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EXPERIMENTAL INVESTIGATION OF A SOLID ROCKET COMBUSTION SIMULATOR

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INTRODUCTION:

The response of solid rocket motor materials to high-temperature corrosive gases is usually accomplished by testing the materials in a subscale solid rocket motor. While this imposes the proper thermal and chemical environment, a solid rocket motor does not provide practical features that would enhance systematic evaluations such as: the ability to throttle for margin testing, on/off capability, low test cost, and a low-hazards test article. Solid Rocket Combustion Simulators (SRCS) are being evaluated by NASA to test solid rocket nozzle materials and incorporate these essential practical features into the testing of rocket materials.

The SRCS, sketched in Figure 1, is designed to generate the thermochemical environment of a solid rocket. It uses hybrid rocket motor technology in which gaseous oxygen (Gox) is injected into a chamber containing a solid fuel grain. Specific chemicals are injected in the aft mixing chamber so that the gases entering the test section match the temperature and a non-dimensional erosion factor B′ to insure similarity with a solid motor. Because the oxygen flow can be controlled, this approach allows margin testing, the ability to throttle, and an on/off capability. The fuel grains are inert which makes the test article very safe to handle.

The objective of this work was to establish the baseline operating characteristics of a Labscale Solid Rocket Combustion Simulator (LSRCS). This included establishing the baseline burning rates of plexiglass fuels and the evaluation of a combustion instability for hydroxy-terminated polybutadyene (HTPB) propellants. The scope of the project included: 1) activation of MSFC Labscale Hybrid Combustion Simulator, 2) testing of plexiglass fuel at Gox ranges from 0.025 to 0.200 lb/s, 3) burning HTPB fuels at a Gox rate of 0.200 lb/s using four different mixing chamber configurations, and 4) evaluating the fuel regression and chamber pressure responses of each firing.

APPROACH:

A complete facility for testing the LSRCS was established at Marshall Space Flight Center during this project. The basic motor hardware was acquired from Thiokol Corporation, Utah. The system was installed in Building 4583, Cell 103. Specific work accomplished included adaptation of an existing Gox feed system, modification of the motor hardware to accept four additional pressure measurements, and installation of a dedicated instrumentation and control system.

Motor controls allowed the starting and stopping of the motor. The Gox flowrate was metered by controlling the pressure upstream of a venturi. Ten seconds prior to ignition, Gox flow was initiated. A current applied to an NSI squib ignited the motor which was allowed to burn for two seconds. Termination of the Gox flow and the immediate introduction of nitrogen gas stopped the combustion.

Instrumentation supplied basic data on the motor pressure, temperature, and fuel burning rate. A forward, an aft, and a differential (forward minus aft) pressure gage measured the low-frequency (0-50 hz, digital; 0-6,500 hz analogue) chamber pressures. High-frequency (10 to 20,000 hz analogue) pressure transducers monitored the pressure fluctuations forward and aft. Eight thermocouples measured the forward and aft external temperature of the motor. A precision balance was used to weigh the grains before and after each test to determine the mass consumed during the test. Video cameras monitored the motor hardware and plume emissions.

The first series of firings determined the effect of Gox flow rate on the burning rate of plexiglass fuel. Flow rates of 0.025, 0.050, 0.100, and 0.200 lb/sec covered the desired operating range. The fuel segments were machined from cast material and pressed into phenolic sleeves. Four 2.5-in. long segments with a 0.82-in. port were stacked inside the motor. The motor was run with a long aft mixing section and a 0.309-in. diameter stainless steel nozzle.

The second series of firings investigated the effect of mixing chamber length on combustion chamber pressure oscillations. A Gox flow rate of 0.200 lb/sec was specified for each of the tests. The HTPB fuel was vacuum cast and contained 85% R45 and 15% N-100 curative. The grains were cast into 2.5-in. long phenolic sleeves. Four grains were used for each motor firing. The motor was tested in four configurations: A) short mixing section, no baffle; B) long mixing section, no baffle; C) short mixing section, stainless steel baffle; and D) long mixing section, wood baffle.

RESULTS/DISCUSSION:

Table 1 summarizes the test data and results for the LSRCS firings. The test number references the test requests for test series P252A. The table lists the average chamber pressure during firing, CP; the maximum skin temperature of the motor; the mass flow rate of the fuel; the actual oxidizer-to-fuel ratio; the motor characteristic velocity, C^*; and the burning rates of each segment and their test average.

Figure 2 shows the average burning rate as a function Gox flow for all the tests. A least-squares curve fit for the plexiglass results yields:

$$r = 0.032\ Gox^{0.029}$$

The excessive scatter in the plexiglass burning rates was unexpected . Examination of the burning rates of individual segments within each firing showed no extreme deviation from the mean rate for the test. Examination of the data yields no immediate explanation for the scatter. The HTPB average burning rates were more consistent.

The results of two HTPB mixing chamber tests are shown in Figure 3. The plots show the head-end chamber pressure

measurements for the short and long aft mixing section tests that were performed without a baffle. The pressure showed 100 psi peak-to-peak oscillations for the short mixing configuration. The amplitude of the oscillation decreased slightly during the burn. The oscillations were greatly attenuated when the HTPB propellant was burned with a long aft mixing section. The peak-to-peak amplitude of the fluctuations was about 50 psi. The attenuation of the pressure oscillations suggest a combustion source rather than an issue related to the Gox feed system.

CONCLUSIONS:

This project established a 6-test-per day testing capability for the LSRCS at the MSFC. Initial studies with plexiglass fuel showed unexpected variability in average burning rates. The HTPB study showed a combustion chamber pressure oscillation that is influenced by the length of the aft mixing chamber. The Labscale Solid Rocket Combustion Simulator will be an effective instrument to investigate the physical mechanisms that control this pressure instability. Validating these combustion mechanisms on a small test provide information for the design of larger scale (more expensive) systems.

Table 1. Test Results for LSRCS Firings

TEST	GOX(DES) LBS/S	GOX(ACT) LBS/S	M/C	FUEL	THROAT DIA. (IN)	PRE TEST WT FWD-AFT (g)	POST TEST WT FWD-AFT (g)	ΔP PSI	TMAX FWD (F)	TMIN AFT (F)	ṁ (Fuel) LBS/S	O/F	C* (FT/S)	r (Whole) IN/S	r (Sect.) IN/S
001	0.025	.020	LONG MIXING SECTION NO BAFFLE	PLEX	0.300	60.722 60.366 60.487 60.553	56.9033 57.7227 58.170 58.3143	50	80	85	0.01383	2.1	2950	0.01183	0.010 0.011 0.009 0.009
002	0.065	.061	LONG MIXING SECTION NO BAFFLE	PLEX	0.300	60.961 60.737 60.341 60.515	53.882 56.4300 58.7040 58.0361	100	125	87	0.0100	2.5	3307	0.01782	0.024 0.016 0.014 0.010
003	0.06	.054	LONG MIXING SECTION NO BAFFLE	PLEX	0.300	60.1643 60.5460 58.5353 58.5825	54.0323 58.7078 56.0065 58.88	100	170	90	0.01833	2.8	3208	0.01733	0.024 0.015 0.014 0.018
005	0.1	.077	LONG MIXING SECTION NO BAFFLE	PLEX	0.300	60.7070 60.3645 60.1267 60.1374	56.4656 57.8173 57.7178 57.1503	140	110	85	0.01345	5.7	3722	0.0122	0.017 0.018 0.010 0.012
006	0.2	.150	LONG MIXING SECTION NO BAFFLE	PLEX	0.300	60.4828 60.1730 60.7271 60.2624	55.7804 57.2818 57.5365 58.0045	270	110	85	0.01655	9.0	3682	0.01402	0.010 0.012 0.013 0.017
007	0.2	.190	LONG MIXING SECTION NO BAFFLE	HTPB	0.300	50.0217 48.7474 50.2002 50.1840	42.340 40.0085 42.2100 42.0357	358	100	80	0.03461	5.5	3564	0.03845	0.030 0.041 0.030 0.038
008	0.2	.201	LONG MIXING SECTION NO BAFFLE	HTPB	.300	50.3085 48.2487 50.104 49.4888	41.8378 40.7473 38.8488 40.8705	460	165	80	0.03000	5.1	4543	0.04203	0.040 0.038 0.052 0.048
009	0.2	.202	LONG MIXING SECTION WOOD BAFFLE	HTPB	.300	50.5304 50.0078 50.214 50.0521	42.011 43.000 41.0455 40.497	470	191	91	0.03500	5.6	4487	0.03843	0.036 0.035 0.040 0.044
010	0.2	.210	SHORT MIXING SECTION NO BAFFLE	HTPB	.300	48.565 50.1400 48.586 50.471	37.9125 38.9633 38.9385 40.1484	400	NA	NA	0.045	4.7	4573	0.04714	0.053 0.047 0.041 0.048
011	0.2	.214	SHORT MIXING SECTION STEEL BAFFLE	HTPB	.300	50.5073 52.2864 50.6536 50.0036	42.0056 43.331 42.4073 40.0015	500	>210	90	0.03704	5.6	4518	0.04026	0.037 0.042 0.038 0.044
012	0.2	.216	LONG MIXING SECTION NO BAFFLE	PLEX	0.300	60.0782 60.388 60.758 60.4460	51.6787 54.7840 54.0034 52.430	340	130	85	0.03109	7.0	3446	0.02721	0.032 0.027 0.034 0.031
013	0.1	0.1*	LONG MIXING SECTION NO BAFFLE	PLEX	0.300	60.7153 60.0064 60.5506 60.7541	56.378 56.2021 56.8700 57.2952	*	*	*	0.01441	5.9	N/A	0.01305	0.017 0.011 0.011 0.013
014	0.06	0.05*	LONG MIXING SECTION NO BAFFLE	PLEX	0.300	60.3736 60.642 60.6225 58.981	56.1872 57.3040 57.5657 56.4047	*	*	*	0.01062	3.8	N/A	0.01490	0.020 0.013 0.012 0.014
015	0.025	0.025*	SECTION NO BAFFLE	PLEX	0.300	60.6471 60.6784 60.4914 60.1480	58.7294 58.7116 58.7384 58.3040	*	*	*	0.00072	7.0	N/A	0.00600	0.013 0.008 0.007 0.007
017	0.2	.205	LONG MIXING SECTION NO BAFFLE	HTPB	0.300	48.7801 48.7187 48.5815 50.5215	40.4700 41.0290 38.2253 38.338	450	165	85	0.0447	4.6	4262	0.04485	0.043 0.041 0.048 0.056
018	0.2	.207	LONG MIXING SECTION NO BAFFLE	HTPB	0.300	48.587 50.2370 50.1555 50.415	40.0048 41.3033 38.5330 37.9290	450	200	85	0.04676	4.5	4220	0.04705	0.044 0.041 0.040 0.037

*DIGITAL AND ANALOG DATA INCOMPLETE

Purpose: Evaluation of SRM Nozzle and Insulator Materials

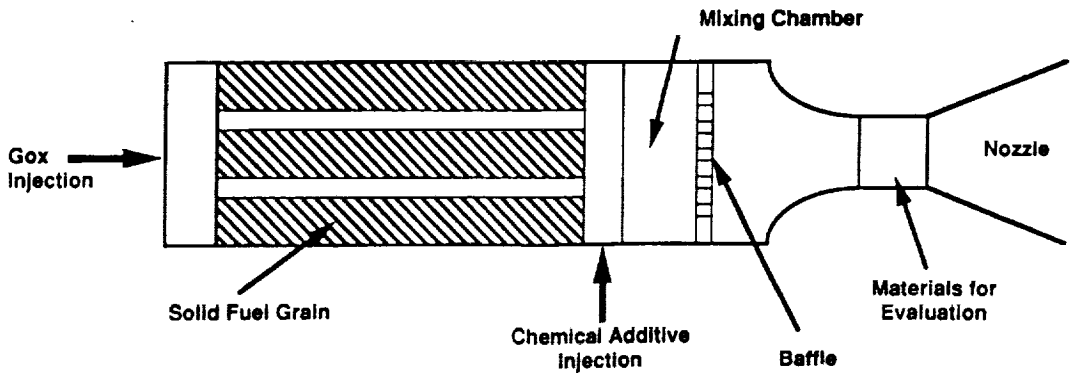

Figure 1. Solid Rocket Combustion Simulator

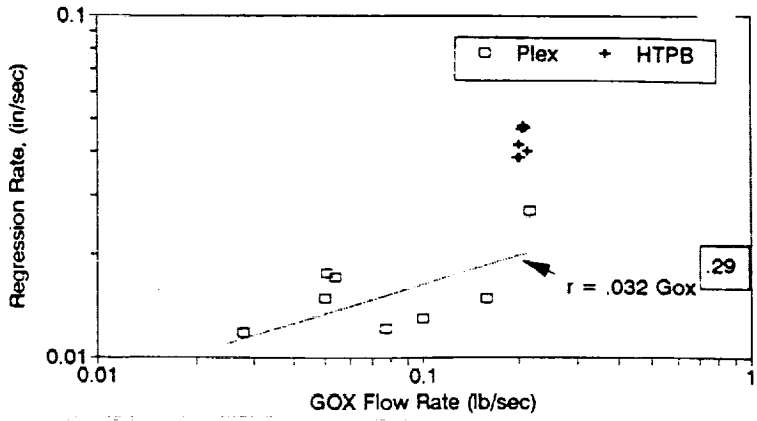

Figure 2. LSRCS Average Burning Rates vs. Gox Flow Rate

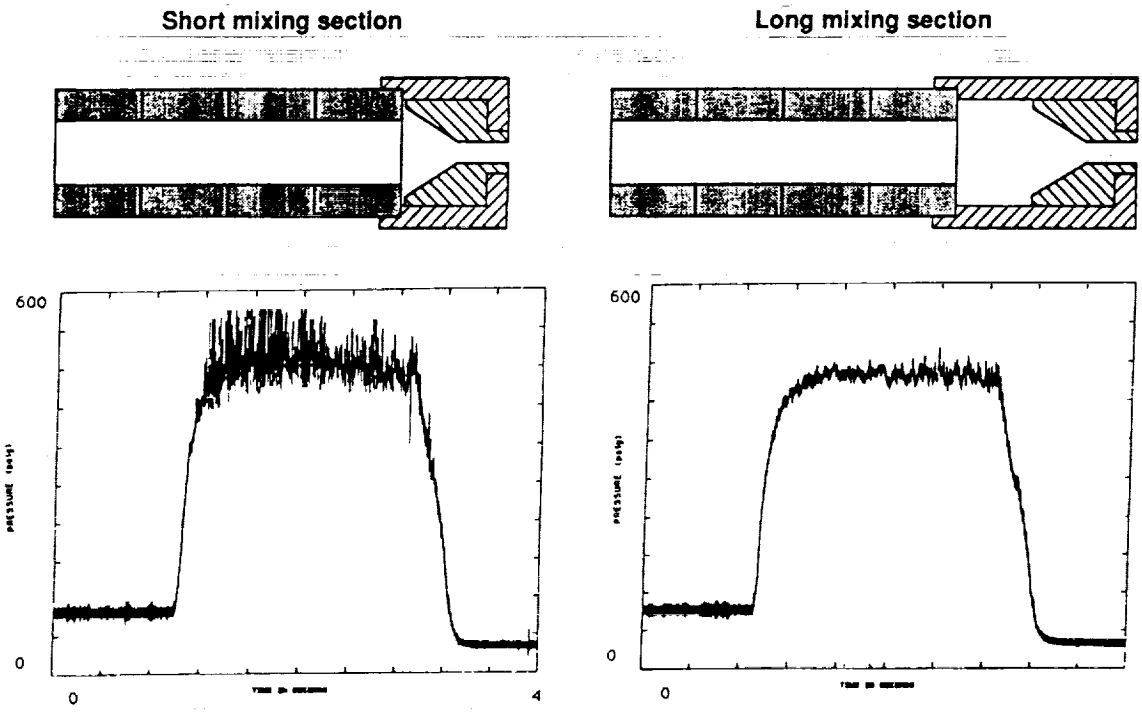

Figure 3. HTPB Mixing Chamber Test Results