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NRO TECHNICAL MEMORANDUM

TIME RESPONSE TEST OF THRUST CHAMBER
THERMOCOUPLES IN SIMULATED ROCKET FIRING

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I INTRODUCTION

Simulated rocket firing tests were conducted in an Aerojet-General arc-plasma facility called the Hyperthermal Environment Simulator (HES). The purpose of these tests was to accurately determine the time constant of a thrust chamber thermocouple in hot flowing hydrogen that simulates the heat transfer characteristics of the NRX thrust chamber gas at three specified engine operating conditions, 13, 44, and 100% of full power. This information is needed to determine the probe time constants for control loop dynamic stability purposes during low and intermediate power conditions.

II CONCLUSIONS AND RECOMMENDATIONS

The requested heat transfer coefficient corresponding to 100% of NRX full power proved to be unattainable in the HES. The highest heat transfer coefficient achieved was 63%. On the basis of tests run at 13, 45, and 63%, the following conclusions were reached:

A. The time constant of each thrust chamber thermocouple is dependent on two factors, probe construction and the gas heat transfer coefficient.

B. The lead bath determined time constant, previously used as the time constant for each thermocouple, is a valid representation of the probe time constant at full power and is a characteristic of the probe construction.

C. The total time constant exceeds the 0.5-sec response requirement at engine power levels below 13% of full power.

D. Although only one thermocouple was used in this experiment, the results are applicable to all thermocouples of this type based on the fact that the lead bath response time is a valid representation of the probe construction factor, and the gas heat transfer coefficient is the same for all probes of the same type.

It is recommended, however, that additional tests be conducted to define the probe response characteristics below 13% of full power if the probes are to be used for engine control within this region.

III DISCUSSION

The NRO Controls Department requested that measurements be made of the response time of a thrust chamber thermocouple in flowing hydrogen, which simulates the temperature and gas heat transfer coefficient of the XE thrust chamber gas at three specified engine power conditions, viz., 13, 44, and 100% of full power. Using these three points, a curve can be drawn to relate

thermocouple time constant to reactor power. With such a curve, the control loop dynamic stability can be calculated when the XE engine is controlled by the thrust chamber thermocouples from about 1000°R to and including full power. This information was needed because a startup experiment of this type is tentatively planned for XE.

Previously, the use of the thrust chamber thermocouples for control purposes had been limited to near full power. The time constant at full power was the only requirement specified and was defined to be not more than $\frac{1}{2}$ second. This full-power time constant has been measured for every thrust chamber thermocouple used to date by immersing the probe into molten lead and timing the response to reach 63% of the total temperature change. This molten lead test is meaningful because the heat transfer coefficient of molten lead to the probe (about 3500 Btu/ft² hr R°) closely approximates the 3345 Btu/ft² hr R° calculated for the probe in gas corresponding to engine full power.

Earlier HES tests had been made in hot flowing nitrogen, but the heat transfer coefficient available with nitrogen were limited to those encountered in the engine at about 10% of full power. Since these tests, the HES has been modified to operate at higher gas pressures and with a large percentage of hydrogen so that higher heat transfer coefficients can be obtained. This report discusses the application of the increased HES capability to provide the needed information regarding the probe time constant as a function of engine power.

Table I lists the three thrust chamber gas conditions specified, the calculated percent of full power, and the respective heat transfer coefficients for the gas to the probe.

Figure 1 shows the calculated gas heat transfer coefficients obtainable in the HES at 4000°R in various hydrogen-helium mixtures and at various mass flow rates. The 3345 Btu/ft² hr R° corresponding to NRX full power can be achieved, but only in gas which is primarily hydrogen and in mass flows above 0.09 lb/sec. Both conditions are difficult to achieve, especially the high hydrogen content because of arc instability.

TABLE I

SPECIFIED CONDITIONS TO BE INVESTIGATED

<u>Flow</u> <u>(lb/sec)</u>	<u>Temperature</u> <u>(°R)</u>	<u>Pressure</u> <u>(psia)</u>	<u>Engine Power</u> <u>(% of full power)</u>	<u>Calculated</u> <u>Heat Transfer</u> <u>Coefficient</u> <u>Btu/ft² hr R°</u>
25.6	1565	123	13.35	1019
32.2	3862	248.3	44.5	2071
69.4	4000	537	100	3345

HES HEAT TRANSFER COEFFICIENT AS A FUNCTION OF TOTAL GAS FLOW RATE AND GAS COMPOSITION AS APPLIED TO THE NRX-A THRUST CHAMBER THERMOCOUPLE IN CROSS FLOW WITH THE PLASMA STREAM

HES OPERATING CONDITIONS:

T_g - 4000°R
 P_c - 450 psia
 D_j - 0.920 in.

NRX Gas Max. Heat Transfer Coefficient

0.150 lbs/sec
 0.100
 0.050
 0.025

Figure 2 shows a similar curve, using nitrogen as the stabilizing gas instead of helium. Despite the lower attainable coefficients, nitrogen was used in the time constant studies reported here because of the greater arc stability obtained with nitrogen and because the test was primarily concerned with time response at lower NRX engine powers. The slightly lower gas heat transfer coefficients obtained with hydrogen-nitrogen mixtures did not interfere with the primary test objectives.

The necessary step-change in gas temperature, which was used to measure the probe time constant, was produced by removing a protective shield from the probe tip in two milliseconds with a pneumatic piston. This two millisecond delay is small compared to the tenths of seconds being measured for the probe and can be neglected.

Signal voltages developed by the thermocouple were amplified by a Dana amplifier, Model 3630-V2, that has a frequency response from 0 to 10 kHz. This amplified signal was recorded by a CEC oscillograph, Model 5-124, that has a No. 7-320 galvanometer movement capable of responding to 600 Hz. The time constant was obtained by measuring (by chart speed) from the time power was applied to the pneumatic piston to the time the recorded thermocouple output reached 63% of the total step change in temperature. The particular thermocouple used had a molten-lead-bath determined time constant of 0.28 seconds.

Table II lists the gas conditions used in the HES and the time constants measured for the six runs made in the HES.

Figure 3 shows a plot of the six HES determined time constants and the lead bath time constant. Except for the 2124°R coefficient point, the points all fall close to the best-fit curve drawn for the other points. The reason for the high reading at 2124°R has not been determined. It may be due to the lower-temperature higher-pressure gas conditions used at this point compared to other points or it may be indicative of the experiment error band.

Assuming that the curve is correct, the total probe time constant in the engine appears to be the sum of two time factors. One factor is determined by the ability of heat to flow from the surface of the probe, through the probe sheath, to the sensory junction located inside the probe tip. This factor is a function of probe construction and is closely approximated by the 0.28-sec measured in the lead bath test; it differs from probe to probe depending on internal fabrication details and can be as long as 0.5-second.

HES HEAT TRANSFER COEFFICIENT AS A FUNCTION OF TOTAL GAS FLOW
 RATE AND GAS COMPOSITION AS APPLIED TO THE NRX-A THRUST
 CHAMBER THERMOCOUPLE IN CROSS FLOW WITH THE
 PLASMA STREAM

HEAT TRANSFER COEFFICIENT - BTU/HR-°R-FT²

HES OPERATING CONDITION.

T_g - 4000°R

P_c - 450 psia

D_j - 0.920 in

NRX Gas Max.
Heat Transfer Coefficient

0.150 lbs/sec
 0.100
 0.050
 0.025

MOLE PERCENT NITROGEN - %
 (BALANCE HYDROGEN)

TABLE II

SUMMARY OF HES OPERATING CONDITIONS AS APPLIED TO THE
NRX-A THRUST CHAMBER THERMOCOUPLE TIME RESPONSE TESTS

HES RUN NO.	MOLE PERCENT N ₂	MOLE PERCENT H ₂	MASS FLOW RATE (LB/SEC)	GAS PRESSURE PSIA	GAS TEMP (°R)	HEAT COEFFICIENT	TIME CONSTANT (SEC)
J-19	0.06	0.93	0.071	398.0	3381	2124.6	0.445
J-20			NO DATA - NO OSCILLOGRAPH TRACE				
J-21-1	0.10	0.89	0.053	238.0	1479	921.5	0.666
J-21-2	0.08	0.92	0.062	335.0	2593	1547.6	0.410
J-22-1	0.076	0.924	0.062	288.0	2295	1447.2	0.470
J-22-2	0.076	0.924	0.062	302.0	3302	1832.0	0.431
J-22-3	0.077	0.923	0.061	351.0	4108	2051.2	0.361

Lead bath time response = 0.28 sec (lead bath temp - 1168°R)

W-5% Re VS W-26% Re IMMERSION THERMOCOUPLE

Figure 3

The second factor is determined by the ability of the gas to transfer heat to the probe surface. Assuming that the external probe surface roughness and dimensions are similar, this factor is almost entirely a function of the gas flow conditions. It is represented by that part of the total time constant above the lead bath time. This difference is shown by the time scale at the right in Figure 3.

The significance of Figure 3 is that the time scale at the right represents a heat transfer correction factor to be added to the lead bath time constant for any similar type probe to give the total time constant for this probe in the engine. Use of this correction factor saves having to make a laborious HES time constant test on each probe installed in the engine.

The second scale at the bottom of Figure 3 shows the correction curve as a function of engine power for the three conditions specified. This scale is provided for estimation purposes only and can be in serious error depending on how far the gas temperature, pressure, and mass flow at the particular point of interest depart from the typical conditions stated in Table I. More accurate results are obtained if the gas heat transfer coefficient at the various conditions is calculated so that the first scale can be used.