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NUCLEAR DIVISION

REPORT NO. RN-S-0473

To
AEC-NASA Space Nuclear Propulsion Office
EVALUATION OF XECF THRUST STRUCTURES

September 1968

NERVA Program

Contract SNP-1

NUCLEAR ROCKET OPERATIONS

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AEROJET - GENERAL CORPORATION
A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY

REPORT NO. RN-S-0473

EVALUATION OF XECF THRUST STRUCTURES

D. W. Tracy

A handwritten signature in black ink, appearing to read "C. M. Rice", with a stylized, flowing script.

C. M. Rice
Program Manager
Nuclear Rocket Operations

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I. INTRODUCTION

Performance of the thrust structures, consisting of an upper thrust structure (UTS), PN 1115459-29, SN 882011, and a lower thrust structure (LTS), PN 1116941-9, SN 880013, was evaluated during the XECF program at NRDS, Jackass Flats, Nevada.

This evaluation is based on strain and temperature data obtained during the test.

II. TECHNICAL DISCUSSION

The loads on the UTS and LTS during the XECF test were insignificant compared with the loads imposed on the structure during the acceptance-proof-test program. However, some temperature and strain measurements were taken on the UTS and were evaluated as follows:

A. TEMPERATURE

Four thermocouples were located on the pump support panels, as shown in Figure 1; and eight thermocouples were positioned to measure the temperature of the gas within the UTS at the locations given below:

<u>Thermocouple No.</u>	<u>Description</u>	<u>Station No.</u>	<u>Radius, in.</u>	<u>Theta Angle, deg</u>
TE898..A	UTS environment	119.0	45.0	120.0
TE899..A	UTS environment	119.0	45.0	310.0
TE900..A	Transducer Box environment	59.0	32.0	310.0
TE901..A	UTS environment	81.7	47.0	120.0
TE902..A	UTS environment	105.0	47.0	120.0
TE903..A	UTS environment	96.0	47.0	300.0
TE904..A	UTS environment above shield	136.6	42.0	41.0
TE905..A	UTS environment above shield	136.6	42.0	221.0

Figure 1 - Pump Support Panel Instrumentation Locations

The primary function of the UTS environment thermocouples was to record the temperature of the purge gas used to prevent condensation of liquid nitrogen within the UTS. During EP-I, the data showed a gradual cooling of the purge gas from ambient temperature down to approximately 515°R. The same trend occurred during EP-II, except the gas cooled down to approximately 500°R. Temperature data at major events during EP-I and EP-II are presented in Tables 1 and 2, respectively.

The thermocouple locations were generally not the same as during the XECF cryogenic test program* performed previously at AGC. However, for those instruments with locations that did correspond, the lowest temperatures during the cryogenic test were lower than at any time during XECF.

B. STRAIN

Six longitudinal strain gages were installed on the UTS. Four gages were installed on the longitudinal stringers at locations shown in Figure 2, and two were installed on the pump-support-panel columns as shown in Figure 1. The four gages on the stringers (MG803L through MG806L) were intended to monitor dynamic strains and were recorded on the wide-band data system. No response was recorded on these channels during EP-I or EP-II, indicating that the strain in the stringers was nearly zero.

The two gages on the pump-support column measured strain imposed on the column by cooling of the pump-inlet line. The analysis of the UTS** shows this column to be in compression; however, tensile strains were recorded on both gages during EP-II as shown in Table 2. No data were obtained from these gages during EP-I because of faulty calibrations. However, the recorded temperatures make it evident that the strain in the column during EP-I was considerably lower than during EP-II.

* Report RN-S-0426, Aerojet-General Corp., Final Report, Cryogenic Test Program.

**Report RN-TM-0331, Aerojet-General Corp., Stress Analysis of Upper Thrust Structure.

TABLE 1 - EP-I TEMPERATURE AND STRAIN DATA

EVENT →	S.G. #2 TO IDLE	S.G. #3 TO IDLE	S.G. #2 TO FULL STREAM	S.G. #3 TO FULL STREAM	PSV OPEN	TPCV START OPEN	PCV-449 OPEN	PCV-449 CLOSED	TPCV CLOSED	PCV-471 OPEN TO 4% FOR WARMUP	S.G. #2 TO IDLE	S.G. #3 TO IDLE	PCV-471 CLOSED WARMUP COMPLETE	S.G. OFF
CRT →	62449	62454	62477	62489	62802	62832.9	62849.8	62867	62868	62997.9	63445	63448	63558	63592
TE 856	537	537	538	536	535	NO DATA FOR THIS CRT	539	536	535	526	498	496	494	494
TE 857	536	536	535	537	537		537	532	533	509	496	491	495	496
TE 858	538	540	539	539	539	↑	537	533	536	529	OUT	←	→	OUT
TE 859	538	541	538	538	536		530	515	521	473	460	463	467	465
TE 898	539	538	535	538	530		528	522	526	529	531	530	530	531
TE 899	549	550	547	550	549		545	549	550	544	544	542	545	545
TE 900	553	550	549	548	555		561	550	548	551	554	556	554	554
TE 901	532	530	529	528	518		517	518	522	515	516	518	518	518
TE 902	532	534	536	535	525		524	519	522	523	524	524	525	527
TE 903	537	541	538	536	533	↓	537	526	529	531	529	528	530	530
TE 904	540	541	539	543	546	NO DATA FOR THIS CRT	542	540	545	544	545	545	546	546
TE 905	532	529	530	530	528		526	528	530	526	528	529	529	526
MG801	INVALID	←											→	INVALID
MG802	INVALID	←											→	INVALID

NOTE: TEMPERATURE IN °R
STRAIN IN MICRO IN./IN.

TABLE 2 - EP-II TEMPERATURE AND STRAIN DATA

EVENT →					DRY PUMP BOOTSTRAP			WET PUMP BOOTSTRAP				FIRST LH ₂ INSERTION		SECOND LH ₂ INSERTION							
	SG #1 TO IDLE	SG #3 TO IDLE	SG #1 TO FULL STREAM	SG #3 TO FULL STREAM	PSV OPEN	TPCV OPEN	TPCV CLOSED	PDV OPEN	TPCV OPEN	TPCV CLOSED	PDV CLOSED	CSV OPEN	PCV-472 START OPEN	PCV-472 CLOSED	CSV OPEN	PCV-472 START OPEN	PCV-472 START CLOSED	SG #1 TO IDLE	SG #3 TO IDLE & STOP	SG #1 TO STOP	
CRT →	44836	44845	44949.7	44960.4	45412.7	45481.5	45509	45981.5	46028.5	46050.6	46067.2	47464.2	47472	47485.7	47533	47540.5	47562	47804	47808	47931	
TE 856	530	529	530	530	533	531	530	464	455	452	448	386	385	384	384	384	384	383	386	390	
TE 857	523	526	525	524	529	526	520	426	421	418	414	394	394	392	390	390	390	402	402	402	
TE 858	533	536	535	534	535	533	532	467	457	454	447	376	376	378	374	375	377	382	384	391	
TE 859	517	519	513	516	523	502	486	320	311	304	306	290	291	287	283	284	280	304	312	324	
TE 898	548	547	547	546	551	548	546	539	537	537	536	511	510	510	509	509	507	505	507	509	
TE 899	564	564	564	564	567	566	565	530	529	527	527	493	493	493	492	491	491	494	493	500	
TE 900	569	571	571	569	572	572	INVALID	←											→	INVALID	
TE 901	535	535	533	533	536	534	534	525	524	523	523	499	498	497	495	494	495	497	499	501	
TE 902	541	540	541	541	544	543	541	534	531	531	530	508	508	508	506	506	505	504	502	506	
TE 903	548	550	547	547	547	548	547	529	528	528	526	505	504	506	504	504	503	504	505	506	
TE 904	552	553	556	555	557	559	558	558	558	557	558	558	557	557	558	557	557	556	556	557	
TE 905	529	529	528	528	528	528	529	529	530	532	532	522	523	524	522	522	522	521	521	521	
MG 801	-84	-90	-87	-76	-95	-217	-217	186	231	253	290	465	456	487	470	456	487	438	431	438	
MG 802	-89	-88	-93	-97	-91	-237	-246	119	151	168	188	364	360	363	367	369	366	355	342	325	
NOTE. TEMPERATURE IN °R STRAIN IN MICRO IN./IN.

GAGE NO.	STATION NO.	RADIUS, IN.	THETA ANGLE
MG 803	95.0	48.5	42°
MG 804	↑	↑	132°
MG 805	↓	↓	222°
MG 806	95.0	48.5	312°

Figure 2 - Dynamic-Strain-Gage Locations

The strain data recorded on MG801 were plotted as a function of control-room time (CRT) along with the support-column temperature, the inlet-line temperature, and the theoretical column strain and are presented as Figure 3. The theoretical strain in the column was calculated from the expression:

$$\Delta \epsilon_c = \frac{E_L A_L (\alpha_L \Delta T_L - \alpha_c \Delta T_c) + \Delta P_{Ext}}{E_L A_L + E_c A_c},$$

- $\Delta \epsilon_c$ = change of strain in column,
- E_c = Young's modulus of column,
- A_c = area of column,
- ΔT_c = change in temperature of column,
- α_c = coefficient of thermal expansion of column,
- E_L = Young's modulus of line,
- A_L = area of line,
- α_L = coefficient of thermal expansion of line,
- ΔT_L = change in temperature of line,
- ΔP_{Ext} = external load on line*

Strain data from MG801 were presented because the output was slightly higher than for data from MG802; however, the trend of going from negative to positive strain after the pump inlet line had reached its stabilizing temperature was the same for both gages, as can be seen from the data in Table 2. The pump-inlet-line temperature as recorded on TE161 was not considered valid during the stabilized portion of the test, as the line was flowing LH₂ at approximately 40°R for 33 min. It was concluded that the line would stabilize at approximately 40°R (probable-inlet-line-temperature curve, Figure 3) and that the channel did not record this temperature because nitrogen was condensing on the line and covering the thermocouple. The theoretical column strain was calculated by using the probable line temperature to get ΔT_L and the recorded column temperature (TE856) to get ΔT_c .

*Obtained from Report RN-TM-0331.

Figure 3 - Temperature and Strain vs CRT - EP-II

Considerable uncertainty is associated with the theoretical strain, because the average ΔT_c is not known and the equation is sensitive to T_c as both α_c and E_c change with the temperature. However, the uncertainty of the calculations cannot account for the large difference between the experimental and theoretical strain. The experimental strain, on the other hand, cannot be fully discredited, as no anomalies were noted in the transducer or the data system and data from both gages (mounted on support columns 180° apart) had the same strain pattern. One possible explanation of the discrepancy could be slippage between the line and the column, at the bolted joint, during the rapid cooldown of the line. This slippage, if it occurred, would not be considered harmful in any manner. A plot of the recorded strain, column temperature, and line temperature for the transient period is shown in Figure 4. This plot shows that the experimental strain started to follow the line temperature curve but stopped at 250 microinches/in. From that point, the shape of the experimental strain curve is almost the same as that for the theoretical strain curve, as seen in Figure 3.

III. CONCLUSIONS

Both the UTS and LTS withstood the XECF loads with no detrimental effects.

Tensile strain was recorded in the pump-support column, whereas the analysis shows this member to be in compression. As no anomalies were noted in the data system, the reason for this discrepancy was not determined. However, a possible reason could be slippage between the line and the thrust-structure support column. In any event, the strain recorded for the column was lower than the strain calculated in the thrust-structure analysis,* which provided a margin of safety of +0.20.

*Report RN-S-0426.

Figure 4 - Temperature and Strain vs CRT - Transient Period - EP-II

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