MULTI-RUN EFFECTS ON THE SOLID FUEL RAMJET COMBUSTION

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ABSTRACT

An experimental investigation was conducted in order to figure out the multiple fire effects on the combustion efficiency and fuel properties of the solid fuel ramjet. Pure HTPB and metallized B_4C/HTPB fuel were studied. Fuel property effects were analyzed by using differential scanning calorimetry.

The thermal or mechanical properties of the fuel grain were not affected and the combustion efficiency was a little increased.

NOMENCLATURE

E_{ha} : temperature-rise combustion efficiency
G : air mass flux, $g/cm^2.s$
H_{exo} : exothermic heat, J/g
L : grain length, inch
P : chamber pressure (in Table)
P : chamber pressure (in Graph)
P_H : head pressure
PHI : equivalence ratio
T_{burn} : grain burn time, s
T_i : inlet air temperature, K
T_{res} : residence time, s
T_{Tr} : differential scanning calorimetry transition temperature, K
T_{PK} : peak temperature of differential scanning calorimetry exotherm, K

INTRODUCTION

Combustion studies on the solid-fuel ramjet have been investigated for the nonmetallized fuel[1,2,3] and for the high energy metallized fuel.[4,5] Recently a B_4C/HTPB fuel has been studied through static motor tests using a Malvern Particle Sizer[6,7]. In that study the effects of motor operating conditions on the motor performance and on the metallic particle behavior within the combustor were investigated.

For the experimental purpose, sometimes we do not need to fire the SFRJ motor for a long time. And for the real application, we may need to extinguish the motor and then reignite and burn again. So it is necessary to understand the mulitiple fire effects: twice or triple firing effects on the fuel properties and the combustion efficiency. In order to investigate this effect, sample specimens taken from the unburned and 1st run fuels were analyzed by using differential scanning calorimetry. And these fuels were fired in a SFRJ motor on a thrust stand again.

The test series were conducted at a constant air mass flux with a constant equivalence ratio. for the same kind of grain. Chamber pressure was maintained between 80 and 110 psia. Instrumentation for determining combustion performance consisted of combustor pressures, inlet air temperature and flow rates. Inlet air temperature, combustor residence time and combustion pressure were held approximately constant for the 1st and the 2nd run of the same grain.

EXPERIMENTAL PROCEDURES

A subscale 63.5mm O.D. axisymmetric combustor configuration was used in the direct connect mode (Fig. 1).

The fuel grain was bolted between the inlet and the mixing chamber. The mixing chamber was insulated with DC93-104 to reduce heat loss through the combustor wall. A sonic nozzle(with graphite insert) was bolted onto the aft mixing chamber.

Air was initially bypassed to the atmosphere until the heater temperature had stabilized. At this time the air was switched to the combustor, initiating a computer controlled sequence of events in which the fuel grain was preheated about 4 seconds, the ramjet combustor was ignited and sustained for approximately 4.5 seconds, and finally quenched at the end of the test. Approximately a one second ignition time was required.

After the 1st run, the fuel grain was measured the weight in order to calculate the regression amount, and sample specimens were taken out. Then this fuel grain was stored in the test cell at a room temperature 1-3 days or half day, depending on the next test schedule. The 2nd test run was followed exactly same procedure as the 1st run. At the 2nd test, the fuel grain was installed at the same direction as the 1st run(head side of the grain goes always head side).

The nozzle throat diameter was sized to maintain a constant combustion pressure for the same kind fuel and the mixing chamber length was also fixed for the same kind fuel. The fuel grain had a nominal initial port diameter of 43mm.

Instrumentation for determining combustion performance consisted of combustor static pressure, inlet air temperature and flow rates.

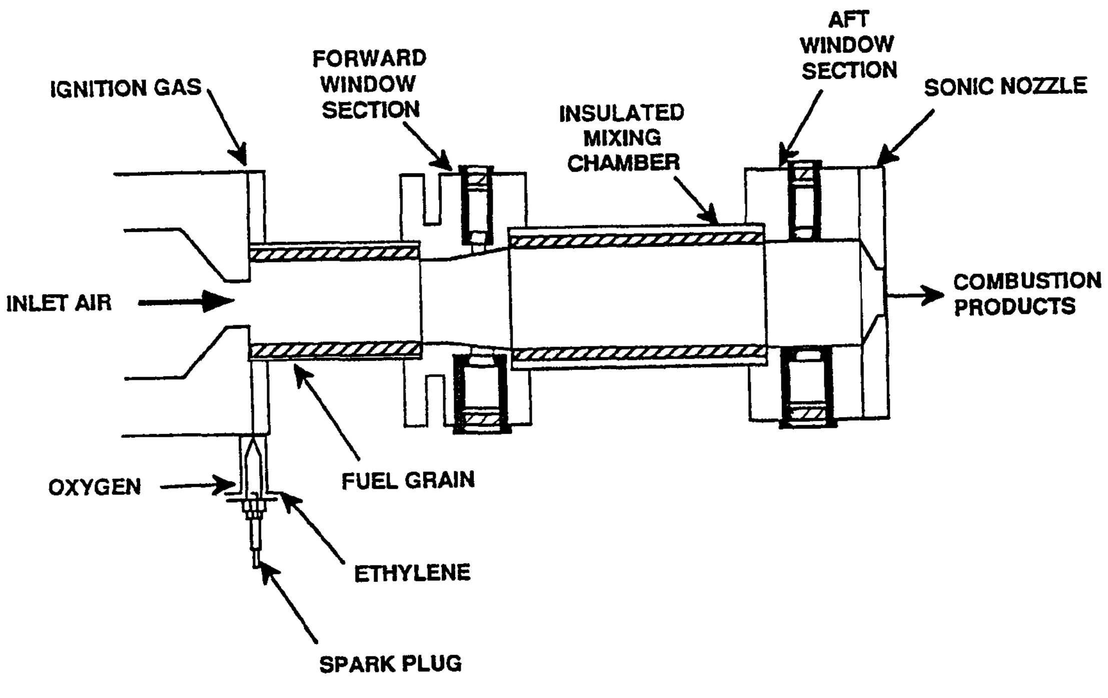

Figure 1. Schematic of SFRJ Combustor.

Table 1. SFRJ Motor Test Results

TEST	G ($g/cm^2.s$)	PHI	L (inch)	T_i (K)	T_{res} (s)	P_4 (psi)	E_{tha}	T_{burn} (s)	Remark (Test date)
1	.302	.435	5.75	1103	3.1	81	.50	4.7	5/10
2	.250	.554	5.75	1070	3.0	82	.56	4.8	5/11
3	.596	.405	6.50	1102	3.5	83	.40	4.3	5/1
4	.455 .50	.423	6.50	1184	3.4	85	.43	4.3	5/4
5	6	.945	13.0	1182	2.9	105	.72	4.4	1/24
6	.373 .50	1.15	13.0	1229	2.9	107	.83	4.4	1/25
7	2	.907	13.0	1250	2.9	105	.79	4.7	3/2
8	.377 .45	1.03	13.0	1226	2.9	110	.85	4.8	3/2
9	4	.800	9.50	1301	2.5	101	.762	4.3	10/20
10	.339	.851	9.50	1182	2.6	104	.868	4.3	10/24
11	.363	.483	6.90	1204	3.11	64	.888	5.05	7/21
12	.370	.502	6.90	1170	3.08	65	.895	5.05	7/21
13	.480	.701	9.50	1242	3.05	104	.849	4.4	10/12
14	.403	.871	9.50	1318	3.02	98	.911	4.4	10/13

Odd number Test : Original Fuel
Even number Test : 2nd run fuel of the previous No.
PHI : Equivalence Ratio
E_{tha} : Temperature Rising combustion efficiency

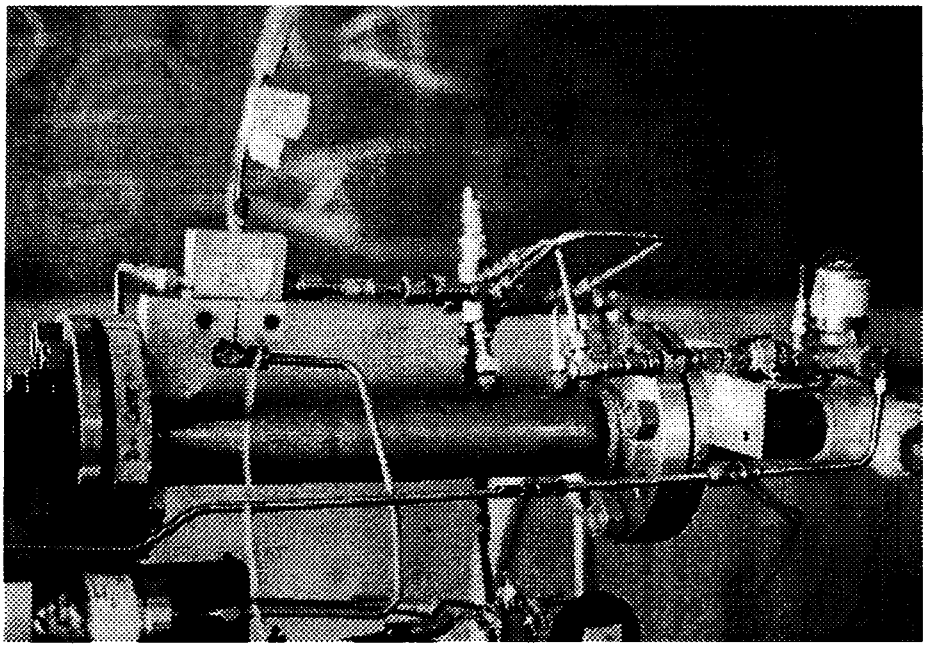

Figure 2. Air Heater

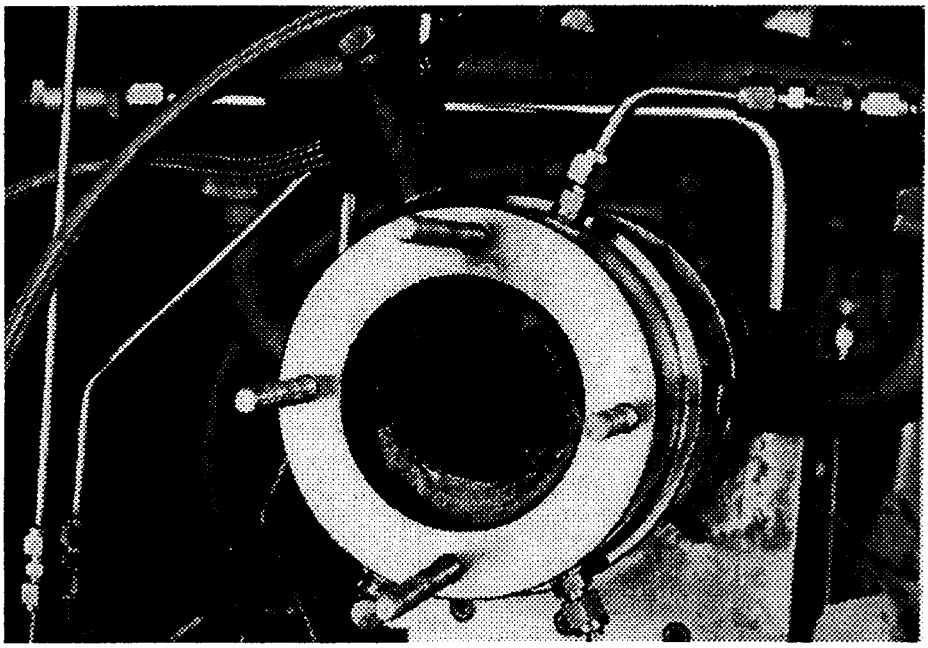

Figure 3. Air Inlet Step & Ignitor

The differential scanning calorimetry tests were made using a Perkins Elmer DSC[8]. During DSC tests the heating rate was fixed at 80 K/min. Nitrogen gas was supplied in order to purge the sample holders for DSC tests.

RESULTS AND DISCUSSION

Fourteen SFRJ motor tests were conducted, and the steady state data are tabulated in Table 1. Air mass flux, inlet air temperature, and combustor residence time were held approximately constant for each fuel. The test results showed that either HTPB or Boron Carbide HTPB always the 2nd run resulted in higher combustion efficiency than the 1st run. Also it is noticed that the equivalence ratio of the 2nd run grain was always larger than that of the 1st one. These phenomena are agreed to the trend of the combustion efficiency verse equivalence ratio[6] : increasing equivalence ratio(increasing grain length) gives increasing combustion efficiency. But in this investigation, the grain length was fixed for the same kind fuel. It means that at the 2nd run, the grain was regressed a little faster than that at the 1st run, probably due to the structural bond was affected.

Mechanical hardness of the specimens and the thermal analysis, DSC data are summarized in Table 2 and Table 3 respectively.

There were not any difference between origin and after run grain of the transition and peak exothermic temperature for the same kind fuel. The exothermic heat amount also seemed close each other. Therefore it seems that this grain might be little affected to heat properties, but a little affected to the structural properties by the 1st run. Then resulted in a slightly higher regression rate, and gave a higher equivalence ratio. So these fuels should have good multi-run characteristics without any fuel property degradation.

CONCLUSIONS

Based on this specific investigation, the conclusions might be as follows :

1. The thermal or mechanical properties of the fuel grain were not affected by the multi-runs.

2. Even if there was little change of the fuel properties, the regression rate of the 2nd run was increased, then resulted in high equivalence ratio.

3. The combustion efficiency of the 2nd run was a little increased, but in this case the equivalence ratio also was increased. Therefore combustion efficiency is strongly dependent on equivalence ratio rather than multi-run itself.

Table 2. Shore Hardness Results

B_4C/HTPB		HTPB	
BEFORE RUN	69,70,71,68	BEFORE RUN	35,35,32,32
AFTER 1ST RUN	67,66,67,66	AFTER 1ST RUN	36,38,35,36
AFTER 2ND RUN	69,69,66,67	AFTER 2ND RUN	39,39,45,45

Table 3. DSC Results

	T_{tr} K	T_{PK} K	H_{exo} J/g	Fuel	Remark
Origin After	621	683	62.5	Mo-96	Perkins
1st Run	625	686	60.4	Mo-96	Elmer
Origin After	654	682-720	45.3	R45-HT	Perkins
1st Run	654	683-722	34.2	R45-HT	Elmer
Origin After	569	609	116	Mo-96/Cat	Du Pont
2nd Run	570	609	136	Mo-96/Cat	

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