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SPECIFICATION

for

PLASMA ARC TESTS

of

SNAP 19 FUEL CAPSULES

by

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There is no objection from the patent point of view to the publication or dissemination of this document:
NY Patent Group

By.....

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ABSTRACT

This specification establishes a plasma arc test program for tantalum fuel-capsule liners that will result in an empirical definition of the ablation rate of thin wall tantalum cylinders as a function of stagnation enthalpy, stagnation pressure, and stagnation heat flux.

I. INTRODUCTION

To validate a design for a fuel capsule liner that exhibits the desired burn-through characteristics, plasma arc tests of tantalum liners will be performed. The program is designed so that the results lend themselves to an empirical derivation of an expression for the ablation of thin wall tantalum cylinders as a function of stagnation enthalpy, stagnation pressure, and stagnation heat flux. The tests will be performed in the Martin Company plasma arc (MPA) facility at Middle River, Md. The configurations to be tested are typical of those used in the radioisotope power supply that will be operated aboard the Nimbus weather satellite. The test specimens will be fabricated of actual production materials.

It should be noted that this program has been designed as a parametric survey rather than a re-entry environment study. Although this consideration prevails, in some instances the range of simulation of which the tunnel is capable is on the same order of magnitude as the pertinent re-entry trajectory regime.

Since the destruction of the capsule is the result of an ablation process due to aerodynamic heating, the rate of ablation and how it is effected by the parameters previously mentioned will be determined in these tests.

Tunnel capability limits are displayed in Figures 1 and 2. The numbered locations show the projected data points at which the liners will be tested.

FIGURE 1
Plasma Arc
Performance Limits

FIGURE 2
Plasma Arc
Performance Limits

II. APPROACH

Currently, three liner thicknesses are being considered for use in SNAP 19 capsules (6 mils, 10 mils and 15 mils). The specimens will be fabricated excluding any fuel simulation since this can be handled analytically. Each liner thickness series will be run at data points 1 thru 12. (See Figure 1). These points have been chosen so as to survey a large portion of the tunnel performance limits for a parametric study, and to provide a certain amount of data applicable in re-entry analyses. The preliminary, theoretical, re-entry conditions are listed in Table 1 while Table 2 shows the conditions at which MPA runs are scheduled. This series will provide basic criteria for the ablation rate of tantalum by simply measuring "time to burn through."

The points 2, 4, 5 and 8 will be used to determine changes in liner ablation rate as influenced by the capsule in a liner-capsule configuration. Having tested liners alone at these points, the capsules alone will be run at the same conditions and finally capsule-liner combinations. In this way the combined response and interaction can be defined.

Referring once more to Figure 1, points 13, 14 and 15 have been chosen in the low pressure facility partially to achieve a wider range in overall pressure data. In addition, there is available in the low pressure tunnel a device capable of maintaining a specimen at a constant longitudinal spin-rate (approximately 93 rpm's) while the specimen is being exposed to the plasma flow.

TABLE 1
THEORETICAL CAPSULE BURN-UP

		Capsule Released	Capsule Burn-up	Burn-up + 80 seconds
h	ft.	269,500	236,450	177,850
V	fps	25,090	23,790	17,770
Mach #		29.6	28.6	16.2
H_{ST}	BTU/lb	12,690	11,450	6,520
P_{ST}	atmos.	.00716	.03565	.17700
$\dot{Q}_{ST}$	BTU/ft ² -sec	263	521	617

TABLE 2
PROGRAMMED TEST POINTS

Data Point	Liner Thickness (Inches)	Stagnation Values			Time to Burn-Through (sec)	Purpose
		Enthalpy (BTU/lb)	Pressure (Atmos.)	Heat Flux (BTU/ft ² -sec)		
1	t ₁ , t ₂ , & t ₃	5,000	.24	105-195	To be Determined	Ablation Rate Determination 36 runs.
2			.14			
3		10,000	.25	170-370		
4			.14			
5			.08			
6		12,500	.40	200-370		
7			.25			
8			.08			
9		15,000	.14	220-490		
10			.055			
11		20,000	.14	270-570		
12			.055			
2	Capsule and Liner	5,000	.14	105-195		Whole system Response 4 runs
4		10,000		170-370		
5			.08			
8		12,500		200-370		
13	t ₃	5,000	.025	26-140		Influence of Spin 3 runs
14		7,500		55-230		
15		10,000		98-310		

The plasma arc capabilities allow for the control of any two of the aforementioned parameters at one time. Although the third parameter will fall within a predictable range, effectively there are two variables at each data point; i.e. the parameter that is intentionally varied and the dependent variation of the third parameter. The incremental changes in liner wall thickness or the use of a particular spin rate for several runs is not meant to infer that either of these will be treated parametrically with respect to liner ablation rate. These data will be used only to establish that there is or there is not a change in ablation rate resulting from such a change in conditions.

The independent variable, time-to-burn-through, which is necessary for calculating ablation rates, is found by using a high-speed photography method to be described later. This provides both for ablation rate calculations and documentation of each post-test specimen for later reference.

Spectrographic analyzes will be performed on representative specimens, following the testing, to determine the products of oxidation.

III. TEST PROCEDURE

A. Facilities

Two separate test chambers are available at the MPA facility. The low pressure configuration (Figure 3) consists of a Plasmadyne Corporation plasma generator, d. c. power supply, vacuum pumping system and instrumentation for determining stream parameters and monitoring specimen behavior. The medium pressure facility is similar with the exception of a Thermodynamic Corporation plasma generator (Figure 4). Arc gas is injected tangentially into the arc chamber, passes through an arc established between the cathode and anode, and is discharged through a contoured supersonic nozzle into the evacuated test chamber. The system will operate with a simulated air mixture; or argon; or nitrogen; or hydrogen; or helium. A comprehensive description of the MPA facility can be found in Reference 1.

Although some slight method differences may occur between MPA tunnels as concerns instrumentation procedures, generally they will be handled as follows:

1. Enthalpy

The total enthalpy of the plasma stream is determined by the heat balance method. Power losses to the arc generator and the nozzle cooling water are subtracted from the measured input power. The net power in the gas is then divided by the measured gas flow rate. The total enthalpy is calculated from the following equation:

$$H_t = \frac{(.948 \times 10^{-3} E_p) - .139(V_{hw}T_{hw} + V_{nw}T_{nw})}{M}$$

FIGURE 3 LOW PRESSURE FACILITY

67232

FIGURE 4 MEDIUM PRESSURE FACILITY

B-68872

FIGURE 5 CONTROL AND DATA GATHERING CONSOLES

68870

where:

H_t	= Total enthalpy	BTU/lb
E	= Voltage	Volts
I	= Current	Amperes
V_{hw}	= Arc generator cooling water flow rate	GPM
T_{hw}	= Arc generator cooling water temp. rise	$^{\circ}F$
V_{nw}	= Nozzle cooling water flow rate	GPM
T_{nw}	= Nozzle cooling water temp. rise	$^{\circ}F$
$\dot{M}$	= Gas flow rate	lb/sec

2. Stagnation Pressure

Measurement of the stagnation pressure downstream of the normal shock wave is made using a pitot probe. The tip of the probe presents a flat face normal to the stream and contains a pressure measuring orifice whose diameter is small in comparison with the outside diameter of the tip to insure that the bow shock wave is normal to the measuring orifice.

3. Surface Temperature

Specimen surface temperature is measured with total radiation and optical pyrometers. The pyrometers are calibrated to black body conditions (i. e. emissivity =1.0). In addition to the black body calibration, these instruments are also checked under actual operating conditions by measuring the apparent surface temperature on a thermocouple-instrumented graphite model. A plot is made of apparent surface temperature (pyrometer reading) versus true surface temperature (thermocouple reading) thereby obtaining the desired calibration.

4. Calorimeter

A heat flux measurement is made at the flat face of a steady-state water-cooled calorimeter. Since it is impossible to exactly determine the position of the thermocouples imbedded in the steady-state calorimeter with the required accuracy, this calorimeter is in turn calibrated against a transient slug calorimeter. The heating rate is calculated from the equation:

$$Q_{cw} = \frac{WC_p}{A} \frac{\Delta T}{\Delta \tau}$$

where:

Q_{cw} = cold wall heating rate

W = weight of copper sensor

C_p = specific heat of copper

A = exposed area of copper sensor

$\frac{\Delta T}{\Delta \tau}$ = temperature rise rate of copper sensor

5. Photographic

A completely automatic 35mm camera is available for recording specimen reaction during test. The system consists of a Flight Research model IV-E camera with a variable shutter and an auxiliary data chamber; a 90mm f/2.8 lens with motorized iris and an integral beam splitter and photocell; and a control panel. The camera operates at a speed of 20 frames per second.

6. Nozzles

Four, contoured, Mach 3, nozzle assemblies are available in the MPA facility. The 1 1/2 inch exit-diameter nozzle will subject a 1 inch diameter flat-faced specimen to heat fluxes as high as 1200 BTU/ ft^2sec . The 3 inch exit-diameter nozzle will produce heat fluxes up to 600 BTU/ ft^2sec on a 2 1/2 inch diameter flat-faced specimen. Both assemblies are constructed from copper and utilize water at 150 psi pressure for cooling purposes.

B. Specimens

The specimens to be used to determine the ablation rate of tantalum are those that were fabricated for the weld feasibility study. Thirty-six of these specimens are available. There are 12 each of wall thicknesses 6 mils, 10 mils and 15 mils. A specimen of each thickness will be tested at each of the data points 1 thru 12 as shown in Figure 1. The test liners will be full scale in circular cross-section (on the order of 1 inch) but less than full-scale in length. The test sections will be capped on each end with an insulating material in order to restrict the heat input to only 2 dimensions. A typical test specimen is shown in Figure 6.

Unless prior tests indicate otherwise, the spin effects tests will use only the tantalum liners as previously described. They will be attached to the constant spin device (Figure 7) and exposed to the plasma flow. The specimen will spin about its longitudinal axis. The 15 mil wall thickness liners will be used for these three runs in order to increase the time during which measurements can be made.

Figure 6 Typical test configuration for all liner thicknesses and/or capsules.

FIGURE 7 SPIN DEVICE USED IN MEDIUM PRESSURE FACILITY

C. Method

The plasma arc tests can be logically sub-divided into 3 distinct series:

1. Determination of ablation rate of thin wall tantalum liner cylinder, parametrically.
2. Definition of response of capsule-liner system, parametrically.
3. Determination of effect of spin on ablation rate of tantalum liners.

The currently planned plasma arc tests for the three series listed above require 47 runs to complete the program. Table 2 lists the parameter values to be used in all series.

The first series will be simply for a straightforward determination of the ablation rates of thin-wall, tantalum, liner cylinders. Twelve specimens of each of the liner thicknesses, 6 mils, 10 mils and 15 mils, will be tested in the first series.

The arc conditions at which these specimens will be run are points 1 thru 12 in Figure 1. High-speed motion pictures will be made of each specimen as it is exposed to the flow so that time to burn through can be determined. The ablation rate is then calculated as the wall thickness divided by the time to burn through. Using this information along with the tunnel test conditions, coincident plots of ablation rate can be constructed as functions of enthalpy, pressure and heat flux.

Each post-test specimen will be photographed for both documentation and later reference. A representative sampling will be taken for spectrographic and chemical analysis. The purpose of these analyses will be to define the products of oxidation, to uncover possible problem areas and to indicate direction for further investigation.

The second series is designed to show any differences in ablation rates as a result of capsule-liner interaction. The ablation rate of liners-only is determined in series (1). Four capsule outer-shells-only will be run at tunnel conditions 2, 4, 5 and 6 (see Figure 1) to establish the outer shell ablation rate. Four operational configurations, outer shell plus liner, will also be run at points 2, 4, 5 and 6 to determine the combined ablation rate. (Ablation rates will again be measured using the high-speed photography method.)

Which liner thickness is used for this series is unimportant but, depending on the information available at the time, the operational liner thickness will be used. Supplementary photo coverage and chemical and spectrographic analyses will remain as detailed in the series (1) description.

The data points that will be run for series (3), points 13, 14 and 15 are shown in Figure 1 in the low pressure tunnel operating regime. It can be seen by inspection that this will provide a range in pressure of two orders of magnitude. Liners-only will be run in this series. The specimens will be maintained at a constant spin rate while they are exposed to the flow. This series is to provide some insight concerning the effect of spin on ablation rate of tantalum liners.

The photographic coverage and the chemical and spectrographic analyses will be as previously described.

Data to be recorded for the tunnel runs of all three series are shown in Table 3.

TABLE 3

TUNNEL DATA TABULATION

Run Number	Data	Data Point	Liner Thickness (mils)	Configuration	Enthalpy	Heat Rate (btu/lb)	Pressure (atm.)	Burn Time (sec)	Heating Pulse	Gas Composition	Remarks
1		1	6	liner	See Table 2						
2		2	6	"		.					
3		3	6	"		.					
.	.	.	.	.		.					
.		.	.	.		.					
.		.	.	.		.					
.		.	.	.		.					
45		13	13	liner		.					
46		14	13	liner		.					
47		15	13	liner		.					

NOTE: Total runs = 47; 36 ablation, 8 capsule-liner, 3 spin influence.
(For each additional spin rate investigated, add 3 more runs)

IV. REFERENCES

1. Schmidt, G.: Martin LUTHEW Plasma Jet Turbine. ER-12112, No. 1011: 1963.