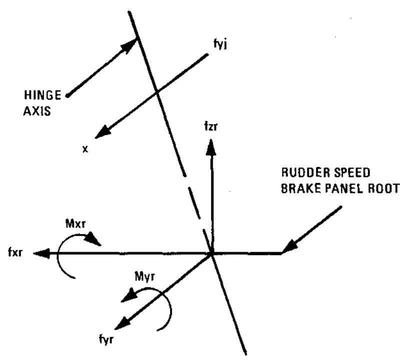

Fig. 2 Rudder speed brake model.

position for any given test condition was best fitted by an interactive program accessing the test-load matrix. All desired loading parameters with the exception of the hinge moment *Mz* were balanced by ratios developed by jacks from other noncritical substructures. The model of a rudder speed brake is shown in Fig. 2.

The strategic placement of the *x* and *y* ratios, *fxr* and *fyr*, at the speed brake panel hinge root assures that the hinge moment of the panel will be developed by the jack, properly located or not. The *z* ratio *fzr* and the moment ratios are supplied to complete the static balance of model.

Final Loads Processing

Derived test-loads data were stored on magnetic tape. These tapes were accessed by the test operation computers to apply the loads and by computers programmed to tabulate, in test report form, the jack data for all test applications. The external test-load matrix and the discrete test-load tape were accessed by computers programmed to provide the applied vs desired loading parameters. The loading parameter plots, produced by the computer, provided the verification of the quality of the discrete test loads.

Summary

The computerized process used to calculate the discrete test loads provided the capability to recompute quickly and efficiently a revised set of test loads caused by last minute changes in basic loading requirements. This capability was a major contributor to the success of the Space Shuttle Orbiter structural test program.

AIAA 80-1171R

Technology Status of a Liquid Fluorine-Hydrazine Rocket Engine

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Introduction

THE Space Storable Propulsion Systems Technology Program was initiated in the fall of 1976. Its objective is to demonstrate the technology readiness of a space storable liquid propulsion system so that this technology can be applied to planetary missions with start dates in fiscal 1982 and beyond. The primary element of the fluorine-hydrazine propulsion system is the rocket engine assembly (REA). The significant design criteria for the assembly are shown in Table 1. The REA incorporates the propellant valves and the thrust chamber assembly (TCA) which consists of the liquid propellant injector and the thrust chamber. Progress on the propellant valves and prior TCA progress has been detailed.[1,2]

Table 1 Rocket engine requirements

Thrust	3560 N (800 lbf)
Chamber pressure	690 kN/m^2 (100 psia)
Total firing duration	4000 s, minimum
Vacuum performance	3626 N-s/kg
$I_{(sp,vac)}$	(370 lbf-s/lbm)
Mixture ratio	1.5
Expansion ratio	60:1 or 80:1
Maximum weight (not including valves)	13.6 kg (30 lb)

Observations of the tests conducted with carbon/carbon composite thrust chambers showed that the film cooling on the chamber walls was at first effective. As time progressed, the film was destroyed by a combination of radial heat flux from the combustion gases and axial heat flux along the chamber wall from the hotter throat section. In addition, head-end combustion gas recirculation (sometimes referred to as radial winds) was adding to the problem of higher-than-predicted wall temperatures. Local corrosion of the inner wall was also experienced. The injector was modified to incorporate additional film cooling (36%) in an attempt to maintain the chamber wall below the ammonia-carbon reaction initiation temperature (the cause of the corrosion) and to block the "radial winds." An alternate like-doublet injector was also fabricated. This design incorporated 27% of the fuel as film cooling.

This Note presents the status of the efforts to develop a lightweight thrust chamber assembly capable of achieving the long-duration performance requirement.

Nickel Chamber Tests

Three tests were conducted at the JPL Edwards Test Station with the reworked propellant injector installed in a heavyweight nickel thrust chamber. Test durations of 5, 15, and 30 s were accomplished. Utilizing the simplified JANNAF[3] methodology, an average extrapolated performance value of 3549 N-s/kg (362 lbf-s/lbm) was achieved at an overall mixture ratio of 1.5 assuming an 80:1 expansion ratio. Post-test inspection showed that the fuel liquid film cooling length extended to the throat of the chamber during the first test. As the test duration was increased, the liquid length receded toward the forward end of the chamber. It was apparent that, as had been previously determined, the heat transfer characteristics could not be predicted through the use of short-duration nickel chamber tests and must be analyzed during long-duration carbon chamber tests. Three 5-s tests were conducted with the alternate injector installed. An average extrapolated performance value of 3578 N-s/kg (365 lbf-s/lbm) was achieved at an overall mixture ratio of 1.5 and an expansion ratio of 80:1. No further testing was conducted with this injector because of cost and schedule restraints.

Unlined Carbon/Carbon Composite Chamber Tests

Two 200-s tests were completed utilizing the reworked propellant injector. The first test incorporated a new chamber. It was found that the occurrence of corrosion just downstream of the injector had been eliminated by maintaining low head-end temperatures through increased film cooling. Substantial corrosion occurred in the convergent and

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throat sections. It appeared that the ammonia remained adjacent to the wall until a section of the chamber was encountered hot enough to initiate the ammonia-carbon reaction. The second test incorporated a previously test-fired chamber. Because of differences in methods of fabrication and final material property characteristics, it was deemed necessary to conduct this test to determine if the different property characteristics would affect the amount or extent of the corrosion being experienced. The results of the test showed that the corrosion occurred in the same portions of the chamber but was not quite as severe. Although not as severe, the amount of corrosion precluded having a chamber operating life equal to the required minimum of 4000 s.

Rhenium-Lined Carbon/Carbon Composite Chamber Tests

Because some portion of the carbon/carbon composite chamber must reach high temperatures to deliver the required minimum vacuum performance, it became obvious that the corrosion previously experienced could not be completely eliminated. It was postulated that a thin inner liner fabricated from a material which could survive the anticipated high-temperature environment and be inert in contact with ammonia and hydrogen fluoride would be a solution for the elimination of the corrosion. Rhenium was chosen as the liner material because of its ductility and high melting point (3182°C, 5760°F). Chemical compatibility with fluorine was also required and confirmed. Two carbon/carbon composite thrust chambers were lined with rhenium utilizing a vapor deposition process. Two tests were conducted with the first chamber, one for a duration of 200 s and the other for a duration of 500 s. The chamber was relined with rhenium between tests. A small portion of the rhenium liner failed in the chamber divergent section during both tests. No corrosion in the unfailed liner sections was experienced. The second chamber, which incorporated improvements in the rhenium vapor deposition process, was operated for a total duration of 1008 s with no relining between tests. Three starts were accomplished with durations of 200, 177, and 631 s. An average extrapolated performance value of 3500 N-s/kg (357 lbf-s/lbm) was achieved at an overall mixture ratio of 1.5. Performance was extrapolated for an expansion ratio of 60:1 to conform to the chamber configuration to be tested in an altitude facility. Visual observation and pyrometer temperature measurements indicated that lower temperatures were being reached during tests with lined chambers than were being reached with the unlined chambers. During the unlined chamber tests, a steady-state throat temperature of 1982°C (3600°F) was reached in 60 s. After approximately 10 s, the temperature started to rise again and had reached 2121°C (3850°F) at cutoff (200 s) with no indication of leveling off. During the lined chamber 631-s test, the throat reached a steady-state temperature of 1566°C (2850°F) in approximately 400 s. Post-test inspection of the chamber showed that no corrosion or erosion had occurred. Some crazing of the liner probably caused by differential thermal expansion was experienced in the convergent section. No other anomalies could be detected. The overall result of rhenium lining the chamber, in addition to eliminating corrosion, has been to render the fuel cooling film more effective. Additional studies as described in the next section are being accomplished to provide data for the final chamber/liner design.

Tasks Presently in Process

Two altitude versions of the carbon/carbon composite thrust chamber are being fabricated for testing in an altitude facility located at the JPL-Edwards Test Station. Figure 1 is a cross section of the chamber. The chambers will be lined with rhenium prior to test. Propellant injector tests are being

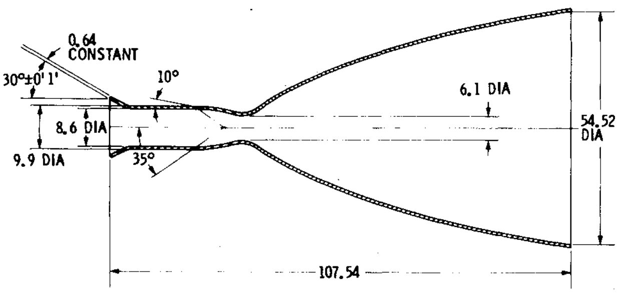

Fig. 1 Preliminary cross section of full length chamber (dimensions in chm).

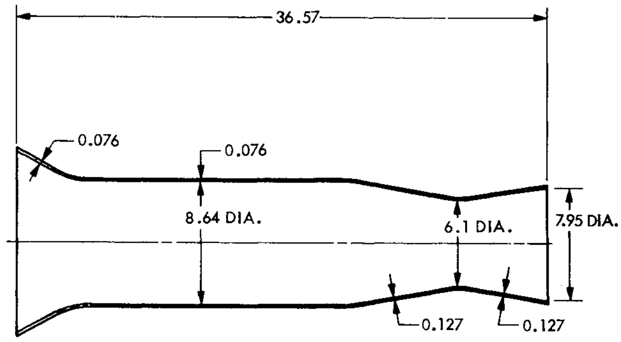

Fig. 2 Free-standing rhenium chamber. Area ratio 1.7:1 (dimensions in cm).

conducted to optimize TCA specific impulse performance and cooling. Selected film cooling orifices will be temporarily plugged and the effect on performance and cooling will be determined. Perfection of the rhenium lining process is continuing. The effect of vapor deposition thickness will be determined. Other methods for applying the lining, such as plasma spraying and sputtering, will be evaluated. Also, the effectiveness of underlayers will be investigated. A freestanding rhenium thrust chamber is being fabricated, using the vapor deposition technique, for sea-level operation as an alternate for the rhenium-lined carbon/carbon composite thrust chamber. The rhenium is deposited on a carbon mandrel which is removed during the finishing process. The rhenium chamber for sea-level operation is estimated to weigh approximately 1.94 kg (4.3 lb). This compares favorably to the present rhenium-lined carbon/carbon composite chamber which weighs 1.86 kg (4.1 lb). Figure 2 is a cross section of the rhenium chamber. An expansion nozzle will be added at a later date for altitude operation if it is decided to continue evaluation of this configuration. The final version of the thrust chamber should have a life well beyond the 4000-s requirement of the Space Storable Propulsion Systems Technology Program.

Concluding Remarks

Progress to date indicates that the present fluorine-hydrazine thrust chamber assembly could be utilized for spacecraft propulsion-system operating durations in the range required, for example, by the NASA Galileo Mission.

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