN TIME ~ SECONDS SOAK BACK TIME ~ MINUTES



TMCA-327

PREPARED BY EVA DAWSON

CHECKED BY

PAGE A-3

DATE

SYMBOL T/C
⊙ T-NUT
◇ T-SCOPE
(CHAMBER THROAT)

ENGINE P/N 13768 S/N 00R1-1
TEST NO. 3403 DATE 3-18-66
CELL NO: ATL "D" RUN No. 1307
CONTRACT NUMBER OF ITEM

DATA @ 30 SEC.
WF = 1.1261
WOX = .2291
WP = .3552
O/F = 1.816
PCH = 96.8

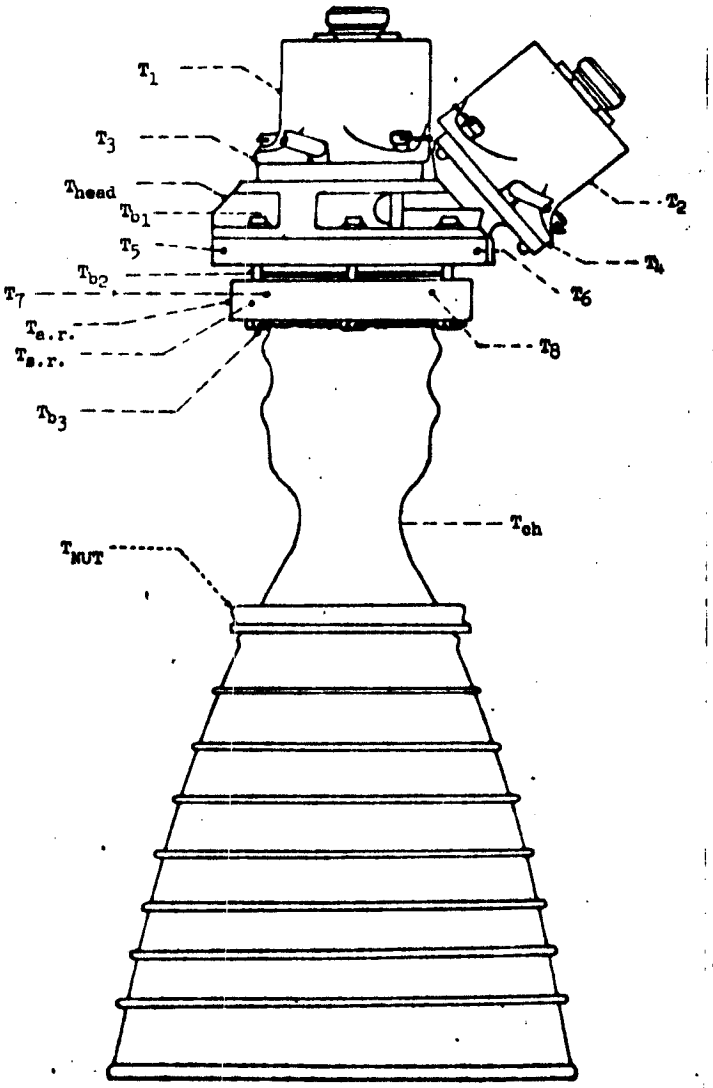
TEMPERATURE ~ °F

2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0

0 10 20 30 40 50 60 70 80 90 100 0 1 2 3 4 5 6 7 8 9

RUN TIME ~ SECONDS

SOAKBACK TIME ~ MINUTES



THE Marquardt CORPORATION

TMCA-327

PREPARED BY EVA DAWSON

CHECKED BY

DATE

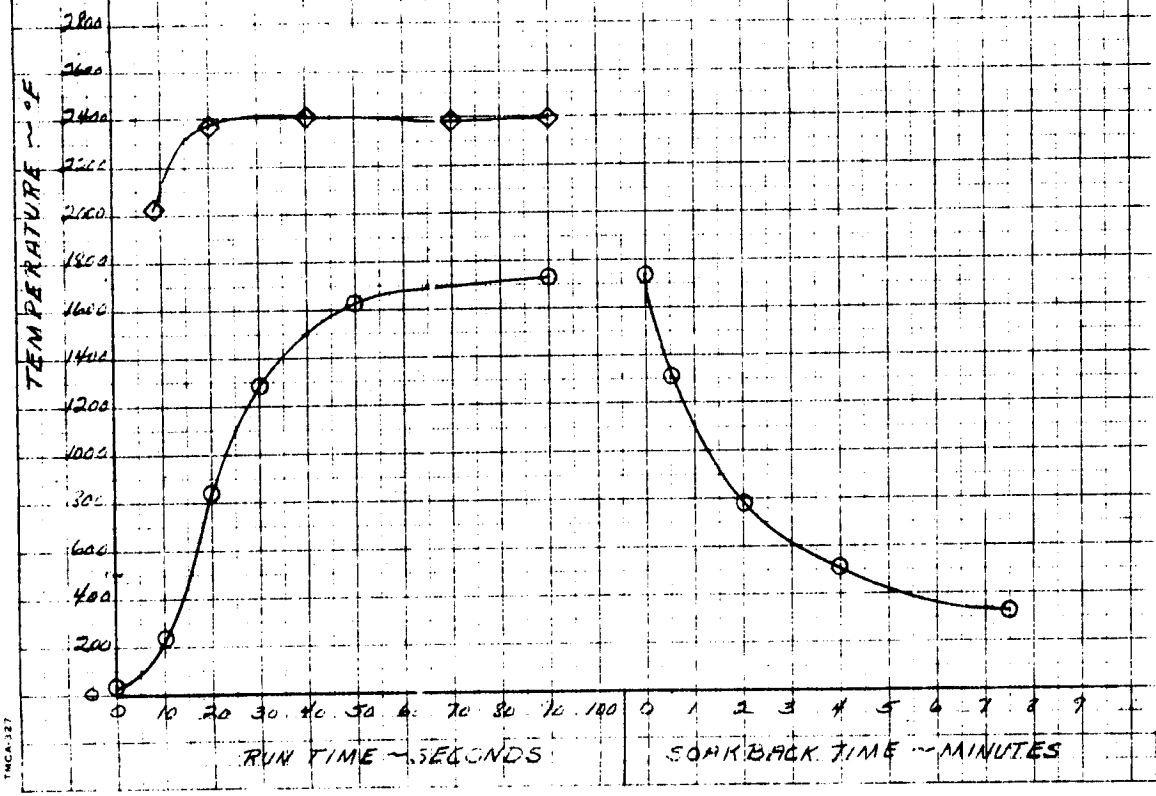
THE Marquardt CORPORATION

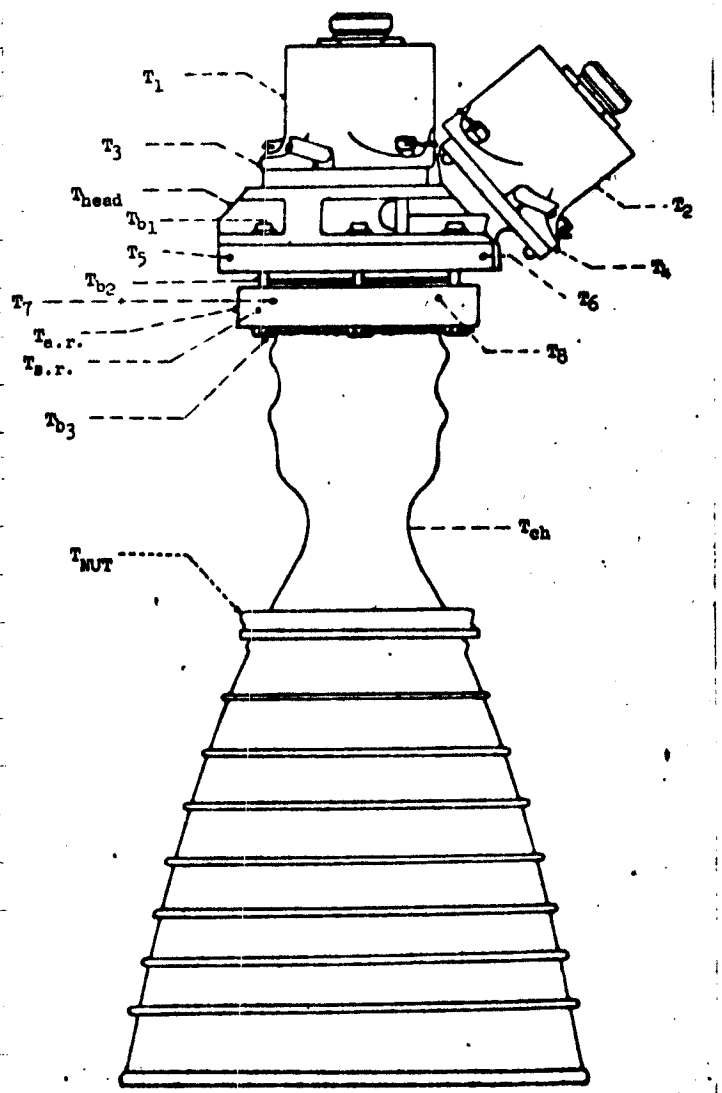
SYMBOL TAG
⊙ T-NUT
◇ T-SCOPE
(CHROMEL-ALUMEL THERMOCOUPLE)

ENGINE P/N 13768 S/N 0001-L
TEST NO. 3401 DATE 3-18-66
CELL NO. ATL "D" RUN No. 1308
CYCLE 1

CONICAL THINWALL SEAL

DATA @ 30 SEC.
WF = .1284
WOF = .2278
WP = .3562
O/F = 1.774
PC = 96.6





TMCA-327

PREPARED BY EVA DAWSON

CHECKED BY

DATE 4-4-66

THE Marquardt CORPORATION

SYMBOL T/C
T-NUT
T-SCOPE
(CHAMBER THROAT)

DATA @ 50 SEC
WF = 1.842
WOX = .7288
WP = .3938
O/F = 1.185
PCH = 94.1

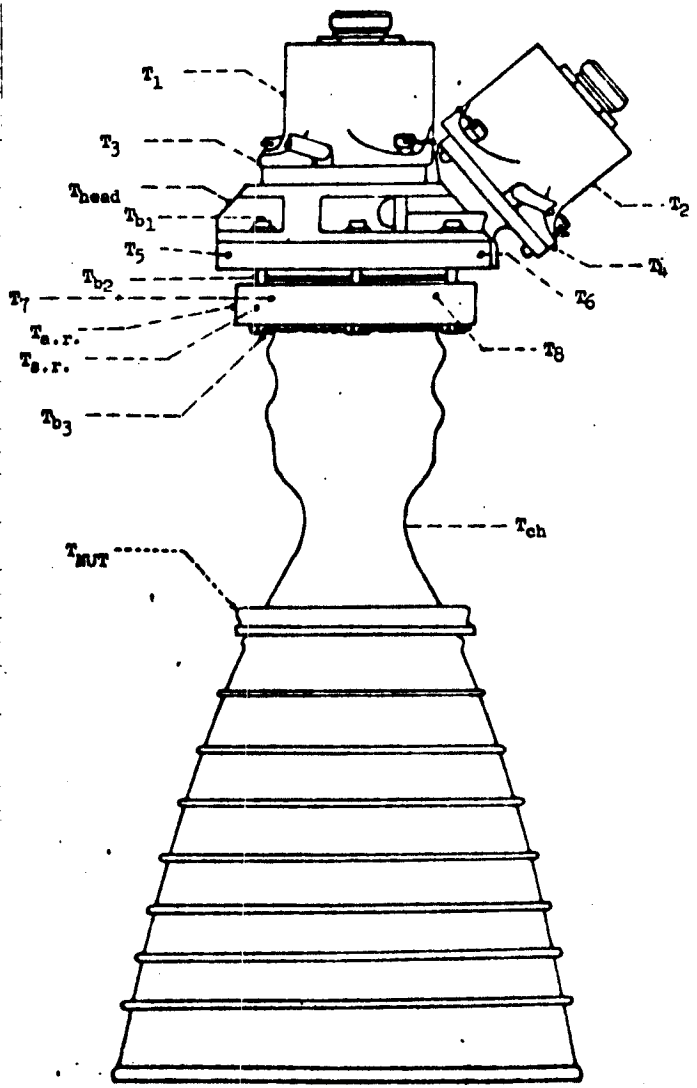
ENGINE P/N 13268 SN0004-1
TEST NO. 3403 DATE 3-18-66
CELL NO. ATL "D" RUN NO. 1368
CYCLE No. 2

CONICAL THINWALL SEAL

TEMPERATURE - °F

RUN TIME ~ SECONDS

SOAKBACK TIME ~ MINUTES



TMCA-327

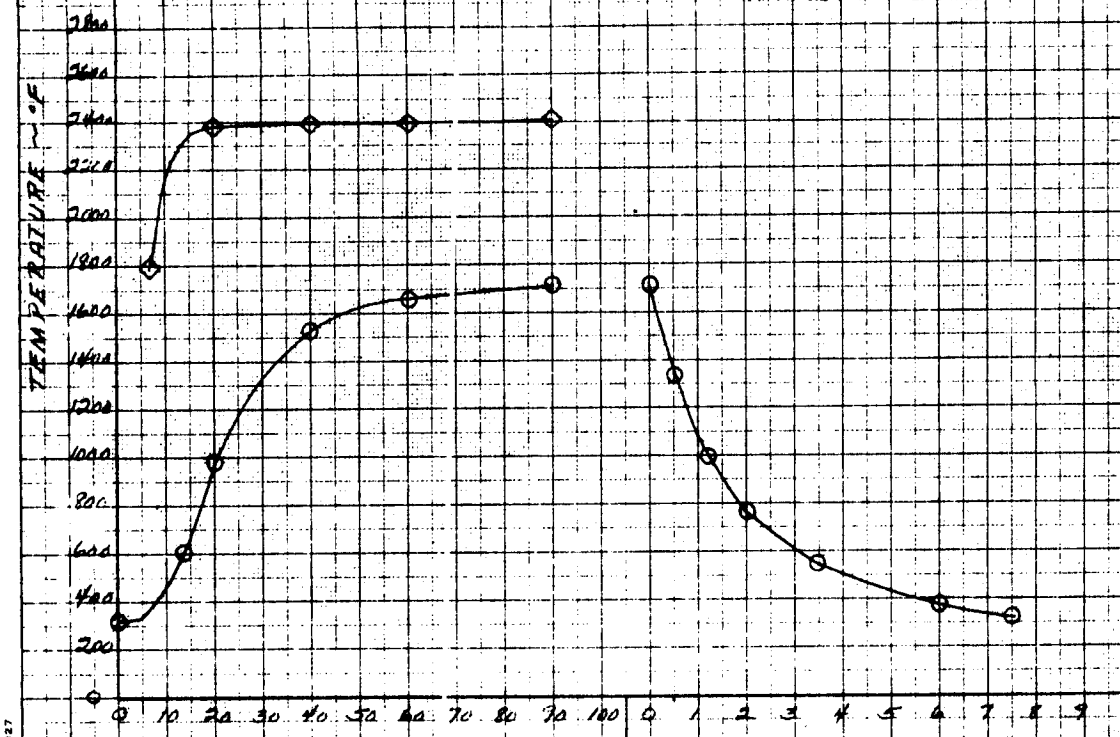
10 X 10 TO THE CENTIMETER 47 1517
KEUFFEL & ESSER CO.

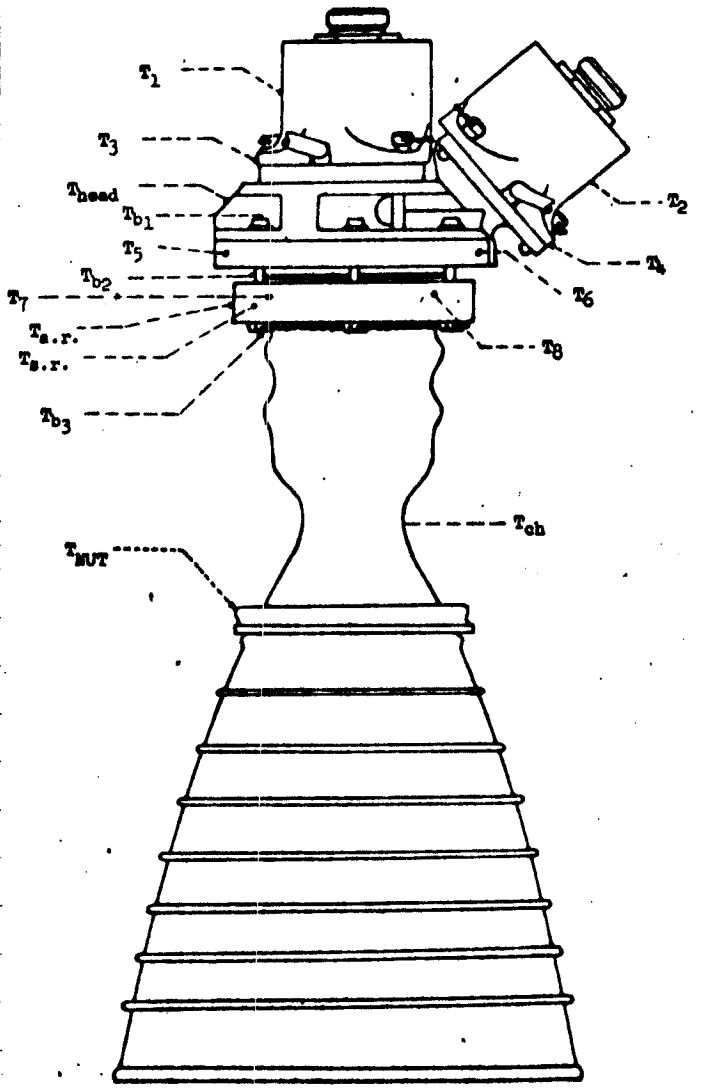
SYMBOL T/C
T-NUT
T-THROAT (CHAMBER THROAT)

ENGINE P/N 13762 SN 0004-1
TEST NO. 3 VAL DATE: 3-12-66
CELL NO. RTL-D1 RUN No. 130P
CYCLE No. 3

CONICAL THIN WALL SEAL

DATA @ 30 SEC.	
WF =	127#
W OX =	223#
MP =	35.4#
OF =	1.76
PC =	94.6





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THE Marquardt CORPORATION

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DATE 4-4-66

SYMBOL T/C

△ T-HEAD

□ TB1

◇ TB2

ENGINE DYN A3768S/M00001-1

TEST NO: 3401 DATE: 3-18-66

CELL: ATL "D" RUN NO. 1385

COMBINED THINWALL SEAL

DATA @ 80 SEC.

WE = 7088

WOX = 2558

WD = 3481

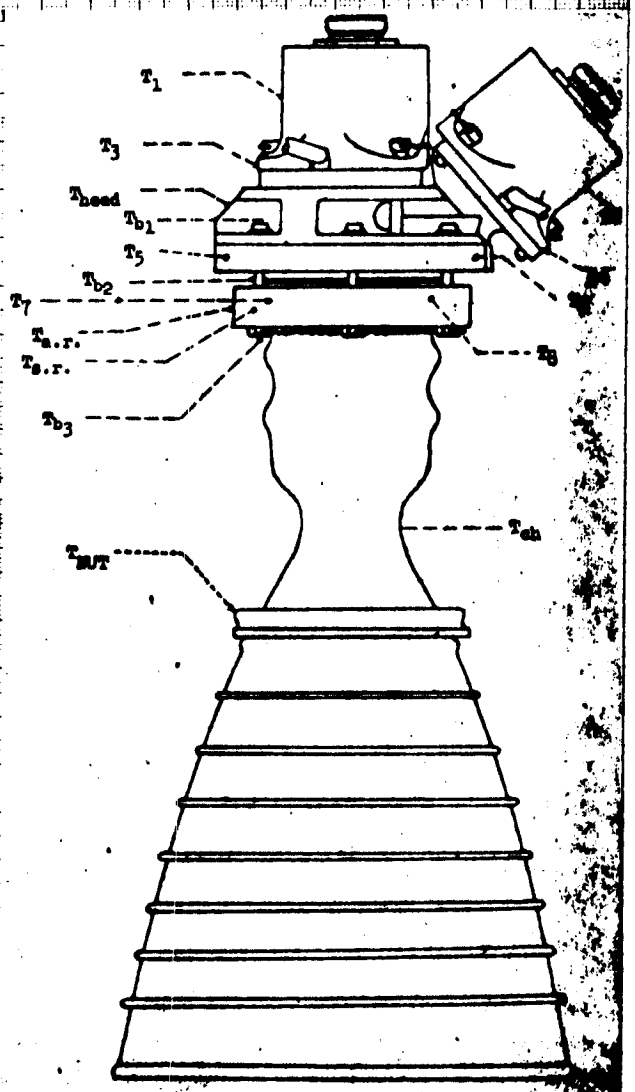
O/F = 2.199

PCH = 89.1

TEMPERATURE - °F

RUN TIME - SECONDS

SOAKBACK TIME - MINUTES



THE Marquardt CORPORATION

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DATE 4-4-66

THE Marquardt CORPORATION

SYMBOL T°C

△ T-HEAD

□ T.1.

◇ T.2.

ENGINE P/N 13768 S/N 0001-1

TEST NO. 3401 DATE: 3-18-64

CELL: ATL-"D" RUN NO. 130 #

CONICAL THRUST CHAMBER

DATA @ 30 SEC.
WF = 1246
WOX = 2304
WP = 3550
O/F = 1.907
PHI = 93.6

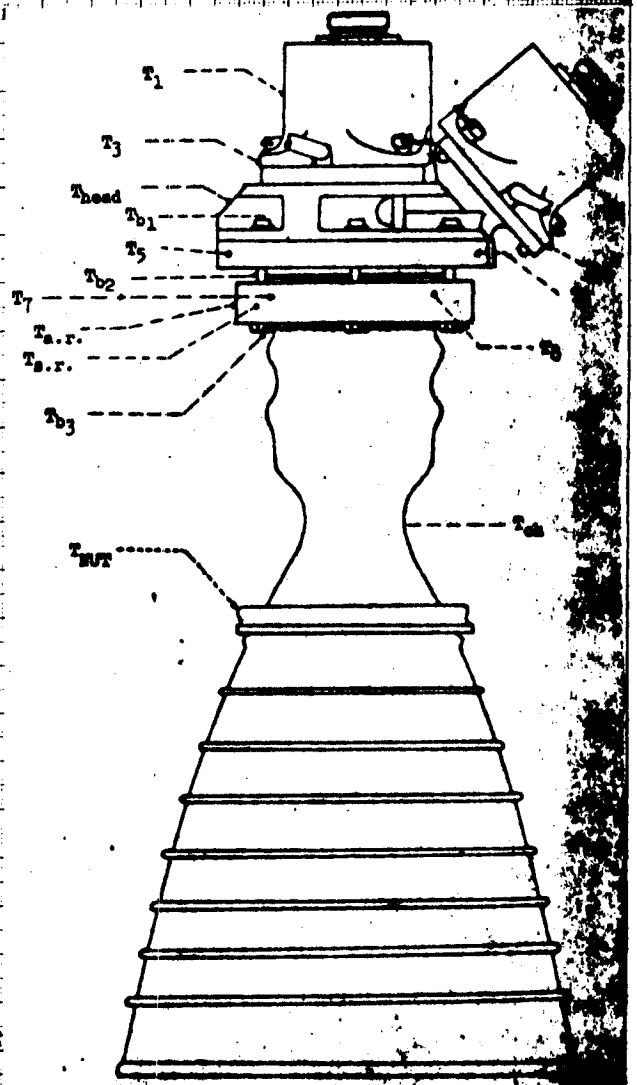
TEMPERATURE - °F

1400
1320
1240
1160
1080
1000
920
840
760
680
600
520
440
360
280
200
120
40

0 10 20 30 40 50 60 70 80 90 100 0 1 2 3 4 5 6 7 8 9 10 11 12

RUN TIME - SECONDS

SOAKBACK TIME - MINUTES



TMCA-327

KEUFFEL & ESSER CO. 10 X 10 TO THE CENTIMETER 47 1517

PREPARED BY EVA DAWSON

CHECKED BY

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DATE 4-4-66

THE Marquardt CORPORATION

SYMBOL T/C
△ : HEAD
○ TB1
◇ TB2

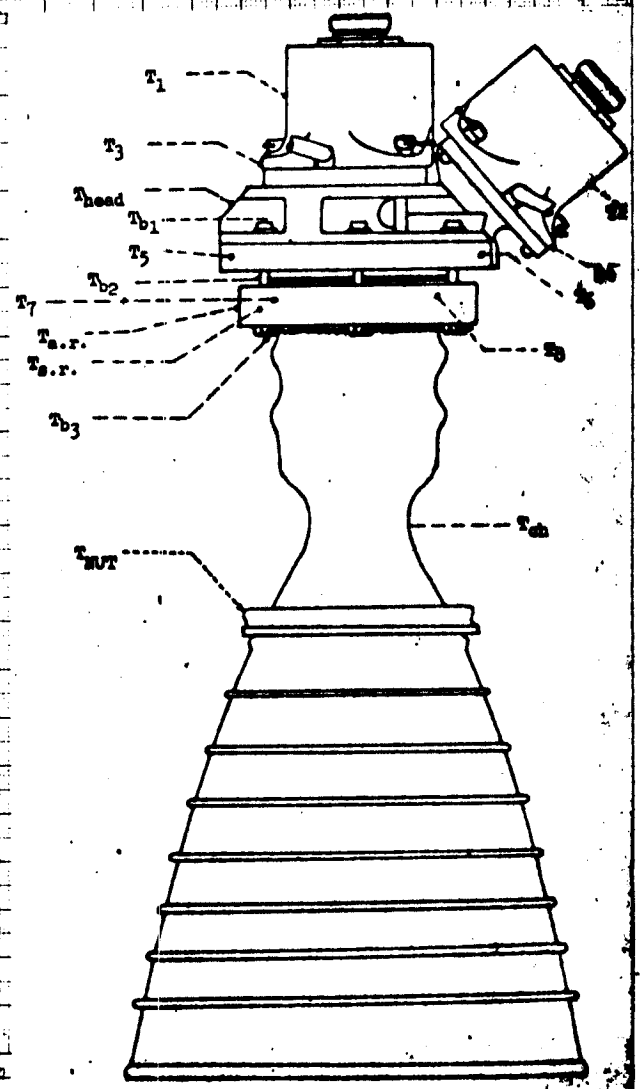
ENGINE P/N 1376RS/N0001-1
TEST NO. 3401 DATE: 3-18-66
CELL: ATL "D" RUN NO. 1807
CONDITION: HINVALL SEAL

DATA @ 30 SEC.
ẇF = 1.241
ẇOX = 2291
ẇP = 3552
O/F = 1.846
PCH = 96.8

TEMPERATURE - °F

RUN TIME - SECONDS

SOAKBACK TIME - MINUTES



TMCA-327

PREPARED BY: EVA DAWSON

CHECKED BY:

DATE 8-4-66

THE Marquardt CORPORATION

SYMBOL T/C
T HEAD
I.31
T12

ENGINE P/N 13768-/N 0001-1
TEST NO: 3401 DATE: 3-18-64
CELL: ATL-"D" RUN NO. 1308
CYCLE 1

CONICAL THINWALL SEAL

DATA @ 30 SEC.
$\dot{W}_F$ = 1.28#
$\dot{W}_{OX}$ = 2.27#
$\dot{W}_P$ = 3.542
O/F = 1.774
PCH = 96.6

TEMPERATURE - °F

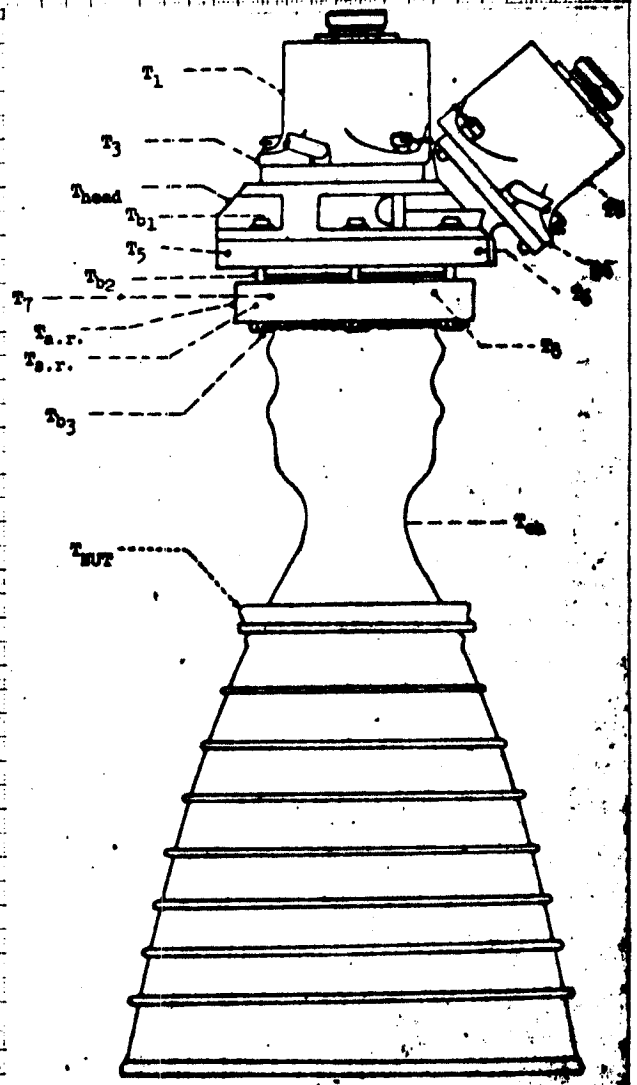
4a0 380 360 340 320 300 280 260 240 220 200 180 160 140 120 100 80 60 40 20 0

0 10 20 30 40 50 60 70 80 90 100

RUN TIME - SECONDS

0 1 2 3 4 5 6 7 8 9 10 11 12

SOAKBACK TIME - MINUTES



TMCA-327

M.C. 10 X 10 TO THE CENTIMETER 47 1517
KEUFFEL & ESSER CO

PREPARED BY EVA DAWSON

CHECKED BY

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DATE 4-4-66

THE Marquardt CORPORATION

SYMBOL TC
T-HEAD
T81
T92

ENGINE P/N 13768 S/N 0001d
TEST NO: 3401 DATE: 3-18-66
CELL: ATL-"D" RUN NO. 1308
CYCLE 2

CONICAL THIN WALL SEAL

DATA @ 90 SEC.
ẇF = 1.267
ẇOX = 2.088
ẇP = 3.355
OF = 1.84 ST
Pc.H = 96.1

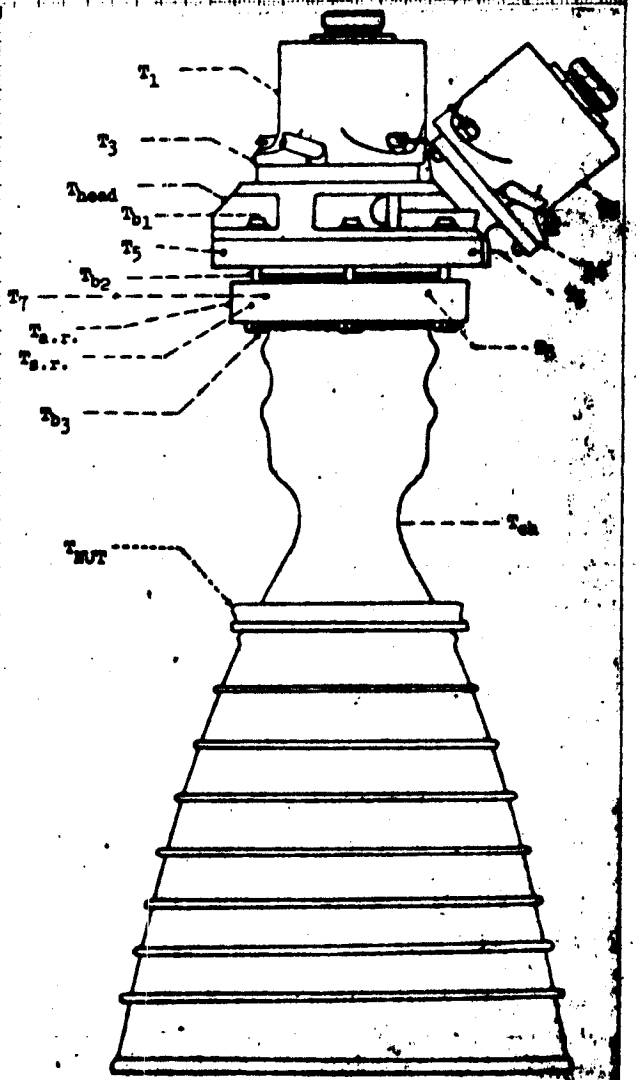
TEMPERATURE - °F

400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0

0 10 20 30 40 50 60 70 80 90 100 0 1 2 3 4 5 6 7 8 9 10 11 12

RUN TIME - SECONDS

SOAKBACK TIME - MINUTES



KOS 10 X 10 TO THE CENTIMETER 47 1517
NEUFFEL & ESSER

TMCA-327

PREPARED BY EVB DAWSON

CHECKED BY

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DATE 4-4-66

SYMBOL T/C
T-HEAD
T1
T2

ENGINE P/N 1376 S/N 0001
TEST NO: 3401 DATE: 3-18-66
CELL: ATL "D" RUN NO. 1308
CYCLE 1

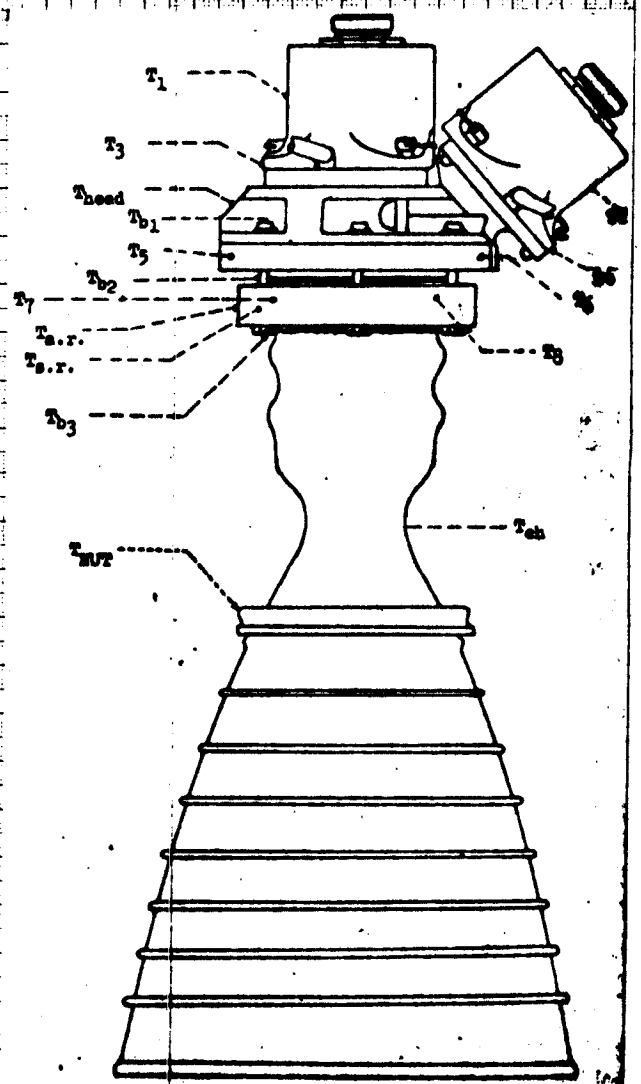
CONICAL THIN WALL SEAL

DATA @ 30 SEC.
WE = .0274
WAB = .2270
WP = .35 Max
O/F = 1.78
PcH = 96.0

TEMPERATURE - °F

RUN TIME - SECONDS

SOAKBACK TIME - MINUTES



The Marquardt Corporation

TMCA-327

PREPARED BY Judy Olson

CHECKED BY

PAGE A-13

DATE 4-4-66

THE Marquardt CORPORATION

SYMBOL T/C

○ T83

□ T4P

◇ T3P

DATA @ 80 SEC.

W/F = .1088

WOX = .2393

W/P = .3481

O/F = 2.199

%A = 89.1

ENGINE P/N 13768 S/N 6001-1

TEST NO. 3404 DATE: 3-18-66

CELL: 1RL-"D" RUN NO. 1905

CONFIG: THRUST CHAMBER SEAL

TEMPERATURE ~ °F

100

200

300

400

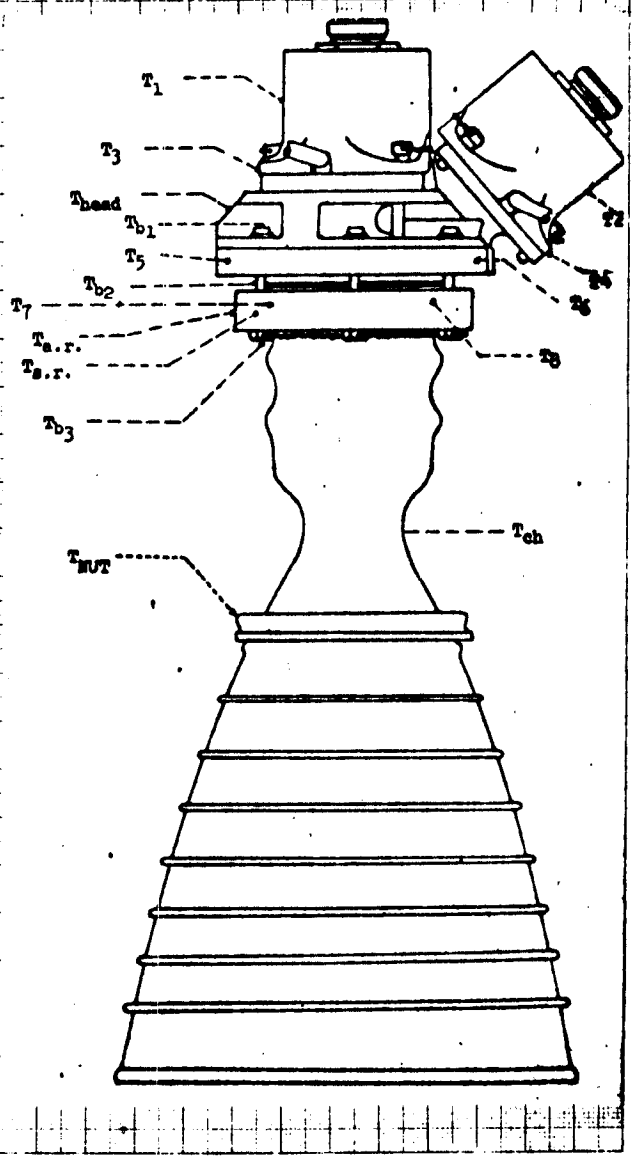
500

0 10 20 30 40 50 60 70 80 90 100

RUN TIME ~ SECONDS

0 1 2 3 4 5 6 7 8 9 10 11 12

SOAK BACK TIME ~ MINUTES



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THE Marquardt CORPORATION

SYMBOL 2%

○ F03

□ 2A

◇ 73A

ENGINE P/N 13763 S/N 0001-1

TEST NO. 3401 DATE: 3-18-66

CELL: ATL "D" RUN NO. 1304

CONICAL THINWALL SEAL

DATA @ 30 SEC.

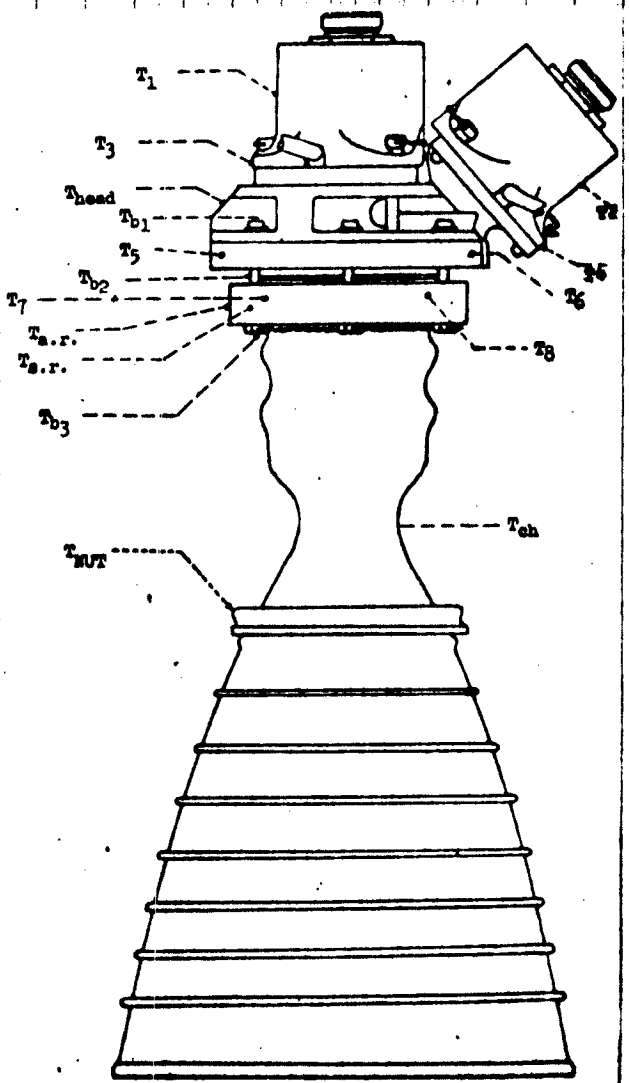
$\dot{W}_F$ = 1.216

$\dot{W}_{OX}$ = 2.381

$\dot{W}_P$ = 3.597

O/F = 1.707

P_{CH} = 93.6



TEMPERATURE - °F

400
300
200
100
0

0 10 20 30 40 50 60 70 80 90 100

RUN TIME - SECONDS

0 1 2 3 4 5 6 7 8 9 10 11 12

SOAK BACK TIME - MINUTES

TMCA-327

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PAGE A-15

DATE 4-7-66

THE Marquardt CORPORATION

SYMBOL T/C

○ 1283

□ 2.9#

◇ 5.5#

ENGINE P/N 49268-5/N6001-1

TEST NO. 3401 DATE: 3-18-66

CELL: ATL-2 RUN NO. 1307

PROPELLANTS: FUEL

DATA @ 30 SEC.

WF = 1241

WOX = 2291

WP = 3552

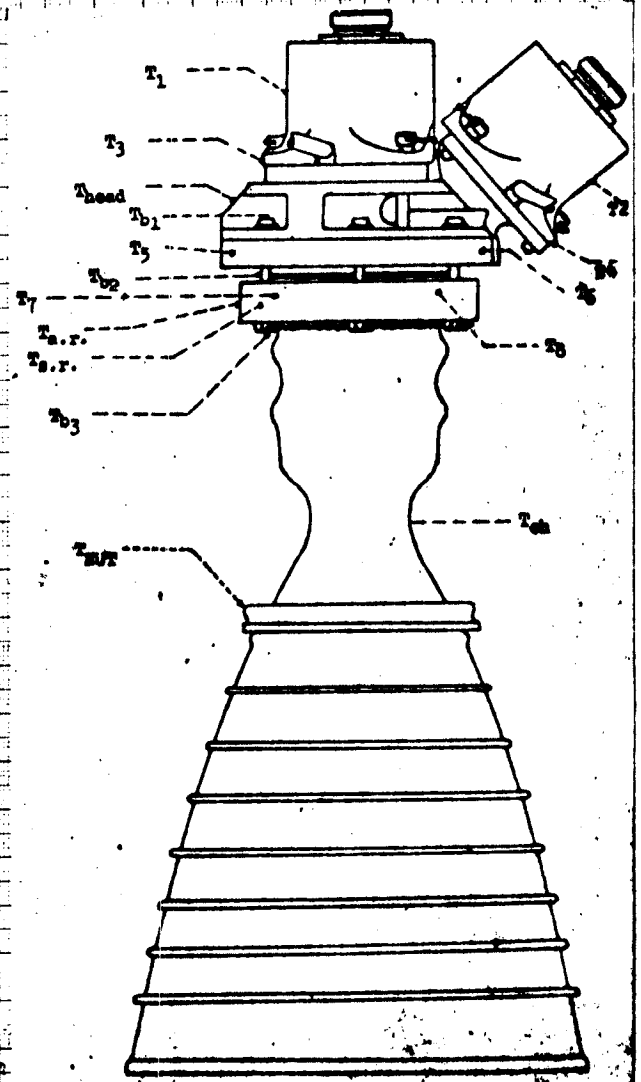
O/F = 1.846

PCN = 96.8

TEMPERATURE - °F

RUN TIME - SECONDS

SOAKBACK TIME - MINUTES



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DATE 4-8-66

THE Marquardt CORPORATION

SYMBOL | %

○ | 23

□ | 24P

◇ | 25E

DATA @ 30 SEC

$\dot{W}_F$ = .1284

$\dot{W}_{OX}$ = .2278

$\dot{W}_A$ = .3562

O/F = 1.774

P_{CH} = 98.6

ENGINE P/N 69244S/M6001-1

TEST NO: 3MA1 DATE: 3-8-66

CELL: ATL-X RUN NO. 1308

CYCLE 1

CENTERLINE THRUWALL SCAL

T_1

T_3

T_{head}

T_{b_1}

T_5

T_{b_2}

T_7

$T_{s.r.}$

$T_{s.r.}$

T_{b_3}

T_8

T_{th}

T_{NUT}

TEMPERATURE - °F

100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500 2600 2700 2800 2900 3000

0 10 20 30 40 50 60 70 80 90 100

0 1 2 3 4 5 6 7 8 9 10 11 12

RUN TIME - SECONDS

SOAKBACK TIME - MINUTES

TMCA-327

K&E 10 X 10 TO THE CENTIMETER 47 1517

25 X [illegible] INCHES

KEUFFEL & ESSER CO.

PREPARED BY Judy Olson

CHECKED BY

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DATE 4-4-66

THE Marquardt CORPORATION

SYMBOL T/C

○ T1

□ T3

◇ T4

ENGINE P/N 13768 S/N 0001-1

TEST NO. 3960 DATE: 3-18-66

CELL: ATL - 20 RUN NO. 4908

CYCLE 2

CONICAL THIN WALL SEAL

AREA @ 34 SEC.

Line: .1267

Shr: .2288

Lip: .3555

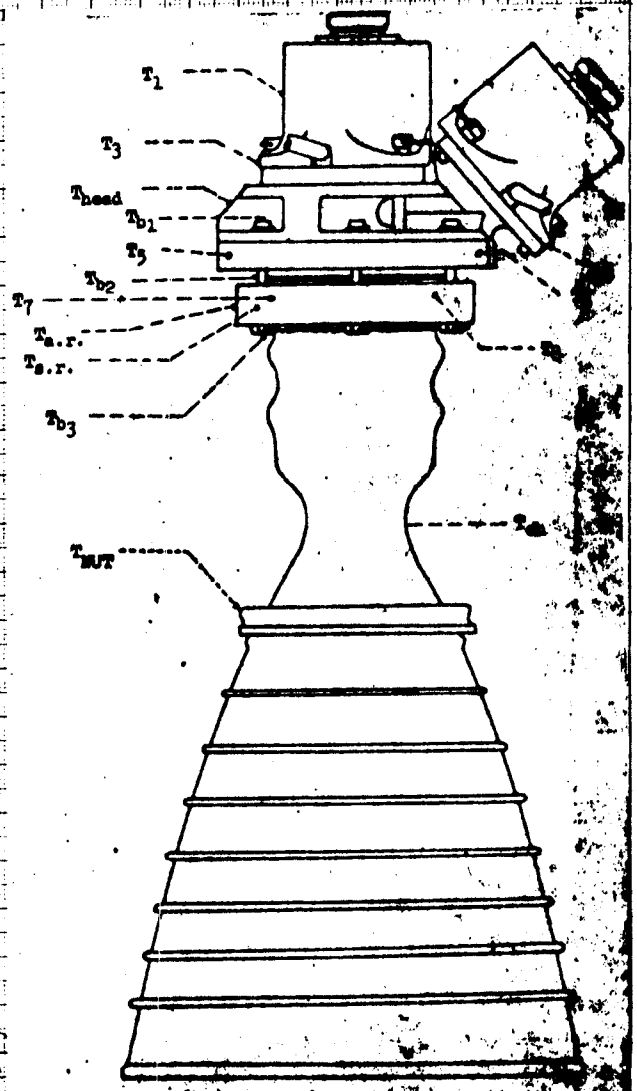
Out: 1.285

Acc: 96.4

TEMPERATURE - °F

RUN TIME - SECONDS

SOAK BACK TIME - MINUTES



TMCA-327

K&S 10 X 10 TO THE CENTIMETER 47 1517

KEUFFEL & ESSER CO.

PREPARED BY Judy Olson

CHECKED BY

PAGE A-18

DATE 4-4-66

THE Marquardt CORPORATION

K&E 10 X 10 TO THE CENTIMETER 47 1517
25 X 25 CM. HANDMADE
KEUFFEL & ESSER CO.

TMCA-327

SYMBOL T/C

ENGINE P/N [illegible] SERIAL

TEST NO: [illegible] DATE: [illegible]

CELL: [illegible] RUN NO. [illegible]

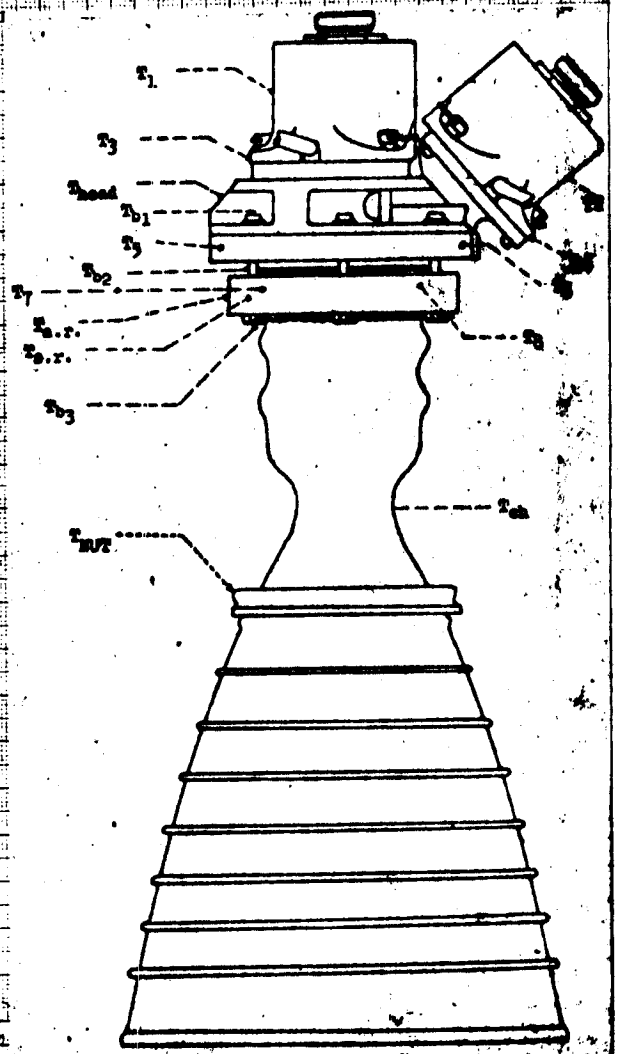
CYCLE #:

CYLINDRICAL TUNNEL SEAL

TEMPERATURE ~ °F

RUN TIME ~ SECONDS

SOAKBACK TIME ~ MINUTES



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DATE 4-4-66

THE Marquardt CORPORATION

SYMBOL T/C

○ 1

□ 2

◇ 3

△ 4

DATA @ 90 SEC

WF = .1088

WOX = .2398

WP = .3481

O/F = 2.199

PCN = 89.1

ENGINE P/N 103768 S/N 0001-1

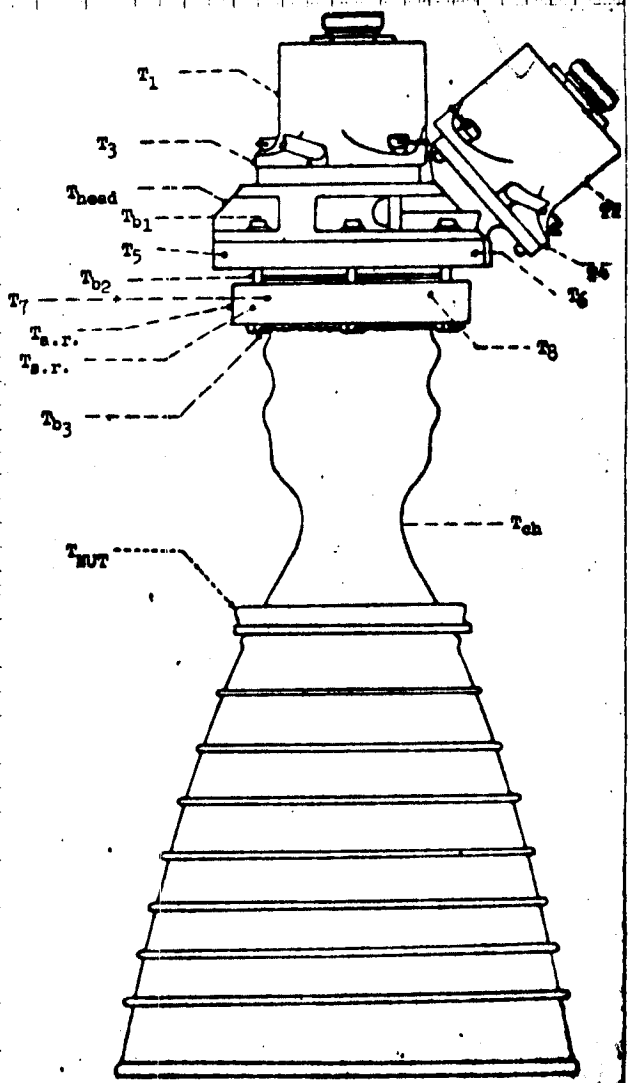
TEST NO. 3401 DATE 3-18-66

CELL: ATK - 10" RUN NO. 1305

TEMPERATURE ~ °F

RUN TIME ~ SECONDS

SOAKBACK TIME ~ MINUTES



TMCA-327

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DATE 4-4-66

THE Marquardt CORPORATION

SYMBOL T/C

○ 1

□ 2

◇ 3

△ 4

DATA @ 90 SEC

ẇF = 1.206

ẇOX = 2.301

ẇP = 3.507

OME = 1.907

PCM = 936

ENGINE P/N 43768-5/A0001-1

TEST NO: 3401 DATE: 3-18-66

CELL: 802 -30" RUN NO: 1304

COMBAL TITAN II EDL

TEMPERATURE ~ °F

100

200

300

400

500

600

700

800

900

1000

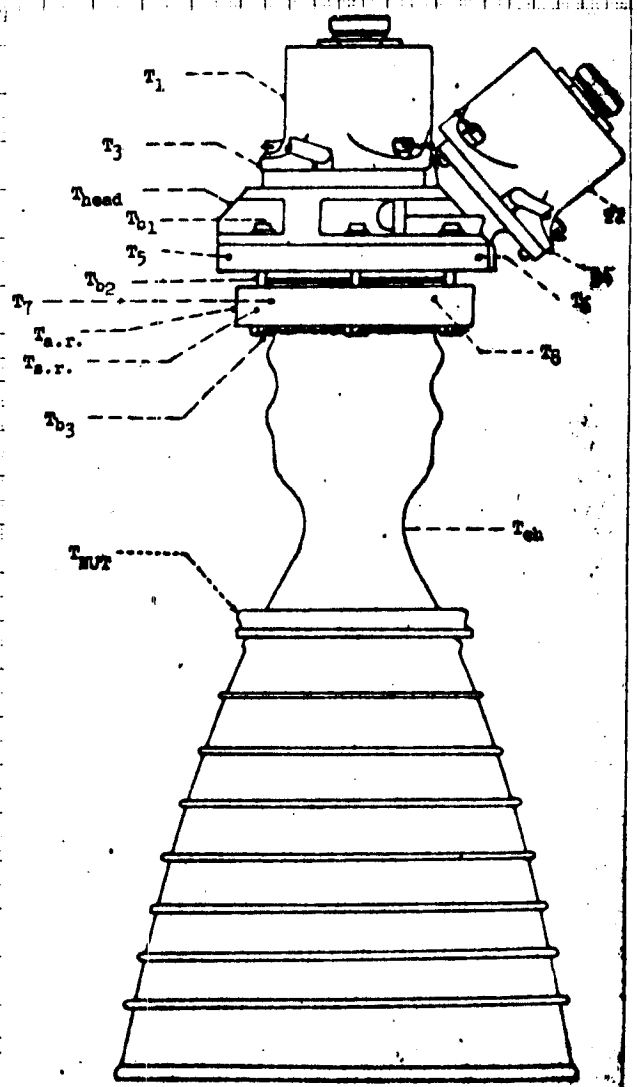
1100

1200

0 10 20 30 40 50 60 70 80 90 100 0 1 2 3 4 5 6 7 8 9 10 11 12

RUN TIME - SECONDS

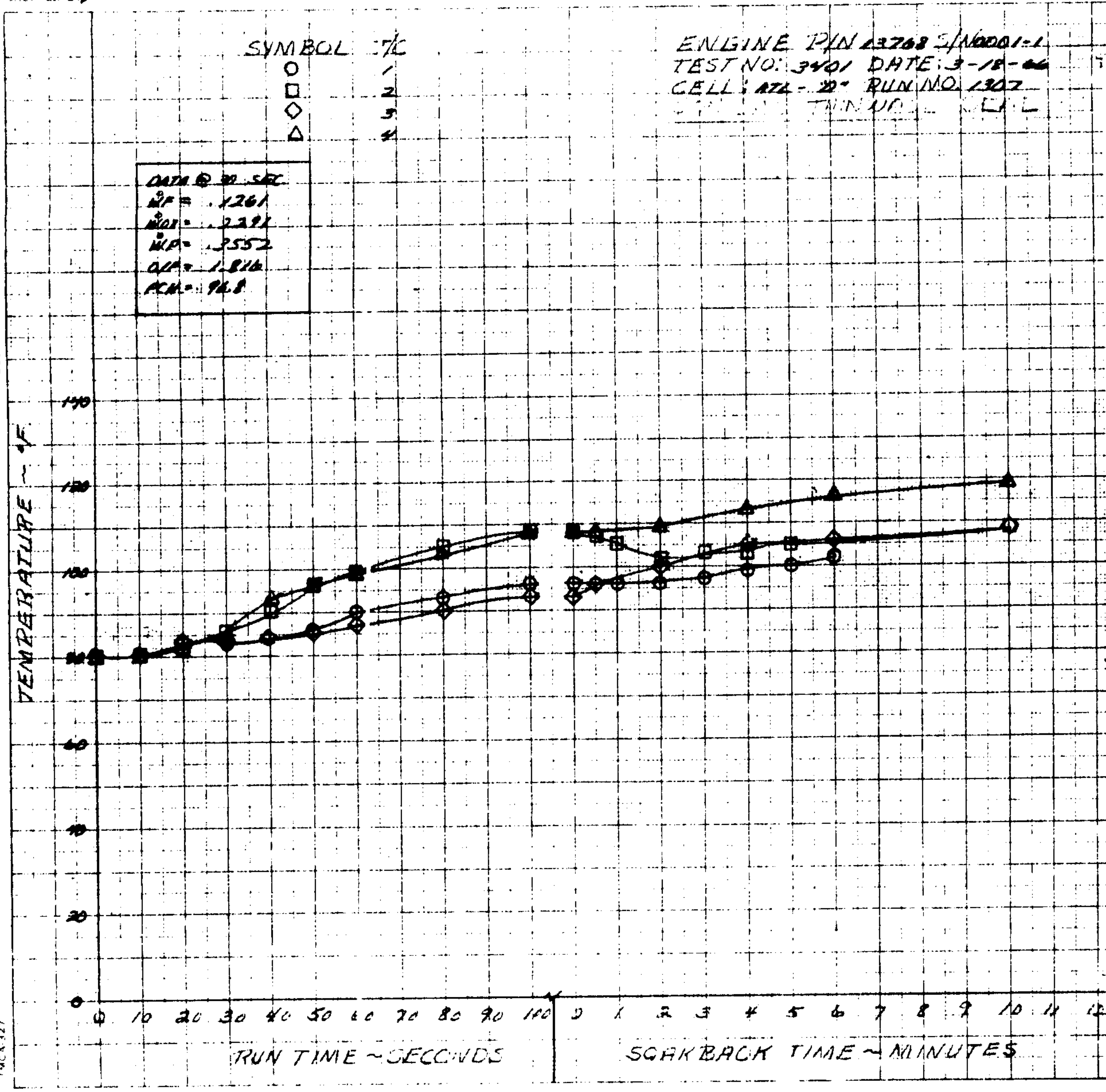
SOAKBACK TIME - MINUTES

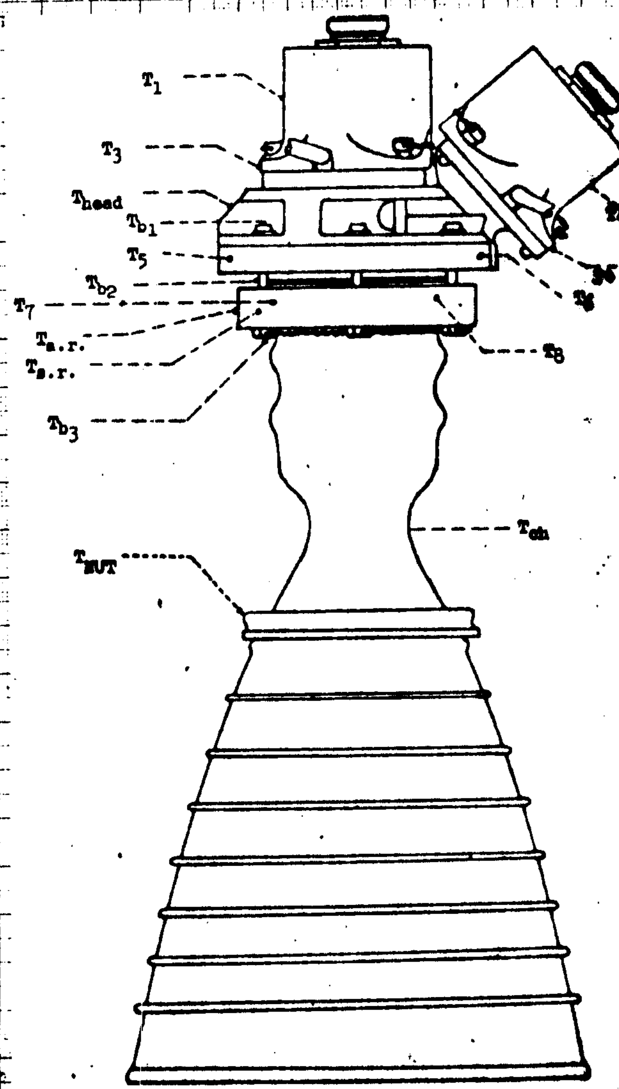


TMCA-327

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PAGE [illegible]
DATE 4-4-66





THE Marquardt CORPORATION

PREPARED BY Judy Olson

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DATE 4-4-66

THE Marquardt CORPORATION

ENGINE P/N 13208 S/N 0001-1

TEST NO: 3401 DATE: 3-18-66

CELL: 47A - "D" RUN NO. 1808

CYCLE 1

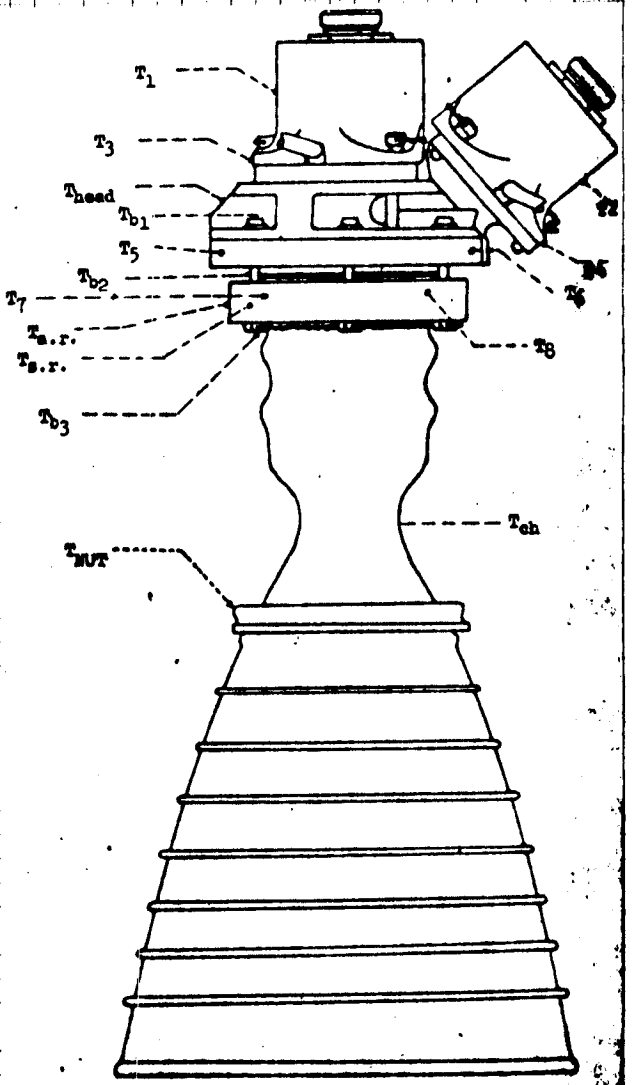
SYMBOL | T/C
○ | 1
□ | 2
◇ | 3
△ | 4

@ 30 sec	
Max.	.2284
Mean	.2279
Min.	.3562
Max	1.7274
Min.	96.6

TEMPERATURE ~ °F

RUN TIME ~ SECONDS

SOAKBACK TIME ~ MINUTES



TMCA-327

K+E 10 X 10 TO THE CENTIMETER 47 1517
KEUFFEL & ESSER CO.

PREPARED BY Judy Gibson

CHECKED BY

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DATE 4-4-66

THE Marquardt CORPORATION

ENGINE P/N 49768-1/A6001-1

TEST NO: 3401 DATE: 3-18-66

CELL: ATA-10 RUN NO. 1008

CYCLE 2

CONICAL THRUST CHAMBER

SYMBOL	T/C
○	1
□	3
◇	5
△	9

DATA @ 30 SEC.	
P_c =	1247
P_{amb} =	2788
ΔP_o =	3555
Q/P =	1.905
MR =	5.41

TEMPERATURE ~ °F

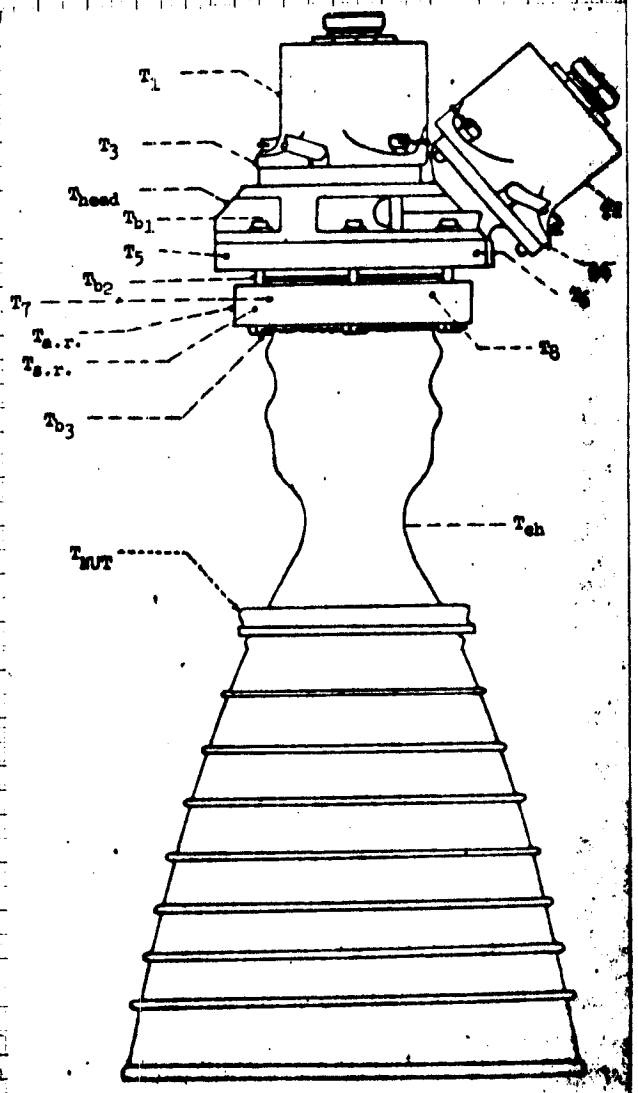
110
100
90
80
70
60
50
40
30
20
0

0 10 20 30 40 50 60 70 80 90 100

RUN TIME ~ SECONDS

0 1 2 3 4 5 6 7 8 9 10 11 12

SOAKBACK TIME ~ MINUTES



TMCA-327

K&E 10 X 10 TO THE CENTIMETER 47 1517

PREPARED BY Judy Olson

CHECKED BY

PAGE 1 of 1

DATE 4-4-66

THE Marquardt CORPORATION

SYMBOL T/C

○ 1

□ 2

◇ 3

△ 4

EN LINE P/N 13268 S/N 0004+1

TEST NO. 3401 DATE: 3-18-66

CELL: ARL - 12" RUN NO. 1308

CYCLE 3

CONTINUATION SEAL

DATA @ 30 SEC.

$\dot{W}_F$ = .1274

$\dot{W}_{ox}$ = .2270

$\dot{W}_O$ = .3544

O/F = 1.781

P_{CH} = 960

TEMPERATURE ~ °F

100

120

140

60

40

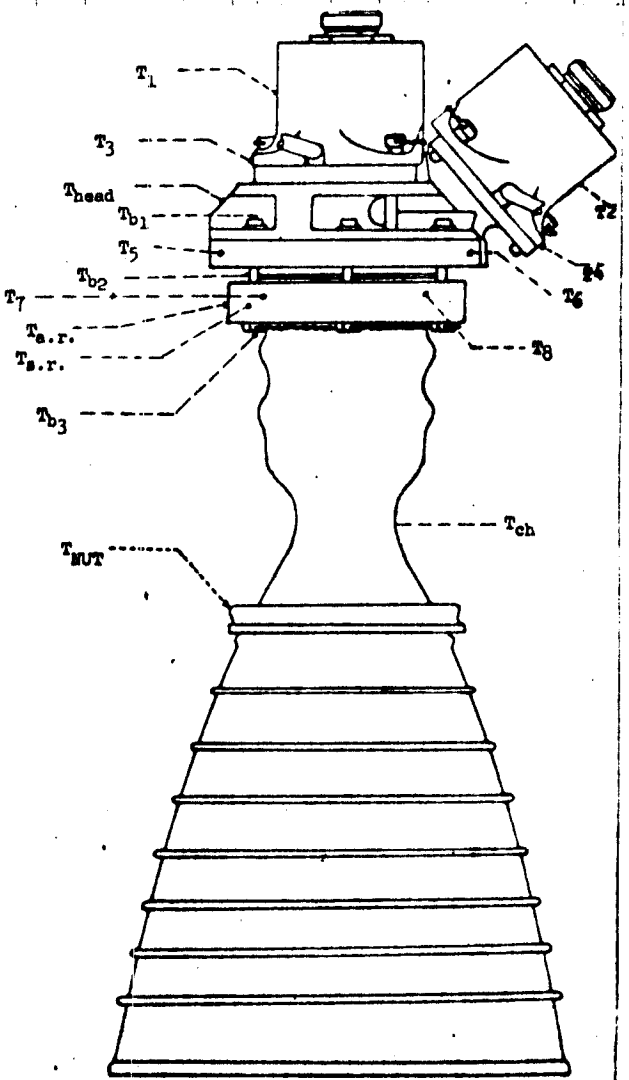
20

0

0 10 20 30 40 50 60 70 80 90 100 0 1 2 3 4 5 6 7 8 9 10 11 12

RUN TIME ~ SECONDS

SOAKBACK TIME ~ MINUTES



TMCA-327

PREPARED BY EVA DAWSON

CHECKED BY

A-25

DATE 4-4-66

THE Marquardt CORPORATION

ENGINE P/N 13768-/N0001-1
TEST NO: 3401 DATE: 3-18-66
CELL: ATL-"D" RUN NO. 1305
CONTROL FIREWALL T/C

SYMBOL	T/C
◇	5
□	6
○	7
△	8

DATA @ 30 SEC
W/F = .1088
W/OX = 2.398
W/P = .3481
O/F = 2.198
PC% = 88.1

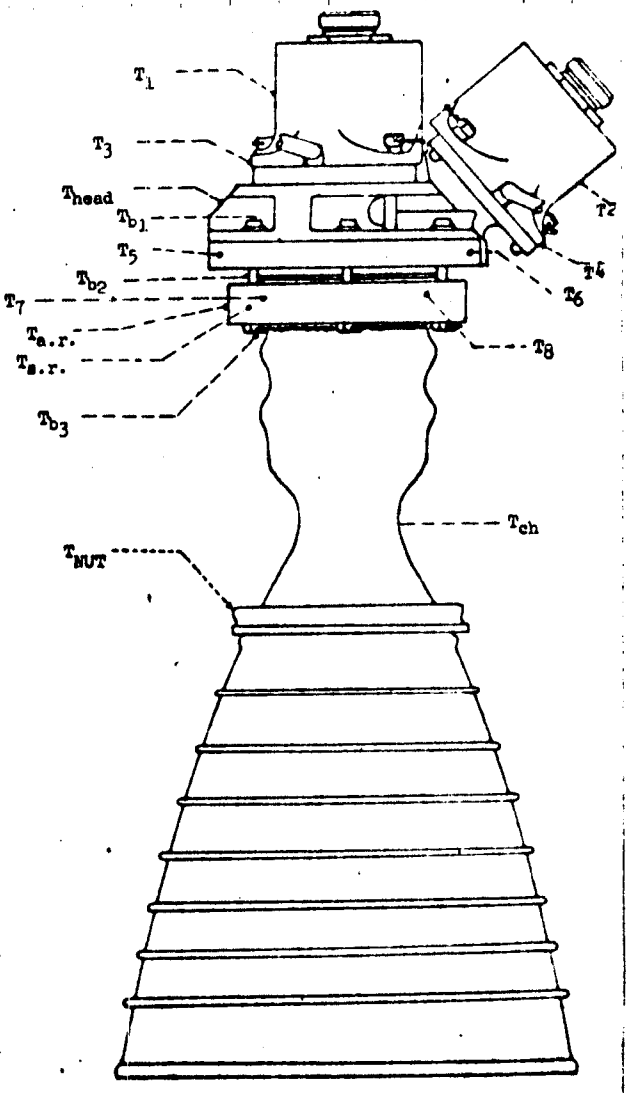
TEMPERATURE ~ °F

0 100 200 300 400 500 600 700 800

0 10 20 30 40 50 60 70 80 90 100 0 1 2 3 4 5 6 7 8 9 10 11 12

RUN TIME ~ SECONDS

SOAKBACK TIME ~ MINUTES



PREPARED BY EVA DAWSON

CHECKED BY

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DATE 4-4-66

THE Marquardt CORPORATION

ENGINE P/N 13768 S/N 0001-1
TEST NO. 3401 DATE: 3-18-66
CELL: AIL-"D" RUN NO. 130 #
CONTROL THRUST CHAMBER

SYMBOL	T/C
◇	5
□	6
○	7
△	8

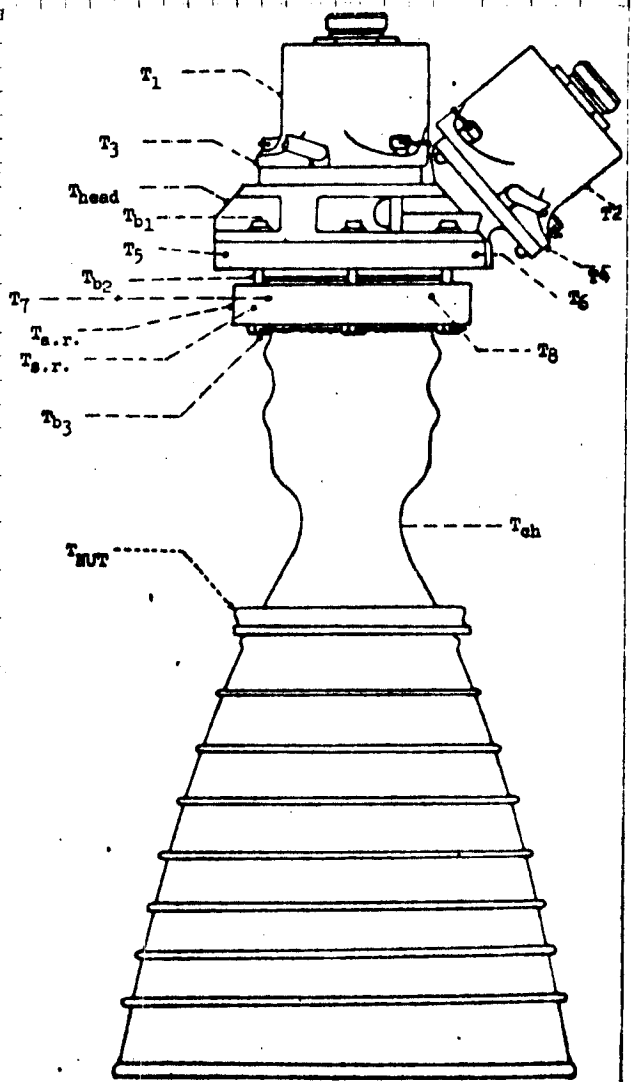
DATA @ 30 sec	
$\dot{W}_{ox}$ =	1.206
$\dot{W}_{max}$ =	1.206
$\dot{W}_{fa}$ =	.8507
O/F =	1.983
P_{CH} =	23.6

TEMPERATURE - °F

800
700
600
500
400
300
200
100
0

0 10 20 30 40 50 60 70 80 90 100 0 1 2 3 4 5 6 7 8 9 10 11 12

RUN TIME - SECONDS | SOAKBACK TIME - MINUTES



TMCA-327

KOS 10 X 10 TO THE CENTIMETER 47 1517
KEUFFEL & ESSER CO.

PREPARED BY EVA DAWSON

CHECKED BY

PAGE A-27

DATE 4-4-66

THE Marquardt CORPORATION

SYMBOL T/C

5

6

7

8

ENGINE P/N 13768-/N0001-1
TEST NO. 3401 DATE: 3-18-66
CELL: ATL "D" RUN NO. 1307
CONTROL THRUST

DATA @ 80 SEC.
$\dot{W}_F$ = .1261
$\dot{W}_{OX}$ = .2781
$\dot{W}_A$ = .3552
O/F = 2.206
PCN = 96.8

TEMPERATURE ~ °F

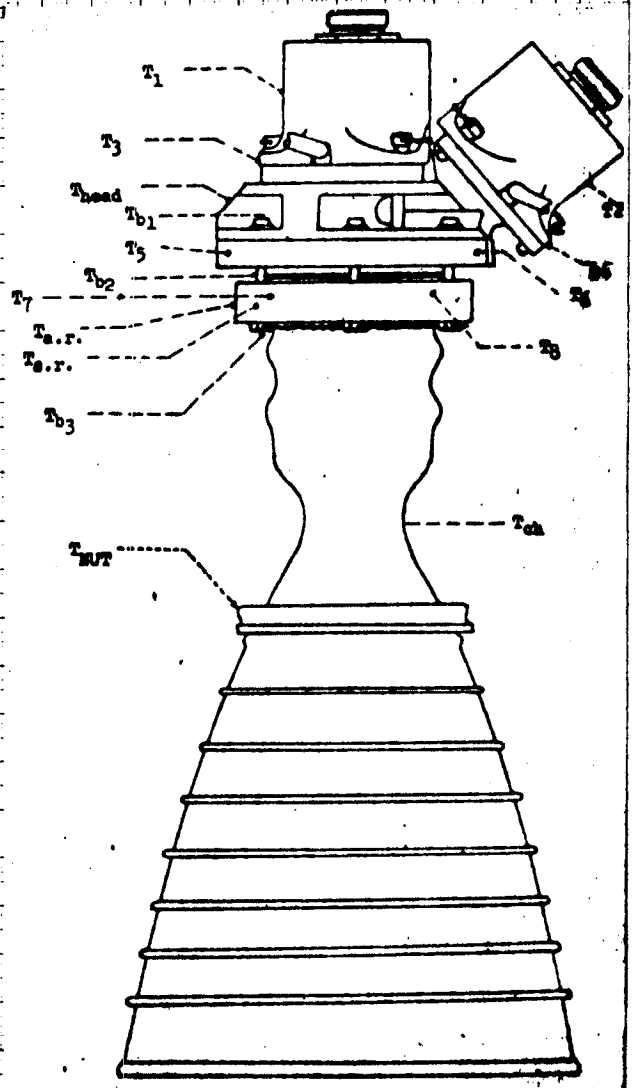
0 100 200 300 400 500 600 700 800

0 10 20 30 40 50 60 70 80 90 100

RUN TIME ~ SECONDS

0 1 2 3 4 5 6 7 8 9 10 11 12

SOAKBACK TIME ~ MINUTES



TMCA-327

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PAGE A-28

DATE 4-4-66

THE Marquardt CORPORATION

SYMBOL T/C

◇ 5

□ 6

▷ 7

△ 8

ENGINE P/N 13782 S/N 0001-1
TEST NO. 3K01 DATE: 3-18-66
CELL: ATL-"D" RUN NO. 1308
CYCLE 1

CONICAL THINWALL SEAL

DATA @ 30 SEC
ẇA = .1289
ẇOX = .2278
ẇA = .3562
OR = 1.774
PCH = 86.6

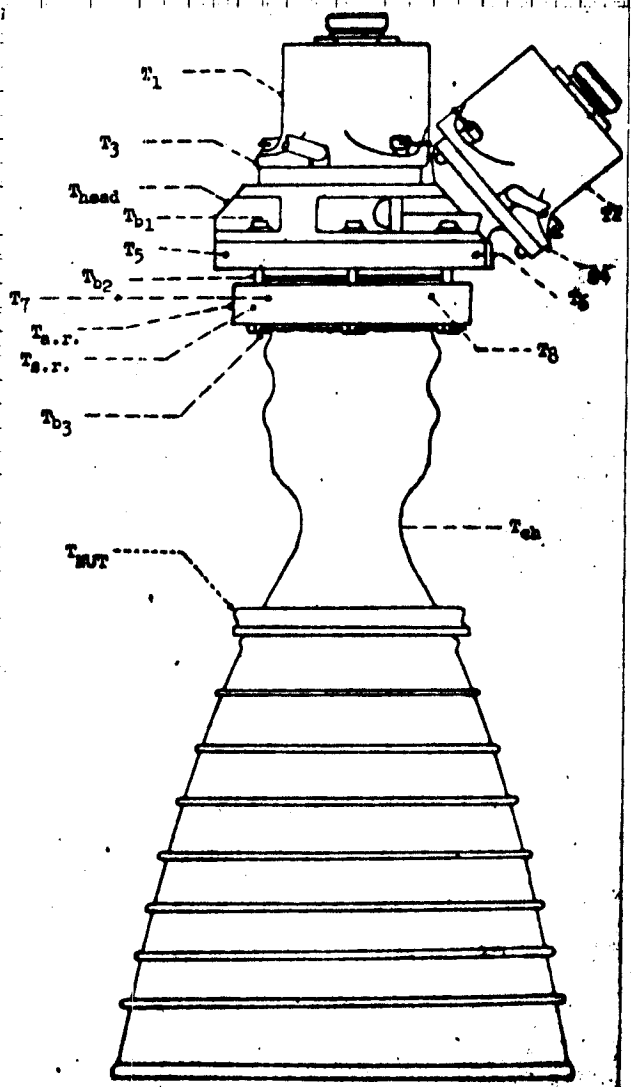
TEMPERATURE ~ °F

800
700
600
500
400
300
200
100
0

0 10 20 30 40 50 60 70 80 90 100 0 1 2 3 4 5 6 7 8 9 10 11 12

RUN TIME ~ SECONDS

SOAKBACK TIME ~ MINUTES



THE Marquardt CORPORATION

SYMBOL T/C
◇ 5
□ 6
○ 7
△ 8

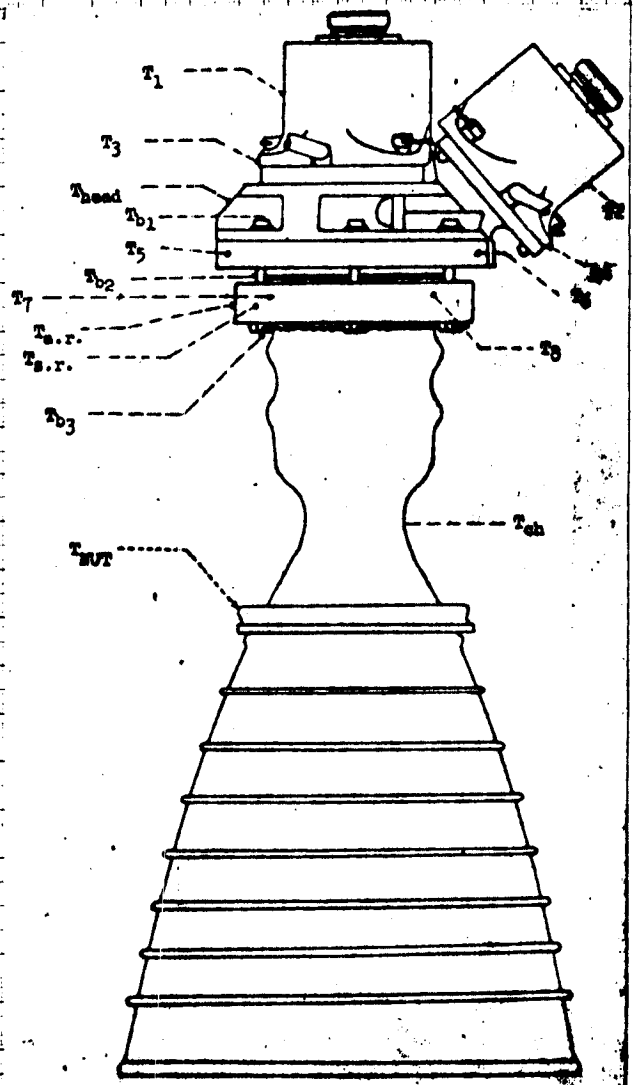
ENGINE P/N 19768 S/N 0001-1
TEST NO. 3402 DATE: 3-18-66
CELL: ATL-"D" RUN NO. 1308
CYCLE 2

TEMPERATURE ~ °F

800
700
600
500
400
300
200
100
0

0 10 20 30 40 50 60 70 80 90 100 0 1 2 3 4 5 6 7 8 9 10 11 12

RUN TIME - SECONDS | SOAKBACK TIME ~ MINUTES



TMCA-327

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DATE 4-4-66

SYMBOL T/C

◇ 5

○ 6

□ 7

△ 8

ENGINE P/N A37685/N 0001-1
TEST NO: 3401 DATE: 3-18-66
CELL: ATL-"D" RUN NO. 1308
CYCLE 3

CONICAL THRUST CHAMBER

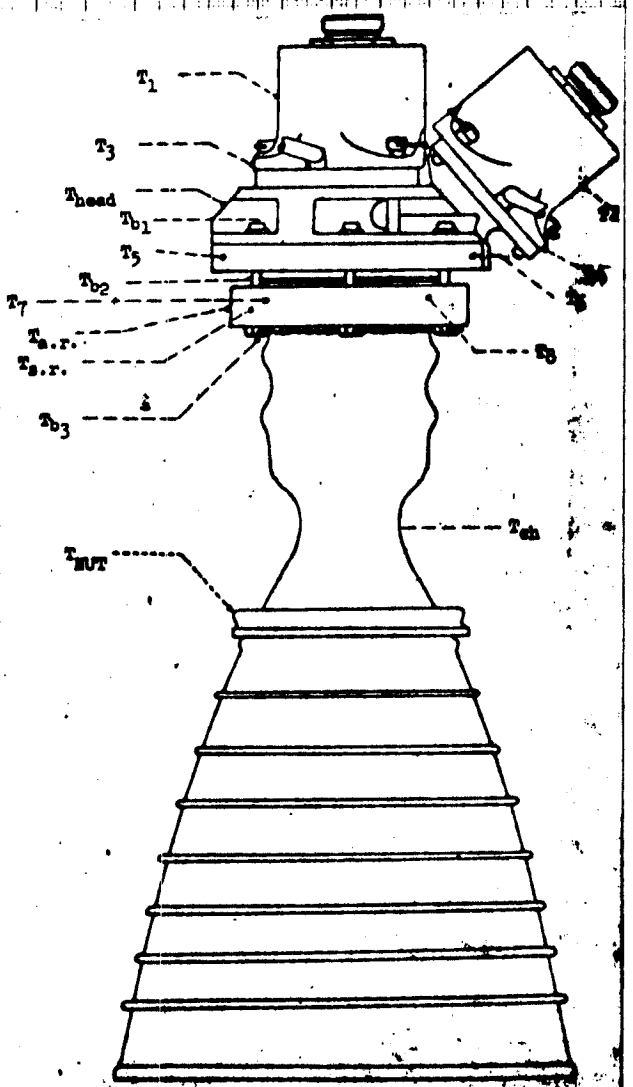
$\dot{W}_F$ =	1.274
$\dot{W}_{OX}$ =	32.70
$\dot{W}_A$ =	3.584
O/F =	1.784
PCH =	286.0

TEMPERATURE ~ °F

800
700
600
500
400
300
200
100
0

0 10 20 30 40 50 60 70 80 90 100 0 1 2 3 4 5 6 7 8 9 10 11 12

RUN TIME ~ SECONDS | SOAKBACK TIME ~ MINUTES



THE Marquardt CORPORATION

TMCA-327

K+E 10 X 10 TO THE CENTIMETER 47 1517
KEUFFEL & ESSER CO

PREPARED BY EVA DAWSON

CHECKED BY

DATE

THE Marquardt CORPORATION

SYMBOL T/C
T=NUT
T=SCOPE (LESS THAN) 1800°F

ENGINE P/N: 123405/N: 0001-7
TEST NO: 3403 DATE: 3-24-66
CELL: ATL-D RUN NO. 1936

Data @ 20 sec
Min = .1440
Max = .2400
Min = .1848
Max = .2280
Ave = .220

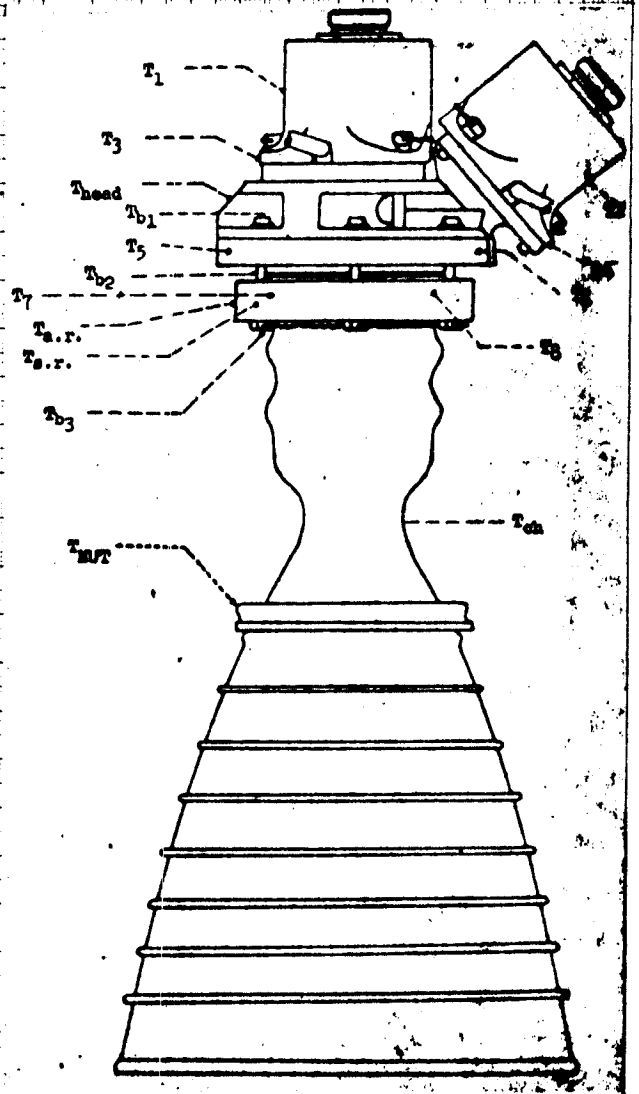
TEMPERATURE - °F

0 10 20 30 40 50 60 70 80 90 100

RUN TIME - SECONDS

0 1 2 3 4 5 6 7 8 9 10 11 12

SOAKBACK TIME - MINUTES



TMCA-327

K&E 10 X 10 TO THE CENTIMETER 47 1517
KEUFFEL & ESSER CO

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DATE

THE Marquardt CORPORATION

SYMBOL T/C
⊙ T-NUT
◇ T-SCOPE

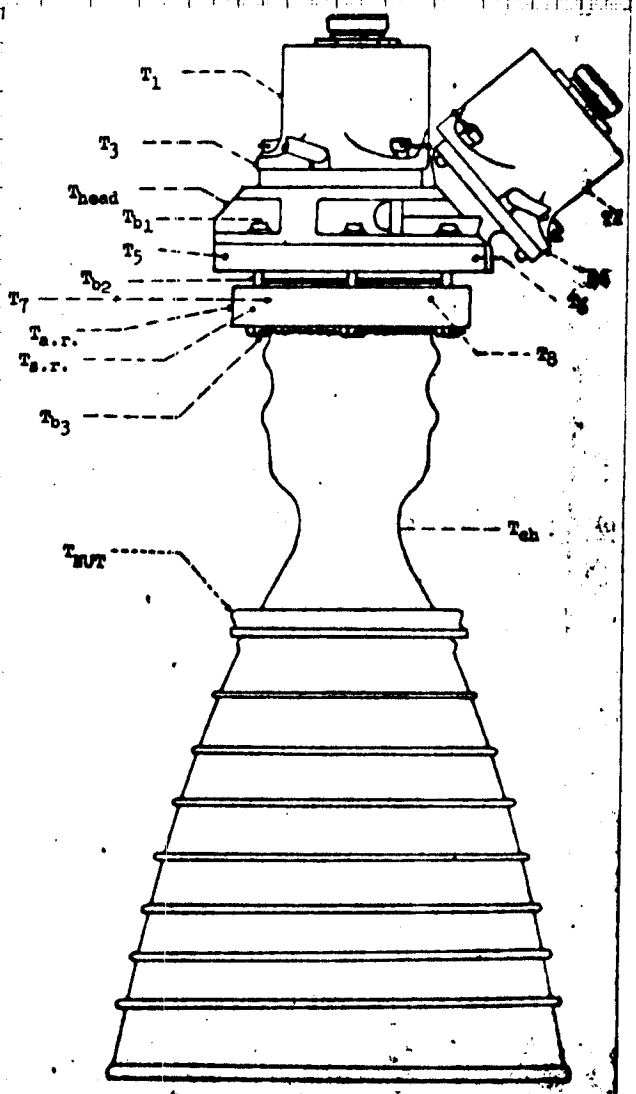
ENGINE P/N: 12340S/N: 0001-7
TEST NO: 3403 DATE: 3-24-66
CELL: ATL-"D" RUN NO. 1398

DATA @ 20 SEC
BA = 1789
NOZ = 1210
THR = 78.5
MR = 2.408
PCN = 85.5

TEMPERATURE - °F

RUN TIME - SECONDS

SOAKBACK TIME - MINUTES



TMCA-327

K+E 10 X 10 TO THE CENTIMETER 47 1517
KEUFFEL & ESSER CO.

SYMBOL [illegible]
[illegible]NUT
[illegible]-SCOPE

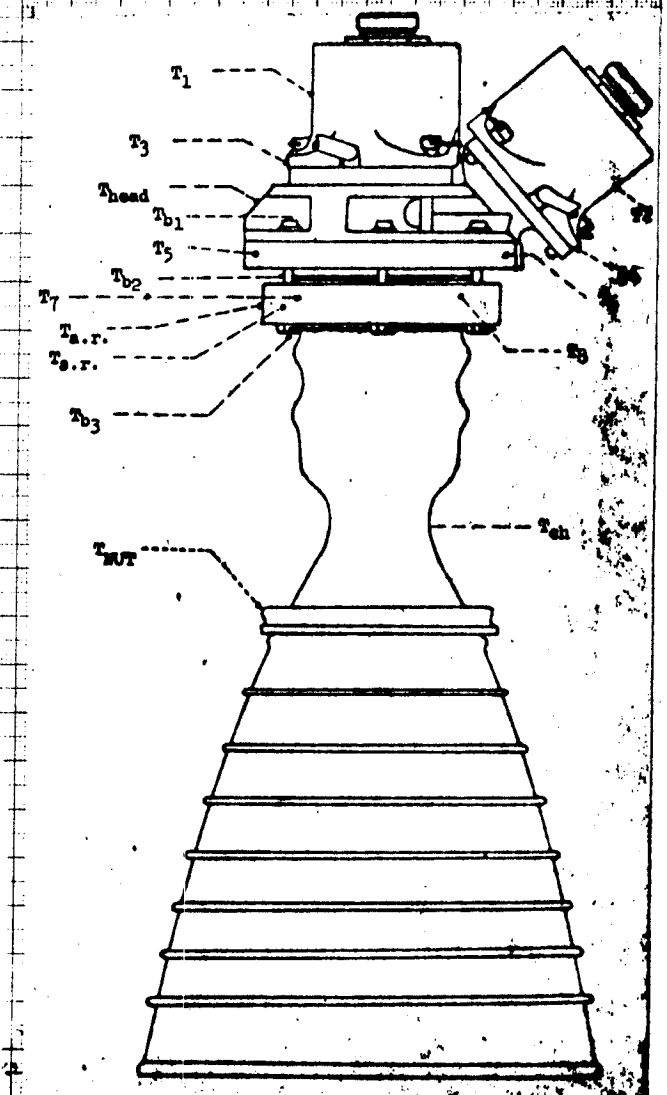
BASE @ 30 SEC.
W.E. .2287
Bal. .2301
ΔBA .0628
ΔWA .0518
BCA 92.7

ENGINE P/N 12340-/N0001-7
TEST NO: 3403 DATE: 8-24-62
CELL: ATL -D RUN NO: 1340
CO[illegible]

TEMPERATURE °F

RUN TIME - SECONDS

SOAKBACK TIME - MINUTES



THE Marquardt CORPORATION
K&E 10 X 10 TO THE CENTIMETER 47 1517
KEUFFEL & ESSER CO
TMCA-527

PREPARED BY: EVA DAWSON

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PAGE 1

DATE 4-4-66

SYMBOL T/C

○ T NUT

◇ T SCOPE

ENGINE P/N 1234 S/N 0001-7

TEST NO. 3403 DATE: 3-24-66

CELL: ATL-D RUN NO. 1344

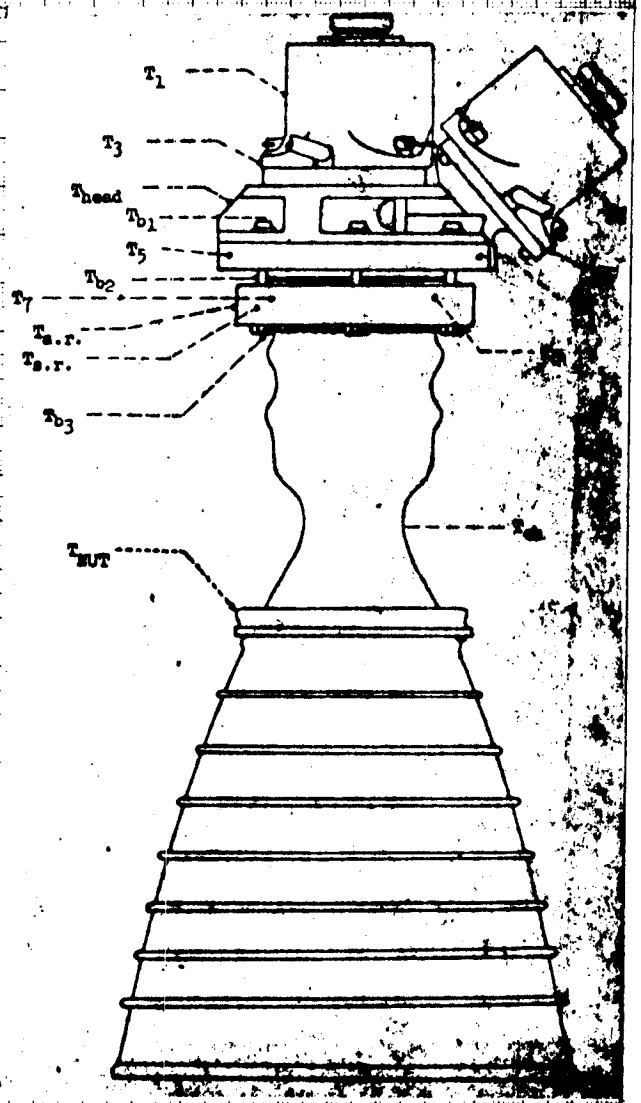
CYCLE 1

Data @ 20 SEC	
GHF=	1296
Wox=	2.34#
MR=	36/1#
O/F=	1.788
Pc=	912

TEMPERATURE - °F

RUN TIME - SECONDS

SOAKBACK TIME - MINUTES



THE Marquardt CORPORATION

TMCA-327

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THE Marquardt CORPORATION

SYMBOL T°C

⊙ T NUT

◇ T SCOPE

ENGINE P/N 123406-S/N 0001-7

TEST NO. 3403 DATE: 3-24-66

CELL: ATL "D" RUN NO. 1364

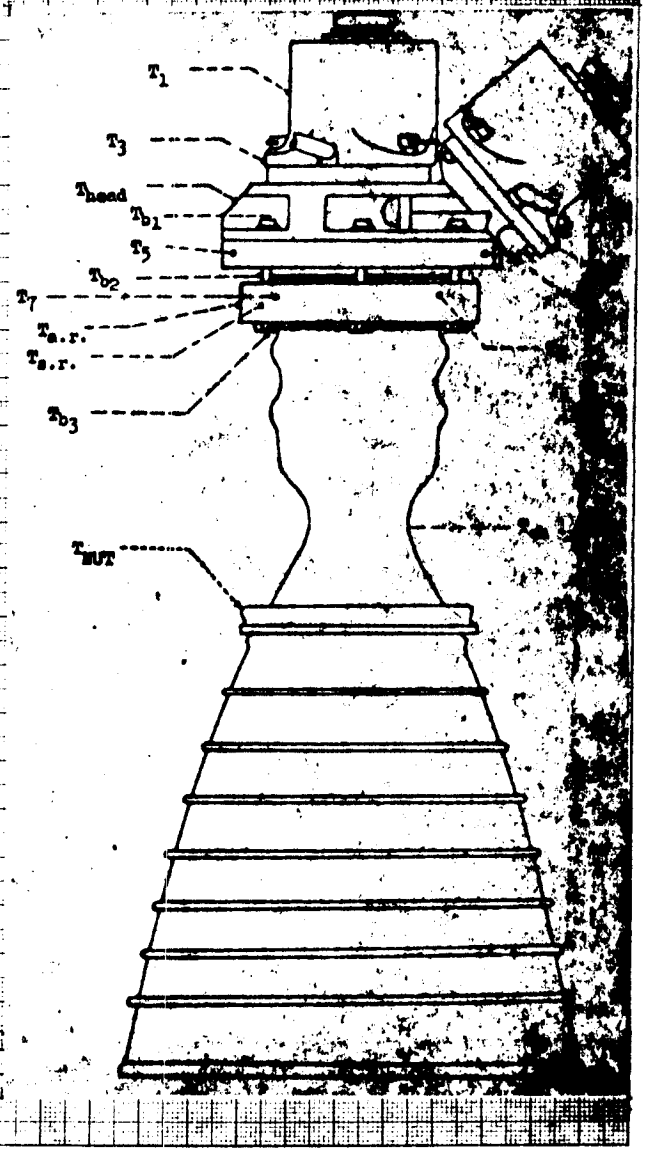
CYCLE 2

DATA @ 20 SEC	
$\dot{W}_F$ =	1286
$\dot{W}_{OX}$ =	3324
$\dot{W}_A$ =	.3870
P_{AMB} =	1.292
P_{CHM} =	825

TEMPERATURE °F

RUN TIME ~ SECONDS

SOAKBACK TIME ~ MINUTES



TMCA-327

K+E 10 X 10 TO THE CENTIMETER 47 1517
KEUFFEL & ESSER CO

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DATE

THE Marquardt CORPORATION

SYMBOL T/C
T-NUT
T SCOPE

ENGINE P/N: 12340 S/N 0001-7
TEST NO: 3403 DATE: 3-24-66
CELL: ATL "D" RUN NO. 13#4
CYCLE 3

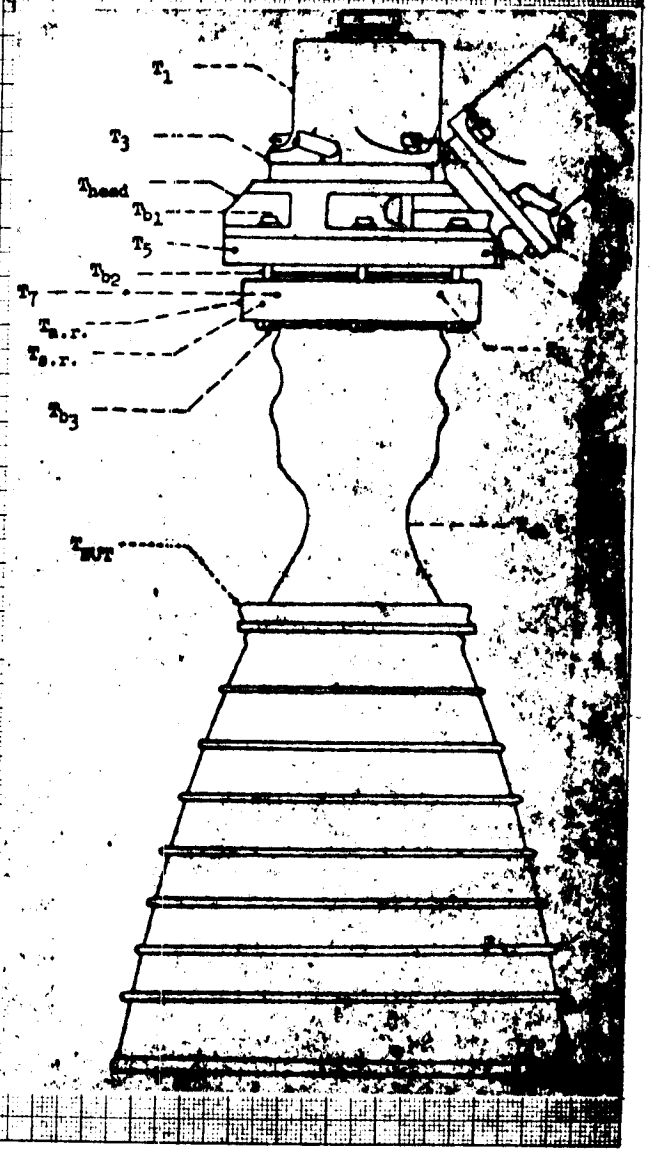
COMPLETE CYCL

DATA @ .01 SEC
T_{NT} = 1128°F
T_{SCOPE} = 1315°F
$T_{T/C}$ = 1268°F
$\Delta T_{T/C}$ = 47°F
P_{CH} = 327 psia

TEMPERATURE °F

RUN TIME — SECONDS

SOAKBACK TIME — MINUTES



TMCA-327

K&E 10 X 10 TO THE CENTIMETER 47 1517
25 X 25 CM. ALBANENE
KEUFFEL & ESSER CO

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PAGE 1 of 7

DATE 4-5-66

THE Marquardt CORPORATION

ENGINE P/N: 1234-5/H/0001-7
TEST NO: 3403 DATE: 3-24-66
CELL: ATL "D" RUN NO. 1336

SYMBOL	T/C
◇	T HEAD
○	T B1
□	T B2
△	T B3
▽	T NOZ.
◁	T S.B.

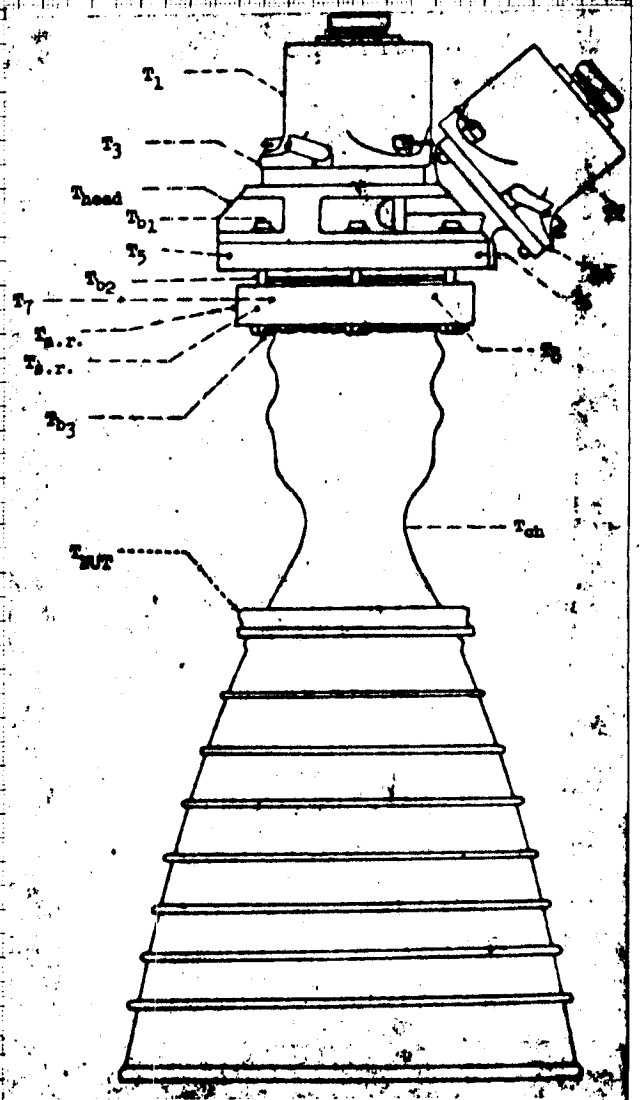
PARAM @ 90 SEC
O/F = .660
MFW = .3787
MF = .3848
PCC = 7.208
MCC = 5.150

TEMPERATURE - °F

500 400 300 200 100

0 10 20 30 40 50 60 70 80 90 100 0 1 2 3 4 5 6 7 8 9 10 11 12

RUN TIME - SECONDS SOAKBACK TIME - MINUTES



TMCA-327

K+E 10 X 10 TO THE CENTIMETER 47 1517
KEUFFEL & ESSER CO.

PREPARED BY EVAN DAWSON

CHECKED BY

PAGE 1

DATE

THE Marquardt CORPORATION

SYMBOL	T/C
◇	T-HEAD
◇	T01
□	T02
◁	T03
△	T.A.R.
▷	T.S.R.

ENGINE P/N: 123405/W0001-7
TEST NO: 3409 DATE: 3-24-66
CELL: ATL-"D" RUN NO. 1397

DATA @ 36 SEC	
MIF:	.1209
MOF:	.2430
MR:	.3639
OAP:	2.909
PCA:	95.4

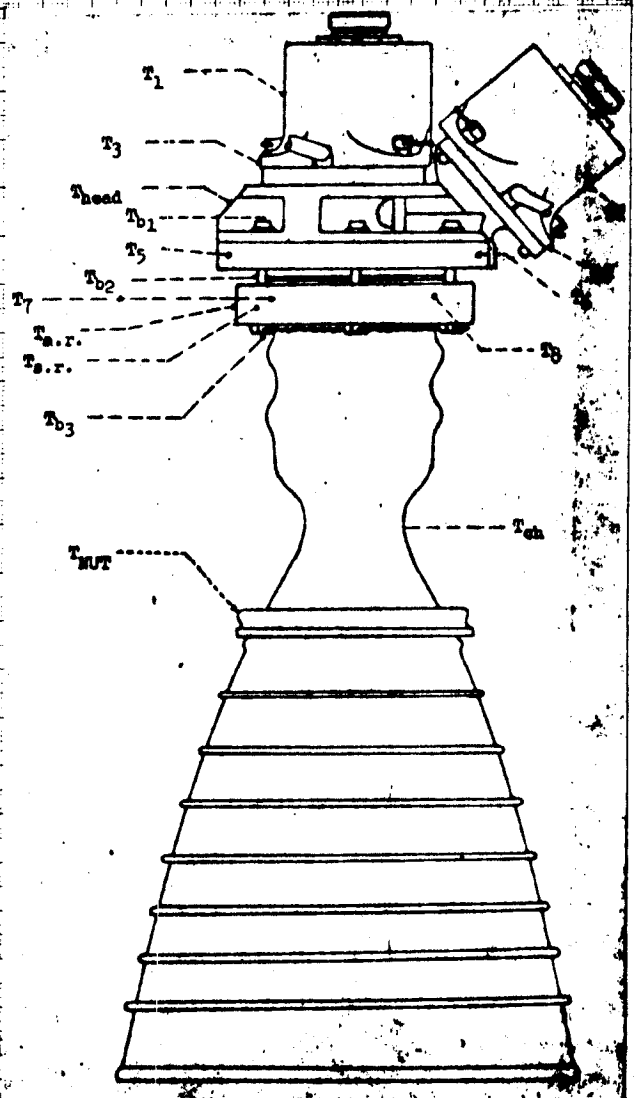
TEMPERATURE - °F

800 700 600 500 400 300 200 100

0 10 20 30 40 50 60 70 80 90 100 0 1 2 3 4 5 6 7 8 9 10 11 12

RUN TIME - SECONDS

SOAKBACK TIME - MINUTES



TMCA-327

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DATE

THE Marquardt CORPORATION

SYMBOL	T/C
◇	F-HEAD
◇	T01
○	T02
△	T03
△	T AIR
□	T SC

ENGINE P/N: 123456/N0001-T
TEST NO: 3#09 DATE: 3-24-62
CELL: ATL-"D" RUN NO. 1340

Chan #	10 sec
MAT =	1383
Noz =	2981
Mid =	3632
Dif =	1.848
Acc =	99.7

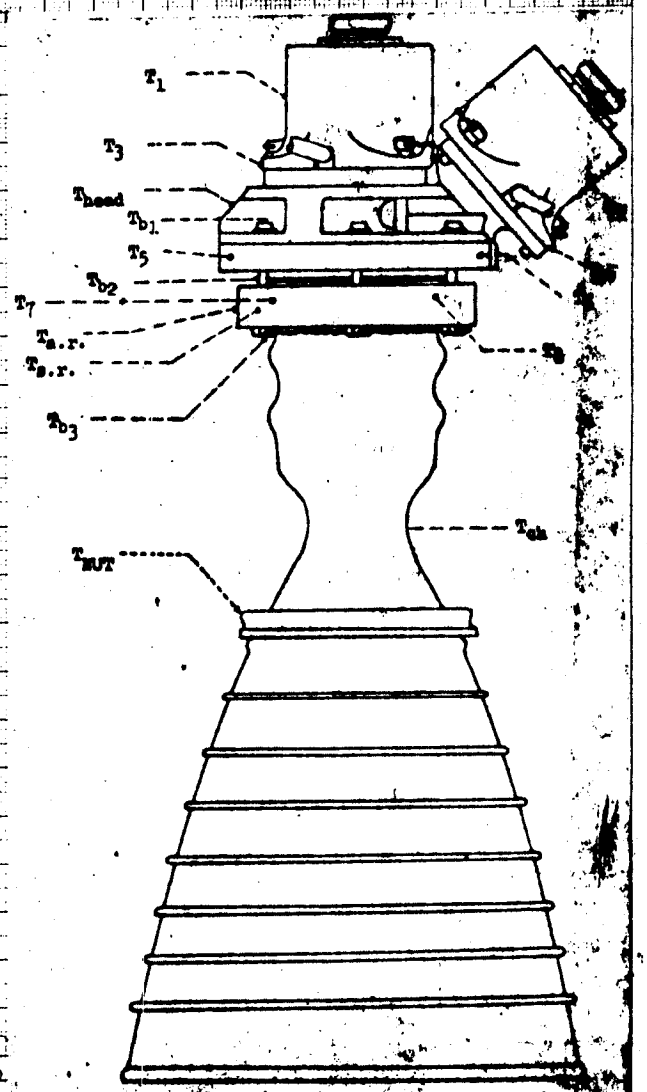
TEMPERATURE ~ °F

800
700
600
500
400
300
200
100

0 10 20 30 40 50 60 70 80 90 100 0 1 2 3 4 5 6 7 8 9 10 11 12

RUN TIME ~ SECONDS

SOAKBACK TIME ~ MINUTES



TMCA-327

K&E 10 X 10 TO THE CENTIMETER 47 1517
KEUFFEL & ESSER CO.

PREPARED BY Eva Dawson

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DATE

THE Marquardt CORPORATION

SYMBOL T/C
- ◇ T=HEAD
- ○ TB1
- △ TB2
- □ TB3
- I AR
- I S.R

ENGINE P/N 103#0 S/N 0001-7
TEST NO: 3#03 DATE: 3-24-66
CELL: ATL-"D" RUN NO. 13#4
Cycle #1

TEMPERATURE ~ °F

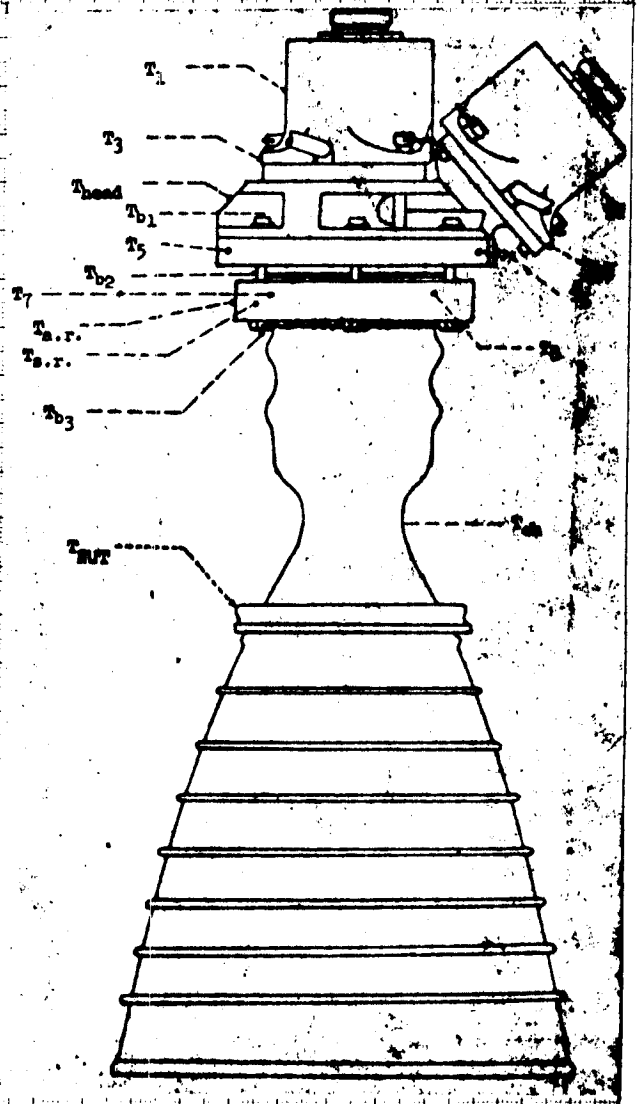
100 200 300 400 500 600 700 800

0 10 20 30 40 50 60 70 80 90 100

RUN TIME ~ SECONDS

0 1 2 3 4 5 6 7 8 9 10 11 12

SOAKBACK TIME ~ MINUTES



TMCA-327

K+E 10 X 10 TO THE CENTIMETER 47 1517
REUFFEL & ESSER CO.

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DATE

SYMBOL : TC
- ◇ T=HEAD
- ○ TB1
- □ TB2
- △ TB3
- ▽ T.A.P.
- ▷ T.S.R.

DATA @ 30 SEC
- ΔT = .1294
- ΔTX = .2334
- ΔTA = .86.30
- ΔTC = 1.792
- ΔTR = 92.5

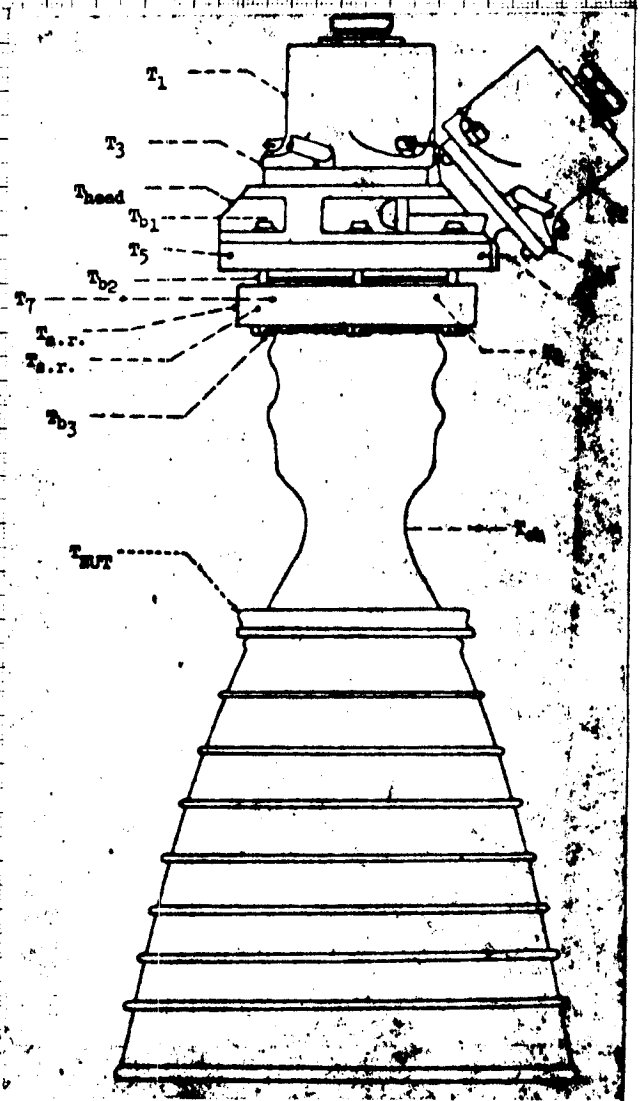
ENGINE P/N: 12340 S/N 0001-7
TEST NO: 3403 DATE: 3-24-66
CELL: ATL-D" RUN NO. 13K4
CYCLE 2

COMBUSTION CHAMBER

TEMPERATURE ~ °F

RUN TIME ~ SECONDS

SOAKBACK TIME ~ MINUTES



THE Marquardt CORPORATION

TMCA-327

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PAGE 1

DATE

ENGINE P/N: 1234OS/N 0001-T
TEST NO: 3403 DATE: 3-24-66
CELL: AT4 "D" RUN NO. 134
CYCLE 3

SYMBOL T/C
F-HEAD
TB1
TB2
TB3
TAE.
TSR.

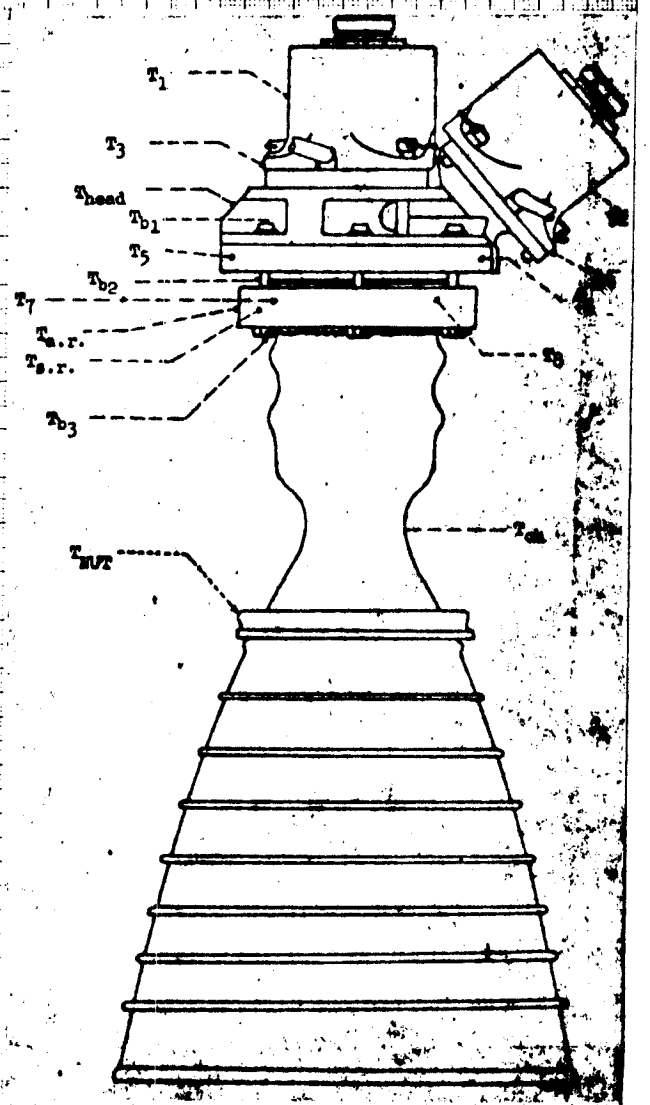
DATA @ 90 SEC.
ΔT1 = .1284
ΔTH = .2345
ΔTF = .3809
ΔTE = .1769
ΔTSR = 22.6

TEMPERATURE ~ °F

TIME ~ SECONDS

RUN TIME ~ SECONDS

SOAKBACK TIME ~ MINUTES



THE Marquardt CORPORATION

TMCA-337

PREPARED BY Judy Olson

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PAGE 1

DATE 4-5-66

THE Marquardt CORPORATION

SYMBOL T_c

ENGINE P/N 423905/N0004-2
TEST NO. 3443 DATE: 3-23-66
CELL: ATL-D RUN NO. 13196

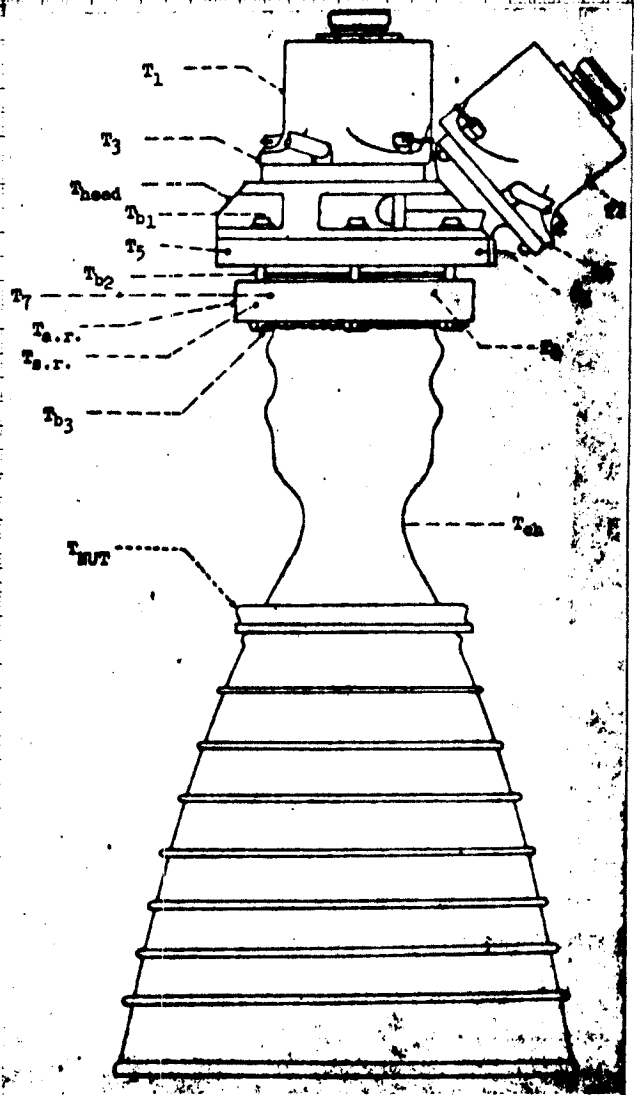
DATA @ 38 SEC	
T_{bs} =	1140
T_{MUT} =	2,508
T_{sh} =	.3647
T_{HE} =	2,900
P_{CH} =	88.0

TEMPERATURE — °F

100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500 2600 2700 2800 2900 3000 3100 3200 3300 3400 3500 3600 3700 3800 3900 4000

0 10 20 30 40 50 60 70 80 90 100 0 1 2 3 4 5 6 7 8 9 10 11 12

RUN TIME ~ SECONDS | SOAKBACK TIME ~ MINUTES



TMCA-327

K+E 10 X 10 TO THE CENTIMETER 47 1517
25 X 25 CM • ALBUMENE
KEUFFEL & ESSER CO

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ENGINE P/N 1234105/N0001-7
TEST NO: 3468 DATE: 3-22-66
CELL: 21 RUN NO. 1939

SYMBOL	
○	1
□	2
◇	3
△	4

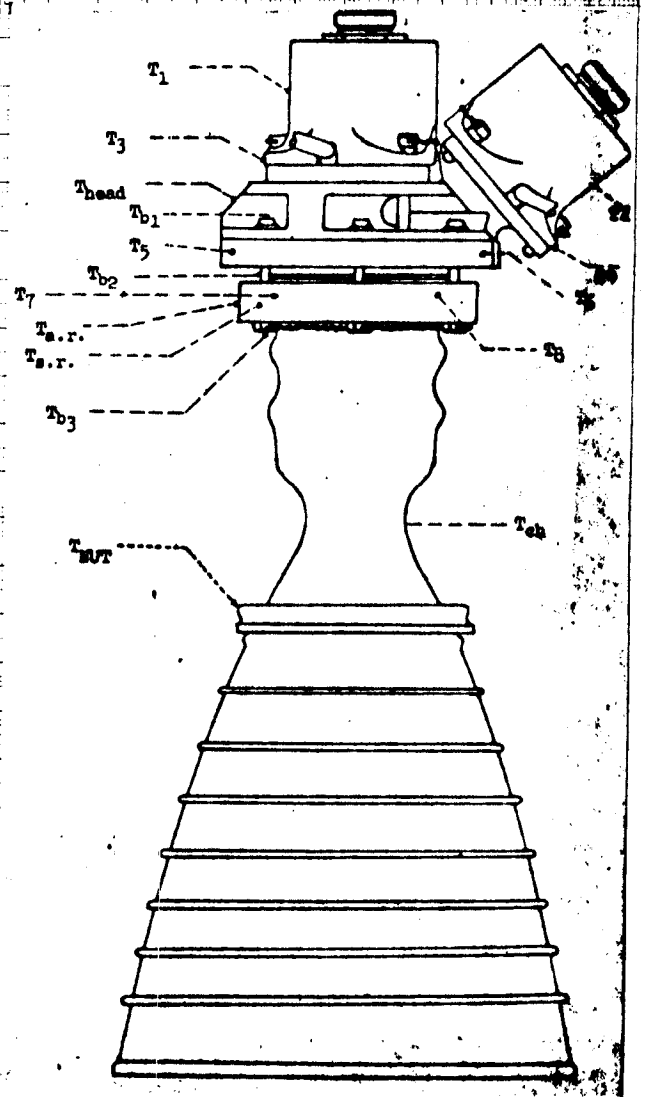
	@ 70.5°C
	1,209
	2430
	2639
	2.001
	251#

TEMPERATURE °F

0 10 20 30 40 50 60 70 80 90 100

0 1 2 3 4 5 6 7 8 9 10 11 12

RUN TIME ~ SECONDS | SOAKBACK TIME ~ MINUTES



THE Marquardt CORPORATION

K-E 10 X 10 TO THE CENTIMETER 47 1517
KEUFFEL & ESSER CO.

TMCA-327

PREPARED BY: Judy Olson

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SYMBOL

○	1
□	2
◇	3
△	K

DATA @ 30 SEC	
T_{b1} =	1287
T_{b2} =	2341
T_{b3} =	3628
T_{MFT} =	1818
T_{MA} =	922.2

ENGINE P/N 2305/N 0001-1

TEST NO. 3403 DATE 3-23-66

CELL 22-A RUN NO. 1940

TEMPERATURE - °F

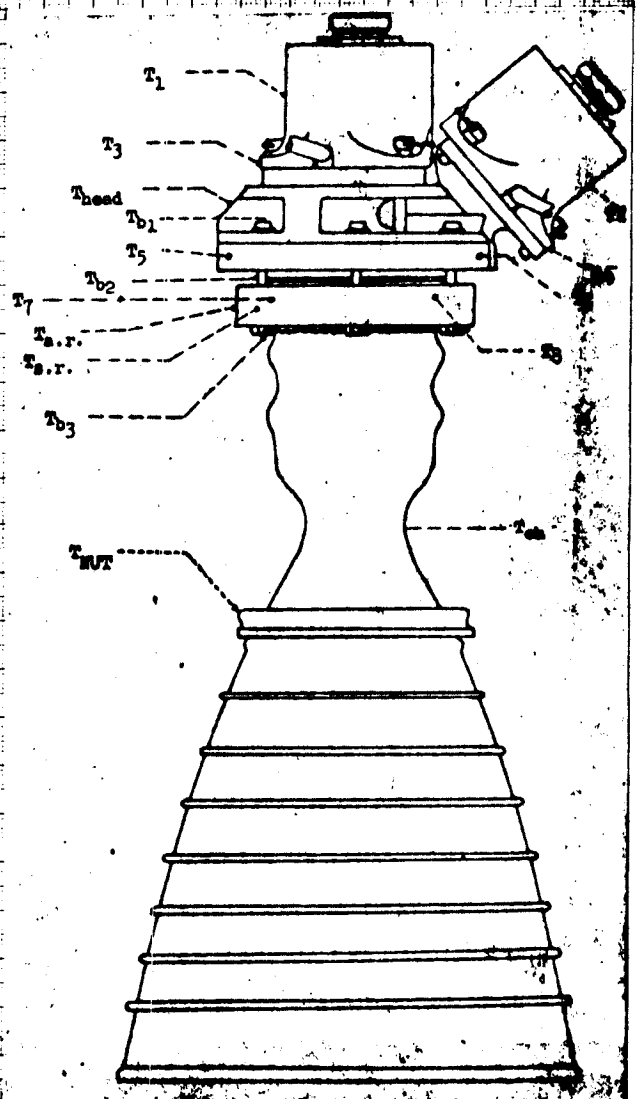
100 200 300 400 500 600 700 800 900 1000

0 10 20 30 40 50 60 70 80 90 100

RUN TIME - SECONDS

0 1 2 3 4 5 6 7 8 9 10 11 12

SOAKBACK TIME - MINUTES



THE Marquardt CORPORATION

K&E 10 X 10 TO THE CENTIMETER 47 1517

KEUFFEL & ESSER CO.

TMCA-327

PREPARED BY: Judy Olson

CHECKED BY:

PAGE 6-66

DATE 4-6-66

THE Marquardt CORPORATION

SYMBOL | T/C
○ | 1
□ | 2
◇ | 3
△ | 4

DATA @ 20 SEC	
P_{LF} =	1295
W_{OX} =	2318
ΔP =	1364
O/F =	1.788
P_{CH} =	922

ENGINE P/N 102340 S/N 0001-2
TEST NO: 3403 DATE: 3-23-66
CELL: 2PL-20 RUN NO. 13477
CYCLE 1

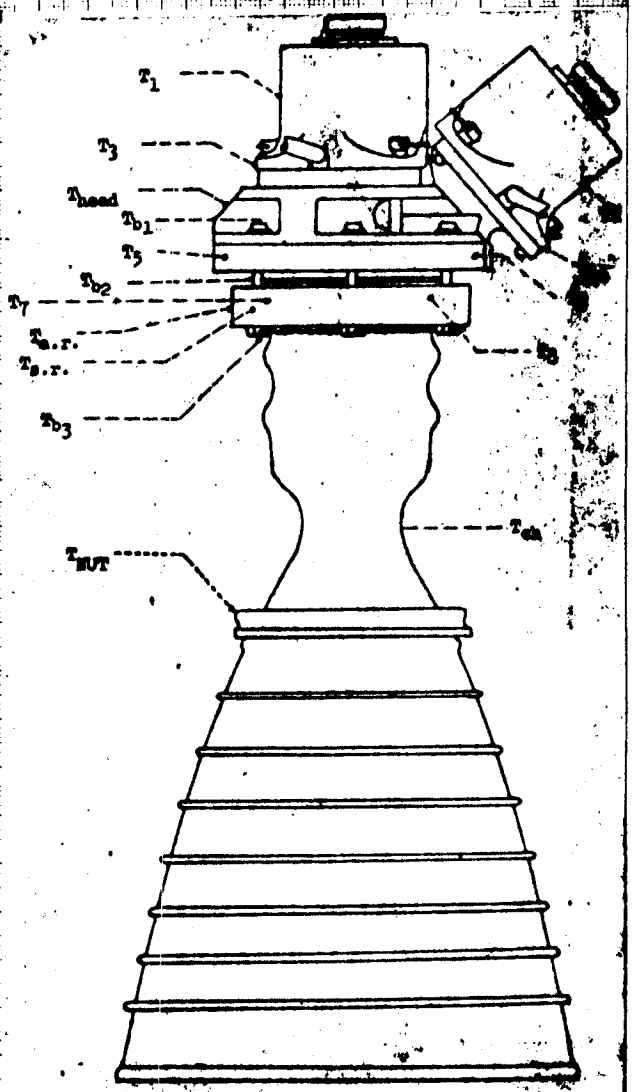
CONTROL TEST

TEMPERATURE ~ °F

100 120 140 60 40 20 0

0 10 20 30 40 50 60 70 80 90 100 | 0 1 2 3 4 5 6 7 8 9 10 11 12

RUN TIME ~ SECONDS | SOAKBACK TIME ~ MINUTES



KOS 10 X 10 TO THE CENTIMETER 47 1517
25 X ... CM ALBANY
REUFFEL & ESSER CO.

TMCA-327

PREPARED BY Judy Olson

CHECKED BY

PAGE 4

DATE 4-6-66

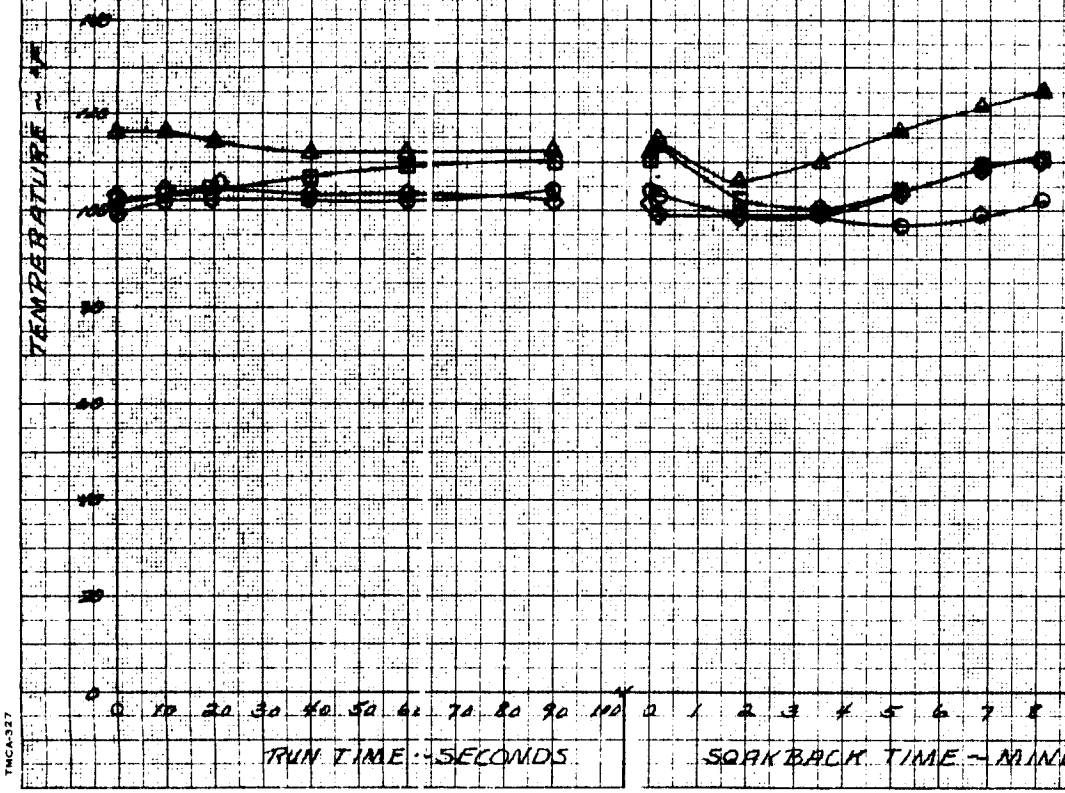
THE Marquardt CORPORATION

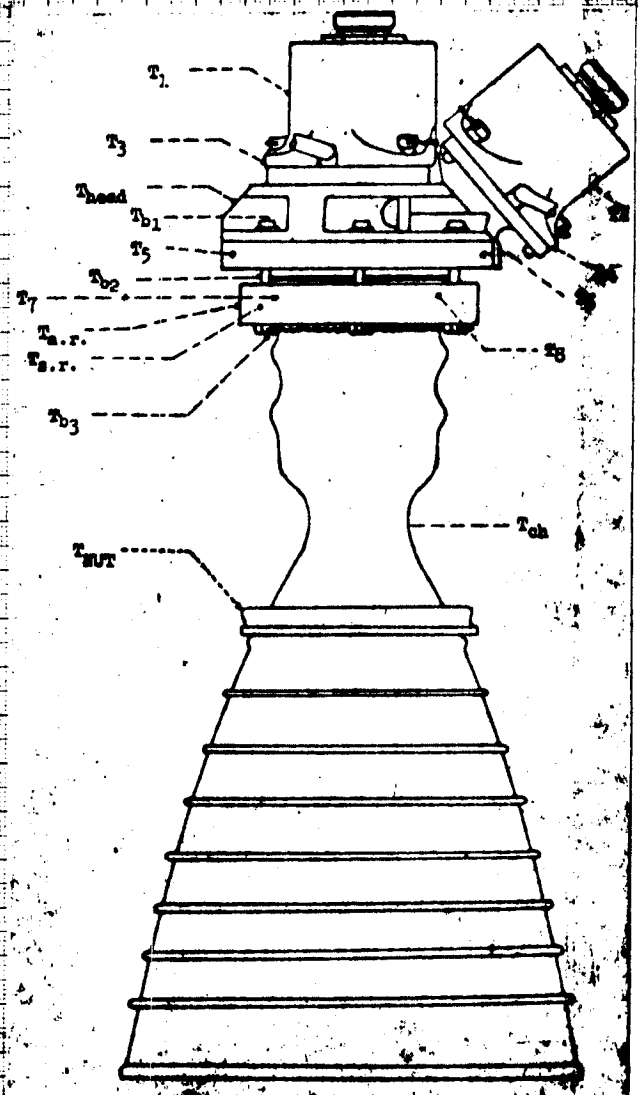
K&E 10 X 10 TO THE CENTIMETER 47 1517
KEUFFEL & ESSER CO

ENGINE P/N 1123405/W 0001-2
TEST NO. 3009 DATE: 3-23-66
CELL: RTK-2 RUN NO. 13KK
CYCLE 2

SYMBOL T/C
○ 1
□ 2
◇ 3
△ 4

DATA @ 90 SEC
T_{b1} = 1296
T_{b2} = 2732
T_{b3} = 3430
T_{oh} = 1798
T_{MT} = 825





TMCA-327

PREPARED BY: Judy Ulsen

CHECKED BY:

PAGE A-43

DATE 4-6-66

THE Marquardt CORPORATION

SYMBOL | TC
○ | 1
□ | 2
◇ | 3
△ | 4

DATA @ SAT
WF = .12797
WOX = .23215
WF = .3609
OF = 1.782
MR = 5.556

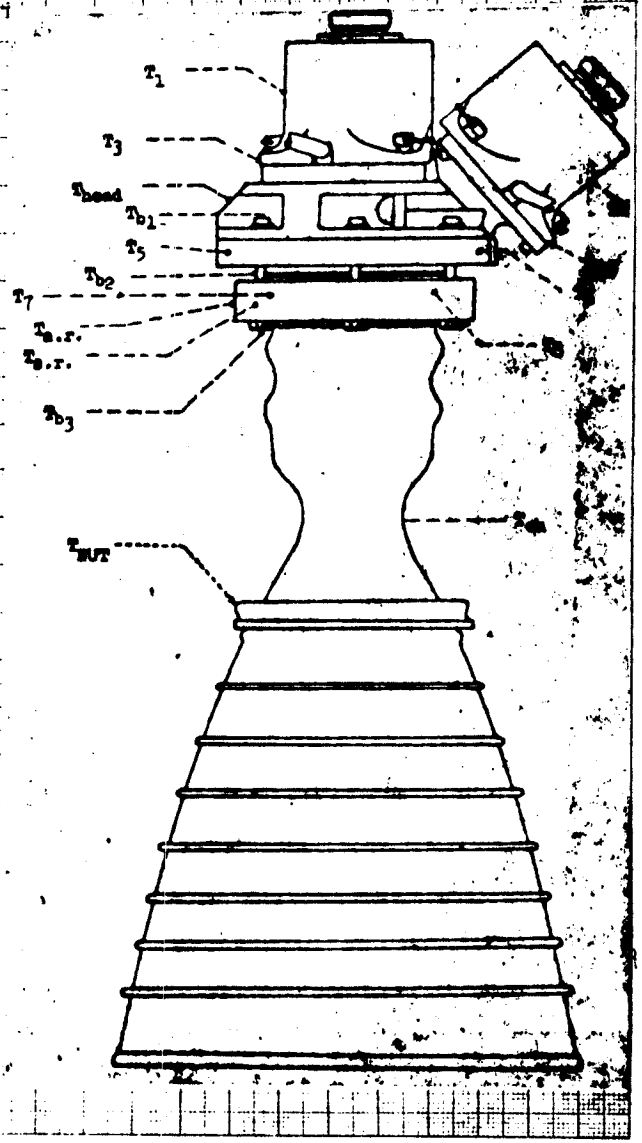
ENGINE PIN 11230 S/N 0001-7
TEST NO: PW-3 DATE: 3-25-66
CELL: AFX-2 RUN NO. 12378
CYCLE 3

C.N

TEMPERATURE - °F

RUN TIME - SECONDS

SOAKBACK TIME - MINUTES



K-E 10 X 10 TO THE CENTIMETER 47 1517

TMCA-327

PREPARED BY Judy Olson

CHECKED BY

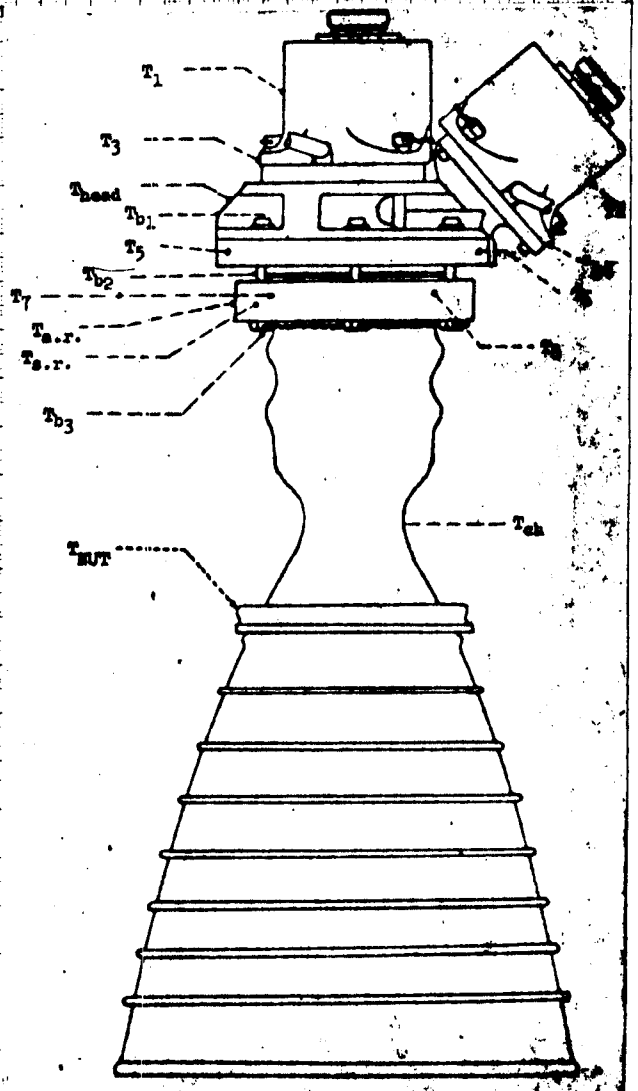
PAGE 1 of 2

DATE 4-4-66

THE Marquardt CORPORATION

SYMBOL	T/C
○	5
□	6
◇	7
△	8

ENGINE P/N TV2-2MS/N 0001-7
TEST NO. 3403 DATE: 3-23-66
CELL: 22-2 RUN NO. 4326
DM



TIME BEFORE IGNITION

RUN TIME - SECONDS

SOAKBACK TIME - MINUTES

TMCA-327

PREPARED BY: Judy Alston

CHECKED BY:

PAGE

DATE: 4-8-66

THE Marquardt CORPORATION

SYMBOL	T/C
○	5
□	6
◇	7
△	8

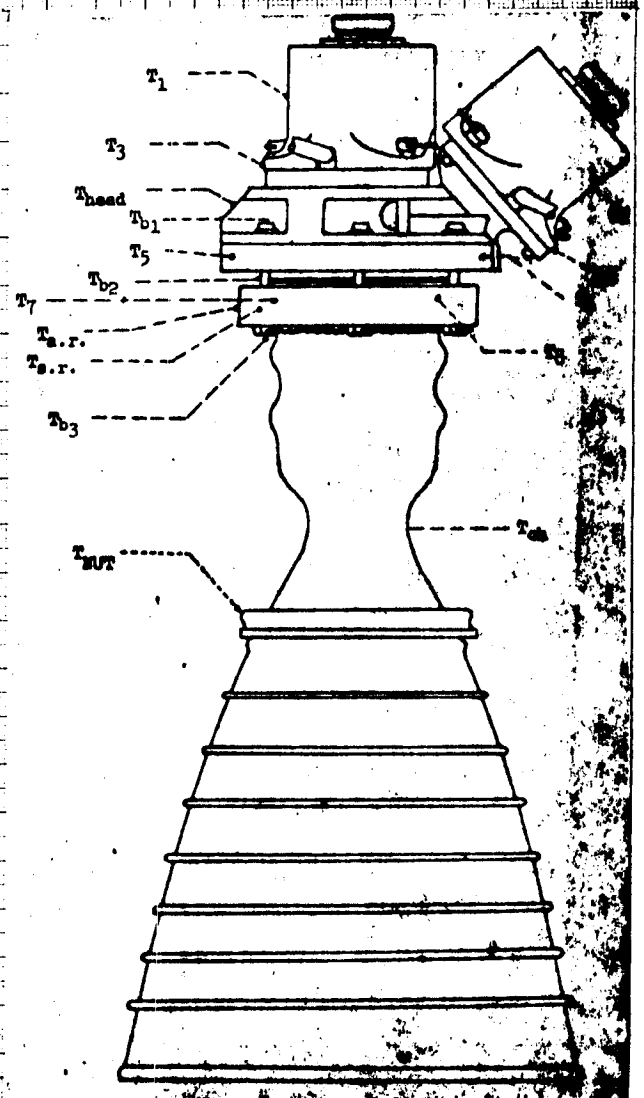
ENGINE P/N 1223405-1/W0001-7
TEST NO: 3903 DATE: 3-28-66
CELL: ATL-20 RUN NO. 1939

DATA @ 30 SEC
$\dot{W}_F$ = .1209
$\dot{W}_{OX}$ = 2.230
$\dot{W}_P$ = 3.639
OF = 2.009
PC = 95.4

TEMPERATURE ~ °F

0 10 20 30 40 50 60 70 80 90 100 0 1 2 3 4 5 6 7 8 9 10 11 12

RUN TIME - SECONDS | SOAKBACK TIME ~ MINUTES



TMCA-327

KOR 10 X 10 TO THE CENTIMETER 47 1517
KEUFFEL & ESSER CO

PREPARED BY Judy Olsen

CHECKED BY

PAGE 6 of 7

DATE 4-4-66

SYMBOL T/C

○
□
◇
△

Data @ 20 sec.	
$\dot{W}_F$ =	.1287
$\dot{W}_{OX}$ =	.2341
$\dot{W}_P$ =	.3628
O/F =	1.818
P_{ch} =	92.7

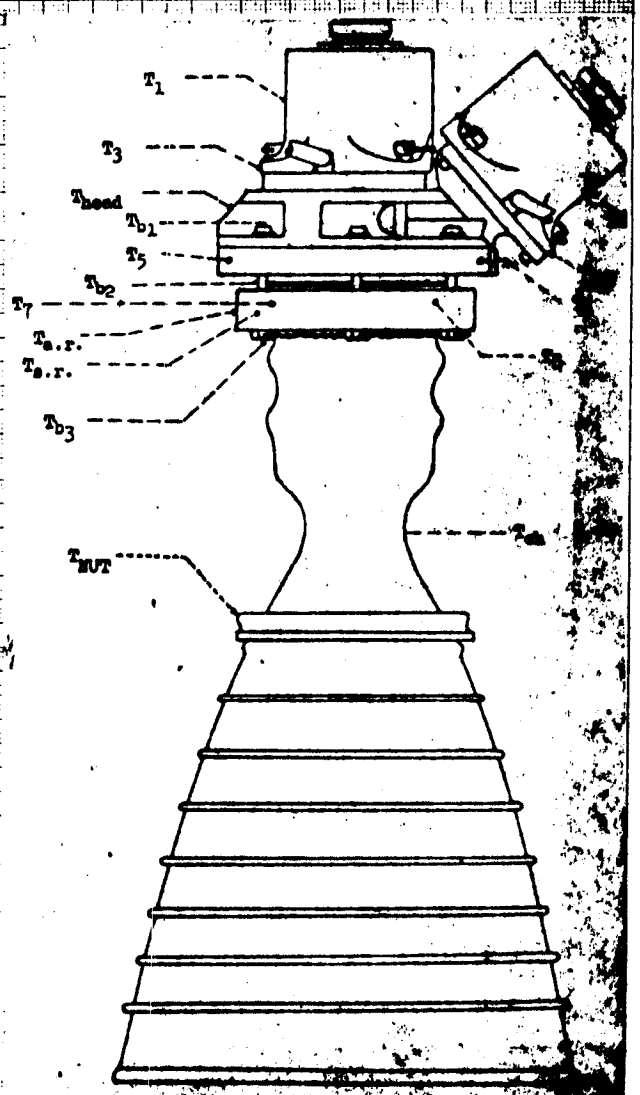
ENGINE P/N 1230S/W0001-7
TEST NO. 3903 DATE: 3-23-66
CELL: ETL-20 RUN NO. 1340
COMMENTS

TEMPERATURE - °F

700
600
500
400
300
200

0 10 20 30 40 50 60 70 80 90 100 0 1 2 3 4 5 6 7 8 9 10 11 12

RUN TIME - SECONDS | SOAKBACK TIME - MINUTES



THE Marquardt CORPORATION

TMCA-327

PREPARED BY Judy Wilson

CHECKED BY

PAGE A-52

DATE 4-4-66

SYMBOL T_C

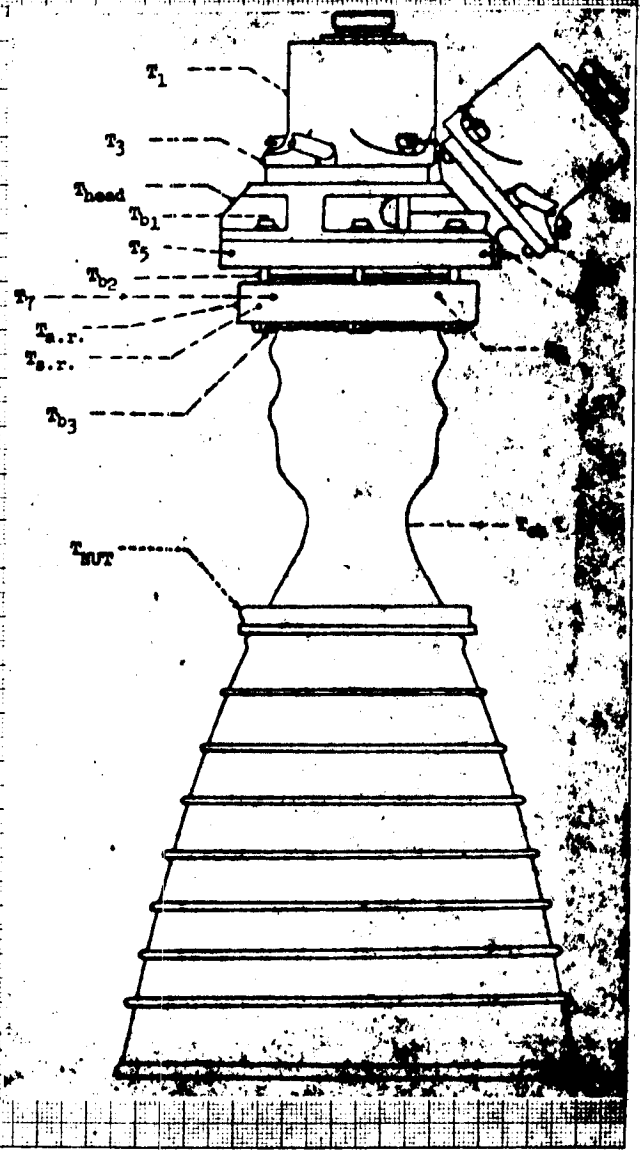
ENGINE P/N 1286 S/N 0001-7
TEST NO: 3903 DATE: 3-23-66
CELL: ATL-"B" RUN NO. 1344
CYCLE 1

DATA @ 20 SEC.
T_{MF} = 1286
T_{MR} = 2818
T_{MO} = 2844
T_{MF} = 1788
T_{MR} = 827

TEMPERATURE - °F

RUN TIME - SECONDS

SOAKBACK TIME - MINUTES



THE Marquardt CORPORATION

TMCA-327

PREPARED BY Judy Olson

CHECKED BY

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DATE 4-4-66

THE Marquardt CORPORATION

SYMBOL T/C

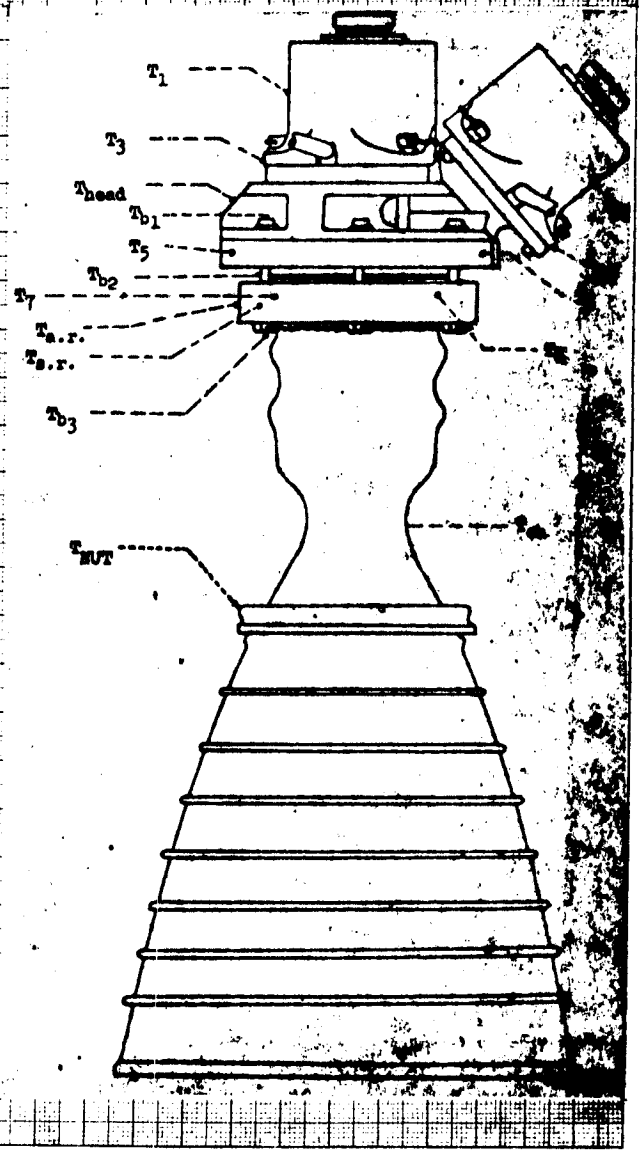
ENGINE P/N 1123005/N 0001-7
TEST NO. 3403 DATE: 3-23-66
CELL: AIL-D RUN NO. 1344
CYCLE 2

	DATA @ 30 SEC
W_f	1286
W_{ox}	2334
MR	1.814
Q_{ox}	1.797
POW	97.5

TEMPERATURE - °F

RUN TIME - SECONDS

SOAKBACK TIME - MINUTES



TMCA-327

K&E 10 X 10 TO THE CENTIMETER 47 1517
KEUFFEL & ESSER CO.

PREPARED BY Judy Olson

CHECKED BY

PAGE A-54

DATE 9-5-66

THE Marquardt CORPORATION

K&E 10 X 10 TO THE CENTIMETER 47 1517
25 X 25 CM. • ALBANENE
KEUFFEL & ESSER CO.

TMCA-327

SYMBOL TC

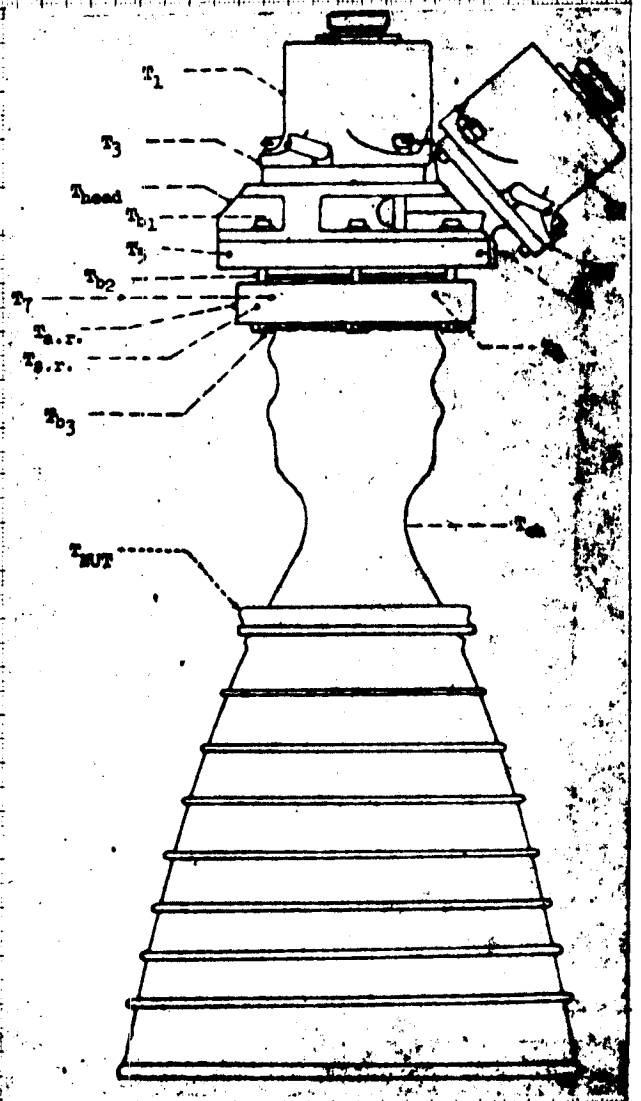
○	5
□	6
◇	7
△	8

ENGINE P/N 3005 S/N 0001-3
TEST NO. 3005 DATE: 9-23-66
CELL: APL-10 RUN NO. 18TH
CHAN 9

COMPLETE

RUN TIME - SECONDS

SOAKBACK TIME - MINUTES



APPENDIX B

Engine Performance Data

ENGINE ASSEMBLY T 13768 S/N 0001-1 PAGE 1 OF 3

TEST NO. 3403 CELL NO. RRL "D" TEST DATE 3-17-66

M.T.P. APPENDIX PARAGRAPH

THE MARQUARDT CORPORATION

STEADY STATE TEST DATA

INPUT / OUTPUT	RUN NO.	TIME	$\dot{w}_o$ - cps	T_{fm_o} - °F	$\dot{w}_f$ - cps	T_{fm_f} - °F	F_{test} - lbs	P_{CELL} - PSIA	$P_{c_{TEST}}$ - PSIA	P_{m_o} - PSIA SET	P_{m_o} - PSIA INLET	P_{m_f} - PSIA SET	P_{m_f} - PSIA INLET
	1304	5	1249	77	1082	82		.0830	94.1				
	1.4340	.8971	.2328	.1203	.3531	1.935				5070			
	1304	30	1243	85	1084	81		.0860	93.6				
	1.4237	.8976	.2301	.1206	.3507	1.907				5078			
	1304	60	1232	72	1068	72		.0880	93.4				
	1.4404	.9021	.2308	.1193	.3501	1.934				5076			
	1304	90	1215	65	1038	65		.0880	93.2				
	1.4494	.9056	.2289	.1165	.3454	1.964				5134			
	1305	5	1296	89	982	86		.0800	89.7				
	1.4186	.8950	.2391	.1089	.3480	2.195				4904			
	1305	30	1294	86	980	84		.0860	89.1				
	1.4224	.8960	.2393	.1088	.3481	2.199				4870			
	1305	60	1280	81	978	81		.0860	88.7				
	1.4289	.8976	.2378	.1088	.3466	2.185				4869			
	1305	90	1287	68	986	68		.0860	88.4				
	1.4456	.9041	.2418	.1104	.3522	2.190				4775			
	1307	5	1233	77	1138	77		.0830	97.4				
	1.4340	.8996	.2298	.1269	.3567	1.810				5195			
	1307	30	1230	78	1132	78		.0890	96.8				
	1.4327	.8991	.2291	.1261	.3552	1.816				5185			
	1307	60	1228	78	1128	78		.0900	96.5				
	1.4327	.8991	.2287	.1256	.3543	1.820				5182			

OUTPUT	SG_o	SG_f	$\dot{w}_{o_{TEST}}$ - pps	$\dot{w}_{f_{TEST}}$ - pps	$\dot{w}_{P_{TEST}}$ - pps	O/F_{TEST}	$F_{vac_{TEST}}$ - lbs	$I_{sp_{vac_{TEST}}}$ - sec	$C_{f_{vac_{TEST}}}$	C^*_{TEST} ft-sec	ΔP_o - psi	ΔP_f - psi

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ENGINE ASSEMBLY T 13768 S/N 0001-1 PAGE 2 OF 3

TEST NO. 3403 CELL NO. RRL "D" TEST DATE 3-17-66

M.T.P. APPENDIX PARAGRAPH

THE MARQUARDT CORPORATION

STEADY STATE TEST DATA

INPUT	RUN NO.	TIME	$\dot{w}_o$ - cps	T_{fm_o} - °F	$\dot{w}_f$ - cps	T_{fm_f} - °F	F_{test} - lbs	P_{CELL} - PSIA	$P_{c_{TEST}}$ - PSIA	P_{m_o} - PSIA SET	P_{m_o} - PSIA INLET	P_{m_f} - PSIA SET	P_{m_f} - PSIA INLET
OUTPUT	SG_o	SG_f	$\dot{w}_{o_{TEST}}$ - pps	$\dot{w}_{f_{TEST}}$ - pps	$\dot{w}_{p_{TEST}}$ - pps	O/F_{TEST}	$F_{vac_{TEST}}$ - lbs	$I_{sp_{vac_{TEST}}}$ - sec	$C_{f_{vac_{TEST}}}$	C^*_{TEST} ft-sec	ΔP_o - psi	ΔP_f - psi	
	1307	90	1222	69	1128	69		.0900	96.1				
	1.4443	.9036	.2295	.1263	.3558	1.817				5139			
	1308 A	5	1224	66	1150	66		.0830	97.2				
	1.4481	.9051	.2304	.1290	.3594	1.786				5146			
	1308 A	30	1212	68	1146	68		.0890	96.6				
	1.4456	.9041	.2278	.1284	.3562	1.774				5160			
	1308 A	60	1208	70	1142	70		.0900	96.4				
	1.4430	.9031	.2266	.1277	.3543	1.774				5177			
	1308 A	90	1215	71	1150	71		.0900	96.1				
	1.4417	.9026	.2278	.1286	.3564	1.771				5130			
	1308 B	5	1212	70	1128	70		.0840	96.8				
	1.4430	.9031	.2274	.1263	.3537	1.800				5207			
	1308 B	30	1220	70	1132	69		.0890	96.1				
	1.4430	.9036	.2288	.1267	.3555	1.805				5143			
	1308 B	60	1217	68	1132	68		.0900	96.0				
	1.4456	.9041	.2287	.1267	.3554	1.805				5139			
	1308 B	90	1219	64	1138	64		.0890	95.9				
	1.4507	.9061	.2298	.1277	.3575	1.799				5104			
	1308 C	5	1223	71	1141	71		.0830	96.6				
	1.4417	.9026	.2292	.1276	.3568	1.796				5151			

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ENGINE ASSEMBLY T 13768 S/N 0001-1 PAGE 3 OF 3

TEST NO. 3403 CELL NO. RRL "D" TEST DATE 3-17-66

M.T.P. APPENDIX PARAGRAPH

THE MARQUARDT CORPORATION

STEADY STATE TEST DATA

INPUT	RUN NO.	TIME	$\dot{w}_o$ - cps	T_{fm_o} - °F	$\dot{w}_f$ - cps	T_{fm_f} - °F	F_{test} - lbs	P_{CELL} - PSIA	$P_{c_{TEST}}$ - PSIA	P_{m_o} - PSIA SET	P_{m_o} - PSIA INLET	P_{m_f} - PSIA SET	P_{m_f} - PSIA INLET
OUTPUT	SG_o	SG_f	$\dot{w}_{o_{TEST}}$ - pps	$\dot{w}_{f_{TEST}}$ - pps	$\dot{w}_{p_{TEST}}$ - pps	O/F_{TEST}	$F_{vac_{TEST}}$ - lbs	$I_{sp_{vac_{TEST}}}$ - sec	$C_{f_{vac_{TEST}}}$	C^*_{TEST} ft-sec	ΔP_o - psi	ΔP_f - psi	
	1308 C	30	1210	70	1138	69		.0880	96.0				
	1.4430	.9036	.2270	.1274	.3544	1.781				5154			
	1308 C	60	1210	68	1132	67		.0890	96.0				
	1.4456	.9046	.2274	.1269	.3543	1.791				5155			
	1308 C	90	1213	64	1140	64		.0890	95.8				
	1.4507	.9061	.2288	.1280	.3568	1.787				5108			

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ENGINE ASSEMBLY T 12340 S/N 0001-7 PAGE 1 OF 3

TEST NO. 3403 CELL NO. RRL "D" TEST DATE 3-23-66

M.T.P. APPENDIX PARAGRAPH

THE MARQUARDT CORPORATION

STEADY STATE TEST DATA

INPUT / OUTPUT	RUN NO.	TIME	$\dot{w}_o$ - cps	T_{fm_o} - °F	$\dot{w}_f$ - cps	T_{fm_f} - °F	F_{test} - lbs	P_{CELL} - PSIA	$P_{c_{TEST}}$ - PSIA	P_{m_o} - PSIA SET	P_{m_o} - PSIA INLET	P_{m_f} - PSIA SET	P_{m_f} - PSIA INLET
	1336	5	1337	71	1007	71		.0880	94.1				
	1.4417	.9026	.2491	.1126	.3617	2.212				4950			
	1336	30	1346	70	1019	70		.0950	93.0				
	1.4430	.9031	.2509	.1140	.3649	2.200				4849			
	1336	60	1343	64	1020	65		.0960	93.0				
	1.4507	.9056	.2517	.1145	.3662	2.198				4832			
	1336	90	1340	65	1016	66		.0960	92.9				
	1.4494	.9051	.2509	.1140	.3649	2.200				4844			
	1339	5	1287	68	1065	68		.0880	96.2				
	1.4456	.9041	.2403	.1193	.3596	2.014				5090			
	1339	30	1300	67	1079	67		.0970	95.4				
	1.4468	.9046	.2430	.1209	.3639	2.009				4988			
	1339	60	1297	64	1072	64		.0970	95.4				
	1.4507	.9061	.2432	.1203	.3635	2.021				4993			
	1339	90	1298	61	1074	61		.0970	95.2				
	1.4546	.9076	.2439	.1208	.3647	2.019				4966			
	1340	5	1238	61	1137	61		.0880	98.7				
	1.4546	.9076	.2327	.1279	.3606	1.819				5208			
	1340	30	1246	61	1145	61		.0960	97.7				
	1.4546	.9076	.2341	.1287	.3628	1.818				5124			
	1340	60	1247	58	1149	58		.0970	97.5				
	1.4584	.9091	.2350	.1295	.3645	1.814				5089			

OUTPUT	SG_o	SG_f	$\dot{w}_{o_{TEST}}$ - pps	$\dot{w}_{f_{TEST}}$ - pps	$\dot{w}_{P_{TEST}}$ - pps	O/F_{TEST}	$F_{vac_{TEST}}$ - lbs	$I_{sp_{vac_{TEST}}}$ - sec	$C_{f_{vac_{TEST}}}$	C^*_{TEST} ft-sec	ΔP_o - psi	ΔP_f - psi

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ENGINE ASSEMBLY T12340 S/N 0001-7 PAGE 2 OF 3

TEST NO. 3403 CELL NO. RRL "D" TEST DATE 3-23-66

M.T.P. APPENDIX PARAGRAPH

THE MARQUARDT CORPORATION

STEADY STATE TEST DATA

INPUT	RUN NO.	TIME	$\dot{w}_o$ - cps	T_{fm_o} - °F	$\dot{w}_f$ - cps	T_{fm_f} - °F	F_{test} - lbs	P_{CELL} - PSIA	$P_{c_{TEST}}$ - PSIA	P_{m_o} - PSIA SET	P_{m_o} - PSIA INLET	P_{m_f} - PSIA SET	P_{m_f} - PSIA INLET
OUTPUT	SG_o	SG_f	$\dot{w}_{o_{TEST}}$ - pps	$\dot{w}_{f_{TEST}}$ - pps	$\dot{w}_{p_{TEST}}$ - pps	O/F_{TEST}	$F_{vac_{TEST}}$ - lbs	$I_{sp_{vac_{TEST}}}$ - sec	$C_{f_{vac_{TEST}}}$	C^*_{TEST} ft-sec	ΔP_o - psi	ΔP_f - psi	
	1340	90	1240	58	1144	57		.0980	97.4				
	1.4584	.9096	.2336	.1290	.3626	1.810				5111			
	1344 A	5	1318	70	1158	75		.0860	98.4				
	1.4430	.9006	.2301	.1292	.3593	1.780				5211			
	1344 A	30	1330	72	1160	73		.0940	97.7				
	1.4404	.9016	.2318	.1296	.3614	1.788				5143			
	1344 A	60	1329	67	1157	67		.0950	97.2				
	1.4468	.9046	.2327	.1297	.3624	1.794				5103			
	1344 A	90	1326	65	1155	65		.0950	97.1				
	1.4494	.9056	.2326	.1296	.3622	1.794				5101			
	1344 B	5	1305	68	1147	69		.0870	98.3				
	1.4456	.9036	.2283	.1284	.3567	1.778				5243			
	1344 B	30	1329	68	1157	68		.0940	97.5				
	1.4456	.9041	.2324	.1296	.3620	1.793				5124			
	1344 B	60	1326	65	1155	65		.0950	97.1				
	1.4494	.9056	.2326	.1296	.3622	1.794				5101			
	1344 B	90	1325	67	1154	68		.0950	97.0				
	1.4468	.9041	.2320	.1292	.3612	1.795				5109			
	1344 C	5	1297	67	1148	68		.0870	98.3				
	1.4468	.9041	.2270	.1286	.3556	1.765				5259			

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ENGINE ASSEMBLY T 12340 S/N 0001-7 PAGE 3 OF 3

TEST NO. 3403 CELL NO. RRL "D" TEST DATE 3-23-66

M.T.P. APPENDIX PARAGRAPH

THE MARQUARDT CORPORATION

STEADY STATE TEST DATA

INPUT	RUN NO.	TIME	$\dot{w}_o$ - cps	T_{fm_o} - °F	$\dot{w}_f$ - cps	T_{fm_f} - °F	F_{test} - lbs	P_{CELL} - PSIA	$P_{c_{TEST}}$ - PSIA	P_{m_o} - PSIA SET	P_{m_o} - PSIA INLET	P_{m_f} - PSIA SET	P_{m_f} - PSIA INLET
OUTPUT	SG_o	SG_f	$\dot{w}_{o_{TEST}}$ - pps	$\dot{w}_{f_{TEST}}$ - pps	$\dot{w}_{P_{TEST}}$ - pps	O/F_{TEST}	$F_{vac_{TEST}}$ - lbs	$I_{sp_{vac_{TEST}}}$ - sec	$C_{f_{vac_{TEST}}}$	C^*_{TEST} ft-sec	ΔP_o - psi	ΔP_f - psi	
	1344	30	1327	71	1156	70		.0940	97.6				
	1.4417	.9031	.2315	.1294	.3609	1.789				5145			
	1344	60	1329	64	1154	64		.0950	97.0				
	1.4507	.9061	.2333	.1296	.3629	1.800				5085			
	1344	90	1324	65	1154	65		.0950	96.9				
	1.4494	.9056	.2322	.1295	.3617	1.793				5097			

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APPENDIX C

Quick Look Data

QUICK LOOK RUN DATA

"K"

ENGINE P/N T13768 — TEST NO. 3403 — MTP NO. 0041
ENGINE S/N 0001-1 — DATE 3-17-66 — APPENDIX F
1190 — FUEL F/M FCC403 — BAROMETRIC PRESS. ____
1194 — OX F/M FCC402 — AMBIENT TEMP. ____
1119 ——→ FCC339

$$C^* = \frac{P_c A_t g}{\dot{w}} \qquad C^* \cong 19\left(\frac{P_c}{\dot{w}}\right)$$

FUEL TYPE 60/50 — S.G. ____ AT 65 °F — BATCH NO ____ — CERTIFICATION NO. ____
OXIDIZER TYPE N_2O_4 — S.G. ____ AT 62 °F — BATCH NO. ____ — CERTIFICATION NO. ____

1 of 3

PAGE C-1

RUN NO.	TIME OF DAY	RUN DURATION S.S. (SEC)	PULSES ON (MS)	PULSES OFF	NO. OF PULSES	MANIFOLD PRESSURES (PSIG) OX SET	OX RUN	FUEL SET	FUEL RUN	SIGHT TUBE LEVEL (CM) OX BEFORE	OX AFTER	FUEL BEFORE	FUEL AFTER	THRUST (LBS) F_t	FLOW RATE (PPS) OX $\dot{w}_o$	FUEL $\dot{w}_f$	O/F RATIO $\dot{w}_o/\dot{w}_f$	TOTAL FLOW (PPS) $\dot{w}_{tp}$	I_{sp} (SEC) $F_t/\dot{w}_p$	CELL PRESS. (PSIA) P_{cell}	CHAMB. PRESS. (PSIA) P_{ch}	TEMPERATURES (°F) ENGINE BELL T/COPE	ENGINE THROAT TO S.B.	FUEL INSERT	PROPELLANTS MANIFOLD OX/RUN	PROPELLANTS FILM COOLANT TOP OF FUEL	REMARKS
										P_{CH}/P_{ch}	C^*																
1292	11:15	5.0				185	161	154	171	?					.230	.131	1.75	.361									IST RUN OF TEST SERIES. TRIM
1293	12:36	5.0				192	160	166	156	?					.240	.120	2.00	.360									
1294	1401	5.0				202	145	146	136	88					.253	?	?	?	FUEL F/M FAILED REPLACED IT WITH FCC 339.								
1295	1537	5.0				191	163	165	153	94	5010				.238	.119	2.00	.357									
1296	1553	5.0				196	167	143	?	87.5	4680				.252	.105	2.39	.357									
1297	1613	5.0				191	162	154	142	91.5					.239	.112	2.13	.351									
1298	1633	5.0				198	170	155	142	94					.247	.115	2.15	.362									
1299	1642	5.0				~~196~~ 197	168	~~152~~ 154	140	92.5	4880				.247	.113	2.20	.360									
1300	1710	5.0				185	?	181	166						.210	.130											OX PRESSURE DECAYED 16 PSI during RUN
1301	1715	5.0				185	155	~~181~~ 179	165	97	5250				.222	.129	1.72	.351									Ditto'
3-18-66																											
1302	1047	5.0				185	156	181	169	96	5180				.223	.129	1.73	.352									
1303	1100	5.0				196	165	180	165	97	5080				.235	.127	1.85	.362	T_{CH}	T_{S_2}	T_{S_1}	T_{BC}	Hood	HWT	T_7	T_8	
→ 1304	1120	100				192	161	166	155	93					.238	.121	1.97	.359	2380	350	340	470	160 / 215	1900	250 / 500	210 / 520	
→ 1305	1307	100				197	164	151	138	90					.246	.110	2.23	.356	2190	325	480	420	150 / 200	1600	270 / 525	200 / 540	
1306	1400	~~100~~ 115				196	161	180	161	94.7	5020				.233	.125	1.87	.358	2650				125 / 180	950	280 / 525	190 / 540	CUT ON TCH

TOTAL RUN TIME ____ — TOTAL NO. OF STARTS ____ — MAXIMUM SINGLE RUN (SEC) ____ — TOTAL NO. OF SOLENOID ACTUATIONS ____ — OX ____ FUEL ____ — TOTAL TIME ENGINE EXPOSED TO TEMPERATURES ____

REASON FOR CONCLUDING TEST ____ OPERATIONS ____
ENGINEER ____

PHOTOS TAKEN YES ☐ NO ☐

QUICK LOOK RUN DATA

ENGINE P/N T13768 | TEST NO 3403 | MTP NO. 0041
ENGINE S/N 0001-1 | DATE 3-19-66 | APPENDIX F
FUEL F/M FCC 329 | BAROME RX PRESS. ____
OX F/M FCC402 (FAC 036) | AMBIENT TEMP ____

FUEL TYPE 50/50 S.G. ____ AT ____ °F | BATCH NO ____ CERTIFICATION NO. ____
OXIDIZER TYPE N2O4 S.G. ____ AT ____ °F | BATCH NO. ____ CERTIFICATION NO. ____

1113
1863

PAGE C-2

RUN NO.	TIME OF DAY	RUN DURATION S.S. (SEC)	PULSES ON	PULSES OFF	NO. OF PULSES	MANIFOLD PRESSURES (PSIA) OX SET	OX RUN	FUEL SET	FUEL RUN	SIGHT TUBE LEVEL (CM) OX BEFORE	OX AFTER	FUEL BEFORE	FUEL AFTER	THRUST CORRECTED (LBS) Ft	FLOW RATE (PPS) OX $\dot{W}_{ox}$	FUEL $\dot{W}_F$	O/F RATIO $\dot{W}_{ox}/\dot{W}_F$	TOTAL FLOW RATE (PPS) $\dot{W}_{ox}+\dot{W}_F$	I_{sp} (SEC) $F_t/\dot{W}_T$	CELL PRESS. (PSIA) P_{CELL}	CHAMB PRESS (PSIA) P_{CH}	TEMPERATURES, (°F) ENGINE			PROPELLANTS		REMARKS
											P_{CH}																
																			T_{CH}	T_{B_2}	T_{SF}	$T_{A_{IR}}$	T_{HOOD}	T_{FUEL}	OX	FUEL	
1307	1530	100				196	163	180	166		96.5				.234	.129	1.82	.363	2350	380	590	500	160 230	1700	260 670	210 675	TB1 DID NOT INR.
1308	1559	90				196	161	180	168		96.5				.232	.129		.361	2400	370	570	500	160 275	1700	255 630	210 650	
			MAX			S_B ON THROAT																					
	1603	90				196	161	180	167		96.5				.235	.128		.361	2370	380	580	510	160 265	1700	275 640	220 660	DUTY CYCLE
			MAX			S_B ON THROAT																					
	1612	90				196	161	180	167		96.5				.232	.128		.360	2400	380	580	510	160 270	1700	275 640	220 660	
					10	MIN S_B																					
						MONDAY, 3-21-66 FAC 036 OX F.M INSTALLED.																					
1309	1029	~~5~~				185		160			FUEL COLD FLOW (INADVERTENT)																
1310	1034	5				185	170	160	153		95				.246	.119	2.06	.365									Ocell pegged out at start, then reset
1311	1045	5				180	66	161	154		95				~~.240~~ .234	.126 ~~.120~~	1.93 ~~2.00~~	.372 ~~.359~~		FUEL FLOW K FACTOR							
1312	1057	5				175	62	154	147		93.5				.235	.123	1.91	.358		WRONG.	S_B	1113					
1313	1104	5				179	165	150	143		91.5	4820			.240	.120	2.00	.360		WAS	1130						
1314	1123	5				179	166	160	153		94.5				.238	.119	2.00	.356									
1315	1230	5				181	167	161	152		95				.239	.119	2.01	.358									

TOTAL RUN TIME ____ TOTAL NO. OF STARTS ____ MAXIMUM SINGLE RUN (SEC) ____ TOTAL NO. OF SOLENOID ACTUATIONS ____ TOTAL TIME ENGINE EXPOSED TO PROPELLANTS ____

REASON FOR CONCLUDING TEST ____ ____ OPERATIONS ENGINEER ____

PHOTOS TAKEN YES ☐ NO ☐

QUICK LOOK RUN DATA

ENGINE P/N T137687 TEST NO 3403 MTP NO. 0041
ENGINE S/N 0001-1 DATE _____ APPENDIX F
FUEL F/M FCC 339 BAROMETRIC PRESS. _____
OX F/M FAC 026 AMBIENT TEMP _____

FUEL TYPE 50/50 S.G. _____ AT _____ °F
BATCH NO _____ CERTIFICATION NO. _____
OXIDIZER TYPE N2O4 S.G. _____ AT _____ °F
BATCH NO. _____ CERTIFICATION NO. _____

PAGE 1 of 3

RUN NO.	TIME OF DAY	RUN DURATION: S.S. (SEC)	PULSES: ON (MS)	PULSES: OFF	NO. OF PULSES	MANIFOLD PRESSURES (PSIA): OX SET	OX RUN	FUEL SET	FUEL RUN	SIGHT TUBE LEVEL (CM): OX	OX	FUEL	FUEL	THRUST COEFFICIENT (LBS) Ft	FLOW RATE (RPS): OX Wo	FUEL Wo	O/F RATIO	TOTAL PRESS (PSIA) Pto	Isp (SEC) F/Wp	CELL PRESS. (PSIA) Pcell	CHAMBER PRESS. (PSIA) Pc	TEMPERATURES (°F): ENGINE		FUEL INJECT			REMARKS
1316	1240		50	50	5	181		161																			
1317	1250		"	"	980	"		"																			
1318	1600		"	"	630	"		"																			Ran out of OX after 630 pulses
1319	1615		"	"	757	"		"	2,372																		
1320	1625		"	"	643	"		"	3,015																		
1321	1637		"	"	732	"		"	3,747																		
1322	1645		"	"	668	"		"	4,415																		
1323	1655		"	"	741	"		"	5,159																		
1324	1703		"	"	361	"		"	5,520	SINK BACK AFTER THIS RUN																	
							END OF TEST																				

TOTAL RUN TIME _____ TOTAL NO. of STARTS _____ MAXIMUM SINGLE RUN (Sec) _____ TOTAL NO. OF SOLENOID ACTUATIONS _____ OF FUEL _____ TOTAL TIME ENGINE EXPOSED TO PROPELLANTS _____

REASON FOR CONCLUDING TEST _____ OPERATIONS _____ ENGINEER _____

PHOTOS TAKEN YES ☐ NO ☐

QUICK LOOK RUN DATA

ENGINE P/N T12340 | TEST NO 3403 | MTP NO. 0041
ENGINE S/N 0001-7 | DATE 3-23-66 | APPENDIX F
FUEL F/M FCC 339 | BAROMETRIC PRESS. ____
OX F/M FAC 036 | AMBIENT TEMP. ____

FUEL TYPE 50/50 S.G. ____ AT 65 °F
BATCH NO ____ CERTIFICATION NO. ____
DILUENT TYPE N2O4 S.G. ____ AT 65 °F
BATCH NO. ____ CERTIFICATION NO. ____

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RUN NO.	TIME OF DAY	RUN DURATION S.S. (SEC)	PULSES ON (MS)	PULSES OFF	NO. OF PULSES	MANIFOLD PRESSURES (PSIA) O SET	FUEL RUN	FUEL SET	FUEL RUN	SIGHT TUBE LEVEL (CM) OX BEFORE	OX AFTER	FUEL BEFORE	FUEL AFTER	THRUST CORRECTED (LBS) F_t	FLOW RATE (RPS) OX W_o	FUEL W_f	O/F RATIO W_o/W_f	TOTAL FLOW RATE (PPS) W_p	I_{sp} (SEC) F_t/W_p	CELL PRESS. (PSIA) P_{cell}	CHAMB. PRESS. (PSIA) P_{cm}	TEMPERATURES (°F) ENGINE BELL	ENGINE MANIFOLD TO S.B.	S.B.	FUEL INJECT	PROPELLANTS REMOTE OX	PROPELLANTS REMOTE FUEL	REMARKS
										Pc																		
1325	1030	5				184	168	168	156	95					237	116	204	.353										POX ACTS LIKE THERE IS A RESTRICTION IN REG
1326	1041	5				187		176																				DITTO
1327	1255	5				187	158	176	165						.23[illegible]	.119												STIL HAVE PROBLEMS.
1328	1322	5				187	159	176	163																			DITTO
1329	1330	5	◀	▶		187	163	176	165	95					.240	.119	2.01	.359										1ST GOOD ONE
1330	1340	5				187	163	176	165	95					.240	.119	2.01	.359										
1331	1400	5				196	170	166	155	93.5					.252	.112	2.25	.364										
1332	1410	5				192	167	167	156	93					.245	.113	2.17	.355										
1333	1445	5				~~189~~ 187	156	192	180	97					.228	.129	1.73	.352										
1334	1459	5				183	159	192	180	98					.229	.129	1.78	.358	Both	Tch	Tmf	Tfm	Tf	To2	SR	AR	TCH LOOKS BAD RE FOCUSED IT
1335	1515	100				187	161	176	164	93½					.238	.117	2.03	.355	180/300	?	1700	160/230	220/330	200/600	215/580	190/490	
→ 1336	1535	100				196	168	167	155	92½					.249	.112	2.22	.361	170/330	<1800	1600	150/215	200/855	190/540	200/520	194/490	
1337	1600	100				186	163	193	180	97					.235	.128	1.83	.363	190/200	2300	1750	170/245	240/700	210/680	260/650	240/550	
1338	1632	~~100~~ 30				190	—	180	—	—					.237	.120	—	Recorders		Not		Turned		ON			RUN CUT
→ 1339	1645	100				190	165	180	167	94.7					.240	.119	2.01	.359	180/360	2240	1700	165/230	220/500	210/595	220/510	210/490	Repeat of Run No. 1335 (TCH)
→ 1340	1700	100				183	160	195	182	97					.232	.128	1.81	.360	200/410	2370	1800	170/245	260/620	220/700	280/660	260/560	Repeat of Run No. 1337 (HAL OK)

TOTAL RUN TIME ____ TOTAL NO. OF STARTS ____ MAXIMUM SINGLE RUN (Sec) ____ TOTAL NO. OF SOLENOID ACTUATIONS ____ TOTAL TIME REMAIN EXPIRED TO PROPELLANTS ____ REASON FOR CONCLUDING TEST ____ OPERATIONS ENGINEER ____ PHOTOS TAKEN YES ☐ NO ☐

QUICK LOOK RUN DATA

(2)

ENGINE P/N T12340 | TEST NO 3403 | MTP NO. 0041
ENGINE S/N 0001-7 | DATE 3-23-66 | APPENDIX F
FUEL F/M FCC 339 | BAROMETRIC PRESS. ____
OX F/M FCC 394 | AMBIENT TEMP. ____
FAC 036

FUEL TYPE 50/50 DENSITY ____ AT 65 °F
BATCH NO ____ SAMPLE NO ____
HYD FLUID TYPE N204 DENSITY ____ AT 62 °F
BATCH NO ____ SAMPLE NO. ____

1122
1758

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RUN NO.	TIME OF DAY	RUN DURATION S.S. (SEC)	PULSES CV	PULSES FUEL	NO. OF STARTS	MANIFOLD PRESSURES (PSIA) OX SET	OX RUN	FUEL SET	FUEL RUN	SIGHT TUBE LEVEL (CM) OX	OX	FUEL	FUEL	THRUST (CORRECTED) (LBS) Ft	FLOW RATE (PPS) OX $\dot{w}_{ox}$	FUEL $\dot{w}_f$	O/F RATIO $\dot{w}_{ox}/\dot{w}_f$	TOTAL FLOW RATE (PPS) $\dot{w}_p$	I_{sp} (SEC) $F_t/\dot{w}_p$	CELL PRESS. (PSIA) P_{cell}	CHAMB PRESS. (PSIA) P_{ch}	TEMPERATURES °F ENGINE BELL			PROPELLANTS MANIFOLD OX		FILM COOL FUEL	REMARKS
										Pc									I_{BOLT}	T_{CH}	T_{NUT}	T_{hd}	T_1	T_8	T_{SR}	T_{MR}		
1341	1725	90				183	160	195	181	97					.230	.128	1.80	.358	180/205	2360	1750	160	240/610	210/900	270/660	240/570		MAX S.B. ON THD
	1735	90 (81)				"		"		RAN OUT OF OX AFTER 81 SEC.																		
3-24-66					CHANGED OX F.M. IS FCC 394 (REMOVED FAC 036)																									
1342	1010	10				183	158	195 (160)	149	90.5					242	.109	2.22	.351			TRIM RUN							PF DROPPED TO 160 WILL TRY AGAIN
1343	1020	10				183	160	195	180	97.5					.234	.127	1.84	.361										
1344 A	1045	90	DUTY CYCLE			183	158	195	182	97					.232	.129	1.80	.361	200/430	2460	1750	160/250	260/680	230/770	300/930	280/610		MSB THD
B	1055	90				"	155	"	182	97					.232	.129	1.80	.361	230/450	2460	1750	160/270	240/700	240/800	340/960	360/800		MSB THD
C	1105	90				"	158	"	182	97					.232	.129	1.80	.361	250/445	2460	1750	170/260	280/670	230/780	320/960	360/630		10 MIN SB
					TRIAL FOR PULSES FROM TRIM TANKS																							
1345	1230	5				177	162	173	165	95					240	.119	2.02	.359										
1346	1243	—	50	50	1	177		173			CUU 1	SHOT A SINGLE BY ERROR																
1347	1245	—	"	"	39	"		"			40	PRACTICE BURST LOOKS GOOD																
1348	1255	—	"	"	1166	"		"			1206																	
1349	1305		"	"	1397	"		"			2603																	
1350	1315		"	"	1404	"		"			4007																	
1351	1328		"	"	992	"		"			4999																	

TOTAL RUN TIME ____ TOTAL NO. OF STARTS ____ MAXIMUM SINGLE RUN (SEC) ____ TOTAL NO. OF SOLENOID ACTUATIONS ____ TOTAL TIME ENGINE EXPOSED TO PROPELLANTS ____

REASON FOR TERMINATING TEST

OPERATIONS ENGINEER ____

ENGTUS TAKEN YES ☐ NO ☐

QUICK LOOK RUN DATA

ENGINE P/N T12340 TEST NO 3403 MTP NO. _____
ENGINE S/N 0001-7 DATE _____ APPENDIX _____
FUEL F/M FCC 339 BAROMETRIC PRESS. _____
OX F/M FCC 394 AMBIENT TEMP _____

FUEL TYPE _____ DENSITY ____ % AT ____ °F
BATCH NO _____ SAMPLE NO. _____
HYDRAZINE TYPE _____ DENSITY ____ % AT ____ °F
BATCH NO _____ SAMPLE NO. _____

RUN NO.	TIME OF DAY	RUN DURATION G.S. (SEC)	RUN DURATION PULSES (MS) ON	RUN DURATION PULSES (MS) OFF	NO. OF STARTS	MANIFOLD PRESSURES (PSIG) OX SET	MANIFOLD PRESSURES (PSIG) OX RUN	MANIFOLD PRESSURES (PSIG) FUEL SET	MANIFOLD PRESSURES (PSIG) FUEL RUN	SIGHT TUBE LEVEL (CM) OX BEFORE	SIGHT TUBE LEVEL (CM) OX AFTER	SIGHT TUBE LEVEL (CM) FUEL BEFORE	SIGHT TUBE LEVEL (CM) FUEL AFTER	THRUST (CORRECTED) (LBS) Ft	FLOW RATE (LBS/S) OX Wo	FLOW RATE (LBS/S) FUEL Wf	O/F RATIO Wo/Wf	TOTAL PROPELLANT (LBS/SEC) Wp	ISP (SEC) Ft/Wp	CELL PRESS. (PSIA) Pcell	CHAMB. PRESS. (PSIA) Pcham	TEMPERATURES °F ENGINE BELL ASSY	TEMPERATURES °F ENGINE HEAD FLANGE	TEMPERATURES °F ENGINE FUEL	TEMPERATURES °F PROPELLANT MANIFOLD OX	TEMPERATURES °F PROPELLANT MANIFOLD FUEL	REMARKS
											CUM.																	
1352	1342		50	50	521	177		173			5520			PLAYBACK LOOKS GOOD, END OF TEST.													

TOTAL RUN TIME _____ TOTAL NO. OF STARTS _____ MAXIMUM SINGLE RUN (Sec) _____ TOTAL NO. OF SOLENOID ACTUATIONS _____ TOTAL TIME ENGINE EXPOSED TO PROPELLANTS _____ REASON FOR TERMINATING TEST _____ OPERATION ENGINEER _____ PHOTOS TAKEN YES ☐ NO ☐

APPENDIX D

PRELOAD CALCULATIONS

GENERAL CALCULATION SHEET

MAC 8830 REV. 4-57

$P = E\left(\frac{\Sigma \Delta L}{L}\right) A$

$E = 3 \times 10^7$

$L = 1.18$

SEAL COMPOSITE
P/N T13618 S/N C

ENGINE P/N T12340
S/N 0001-7

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
BOLT NO.	ASSEMBLED LENGTH	FREE LENGTH	ΔL	$\Sigma \Delta L$										
	in.	in.	in.	in										
1	1.4739	1.4710	0.0029											
2	1.4740	1.4709	0.0031					BOLT DIA.		= 0.1211 in				
3	1.4740	1.4713	0.0027					BOLT AREA		$= \pi (0.0605)^2$				
4	1.4739	1.4711	0.0028							$= 1.15 \times 10^{-2}$				
5	1.4739	1.4711	0.0028					$P = \left(\frac{1.73}{1.18}\right)(1.15)(3)(10^{-2})(10^{-2})(10^7)$						
6	1.4743	1.4713	0.0030					$P = 5,060$ LBS						
				.0173										
				PRE-TEST										

GENERAL CALCULATION SHEET

MAC B830 REV. 4-57

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
BOLT NO.	ASSEMBLED LENGTH	FREE LENGTH	ΔL	ΔL_{AV}										
	in.	in.	in	in										
1	1.4736	1.4710	0.0026											
2	1.4741	1.4709	0.0032											
3	1.4738	1.4713	0.0025											
4	—	1.4711	—											
5	1.4738	1.4711	0.0027											
6	1.4734	1.4713	0.0021											
				0.00262										

$$P = \left(\frac{2.62}{1.18}\right)(1.15)(3)(6)(10^{7})(10^{-3})(10^{-2})$$

$P = 4,600$ LBS

PRE-FIRE

GENERAL CALCULATION SHEET

MAC 8030 REV. 4-57

$$P = E\left(\frac{\Delta L}{L}\right) A \times 6$$

$E = 3 \times 10^7$

$L = 1.18$ in.

SEAL COMPOSITE P/N T13618, S/N C

ENGINE P/N T12340 S/N 0001-7

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
BOLT NO.	ASSEMBLED LENGTH	FREE LENGTH	ΔL	ΔL_{AV}										
	in.	in.	in	in										
1	1.4731	1.4711	0.0020											
2	1.4727	1.4709	0.0018					BOLT DIA = 0.121 in.						
3	1.4727	1.4715	0.0012					BOLT AREA = 1.15×10^{-2} in^2						
4	—	—	—					$P = \left(\frac{1.78}{1.18}\right)(1.15)(3)(6)(10^{-3})(10^{-2})(10^7)$						
5	1.4733	1.4712	0.0021					P = 3,130 LBS						
6	1.4729	1.4711	0.0018											
				0.00178										
			POST FIRE											

GENERAL CALCULATION SHEET

MAC B830 REV. 4-57

$P = E\left(\frac{\Sigma \Delta L}{L}\right) A$

$E = 3 \times 10^7$

$L = 1.18$ "

SEAL CONICAL P/N T13622 S/N C

ENGINE P/N T13768 S/N 0001-1

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
BOLT NO.	ASSEMBLED LENGTH	FREE LENGTH	ΔL	$\Sigma \Delta L$										
	in.	in.	in.	in.										
1	1.4500	1.4470	0.0030											
2	1.4506	1.4473	0.0033											
3	1.4504	1.4472	0.0032											
4	1.4501	1.4471	0.0030											
5	1.4499	1.4472	0.0027											
6	1.4502	1.4469	0.0033											
				.0185										

BOLT DIA = 0.1125 in

BOLT AREA = 9.99×10^{-3} in^2

$P = \left(\frac{0.0185}{1.18}\right)(9.99)(3)(10^7)(10^{-3})$

$P = 4,700$ LBS

PRE TEST

GENERAL CALCULATION SHEET

MAC 8830 REV. 4-57

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
BOLT NO.	ASSEMBLED LENGTH	FREE LENGTH	ΔL	ΔL_{AV}										
	in.	in.	in.	in.										
1	1.4503	1.4470	0.0033											
2	1.4506	1.4473	0.0033											
3	1.4502	1.4472	0.0030											
4	—	1.4471	—											
5	1.4499	1.4472	0.0027											
6	1.4501	1.4469	0.0032											
				0.00310										
		PRE FIRE												

$$P = \left(\frac{3.10}{1.18}\right)(9.99)(3)(6)(10^{7})(10^{-3})(10^{-3})$$

$P = 4,725$ LBS

GENERAL CALCULATION SHEET

MAC B830 REV. 4-57

$P = E\left(\frac{\Delta L}{L}\right) A\ (6)$

$E = 3 \times 10^7$

$L = 1.18$

SEAL CONICAL
P/N T13622, S/N C
ENG. P/N T13768
S/N 0001-1

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
BOLT No	ASSEMBLED LENGTH	FREE LENGTH	ΔL	$\Delta L_{AV.}$										
	in.	in.	in.	in.										
1	1.4500	1.4470	0.0030											
2	1.4503	1.4472	0.0031											
3	1.4501	1.4472	0.0029											
4	—	—	—											
5	1.4495	1.4472	0.0023											
6	1.4500	1.4471	0.0029											
				.00284										
			POST	FIRE										

BOLT DIA. = 0.1125 in

BOLT AREA = $\pi(0.0563)^2$
$= 9.99 \times 10^{-3}\ in^2$

$P = \frac{2.84}{1.18} \times 9.99 \times 3 \times 10^7 \times 10^{-3} \times 10^{-3} \times 6$

$P = 4320$ LBS

ATTACHMENT 14

THE Marquardt CORPORATION VAN NUYS, CALIFORNIA

DESIGN REPORT

on

DESIGN & CONCEPTUAL STUDIES

for

APOLLO SERVICE MODULE

REACTION CONTROL SYSTEM ENGINE

CHAMBER SEAL STUDY

PREPARED UNDER CONTRACT NAS 9-4775

TMC 3008

Prepared by J. Puntar
Design Engineering

Approved by E. P. Perlman
Program Manager

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REFERENCE: 1. Chamber/Head Seal Cavity Peak Pressure Analysis for Apollo S/M RCS Engine Chamber Seal Study - H. Iwata, W. Juran.

I. INTRODUCTION

This report covers design and conceptual studies performed in evolving high thermal resistance injector head/combustor seal designs suitable for application to the Apollo Service Module Reaction Control System (S/M RCS) Engine. Included herein are the various design considerations which were made in meeting the program objective seal thermal resistance = 5 Hr-°F/BTU under Contract NAS 9-4775.

II. SUMMARY

Design layout and trade-off studies resulted in the adoption of two (2) basic design concepts (composite and thinwall) selected for test evaluation in this program.

Composites utilized a combination of metallic and non-metallic materials arranged to provide more than one heat transfer path from one end of the seal to the opposite end. Studies showed that this concept was the only one conceived in the program which was theoretically capable of meeting the thermal resistance objective 5.0 Hr-°F/BTU within the present engine seal cavity.

Thinwalls, monolithic and simple by comparison to the composites, employed a single heat transfer path through metal. To achieve the objective thermal resistance, this concept requires an extended seal cavity necessitating engine component modification.

Effort was devoted throughout the program period to devise design improvements in these basic concepts, aimed at increasing performance levels. Various design approaches were also studied which considered methods whereby high resistance seals could be incorporated in the Apollo S/M RCS engine.

In the latter phases of the program, the design and conceptual study effort, aided by development test data, succeeded in developing theoretical designs with improved thermal and structural capability. These designs are described briefly in Figures 1 and 2.

III. DISCUSSION

The Apollo S/M RCS engine is radiation cooled. Engine testing, conducted by Marquardt during development of this engine under separate contract with NAA/S&ID, has determined that the minimum allowable injector head temperature is 20°F for repeatable engine operation for a pulsing duty cycle mission. For "engine OFF" periods, the heat required to maintain the injector head temperature above 20°F would have to be supplied by the spacecraft through the vehicle/engine attachment. Active heating systems represent power and weight penalties. An alternate passive approach, consistent with the objectives of this program, is to provide a thermal block at the injector head/combustor interface which can effectively achieve the same results during "engine OFF" periods as an active heating system without power and weight penalty.

The heat transfer paths from this rocket engine to space during non-operating periods are complex and highly dependent upon the vehicle attach arrangement, the engine chamber surface characteristics, and the structural configuration of the engine itself.

The chamber and expansion nozzle are emitting heat all along the surface. The amount of heat follows the radiation heat transfer equation:

$$q = KT_{ch}^4$$

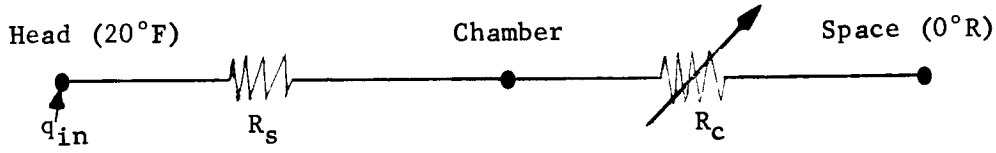
where:

q = heat loss rate $\sim$ BTU/Hr

K = overall constant including emmissivity and shape factors

T_{ch} = chamber wall temperature $\sim$ °R

The heat transfer in this engine can be idealized to:



R_s = seal resistance $\sim$ Hr-°F/BTU

R_c = variable resistance to space from the chamber, proportional to $1/T^4$ $\sim$ Hr-°F/BTU

q = heat in BTU/Hr

For any heat rate into the head, the chamber will seek an equilibrium temperature. If $R_s + R_{ch}$ is large, then q required to maintain 20°F is small. The required heating rate is proportional to the seal resistance for a constant head temperature.

The present Apollo S/M RCS engine embodies an injector head/combustor seal with a thermal resistance of 0.5 Hr-°F/BTU. The objective of this program is to increase this resistance to 5.0 Hr-°F/BTU consistent with meeting structural and leakage requirements.

The seal has three primary functions:

1. Prevent gas from leaking out of the combustion chamber at the joint between the chamber and the head.
2. Provide for structural mounting of the combustion chamber to the injector head by supplying adequate compression loading in combination with the attach hardware.

3. Control* heat transfer between the injector head and the combustion chamber.

(*) Denotes: For this program "control" is interpreted to mean "minimize".

On the basis of these functions, temperature and load design criteria for the present seal (R = 0.5 Hr-°F/BTU) were established. These criteria and the present Apollo S/M RCS engine seal configuration are shown in Figure 3. It is important to note that this configuration was originally designed for higher operating temperatures before the present engine design requirements were defined. Throughout engine development, this design performed satisfactorily; therefore, the seal design was frozen, thus explaining the high safety margins shown in Figure 3. These high margins, although they contribute greatly to engine reliability, were considered redundant and inconsistent with meeting thermal design requirements for high resistance seals.

In this engine, the primary mode of heat transfer between the injector head and combustion chamber is conduction. Radiation heat transfer is neglected due to low temperatures. Convective heat transfer is neglected due to vacuum in space.

The resistance to heat transfer between these two points is determined by the geometry of the connecting structure (seal and combustion chamber attach hardware) and the material thermal properties.

For design purposes, the thermal resistance of the seal is defined by:

$$R_t = \frac{L}{KA}$$

where:

R_t = Thermal Resistance Hr-°F/BTU

K = Thermal Conductivity $\frac{\text{BTU-Ft}}{\text{Hr-°F-Ft}^2}$

L = Length of Heat Path - Ft

A = Cross Sectional Area of Heat Path - Ft^2

This equation provided the basis for thermal considerations in all the seal design studies.

Heat transfer analysis, which supported design studies, indicated that a seal design could be optimized to have the required thermal resistance. However, structural requirements then become critical. The loads, temperatures and safety margins (shown in Figure 3) represented base points from which new design criteria (specifically oriented towards high thermal resistance seals) were later established. These new criteria, to be discussed in latter portions of this text, were derived from the Apollo S/M RCS engine specification requirements in combination with analyses previously conducted by Marquardt in the Apollo Program in addition to analyses performed in this program.

Initial seal design conceptual studies produced design concepts shown in Figure 4. These studies considered various candidate metallic and non-metallic materials. Different configurations were studied.

Although the contract did not place a constraint on the seal dimensional envelope, it was desirable to meet the program objectives with seals that fit the current seal cavity. As shown in Figure 4, some of the configurations required engine component modification in the area of the seal cavity. A brief discussion on the design concepts, shown in Figure 4, follows:

Configuration 1a defines a thinwall concept with various metallics to fit into the existing engine envelope without any modification, but with margins of safety. However, the thermal resistance appears inadequate. Configuration 1b shows a long thinwall design with various metallics and their structural margins of safety. This design requires modification to the injector head only and could be retrofitted. Configurations 5, 6, and 7 are long thinwall designs which ideally fit into the cavity and meet the thermal resistance requirement. However, these designs were structurally unsuitable. Configurations 2a and 2b are of non-metallic material. The first design concept contained the pressure, but it did not satisfy the thermal requirements. The second thinwall design was based upon minimum compression load bearing capability of the material which will require additional investigation to satisfy both the thermal and structural requirements. Configuration 3, composite design, was based upon a high resistance material with high compression capability taking the compression load while the inner ring was designed to take the gas pressure load. A low conductivity spacer surrounds the compression carrying member to thermally isolate the two materials as well as keep it in position. Analysis indicated that this design also satisfied structural requirements, but will require additional design work to satisfy thermal requirements. Configuration 4, convolution design, is based upon the idea of trying to fit the longest possible heat path length in a given cavity. Structurally, the design requires a spacer of low conductivity to take compression load and a spacer to isolate and contain it, while the metallic member resists the pressure loading. However, stress analysis indicated that the design was unstable.

Analytical studies supported these initial design studies.

A stress analysis of the existing engine seal indicated that it was capable of containing 10,000 psi internal pressure at the yield point.

Dynamic analysis indicated that all new seal designs under consideration should be capable of withstanding high internal pressure. The analysis (Reference 1) showed that:

Two separately distinct phenomena can be responsible for generating high seal cavity pressures. The first, a pressure originating in the combustion chamber, is due to engine ignition overpressure which is transmitted to the seal cavity. The second phenomenon is attributed to pressures generated in the seal cavity resulting from the reaction of propellants which might accumulate within the cavity.

It was reasonable to consider a maximum cavity pressure which would not exceed the capabilities of the present Apollo S/M RCS engine seal. For design purposes, a 10,000 psi maximum pressure was established. Of the two pressure phenomena investigated, the low pressure (1,200 psi) was selected for the first generation, high thermal resistance, seal designs because the Apollo engine combustion chamber was designed for 1,500 psia, as indicated in Figure 3. The high pressure criteria (10,000 psi) was used for follow-on (improved) designs.

To guide these design and conceptual studies, a matrix (Figure 5) was formulated which tabulates the major considerations, criteria constants, variables and materials for composite and thinwall seals only.

The criteria (A through G), identified as "constants" in the matrix, represent thermal and structural design requirements which were adopted specifically for high thermal resistance seals.

The criteria (H through T), identified as "variables", represent a part of the variety of design approaches which considered methods whereby high resistance seals could be incorporated in the Apollo S/M RCS engine.

As shown, at least fifty-one (51) iterations were identified with seal design/material combinations and engine assembly variations. All iterations shown are technically feasible although not necessarily economical.

Not all iterations shown were carried through detail design or analysis in these studies. Only Iterations 1 and 2 (composite) and 33 through 36 (thinwall) were developed in detail and adopted for test evaluation early in this program. As shown, only two of these six were theoretically capable of meeting the seal thermal resistance requirement (Criterion A). None of the six were designed to meet the structural requirement (Criterion G).

The matrix also suggests that composite iterations 6 through 32 reflect different seal design configurations. This is not necessarily true as each of these could be identical in configuration with variations in materials only. The same suggestion holds true for some of the thinwall iterations. With close analysis of the matrix, literally hundreds of iterations are possible providing that configuration variations are interlaced with material combinations.

Additional numbers of iterations are possible if intermediate thermal resistances ($\geq$ 0.5 but $\leq$ 5.0) are desired by ignoring Criterion A. For example, by utilizing Criterion H, which complies with Major Consideration I, thinwall seals

with resistances as high as 2.1 can be designed without need for any changes to the basic engine. Further, if Criterion L is used, thinwall seals with resistances $\geq$ 2.1 but $\leq$ 5.0 can be designed to fit an extended seal cavity with no engine component modifications required. In this case, the only effect on the engine assembly is a slight increase in the chamber L* and engine overall length.

Examination of the matrix variables H through T suggests that some of the approaches may even offer design features which could be beneficial from the standpoint of engine weight reduction or performance escalation. Specifically, these are ones that deal with combustion chamber geometry (L*) and expansion nozzle expansion ratio (ϵ) changes.

As indicated previously, not all iterations were designed in detail; however, thinwall iterations (37 through 51) were carried through preliminary design stages. Figure 2 describes the design improvements rendered to conical thinwall seals. This design was aimed at increasing the hoop strength in the event that high seal cavity pressures (10,000 psi) occur. The design shown, theoretically satisfies Criterion G by modification of the basic conical thinwall seal with the addition of a "bumper" ring resulting in no penalty to thermal characteristics.

In the latter phases of the program, design improvements were made to composite seals. Thermal evaluation tests conducted on composite seals (Iterations 1 and 2) and the Zirconium Oxide materials therein, indicated that the seal thermal resistance requirement (Criterion A) could not be met with the original composite seal design made earlier in the program. Design studies were concentrated on improving the thermal resistance of the Zirconium Oxide heat path in this seal by increasing the length-to-diameter ratio of the Zirconia compression members.

The concentrated studies were successful in establishing a new composite design based on the original composite principles and materials. The resultant configuration, details of which are shown in Figures 6 through 9, although more complex than the original composite design, is capable of fitting the existing engine seal cavity without need for engine component modification to facilitate retrofit. Iteration 6, in the matrix, identified this design.

Thermal resistance predictions, for the new design, are 4.3 minimum to 5.0 Hr-°F/BTU maximum neglecting internal contact resistances which will raise the actual total resistance a few percentage points higher.

Additional features in this design are:

1. Possible Improvement in Structural Performance (Criterion G is theoretically satisfied).
2. Improved Leakage Performance (the comparatively higher leakage rates exhibited by the original composite seal were attributed to excessive deflections in the Titanium jacket wall adjacent and between the Zirconia compression members. These deflections were minimized in the new design by decreasing the unsupported distance between cylinders by increasing their number).
3. Positive Thermal Isolation of the External Jacket and the Internal Bumper Set (the previous design did not guarantee this isolation).

Exhibit A, Thermal Analysis, presents the detailed heat transfer calculations performed on this seal design.

Although a complete structural analysis was not performed, compression tests of the most critical element were conducted. Zirconium Oxide (Zircoa "C", full dense) material was fabricated into cylinders in the size required for this design. Compression tests were conducted on three "triplet" sets of cylinders (consisting of 3 cylinders/set) with the following results. The test setup and procedures used were similar (although not identical) to previous tests on this type of material:

TRIPLET SET NO.	APPLIED LOAD - LBS. ($\frac{P_{total}}{3} = P_{cyl}$)	DEMONSTRATED EQUIV. COMPRESSIVE STRESS - psi x 10^3	REQUIRED ULTIMATE COMPRESSIVE STRENGTH - psi x 10^3
1	44.3*	71.15	134.95**
2	44.3*	71.15	
3	38.3*	61.5	

* Denotes: Failure load applied at .05 - 1 lb/sec.

** Denotes: Maximum Apollo Launch Boost Limit σ x M.S. (1.5) = Maximum Ultimate σ = (89.9 x 1.5) x 10^3 for individual cylinder.

As noted, all specimens tested failed to meet the required performance. This failure tends to invalidate the specific design, but the fundamental concept of lengthening the heat flow path by staggering the compression members remains valid. Further study of this concept is recommended.

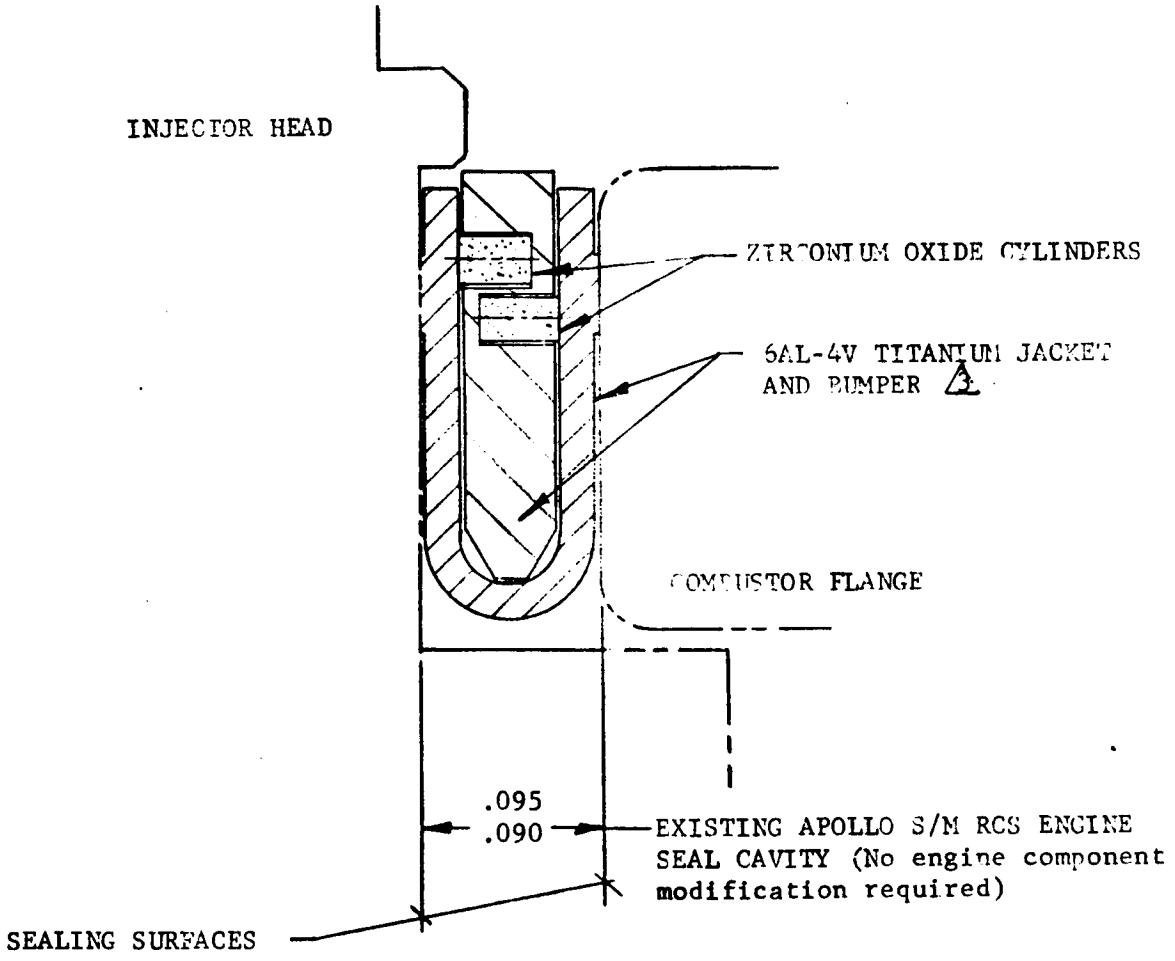
Although the data obtained was limited, it was consistent but by no means conclusive. Due to the limited time available at the close of the program, no investigation in depth was made to determine the cause for the less than adequate performance. However, the following is a preliminary list of possible causes:

A. Test setup differences from previous tests - (ends of these cylinders were bearing on molybdenum; previous tests used Titanium).

B. Scale factor - (these specimens had diameters approximately half as large as previous cylinders tested and L/D ratios approximately 50% greater).

C. Material variables - (these specimens were made from .035 inch diameter Zirconium Oxide (Zircoa "C", full dense) rod. Previous cyclinders used .080 inch diameter rod. Manufacturing history of these rods may indicate that manufacturing variables might also have contributed to variations in mechanical properties).

MODIFIED COMPOSITE SEAL DESIGN

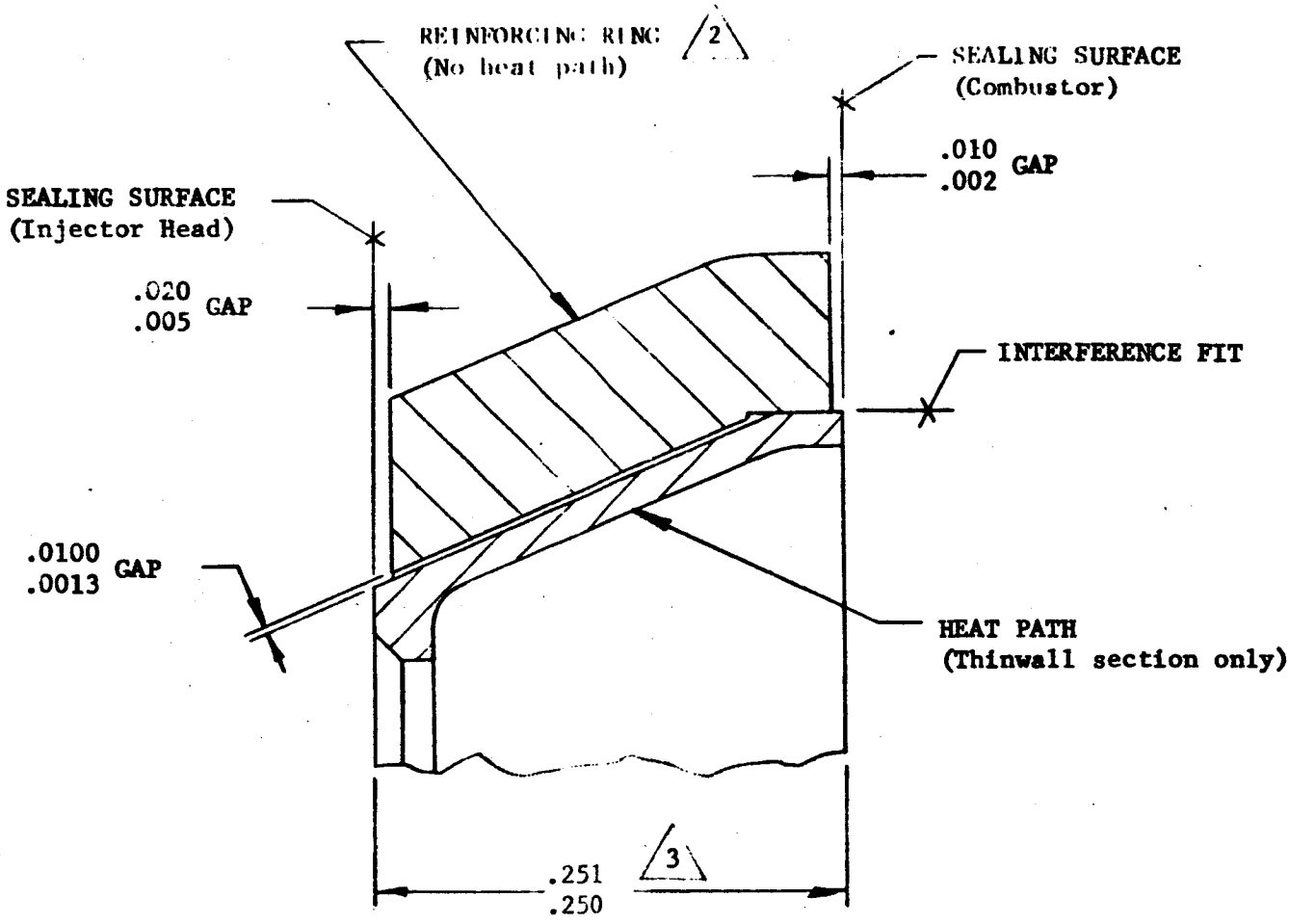


COMMENTS:

1. Seal contains dual heat path.
2. Calculated seal thermal resistance = 4.3/5.0 Hr-°F/BTU. (All contact resistances are neglected)
3. Jacket and Bumper combination designed to contain 10,000 psia seal cavity pressure.

FIGURE 1

IMPROVED CONICAL THINWALL SEAL DESIGN



COMMENTS:

1. **Typical materials and thermal resistances* (R = Hr-°F/BTU)**

   6AL-4V Titanium ------ 6.6
   Rene' 41 ------------ 5.2
   L-605 --------------- 5.8

   *Contact resistances neglected.

2. **Reinforcing Ring (Bumper) designed to contain 10,000 psia seal cavity pressure.**

3. **Extended Seal Cavity (engine component modification is required).**

   (See Figure 10 for further design details and alternate methods of extending seal cavity.)

FIGURE 2

DESIGN CRITERIA
APOLLO SMRCS ENGINE
ATTACH HARDWARE

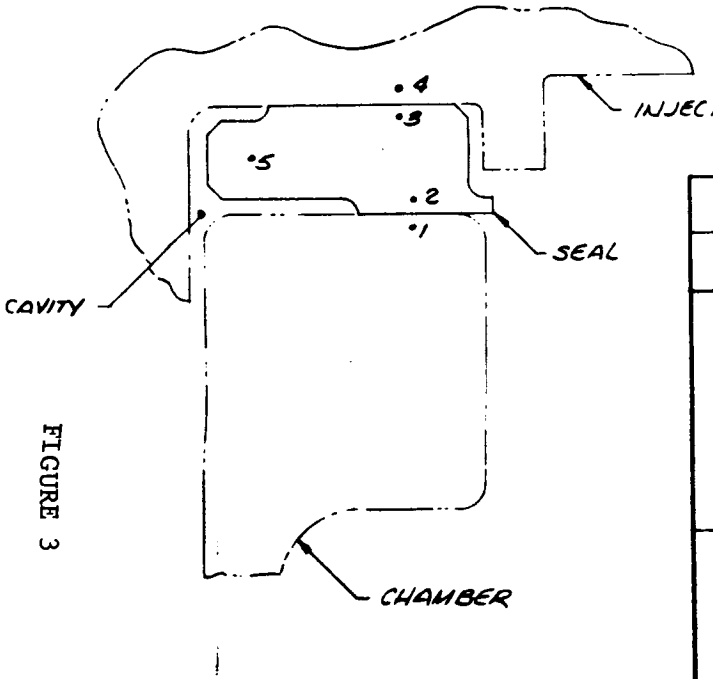


FIGURE 3

DESIGN CRITERIA				
LOCATION POINTS	ORIGINAL DESIGN		(QUAL) APOLLO SMRCS ENG.	
	MAX. TEMP ~ °F (OPERATION)	③ M.S. (COMP.) PRELOAD + ΔT	MAX. TEMP ~ °F ISOAK-BACK	③ M.S. (COMP) PRELOAD + ΔT
1	2000	.15	650	2.0
2	1900	.28	650	1.7
3			350	5.3
4	500	2.9	350	4.2
BOOST CONDITION 1	①	①	150	2.3
2				2.2
3				5.3
4			150	4.3
APOLLO STEADY STATE CHAMBER PRESSURE = 100 PSIA, SPIKE PRESSURE = 1500 PSIA ②				
5	0.0	5.8	0.0	5.8

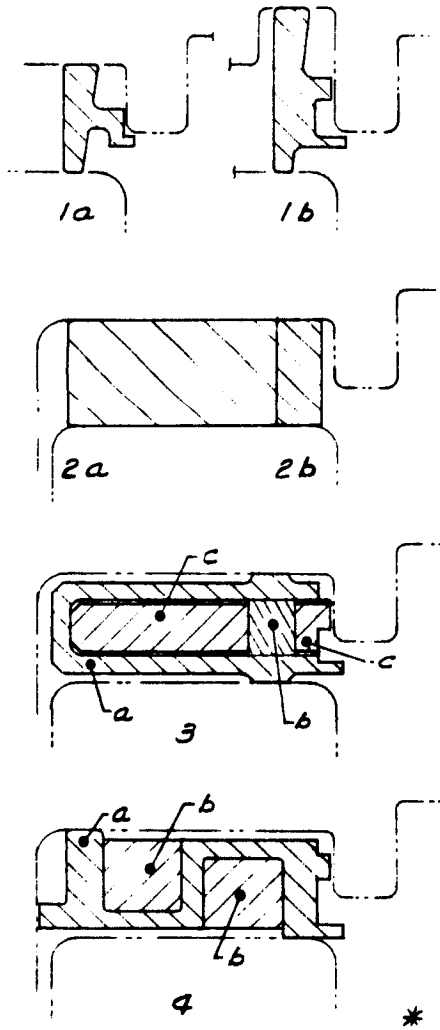
① BOOST CONDITION DESIGN CRITERIA NOT AVAILABLE AT TIME OF ANALYSIS

② ACTUAL PRESSURE IN CAVITY MORE CRITICAL FOR THIN-WALL HIGH RESISTANCE SEALS TO BE EVALUATED.

③ $M.S. = \frac{\text{ALLOWABLE STRESS (PSI)}}{\text{INDUCED STRESS} \times \text{F.S (PSI)}} - 1$
(MARGIN OF SAFETY)

SEAL CONCEPT STUDY

CONFIGURATION	MATERIAL	* STRUCTURAL M.S	** THERMAL RESISTANCE (CALCULATED)
1a THIN-WALL	L-605	+.07 ULT AL. HD-BEARING	1.45
	WASPALOY	+.07 ULT AL HD-BEARING	1.28
	RENE' 41	+.07 ULT AL HD-BEARING	1.38
	Ti (6AL4V)	+.03 ULT TI SEAL-BEARING	1.96
1b	L-605	+.07 ULT AL HD- BEARING	1.84
	WASPALOY	+.07 ULT AL HD- BEARING	1.61
	RENE' 41	+.07 ULT AL HD BEARING	1.73
	Ti (6AL4V)	+.03 ULT TI SEAL-BEARING	2.50
NON METALLIC			
2a	PYROLYTIC GRAPHITE	+.10 ULT GRAPHITE-HOOP	0.6
	ZIRCONIUM OXIDE	– FAILURE-HOOP	1.51
2b	PYROLYTIC GRAPHITE	0.0 ULT GRAPHITE-HOOP	3.43
	ZIRCONIUM OXIDE	– FAILURE-HOOP	8.85
COMPOSITE			
3	a. Ti (6AL 4V)	0.0 ULT GRAPHITE-BEARING	3.26
	b. ZIRCONIUM OXIDE OR PYROLYTIC GRAPHITE	0.0 ULT GRAPHITE-BEARING	
	c. PHENOLIC INSULATOR		
CONVOLUTION			
4	a. L-605	– HIGH STRESS IN b	ROTATIONAL INSTABILITY SHORT CIRCUITS RESISTANCE TO LOW LEVEL.
	WASPALOY	– HIGH STRESS IN b	
	RENE' 41	– HIGH STRESS IN b	
	Ti (6AL 4V)	– HIGH STRESS IN b	
	b. ZIRCONIUM OXIDE		



* ULT M.S. = $\frac{\text{ALLOWABLE STRESS}}{\text{INDUCED STRESS} \times 1.5} - 1$

** R = $\frac{\text{HR.}^\circ\text{F}}{\text{BTU}}$

FIGURE 4
Sht. 1 of 2

SEAL CONCEPT STUDY

CONFIGURATION	MATERIAL	*STRUCTURAL M.S.		**THERMAL RESISTANCE
LONG THIN-WALL 5	L-605	-	HIGH ECCENTRIC LOAD	-
	WASPALOY	-		-
	RENE' 41	-		-
	Ti (6AL 4V)	-		-
LONG THIN-WALL 6	L-605	-	HIGH ECCENTRIC LOAD	-
	WASPALOY	-		-
	RENE' 41	-		-
	Ti (6AL 4V)	-		-
LONG THIN WALL 7	L-605	-	HIGH ECCENTRIC LOAD	-
	WASPALOY	-		-
	RENE' 41	-		-
	Ti (6AL 4V)	-		-

FIGURE 4
Sht. 2 of 2

* ULT M.S. = $\frac{\text{ALLOWABLE STRESS}}{\text{INDUCED STRESS} \times 1.5} - 1$

** $R = \frac{\text{HR} \cdot {}^\circ\text{F}}{\text{BTU}}$

DESIGN AND CONCEPTUAL STUDIES

MAJOR CONSIDERATIONS	
I	a. EXTERNAL SEAL CAVITY b. ENGINE ENVELOPE CHANGE c. ENGINE INTERFACE CHANGE d. NO INTERFACE CHANGE
II	a. EXTERNAL SEAL CAVITY b. ENGINE ENVELOPE CHANGE c. ENGINE INTERFACE CHANGE d. NO INTERFACE CHANGE
III	a. EXTERNAL SEAL CAVITY b. ENGINE ENVELOPE CHANGE c. ENGINE INTERFACE CHANGE d. NO INTERFACE CHANGE
IV	a. EXTERNAL SEAL CAVITY b. ENGINE ENVELOPE CHANGE c. ENGINE INTERFACE CHANGE d. NO INTERFACE CHANGE
V	a. EXTERNAL SEAL CAVITY b. ENGINE ENVELOPE CHANGE c. ENGINE INTERFACE CHANGE d. NO INTERFACE CHANGE
VI	a. EXTERNAL SEAL CAVITY b. ENGINE ENVELOPE CHANGE c. ENGINE INTERFACE CHANGE d. NO INTERFACE CHANGE

NOTES

FOR ALL ITERATIONS, THE SEAL LATERAL PROJECTION FROM [illegible] REMAIN FIXED TO OUT. THE SEAL ARE CRITERIA THAT MUST BE MET. ANY OTHER PARAMETERS ARE MANIPULATED ACCORDINGLY TO ATTAIN THE OPTIMUM SEAL DESIGN CONSISTENT WITH CRITERIA.

IN THE HEAT TRANSFER EQUATION $R_T = \frac{L}{K}$ THE TERMS ARE

R_T = TOTAL THERMAL RESISTANCE (HR-°F/BTU)

L = LENGTH OF HEAT PATH (INCHES) AT INCREMENTAL ELEMENT OF

K = THERMAL CONDUCTIVITY OF WATER AT BULK TEMPERATURE

A = AREA OF HEAT PATH (IN²)

⚠ VALUE BASED ON THE MINIMUM ENGINE ENVELOPE THAT WILL ENCLOSE PLUME ENGINE SEAL CAVITY AND HEAT SHIELD

⚠ SEAL UNDERGOING TEST EVALUATION ON THIS PROGRAM

LEGEND

MATERIALS
- 6AL-4V TITANIUM (OXIDIZED)
- RENE 41 (6AL-4V TITANIUM WITH OXIDE)
- 70% COLD WORKED (CRES WITH TITANIUM OXIDE)
- 6AL-4V TITANIUM
- RENE 41
- 70% COLD WORKED (CRES)

☆ DENOTES COMPLIANCE WITH CRITERIA

		CRITERIA	STUDIES: COMPOSITE	STUDIES: THINWALL
CONSTANTS	A	SEAL THERMAL RESISTANCE AT P.F. 5.8 HR °F/BTU		
	B	COMPRESSIVE PRELOAD GENERATED DURING ENGINE ASSEMBLY 70°F 5800 LBS MAX LIMIT		
	C	COMPRESSIVE PRELOAD - THERMAL LOAD RESULTING FROM ENGINE HEAT SOAKBACK WITH SEAL 470°F 8286 LBS LIMIT		
	D	COMPRESSIVE LOAD RESULTING FROM APOLLO LAUNCH BOOST VIBRATION + AERODYNAMIC PRESSURE WITH SEAL 150°F 7500 LBS LIMIT 12750 LBS ULT		
	E	STEADY STATE CHAMBER PRESSURE WITH SEAL TEMP 1250°F 100 PSIA LIMIT		
	F	SEAL CAVITY PEAK PRESSURE RESULTING FROM CHAMBER PRESSURE ON THRUST SPIKE 70°F 1200 PSIA LIMIT 1800 PSIA ULT		
	G	SEAL CAVITY PEAK PRESSURE RESULTING FROM SEAL CAVITY PROPELLANT EFFLUX ON 70°F 9,000 PSIA ⚠		
VARIABLES	H	PRESENT APOLLO SM RCS ENGINE SEAL CAVITY & CURRENT EXTERNAL ENGINE ENVELOPE (NO ENGINE MODIFICATION)		
	I	INCREASE SEAL CAVITY LENGTH (MODIFY INJECTOR HEAD ONLY) NO CHANGE TO EXTERNAL ENGINE ENVELOPE		
	J	INCREASE SEAL CAVITY LENGTH (MODIFY COMBUSTOR FLANGE ONLY) NO CHANGE TO EXTERNAL ENGINE ENVELOPE		
	K	INCREASE SEAL CAVITY LENGTH (MODIFY INJECTOR HEAD & COMBUSTOR FLANGE ONLY) NO CHANGE TO EXTERNAL ENGINE ENVELOPE		
	L	INCREASE SEAL CAVITY LENGTH BY INCREASING EFFECTIVE LENGTH OF EXISTING BOLTS (DO NOT MODIFY BOLTS) MINOR CHANGE IN ENGINE ENVELOPE IN REGION OF HEAD COMBUSTOR JOINT SLIGHT INCREASE IN L* & OVERALL ENGINE LENGTH		
	M	INCREASE SEAL CAVITY LENGTH LENGTHEN ATTACH BOLTS & SHORTEN ATTACH RING NO CHANGE IN ENGINE ENVELOPE IN REGION OF HEAD COMBUSTOR JOINT SLIGHT INCREASE IN L* & OVERALL ENGINE LENGTH		
	N	INCREASE SEAL CAVITY LENGTH LENGTHEN ATTACH BOLTS & [illegible] MINOR CHANGE IN ENGINE ENVELOPE IN REGION OF HEAD COMBUSTOR JOINT SLIGHT INCREASE IN L* & OVERALL ENGINE LENGTH		
	O	INCREASE SEAL CAVITY LENGTH LENGTHEN ATTACH BOLTS & [illegible] BELL MINOR CHANGE IN ENGINE ENVELOPE IN REGION OF HEAD COMBUSTOR JOINT SLIGHT INCREASE IN L* & SLIGHT DECREASE IN EXPANSION RATIO NO CHANGE IN ENGINE OVERALL LENGTH		
	P	INCREASE SEAL CAVITY LENGTH LENGTHEN ATTACH BOLTS & SHORTEN COMBUSTOR MINOR CHANGE IN ENGINE ENVELOPE IN REGION OF HEAD COMBUSTOR JOINT NO CHANGE IN L* OR ENGINE OVERALL LENGTH		
	Q	INCREASE SEAL CAVITY LENGTH SHORTEN ATTACH RING & COMBUSTOR NO CHANGE IN L* OR EXTERNAL ENGINE ENVELOPE		
	R	INCREASE SEAL CAVITY LENGTH LENGTHEN ATTACH BOLTS & SHORTEN COMBUSTOR FLANGE MINOR CHANGE IN ENGINE ENVELOPE IN REGION OF HEAD COMBUSTOR JOINT NO CHANGE IN ENGINE OVERALL LENGTH		
	S	INCREASE SEAL CAVITY LENGTH LENGTHEN ATTACH BOLTS & SHORTEN [illegible] FLANGE AND INJECTOR HEAD) MINOR CHANGE IN ENGINE ENVELOPE IN REGION OF HEAD COMBUSTOR JOINT NO CHANGE IN ENGINE OVERALL LENGTH		
	T	INCREASE SEAL CAVITY LENGTH LENGTHEN ATTACH BOLTS & SHORTEN ATTACH RING MODIFY COMBUSTOR & INJECTOR HEAD MINOR CHANGE IN ENGINE ENVELOPE IN REGION OF HEAD COMBUSTOR JOINT NO CHANGE IN ENGINE OVERALL LENGTH		

FIGURE 5

1

2

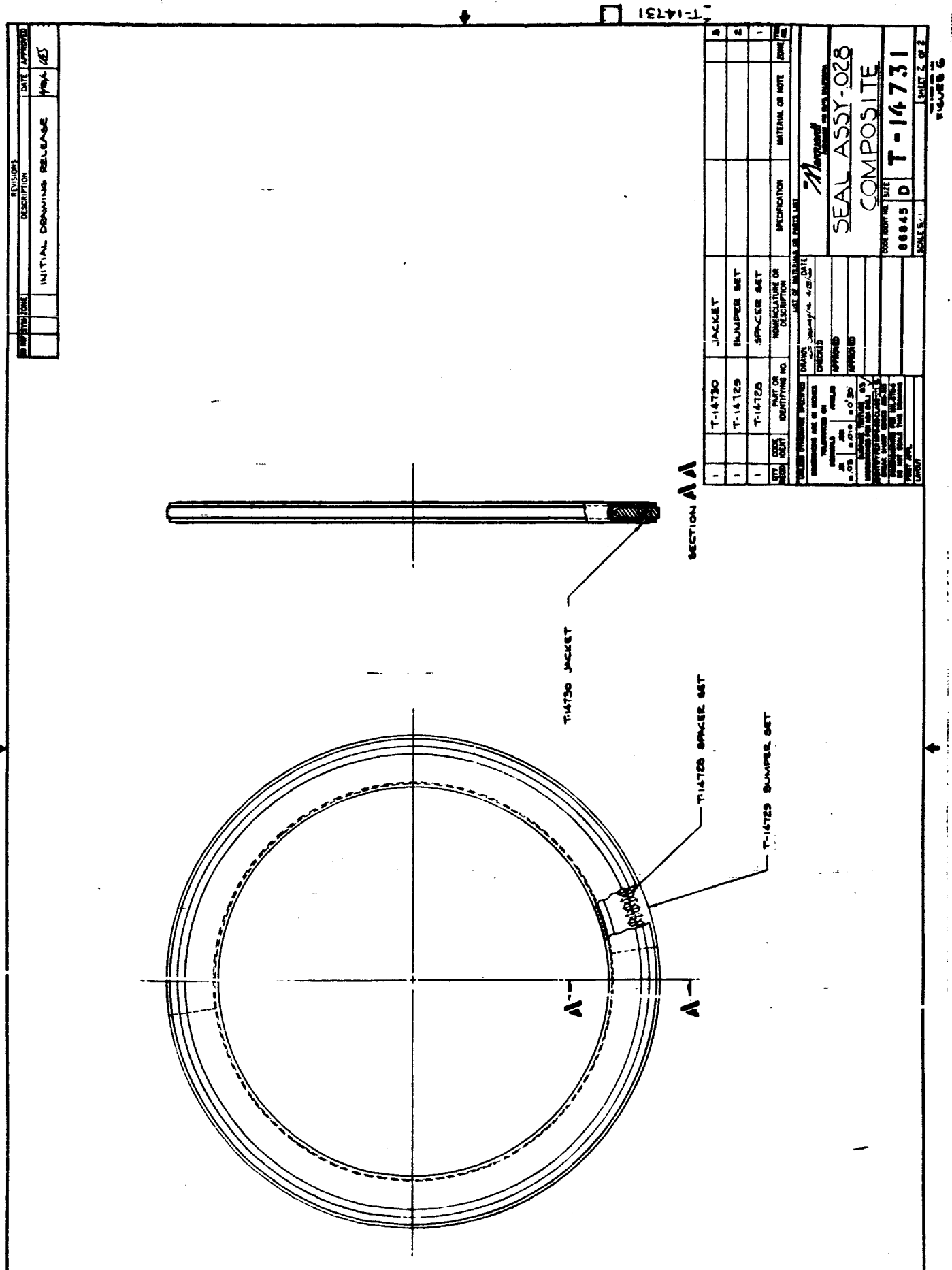

T-14731
SECTION A-A
T-14730 JACKET
T-14728 SPACER SET
T-14729 BUMPER SET
SEAL ASSY-028
COMPOSITE
T-14731

FIGURE 6

ACTUAL SIZE

REVISIONS					
ECO REF	SYM	ZONE	DESCRIPTION	DATE	APPROVED
			INITIAL DRAWING RELEASE	4/60	

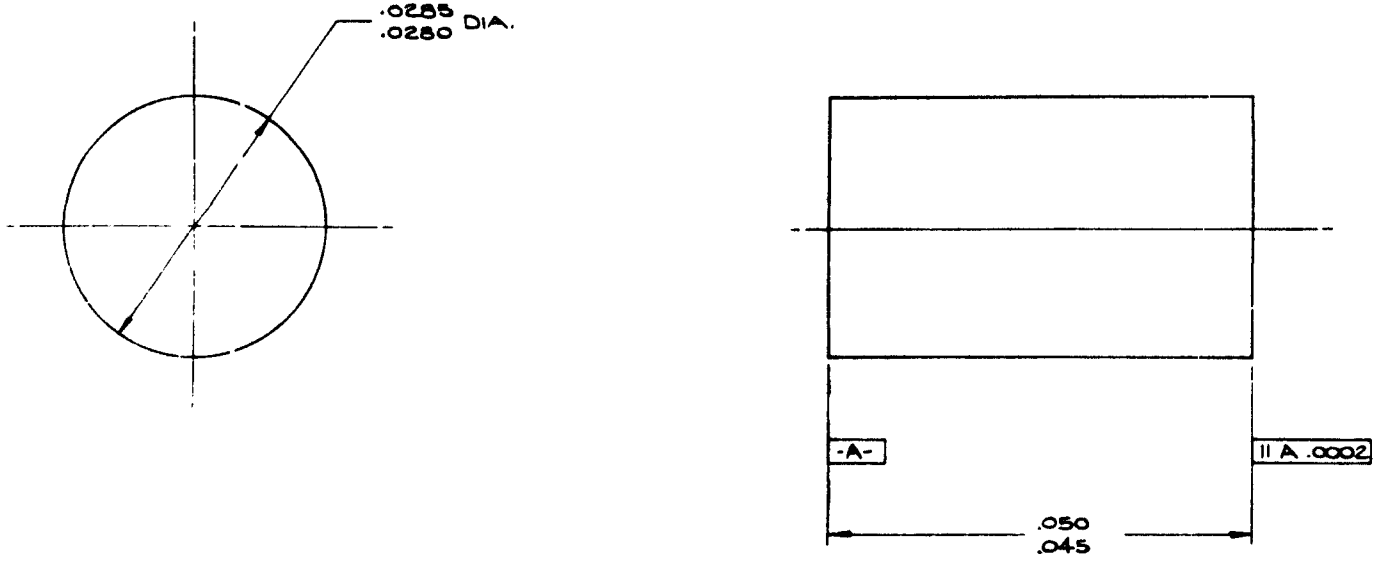


FIGURE 7

2. BREAK EDGES .000 -.003

⚠1 360 CYLINDERS REQUIRED FOR FULL SET QUANITY SHOWN INCLUDES SPARES.

NOTES- UNLESS OTHERWISE SPECIFIED

QTY REQD	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	SPECIFICATION	MATERIAL OR NOTE	ZONE	ITEM NO.
⚠1 396			CYLINDER	COM'L	ZIRCOA "C" ROD .09 DIA x .050 LG		

LIST OF MATERIALS OR PARTS LIST

UNLESS OTHERWISE SPECIFIED	DRAWN DATE
DIMENSIONS ARE IN INCHES	CHECKED
TOLERANCES ON DECIMALS XX ±.03 XXX ±.010 ANGLES ±0°30'	APPROVED
SURFACE TEXTURE MICROINCHES PER ASA B46.1 63	APPROVED
IDENTIFY PER MPS-800 CLASS VII B	
BREAK SHARP EDGES	
DIMENSIONING PER MIL-STD-8 DO NOT SCALE THIS DRAWING	
FIRST APPL	
LAYOUT	

The Marquardt Corporation VAN NUYS, CALIFORNIA

SPACER SET - .028
COMPOSITE SEAL

CODE IDENT NO.	SIZE	
86845	C	T-14728

SCALE 100/1 SHEET 2 OF 2

THIC AMSD REV. 1-64

-T-14728-

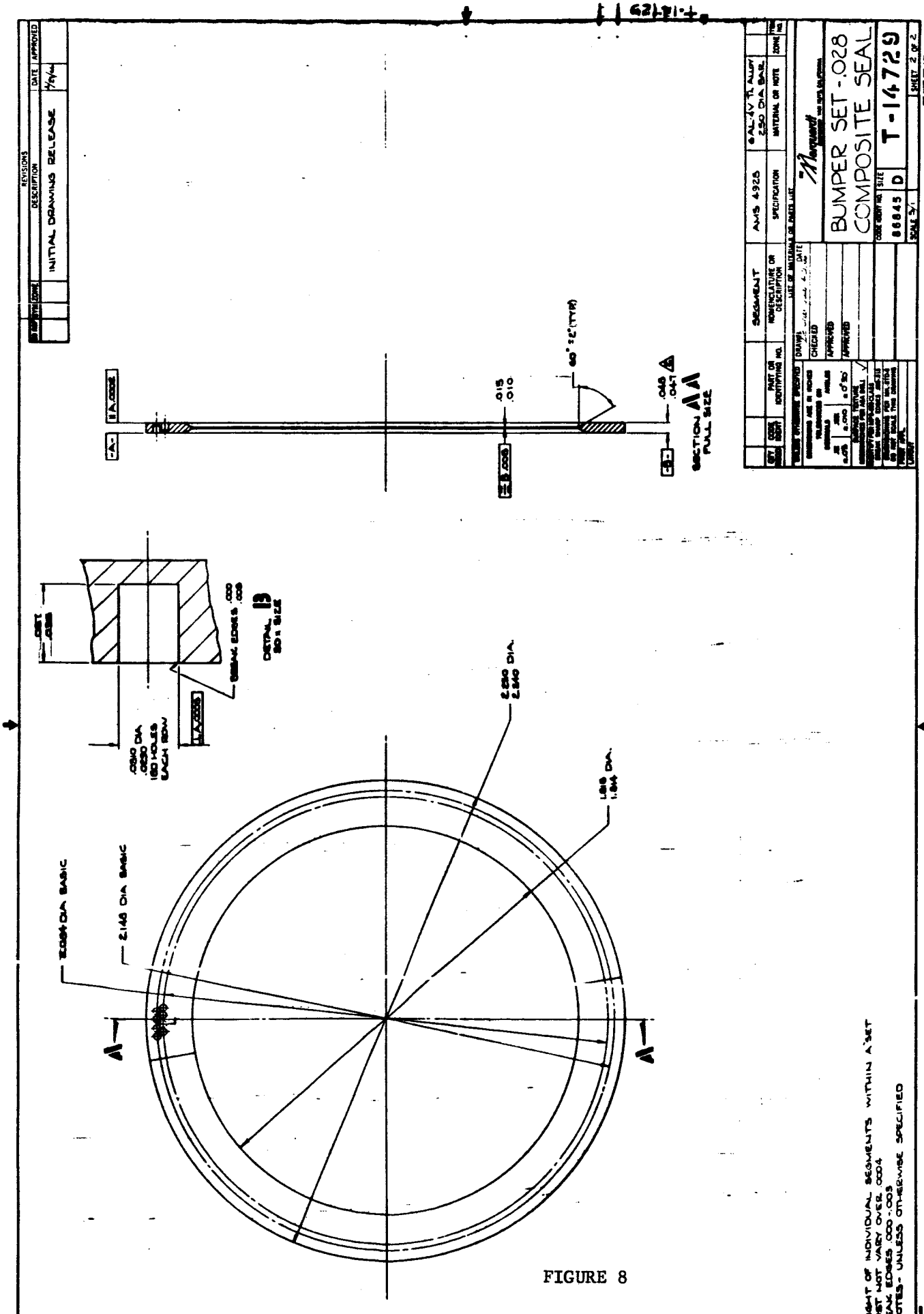


FIGURE 8

HEIGHT OF INDIVIDUAL SEGMENTS WITHIN A SET
MUST NOT VARY OVER .0004
BREAK EDGES .020-.005
NOTES- UNLESS OTHERWISE SPECIFIED

FIGURE B

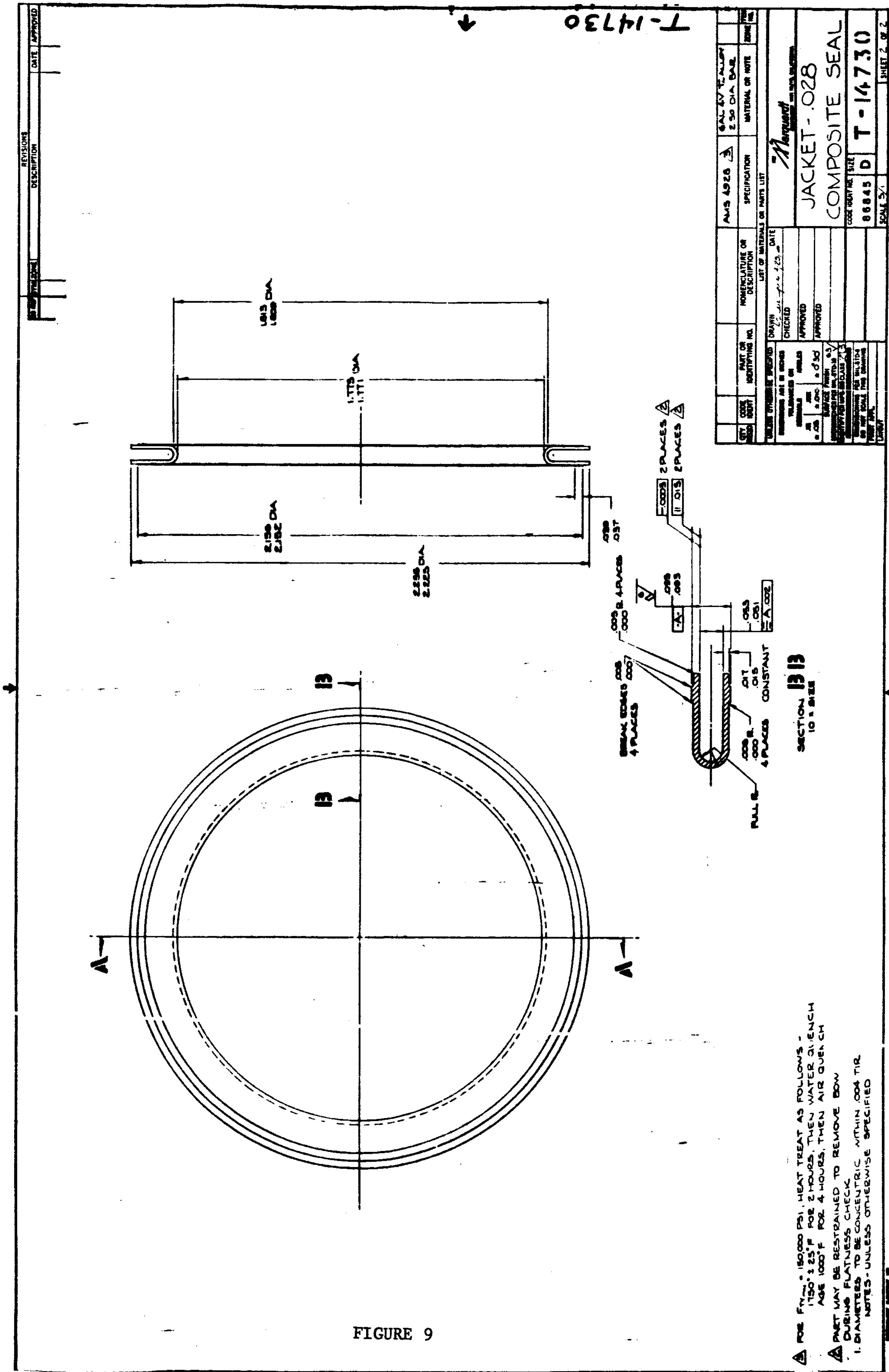

T-14730
REVISIONS
DESCRIPTION
DATE
APPROVED
AMS 4928
6AL 4V Ti ALLOY 2.30 DIA BAR
SPECIFICATION
MATERIAL OR NOTE
JACKET - .028
COMPOSITE SEAL
T-14730
SECTION B B
10 X SIZE
FULL R
CONSTANT
2 PLACES
3 FOR Ftu = 150,000 PSI, HEAT TREAT AS FOLLOWS - 1750° ± 25°F FOR 2 HOURS, THEN WATER QUENCH
AGE 1000°F FOR 4 HOURS, THEN AIR QUENCH
2 PART MAY BE RESTRAINED TO REMOVE BOW DURING FLATNESS CHECK
1. DIAMETERS TO BE CONCENTRIC WITHIN .004 TIR
NOTES - UNLESS OTHERWISE SPECIFIED

FIGURE 9

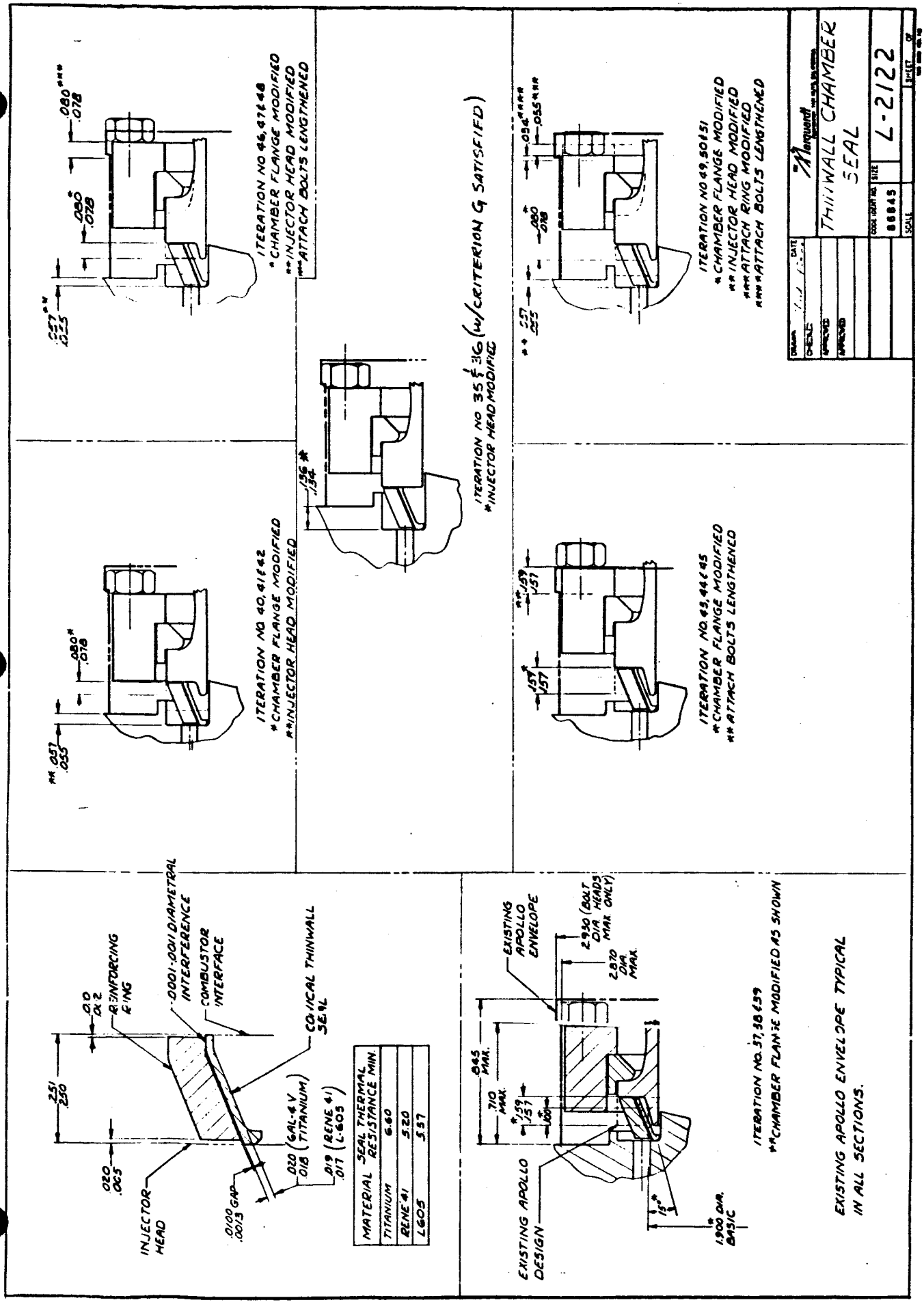

ITERATION NO 46,47&48
*CHAMBER FLANGE MODIFIED
**INJECTOR HEAD MODIFIED
***ATTACH BOLTS LENGTHENED
ITERATION NO 35 & 36 (w/CRITERION 4 SATISFIED)
*INJECTOR HEAD MODIFIED
ITERATION NO 40,41&42
*CHAMBER FLANGE MODIFIED
**INJECTOR HEAD MODIFIED
ITERATION NO 49,50&51
*CHAMBER FLANGE MODIFIED
**INJECTOR HEAD MODIFIED
***ATTACH RING MODIFIED
****ATTACH BOLTS LENGTHENED
ITERATION NO 43,44&45
*CHAMBER FLANGE MODIFIED
**ATTACH BOLTS LENGTHENED
THINWALL CHAMBER SEAL
L-2122
88845
INJECTOR HEAD
REINFORCING RING
COMBUSTOR INTERFACE
CONICAL THINWALL SEAL
.0001-.0011 DIAMETRAL INTERFERENCE
.020 GAP
.020 (GAL-4 V TITANIUM)
.019 (RENE 41)
.017 (L-605)
MATERIAL SEAL THERMAL RESISTANCE MIN.
TITANIUM 6.60
RENE 41 5.20
L605 5.57
EXISTING APOLLO ENVELOPE
2.930 (BOLT HEADS DIA. MAX. ONLY)
2.870 DIA MAX.
.845 MAX.
.710 MAX.
EXISTING APOLLO DESIGN
1.900 DIA. BASIC
ITERATION NO. 37,38&39
**CHAMBER FLANGE MODIFIED AS SHOWN
EXISTING APOLLO ENVELOPE TYPICAL IN ALL SECTIONS.

FIGURE 10

E X H I B I T A

THERMAL ANALYSIS OF IMPROVED COMPOSITE SEAL DESIGN

for

APOLLO SERVICE MODULE

REACTION CONTROL SYSTEM ENGINE

CHAMBER SEAL STUDY

PREPARED UNDER CONTRACT NAS 9-4775

Prepared by P. Purgalis
P. Purgalis

C. S. Hill
C. S. Hill

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III	DISCUSSION	A-1
IV	ASSUMPTIONS	A-2

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A- A	CROSS SECTION OF COMPOSITE SEAL	A-3
A- B	DETAIL RESISTANCES	A-4

I. INTRODUCTION

This report describes the thermal analysis performed in support of the design of an improved composite type, high thermal resistance injector/chamber seal for the Apollo S/M RCS engine under Contract NAS 9-4775. The thermal resistance calculations of the redesigned composite seal are presented.

II. SUMMARY

The thermal resistance of an improved composite seal was calculated for the configuration shown in Figure A-A. The dimensions used in the calculations were obtained from the detail drawings and the jacket resistances (R_8, R_9, R_{10}) were taken from Report 3008-2Q, Attachment 5.

The following maximum and minimum thermal resistance values were obtained:

$$R_{max} = 5.0 \frac{Hr-°F}{BTU}$$

$$R_{min} = 4.3 \frac{Hr-°F}{BTU}$$

III. DISCUSSION

The resistance to heat transfer across the seal extremities is determined by the geometry of the connecting structure and the material properties. This thermal resistance is defined by:

$$R_t = \frac{L}{KA}$$

where:

R_t = Thermal Resistance Hr-°F/BTU

K = Thermal Conductivity BTU-ft/ft^2/Hr/°F

L = Length of Heat Path - Ft

A = Cross Sectional Area of Heat Path - Ft^2

The seal contains two heat paths, one through the zirconium oxide members and one through the external jacket.

The total thermal resistance for these two heat paths in this seal configuration was obtained by calculating the thermal resistance of small sections and combining these into an equivalent series and parallel network. This network, shown in Figure A-A, was then reduced to an equivalent overall thermal resistance. Detail resistances of the network are shown in Figure A-B.

IV. ASSUMPTIONS

1) Only conduction was considered.

2) Neglect all contact resistances.

3) The area for conduction in the bumper is between Radius = 1.105 in. and Radius = 1.011 in.

4) Only the ends of the zirconia cylindrical spacers make contact with the bumper and jacket.

5) The area for conduction in the jacket for R_1 and R_7 is the area of the raised portion.

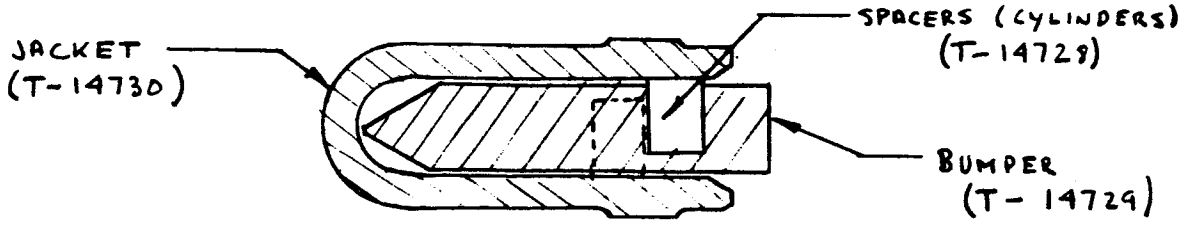
6) The area for conduction in the jacket for R_2 and R_6 is the average area of the raised portion and the contact area of the cylindrical spacers.

7) Properties at room temperature were used.

   a) Thermal conductivity Titanium 6AL-4V = 4.0 BTU-ft/ft^2/Hr/°F

   b) Thermal conductivity Zirconia = 1.2 BTU-ft/ft^2/Hr/°F

   (as determined by Marquardt tests)



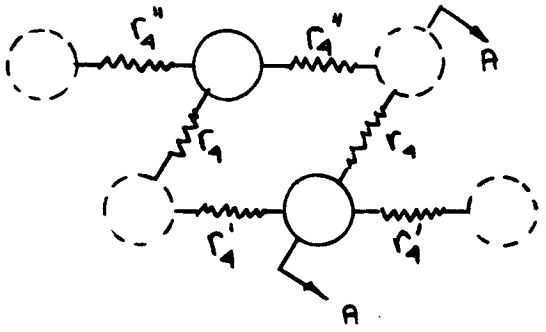
CROSS SECTION OF COMPOSITE SEAL

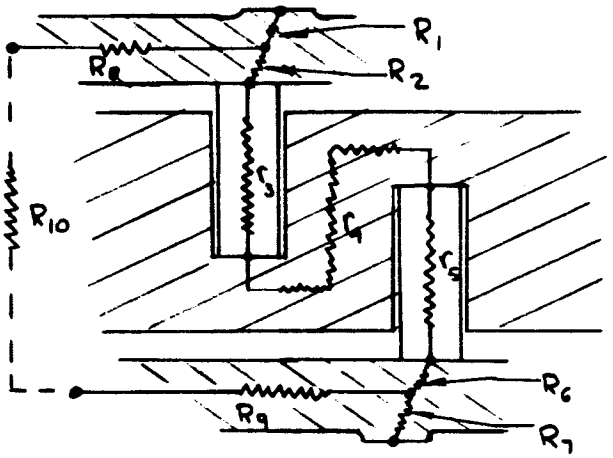
$r = \frac{L}{KA}$, $\frac{HR-°F}{BTU}$

WHERE:

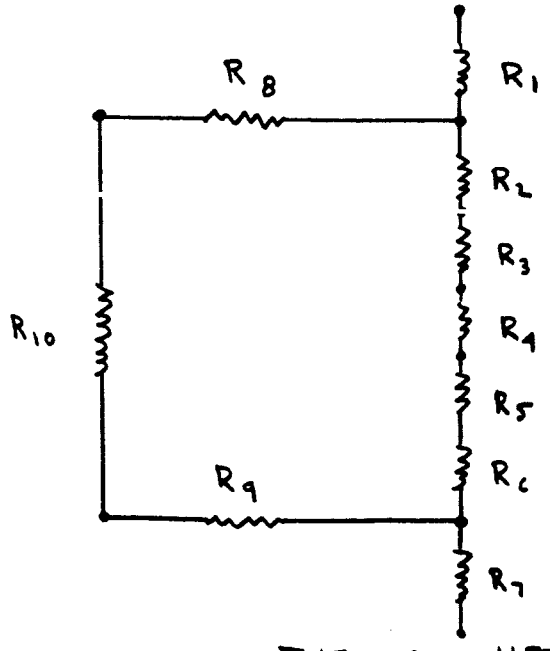
L = LENGTH, FT. , A = AREA, FT^2

K = THERMAL CONDUCTIVITY $\frac{BTU-FT}{FT^2\ HR-°F}$





DETAIL OF BUMPER THERMAL NETWORK



$R_3 = \Sigma r_3$ IN PARALLEL

$R_4 = \Sigma r_4 + \Sigma r_4' + \Sigma r_4''$ IN PARALLEL

$R_5 = \Sigma r_5$ IN PARALLEL

THERMAL NETWORK OF SEAL

FIG. A-A

PREPARED BY P PURGALIS
CHECKED BY
CLASSIFICATION

THE MARQUARDT CORPORATION

DETAIL RESISTANCES

R	PART	RESISTANCE, HR-°F/BTU	
		MAXIMUM	MINIMUM
1	JACKET	0.13	0.12
2	JACKET	0.18	0.17
3	SPACER	3.61	3.18
4	BUMPER	0.29	0.24
5	SPACER	3.61	3.18
6	JACKET	0.18	0.17
7	" "	0.13	0.12
8	" "	5.01	4.20
9	" "	1.66	1.29
10	JACKET	5.01	4.20

$$R_{TOTAL} = R_1 + \frac{(R_2+R_3+R_4+R_5+R_6)(R_8+R_9+R_{10})}{(R_2+R_3+R_4+R_5+R_6+R_8+R_9+R_{10})} + R_7$$

$R_{MAXIMUM}$ = 5.00 HR-°F/BTU

$R_{MINIMUM}$ = 4.29 HR-°F/BTU

FIG. A-B

ATTACHMENT 15

1.0 Object

The object of these tests is to evaluate experimental, high thermal resistance, injector head to combustion chamber seals designed for the Apollo Service Module Reaction Control System (SM/RCS) Engine. Evaluation shall consist of exposing various seals to simulated load and environmental conditions while contained in test fixtures or test engines. Combinations of non-firing and firing tests are designed to determine:

I. Structural Performance
II. Leakage Integrity
III. Thermal Resistance
IV. Performance Under Engine Firing Conditions

2.0 Description of Test Items

2.1 Experimental Seals

The test program shall utilize experimental seals designed to fit seal cavities at the injector head/combustor interface. Some of the seals to be tested require standard seal cavities while others require modified seal cavities. Table 1 lists part numbers, a brief description of each seal, quantities and projected usage. Tests shall not necessarily be limited to those items shown in Table 1. Due to the exploratory nature of this program, modifications may be required to seals shown in Table 1 to improve their performance.

2.2 Associated Test Hardware

Test hardware to be used in support of these tests shall consist of special test rigs, standard and modified Apollo SM RCS Engine parts, sub-assemblies and fireable and non-fireable engine assemblies.

Detail descriptions of special test rigs are shown on REMD layouts L-2053 and L-2054. Engine parts, sub-assemblies and/or complete engine assemblies shall be similar or equivalent to the Apollo SM RCS Qualification Engine assembly described on Drawing 228687.

3.0 General Test Requirements

3.1 General Considerations

3.1.1 Handling and Cleanliness

All test hardware shall be carefully handled during transport, set-up and conduct of tests to obviate damage and maintain cleanliness appropriate to the test being performed. Existing TDPs of each test facility shall be utilized, where applicable.

3.1.2 Equipment

All facility equipment, fluid systems, electrical systems, etc. shall be so constructed to assure compatibility with the tests being performed.

3.1.3 Facility Setup

The Test Department will make all test setups per the appropriate appendix. Existing TDPs maybe utilized in conjunction with appendices, where applicable.

3.1.3.1 Approval

Test setups and setup checkout procedures shall be reviewed and approved by the project delegate assigned to monitoring the test. The results of the checkout must substantiate the accuracy, repeatability and susceptibility to change of environment of the test setup.

After approval of the test setup, no changes are to be made without approval of the project delegate. This requirement shall not apply to instrumentation which may be replaced at any time provided these replacement instruments are certified. If a test is in operation, instruments tagged for overdue calibration shall be brought to the attention of the Program Manager. The test may be continued at the Project Manager's direction.

3.2 Test Fluids

3.2.1 Firing Tests

Propellants used in the firing tests will be nitrogen tetroxide (N_2O_4) and a fuel blend of 50% hydrazine (N_2H_4) and 50% unsymmetrical dimethylhydrazine (UDMH), conforming to MIL-P-26539A and MIL-P-27402, respectively. Propellants shall be filtered (minimum 95%, 5 micron, 100% 18 micron) prior to entering facility tanks. Verification of compliance to the above specifications will be required. Existing TDPs may be applied to determine compliance.

3.2.2 Non-Firing Tests

Other test fluids (i.e., dry nitrogen, argon or water) that are flowed through engine propellant passages shall be free of contaminants such as grease, oil, etc. and be filtered free of all particles 18 microns or greater and a minimum of 95% of 5 micron particles and shall meet the requirements of MPS 210. Existing TDPs may be applied, if applicable.

Test fluids (i.e., liquid nitrogen, alcohol) used for conditioning environments shall be used as commercially available.

3.3 Test Procedures

Test procedures shall be in accordance with appendices categorized and listed below:

3.3.1 Non-Firing Tests

Appendix A - Structural Tests-Static Load

Appendix B - Seal Thermal Resistance-Simulated Engine

Appendix C - Vibration Test-Non-Fireable Engine

Appendix D - Corrosion Test-Simulated Engine

Appendix E - Seal Thermal Resistance-Fireable Engine

3.3.2 Firing Tests

*Appendix F - Firing Test - Apollo SM/RCS Engine W/High Thermal Resistance Head to Chamber Seal

*Includes pre and post burn calibrations

3.3.3 Test Sequence

Sequence of tests described in Paragraph 3.3.1 and 3.3.2 shall be determined by the project and coordinated with the Test Department.

3.3.4 Changes

Due to the exploratory nature of this test program, changes to the test procedures defined in the appendices may be made at the discretion of the cognizant project delegate without formal change to this MTP. In addition, any test may be terminated, extended or re-run as deemed necessary by the project delegate. Formal changes to this document will be made for the record after the fact.

3.4 Data Handling

All test data (i.e., data sheets, tapes, etc.) shall be clearly marked with all necessary information to completely identify it. Identification shall include, but not be limited to the following:

1. Test Number
2. Run Number (s)
3. Facility Identification
4. Date
5. P/N and S/N of Test Item
6. Parameter Identification
7. MTP Number, Appendix and Paragraph Thereof

Additional test records (narrative logs) shall be maintained in a neat, legible manner on reproducible forms.

3.5 Witnesses

3.5.1 Inspection

Marquardt Corporation inspection witnessing of tests shall not be required unless specifically requested in the test appendices.

3.5.2 RESD Engineering

A project appointed delegate shall witness all tests. In the event that said delegate cannot be present, tests may be conducted providing that full cognizance is maintained by the project through adequate liaison.

TABLE - FULL SCALE SEAL SPECIMENS
& PROJECTED USAGE

* CALCULATED MIN. THERMAL RESISTANCE = $\frac{42.-°F}{B.T.U.}$

DESIGN DESCRIPTION	P/N	MATERIALS	THERMAL RESISTANCE *	SPECIMEN IDENT (FEA. FEAD)	PROJECTED USAGE TESTS: THERMAL (RESISTANCE)	STRUCTURAL (STATIC LOAD)	VIBRATION	ENVIRON. (CORROSION)	FIRING	SPACERS	COMMENTS
CONICAL THINWALL (.248/.252 LONG)	T-13621	① REENE'41	3.68	D	X	X	X		X	X	SEAL CAVITY MODIFICATION REQUIRED.
				C							
				B		X	X				
				A	X						
	T-13622	① GAL-4V TITANIUM	5.30	D					X	X	
				C							
				B		X	X				
				A	X						
STRAIGHT THINWALL (.090/.095 LONG)	T-13612	① REENE'41	1.21	D	X	X	X		X	X	NO SEAL CAVITY MODIFICATION IS REQUIRED.
				C							
				B		X	X				
				A	X						
	T-13611	① GAL-4V TITANIUM	1.82	D	X	X	X		X	X	
				C							
				B		X	X				
				A	X						
COMPOSITE (.090/.095 LONG)	T-13619	① 316 CRES ② ZIRCONIUM OXIDE ③ GAL-4V TITANIUM ④ REENE'41	3.77	D	X	X	X	X	X	X	
				C							
				B		X	X				
				A	X						
	T-13618	① 316 CRES ② ZIRCONIUM OXIDE ③ GAL-4V TITANIUM ④ REENE'41	4.67	D					X	X	
				C							
				B		X					
				A	X						

TABLE 1

A-1.0 Objective

The objective of these tests is to evaluate leakage and structural performance of candidate seals under environmental conditions simulating:

I. Engine Heat Soak Back
II. Chamber Pressure Spike (Static)
III. Seal Cavity Propellant Explosion (Static)
IV. Creep (Short Term/Hi Temperature)
V. Storage (Long Term)

A-2.0 Scope

During all tests, candidate seals will be assembled in a special test fixture simulating the current Apollo SM RCS Engine Injector Head/Combustor Joint. Seals will be preloaded in accordance with established Apollo Engine assembly procedures. The seals and all components will be examined and inspected before and after each assembly and disassembly for changes to critical dimensions and assembly leakage rates prior to and after exposure to simulated environmental conditions.

A-3.0 Test Requirements

A-3.1 Simulated Engine Heat Soak Back

This test is designed to evaluate buckling, compression and/or bearing characteristics of candidate seals and adjacent hardware at temperatures simulating engine heat soak back conditions. Sealing capability will also be evaluated.

A-3.1.1 Test Rig

The test rig components described on RESD layout L-2053 shall be used to contain specimen seals. Test rigs will be furnished to the Test Department by the project in a completely assembled condition. Two test rigs will be available.

A-3.1.2 Seal Specimens

Experimental seals will be furnished pre-assembled in the test rigs by the project. Typical candidate seals are described in Table I.

A-3.1.3 Facilities

A-3.1.3.1 Precision Assembly Department, Building 3

This facility shall be used for inspection and evaluation of seals and all test rig components. Assembly and disassembly and pressure test operations shall also be conducted in this area with available Apollo Engine tools and equipment.

A-3.1.3.2 Structures Laboratory, Building 31

Tests, simulating engine heat soak back conditions, shall be performed in this facility. Heat generating equipment, controls and temperature recorders will be utilized.

A-3.1.4 Test Setup

The test setup shall be in general accordance with Figure 1.

A-3.1.5 Instrumentation

Thermocouples will be used to monitor test rig temperatures. Identification, location, type and range of thermocouples is shown in Figure 1. Installation of this instrumentation shall be in accordance with RESD layout L-2053.

A-3.1.6 Procedure

A-3.1.6.1 Inspect and record critical dimensions and features of candidate seal and sealing surfaces of adjacent components of test rig shown on Figure 2.

A-3.1.6.2 Assemble test rig per RESD layout L-2053. Record bolt torque and length information as shown on Figure 2.

A-3.1.6.3 Pressurize the test rig assembly to 175 ± 5 psig with dry nitrogen. Isolate pressure source and record pressure decay in 5 minutes as shown in Figure 2.

A-3.1.6.4 Deliver assembled test rig to structures laboratory and set up in general accordance with Figure 1.

A-3.1.6.5 Photograph setup as required.

A-3.1.6.6 The heating cycle shown on Figure 3 shall be applied to the test rig by energizing the quartz lamp circuits. A number of preliminary runs may be required to obtain satisfactory temperature transients, after establishment of proper programming, a total of 6 cycles shall be conducted and recorded. Each cycle shall be

started with the test rig hardware at approximately room temperature. Forced convection cooling may be employed to accelerate testing.

A-3.1.6.7 Disconnect test rig and deliver to precision assembly department.

A-3.1.6.8 Repeat paragraph A-3.1.6.3.

A-3.1.6.9 Prior to disassembly, inspect and record bolt lengths. Disassemble test rig and repeat paragraph 3.1.6.1. Note or photograph, as required, any macroscopically apparent deficiencies.

A-3.1.6.10 Refurbish and/or reclean components as required in preparation for next seal specimen.

A-3.2 Simulated Chamber Pressure Spike (Static)

This test is designed to evaluate structural characteristics, hoop load capacity and sealing capability of candidate seals at steady state pressure and temperature simulating chamber pressure spike conditions.

A-3.2.1 Test Rig

The test rig components described on RESD layout L-2053 shall be used to contain specimen seals. Test rigs will be furnished to the Test Department by the project in a completely assembled condition. Two test rigs will be available.

A-3.2.2 Seal Specimens

Experimental seals will be furnished pre-assembled in the test rigs by the project. Typical candidate seals are described in Table I.

A-3.2.3 Facilities

A-3.2.3.1 Precision Assembly Department, Building 3

This facility shall be used for inspection and evaluation of seals and all test rig components. Assembly and disassembly and pressure test operations shall also be conducted in this area with available Apollo Engine tools and equipment.

A-3.2.3.2 Structures Laboratory, Building 31

Tests, simulating engine chamber pressure spike conditions shall be performed in this facility. Low temperature generating equipment, hydrostatic pressurizing systems and temperature recorders will be utilized.

A-3.2.4 Test Setup

The test setup shall be in general accordance with Figure 4.

A-3.2.5 Instrumentation

A thermocouple and pressure gage will be used to monitor temperature and pressure. Identification, location, type and range is shown in Figure 4. Installation of the thermocouple shall be in accordance with RESD layout L-2053.

A-3.2.6 Procedure

A-3.1.6.1 Inspect and record critical dimensions and features of candidate seal and sealing surfaces of adjacent components of test rig shown on Figure 2.

A-3.2.6.2 Assemble test rig per RESD layout L-2053. Record bolt torque and length information as shown on Figure 2.

A-3.2.6.3 Pressurize the test rig assembly to 175 ± 5 psig with dry nitrogen. Isolate pressure source and record pressure decay in 5 minutes as shown in Figure 2.

A-3.2.6.4 Deliver assembled test rig to structures labroatory and setup in general accordance with Figure 4.

A-3.2.6.5 Photograph setup as required.

A-3.2.6.6 The entire test rig assembly shall be subjected to a temperature of $\cong 0^{o}F$ by immersion in a mixture of alcohol and dry ice. After temperature stabilization has been achieved, the test rig shall be pressurized hydrostatically with alcohol to 1200 psig in steps of 200 psi. At each step, the pressure within the test rig shall be isolated from the pressure source and pressure decay shall be recorded in one minute. One (1) pressurization cycle shall be conducted. At the conclusion of the test, forced convection heating to room temperature may be employed to accelerate operations.

A-3.2.6.7 Disconnect test rig and deliver to precision assembly department.

A-3.2.6.8 Repeat paragraph A-3.2.6.3

A-3.2.6.9 Prior to disassembly, inspect and record bolt lengths. Disassemble test rig and repeat paragraph 3.2.6.1. Note or photograph as required, any macroscopically apparent deficiencies.

A-3.2.6.10 Refurbish and/or reclean components as required in preparation for next seal specimen.

A-3.3 Simulated Seal Cavity Propellant Explosion (Static)

This test is designed to evaluate structural characteristics, hoop load capacity and sealing capability of candidate seals at steady state pressure and temperatures simulating seal cavity pressure spikes due to propellant reactions within the seal cavity.

Similarities between this test and test A-3.2 may permit combining said tests in certain cases at the discretion of the project.

A-3.3.1 Test Rig

Same as described in A-3.2.1

A-3.3.2 Seal Specimens

Same as described in A-3.2.2.

A-3.3.3 Facilities

Same as described in A-3.2.3.

A-3.3.4 Test Setup

The test setup shall be in general accordance with Figure 5. When this test is combined with Test A-3.2, the setup shall be identical to that described in A-3.2.4.

A-3.3.5 Instrumentation

A pressure gage will be used to monitor pressure. Pressure range shall be as indicated in Figure 5. When this test is combined with Test A-3.2, the instrumentation shall be identical to that described in A-3.2.5.

A-3.3.6 Procedure

A-3.3.6.1 Same as described in A-3.2.6.1.

A-3.3.6.2 Same as described in A-3.2.6.2.

A-3.3.6.3 Same as described in A-3.2.6.3.

A-3.3.6.4 Same as described in A-3.2.6.4.

A-3.3.6.5 Same as described in A-3.2.6.5.

A-3.3.6.6 The entire test rig assembly shall be stabilized to room temperature. Automatic temperature monitoring through recorders is not required. The test rig shall be pressurized hydrostatically with alcohol to levels exceeding 1200 psig until loss of pressure containment, as indicated by gross leakage and rapid pressure decay

are apparent. Pressure steps and cutoff pressure level shall be determined by the cognizant project delegate.

When this test is combined with Test A-3.2, the requirements of A-3.2.6.6 shall prevail except pressure level shall be as indicated above.

A-3.3.6.7 Same as described in A-3.2.6.7.

A-3.3.6.8 Repeat paragraph A-3.3.6.3.

A-3.3.6.9 Same as described in A-3.2.6.9.

A-3.3.6.10 Same as described in A-3.2.6.10.

A-3.4 Creep (Short Term/High Temperature)

This test is designed to evaluate creep characteristics and sealing capability of candidate seals after exposure to prolonged high temperature environment. The time/temperature environment will simulate cumulative engine heat soak back conditions.

Similarities between this test and Test A-3.1 may permit combining these tests in certain cases at the discretion of the project.

A-3.4.1 Test Rig

Same as described in A-3.1.1.

A-3.4.2 Seal Specimens

Same as described in A-3.1.2.

A-3.4.3 Facilities

Same as described in A-3.1.3.

A-3.4.4 Test Setup

Same as described in A-3.1.4.

A-3.4.5 Instrumentation

Same as described in A-3.1.5.

A-3.4.6 Procedure

A-3.4.6.1 Same as described in A-3.1.6.1

A-3.4.6.2 Same as described in A-3.1.6.2

A-3.4.6.3 Same as described in A-3.1.6.3

A-3.4.6.4 Same as described in A-3.1.6.4

A-3.4.6.5 Same as described in A-3.1.6.5

A-3.4.6.6 The heating cycle shall be the same as shown in Figure 3 except that peak temperatures shall be maintained for 30 minutes. The test rig temperatures shall be maintained by energizing and modulating the quartz lamp circuits and/or the cold sink as required. A number of short preliminary runs may be required to establish satisfactory conditions. After establishment of proper programming, one (1) cycle consisting of a 30 minute dwell at peak temperatures shall be conducted and recorded. Forced convection cooling shall be applied as required to facilitate operations.

When this test is combined with Test A-3.1, it shall be performed at the conclusion of paragraph A-3.1.6.6.

A-3.4.6.7 Same as described in A-3.1.6.7.

A-3.4.6.8 Repeat paragraph A-3.4.6.3.

A-3.4.6.9 Same as described in A-3.1.6.9.

A-3.4.6.10 Same as described in A-3.1.6.10.

A-3.5 Storage (Long Term)

This test is designed to evaluate creep characteristics and sealing capability of candidate seals after prolonged exposure to conditions simulating storage.

Similarities between this test and Test A-3.4 may permit combining these tests in certain cases at the discretion of the project.

A-3.5.1 Test Rig

Same as described in A-3.1.1 or suitable alternate consisting of a partial engine assembly sufficient to accommodate simulation.

A-3.5.2 Seal Specimens

Same as described in A-3.1.2.

A-3.5.3 Facilities

A-3.5.3.1 Same as described in A-3.1.3.1.

A-3.5.3.2 Structures Laboratory, Building 31

Tests, simulating storage conditions shall be performed in this facility. Radiation heat generating equipment shall be utilized.

A-3.5.4 Test Setup

The setup shall be in general accordance with Figure 6. When this test is combined with Test A-3.4, the setup shall be similar to that described in A-3.1.4 with appropriate modification to suit test conditions and facilitate economy.

A-3.5.5 Instrumentation

A standard thermometer, as indicated in Figure 6, shall be used to monitor the temperature environment.

A-3.5.6 Procedure

A-3.5.6.1 Same as described in A-3.1.6.1.

A-3.5.6.2 Same as described in A-3.1.6.2.

A-3.5.6.3 Same as described in A-3.1.6.3.

A-3.5.6.4 Same as described in A-3.1.6.4.

A-3.5.6.5 Same as described in A-3.1.6.5.

A-3.5.6.6 The entire test rig assembly shall be heated to a temperature of 120°F ± 10°F by heat lamps. The temperature shall be maintained continuously for 30 days.

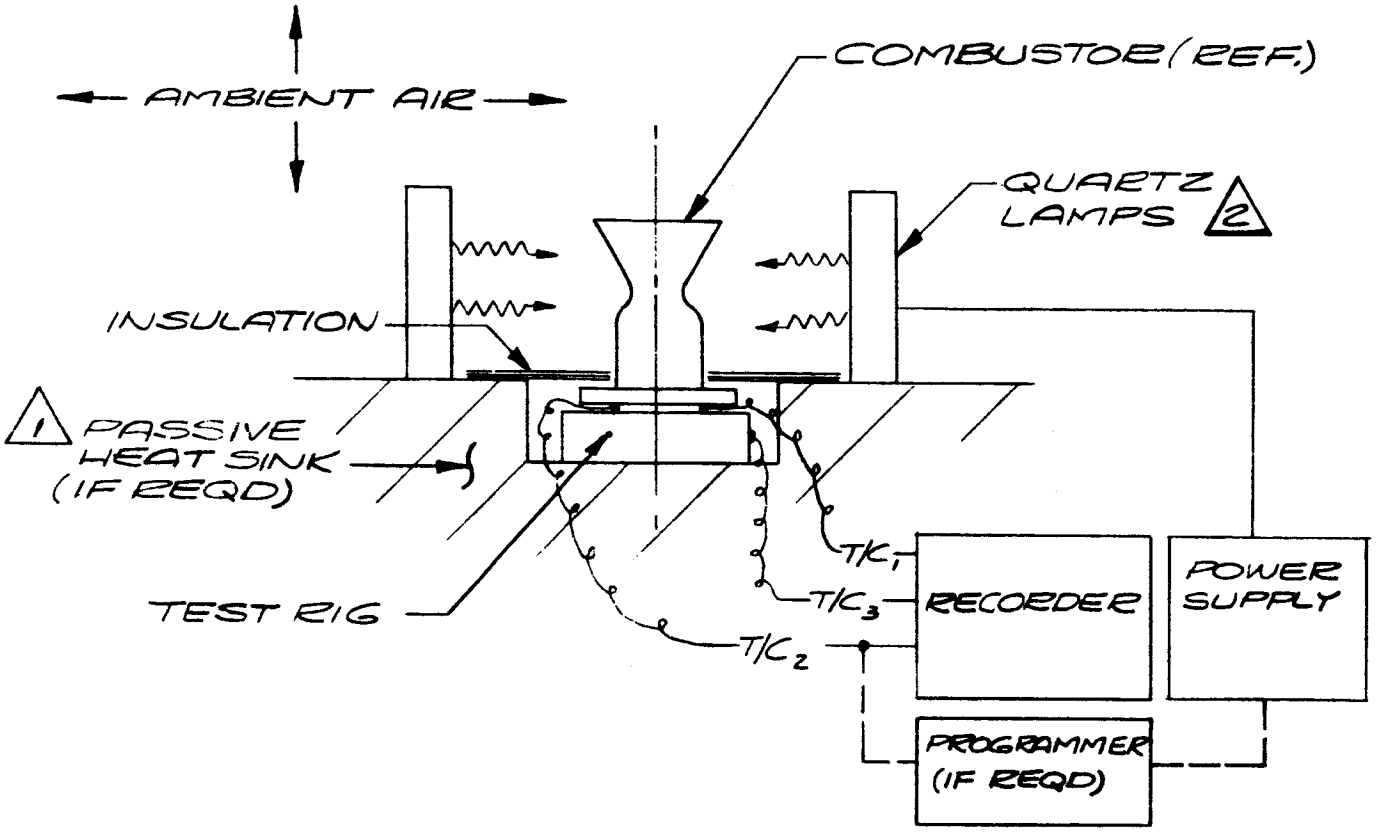
A-3.5.6.7 Same as described in A-3.1.6.7.

A-3.5.6.8 Repeat paragraph A-3.5.6.3.

A-3.5.6.9 Same as described in A-3.1.6.9.

A-3.5.6.10 Same as described in A-3.1.6.10.

SCHEMATIC OF SETUP FOR TESTS A-3.1 & A-3.4



T/C NO.	LOCATION	TYPE	RANGE °F
1	COMBUSTOR FLANGE	C/A	75-600+
2	COMBUSTOR FLANGE (180° OPPOSITE T/C 1)	C/A	75-600+
3	HEAD	C/A	75-350

(1) PASSIVE HEAT SINK PREFERRED. A SIMPLE, ACTIVE HEAT SINK MAY BE REQUIRED TO OBTAIN DESIRED TEMPERATURE DISTRIBUTION.

(2) QUANTITY AND SPACING AS REQUIRED TO OBTAIN UNIFORM HEATING OF COMBUSTOR.

DIMENSIONAL & LEAKAGE RATE RECORD

PART NO. _____
S/N _____

MTP0041 TEST NO. _____
AND/OR
TEST APPENDIX LTR. _____

PRE-TEST REQUIREMENTS

ITEM	PARAMETER	INSPECTION RECORD
SEAL	DIMENSIONAL INSPECTION	ATTACH COPY OF RECEIVING INSPECTION DIMENSIONAL REPORT FOR P/N & S/N SHOWN ABOVE. (SUPPLIED BY ENGRG.)
HEAD	SEALING SURFACE ROUGHNESS & FLATNESS	(1) ✓ SURFACE ROUGHNESS _____ FLATNESS
COMBUSTOR FLANGE		(1) ✓ SURFACE ROUGHNESS _____ FLATNESS
COMBUSTOR ATTACH BOLTS (6)	FREE LENGTH	1 | 2 | 3 | 4 | 5 | 6
	ASSEMBLY TORQUE	
	ASSEMBLED LENGTH	
TEST RIG ASSY	SEAL LEAKAGE	_____ PSI DECAY/5 MINUTES

POST-TEST REQUIREMENTS

ITEM	PARAMETER	INSPECTION RECORD
SEAL	DIMENSIONAL INSPECTION	CRITICAL DIMENSIONS TO BE DETERMINED BY ENGRG. RECORD DIM'S ON INSP. RECORD FORM MAC 8889 & ATTACH HERETO.
HEAD	SEALING SURFACE CHARACTERISTICS	(2)
COMBUSTOR FLANGE		(2)
COMBUSTOR ATTACH BOLTS (6)	ASSEMBLED LENGTH	1 | 2 | 3 | 4 | 5 | 6
	DISASSEMBLY TORQUE	
	FREE LENGTH	
TEST RIG ASSY	SEAL LEAKAGE	_____ PSI DECAY/5 MINUTES

(1) NEED FOR THIS INSPECTION TO BE DETERMINED BY PROJECT DELEGATE.

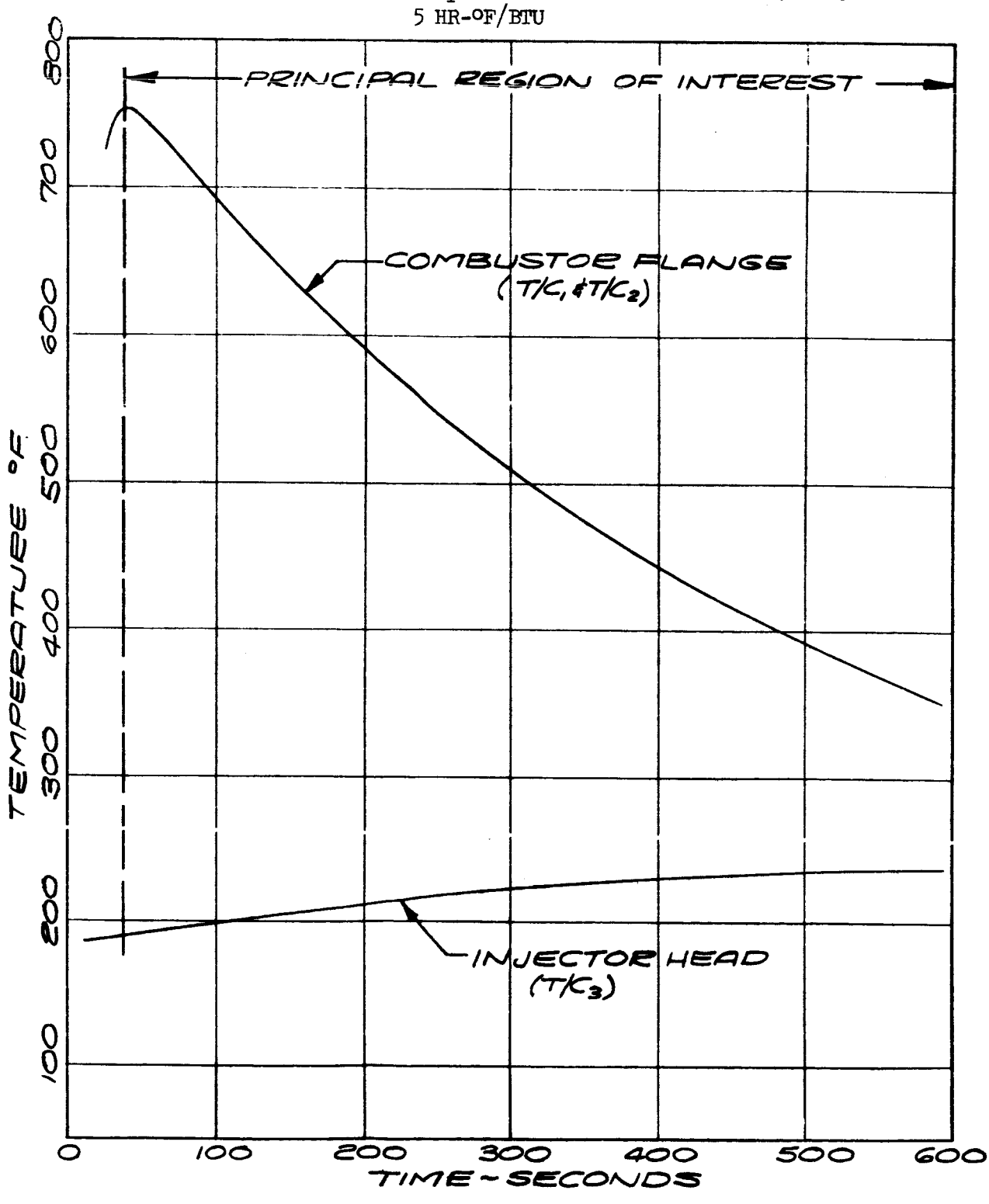
(2) PARTICULAR CHARACTERISTICS TO BE RECORDED (IF ANY) TO BE DETERMINED BY PROJECT DELEGATE. ATTACH SEPARATE INSP. REPORT IF NECESSARY.

FIGURE 2

HEATING CYCLE - TEST A-3.1

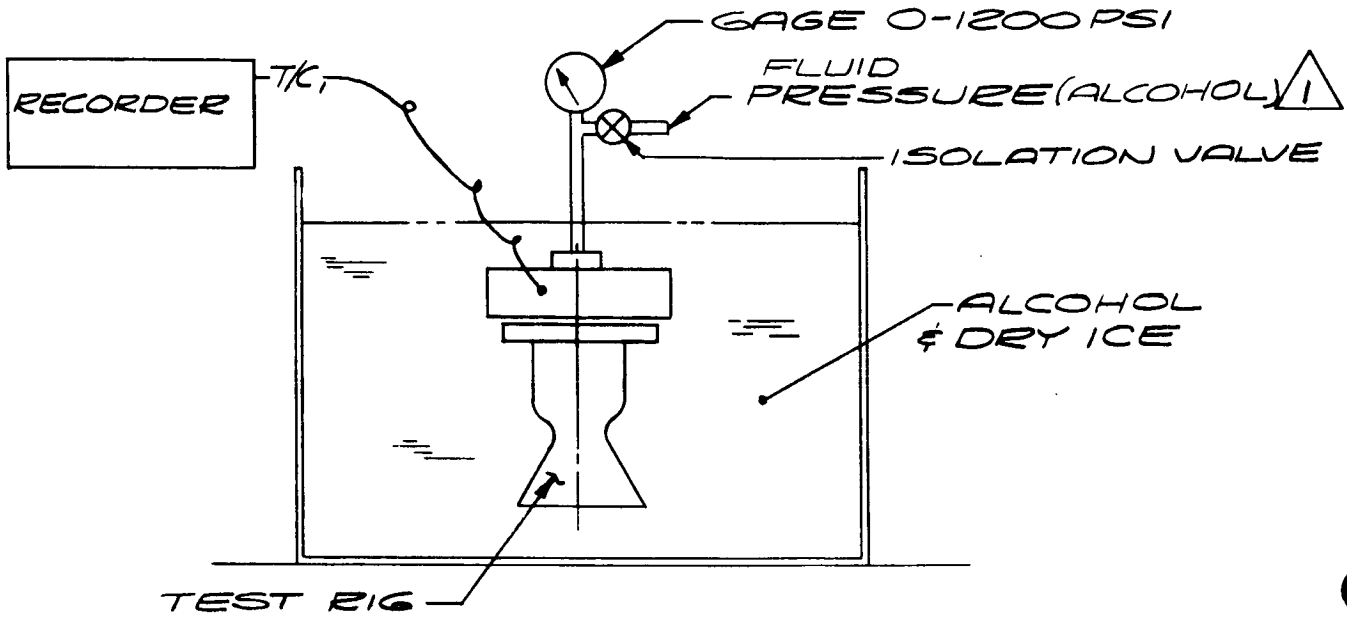
NOTE: Temperature transients shown are theoretical* for engine heat soakback after a steady state burn. Transients shown in the region of interest shall be regarded as targets for this test.

*Computed for seal thermal resistance 5 HR-°F/BTU



FIGUEE 3

SCHEMATIC OF SETUP FOR TEST A-3.2

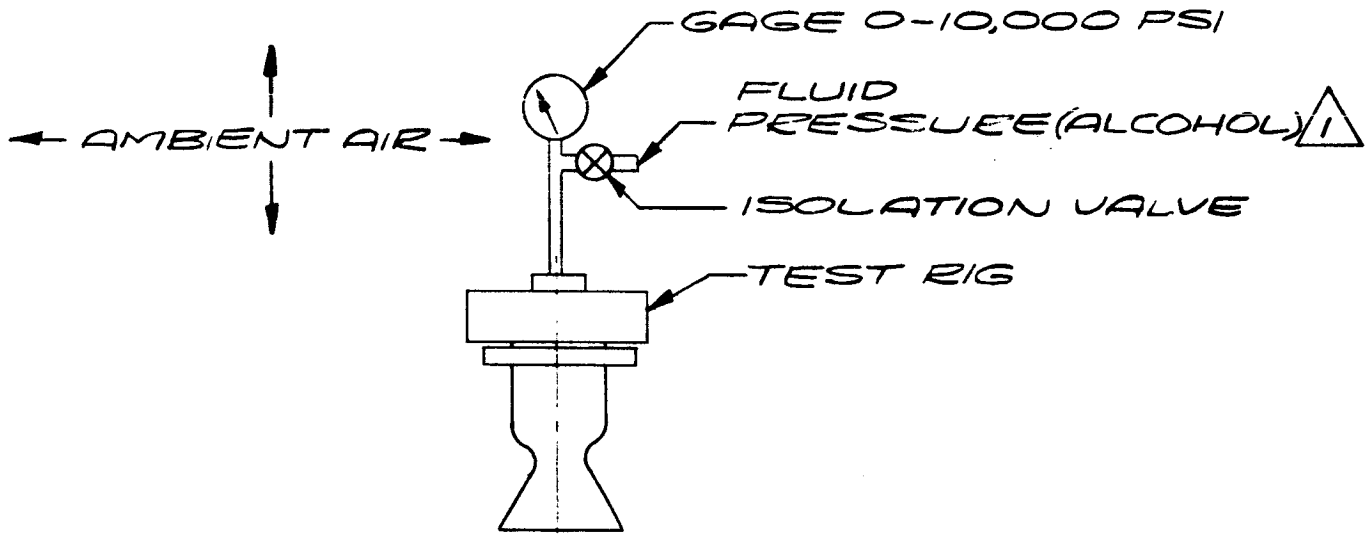


T/C NO.	LOCATION	TYPE	RANGE °F
1	COMBUSTOR FLANGE	I/C	-20°-75°

1 PRESSURE SOURCE - HAND OPERATED PUMP

FIGURE 4

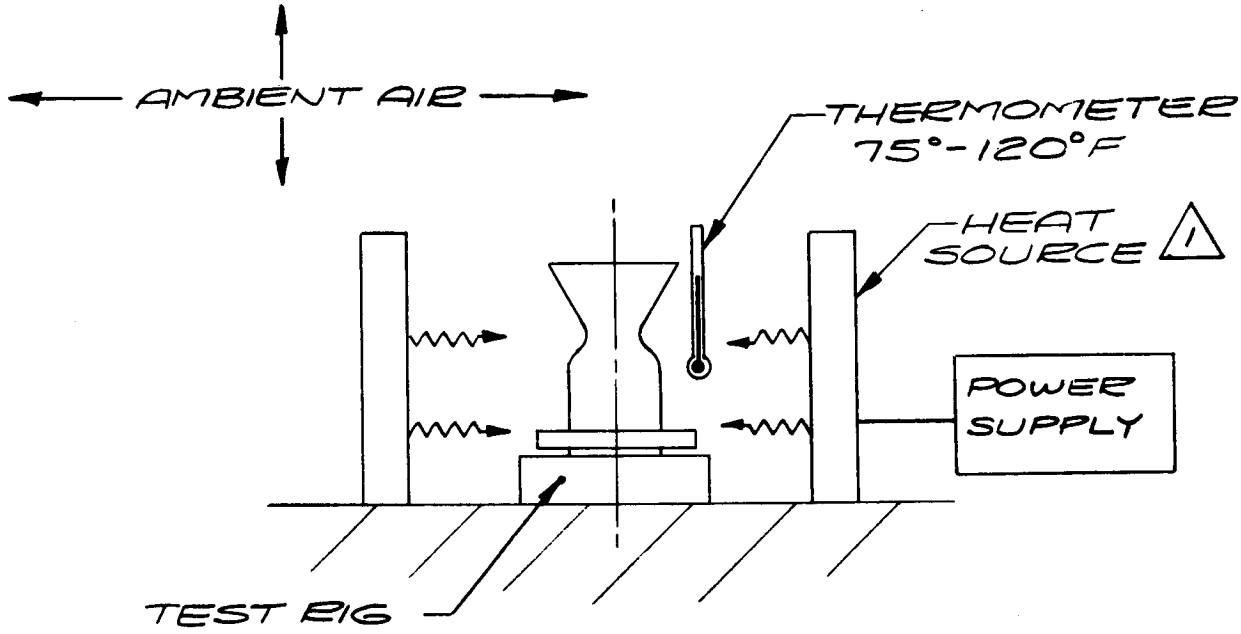
SCHEMATIC OF SETUP FOR TEST A-3.3



1 PRESSURE SOURCE - HAND OPERATED PUMP

FIGURE 5

SCHEMATIC OF SETUP FOR TEST A-3.5



1 HEAT LAMPS, HOT BOX, ETC. - AS REQUIRED TO OBTAIN UNIFORM HEATING OF TEST RIG.

FIGURE 6

B-1.0 Objective

The objective of these tests is to measure the thermal resistance of candidate high thermal resistance seals in a simulated engine.

B-2.0 Scope

During all tests, candidate seals will be assembled in a special test fixture simulating the current Apollo SM RCS Engine Injector Head/Combustor Joint. Seals will be pre-loaded in accordance with established Apollo Engine assembly procedures. The seals will be pressure tested in the fixture prior to and after the thermal resistance measurement tests.

B-3.0 Test Requirements

B-3.1.1 Test Rig

The test rig components described on RESD layout L-2054 shall be used to contain specimen seals. The test rig will be furnished to the Test Department by the project in a completely assembled condition. One test rig, capable of testing two seals simultaneously, will be available.

B-3.1.2 Seal Specimens

Experimental seals will be furnished pre-assembled in the test rig by the project. Typical candidate seals are described in Table I.

B-3.1.3 Facilities

B-3.1.3.1 Precision Assembly Department, Building 3

This facility shall be used for assembly, disassembly and pressure test operations of the test rig assembly.

B-3.1.3.2 Cold Wall Space Simulator, Building 32

Tests, simulating engine cold soak conditions, shall be performed in this facility. The liquid nitrogen cooled vacuum chamber, electrical power supplies, controls and temperature recorders will be utilized.

B-3.1.4 Test Setup

The test setup shall be in general accordance with Figure 1.

B-3.1.4.1 Description (Ref: Layout L-2054 and Figure 1)

Vacuum Chamber - The coldwall shall be capable of being cooled by liquid nitrogen to - 320°F. The coldwall surface emissivity shall be >0.9. The vacuum system shall be capable of steady state vacuum chamber pressure of 10^{-4}MM of Hg for a minimum of 72 hours.

Guard Boundary - A resistance heating element blanket wrapped on the exterior of the aluminum guard boundary tube shall maintain the boundary temperature the same as the simulated injector heads. Interior wall emissivity shall be >0.9. Alternating current power will be used to energize the heating element.

Simulated Injector Head - A simulated injector head shall contain a specimen seal within its cavity. Regulated D.C. power shall be supplied to an electrical heater on the head to provide heat input to the thermal circuit. One or two heads may be used in the setup.

Combustor & Attach Hardware - Apollo SM RCS Engine combustor and attach hardware shall provide seal clamping load in combination with the simulated head. One combustor and set of attach hardware is used with each head to conduct heat to the radiator.

Radiator - An aluminum cylindrical radiator collects heat from the combustor and rejects it to the vacuum chamber coldwall.

B-3.1.5 Power Supplies

The facility shall provide three separate power supplies for:

1. Boundary Heater - Variac controlled A.C., adjustable from 0 to 120 volts (1 required).

2. Injector Head Heaters - D.C., adjustable from 0 to 100 volts (2 required).

B-3.1.6 Instrumentation

Thermocouples and internal reference point Brown recorders will be used to monitor test rig temperature gradients and coldwall temperatures. Identification, location and type of thermocouples are shown in Figure 2. Installation of thermocouples on the test rig shall be in accordance with RESD layout L-2054.

B-3.1.7 Procedure

B-3.1.7.1 Inspect and record critical dimensions and features of candidate seal and sealing surfaces of adjacent components of test rig shown on Figure 3.

B-3.1.7.2 Assemble test rig per RESD layout L-2054. Record bolt torque and length information as shown on Figure 3.

B-3.1.7.3 Pressurize the test rig assembly to 175 ± 5 psi with dry nitrogen. Isolate pressure source and record pressure decay in five minutes as shown on Figure 3.

B-3.1.7.4 Deliver assembled test rig to coldwall space simulator facility, Building 32 and set up in general accordance with Figure 1.

B-3.1.7.5 Photograph setup as required.

B-3.1.7.6 Thermal Resistance Measurement Test Operation:

B-3.1.7.6.1 Start vacuum pump.

B-3.1.7.6.2 Start temperature recorders and LN_2 flow when pressure $\leq 10^{-2}$ MM H_g. Recorders are to be left on at all times during the test. Sufficient LN_2 will be available at the start to allow continuous operation for 40 hours.

B-3.1.7.6.3 Turn on all heaters.

B-3.1.7.6.4 Regulate heat input until the desired temperature of the simulated injector head(s) is obtained. Three different heat input levels will be conducted in series starting with a seal temperature of $\simeq 0^{\circ}F$. The remaining two input levels shall be determined by the cognizant project delegate.

B-3.1.7.6.5 At each heat input level, the supply voltage to the heaters shall be kept constant for one hour. All temperatures will then be allowed to reach steady state and recorded along with heater voltage and current.

B-3.1.7.6.6 Turn off LN_2 and vacuum pumps and secure system.

B-3.1.7.6.7 Open chamber and remove test rig. Allow test rig to stabilize to approximate room temperature. No attempt to accelerate warming time shall be made.

B-3.1.7.7 Deliver test rig to precision assembly department.

B-3.1.7.8 Repeat paragraph B-3.1.7.3.

B-3.1.7.9 Prior to disassembly, inspect and record bolt lengths. Disassemble test rig and repeat paragraph B-3.1.7.1. Note or photograph, as required, any macroscopically apparent deficiencies.

B-3.1.7.10 Refurbish and/or reclean components as required in preparation for next seal specimen.

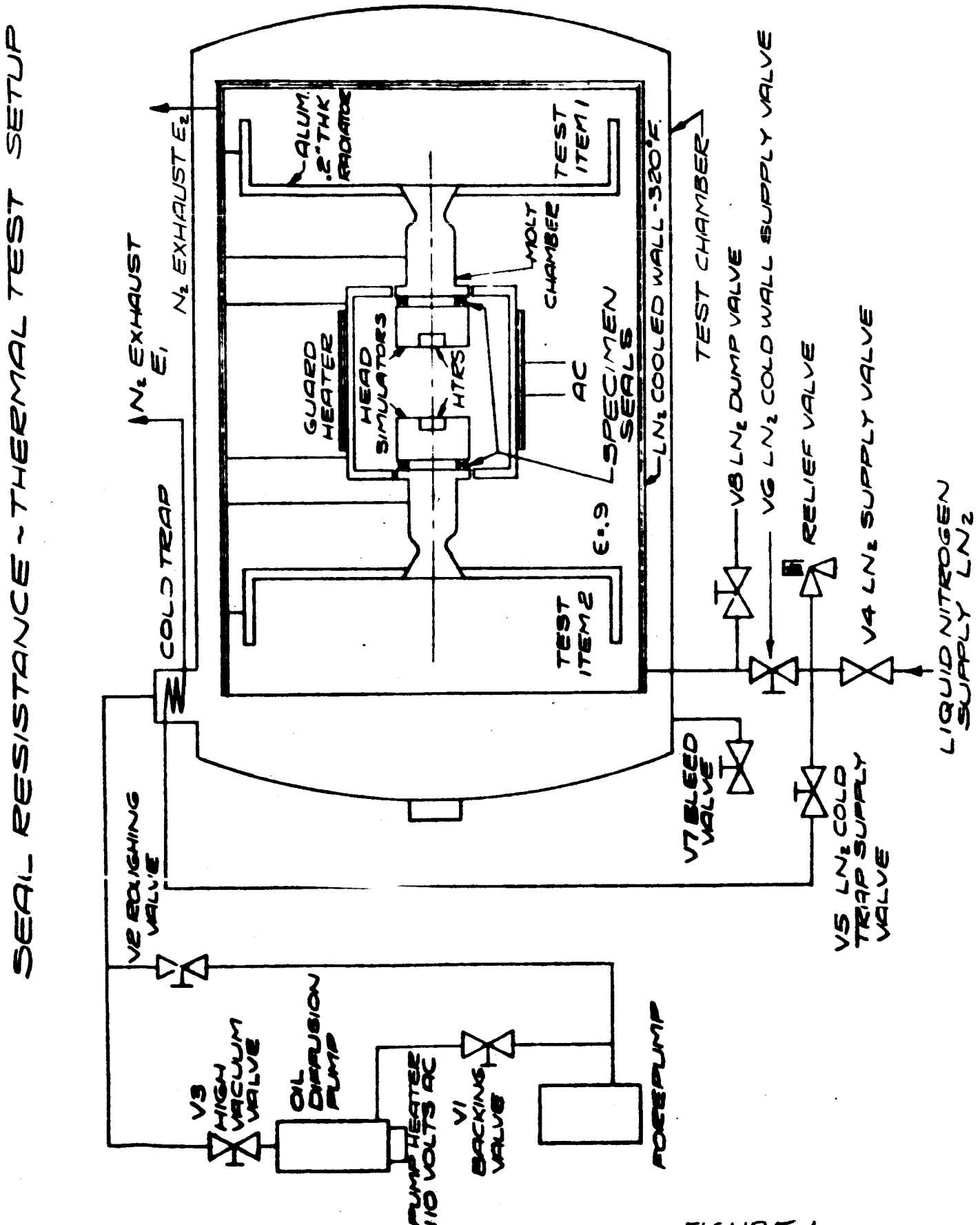
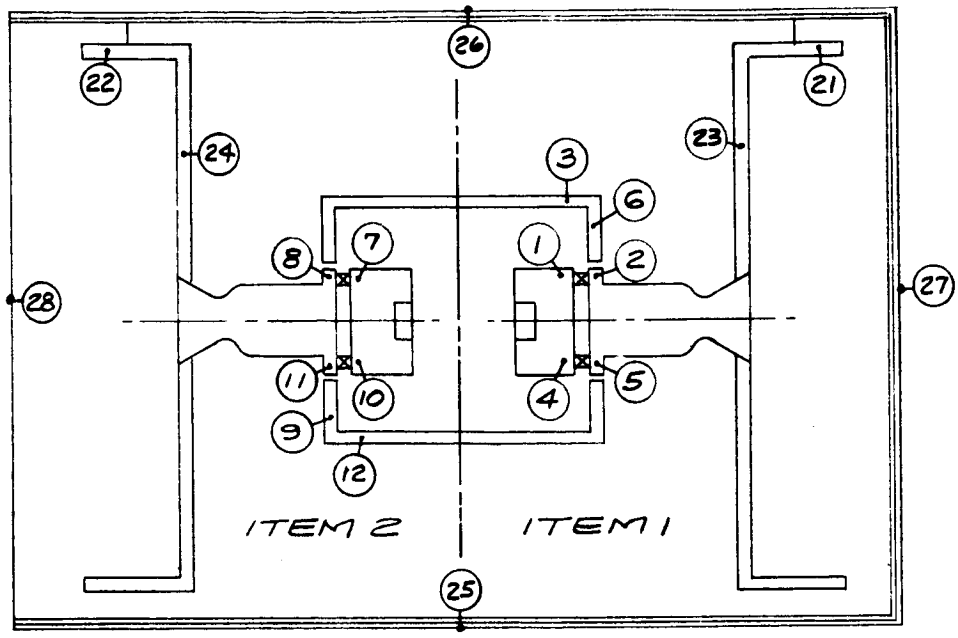

SEAL RESISTANCE - THERMAL TEST SETUP
ALUM. .2" THK RADIATOR
TEST ITEM 1
MOLY CHAMBER
GUARD HEATER
HEAD SIMULATORS
HTRS
AC
SPECIMEN SEALS
LN2 COOLED WALL -320°F
TEST CHAMBER
TEST ITEM 2
ε: 9
N2 EXHAUST E2
N2 EXHAUST E1
COLD TRAP
V8 LN2 DUMP VALVE
V6 LN2 COLD WALL SUPPLY VALVE
RELIEF VALVE
V4 LN2 SUPPLY VALVE
LIQUID NITROGEN SUPPLY LN2
V7 BLEED VALVE
V5 LN2 COLD TRAP SUPPLY VALVE
V2 ROUGHING VALVE
V3 HIGH VACUUM VALVE
OIL DIFFUSION PUMP
PUMP HEATER 110 VOLTS AC
V1 BACKING VALVE
ROTARY PUMP

FIGURE 1

SCHEMATIC OF INSTRUMENTATION



T/C NO.	LOCATION	ITEM	TYPE
1	INJ. HD. ADJACENT TO SEAL	1	I/C
2	COMBUSTOR FLANGE OPPOSITE T/C 1	1	I/C
3	TOP OF BOUNDARY FIXTURE	1	I/C
4	INJ. HD ADJACENT TO SEAL (180° OPP. T/C 1)	1	I/C
5	COMBUSTOR FLANGE OPPOSITE T/C 4	1	I/C
6	END OF BOUNDARY FIXTURE OPP. T/C 3	1	I/C
7	INJ. HD. ADJACENT TO SEAL	2	I/C
8	COMBUSTOR FLANGE OPPOSITE T/C 7	2	I/C
9	END OF BOUNDARY FIXTURE	2	I/C
10	INJ. HD. ADJACENT TO SEAL (180° OPP. T/C 7)	2	I/C
11	COMBUSTOR FLANGE OPPOSITE T/C 10	2	I/C
12	BOTTOM OF BOUNDARY FIXTURE OPP. T/C 9	2	I/C
13			
14			
15			
16			
17			
18			
19			
20			
21	TOP OF RADIATOR	1	C/A
22	TOP OF RADIATOR	2	C/A
23	WALL OF RADIATOR	1	C/A
24	WALL OF RADIATOR	2	C/A
25	BOTTOM OF LN_2 COOLED WALL	-	C/A
26	TOP " " " "	-	C/A
27	END " " " "	-	C/A
28	UNCOOLED WALL	-	C/A

FIGURE 2

DIMENSIONAL & LEAKAGE RATE RECORD

PART NO. _____
S/N _____

MTP0041 TEST NO. AND/OR TEST APPENDIX LTR. _____

PRE-TEST REQUIREMENTS

ITEM	PARAMETER	INSPECTION RECORD
SEAL	DIMENSIONAL INSPECTION	ATTACH COPY OF RECEIVING INSPECTION DIMENSIONAL REPORT FOR P/N & S/N SHOWN ABOVE. (SUPPLIED BY ENGRG.)
HEAD	SEALING SURFACE ROUGHNESS & FLATNESS	(1) ___√___ SURFACE ROUGHNESS ___–___ FLATNESS
COMBUSTOR FLANGE		(1) ___√___ SURFACE ROUGHNESS ___–___ FLATNESS
COMBUSTOR ATTACH BOLTS (6)	FREE LENGTH	1 _____ 2 _____ 3 _____ 4 _____ 5 _____ 6 _____
	ASSEMBLY TORQUE	_____ _____ _____ _____ _____ _____
	ASSEMBLED LENGTH	_____ _____ _____ _____ _____ _____
TEST RIG ASSY	SEAL LEAKAGE	_____ PSI DECAY/5 MINUTES

POST-TEST REQUIREMENTS

ITEM	PARAMETER	INSPECTION RECORD
SEAL	DIMENSIONAL INSPECTION	CRITICAL DIMENSIONS TO BE DETERMINED BY ENGRG. RECORD DIM'S ON INSP. RECORD FORM MAC 5869 & ATTACH HERETO.
HEAD	SEALING SURFACE CHARACTERISTICS	(2)
COMBUSTOR FLANGE		(2)
COMBUSTOR ATTACH BOLTS (6)	ASSEMBLED LENGTH	1 _____ 2 _____ 3 _____ 4 _____ 5 _____ 6 _____
	DISASSEMBLY TORQUE	_____ _____ _____ _____ _____ _____
	FREE LENGTH	_____ _____ _____ _____ _____ _____
TEST RIG ASSY	SEAL LEAKAGE	_____ PSI DECAY/5 MINUTES

(1) NEED FOR THIS INSPECTION TO BE DETERMINED BY PROJECT DELEGATE.

(2) PARTICULAR CHARACTERISTICS TO BE RECORDED (IF ANY) TO BE DETERMINED BY PROJECT DELEGATE. ATTACH SEPARATE INSP. REPORT IF NECESSARY.

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FIGURE 3

C-1.0 Objective

The objective of this test is to evaluate leakage and structural performance of candidate high thermal resistance seals after exposure to vibratory loading conditions.

C-2.0 Scope

During the vibration tests, candidate seals will be assembled in a non-fireable engine simulating the current Apollo SM-RCS Engine. Seals will be pre-loaded in accordance with established Apollo engine assembly procedures. The seals and all components comprising the head/combustor joint will be examined and inspected before and after each assembly and disassembly for changes to critical dimensions and assembly leakage rates prior to and after exposure to random boost vibration loadings simulating Apollo launch aerodynamic turbulance.

C-3.0 Test Requirements

C-3.1 Random Vibration Test

C-3.1.1 Test Rig

The test rig shall be comprised of a non-fireable "T" engine and vibration test fixtures. The test fixtures shall be those which were utilized in Apollo PFRT and qualification engine tests.

C-3.1.2 Seal Specimens

Experimental seals will be furnished pre-assembled in the test engine by the project. Typical candidate seals are described in Table I.

C-3.1.3 Facilities

C-3.1.3.1 Precision Assembly Department - Building 3

This facility shall be used for assembly, disassembly and pressure test operations of the test engine.

C-3.1.3.2 Vibration Laboratory, Building 44

Tests simulating aerodynamic turbulance (random vibrations) shall utilize shaker(s), controls and power equipment in this facility. Spectral analysis equipment, available in Bldg. 32, will also be utilized for magnetic tape data reduction.

C-3.1.4 Test Setup-Vibration

The test setup shall be in general accordance with Figures 2a and 2b.

C-3.1.5 Instrumentation - Vibration

The engine shall be instrumented per Figure 3. The instrumentation may be installed per existing test department procedures (TDP). Accelerometers for all recorded parameters shall have a facility calibration prior to vibration of the engine unless otherwise directed by the cognizant project delegate.

C-3.1.6 Procedure

C-3.1.6.1 Inspect and record critical dimensions and features of candidate seal and sealing surfaces of adjacent components comprising the head/combustor joint shown on Figure 1.

C-3.1.6.2 Assemble engine per E.E.O. or T.W.E.O. provided by the project. Record bolt torque and length information as shown in Figure 1.

C-3.1.6.3 Pressurize the engine assembly (combustor and seal cavity) to 175 ± 5 psig with dry nitrogen. Isolate pressure source and record pressure decay in 5 minutes as shown in Figure 1.

C-3.1.6.4 Deliver assembled engine to vibration laboratory, Bldg. 44 and set up in general accordance with Figures 2a and 2b.

C-3.1.6.5 Photograph setup as required.

C-3.1.6.6 Random Vibration Test Operation:

C-3.1.6.6.1 The vibration test sequence shall be conducted as shown in the Table below. Instrumentation shall be in accordance with Figure 3 for the axis and type of test shown.

Preferred Order of Test*	Axis	Vibration Requirements
1	Longitudinal (L)	Para. 3.1.6.6.2
2	Pitch (P)	Para. 3.1.6.6.2
3	Yaw (Y)	Para. 3.1.6.6.2

*Order of tests other than shown is permitted under cognizance of project delegate.

C-3.1.6.6.2 Random vibration levels will be as shown in Figure 4. Vibration tolerances shall be as follows:

A) Amplitude Tolerance: Plus or minus 3 decibels

B) Frequency Tolerance: Plus or minus 5 percent

Should operation in excess of the above tolerances occur, the cognizant project delegate shall determine the need for re-run.

Duration of tests shall be 5.0 minutes plus 10 seconds, minus zero second in each of the three axes. Loads shall be applied to the engine mounting surface.

C-3.1.6.6.3 Data reduction shall consist of spectral analysis of one magnetic tape loop cut from the magnetic tape recording. The loop will be taken from the first 1 1/2 minutes of the test. The magnetic tape data shall be analyzed with equpment that has the following tolerances:

A) Normal Analyzer Filter Band Width

Frequency (CPS)	Band Width (CPS)
10 - 100	5
100 - 200	10
200 - 500	20
500 - 2000	50

B) Analyzer Time Constant - 4 seconds minimum

C-3.1.6.7 Remove engine from fixture and deliver to Precision Assembly Department.

C-3.1.6.8 Repeat paragraph C-3.1.6.3

C-3.1.6.9 Prior to disassembly, inspect and record bolt lengths. Disassemble engine at head/combustor joint only and repeat paragraph C-3.1.6.1. Note or photograph, as required, any macroscopically apparent deficiencies.

C-3.1.6.10 Refurbish and/or reclean components as required in preparation for next seal specimen.

The Marquardt Corporation

TEST PLAN

DIMENSIONAL & LEAKAGE RATE RECORD

PART NO. _____ MTP0041 TEST NO. _____
S/N _____ AND/OR TEST APPENDIX LTR. _____

PRE-TEST REQUIREMENTS

ITEM	PARAMETER	INSPECTION RECORD
SEAL	DIMENSIONAL INSPECTION	ATTACH COPY OF RECEIVING INSPECTION DIMENSIONAL REPORT FOR P/N & S/N SHOWN ABOVE. (SUPPLIED BY ENGRG.)
HEAD	SEALING SURFACE ROUGHNESS & FLATNESS	(1) ✓ SURFACE ROUGHNESS _____ FLATNESS
COMBUSTOR FLANGE		(1) ✓ SURFACE ROUGHNESS _____ FLATNESS
COMBUSTOR ATTACH BOLTS (6)	FREE LENGTH	1 . 2 3 4 5 6
	ASSEMBLY TORQUE	
	ASSEMBLED LENGTH	
TEST FIG ASSY	SEAL LEAKAGE	_____ PSI DECAY/5 MINUTES

POST-TEST REQUIREMENTS

ITEM	PARAMETER	INSPECTION RECORD
SEAL	DIMENSIONAL INSPECTION	CRITICAL DIMENSIONS TO BE DETERMINED BY ENGRG. RECORD DIM'S ON INSP. RECORD FORM MAC 8889 & ATTACH HERETO.
HEAD	SEALING SURFACE CHARACTERISTICS	(2)
COMBUSTOR FLANGE		(2)
COMBUSTOR ATTACH BOLTS (6)	ASSEMBLED LENGTH	1 2 3 4 5 6
	DISASSEMBLY TORQUE	
	FREE LENGTH	
TEST FIG ASSY	SEAL LEAKAGE	_____ PSI DECAY/5 MINUTES

(1) NEED FOR THIS INSPECTION TO BE DETERMINED BY PROJECT DELEGATE.

(2) PARTICULAR CHARACTERISTICS TO BE RECORDED (IF ANY) TO BE DETERMINED BY PROJECT DELEGATE. ATTACH SEPARATE INSP. REPORT IF NECESSARY.

TMC A1633-1

FIGURE 1

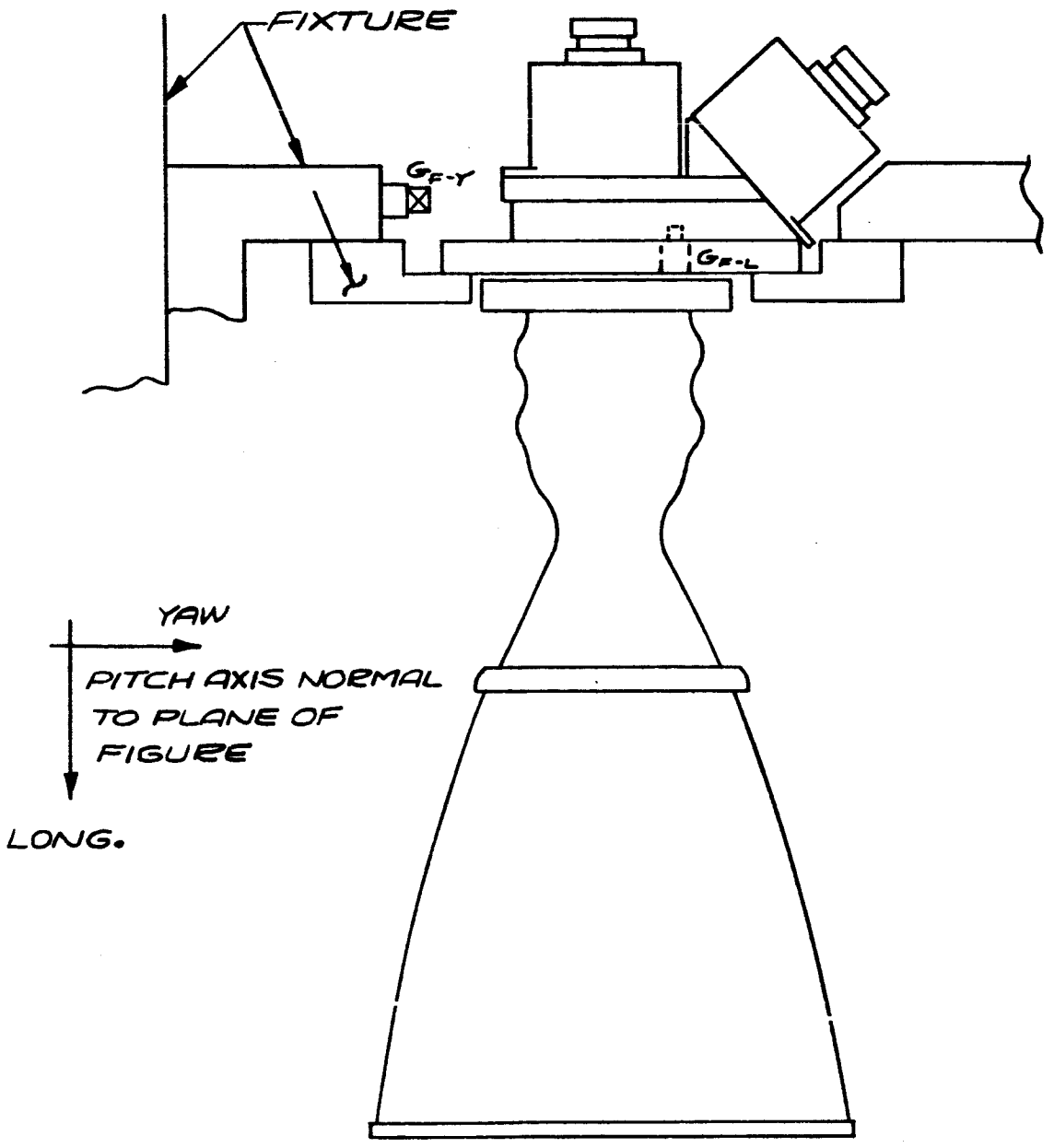

FIXTURE
G_{F-Y}
G_{F-L}
YAW
PITCH AXIS NORMAL TO PLANE OF FIGURE
LONG.

FIGURE 2a

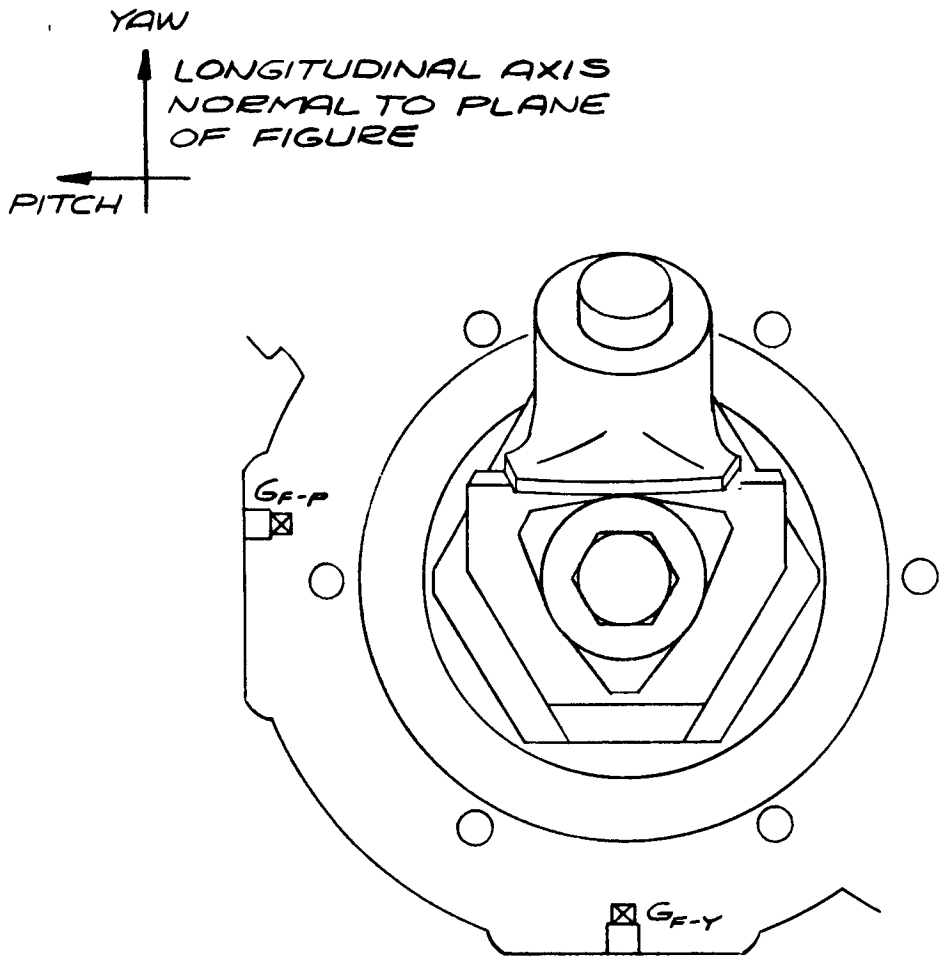

YAW
LONGITUDINAL AXIS
NORMAL TO PLANE
OF FIGURE
PITCH
G_{F-P}
G_{F-Y}

FIGURE 2b

VIBRATION INSTRUMENTATION

Parameter	Parameter Used for Test on Axis			Symbol	Range of Interest	Readout	Accuracy
	Long	Pitch	Yaw				
*Control accelerometer	X			G_f-l	0 to 100 g rms	Magnetic tape	± 11.5%
		X		G_f-p			
			X	G_f-y			

*Only the accelerometers in the axis of vibration input shall be recorded.

FIGURE 3

BOOST VIBRATION SPECTRUM (RANDOM)

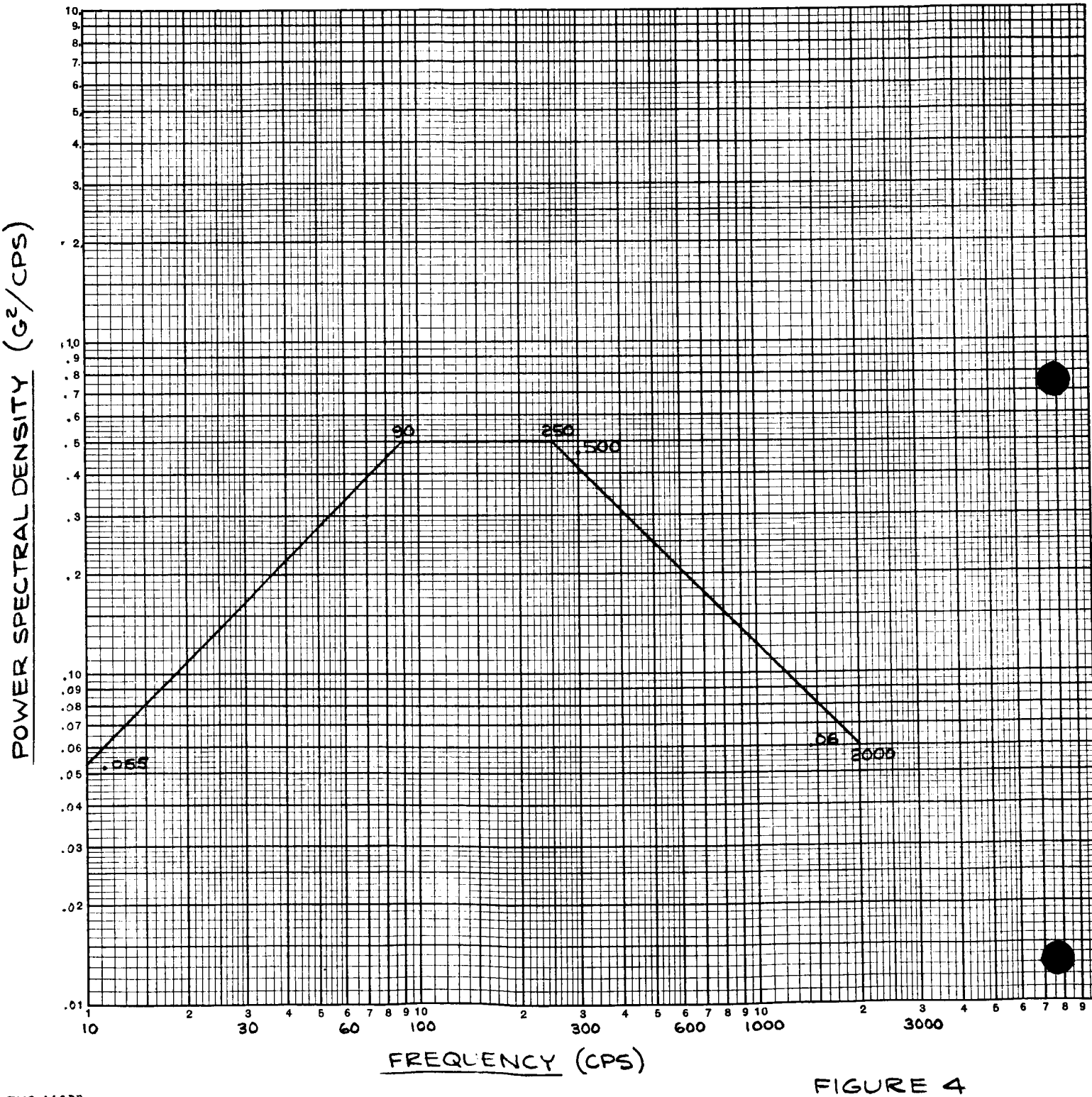


FIGURE 4

D-1.0 Objective

The objective of this test is to evaluate leakage performance of candidate high thermal resistance seals and degradation of materials comprising the head/seal/combustor interface after exposure to salt fog environment

D-2.0 Scope

During the corrosion tests, candidate seals will be assembled with components simulating the current Apollo SM RCS Engine injector head/combustor joint. Seals will be pre-loaded in accordance with established Apollo engine assembly procedures. The seals and adjacent componentscomprising the head/combustor joint will be examined and inspected before and after each assembly and disassembly for changes to critical dimensions and assembly leakage rates prior to and after exposure to Apollo SM RCS engine specification salt fog environment.

D-3.0 Test Requirements

D-3.1 Corrosion Test

D-3.1.1 Test Rig

The test rig components described on RESD layouts L-2053 and L-2054 or suitable alternate consisting of a partial engine assembly sufficient to accommodate simulation shall be used to contain specimen seals. Multiple test rigs will be available (2 min. - 4 max.).

D-3.1.2 Seal Specimens

Experimental seals will be furnished pre-assembled in the test rigs by the project. Typical candidate seals are described in Table I.

D-3.1.3 Facilities

D-3.1.3.1 Precision Assembly Department - Building 3

This facility shall be used for inspection and examination of seals and all test rig components. Assembly and disassembly and pressure test operations shall also be conducted in this area with available Apollo engine tools and equipment.

D-3.1.3.2 MJL - Building 16

Tests, simulating the salt fog environment, shall be performed in this facility. Controlled atmosphere equipment (salt fog corrosion test cabinet), shall be utilized.

D-3.1.4 Test Setup

The test setup shall consist of a test rig(s)*, described in D-3.1.1 and the model CA-1 test cabinet shown in Figure 2. The test rig(s) shall be installed into the exposure chamber by hanging vertically with nylon cords from the support bars with the thrust chamber down.

*Ganging with more than one rig is permissible.

D-3.1.5 Instrumentation

Instrumentation shall be as required to obtain:

a) Dry bulb temperature
b) Temperature of saturating tower
c) Pressure of saturating tower
d) P_H salt solution
e) Specific gravity of solution

D-3.1.6 Procedure

D-3.1.6.1 Inspect and record critical dimensions and features of candidate seal and sealing surfaces of adjacent components of test rig shown on Figure 1.

D-3.1.6.2 Assemble test rig per RESD layouts L-2053 or 2054. Record bolt torque and length information as shown on Figure 1.

D-3.1.6.3 Pressurize test rig assembly to 175 ± 5 psig with dry nitrogen. Isolate pressure source and record pressure decay in five minutes as shown on Figure 1.

D-3.1.6.4 Deliver assembled test rig(s) to MJL, Bldg. 16 and set up in general accordance with paragraph D-3.1.4.

D-3.1.6.5 Photograph setup as required.

D-3.1.6.6 Corrosion Test Operation:

D-3.1.6.6.1 Perform salt fog test per MIL-STD-810, Procedure 509.

D-3.1.6.6.2 Record date, time and parameters as called for in paragraph D-3.1.5 when steady state conditions have been reached at the beginning of the test.

D-3.1.6.6.3 Repeat parameter recordings, except (d) and (e), periodically during the test (Note: This requirement is not mandatory).

D-3.1.6.6.4 Record all parameters as called for in paragraph D-3.1.5 in the last half hour of the test.

D-3.1.6.6.5 Perform cabinet shutdown and purge procedures as required after 48 hours of testing "on condition."

D-3.1.6.6.6 Remove test rig(s) from exposure chamber. Do not rinse. Photograph as required.

D-3.1.6.6.7 Rinse with clear tap water and dry outside surfaces with heat gun. Re-photograph as required.

D-3.1.6.7 Deliver test rig(s) to Precision Assembly Department.

D-3.1.6.8 Repeat paragraph D-3.1.6.3.

D-3.1.6.9 Prior to disassembly, inspect and record bolt lengths. Disassemble test rig(s) and repeat paragraph D-3.1.6.1. Note or photograph, as required, any macroscopically apparent deficiencies.

D-3.1.6.10 Refurbish and/or reclean components as required in preparation for next seal specimen.

DIMENSIONAL & LEAKAGE RATE RECORD

PART NO. _____
S/N _____

MTP0041 TEST NO. _____
AND/OR
TEST APPENDIX LTR. _____

PRE-TEST REQUIREMENTS

ITEM	PARAMETER	INSPECTION RECORD
SEAL	DIMENSIONAL INSPECTION	ATTACH COPY OF RECEIVING INSPECTION DIMENSIONAL REPORT FOR P/N & S/N SHOWN ABOVE. (SUPPLIED BY ENGRG.)
HEAD	SEALING SURFACE ROUGHNESS & FLATNESS	(1) ____√____ SURFACE ROUGHNESS ± _____ FLATNESS
COMBUSTOR FLANGE		(1) ____√____ SURFACE ROUGHNESS ± _____ FLATNESS
COMBUSTOR ATTACH BOLTS (6)	FREE LENGTH	1 | 2 | 3 | 4 | 5 | 6
	ASSEMBLY TORQUE	
	ASSEMBLED LENGTH	
TEST RIG ASSY	SEAL LEAKAGE	_____ PSI DECAY/5 MINUTES

POST-TEST REQUIREMENTS

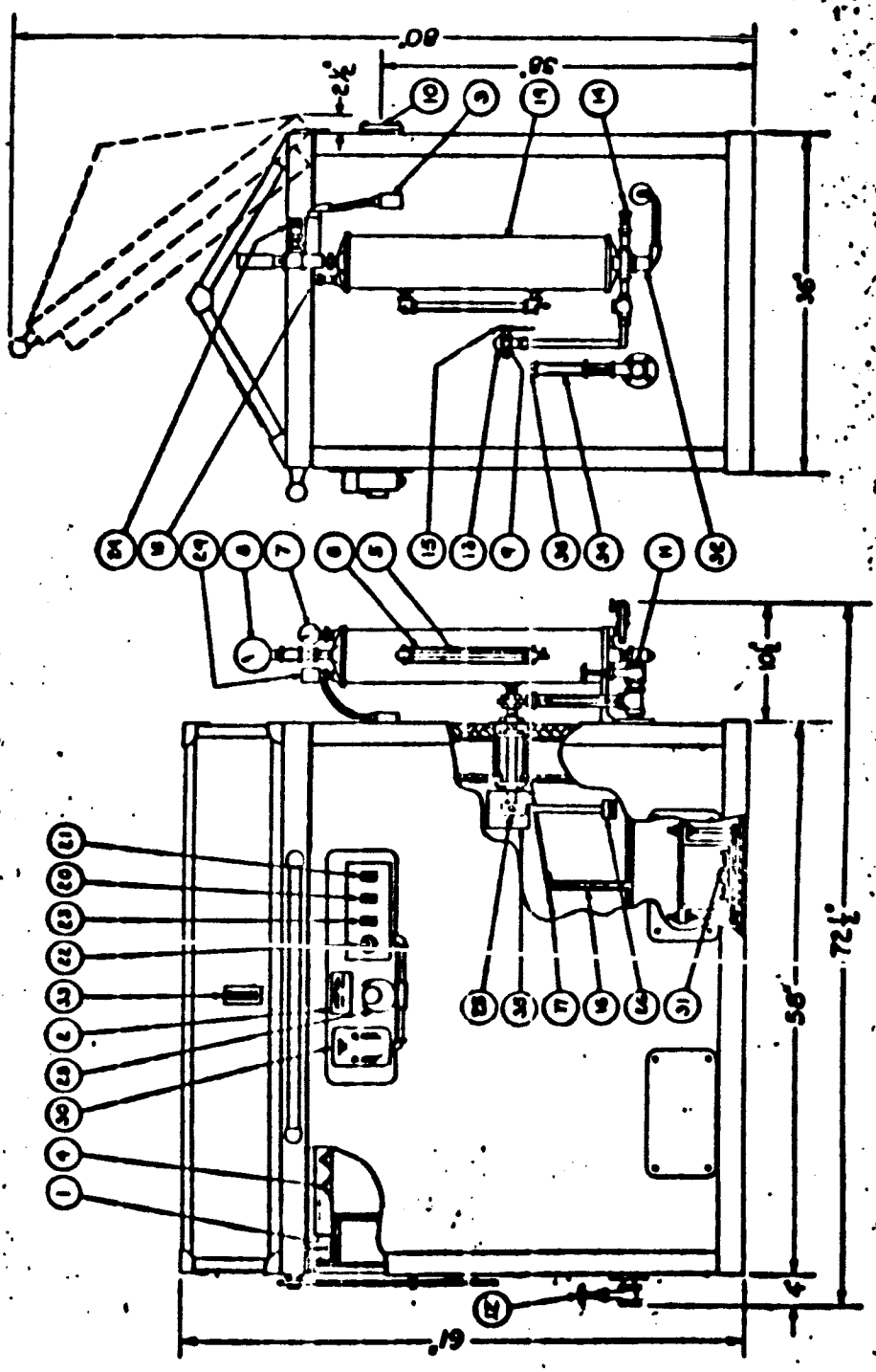
ITEM	PARAMETER	INSPECTION RECORD
SEAL	DIMENSIONAL INSPECTION	CRITICAL DIMENSIONS TO BE DETERMINED BY ENGRG. RECORD DIM'S ON INSP. RECORD FORM MAC 8889 & ATTACH HERETO.
HEAD	SEALING SURFACE CHARACTERISTICS	(2)
COMBUSTOR FLANGE		(2)
COMBUSTOR ATTACH BOLTS (6)	ASSEMBLED LENGTH	1 | 2 | 3 | 4 | 5 | 6
	DISASSEMBLY TORQUE	
	FREE LENGTH	
TEST RIG ASSY	SEAL LEAKAGE	_____ PSI DECAY/5 MINUTES

(1) NEED FOR THIS INSPECTION TO BE DETERMINED BY PROJECT DELEGATE.

(2) PARTICULAR CHARACTERISTICS TO BE RECORDED (IF ANY) TO BE DETERMINED BY PROJECT DELEGATE. ATTACH SEPARATE INSP. REPORT IF NECESSARY.

FIGURE 1

NO	REFERENCE LIST:
1	WATER SEAL
2	NAME PLATE
3	CONDUIT BOX - POWER INLET
4	SPECIMEN SUPPORT BARS
5	SIGHT GLASS
6	GUARD RODS
7	THERMOMETER - SATURATOR TOWER
8	PRESSURE GAUGE
9	AIR INLET
10	EXHAUST VENT
11	DRAIN VALVE - SALT SOLUTION
12	DRAIN VALVE - CABINET
13	FOG PURGE INLET
14	DRAIN COCK - SATURATOR
15	AIR INLET COCK (THREE-WAY)
16	SALT SOLUTION COMPARTMENT
17	COVER FOR 16
18	WATER CAP
19	SATURATOR TOWER
20	MAIN SWITCH
21	PILOT LIGHT FOR 32
22	THREE-HEAT SWITCH
23	PILOT LIGHT FOR 31
24	AIR RELIEF VALVE
25	ATOMIZER
26	FILTER CLOTH FOR ATOMIZER
27	
28	THERMOSWITCH FOG CABINET
29	CONDUIT BOX - THERMOSWITCH TOWER
30	RELAY SWITCH
31	HEATING ELEMENTS FOR CABINET
32	IMMERSION HEATER FOR 19
33	THERMOMETER FOR CABINET
34	SIGHT GLASS & FILLER TUBE
35	SPRAY BAFFLE
36	SALT SOLUTION CAP



SALT FOG TEST SETUP

FIGURE 2

E-1.0 OBJECTIVE

Objective of these tests is to measure the thermal resistances of the two seals which are selected for firing tests in fireable engine assemblies.

E-2.0 SCOPE

The two selected seals shall be assembled into fireable, Apollo S/M RCS Qualification-type engines per the current Apollo assembly procedures. The engine assemblies, previously pressure tested for seal leakage, shall then be installed into Marquardt's cold wall space simulator and simultaneously tested to determine thermal resistances of the seals. Test chamber pressure and temperature corresponding to a cold soak space environment shall prevail. Upon conclusion of the test, the assemblies shall be pressure tested again for seal leakage.

E-3.0 TEST REQUIREMENTS

E-3.1 Test Item

Two chamber seals previously selected jointly by TMC and NASA will be tested for their thermal resistances in two instrumented engine assemblies which shall subsequently be combustion tested per Appendix F of this MTP. Typical candidate seals are described in Table I.

E-3.2 Facility

Marquardt's Cold Wall Space Simulator Chamber in Building 32 shall be utilized for this test. The test chamber shall be capable of meeting the following requirements:

E-3.2.1 Chamber Pressure

The facility vacuum system shall be capable of steady state vacuum chamber pressure of 10^{-4} mm Hg for a minimum of 72 hours.

E-3.2.2 Wall Temperature

Chamber cold wall shall be cooled by liquid nitrogen to -320°F.

E-3.2.3 Wall Emissivity

Chamber cold wall shall have a surface emissivity $\geq$ 0.9.

E-4.0 TEST SETUP

The engines and the Thermal Boundary shall be assembled onto a suspension bar as illustrated in Figure E-1. The test rig, as shown in Figure E-1, shall be assembled in close proximity of the vacuum chamber site in order to prevent engine damage in transit. Assembly of the rig shall be performed jointly by Test Department and Project personnel.

Upon satisfactory assembly of the test rig, it shall be mounted into the Cold Wall Space Simulator Chamber by the mounting hooks.

E-4.1 Thermal Boundary

An aluminum cylinder, provided by the project, shall encase injector heads of both engines and shall provide a radiation boundary for the engines. It shall have an emissivity of $\geq$ 0.9 on the interior surface and shall be heated by a resistance heating element blanket wrapped on its exterior surface.

E-4.2 Engine Injector Head Heaters

Each engine injector head shall be equipped with a small button type electric heater which shall be mounted in the normal "head temperature" mounting port. The heaters will be operated with d-c power and will have separate facility power controls.

E-5.0 POWER SUPPLIES

The facility shall provide three separate power supplies for:

1. Thermal Boundary Heater - Variac controlled a-c, adjustable from zero to 120 volts (1 required).
2. Injector Head Heaters - d-c, adjustable from zero to 100 volts (2 required).

E-6.0 INSTRUMENTATION

Instrumentation of the engine, thermal boundary and facility cold wall chamber shall be in accordance with Table E-I. Engine thermocouple instrumentation is presented in detail in Figure E-2.

Thermocouple leads from engine thermocouples other than those shown in Figure E-2 (firing test thermocouples may be present) shall be neatly bundled and routed outside of the thermal boundary. Care shall be exercised not to damage any thermocouples.

E-7.0 TEST PROCEDURE

E-7.1 Start vacuum pump.

E-7.2 Start temperature recorders and LN_2 flow when pressure $\leq 10^{-2}$ mm Hg. Recorders are to be left on at all times during the test. Sufficient LN_2 will be available at the start to allow continuous operation for 40 hours.

E-7.3 Turn on all heaters.

E-7.4 Regulate heat input until the desired temperature of the injector heads is obtained. Two different heat input levels will be conducted, starting with a seal temperature of ≥ 0°F. The other input level shall be determined by the cognizant project delegate. Additional power input level tests may be conducted at the discretion of the cognizant project delegate.

E-7.5 At each heat input level, the supply voltage to the heaters shall be kept constant for one hour. All temperatures will then be allowed to reach steady state and recorded along with heater voltage and current.

E-7.6 Turn off LN_2 and vacuum pumps and secure system.

E-7.7 Open chamber and remove test rig. Allow test rig to stabilize to room temperature. No attempt to accelerate warming time shall be made.

E-8.0 POST TEST REQUIREMENTS

The engines shall be carefully removed from the test rig and delivered to the Precision Assembly Department, Building 3, where a chamber seal leakage rate test shall be performed.

The engines shall then be inspected by Project and delivered to the Test Department in preparation for Appendix F firing tests in RRL-Pad D.

TABLE E-I

THERMOCOUPLE INSTRUMENTATION

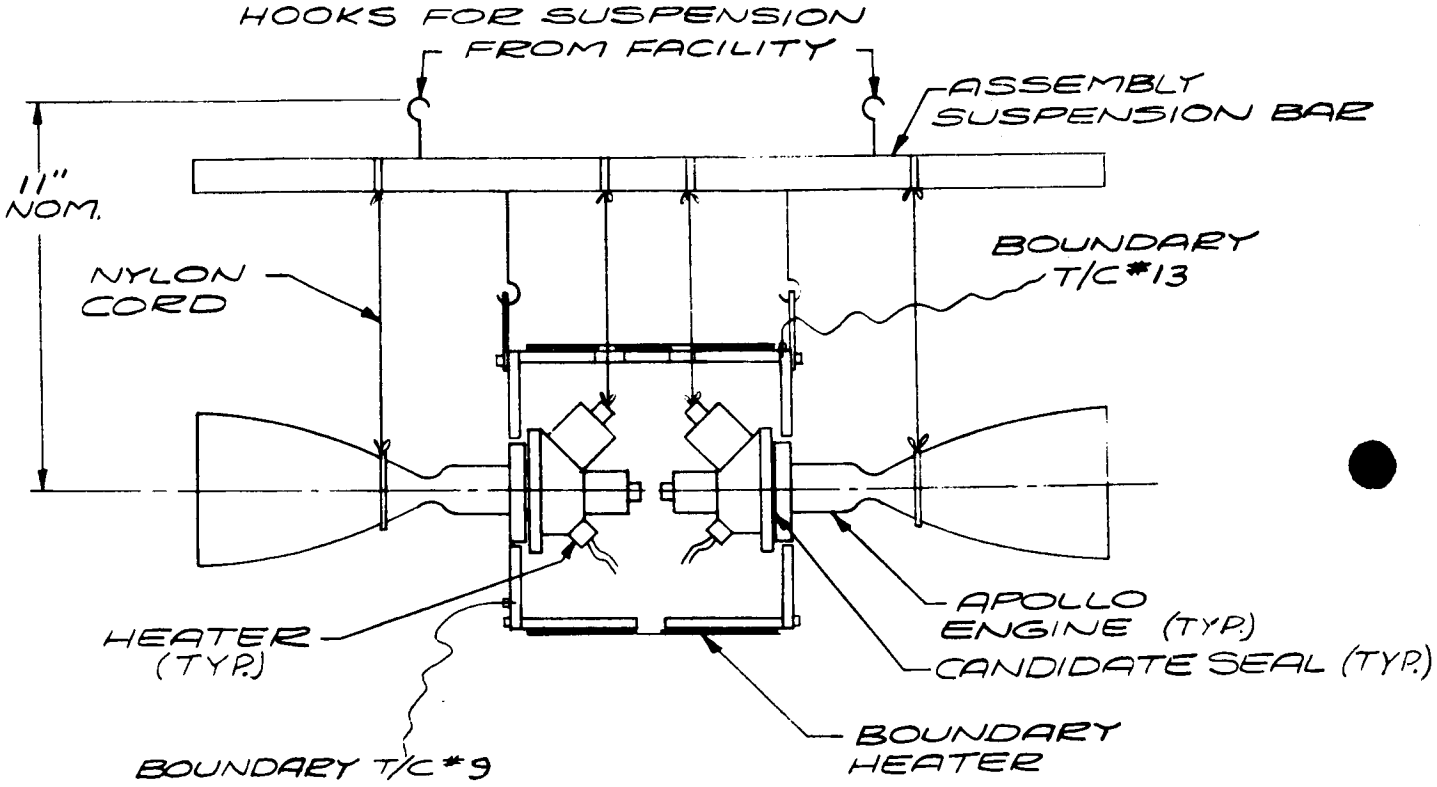
T/C	Location	Type	Range, °F
Engine Thermocouples (Two Engines) (1)			
T_1	Oxidizer Valve Case	I/C	-50 to +200
T_2	Fuel Valve Case	I/C	-50 to +200
T_6	Aluminum Flange, Fuel Side	I/C	-50 to +200
T_8	Moly Flange, Fuel Side	I/C	-50 to +200
T_{head}	Injector Head	I/C	-50 to +200
T_{ch}	Chamber Throat	C/A	-320 to +90
T_{nut}	Bell Nut	C/A	-320 to +90
Thermal Boundary Thermocouples (2)			
T_9	End of Boundary Fixture	I/C	Zero to +200
T_{13}	Top of Boundary Fixture	I/C	Zero to +200
Space Simulator Chamber Thermocouples (3)			
T_{25}	Bottom of LN_2 Cooled Wall	C/A	-320 to +90
T_{26}	Top of LN_2 Cooled Wall	C/A	-320 to +90
T_{27}	End of LN_2 Cooled Wall	C/A	-320 to +90
T_{28}	Uncooled Wall	C/A	-320 to +90

(1) See Drawing 228541 for guide to thermocouple installation

(2) See Figure E-1 for guide to thermocouple installation

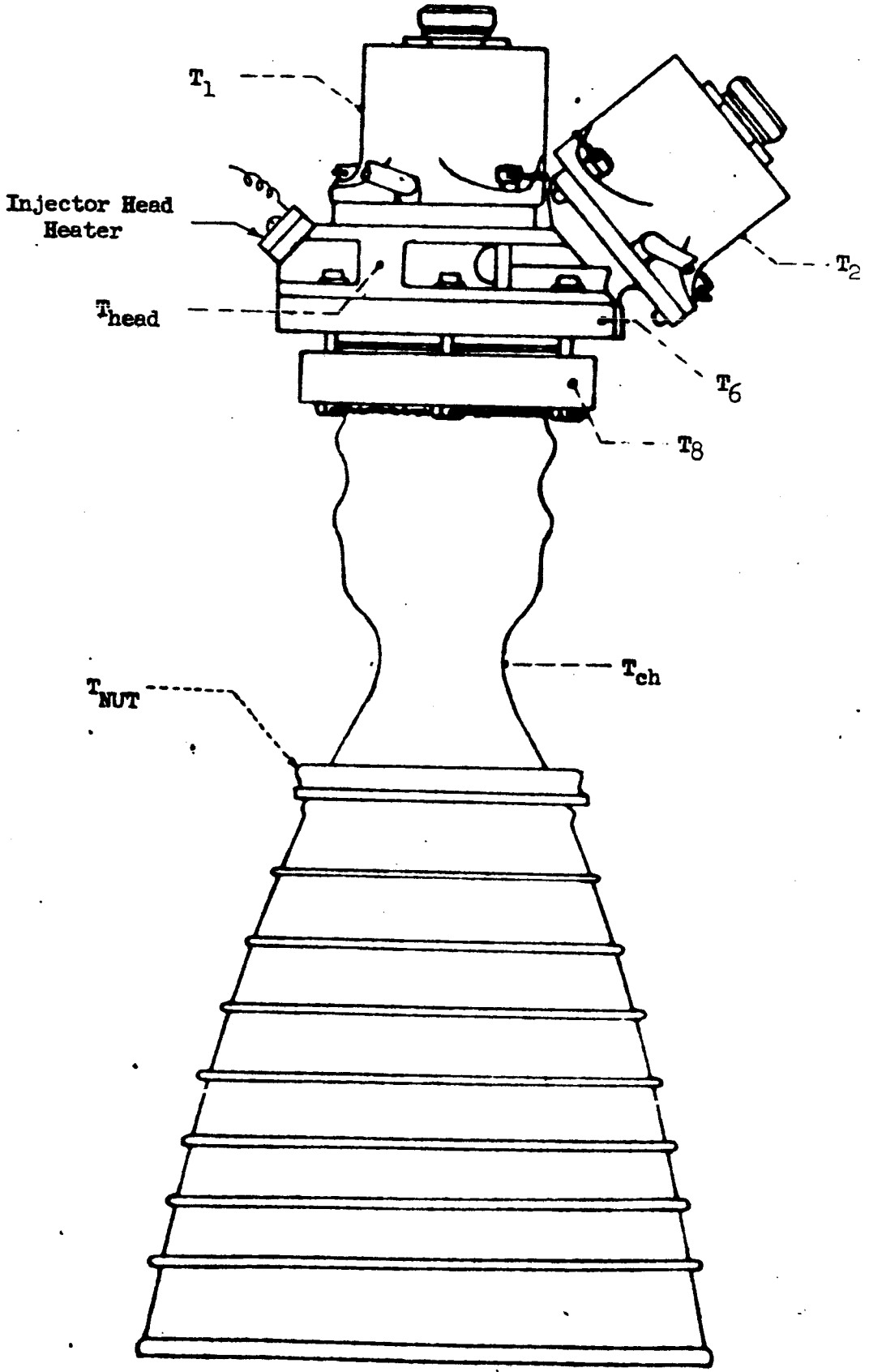
(3) See MTP 0041, Appendix B, Figure 2 for guide to thermocouple installation

SEAL THERMAL RESISTANCE TEST RIG



TEMPERATURE INSTRUMENTATION SCHEMATIC

FIGURE E-2



F-1.0 OBJECTIVE

The objective of these tests is to evaluate the performance of two candidate high thermal resistance seals in actual engine assemblies by steady state and pulse firings of the engines in a simulated high altitude environment.

F-2.0 SCOPE

The two candidate high thermal resistance seals shall be assembled into two Apollo Service Module RCS Qualification type engines which shall then be combustion tested. The combustion tests shall be so oriented to provide information on engine temperature distributions during engine firing and soakback and shall provide a structural evaluation of the seals under actual engine operating conditions. Seal leakage rates before and after firings shall be recorded and compared to Apollo S/M RCS Qualification engines requirements. Chamber attach bolt lengths shall be measured before and after testing, and both engine head-to-chamber seal and chamber seal-to-combustor surfaces shall be visually inspected. Further disassembly and/or inspection of each engine may be performed as required.

F-3.0 ENGINE ASSEMBLIES

There shall be two engine assemblies, one for each of the two candidate high thermal resistance seals. Both engines shall be of the SMRCS Qualification type. They shall both be assembled in Precision Assembly per directions (Engineering Order) issued by the Project office.

Prior to combustion testing, both engines will be water flow calibrated to insure conformance to the latest Apollo S/M RCS engine requirements.

F-4.0 TEST REQUIREMENTS

F-4.1 Engine Installation

Both engines shall be installed in Marquardt's altitude test cell, Rocket Research Laboratory, Pad D, for these tests. TDP 7016 may be utilized as a guide for installation procedures.

NOTE: Thrust measurement is not required for these tests. A load cell may be used in engine buildup, but shall not be connected to a recorder.

F-4.2 Instrumentation Requirements

The engine shall be instrumented per Table F-I and Figure F-1. TDP 7173 may be utilized as a guide for the necessary instrumentation setup and calibrations.

F-4.3 Instrumentation Calibrations

Instrumentation for all recorded parameters shall have a facility calibration prior to and following the test series. Additional calibrations may be required by the Project Delegate.

F-4.4 Instrumentation Certification

All facility instruments shall be in certification prior to the start of the test series. Should the certification deadline for any instrument elapse during the test series, it shall be left to the discretion of the Project Delegate whether that instrument be recertified, replaced, or have certification extended per TMC 3008 Quality Assurance Plan.

F-4.5 Cell Pressure

Altitude cell pressure shall be 0.2 psia or less prior to initiation of any engine firing.

F-4.6 Valve Set Voltage

Valve set voltage shall be 27 ± 0.5 volts d-c.

F-4.7 Propellant Temperature

Propellant temperatures shall be ambient within the limits of 40°F and 90°F.

F-4.8 Engine Head Temperature

Prior to firing the engine, the head temperature shall be between 40°F and 125°F.

F-5.0 TEST SEQUENCE

F-5.1 Normal Steady State and Thermal Test Firings

All of the following tests shall be made from the facility propellant storage tanks.

F-5.1.1 Trim Runs

Conduct 5-second steady state runs as required to obtain tank set pressures for O/F = 1.8, 2.0 and 2.2 at a total propellant flow rate of 0.360 ± 0.003. O/F tolerance shall be ± 0.05 based on quick-look data.

F-5.1.2 Record Runs

At tank set pressures determined in Paragraph F-5.1.1, conduct steady state runs at O/F = 1.8, 2.0 and 2.2 for 100 seconds duration or until all temperatures reach steady state, whichever time is greater.

F-5.2 Maximum Soakback Duty Cycle

With tank set pressures which resulted in O/F = 1.8 as determined in Paragraph F-5.1.1, conduct the following duty cycle from the main tanks:

90 seconds on
Maximum soakback on T_{head} (about 4-1/2 minutes)
90 seconds on
Maximum soakback on T_{head} (about 4-1/2 minutes)
90 seconds on
10-minute soakback

F-5.3. Structural Duty Cycle Pulse Series

This pulse series shall be conducted from the pulse tanks.

F-5.3.1 Trim Runs

Conduct 5-second steady state runs as required to obtain tank set pressures for $O/F = 2.0 \pm 0.05$ and $\dot{w}_p = 0.360 \pm 0.003$.

F-5.3.2 Record Runs

Conduct a total of $5500 \begin{smallmatrix}+50\\-0\end{smallmatrix}$ pulses of 50 milliseconds on, 50 milliseconds off. Pulse tanks shall have to be refilled after each 1400 pulses or as required so propellants will not be exhausted.

F-6.0 POSTFIRE REQUIREMENTS

F-6.1 Water Calibrations

Upon completion of firing tests, each engine shall be delivered to Building 32 for postfire water calibrations, which shall consist of water flow rate measurement through both the fuel and oxidizer sides of the engine at $\Delta P = 72$ psid.

The engines shall then be delivered to Precision Assembly for seal leak check and teardown.

F-6.2 Seal Leak Check and Teardown

Seal leakage rates shall be recorded, attach bolt lengths measured, and chambers shall be disassembled from the engines and sealing surfaces shall be visually inspected only under the cognizance of a Project Delegate.

F-7.0 INSPECTION REQUIREMENTS

Monitoring of engine setup and firing will be performed by Project. Project will maintain engine logs with Test Operations assistance. Inspection Department monitoring of setup and firing is not required. Inspection Department witness of postfire teardown may be required.

TABLE F-I

CELL INSTRUMENTATION (FIRING TESTS)

Parameter	Description	Range of Interest	Data Readout
$\dot{w}_o$	Oxidizer Flow (s.s.)	0 to .330 pps	Systron & Oscillograph
$\dot{w}_f$	Fuel Flow (s.s.)	0 to .165 pps	Systron & Oscillograph
P_{m_f}	Fuel Valve Inlet Pressure (s.s.)	140 to 240 psig	Bristol & Oscillograph
P_{m_o}	Oxidizer Valve Inlet Pressure (s.s)	140 to 240 psig	Bristol & Oscillograph
$P_{c_{test}}$	Chamber Pressure (s.s.)	1 0 to 110 psia	Bristol & Oscillograph
P_{cell}	Cell Pressure	0 to .4 psia	Bristol & Oscillograph
V_E	Valve Electrical Characteristic	- - - - -	Oscillograph
t	Engine Electrical "ON" Time	- - - - -	All Recorders
Ref. 0	Zero Reference	- - - - -	Oscillograph
T_{head}	Head Temperature	0 to 400°F	Bristol
T_{nut}	Bell Nut Temperature	0 to 2000°F	Bristol
T_1	Oxidizer Valve Case Temperature	0 to 200°F	Brown
T_2	Fuel Valve Case Temperature	0 to 200°F	Brown
T_3	Oxidizer Valve Flange Temperature	0 to 200°F	Brown
T_4	Fuel Valve Flange Temperature	0 to 200°F	Brown
T_5	Aluminum Flange, Oxidizer Side	0 to 400°F	Bristol
T_6	Aluminum Flange, Fuel Side	0 to 400°F	Bristol
T_7	Moly Flange, Oxidizer Side	0 to 1000°F	Bristol
T_8	Moly Flange, Fuel Side	0 to 1000°F	Bristol
T_{m_f}	Fuel Inlet Temperature	30 to 110°F	Brown
T_{m_o}	Oxidizer Inlet Temperature	30 to 110°F	Brown
T_{fm_f}	Steady State Fuel Flow Meter Temperature	30 to 110°F	Brown
T_{fm_o}	Steady State Oxidizer Flow Meter Temperature	30 to 110°F	Brown
T_{ch}	Chamber Throat Temperature (Thermoscope)	1800 to 2800°F	Bristol
T_{b_1}	Bolt Nut	0 to 1000°F	Bristol
T_{b_2}	Bolt Middle	0 to 1000°F	Bristol
T_{b_3}	Bolt Head	0 to 1000°F	Bristol
$T_{s.r.}$	Split Ring	0 to 1000°F	Bristol
$T_{a.r.}$	Attach Ring	0 to 1000°F	Bristol

TEMPERATURE INSTRUMENTATION SCHEMATIC

FIGURE F-1

