N69-10335

NASA CR 72436

FINAL REPORT

DESIGN AND MANUFACTURE OF PARASITIC LOAD RESISTORS FOR BRAYTON POWER CONVERSION SYSTEM

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

July 23, 1968

CONTRACT NAS3-10777

Technical Management
NASA Lewis Research Center
Cleveland, Ohio

HEAT ENGINEERING & SUPPLY COMPANY
213 East Valley Boulevard
San Gabriel, California 91776

DESIGN AND MANUFACTURER OF PARASITIC LOAD RESISTORS FOR BRAYTON POWER CONVERSION SYSTEM

HEAT ENGINEERING & SUPPLY COMPANY

SUMMARY

The NASA Lewis Research Center is currently engaged in a Brayton-Cycle space power technology program. The Brayton power conversion system is expected to have applicability for both solar and radio-isotopes space power systems in the net power range of 2.25 to 10.5 KWe at 1200 Hertz.

The Brayton rotating unit (BRU) of the Brayton PCS is a constant speed single shaft unit. The 1200 Hertz alternator shaft is supported by gas bearings with a compressor overhung on one end of the single shaft and a turbine overhung on the other end of the single shaft.

The constant speed of the Brayton BRU is maintained by a frequency sensitive parasitic type speed control on the electrical output of the alternator. As the net shaft input power from the turbine varies or as the demand for useful vehicle load varies, the speed control maintains a constant shaft speed by dissipating the excess generated power into an electrical parasitic load. Therefore, with a constant input power to the alternator, the output on the alternator is maintained constant by varying the amplitude of the parasitic load so that the sum of the useful vehicle load and the parasitic load is constant.

The parasitic load, or Parasitic Load Resistor (PLR) consists of nine sections. Each section is capable of absorbing 2 kw of electrical power at 120 Volts potential and 1200 Hertz. Each section is also capable of rejecting the 2 kw of electrical power by radiation to space in a hard vacuum.

INTRODUCTION

Previous work by the contractor on parasitic load resistors for the NASA SNAP-8 Program led to the selection of tubular metal sheath electric heaters as the basic energy dissipating unit. This is commonly known as the tubular electric heater throughout industry and is an effective means of converting electrical energy to heat energy and an effective means of radiating that heat energy. To meet the requirements of the Brayton Program the attachment of these basic resistor elements (tubular electric heaters) to a radiating plate to provide mechanical supporting structure as well as a suitable physical configuration for radiation led to the design concept of furnace brazing the resistor elements into radiator plates. The selection of nine individual plates, each containing three resistor elements, was dictated by the number of steps desired in the parasitic load. Each section is free to expand and contract independently of the other sections.

A nominal surface temperature of 1250°F was selected as one which would give a temperature potential for heat radiation without incurring a penalty for excessive weight in the unit because of reduced strength of materials at high temperatures.

DESIGN

Heat Engineering & Supply Company drawing No. 12193-5, sheets 1 through 4 shows the final design configuration. Heat Engineering & Supply Company photograph No. 12193-1 gives an overall view of a complete PLR assembly. The detailed design calculations are given in the Appendix, pages 1 through 23.

On drawing 12193-5, sheet 1, it will be noted that the radiating plates are supported by bolting to titanium mounting channels. This arrangement provides a thermal as well as an electrical isolation from the space vehicle. The bolting of the resistor plates to the titanium mounting channels is shown in detail on sheet 3. Micamat insulation has been provided between the resistor plate and the mounting channel, and Micamat bushings have been used under the titanium bolt and nut to restrict the flow of heat from the radiator plate into the titanium mounting channel.

Titanium gussets are used in six places on each of the titanium mounting channels. These gussets were added at a weight penalty after stress analysis showed that such reinforcement was necessary to meet the design parameters.

Meteorite shields have been attached over each electrical connector of each Calrod resistor element. The electrical connector at each end of each resistor element is a ceramic to metal hermetic seal. This seal assembly would be susceptible to damage from impact of meteorites and it is even possible that dust could collect on the ceramic insulator portion of the seal and thereby form a short circuit path from the connector portion of the seal to the grounded portion which is welded to the sheath of the Calrod resistor element. These meteorite shields are fabricated of stainless steel tubing and are welded to a suitable bushing which in turn is welded to the sheath of the Calrod resistor element as shown on sheet 2 of drawing 12193-5.

The use of the relatively fragile hermetic seals is not dictated by the space environment but rather by the need to prevent the absorbtion of moisture from the air while the PLR is in the earth's atmosphere. The magnesium oxide used to insulate the resistor wire from the resistor sheath (and at the same time conduct heat from the wire to the sheath) readily absorbs moisture from the air. This moisture can have the simple effect of reducing the insulation resistance from wire to sheath. Also, under very humid atmosphere conditions, enough moisture can be absorbed into the magnesium oxide to create a hazardous steam pressure within the resistor when it is energized. The ceramic to metal type of hermetic seal is the only one known today capable of meeting the requirements of this application.

Flexible nickel braid is used for the electrical connections between the individual resistor elements. The selection of nickel over a more common conductor such as copper was made because of the requirement to weld rather than hand torch braze the points of electrical connection. The cold terminal of the individual resistor elements and the metallic cap portion of the ceramic to metal seal are both pure nickel. Therefore, nickel was selected as an ideal metal for the flexible braid electrical connections. Fiberglass sleeving is installed over the flexible nickel braid in those areas which are not covered by the meteorite shield. This is done to prevent a possible build up of meteorite dust on the conductor which could possibly lead to an electrical short circuit.

Sheet 4 of drawing 12193-5 shows that each group of three resistor elements comprising the elements of a given radiator plate are wired in a single phase, parallel configuration. This allows the PLR to provid three, balanced, three phase inclements of electrical load.

PROTOTYPE TESTING

It was recognized at the start of the contract that prototypes would have to be built and evaluated to prove the design calculations before the full quantity of PLR assemblies could be manufactured. The most important considerations to be proved by prototype evaluation were the brazing method, the ability of the radiator plates to remain dimensionally stable in thermal cycling operation, the temperature uniformity that could be expected in the radiator plates and the adequacy of the iron titanate coating to withstand the service. This question of the iron titanate coating was particularly relevant because the subcontractor, Plasmadyne, although having had many years of experience with plasma coating, had never used this specific compound. Further, the work performed by Pratt & Whitney Aircraft under contract to NASA did not involve testing the coating as applied to a heat generator; the samples coated and tested by this contractor were heated by an external heat source in a vacuum chamber and therefore experienced much slower changes of temperature than were to be expected with the PLR under this contract.

It was decided to test a radiator plate assembly for temperature uniformity in operation and dimensional stability, then have that same plate, if satisfactory, plasma sprayed with the iron titanate and repeat the thermal cycling tests with the coating in place.

As reported in "Discussion of Test Procedures and Results" the initial tests on the prototypes for temperature uniformity and dimensional stability were excellent.

The prototype was then grit-blasted and plasma sprayed with the iron titanate coating. The appearance of the coating was excellent with only one or two small pitted areas detectable under microscopic examination. In consultation with the subcontractor, Plasmadyne, these pits were caused by an operational procedure which could be changed and the surface defect avoided on the production units. It was further learned that repairing such a surface defect is not difficult.

Tests were conducted on the coated plate by applying 60 Hertz power at the appropriate voltage level. The temperature uniformity of the coated plate appeared excellent, although no different from the tests run on the uncoated surface. The test was continued for four hours at full power with a surface temperature in excess of 1300°F. It was the intention to run eight hour tests every day for several weeks to be sure that the coating was stable and did not experience any detrimental changes because of thermal cycling. When the power was removed at the end of this initial four hour run the coating "popped" off of the plate in the form of small flakes and powder. This occured uniformly over the entire coated surface.

The failure of the coating was discussed in a conference with NASA engineers and the coating subcontractor, Plasmadyne. The most logical theory presented was that the rapid contraction of the radiator plate beneath the coating resulting from the instantaneous removal of power set up stresses that the coating could not stand and it disintegrated. The coating subcontractor offered the possibility of using a "staged coating" as a solution to the problem. This would involve applying a number of thin coatings, starting with pure stainless steel powder at the radiator surface, then using a mixture of ever higher percentages of iron titanate and lower percentages of stainless steel powder until the outer surface was pure iron titanate. The contract did not provide for the time or expense involved in such a development program and the decrease in emissivity of an oxidized stainless steel condition from that of the iron titanate did not appear to justify the investment of time or expense. It was, therefore, agreed that a comparable surface condition would be achieved by deliberately oxidizing the plates as part of the contract. Therefore the coating was formally deleted from the contract.

Thermal cycling tests were conducted to determine the dimensional stability of the units under repeated heating and cooling. The dimensional change stabilized at a total distortion of 0.05" and after two weeks of continued cycling without any further distortion the tests were discontinued as having established that the assembly is dimensionally stable under predicted operating conditions.

In the original concept, it was planned that radiographic inspection would be used to determine the porosity of the brazed joint between the resistor elements and the plates. This joint was to have less than 20% porosity as determined by X-Ray. Three prototype units were built varying the brazing technique and all three appeared to be in excess of minimum specifications as judged by radiographic inspection. However, contradictory results were obtained from different radiographic inspectors as to the percentage of voids in the brazed joint. A cross check was made by ultrasonic inspection and again contradictory interpretations were given by qualified laboratory inspectors. Therefore, it was decided to operate each section at a temperature substantially in excess of operating temperature for a minimum of eight hours and judge the quality of the brazing by actual performance rather than the inconclusive inspection procedures. Each section was tested at a temperature in excess of 1350°F and carefully inspected for uniformity of temperature because any detrimental voids in the braze joint would cause hot spots. It was agreed that to be detrimental a hot spot would have to be visible. On none of the sections tested was any discontinuity detectable.

PRODUCTION TESTING

In consultation with NASA engineers, a plan of test procedures for the components and assemblies was worked out and set up as a minimum program. This involved electrical testing of the individual Calrod resistor elements for dielectric strength, insulation resistance, ohmic resistance and X-Ray examination of the resistor coil inside each resistor element for evidence of integrity of manufacture.

Helium testing was selected as the method for assuring the integrity of the weld of the hermetic seal to the adaptor bushing and the weld of the adaptor bushing to the sheath of the individual Calrod resistor element. Helium leak testing was a final test although a preliminary test using dye penetrant per MIL-I-6866 was to be used to detect any gross defects in these same welds. Helium leak testing would also prove the integrity of the hermetic seal itself and this was deemed advisable because there are furnace brazed joints inside of the seal which are not visible for inspection by dye penetrant or other means. Thus, the helium leak testing would disclose any hidden defects in these hermetic seals.

For more detailed discussion refer to the section "Discussion of Test Procedures and Results".

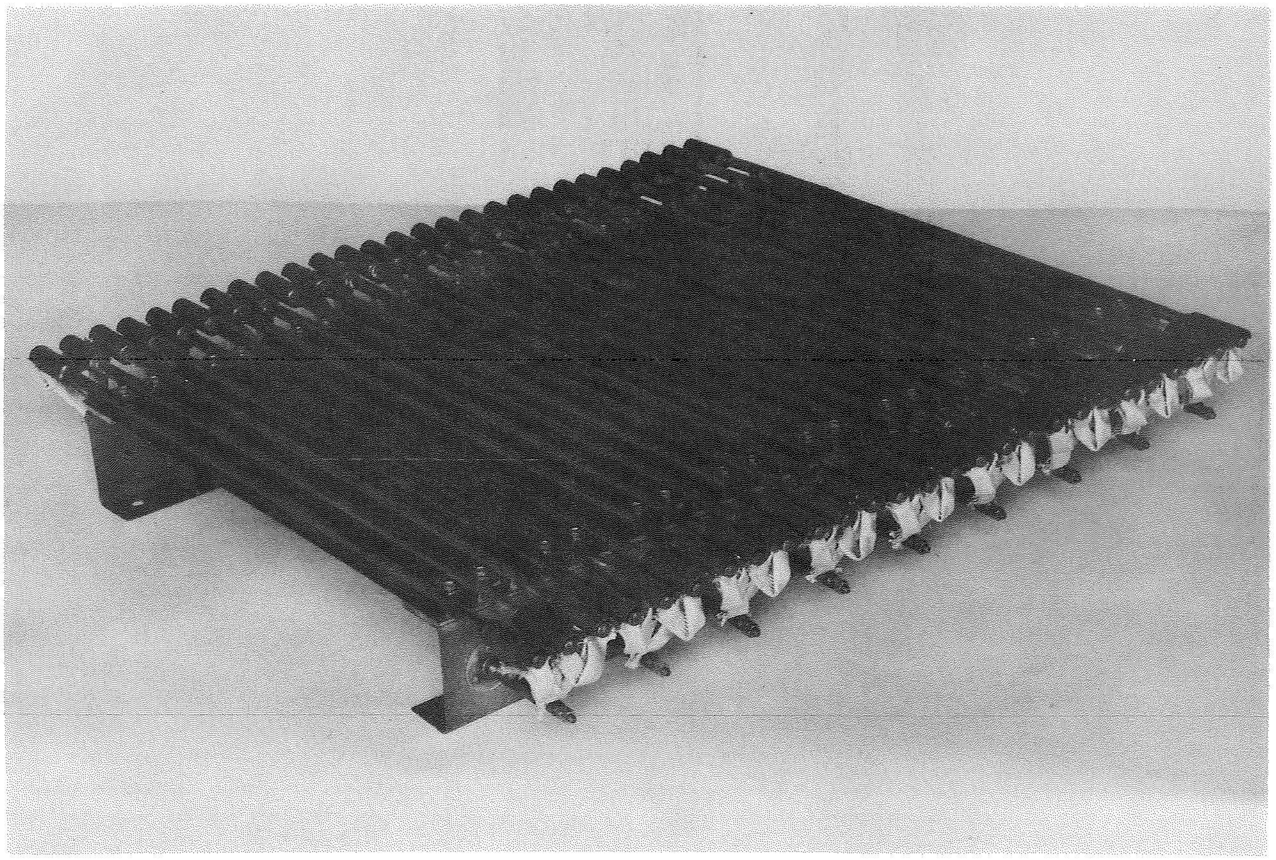
DISCUSSION OF CALCULATIONS

As covered on page 5, previous experience led to the selection of the basic design, that of metal sheath tubular heaters, brazed to a radiating plate for supplementary heat transfer surface. The weight goal of a maximum of 75 pounds set forth in the NASA specifications led to the cross section shown on page 13. Actually this is the final machined configuration and the part shown was made of plate 3/4" thick with the bulk of the material machined away for lightening.

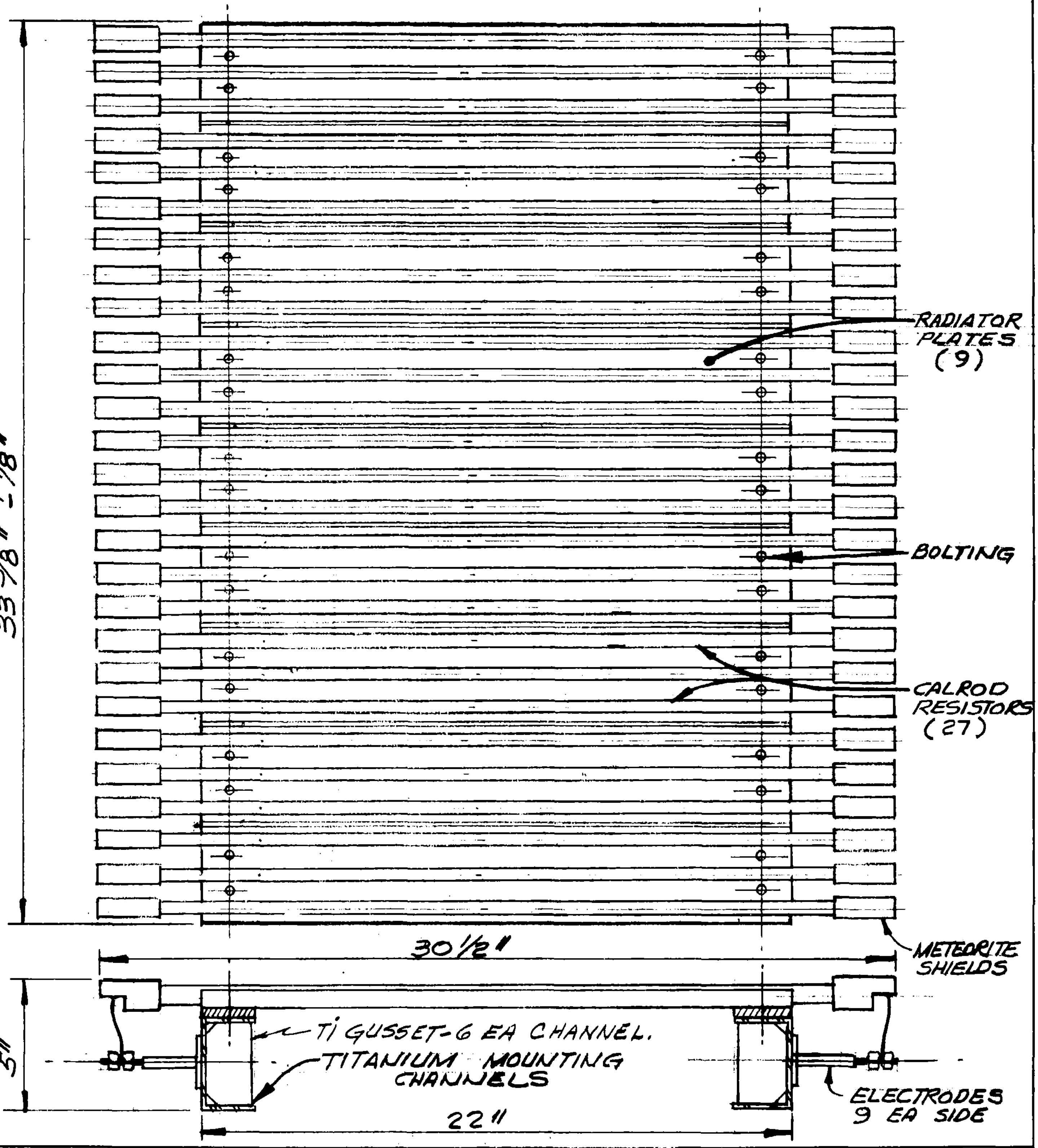
Similarly, titanium channels and mounting hardware were substituted for stainless steel in order to accomplish further weight reduction and bring the weight within the goal established.

Once the configuration necessary from a heat transfer stand point and a weight stand point had been determined, it was then necessary to evaluate the proposed design from a stress basis, using the parameters of shock, vibration and acceleration set forth in the NASA specifications. The calculations of pages 1 through 23 of the appendix showed that the desired configuration would meet the weight and heat transfer requirements and would withstand the stresses imposed by the predicted flight conditions.

The one exception to the spress analysis is the case of the 18 electrodes mounted nine to each side channel for the electrical connections to the parasitic load resistor. NASA had not defined the harness arrangement to the parasitic load resistor, but in a "flyable" unit these 18 electrodes would be eliminated. These 18 electrodes allow multiple connects and disconnects of the parasitic load resistor without potential undue stress and strain on the ceramic terminals of the resistor elements of the parasitic load resistor.

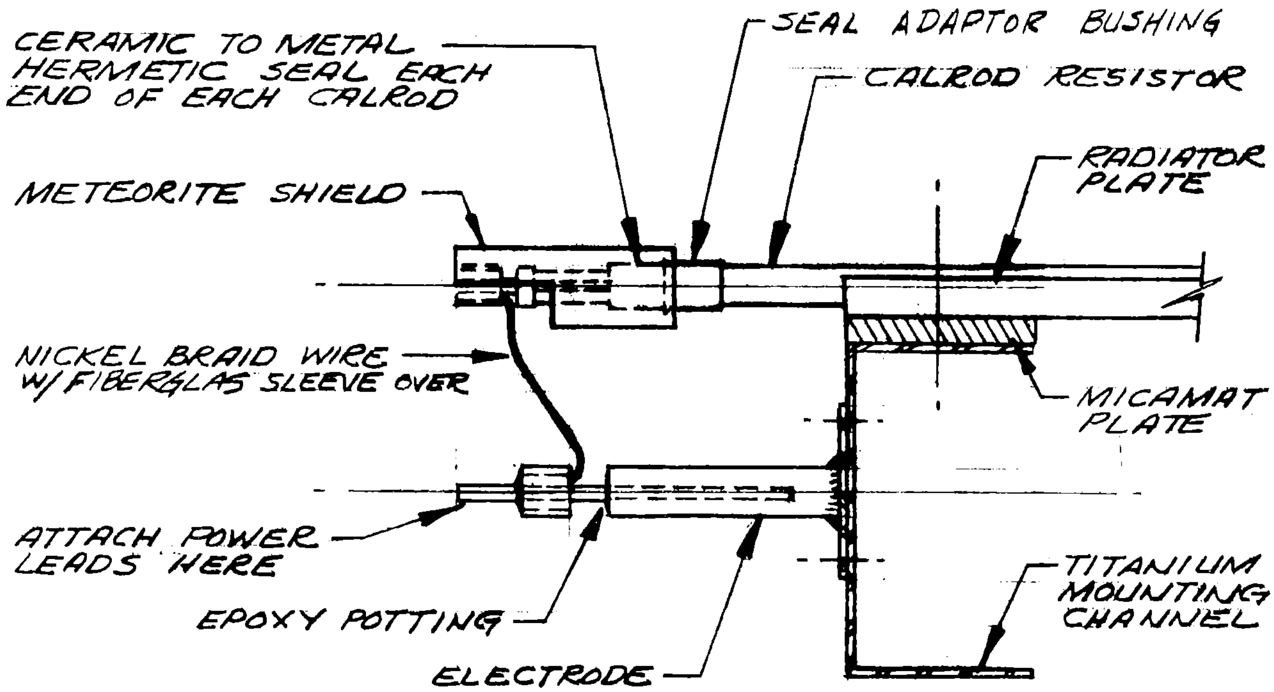


PHOTOGRAPH #12193-1

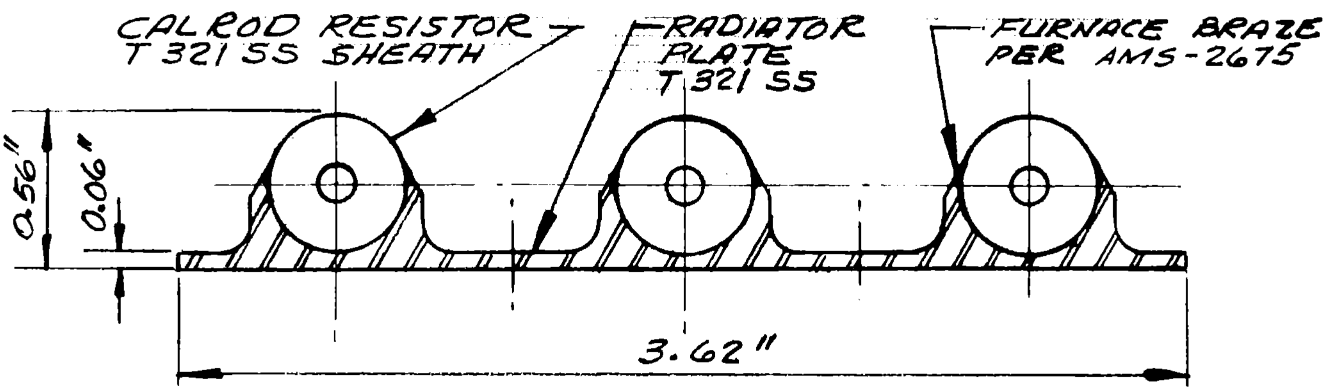


HEAT ENGINEERING & SUPPLY CO.
SAN GABRIEL, CALIF.

DRWN.	J. F	BRAYTON CYCLE PARASITIC LOAD RESISTOR GENERAL ARRANGEMENT	DRAWING NUMBER R-12193-5	SHEET NO. 1 OF 4
APP'D.				
SCALE	NONE			
DO NOT SCALE				REV. 0



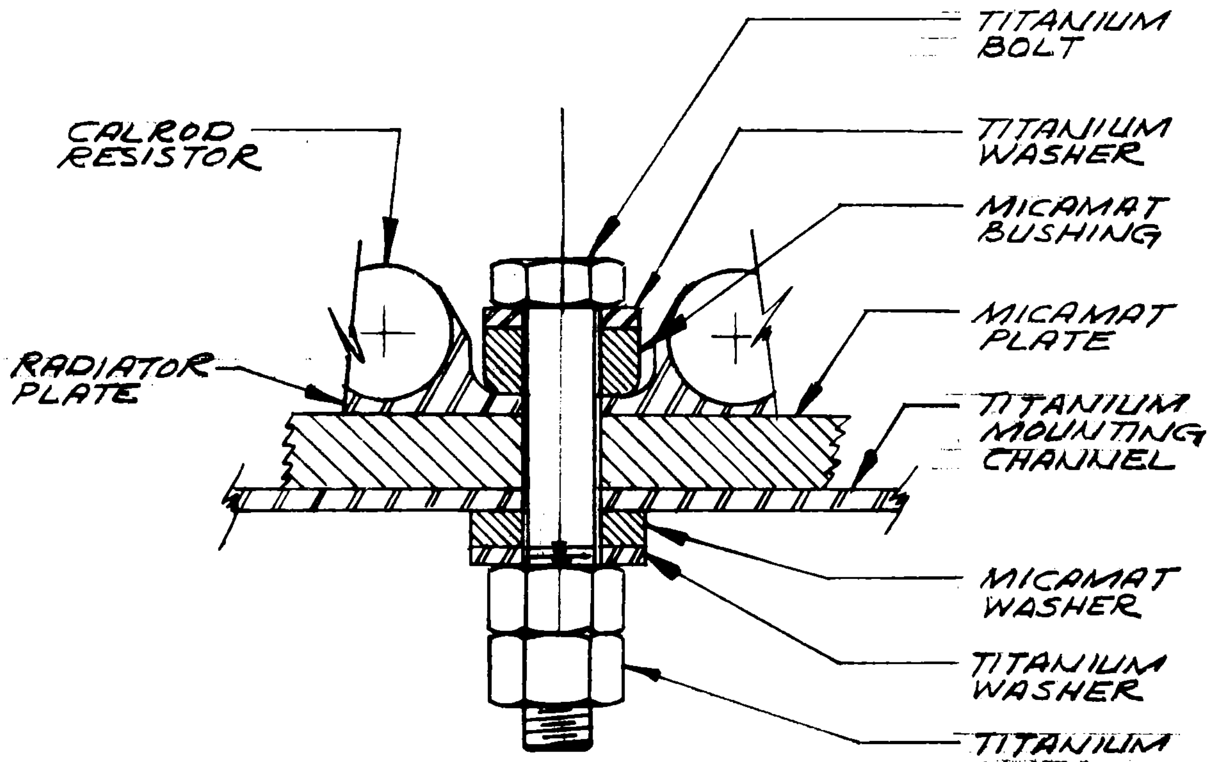
TERMINAL DETAILS



SECTION THRU RESISTOR PLATE

HEAT ENGINEERING & SUPPLY CO.
SAN GABRIEL, CALIF.

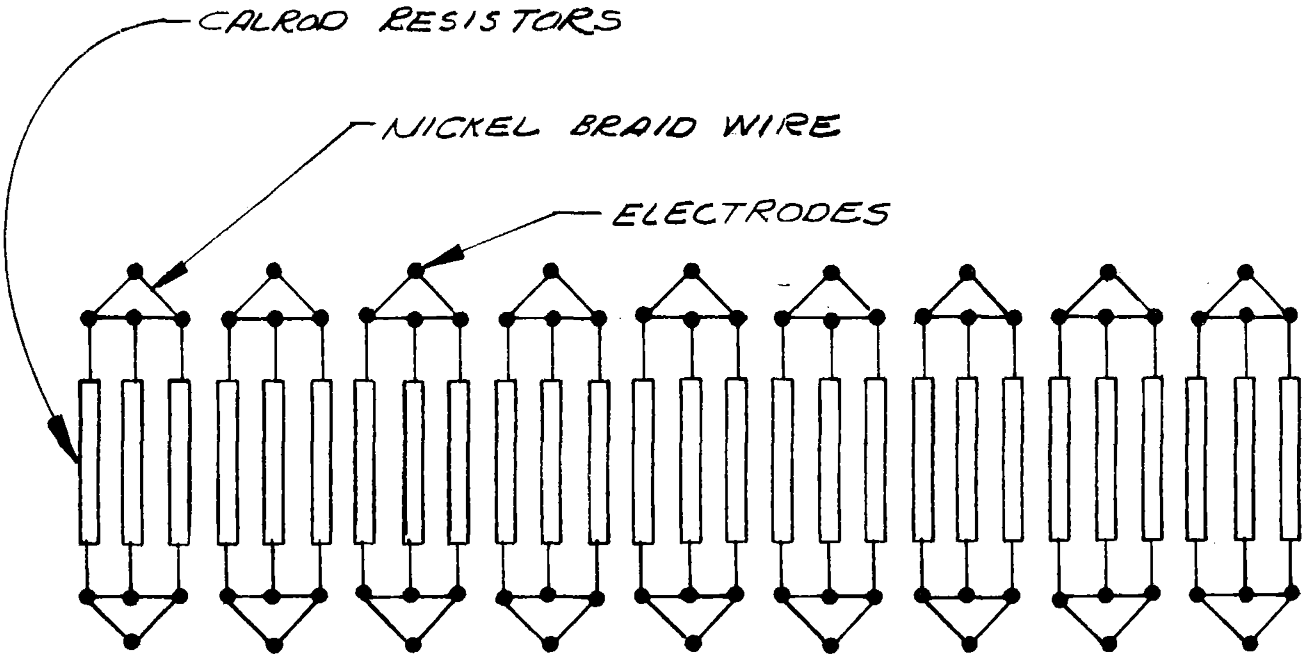
DRWN.	J. F.	BRAYTON CYCLE PARASITIC LOAD RESISTOR	DRAWING NUMBER R-12193-5	SHEET NO. 2 OF 4
APP'D.				
SCALE	NONE			
DO NOT SCALE				REV. 0



BOLTING DETAILS
(2 PLACES EACH END OF EACH PLATE)

HEAT ENGINEERING & SUPPLY CO.
SAN GABRIEL, CALIF.

DRWN.	J. F	BRAYTON CYCLE PARASITIC LOAD RESISTOR	DRAWING NUMBER
APP'D.			R-12193-5
SCALE	NONE		SHEET NO. 3 OF 4
DO NOT SCALE			REV. 0



WIRING DIAGRAM

HEAT ENGINEERING & SUPPLY CO.
SAN GABRIEL, CALIF.

DRWN. V.F.	BRAYTON CYCLE PARASITIC LOAD RESISTOR	DRAWING NUMBER	SHEET NO. 4 OF 4
APP'D.		R-12193-5	REV. 0
SCALE NONE			
DO NOT SCALE			

DISCUSSION OF TEST PROCEDURES AND RESULTS

The temperature profile of one resistor plate was measured carefully to verify the predicted temperature uniformity derived on page 22. The test setup used is shown on page 37 as is the measured temperature profile.

Because the temperature profile test was conducted in air rather than in a vacuum, it was necessary to operate at a substantially higher power level than would be required in space to obtain the plate temperature desired. This is because substantial heat is carried away from the assembly by natural convection currents even though steps were taken to reduce them as much as possible. This increased operating power level increases the temperature gradient beyond that which will be experienced by radiation heat transfer only. Similarly, convection current accentuates the rate of temperature decay at the ends of the part although even in space the heat lost through the micamat insulator and the mounting hardware will cause some temperature decay as well as the heat carried out into the cold section of the individual resistor elements.

In spite of these pessimistic conditions, the measured temperature profile was excellent.

After the temperature profile was measured, one plate was operated at this same power and temperature level for eight hours per day for two weeks to determine the dimensional stability. Each morning, before energizing the plate, it was set on a flat surface and the distortion measured. After the third day of testing, there was no further measurable change in the configuration of the plate and after two weeks this test was discontinued because the dimensional stability appeared to have been established. The distortion shown is quite reasonable and acceptable to NASA engineers.

The helium leak testing of the welds of the bushing to the resistor sheath, the seal to the bushing as well as the integrity of the brazed joints within the seal was accomplished by the spray method. The vacuum sensing line for the leak detector was attached to the end of the seal and at this time the weld of the seal to the resistor cold terminal had not been accomplished. Therefore, a vacuum pull at this point could pull helium in from any leak in either of the two welds or in any of the joints in the seal itself. The helium was carefully sprayed around the joints to be tested and the leakage rate measured. The number of leaks detected was kept to a minimum by making careful dye-penetrant inspection of the two welds before submitting the assemblies for testing but even so some very small leaks were detected and repairs made as shown by the certified helium leak test reports.

After the welding of the nickel braid to the end of the seal, which welding also joined the seal to the cold terminal of the resistor, there was no longer any way to conduct a helium leak test. Therefore, a test was devised which was not listed in the NASA specifications, wherein the entire assembly was soaked for 24 hours in water. After removal it was necessary to blow the water out of the braid and the fibreglass sleeving covering it and then high potential and insulation resistance tests were conducted to clarify that there were no leaks. In only one case was a leak found and this was in the epoxy potting of one of the electrodes and the repair of the potting corrected this difficulty.

DESIGN AND MANUFACTURE OF PARASITIC LOAD RESISTORS FOR BRAYTON POWER CONVERSION SYSTEM

HEAT ENGINEERING & SUPPLY COMPANY

ABSTRACT

The contract covered the design, manufacture and testing of Parasitic Load Resistors to dissipate 18 KWe electric power at 120 Volts and 1200 Hertz by coverting the electrical energy to heat energy and radiating that energy to hard vacuum.

BRAYTON CYCLE CONTRACTS

BASIC FINAL REPORT DISTRIBUTION LIST

NASA - Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135
Attention:

Project Manager Mail Stop 500-201	(3)	Fluid System Components Div. Mail Stop 5-3	(1)
D. G. Beremand Mail Stop 500-201	(1)	D. T. Bernatowicz Mail Stop 500-201	(1)
V. F. Hlavin Mail Stop 3-14	(1)	T. A. Moss Mail Stop 500-201	(1)
H. O. Slone Mail Stop 500-201	(1)	W. E. Park Mail Stop 500-312	(1)
B. Lubarsky Mail Stop 500-201	(1)	P. E. Fostor Mail Stop 3-19	(1)
N. T. Musial Mail Stop 501-3	(1)	Library Mail Stop 60-3	(2)
Reliability & Quality Assurance Office Mail Stop 500-203	(1)	Report Control Office Mail Stop 5-5	(1)

NASA Lewis Research Center (1)
Plum Brook Station
Taylor Road
Sandusky, Ohio 44870
Attention: J. C. Nettles
Mail Stop 7141-6

National Aeronautics and Space Administration
Washington, D.C. 20546
Attention: Herbert D. Rochen (1)
Code RNP

Arvin Smith (1)
Code RNW

NASA Scientific & Technical Information Facility
Post Office Box 5700
Bethesda, Maryland 20014
Attention: Acquisitions Branch (SQT-34054) (1 + Reproducible)

AiResearch Manufacturing Company (1)
402 South 36 Street
Phoenix, Arizona 85034
Attention: Library

AiResearch Manufacturing Company (1)
402 South 36 Street
Phoenix, Arizona 85034
Attention: H. Milligan

AiResearch Manufacturing Company (1)
402 South 36 Street
Phoenix, Arizona 85034
Attention: Lyle Six

AiResearch Manufacturing Company (1)
9851 Sepulveda Boulevard
Los Angeles, California 90009

Bendix Research Labs. Division (1)
Aero-Space Division
Box 3707
Seattle, Washington 98124
Attention: Library

Borg-Warner Corporation (1)
Pesco Products Division
24700 North Miles Road
Bedford, Ohio 44014
Attention: Library

Continental Avaiation & Engr. Corp.(1)
12700 Kercheval Avenue
Detroit, Michigan 48215
Attention: Library

Douglas Aircraft Company (1)
3000 Ocean Park Blvd.
Santa Monica, California 90406
Attention: Library

Curtiss-Wright Corporation (1)
Wright Aero Division
Main & Passaic Streets
Woodridge, New Jersey 07075
Attention: Library

General Electric Company (1)
Mechanical Technology Laboratory
R & D Center
Schenectady, New York 12301
Attention: Library

General Dynamics Corporation (1)
16501 Brookpark Road
Cleveland, Ohio 44142
Attention: Library

General Electric Company (1)
Flight Propulsion Division
Cincinnati, Ohio 45215
Attention: Library

Aerospace Corporation (1)
P. O. Box 95085
Los Angeles, California 91745
Attention: Library

McDonnell Douglas Corporation (1)
Missile & Space Systems Division
3000 Ocean Park Boulevard
Santa Monica, California 90406
Attention: Library

General Electric Company (1)
Missile & Space Vehicle Dept.
3189 Chestnut Street
Philadelphia, Pennsylvania 19104
Attention: Library

General Motors Corporation (1)
Indianapolis, Indiana 46206
Attention: Library

NASA Ames Research Center (1)
Moffett Field, California 94035
Attention: Library

NASA Flight Research Center (1)
Post Office Box 273
Edwards, California 93523

NASA Goddard Space Flight Center (1)
Greenbelt, Maryland 20771
Attention: Library

NASA Langley Research Center (1)
Langley Station
Hampton, Virginia 23365

NASA Manned Spacecraft Center (1)
Houston, Texas 77058
Attention: Library

NASA Manned Spacecraft Center (1)
Houston, Texas 77058
Attention: Tony Redding

NASA Marshall Space Flight Center (1)
Huntsville, Alabama 35812
Attention: Library

Jet Propulsion Laboratory (1)
4800 Oak Grove Drive
Pasadena, California 91103
Attention: Library

U.S. Army Engineer R & D Labs (1)
Gas Turbine Test Facility
Fort Belvoir, Virginia 22060
Attention: W. Crim

Battelle Memorial Institute (1)
505 King Avenue
Columbus, Ohio 43201
Attention: Library

Hughes Aircraft Corporation (1)
Centinda & Teale Avenue
Culver City, California 90230
Attention: Library

Bureau of Naval Weapons (1)
Department of the Navy
Washington, D. C. 20025
Attention: Code RAPP

Air Force Systems Command (1)
Aeronautical Systems Division
Wright-Patterson Air Force Base,
Ohio 45433
Attention: Library

Institute for Defense Analyses (1)
400 Army-Navy Drive
Arlington, Virginia 22202
Attention: Library

Power Information Center (1)
University of Pennsylvania
3401 Market Street, Room 2107
Philadelphia, Pennsylvania 19104

Aerojet-General Corporation (1)
Von Karman Center
Azusa, California 91702
Attention: Library

Aerojet-General Corporation (1)
Von Karman Center
Azusa, California 91702
Attention: S. L. Bradley
Dept. 4936, Bldg. 160

Aerojet-General Corporation (1)
Von Karman Center
Azusa, California 91702
Attention: R. L. Hill
Dept. 4936, Bldg. 160

Lear Siegler, Incorporated (1)
3171 S. Bundy Drive
Santa Monica, California 90406
Attention: Library

Lockheed Missiles & Space Co. (1)
P. O. Box 504
Sunnyvale, California 94088
Attention: Library

Massachusetts Institute of Technology (1)
Cambridge, Massachusetts 02139
Attention: Library

Mechanical Technology Inc. (1)
968 Albany-Shaker Road
Latham, New York 12110

North American Aviation, Inc. (1)
Space & Information Systems, Div.
Downey, California 90241
Attention: Library

Northern Research & Engineering Company (1)
219 Vassar Street
Cambridge, Massachusetts 02139
Attention: Library

Pratt & Whitney Aircraft (1)
400 Main Street
East Hartford, Connecticut 06108
Attention: Library

McDonnell-Douglas (1)
Lambert Field
St. Louis, Missouri 63166
Attention: Library

Solar, Div. of International Harvester (1)
2200 Pacific Highway
San Diego, California 92112
Attention: Library

Space Technology Labs. Inc. (1)
One Space Park
Redondo Beach, California 90278
Attention: Library

Sunstrand Denver (1)
2480 West 70 Avenue
Denver, Colorado 80221
Attention: Library

TRW Accessories Division (1)
23555 Euclid Avenue
Cleveland, Ohio 44117
Attention: Library

United Aircraft Research Lab. (1)
East Hartford, Connecticut 06108
Attention: Library

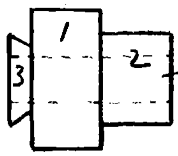
Williams Research (1)
Walled Lake, Michigan 48088
Attention: Library

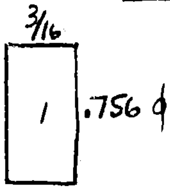
Westinghouse Electric Corp. (1)
Astronuclear Laboratory
P. O. Box 10864
Pittsburgh, Pennsylvania 15236
Attention: Library

PARASITIC LOAD RESISTOR

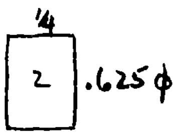
WEIGHT CALCULATIONS.

			lbs
1.	CALRODS		
	26.875" LG × .0342 #/IN × 27 QUAN	=	24.85
2.	ADVACS (CALROD END TERMINALS)		
	.0313 # EA × 54 QUAN.	=	1.69
3.	CALROD SLEEVES		

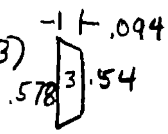


(1)


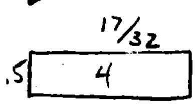
$.756^2 \cdot .785 \cdot .1875 = .0841\ IN^3$

(2)


$.625^2 \cdot .785 \cdot .25 = .0767\ IN^3$

(3)


$\left(\frac{.578 + .540}{2}\right)^2 \cdot .785 \cdot .094 = .0231\ IN^3$

(4)


$.5^2 \cdot .785 \cdot .5313 = .104\ IN^3$

$V = .0841 + .0767 + .0231 - .104 = .0799\ IN^3$

$.0799\ IN^3 \cdot .29\ \#/IN^3 \cdot 54\ pcs$ = 1.253

HEAT ENGINEERING & SUPPLY CO.
SAN GABRIEL, CALIF.

DRWN.	7-6-67	PARASITIC LOAD RESISTOR	DRAWING NUMBER
APP'D.		CALCS (WEIGHT)	R-12193
SCALE			SHEET NO. OF
DO NOT SCALE			REV.

APPENDIX — PAGE 1

4. NICKEL BRAID CONDUCTORS. — lbs

EA LEAD - 384 STRANDS #36 AWG. 18 SETS 22" LG

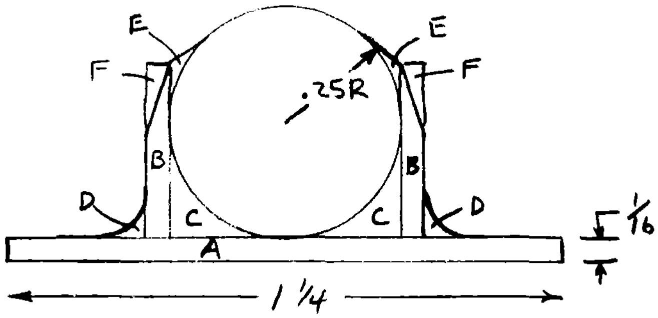
$.005^2 \cdot .785 \cdot 384 = .00753\ IN^2 \cdot 22'' = .166\ IN^3$

$.166\ IN^3 \cdot 18\ SETS \times .322\ \#/IN^3 =$ — .962

5. NICKEL SLEEVES 1/2" OD x 13/32 ID x 1/4" LG.

$(.5^2 - .4063^2) \cdot .785 \cdot .25 = .0168\ IN^3 \times .322\ \#/IN^3 = .00542\# \times 54\,pcs = .292$

6. RADIATOR PL. (ONE CALROD MODULE)



$A - 1.25 \cdot .0625 \cdot 22\,LG = 1.72\ IN^3$

$2B - 2 \cdot .375 \cdot .0625 \cdot 22 = 1.032\ IN^3$

$2C - .25^2 \left(\frac{.5^2 \cdot .785}{4}\right) \cdot 22 \cdot 2 = 0.594\ IN^3$

$2D - .125^2 - \left(\frac{.25^2 \cdot .785}{4}\right) \cdot 22 \cdot 2 = 0.147\ IN^3$

$2E - 2\left[\left(\frac{.125 \cdot .25}{2}\right) - .5^2 \cdot .785 \cdot \frac{26.5}{360}\right] 22 \cdot 2 = .1056\ IN^3$

$2F - 2 \cdot \frac{.187 \cdot .062}{2} \cdot 22 = .258\ IN^3$

$GAP - \frac{2 \cdot .062 \cdot .062}{3} \cdot 22 = .0573\ IN^3$

HEAT ENGINEERING & SUPPLY CO.
SAN GABRIEL, CALIF.

DRWN. 7-6-67	PARASITIC LOAD RESISTOR CALCS - (WEIGHT)	DRAWING NUMBER R12193	SHEET NO. ___ OF ___
APP'D.			REV.
SCALE			
DO NOT SCALE			

6 (CONT.) **lbs**

$1.72 + 1.032 + 0.594 + 0.147 + 0.1056$

$- 0.258 - 0.0573 \qquad = 3.2833\ in^3$

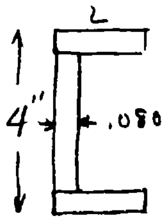
$3.2833 \cdot .29\ \#/IN^3 \times 27$ MODULES $=$ 25.74

7. MICA MAT INSULATION.

$2\ @\ 2'' \times 1/4'' \times 33\ 5/8$ LG $= 16.84\ IN^3$

$16.84\ IN^3 \cdot .0794\ \#/IN^3 =$ 1.34

8. TITANIUM CHANNELS



$2 \times .080 \times 2 = .320$

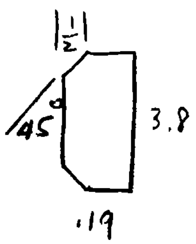
$3.84 \times .080 = .307$

$.627\ in^2$

$.627\ IN^2 \cdot 33.625 \cdot 2 = 84.25\ IN^3 \cdot .16\ \#/IN^3 =$ 6.74

9. GUSSETS FOR LATERAL CHANNEL STIFFENING.

6 GUSSETS / CHAN. 0.080 THICK.



$3.8 \cdot .19 \cdot .080 = .577\ IN^3$

LESS $\frac{.5 \cdot .5}{2} \cdot 2 \cdot .080 = .020$

$.557\ IN^3$

ADD FOR WELD 1/16" FILLET.

$.06 \cdot .06 \cdot .5 \cdot 11.2 \times 2 = .0403\ IN^3$

$.557 + .0403 = .5973 \times 12 = 7.17\ IN^3 \times .16\ \#/IN^3 =$ 1.147

HEAT ENGINEERING & SUPPLY CO.
SAN GABRIEL, CALIF.

DRWN. 7-6-67	PARASITIC LOAD RESISTOR CALCS (WEIGHT)	DRAWING NUMBER R 12193	SHEET NO. OF
APP'D.			REV.
SCALE			
DO NOT SCALE			

10. BOLTING lbs

PLATE TO CHANNELS. 4/SECTION, 9 SECTIONS

36 SCREWS 1/4" RH x 1 1/4" LG TITANIUM = 0.359#

36 NUTS 1/4 HEX @ .00392#EA Ti = 0.141

36 WASHERS Ti 9/16 OD x 17/64 ID x 1/16 @ .00124#EA = 0.045

36 MICAMAT WASHERS
5/8 OD x 17/64 ID x 1/8 @ .0014#EA = 0.051

36 MICA MAT BUSHINGS
$.1588\ IN^3 \cdot .0795\ \#/IN^3 \cdot 36$ = 0.454

36 Ti WASHERS 5/8 OD x 17/64 ID x 1/16" @ .00255#EA = 0.092

1.142

LESS

5/16 x 3/4 SLOT IN PL x 36 = .150

9/32 HOLE IN [x 36 = .028 → − .178 → 0.964

11. METEORITE SHIELDING SLEEVES.
(2 3/8 LG x 13/16 OD x .028 WALL)

$2.375\ IN \cdot .01956\ \#/IN \cdot 54$ SHIELDS = 2.51

12 FIBER GLASS SLEEVING @ .5#/100 FT

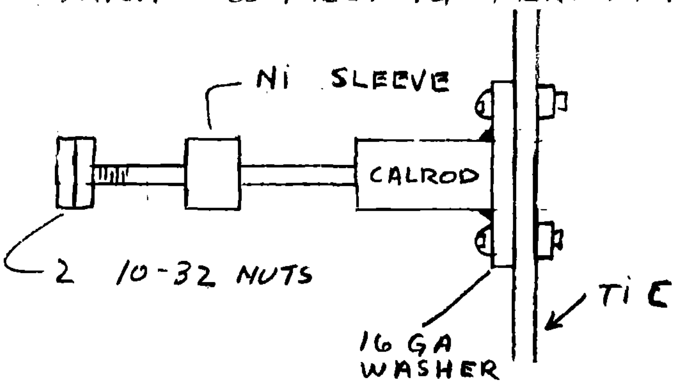
18 SETS • 22"/SET = 360"

$\frac{360}{12} \cdot .005\ \#/FT$ = 0.15

HEAT ENGINEERING & SUPPLY CO.
SAN GABRIEL, CALIF.

DRWN. 7-6-67	PARASITIC LOAD RESISTOR CALCS (WEIGHT)	DRAWING NUMBER R-12193	SHEET NO. ___ OF ___
APP'D.			REV.
SCALE			
DO NOT SCALE			

13. ELECTRICAL CONNECTING TERMINALS (18 pcs) lbs



CALROD

$4\frac{3}{4}$" LG × .0342#/IN = .1625#

PLUS STUBS .0135#

.1760 × 18 PCS = 3.17#

NICKEL SLEEVES (SEE (5)) .00542#EA × 18 = .097

10-32 NUTS (SS) 36 EA = .138

SS WASHERS 17/32 OD × 1 1/16 OD × .065

.009# EA × 18 EA = .294

Ti SCREWS 10-32 × 3/16 (EFF LENGTH) = .094

Ti NUTS 10-32 HEX = .114

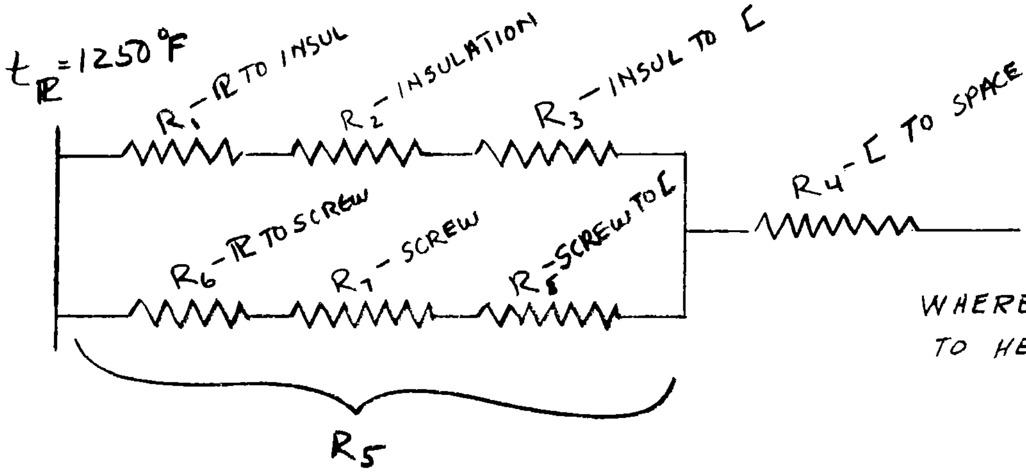
3.907 → 3.907

TOTAL WEIGHT 71.608#

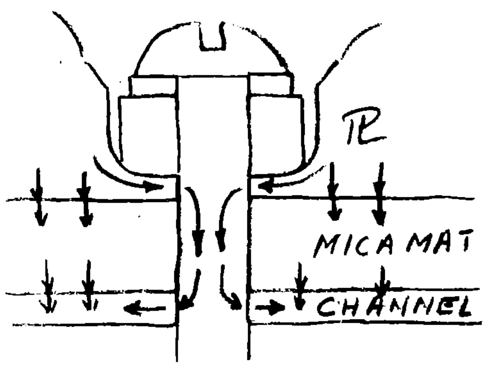
HEAT ENGINEERING & SUPPLY CO.
SAN GABRIEL, CALIF.

DRWN. 7-6-67	PARASITIC LOAD RESISTOR	DRAWING NUMBER	SHEET NO.
APP'D.	CALCS - (WEIGHT)	R 12193	OF
SCALE			
DO NOT SCALE			REV.

HEAT FLOW FROM ℝ TO C. THERE ARE TWO || PATHS FOR FLOW: ℝ TO C THROUGH MICA MAT, ℝ TO C THROUGH BOLTING AS SHOWN IN THE FOLLOWING DIAGRAM.



WHERE R = RESISTANCE TO HEAT FLOW, $\frac{°F-hr}{BTU}$



FLOW PATHS

$$\frac{1}{R_5} = \frac{1}{R_1 + R_2 + R_3} + \frac{1}{R_6 + R_7 + R_8}$$

2 SCREWS/MODULE

$$\Sigma R = R_4 + R_5$$

HEAT ENGINEERING & SUPPLY CO.
SAN GABRIEL, CALIF.

DRWN. 7-6-67	PARASITIC LOAD RESISTOR CALCS - (CHANNEL TEMP)	DRAWING NUMBER R-12193	SHEET NO. ___ OF ___
APP'D.			REV.
SCALE			
DO NOT SCALE			

$$R_1 = \frac{1}{hA} = \frac{1}{100 \cdot .101} = 10$$

$$R_2 = \frac{\ell}{kA} = \frac{.0208}{.0843 \cdot .101} = 2.42$$

$$R_3 = \frac{1}{hA} = \frac{1}{100 \cdot .101} = 10$$

WHERE h = CONTACT CONDUCTANCE, $\frac{BTU}{hr - ft^2 - {}^\circ F}$

A = AREA, ft^2

K = THERMAL CONDUCTIVITY $\frac{BTU}{hr - ft^2 \cdot {}^\circ F} / ft$

ℓ = DISTANCE, ft

$$R_6 = 2\left[\frac{1}{hA}\right] = 2\left[\frac{1}{22 \cdot .00041}\right] = 222$$

$$R_7 = 2\left[\frac{\ell}{kA}\right] = 2\left[\frac{.026}{15 \cdot .0333}\right] = .104$$

$$R_8 = 2\left[\frac{1}{hA}\right] = 2\left[\frac{1}{100 \cdot .00041}\right] = 48$$

$$\frac{1}{R_5} = \frac{1}{R_1 + R_2 + R_3} + \frac{1}{R_6 + R_7 + R_8}$$

$$= \frac{1}{10 + 2.42 + 10} + \frac{1}{222 + .104 + 48}$$

$$= \frac{1}{22.4} + \frac{1}{270}$$

$$\frac{1}{R_5} = .0474$$

$$R_5 = 21.1$$

HEAT ENGINEERING & SUPPLY CO.
SAN GABRIEL, CALIF.

DRWN. 7-6-67	PARASITIC LOAD RESISTOR CALCS - (CHANNEL TEMP)	DRAWING NUMBER R-12193	SHEET NO. OF
APP'D.			REV.
SCALE			
DO NOT SCALE			

$$R_4 = \frac{1}{h_r A}$$

ASSUME $t_c = 205°F$

$$h_r = \frac{.173\,\epsilon_s\left[\left(T_s/100\right)^4 - \left(T_e/100\right)^4\right]}{T_s - T_e}$$

McADAMS 2ND ED
PAGE 63.

WHERE:

ϵ_s = EMMISIVITY OF Ti C = .4 ASSUMED

$T_s = t_{CHANNEL} + 460$

$T_e = t_{SPACE} + 460$

$$h_r = \frac{(.173 \cdot .4)\left[6.65^4 - 4.1^4\right]}{665 - 410}$$

$$= \frac{.0692\,(1955 - 280)}{255}$$

$h_r = .457$

THEN

$$R_4 = \frac{1}{.457 \cdot .395} = 5.54$$

$\Sigma R = R_4 + R_5 = 5.54 + 21.1 = 26.64$

HEAT ENGINEERING & SUPPLY CO.
SAN GABRIEL, CALIF.

DRWN.	7-6-67	PARASITIC LOAD RESISTOR CALCS - CHANNEL TEMP	DRAWING NUMBER: R-12193	SHEET NO. OF
APP'D.				
SCALE				REV.
DO NOT SCALE				

$$q = \frac{\Delta t}{\Sigma R} = \frac{1250-(-50)}{26.64} = 48.8$$

$$\Delta t_C = R_4 q = 5.54 \cdot 48.8 = 261$$

$$t_C = 261 + (-50) = \underline{\underline{211}} \ ^\circ F$$

CLOSE TO ASSUMED VALUE OF 205°.

CHANNEL TEMP

HEAT ENGINEERING & SUPPLY CO.
SAN GABRIEL, CALIF.

DRWN. 7-6-67	PARASITIC LOAD RESISTOR	DRAWING NUMBER	
APP'D.	CALCS CHANNEL TEMP	R-12193	SHEET NO. ___ OF ___
SCALE			REV.
DO NOT SCALE			

4.1.2. (a) Heater sheath temp. Sheath temp equals plate temp.

Per segment: Area = $3\frac{5}{8} \times 22''$ = 79.3 sq in (top only)

$q = (3)(667) = 2$ Kw

$q/A = \frac{2 \text{ Kw}}{79.3} = 25.3$ wsi = 12.5 KBH/sq ft

incident solar radiation est. = 600 BH/sq ft

total radiation = 13.1K BH/sq ft

$$q/A = \sigma \epsilon \left[\left(\frac{T_P}{100}\right)^4 - \left(\frac{T_S}{100}\right)^4 \right]$$

T_S = Temp sink = −50°F (est)

ϵ = emissivity iron titanate coating on PLR = 0.88 per NASA spec C-320867

$$\left(\frac{T_S}{100}\right)^4 = \left(\frac{-50+460}{100}\right)^4 = \left(\frac{410}{100}\right)^4 = 290$$

$$\left(\frac{T_{PLR}}{100}\right)^4 = \frac{q/A}{\sigma \epsilon} + \left(\frac{T_S}{100}\right)^4 = \frac{13.1K}{(0.174)(.88)} + 290$$

$$= 85.5K + 290 = 85.8K$$

$$\frac{T_{PLR}}{100} = \sqrt[4]{85.8K} = \sqrt{292} = 17.1$$

T_{PLR} = 1710°R = 1250°F

REVISING FOR OXIDIZED SS w/o IRON TITANATE (SEE P 5 & 6):

$$\left(\frac{T_P}{100}\right)^4 = \frac{13.1K}{(0.174)(0.75)} + 290$$

$$= 101000$$

$$\frac{T_P}{100} = \sqrt[4]{101000} = 17.8$$

T_P = 1780°R = 1320°F

ϵ = 0.75 OXIDIZED 18-8 S.S. PER MC ADAMS 3RD ED.

4.1.2. (b) Resistor flux

$$q/A = \frac{667 \text{ w}}{(\pi)(0.499)(21.75)} = 19.5 \text{ wsi nominal}$$

4.1.2. (c) Wire temp. (from proprietary GE Curve #114HB291):

$$T_W = T_S + 150°F = 1250 + 150 = 1400°F$$

q = ENERGY RATE, KW-HR/HR OR BTU/HR (BH)

A = AREA, ft²

σ = STEFAN BOLTZMANN CONSTANT = 0.174

HEAT ENGINEERING & SUPPLY CO.
SAN GABRIEL, CALIF.

DRWN.	6-14-67	PARASITIC LOAD RESISTOR	DRAWING NUMBER
APP'D.	RWD	CALCS - CALROD	R-12193
SCALE			SHEET NO. OF
DO NOT SCALE			REV.

4.1.2 (e) Optimum nbr resistor elements - fixed by NASA @ 27.

4.1.2. (f) Thermal expansion. ℄ $3\,5/8'' \times 22''$, $T = 1250°F$

$C = 0.0000112$ in/in/°F to 1500°F (Metals Handbook, 8th ed. p423)

$W_{1250} = (W_{70})(1 + C\Delta T) = (3.63)[1 + (0.0000112)(1180)]$

$= (3.63)(1.013)$

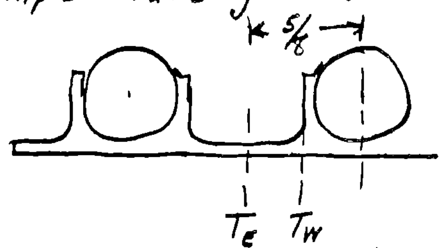
$= \underline{3.67''}$ $\qquad \underline{\Delta W = 0.04''}$

$L_{1250} = (22)(1.013) = 22.2''$ $\qquad \underline{\underline{\Delta L = 0.2''}}$

4.1.2 (h)(i)(j) See drawing 1466 Sheet 2, GE MgO specs & Advac drawing # A-217-SV-157 Rev 1

4.1.2 (K) See drawing 1466 Sheet 1

Temperature gradient from Calrod ℄ to ℄ between Calrods



τ = ambient temp = -50°F

T_W = temp at edge = +1250°F

T_E = temp at ℄

From Boelter et al "Heat Transfer Notes" p39, (2.47):

$$\frac{T_E - \tau}{T_W - \tau} = \frac{1}{\cosh mL} \qquad m = \sqrt{\frac{hp}{KA}}$$

h = heat transfer conductance fin to ambient

p = length heat trans. surface

k = thermal conductivity

A = heat flow area

h = 13 (McAdams, "Heat Transmission" 2nd Ed p63

$$m = \sqrt{\frac{(13)(1.83)}{(12)(0.0953)}} = \sqrt{20.9} = 4.57$$

$mL = (4.57)(0.0260) = 0.116$

$\cosh 0.116 = 1.006$

$$\frac{T_E - \tau}{T_W - \tau} = \frac{1}{1.006} \cong 1$$

Therefore no significant gradient is predicted; resistance to heat transfer by radiation to space is so great compared to resistance to conduction thru the metal plate that gradient is negligible.

NB 7-26-68 TESTS WITH TEMP. SENSITIVE PAINT SHOWED GRADIENT LESS THAN 50°F.

HEAT ENGINEERING & SUPPLY CO.
SAN GABRIEL, CALIF.

DRWN.	6-14-67	PARASITIC LOAD RESISTOR	DRAWING NUMBER	
APP'D.	BWD	CALCS - EXPANSION, GRADIENT	R 12193	SHEET NO. OF
SCALE				
DO NOT SCALE				REV.

— SYMBOLS —

Symbol	Definition
w	Weight per unit length, lb./in.
W	Weight, lbs.
ρ, γ	Density lbs./in.^{3}
D	Diameter, in.
r	Radius, in.
L, ℓ	Length, in.
h	Section height
a	Acceleration in/sec.^{2}
g	Gravitational constant, 386 in/sec.^{2}
G	Gravitational units ($= a/g$) dimensionless
f	Frequency, cycles/sec.
E	Modulus of elasticity, lb./in.^{2}
V	Volume, in.^{3}

— SUBSCRIPTS —

Notation	Definition	Notation	Definition
C	Calrod	P	Panel
I	Inside	S	Terminal Shield
RT	Heater Rod Tube	t	Titanium Channel
R	Radiator	T	Total

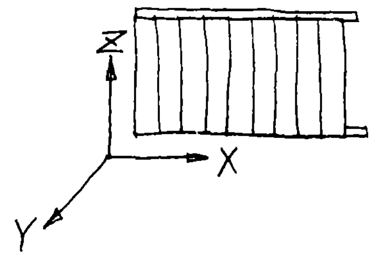
HEAT ENGINEERING & SUPPLY CO.
SAN GABRIEL, CALIF.

DRWN.		PARASTIC LOAD RESISTOR STRESS ANALYSIS	DRAWING NUMBER
APP'D.			R-12193
SCALE			SHEET NO. ___ OF ___
DO NOT SCALE			REV.

I. Dynamic Loading

TOTAL UNIT WEIGHT EST 71.6# (P. 16)

A. Non Operating



	±X	±Y	+Z	-Z	
SHOCK	20	20	20	20	
VIBRATION	7.8(max.)	7.8(max.)	7.8(max.)	7.8(max.)	5-33cps
	8.0	8.0	8.0	8.0	33-140cps
	23.5(max.)	23.5(max.)	23.5(max.)	23.5(max.)	140-240cps
	15.0	15.0	15.0	15.0	240-2000cps
ACCELERATION	2	2	6	3	
*COMBINED(max.)	45.5	45.5	49.5	46.5	

B. Operating

	±X	±Y	+Z	-Z
SHOCK	3g.	3g.	3g.	3g.
VIBRATION	.25g.	.25g.	.25g.	.25g.
ACCELERATION	1g.	1g.	$3\frac{1}{2}$g.	—

*Ref. Para 2.2.1, Att."B", Spec. No. P1224-1 "simultaneous launch loads."

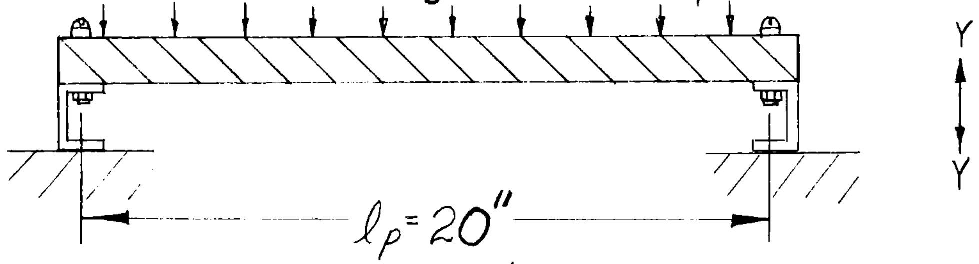
HEAT ENGINEERING & SUPPLY CO.
SAN GABRIEL, CALIF.

DRWN.		PARASTIC LOAD RESISTOR	DRAWING NUMBER	SHEET NO.
APP'D.			R-12193	OF
SCALE		STRESS ANALYSIS		REV.
DO NOT SCALE				

III. Load Analysis

(A) Y-Y Axis ~ 1. Individual panel, section supported between Titanium channels.

Channels assumed rigid with respect to this axis.



$\omega = .0342\ lb/in. + .1282\ lb/in.$

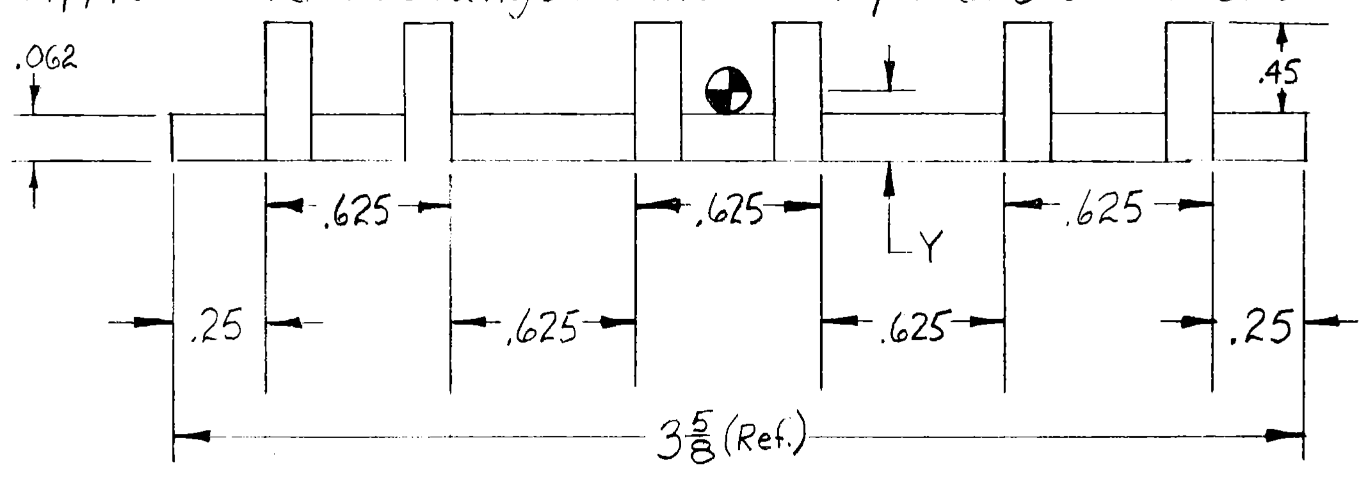
$\omega = .1624\ lb/in.$

Stress(1) $S = \dfrac{M_{max.} C}{I}$

$M_{max.} = \frac{1}{8} w \ell^2 = \frac{1}{8} \cdot .1624\ lb/in. \cdot 400\ in^2$

$M_{max.} = 8.12\ in\text{-}lb.$

Approximate rectangular model of panel cross section



(1) Formulas for Stress & Strain, R.J. Rourk, McGraw-Hill, 4th Ed., 1965

HEAT ENGINEERING & SUPPLY CO.
SAN GABRIEL, CALIF.

DRWN.		PARASTIC LOAD RESISTOR STRESS ANALYSIS	DRAWING NUMBER R-12193
APP'D.			SHEET NO. ___ OF ___
SCALE			
DO NOT SCALE			REV.

Centroid of Section

$C = \bar{Y}$ [2] $A\bar{Y} = \sum A_i Y_i$

$A_1 = \frac{1}{16}\left(\frac{14}{8}\right) = .1093 \text{ in}^2 \quad Y_1 = \frac{1}{32}$

$A_2 = (.512)\left(\frac{15}{8}\right) = .961 \text{ in}^2 \quad Y_2 = .256$

$A = 1.0703 \text{ in}^2$

$$C = \bar{Y} = \frac{.1093\left(\frac{1}{32}\right) + .961(.256)}{1.0703} = \frac{.00342 + .246}{1.07}$$

$C = .233 \text{ in}$

Moment of Inertia of Section

[2] $I_x = \sum (I_i)_x$

(1) $I_1 = \frac{13}{4}\left(\frac{1}{1.6}\right)^3\left(\frac{10^{-3}}{12}\right) = 4.75 \times 10^{-5} \text{ in.}^4$

(2) $I_2 = \frac{3}{8}\frac{(.512)^3}{3} = 16.1 \times 10^{-3} \text{ in.}^4$

(3) $I_x = I_G + Ad_x^2 - a$

$I_x = \frac{\pi}{4}\left(r_0^4 - r_1^4\right) + \pi\left(r_0^2 - r_1^2\right)\left(r_0 + .031\right)^2$

$I_x = \frac{\pi}{4}\left(.245^4 - .196^4\right) + \pi\left(.245^2 + .196^2\right)(276)^2$

$I_x = 1.67 \times 10^{-3} + 5.17 \times 10^{-3} = 6.84 \times 10^{-3} \text{ in}^4$

$I = 2.299 \times 10^{-2} \text{ in.}^4$

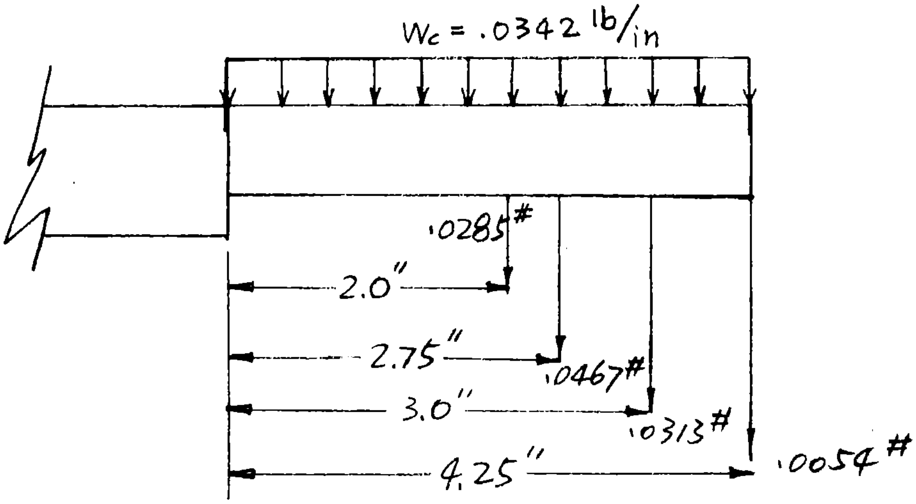
Stress $S_{max.} = \frac{MC}{I} = \frac{8.12 \text{ in-lb.}(.233)\text{in}}{2.299 \times 10^{-2} \text{ in}^4} = 82.3 \text{ G psi}$

$S_{max.} = 82.3 \text{ G psi}$

[2] Engr. Mech., Cox & Plumtree, Van Nostrand, 1954

HEAT ENGINEERING & SUPPLY CO.
SAN GABRIEL, CALIF.

DRWN.		PARASTIC LOAD RESISTOR	DRAWING NUMBER	
APP'D.				SHEET NO.
SCALE		STRESS ANALYSIS	R-12193	OF
DO NOT SCALE				REV.



2. Individual Panel, Calrod seal. sleeve. Cantilever at Each End.

$$(M)_{max} = \frac{1}{2} w \ell^2 + w_1 \ell_1 + w_2 \ell_2 + w_3 \ell_3 + w_4 \ell_4$$

$$= \frac{1}{2}(.0342)(4.25)^2 + .0467(2.75) + .0285(2)$$

$$+ .0313(3) + .0054(4.25)$$

$$= .611 \text{ in-lbs.}$$

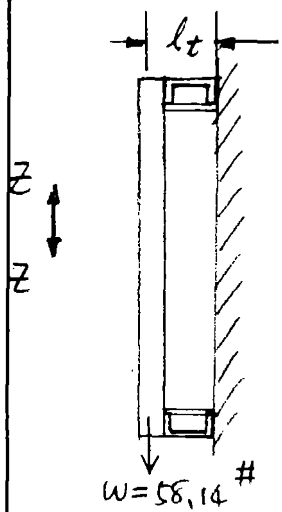
$$Z = \pi(r_o^4 - r_i^4)/4r_o \quad \text{for hollow shaft.}$$

$$S_{max} = \frac{M_{max}}{Z} = \frac{.611(4)(.245)}{\pi(.245^4 - .196^4)} = 95.2 \text{ G psi.}$$

HEAT ENGINEERING & SUPPLY CO.
SAN GABRIEL, CALIF.

DRWN.		PARASTIC LOAD RESISTOR STRESS ANALYSIS	DRAWING NUMBER	SHEET NO.
APP'D.			R-12193	OF
SCALE				REV.
DO NOT SCALE				

(B) Z-Z Axis: Total panel supported by Titanium channels.



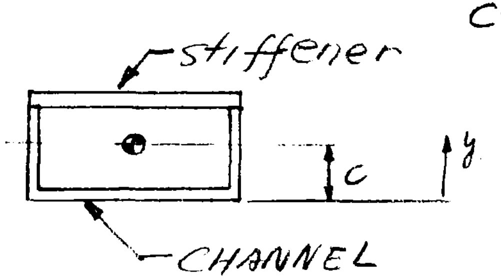
$l_t \cong 4.25 + .23 - .08 = 4.4$ in

Assume Cantilever beam with each beam supporting $\frac{1}{2}$ the weight lumped at $l_t = 4.4$ in.

$$M_{max} = \frac{1}{2} w l_t = \frac{1}{2}(29.1)(4.4) = 64 \text{ in-lb}$$

$$I = \Sigma A y^2 + \Sigma I_o = 2.388 \text{ in}^4$$

$$c = \frac{\Sigma A y}{\Sigma A} = 1.18 \text{ in}$$



$$S_{max} = \frac{M_{max}\, C}{I} = \frac{64 \times 1.18}{2.388}$$

$$= 31.86 \text{ psi.}$$

(C) Stress Summary

1. Combined Loads

Subsystem	Stress = Const. x G	G_{max}	S_{max}	Safe
Rod Cantilever	95.2 G	50.5	4807 psi	Yes
Panel between channels	82.3 G	50.5	4150	Yes
Titanium channel	31.8 G	50.5	1600	Yes

* Based on simultaneous shock, vibration & acceleration. Axes of unit not defined so each loading condition is assumed to be occuring with that section in the Z-axis.

2. Maximum single load condition

Subsystem	Stress = Const. x G.	G_{max}	S	Safe
Rod Cantilever	95.2 G	23.5	2237 psi	Yes
Panel between channels	82.3 G	23.5	1930	Yes
Titanium channel	31.8 G	23.5	747	Yes

HEAT ENGINEERING & SUPPLY CO.
SAN GABRIEL, CALIF.

DRWN.		PARASTIC LOAD RESISTOR STRESS ANALYSIS	DRAWING NUMBER R-12193	SHEET NO.
APP'D.				OF
SCALE				REV.
DO NOT SCALE				

IV. Resonant Frequency Analysis

A. Calrod Seal Cantilever

Distribute all the pieces attached to the calrod along the $4\frac{1}{4}''$ length, and treat this as a cantilever, loaded by its own weight.

$I = 5.82 \times 10^{-3}\ in.^4 \quad E = 30 \times 10^6\ lb/in.^2 \quad g = 386\ in./sec.^2$

$$A = \pi(.307^2 - .196^2) = .176\ in.^2$$

$$\gamma = \frac{W}{V} = \frac{W}{AL}$$

Total weight of Cantilever $W = .0342(4.25) + .0285 + .0467 + .0054 + .0313$

$W = .2572\ lb.$

$$\gamma = \frac{.2572}{.176(4.25)} = .344\ lb/in.^3$$

The frequency of vibration of the i^{th} mode is given as follows:

(3) $F_i = \frac{a K_i^2}{2\pi}$ with roots $\frac{K_1 l}{1.875}$ $\frac{K_2 l}{4.694}$ $\frac{K_3 l}{7.855}$

$K_1 l = 1.875 \quad l = 4.25 \quad K_1 = .441$

$K_2 l = 4.694 \quad l = 4.25 \quad K_2 = 1.10$

(3) $$a = \sqrt{\frac{EIg}{A\gamma}} = \sqrt{\frac{3.0\times10^6\ 5.82\times10^{-3}\ 3.86\times10^2}{1.76\times10^{-1}\ 3.44\times10^{-1}}} = \sqrt{11.15\times10^8} = 3.34\times10^4$$

$$F_i = \frac{a}{2\pi}K_i^2 = \left(\frac{3.34\times10^4}{2\pi}\right)(K_i)^2 = 5.32\times10^3 K_i^2$$

$$F_1 = (5.32\times10^3)(.441)^2 = 1034\ cps$$

$$F_2 = (5.32\times10^3)(1.10)^2 = 6437\ cps$$

(3) S. Timoshenko, Vibration Problems in Engineering, Van Nostrand, 3rd Ed., 1955

HEAT ENGINEERING & SUPPLY CO.
SAN GABRIEL, CALIF.

DRWN.		PARASTIC LOAD RESISTOR	DRAWING NUMBER	
APP'D.				SHEET NO.
SCALE		STRESS ANALYSIS	R-12193	OF
DO NOT SCALE				REV.

B. Shielding Sleeve Cantilever

$I = \frac{\pi}{4}(.375^4 - .315^4) = 7.77 \times 10^{-3} in.^4$ $A = \pi(.141 - .099) = .132 in^2$

$E = 30 \times 10^6$ $g = 3.86\ in/sec^2$ $\gamma = .29\ lb/in.^3$

$$a = \sqrt{\frac{(30\times10^6)7.77\times10^{-3}\,3.86\times10^2}{1.32\times10^{-1}\,2.9\times10^{-1}}} = \sqrt{23.5\times10^8} = 4.84\times10^4$$

$$K_1 = \frac{1.875}{2} = .938$$

$$K_2 = \frac{4.694}{2} = 2.35$$

(3) $Fi = \frac{a}{2\pi} Ki^2 = \frac{4.84\times10^4}{2\pi} Ki^2 = 7.71\times10^3 Ki^2$

$F_1 = 6783$ cps

C. Individual panel, clamped at Titanium channels.

(3) $Fi = \frac{a}{2\pi} Ki^2$ $I = 2.299\times10^{-2} in^4$ $A = 1.07 in^2$ $g = 386\ in/sec^2$

$\gamma = .29\ lb/in.^3$ $E = 30\times10^{-6}$ $l_p = 20$ in.

$$a = \sqrt{\frac{EIg}{A\gamma}} = \sqrt{\frac{(30\times10^6)(2.30\times10^{-2})(3.86\times10^2)}{(1.07)(.29)}} = 2.93\times10^4$$

(4) J.N. MacDuff, R.P. Felgar, Vibration Design Charts, ASME, Nov. 1956

HEAT ENGINEERING & SUPPLY CO.
SAN GABRIEL, CALIF.

DRWN.		PARASTIC LOAD RESISTOR	DRAWING NUMBER	SHEET NO.
APP'D.		STRESS ANALYSIS	R-12193	OF
SCALE				REV.
DO NOT SCALE				

$K_1 l$	$K_2 l$	$K_3 l$	$K_4 l$	$K_5 l$
0	4.730	7.853	10.996	14.137

$K_1 = 0$ $K_2 = .2365$ $K_3 = .393$ $K_4 = .55$ $K_5 = .707$

$F_i = 4660\, K_i^2$

$F_1 = 0$ (corresponds to the static mode)

$F_2 = 260$ cps.

$F_3 = 720$ cps.

$F_4 = 1410$

$F_5 = 2330$ cps

or as an alternate:

$$F_i = \frac{r\, C_i}{l_p^2} \qquad r = \sqrt{\frac{I}{A}} = \sqrt{\frac{2.3 \times 10^{-2}}{1.07}} = 1.47$$

$$\frac{r}{l_p^2} = \frac{.147}{400} = 3.67 \times 10^{-4}\, C_i$$

C_2	C_3	C_4	C_5
71.95	198.29	388.7	643

(given as C_2-C_5 to correspond with K_2-K_5 given above)

$F_2 = 263$ cps

$F_3 = 728$ cps

$F_4 = 1420$ cps

$F_5 = 2380$ cps

HEAT ENGINEERING & SUPPLY CO.
SAN GABRIEL, CALIF.

DRWN.		PARASTIC LOAD RESISTOR	DRAWING NUMBER
APP'D.			SHEET NO.
SCALE		STRESS ANALYSIS	R-12193 OF
DO NOT SCALE			REV.

D. Titanium channels

Assume each channel supports $\frac{1}{2}$ the weight of the panels. And that the weight is lumped 4.4. in from the wall.

$W_t = 58.14$ lb.

Calculate first mode of vibration by the classical:

(5) $F = \frac{1}{2\pi}\sqrt{\frac{K}{m}}$

For cantilever beam, $K = \frac{F}{\gamma} = \frac{3EI}{l_t^{\,3}}$

$I = 2.388\ in^4$

$$K = \frac{90 \times 10^6 (2.388)}{(3.363)^3 \times 10^3} = 5660$$

$$F = \frac{1}{2\pi}\sqrt{\frac{5660\ lb\ 386\ in}{in\ 58.14\ lb/sec^2}} = 30.8\ cps$$

$F = 30.8$ cps

(5) Freberg & Kember, Element of Mech. Vibration, Wiley & sons, 2nd Ed., 1960

HEAT ENGINEERING & SUPPLY CO.
SAN GABRIEL, CALIF.

DRWN.		PARASTIC LOAD RESISTOR	DRAWING NUMBER	
APP'D.				SHEET NO.
SCALE		STRESS ANALYSIS	R-12193	OF
DO NOT SCALE				REV.

E. Resonant Frequency Summary

Resonant frequency cps

Section	F_1	F_2	F_3	F_4	F_5
Calrod Seal Cantilever	1034	6437	—	—	—
Shielding Sleeve Cantilever	6783	—	—	—	—
Panel, Clamped between channels	0	260	720	1410	2330
Titanium channels	30.8	—	—	—	—

HEAT ENGINEERING & SUPPLY CO.
SAN GABRIEL, CALIF.

DRWN.		PARASTIC LOAD RESISTOR	DRAWING NUMBER
APP'D.		STRESS ANALYSIS	R-12193
SCALE			SHEET NO. OF
DO NOT SCALE			REV.