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UPPER THRUST STRUCTURE S/N 0000001
STATIC STRUCTURAL TEST EVALUATION

MASTER

APRIL 1965

NERVA PROGRAM

CONTRACT SNP-1

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

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UPPER THRUST STRUCTURE S/N 0000001
STATIC STRUCTURAL TEST EVALUATION

ROCKET ENGINE OPERATIONS - NUCLEAR

NERVA PROGRAM

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ABSTRACT

A static structural test was conducted on the NERVA E-Engine Upper Thrust Structure S/N 0000001 at Aerojet-General. The major test results and data evaluation are presented for 12 loading conditions which simulated boost and operating loads to which the structure would be subjected during flight or ground testing. The structure showed more than adequate capacity to withstand these loads.

W. D. Stinnett
Program Manager
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I. INTRODUCTION

A static structural test was conducted on the NERVA E-Engine Upper Thrust Structure (UTS) S/N 0000001, during September 1963 at the Aerojet-General Corporation Structural Testing Laboratory, Solid Rocket Operations, Sacramento, California. This document presents the major experimental results and an evaluation of the data regarding the design. The test was set up and conducted per AGC Report 749N-TP, "Test Specifications for the Static Structural Test of the NERVA Upper Thrust Structure."

The UTS was tested under 12 different loading conditions to simulate the boost and operating loads, to which the UTS could be subjected during flight or ground testing. These loading conditions were derived from the "NERVA TCA Structural Loads Document" Report No. 9443-62-16.* The planned and actual applied loads for the 12 loading conditions are listed in Table 1.

*Copies of the reports are available from AGC Department 7456.

TABLE 1

SUMMARY OF DESIRED AND ACTUAL TESTING LOADING CONDITIONS

Case No.	Load Sequence	Desired Condition (KIPS)					Actual Condition (KIPS)				
		F	V_p	V_y	A_p	A_y	F	V_p	V_y	A_p	A_y
1	1	112.0	0	0	0	0	112	-	-	-	-
2	9	-33.6	4.2	0	35.0	0	**	-	-	-	-
3	10	33.6	-4.2	0	-35.0	0	**	-	-	-	-
4	12	-33.6	0	4.2	0	35.0	**	-	-	-	-
5	7	33.6	0	-4.2	0	-35.0	32.1	-	-4.14	-	-32.65
6	3	78.4	4.2	0	35.0	0	78.4	4.19	-	35.4	-
7	5	145.6	-4.2	0	-35.0	0	145.6	-4.39	-	-33.7	-
8	8	64.5	3.0	3.0	24.7	24.7	65.5	3.125	2.98	22.85	24.7
9	4	159.5	-3.0	-3.0	-24.7	-24.7	168.5	-3.0	-3.025	-24.25	-24.6
10	2	-52.7	0	0	0	0	-52.7	-	-	-	-
11	6	-86.3	4.2	0	35.0	0	-83.3	4.31	-	36.0	-
12	11	-19.1	-4.2	0	-35.0	0	**	-	-	-	-

- NOTES: 1. Loads Positive as shown.
 2. Ref. Document 9548 - 62 - 7, Rev. B, 3 June 1963, "STRUCTURAL DEVELOPMENT PROGRAM, NERVA THRUST STRUCTURE".
 3. ** denotes data was not reduced.

II. OBJECTIVES

The objectives of Test 749N were:

1. Demonstrate the capability of the NERVA UTS to perform satisfactorily while being subjected to simulated boost and operating loads.
2. Determine the axial and lateral stiffness of the upper thrust structure.
3. Provide information on thrust misalignment caused by upper thrust structure deflections.
4. Provide information for design improvement.
5. Obtain data to compare with theoretical analysis.

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III. DESCRIPTION OF TEST

A. TEST ASSEMBLY

The test assembly consisted of the NERVA Upper Thrust Structure, S/N 0000001, fabricated by the Aerojet-General Corporation, Liquid Rocket Operations, Sacramento, California, the RIFT simulator, AGC P/N T-417189, and the RIFT - UTS Marman type clamp, AGC P/N T-417190. The test article was supported in test fixture T-417187 while being loaded with hydraulic jacks. A lug-plate was fabricated to be joined to the gimbal housing and permit axial and lateral loads to be applied to the structure. The test assembly is shown in Figures 1 and 2.

AGC P/N 280200-9 describes the NERVA Upper Thrust Structure. This part was designed to perform the following functions.

1. Transmit boost and operating loads from the lower thrust structure to the RIFT propellant tank, through the gimbal.
2. Provide the upper supports for the pitch and yaw gimbal actuators.
3. Serve as part of the pump suction line.
4. Provide support for, and access to, the propellant tank shutoff valve.

To accomplish these design objectives economically, the UTS was fabricated of CRES 347 stainless steel. The UTS consists primarily of an 0.156-in. thick, 45° conical section with four access holes, which is welded to an 80 in. diameter flange at the forward end and the gimbal housing at the aft end. The gimbal housing is a forged and welded assembly which serves as the forward section of the pump suction line and permits attachment to the gimbal assembly with six 5/8-in. A-286 bolts. The pitch and yaw actuator support frames are tubular members welded to the RIFT-UTS flange at one end and an attaching yoke at the other.

Figure 1

Structural Test Setup Showing Tool Designation

Figure 2

Structural Test Setup

B. INSTRUMENTATION

A total of 238 strain gages and 44 deflection transducers were used in instrumenting the UTS. The locations of this instrumentation are shown in Figures 3, 4, 5, and 6.

Strain gages and deflection transducers as shown in Figure 7 were used adjacent to the RIFT joint at the 0° and 135° locations to determine the membrane stresses and joint movements. The instrumentation at the gimbal housing - conical frustrum joint was limited to one location (135°) since this joint is axi-symmetrical. One frustrum access port was instrumented in the radial and tangential direction with respect to the opening to determine typical stresses around the ports. The clamp was completely instrumented at 0° , 135° and adjacent to the connecting bolt. With four strain gages each, all gimbal actuator frame members were instrumented at their center points to determine average axial load. Four members (11, 12, 13 and 14) on the pitch actuator frames had four additional strain gages per member adjacent to the RIFT joint to obtain data for the determination of end moments and shear loads. The frame numbering sequence may be seen in Figure 3.

Deflection transducers in the X, Y, and Z directions were used at the center of the UTS and each gimbal actuator support to determine spring constants. A typical transducer pattern at the actuator support is shown in Figure 8.

Stresscoat was applied over approximately 25% of the upper thrust structure surface prior to Case 6 loading. The Stresscoat cracking patterns will be presented in the experimental results section, below.

C. TEST OPERATIONS

The following events summarize the test assembly and operations.

1. A thorough dimensional inspection was made of the UTS, RIFT simulator and clamp prior to test. Wall thickness measurements were recorded at each strain gage location along the 135° line where inside and outside gages were used.

Figure 3

9

UTS Strain Gage Locations

RM-S-0205

Figure 4
Location of Deflection Gages

Figure 5
Location of Deflection Transducers

Figure 6
LOCATION OF STRAIN CAGES

9-63SP 1036

FM-S-0205

Figure 7

UTS-Rift Interface Deflection Transducer Setup - 0°

Figure 8

Actuator Deflection Transducer Setup - 270° (Typical)

2. All strain gages were mounted.
3. The test unit was assembled in the thrust structure test fixture.
4. Clamp installation strains were recorded while preloading the clamp attaching bolts to 50, 100, 150 and 175 ft-lbs torque.
5. Deflection transducers were installed where specified.
6. The center hydraulic jacks were installed. Loading cases 1 and 10 were then conducted. Data from 20, 40, 60, 80, 100, 20 and 0% load increments were recorded on both cases.
7. The actuator hydraulic jacks were installed. Stresscoat was applied and cured; then the loads per Case 6 were conducted in the increment order listed above. The crack pattern was marked after each load increment.
8. Loading conditions 9, 7, 11, 5, 8, 2, 3 and 4 were conducted in the order listed above. Instrumentation was zeroed between each loading condition.
9. The test assembly was disassembled. A planned post-test inspection was deleted on the UTS, clamp and RIFT simulator, as this hardware was urgently needed to conduct dynamic testing of the TCA components and to serve as a pump suction line for the TPA test.

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IV. EXPERIMENTAL RESULTS

A. STRAIN DISTRIBUTION

Measured strains on the upper thrust structure were found to have maximum values for the Case No. 9 loading condition. These strains were reduced to stresses and are presented in Table 2. To illustrate their nature and magnitude, the stress values are shown plotted in Figures 9 through 15. Strain results on the pitch actuator frames from gages located at mid-span are shown in Table 3. These values were further reduced to axial stresses and loads.

Installation of the four-segment, Marman-type clamp resulted in strains which were reduced to stresses and are shown in Table 4 and in Figures 16 through 18. Strain gages located on the RIFT simulator permitted stresses to be calculated for Case No. 9 and are shown in Figures 19 through 22.

B. DEFLECTION

Tabulated values of deflection at 100% load for Cases 1, 6, 7, 8, 9, 10, and 11 are given in Table 5. The absolute axial and radial deflections and associated rotations for the component parts of the UTS-RIFT joint are shown in Table 6. Movements of the cone apex and actuator yoke relative to the UTS-RIFT interface are shown in Table 7.

C. STRESSCOAT

Cracking patterns of the Stresscoat at various UTS locations are shown in Figures 23 through 25.

TABLE 2

MAXIMUM STRESSES AT 100% LOAD, CASE 9

Gage No.	Total Stress				Membrane Bending			
	Outside		Inside		H		M	
	M	H	M	H	M	H	M	H
58	11,200	-12,450	54,800	-4,150	33,000	-8,300	-21,800	-4,150
59	27,200	-7,440	33,800	-7,110	30,500	7,275	-3,300	-165
60	20,920	41	22,240	379	21,580	210	-660	-169
61	8,870	4,230	5,150	3,260	7,010	3,740	1,860	484
62	15,170	5,620	-2,750	1,180	6,210	3,400	8,960	2,220
63	17,200	4,640	-13,318	-4,662	1,940	-13	15,260	4,650
71	7,020	3,120	6,180	2,720	6,600	2,920	420	200
72	6,500	1,400	6,850	1,750	6,675	1,525	-175	-125
151	21,100	10,100	16,530	-1,654	12,815	4,225	2,285	5,875
152	15,710	5,790	15,720	3,210	15,720	4,500	-5	1,290
153	11,250	2,880	13,450	4,030	12,350	3,460	-1,101	-577
68	13,710	8,660	-4,047	3,140	4,830	5,900	8,880	2,760
69	6,540	5,640	4,160	5,160	5,350	5,400	1,190	241
70	4,080	3,410	5,820	3,920	4,850	3,665	-770	-255
97	8,580	456	6,640	484	7,610	470	967	-14
98	5,680	-414	6,090	2,900	5,880	1,240	-207	-1,657
100	4,620	1,390	-3,703	-67	459	660	4,160	727
141			6,750	2,780	-	-	-	-
146	-15,297	-10,099	12,530	-389	-1,385	-5,244	-13,912	-4,855
147	-5,223	-4,844	3,540	-1,635	-841	-3,239	-4,382	-1,605
148	4,890	2,480	-4,487	800	202	1,640	4,690	841
155	-	-	-	-	-	-	-	-
156	1,790	-1,087	4,090	2,330	2,940	621	-1,150	-1,708
157	3,350	-1,692	8,410	1,450	5,880	-121	-2,530	-1,571
158	12,080	433	-4,519	-2,690	3,780	-1,128	8,300	1,560
159	-6,724	-5,787	9,630	771	1,450	-2,508	-8,176	-3,279
160	9,280	2,230	-7,027	-3,703	1,130	-735	8,160	2,970
161			-7,043	1,950	-	-	-	-
162	-10,612	-3,184	14,340	4,300	1,860	559	-12,476	-3,743
163	14,820	8,200	-3,748	3,460	5,540	5,840	9,280	2,380
164	-5,089	-2,078			-	-	-	-
165	-7,706	-5,966	5,790	1,040	-956	-2,462	-6,750	-3,504

NOTE:

1 H = Hoop Direction M = Meridional Direction

M represents tangential to the hole, H radial to the hole. Data at gage locations 57 and 99 considered faulty. The strains for gages at 155 were very small or zero for all cases. The following strain channels were considered faulty. 141-MO, 161-HO. Inside hoop strains were not reported.

Figure 9

Gimbal Housing - Frustrum Meridional Stresses
At 100% Load, Case 9

Figure 10

Gimbal Housing - Frustrum Hoop Stresses
at 100% Load, Case 9

Figure 11

UTS Meridional Stresses at Rift Joint
at 100% Load, Case 9 ($\theta = 0^\circ$)

Figure 12

UTS Hoop Stresses at Rift Joint ($\theta = 0^\circ$)
at 100% Load, Case 9

Figure 13

UTS Meridional Stresses at Rift Joint ($\Theta = 135^\circ$)
at 100% Load, Case 9

Figure 14

UTS Hoop Stresses at Rift Joint ($\Theta = 135^\circ$)
at 100% Load, Case 9

Figure 15

Access Hole Radial and Tangential Stress
at 100% Load, Case 9

TABLE 3

ACTUATOR FRAME MEMBER AXIAL LOADS AND STRESSES

Case No.	Member	Average Strain ⁶ micro-in./in.	Axial Stress psi	Axial Load lb
5 ¹	1	96	2,780	1,970
	2	-417	-12,100	-8,680
	3	-290	-8,410	-6,040
	4	-279	-8,100	-4,080
	5	-298	-8,650	-6,210
	6	-427	-12,400	-8,900
	7	100	2,900	2,080
6 ²	8	43	1,250	900
	9	479	13,900	9,960
	10	302	8,750	6,280
	11	371	10,750	5,410
	12	392	11,350	8,150
	13	560	16,250	11,680
	14	30	870	620
7 ³	8	62	1,800	1,290
	9	-498	-14,450	-10,400
	10	-330	-9,570	-6,870
	11	-338	-9,800	-4,940
	12	-357	-10,350	-7,450
	13	-533	-15,450	-11,100
	14	82	2,380	1,710
11 ⁴	8	-8	-230	-165
	9	502	14,570	10,450
	10	320	9,280	6,660
	11	389	11,300	5,700
	12	352	10,400	7,400
	13	543	15,750	11,280
	14	Out	-	-

¹ Load $A_y = -32,650$ lb

² Load $A_p = 35,400$ lb

³ Load $A_p = -33,700$ lb

⁴ Load $A_p = 36,000$ lb

⁵ Area of frame members 4 and 11 were .504 in.². All others were .718 in.².

⁶ Average Strain obtained from uniaxial strain gages located at midspan.

TABLE 4

RIFT JOINT CLAMP INSTALLATION STRESSES AT 175 FT LB TORQUE

Gage No.*	Total Stresses, psi	
	<u>M</u>	<u>H</u>
64	-8617	11680
65	-4831	16760
66	-6501	20670
67	-3091	26620
73	-4245	33400*
74	2710	29500*
75	5930	38250*
142	-8987	12090
143	-4605	17030
144	-6629	18310

*Note: Stresses calculated as linear stresses and adjusted to true stresses, using the CRES 347 stress-strain diagram. (Ref. NERVA Materials Properties Data Book)

Figure 16

Rift Simulator Meridional Stresses at Rift Joint
(Theta = 0°) at 100% Load, Case 9

Figure 17

Rift Simulator Hoop Stresses at Rift Joint
($\theta = 0^\circ$) at 100% Load, Case 9

Figure 18

Rift Simulator Meridional Stresses at Rift Joint
($\theta = 135^\circ$) at 100% Load, Case 9

Figure 19

Rift Simulator Hoop Stresses at Rift Joint
(Theta = 135°) at 100% Load, Case 9

NOTES:

1. APPLIED STRESSES: CASE 9, 100% LOAD
2. INSTALLATION STRESSES: 175 FT.-LB. TORQUE
3. GAGE 145 NOT RECORDED DURING INSTALLATION OF CLAMP

Figure 20

Clamp Installation Versus Applied Stresses
(Theta = 0°)

Figure 21

Clamp Installation Versus Applied Stresses
(Theta = 135°)

Figure 22

Clamp Installation Stress at Attaching Bolt Location
at Maximum Torque

TABLE 5

MEASURED DEFLECTIONS AT 100% LOAD FOR VARIOUS CASES

Deflection Gage No.	1	6	Case No.		9	10	11
			7	8			
101	.0297	.0679	-.0589	.0398	-.0421	-.0058	.0525
102	-.0011	.0306	-.0348	.0154	-.0244	-.0012	.0274
103	.0110	.0635	-.0452	.0370	-.0255	-.0045	.0312
104	.0061	.0080	.0014	.0089	-.0015	-.0014	.0014
105	.0134	-	.0480	.0075	.0747	-.0059	-.0260
109	-.0081	-.0016	-.0143	-	-.0164	.0037	.0078
110	.0125	-	.0206	.0028	.0220	-.0049	-.0109
111	.0022	.0033	-.0037	-	-.0024	-.0018	-.0013
112	.0113	-	.0267	.0054	.0218	-.0047	-.0136
115	.0096	-	.0107	.0396	-.0162	-.0035	.0075
118	.0069	-	.0912	-.0666	.0480	-	-.0812
118A	.0143	-.1152	.0951	-.0727	.0719	-	-.0675
119	-.0112	-	.0016	-.0027	.0091	-	-.0061
120	.0253	.0387	-.0513	.0227	-.0230	-	-
124	.0009	-	.0262	-.0196	.0210	0	-.0289
125	-.0019	-	0	-.0173	.0205	.0025	-.0033
126	.0496	-	.0661	.0333	.0652	-.0224	-.0335
126A	.0485	-	-	.0368	.0719	-.0196	-
127	.0251	-	-.0183	.0348	-.0071	-.0082	.0171
128	-.0021	-	-.0358	.0309	-.0296	-.0010	.0339
129	.0141	-	-.0405	.0321	-.0195	-.0046	.0255
130	.0160	.0439	-.0235	.0295	-.0101	-.0062	.0236
131	.0060	.0523	-.0345	.0283	-.0237	-.0012	.0292
132	.0128	.0465	-.0395	.0305	-.0167	-.0045	.0244

See Figures 5 and 6 for measurement location and sign convention.

Measured deflections are shown as part of an inch.

TABLE 6

UTS-RIFT JOINT MOVEMENT IN JUNCTURE
WITH PITCH ACTUATOR FRAMES

Case No.	Rotation 10^{-3} Rad			Axial Deflection Inch			Radial Deflection Inch		
	UTS	Clamp	Rift	UTS	Clamp	Rift	UTS	Clamp	Rift
1	3.74	2.20	.64	.011	.014	.013	.001	.002	.006
6	.88	-	-.52	.054	-	.047	.031	-	.052
7	-2.7	4.4	2.2	-.045	-.041	-.040	-.035	-.036	-.035
8	.56	.54	-.24	.037	.032	.031	.015	.031	.028
9	-3.3	2.5	1.3	-.021	-.020	-.017	-.024	-.030	-.024
10	-.26	-.72	-.34	-.005	-.005	-.005	-.001	-.001	-.001
11	4.3	-1.7	-.16	.031	.026	.024	.027	.034	.029

NOTE: Values shown are for 100% Load

Deflections have been rounded off to nearest .001 inch

TABLE 7

CONE AND ACTUATOR FRAME DEFLECTION SUMMARY

<u>Case No</u>	Cone		Actuator Frame	
	<u>Δ X c</u> <u>Inch</u>	<u>Δ Yc</u> <u>Inch</u>	<u>Δ Xa</u> <u>Inch</u>	<u>Δ Ya</u> <u>Inch</u>
1	.037	-	.014	.012
6	-	-	-.025	-.146
7	.039	.013	.006	.128
8	.029	.026	-.014	-.088
9	.058	.014	+.001	+.079
10	-.017	-	-	-
11	-.023	.022	-.008	-.098

NOTES:

$$1. \quad \Delta X_c = \frac{\delta_{126} + \delta_{126A}}{2} - \frac{\delta_{103} + \delta_{105} + \delta_{110} + \delta_{112} + \delta_{115}}{5}$$

Exceptions: axial deflection at juncture with loaded actuator frames were not used due to local deformation (i.e. δ_{103} for Case 7, 8, 9 and 11, δ_{115} for Cases 8 and 9).

$$2. \quad \Delta Y_c = \delta_{124} - .707 (\delta_{109} + \delta_{111}) \text{ for Cases 6, 7 and 11.}$$

$$= .707 (\delta_{124} + \delta_{125}) - \delta_{109} \text{ for Cases 8 and 9.}$$

$$3. \quad \Delta X_a = \delta_{120} - \delta_{103}$$

$$4. \quad \Delta Y_a = \frac{\delta_{118} + \delta_{118A}}{2} - \delta_{102}$$

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Figure 23

Stresscoat Crack Pattern -
Pitch Actuator Support Yoke

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Figure 24

Stresscoat Crack Pattern -
Pitch Actuator Support Members

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Figure 25

Stresscoat Crack Pattern -
Gimballed End of UTS at 45°

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V. DISCUSSION

A. STRUCTURAL INTEGRITY

Results of all loading conditions showed that the upper thrust structure successfully withstood the applied static loads which simulated expected NERVA boost and operation flight loads. The maximum stress level at any measured point occurred near the junction of the cone and the gimbal housing. In Figure 9 at Station 58 an indicated meridional stress of 54,800 psi on the inner surface resulted from a high membrane stress combined with bending due to the natural geometrical discontinuity and mismatch resulting from welding. Extreme fiber yielding undoubtedly occurred at this point and the actual stress level could be determined from actual material stress - strain properties. It is significant to note that, in spite of this plastic condition, the permanent strain of approximately 300 micro-inches per inch was considerably less than the limit value of .2% permanent deformation. At no other gage location were measured strains in excess of the inner meridional strain at Station 58 for Class 9.

Stress distribution around a reinforced hole in the cone, as shown in Figure 15, is similar to that expected in a flat plate under uniaxial tension loading. The highest stress, approximately twice that in the skin, is at the inner surface of the reinforcement and the stress level drops rapidly away from the hole. This demonstrates the adequacy of this hole reinforcement.

The stresses in the cone and ring at the UTS-RIFT joint, as shown in Figures 11 through 14, vary considerably around the circumference because of the local influence of the loaded actuator frames. In no case were the stresses close to the yield strength of the material; the highest value measured was 17,500 psi. This shows that the load carrying capability in this area was more than adequate.

Of the seven tubular members forming each actuator support, only the inner five carried any appreciable load, as indicated in Table 3. Of these five, the two outer members carried the greatest axial load. The evaluation of bending

stresses, which were greatest at the junction with the ring, indicated that at this point bending produced higher strains than did axial load. For example, at the base of frame number 12 an axial stress of 9,600 psi and a bending stress of 27,100 psi were measured giving a combined stress of 36,700 psi. A combined stress of 21,500 psi was measured at mid-span. In no case, however, was the yield capacity of any frame exceeded. The variation in member loads from one set of frames to the other varied by approximately 15%, which can be primarily attributed to manufacturing differences. For an optimized flight structure the difference would need to be reduced by more careful design and manufacturing techniques.

B. AXIAL AND LATERAL STIFFNESS

As shown in Table 8, cone spring constants computed from deflection data in Table 7 are given for axial and lateral directions. The approximate magnitudes are 31×10^5 pounds per inch and 2.4×10^5 pounds per inch, respectively. Actuator spring constants are also given; however, these should be considered as apparent values since the influence of the ring on the measured yoke deflection was large. Because of the combined loading condition, it was not possible to determine absolute spring constants of the actuator supports. The movement of the UTS-RIFT joint which is the foundation of the actuator supports is greatly influenced by the actuator loads, as shown in Table 6.

C. THRUST ALIGNMENT

The deflection of the structure, as shown in Table 7, for the various loading conditions can be used in evaluating the effect of this engine component on possible thrust misalignment.

D. DESIGN IMPROVEMENT

Although the UTS ring at the RIFT joint successfully withstood all of the loading conditions, it would be desirable to improve its deflection characteristics especially in the vicinity of the actuator supports. As noted in Case 1, the actuator yokes deflected although no load was being transmitted in the frames. The

TABLE 8

SPRING CONSTANT SUMMARY

<u>Case No.</u>	K_{xc} <u>lbs/in.</u>	K_{yc} <u>lbs/in.</u>	K_{xa} <u>lbs/in.</u>	K_{ya} <u>lbs/in.</u>
1	30×10^5	-	-	-
6	-	-	-14×10^5	$-.67 \times 10^5$
7	37	3.2×10^5	54	.77
8	23	1.6	-16	-.72
9	29	3.0	233	.85
10	-31	-	-	-
11	-36	1.9	-43	-1.0
	<hr/> 31×10^5	<hr/> 2.4×10^5		

magnitude in the Y direction was approximately 10% of that measured by maximum loading in the actuator supports. See Table 7. This deflection, attributed to the base of the support or ring, is considered to be undesirable. Possible solutions would be to increase the ring cross-section, to provide local stiffening of the existing ring, or to replace the frame members with a one piece curve plate.

The welded joints at either end of the cone in the structure contained considerable mismatch which can be attributed to both inadequate design and weld tooling. These imperfections or discontinuities contributed additional local bending which resulted in higher stresses than normal. Similar structures being planned in the future should consider a redesigned weld joint and the use of proper weld tooling.

A strain gage rosette was placed on two of the eight gimbal housing struts, which were welded in place, and transmitted the axial loads from the gimbal to the cone. As shown in the sketch the maximum principal stresses determined were approaching the yield point of the material.

The welds at either end of the strut were subjected to a combined shear and bending load which was considered critical. The Stresscoat pattern shown in Figure 25

provides more information on the tensile strains in the vicinity of these welds. Since the location of the welds does not lend itself to adequate radiographic inspection, a degree of uncertainty combined with the high stress intensity suggests that elimination of the welds by the use of a one piece gimbal housing is very desirable. This feature was incorporated into later designs.

As was previously mentioned, the stress concentration factor around the holes in the skin was reduced to approximately 2 by the reinforcement. For future considerations of this design, an optimization study could result in a lower factor which would permit more efficient utilization of the cone's skin thickness.

Although a cone possesses good inherent stiffness, internal gussets near the apex would increase the stiffness if required by the engine dynamic characteristics.

E. THEORETICAL ANALYSIS

A considerable amount of experimental data have been obtained for various static loading conditions simulating expected NERVA flight loads. A comparison with theoretical data was not made since the analyses for the testing condition was not completed because of program redirection deleting E-engine thrust structure development.

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VI. CONCLUSIONS

With the exception of the last item, all test objectives were successfully satisfied. Based upon the evaluation of the experimental data it can be stated that the integrity of the structure would be certain for loads as much as 10 - 20% greater than those applied. In other words, the structure has more than adequate capacity to withstand the simulated NERVA flight loads. It is felt that future effort on a structure of this type should take into consideration, among other things, the items of design improvement previously discussed.