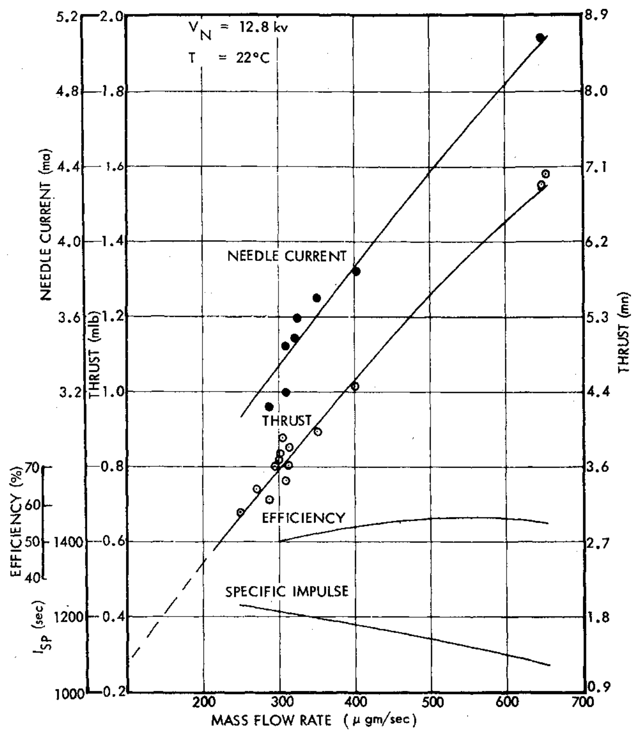

Fig. 3 Thruster performance vs mass flow (constant needle voltage and thruster temperature).

Other Component Data

Five neutralizers were subjected to accelerated life tests.[7] The neutralizer filament is a 6.3-cm (2.5-in.) length of 0.053-mm (2.1-mil) diam bare tungsten wire. The tests showed that an 8.5% reduction in filament diameter will occur after 24,000 hr. At this point the filament temperature profile remained uniform. Actual burn-out was not observed until a 12% reduction in diameter had taken place. Operation beyond 24,000 hr, however, will be unsatisfactory because of nonuniform electron emission that required increased injection potential.

The propellant feed system has shown satisfactory characteristics in component tests. In system integration tests, however, propellant tension has not been maintained in the volume between the propellant flow controller valve seat and the thruster needle tips when the valve is closed. It is believed that a gas bubble was trapped during initial propellant filling of this volume. As a consequence, system start-up and shutdown remain to be evaluated. PCCS performance data have previously been reported in Ref. 10.

Conclusion

Difficulties have been encountered in attempting to reproducibly demonstrate design level performance in ground test facilities. The results (Table 1) are influenced by the wetting characteristics of the needle tips in the test environment.

Life test results to date have been encouraging. A module has operated for over 3000 hr at 69% thruster efficiency and about 1350-sec I_{sp}. The breadboard thruster system was operated over 1000 hr. Accelerated neutralizer life tests in a separate vacuum bell jar indicated 24,000 hr of filament life.

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Material Evaluation under Direct Rocket Exhaust Impingement

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Introduction

THE multiple independent re-entry vehicle (MIRV) capability was added to the Minuteman weapon system effective with the Minuteman III model. A major change required was the addition of a post boost propulsion system (PBPS) to add velocity and positional adjustments to the final stage for each re-entry vehicle deployment. Bell Aerospace Co. developed the PBPS under subcontract to North American Rockwell Autonetics Div.

The Post-Boost-Propulsion System is housed in the aft 18 in. of the 52 in. diam fourth stage. Final staging is effected by a circumferential separation ordnance ring at the aft plane of the fourth stage. Activation of the separation ring is followed by third stage retrothrust which is achieved by opening six uniformly spaced ports to the third stage combustion chamber. Exhaust from each port is ducted forward at a 45° angle forming a conical expanding flow around the fourth stage. The third stage retrothrust does not pass through the third stage c.g. and as the stages separate third stage pitch/yaw rotation sweeps the retrothrust gases across the aft surface of the fourth stage.

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Index categories: Material Ablation; Liquid Rocket Engines; Properties of Materials.

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Table 1 Fourth stage aft surface worst case environment [1,2]

Source stagnation temperature	5600°R
Peak particulate impingement rate	0.062 lb/ft^2-sec
Total particulate impingement	0.030 lb/ft^2
Peak heating rate	82 Btu/ft^2-sec
Total heat	58 Btu/ft^2
Time for 90% of total heat	1.0 sec
Plume constituents	
Gases: HCl, CO, H_2O, CO_2, N_2, H_2	73% by wt
Solids	
Materials	Al_2O_3
Size range (diameter)	0.68–3.6 μ
Average size (diameter)	1.5 μ
Velocity	6700–10,000 fps

Two basic approaches were considered to make the system compatible with the staging environment. One approach to coat all heat sensitive elements with an insulating material was eliminated in favor of an aft surface insulating blanket. The blanket required less and more repeatable weight and minimized fabrication costs. Tests were conducted to demonstrate the suitability of the blanket.

Environmental Design Criteria

Data provided by the Aerojet General Co. were incorporated into an analysis performed by the Boeing Co. to quantify the staging environment to which the PBPS is exposed. The analysis considered two phase exhaust expansion, and the relative motion between the third and fourth stages. Table 1 presents the worst case design criteria resulting from the Boeing study.

Silicone rubber, to Aeronautical Material Specification 3345, was selected for the insulative component of the blanket based on the properties generated by previous Minuteman contracts. The strength of the blanket was provided by glass cloth backing (J. P. Stevens Fiberglass No. 1564). The composite thickness was 0.065$\pm$0.005 in. The rubber properties are shown in Table 2. Conservative thermal analysis of the system showed adequate system protection and a maximum insulation blanket system-side temperature of 350°F.

Test Setup

Samples 1½ in. in diameter of the insulation blanket were held in the exhaust of a solid rocket motor in a vacuum test facility. Samples included seamed and unseamed configurations and were mounted with and without axial support to simulate each area of the full scale blanket. Aerojet General Corp. motors which are used to batch-test the ANB 3066 solid propellant for the third stage were used. The batch motors were ordered with as large a throat diameter (1.15 in.) that would permit stable operation, and were fitted with as large an area ratio divergent nozzle (297:1) which would flow-full in the Bell altitude facility at 0.10 psia ambient pressure. These changes were calculated to reduce the mass flow rate and the size of the solid particles and to increase the efflux velocity to approximate the criteria as shown in Table 3, with the sample placements shown in Fig. 1.

Table 2 Silicone rubber AMS3345 properties

Temperature of ablation	1000°F
Heat of ablation	1350 Btu/lb
Specific heat	0.35 Btu/lb-°F
Thermal conductivity	2.1 Btu-in./hr ft^2-°F
Density	0.048 lb/in.^{3}
Continuous temp limit	500°F

Table 3 Predicted test environment vs criteria

		Test method prediction
Stagnation temp (°R)	5600	5600
Al_2O_3 impingement peak rate (lb/ft^2-sec)	0.062	0.085
Gas	HCl, CO, H_2O	Same
Constituents	CO_2, N_2, H_2	Same
Al_2O_3 size (microns)	0.68–3.36	0.41–2.05
Al_2O_3 velocity (fps)	6700–10,000	7960–9470

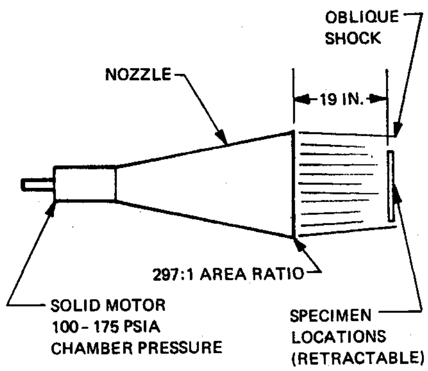

Fig. 1 Solid motor and sample placement.

Tests and Test Results

Six tests were run with up to three test samples per test. The tests provided exposure durations of approximately 1.3, 3.0 and 4.2 sec.

Environmental measurements

The total heat flux to the sample locations was approximately proportional to the exposure time. Samples exposed for 4.2 sec were exposed to a total heat flux of 420 to 480 Btu/ft^2. Samples exposed for 3.0 sec were exposed to a total heat flux of from 260 to 290 Btu/ft^2 and the 1.3-sec duration samples to a total flux of from 70 to 120 Btu/ft^2. The resulting test total heat flux ranged from 1.2 to 8.3 times the total heat flux criteria of 58 Btu/ft^2 as shown by Table 4.

The peak heat fluxes—obtained on all calorimeter measurements—varied from 120 to 210 Btu/ft^2-sec. This ranges from 1.5 to 2.7 times the requirement criteria of 82 Btu/ft^2.

Condition of samples

The 4.2-sec exhaust plume exposures resulted in complete loss of the Silicon rubber surface material. Damage to the Fiberglass backing varied from complete loss over the entire 1½ in. diam to light erosion of the 0.015-in. thick weave.

The shorter duration exposures produced no damage beyond the surface material except for one sample which was

Table 4 Test total heat flux ranges

Sample exposure duration, sec	Total heat flux range divided by requirement criteria	No. of heat flux measurements
4.2	7.2 to 8.3	3
3.0	4.5 to 5.0	5
1.3	1.2 to 2.1	7

Table 5 Material-loss measurements

Exposure duration	No. of samples	Surface material loss[a]		
		%	g	in.
4.2 sec	4-Tent material	100	1.5	0.045
3.0 sec	3-Tent material	65 to 78	0.97 to 1.17	0.029 to 0.035
1.3 sec	6-Tent material	13 to 29	0.19 to 0.43	0.006 to 0.013
1.3 sec	1 Dynatherm	60	0.456	0.013
1.3 sec	1 Aluminum	0	0	0

[a] The 4.2 sec. exposure also resulted in 0 to 100% loss of the fiberglass backing weave.

one of 4 samples exposed for 3.0 sec. The Fiberglass was exposed and charred over half of this sample which was closest to the nozzle centerline. A sample located on the centerline received no Fiberglass exposure during the same test. It was hypothesized that full retraction of the outer sample was delayed invalidating the condition of the sample. The material losses of the remaining 15 samples is summarized in Table 5.

The general surface condition of the 9 tent material samples from the 3.0- and 1.3-sec exposures was a clean, slightly roughened surface, with no discoloration. Three samples had single large craters (300, 600, and 750 μ). The 750-μ crater penetrated to the Fiberglass weave. The bottom of the 600- and 300-μ craters were 0.027 and 0.012 in. from the Fiberglass backing. Due to the large size and irregular shape of these particles they were believed to be particles from the rocket motor igniter or inhibitor.

The ablative sample showed a uniform material loss, and some delamination from the steel backing near the edges. The material was embrittled as indicated by cracking on one side during removal of the sample. The aluminum sample showed no deterioration. The four rubber samples instrumented for temperature attained maximum backside temperatures at 30–90 sec after the exposure. The peak temperatures were as shown in Table 6. The maximum temperature of 165°F was well below the system design thermal analysis which showed no degradation to system components at a 350°F backside temperature.

Conclusion

Silicone-rubber, Fiberglass-laminated tent material gives adequate protection to the internal components of the PBPS from the third-stage exhaust plumes, temperatures and particles during stage separation.

The Dynatherm ablative thickness of 0.022 in. is sufficient for nonload bearing parts subjected to a nominal worst-case exhaust plume exposure. However it does become brittle and caution should be taken in considering its use for load bearing applications.

Table 6 Maximum sample backside temperatures

Sample type	Thermocouple placement	Impingement duration (sec)	Peak temperature
Unsupported	Fiberglass back	3.0	165°F
Unsupported	Fiberglass back	1.3	154°F
Supported	Stainless back	1.3	144°F
Supported	Stainless back	1.3	150°F

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Mach Number and Reynolds Number Effect on Orbiter/Tank Interference Heating

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Nomenclature

H = measured heat-transfer coefficient to tank alone configuration
H_m = measured heat-transfer coefficient to tank in mated configuration
H_S = stagnation point heat-transfer coefficient on scaled 1-ft radius sphere
H_T = calculated turbulent sonic point heat-transfer coefficient on a scaled 1-ft radius sphere
$\bar{H}$ = H_m/H
$\bar{H}_T$ = H_m/H_T
L = tank length (for model, $L = 9.83$ in.; full scale, $L = 163.8$ ft)
M_∞ = freestream Mach number
X = distance along body
$R_{\infty,L}$ = freestream Reynolds number based on tank length

THE current version of the space shuttle configuration during ascent consists of a delta wing orbiter, a tank attached parallel to the bottom of the orbiter, and two solid fuel rocket boosters along the sides of the tank. For liftoff and early ascent flight the booster solid rocket motors and the orbiter liquid fuel engines are fired. At an altitude of about 130,000 ft, the solid fuel rockets are separated from the orbiter and tank which continue ascent. A typical velocity, altitude and reference sphere heating rate trajectory is presented in Fig. 1. At booster separation there is a small peak in the heat-transfer rate. This small peak is followed by another much larger peak of 26.8 Btu/ft²sec. The maximum heat-transfer rate occurs at orbit insertion [Mach number of approximately 28 and Reynolds number ($R_{\infty,L}$) of 5.5×10^4].

Previous Shuttle interference heating tests (for example, see Brevig et al.[1]) have been concerned primarily with fully reusable two stage concepts in which only the orbiter experienced speeds higher than Mach 10. Consequently, interference heating occurred on these mated configurations at lower Mach numbers and much lower altitudes than for the present concept. Data are now needed at higher Mach numbers and lower Reynolds numbers than previously investigated. Since data at high Mach number and low Reynolds number are presently nonexistent, the present study was undertaken to determine how these two body interference heating rates vary with Mach number and Reynolds number. Results extend the Mach number range up to 19 and the Reynolds number

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