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A STUDY OF THE RESULTS OF TESTS INVESTIGATING THE EFFECT OF ACCELERATION AND GAS COMPOSITION ON THE BURNING RATE OF SPACECRAFT MATERIALS

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ABSTRACT

Combustion characteristics of thirteen "vertically oriented" nonmetallic spacecraft materials were investigated in a recent test program at the NASA MSC White Sands Test Facility (References 1 through 15). Presented in this report are the results of an analysis of the burning rate data obtained in the above test program.

It was found that the average value of the ratio of the "upward" to "downward" burning rates at 1 "g" was 2.9. Both the "upward" and the "downward" burning rates increased with increasing acceleration, with the "upward" increasing at the greater rate. The "upward" burning rates at 1 "g" were found to depend monotonically on the oxygen partial pressure. The "downward" burning rates appeared to be affected by the presence of the diluent nitrogen.

1.0 INTRODUCTION

A test program to investigate the combustion characteristics of various spacecraft materials is being carried out at the NASA MSC White Sands Test Facility. This program is designed to determine the effect of acceleration and environment on the combustion characteristics of these spacecraft materials. The test procedure (described in References 1 and 2) requires that the test specimen be mounted in a centrifuge in such a way that the resultant g-vector is parallel to the specimen. Combustion is initiated at either the "top" or the "bottom" edge resulting in "downward" or "upward" burning respectively. Resultant acceleration levels of 1, 3, 7, 10 and 15 g's were employed. Three environments were used; 16.5 psia pure oxygen (environment A), 16.5 psia 60% oxygen - 40% nitrogen (environment B), and 6.2 psia pure oxygen (environment C), all at 75° ± 5° F.

Of particular interest in this study is the burning rates which were measured in the above test program. Five measurements of the burning rate were made during each test. Three with thermocouple rakes located 1/16 inch from one side of the specimen, one with a thermocouple rake located 1/16 inch from the opposite side, and one using the motion picture records of the test.

A similar study emphasizing the effect of gravity on the burning rates for seven materials was conducted (Reference 18).

2.0 OBJECTIVE

The objective of this study is to identify general trends regarding burning rate which are characteristic for all of the materials tested. These trends may then be used in developing or testing theoretical models for this phenomena.

3.0 DATA ANALYSIS TECHNIQUE

The results of tests on thirteen materials are available (References 3 through 15). Three specimens of each material were tested at each test condition. For each material there were thirty test conditions corresponding to all combinations of the two directions of burning, the three environments, and the five acceleration levels.

Since the burning rate data as determined from the motion pictures was a) not reported in detail and original form, b) incomplete, and c) frequently not available for the 1 "g" case, it was decided to disregard it and use only the data obtained from thermocouple rakes. Four thermocouple rakes were used and three specimens of each material were tested at each condition resulting in twelve measurements of the burning rate per material at each test condition. From these data the mean and standard deviation were computed. Chauvenet's criterion (Reference 16) was used to reject outliers and the mean and standard deviation were re-computed. All computational results for a particular burning direction and environmental condition were then normalized to the 1 "g" burning rate at those same conditions. This procedure was carried out at each test condition for each material tested. The mean value (for all materials) of the burning rate was then computed at each of the thirty test conditions (this final result is termed the "normalized mean burning rate" in this report). From these results the various conclusions reported in the following sections were drawn.

4.0 DISCUSSION OF RESULTS

The results of this analytical study are shown in Tables 1 through 4 and in Figures 1, 2, and 3. The mean burning rates at 1 "g" for the thirteen materials tested are given in Table 1 ("upward" burning) and Table 2 ("downward" burning). The average value of the ratio "upward" to "downward" burning rate was found to be 2.9 and the average value of the ratio "downward" to "upward" burning rate was found to be 0.54 (Table 3). These results agree with the findings of others (e.g., Reference 17).

The effect of environment on the 1 "g" burning rate is shown in Table 4. For "upward" burning at 1 "g" the mean value of the ratio of the burning rate in environment B (16.5 psia 60% O_2 - 40% N_2) to the rate in environment A (16.5 psia 100% O_2) was 0.8. The mean value of the ratio of the burning rate in environment C (6.2 psia 100% O_2) to the rate in environment A was 0.42. This result indicates that for "upward" burning at 1 "g" the burning rate increases monotonically with oxygen partial pressure over the range explored. This was not found to be the case for "downward" burning (Table 4). It should be noted that the uncertainty in this ratio (as indicated by the standard deviation) was much greater for "downward" burning.

The normalized burning rate for nearly every material tested, for both "upward" and "downward" propogation, exhibited a general increasing trend with increasing acceleration level.[1]

[1] For the study discussed in this report, no data was taken in the following ranges of acceleration level, a; $0 \leq a < 1$ "g" and $1 < a < 3$ "g". Thus, this conclusion is dependent upon the resolution of the data available, particularly in the range of $0 \leq a < 3$ "g". A similar (but not comparable) study, Reference 18, indicated a downward trend in this range of a followed by an upward trend for $a > 3$ "g".

This result is summarized in Figure 1 where the average of all normalized mean rates for "upward" propogation and the average of all normalized mean rates for "downward" propogation are plotted as a function of acceleration level. It is seen that the "downward" burning rate increases with acceleration at a lesser rate than does the "upward" rate. The differences could be attributed to the opposite effects of convective heat transfer for the two cases. It is interesting to note that there appears to be dominant mechanisms which cause the burning rate to increase with increasing acceleration level for propogation in either direction. For the "upward" direction this could be convective heat transfer and for the "downward" direction it could be the migration of hot particles and/or melt.

The effect of the environment on the rate of increase of normalized mean burning rate with increasing acceleration level is shown in Figures 2 and 3. For "upward" propogation (Figure 2) the burning rate in environment B (containing nitrogen) increases more slowly with acceleration level than does the rates in the pure oxygen environment. For "downward" burning (Figure 3) no such trend is detected.

The general trends described above are based upon a statistical analysis of a large quantity of original data presented in References 3 through 15. Significant scatter was usually present in the data taken at each of the thirty test conditions for each material. Typically the standard deviation in the burning rate at a particular test condition would be from 10% to 50% of the mean value.

As was stated in Section 3.0 the values of the burning rate taken from the motion picture records were not used in this study. In general, these values were in approximate agreement with the burning rates taken from the thermocouple rakes for "downward" burning but were less than the thermocouple rates for "upward" burning.

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TABLE 1

Mean Values of the Upward Burning Rate at 1 'g' for Materials Tested

Material	Burning Rate (in/sec)		
	Environment A	Environment B	Environment C
Neoprene Elastomer	0.71	0.46	0.22
Fiberglass	1.27	1.22	0.63
Urethane Foam	3.59	2.79	1.57
Adhesive Foil	1.70	1.17	0.87
Teflon Tubing	0.22	0.154	0.063
Polyurethane Foam	6.25	3.00	2.03
Polyurethane Coating	0.65	0.83	0.34
RTV-577 Silicone	0.24	0.14	0.07
RTV-30 Silicone	0.344	0.23	0.13
Lexane Polycarbonate	0.19	0.16	0.08
Plexiglas	0.49	0.35	0.21
Urethane Potting Compound	0.87	1.02	0.31
Polyester Adhesive Tape	2.98	2.30	2.02

Environment A is 16.5 psia 100% O_2 at 75° ± 5° F

Environment B is 16.5 psia 60% O_2 - 40% N_2 at 75° ± 5° F

Environment C is 6.2 psia 100% O_2 at 75° ± 5° F

TABLE 2

Mean Values of the Downward Burning Rate at 1 'g' for Materials Tested

Material	Burning Rate (in/sec)		
	Environment A	Environment B	Environment C
Neoprene Elastomer	0.23	0.08	0.06
Fiberglass	0.17	0.086	0.12
Urethane Foam	2.33	0	1.34
Adhesive Foil	0.5	0	0.2
Teflon Tubing	0.17	0	0
Polyurethane Foam	3.71	1.24	1.73
Polyurethane Coating	0.56	0.75	0.62
RTV-577 Silicone	0.12	0.05	0.05
RTV-30 Silicone	0.15	0.07	0.08
Lexane Polycarbonate	0.10	0.05	0.07
Plexiglas	0.21	0.09	0.11
Urethane Potting Compound	0.35	0.35	0.55
Polyester Adhesive Tape	1.06	0.76	0.91

Environment A is 16.5 psia 100% O_2 at 75° ± 5° F

Environment B is 16.5 psia 60% O_2 - 40% N_2 at 75° ± 5° F

Environment C is 6.2 psia 100% O_2 at 75° ± 5° F

TABLE 3

Comparison of Mean Upward and Downward Burning Rates at 1 'g'

Ratio of Burn Rates	Mean Value	Standard Deviation
Upward/Downward	2.9	2.47
Downward/Upward	0.54	0.39

TABLE 4

Effect of Environment on Burning Rates at 1 'g'

Direction	Ratio of Burn Rates	Mean Value	Standard Deviation
Downward	Environment B/Environment A	.60	.33
Downward	Environment C/Environment A	.68	.36
Upward	Environment B/Environment A	.80	.22
Upward	Environment C/Environment A	.42	.11

Environment A is 16.5 psia 100% O_2 at 75° $\pm$ 5° F

Environment B is 16.5 psia 60% O_2 - 40% N_2 at 75° $\pm$ 5°F

Environment C is 6.2 psia 100% O_2 at 75° $\pm$ 5° F

FIGURE 1

EFFECT OF DIRECTION OF BURN ON THE VARIATION OF THE NORMALIZED MEAN BURNING RATE WITH THE ACCELERATION LEVEL

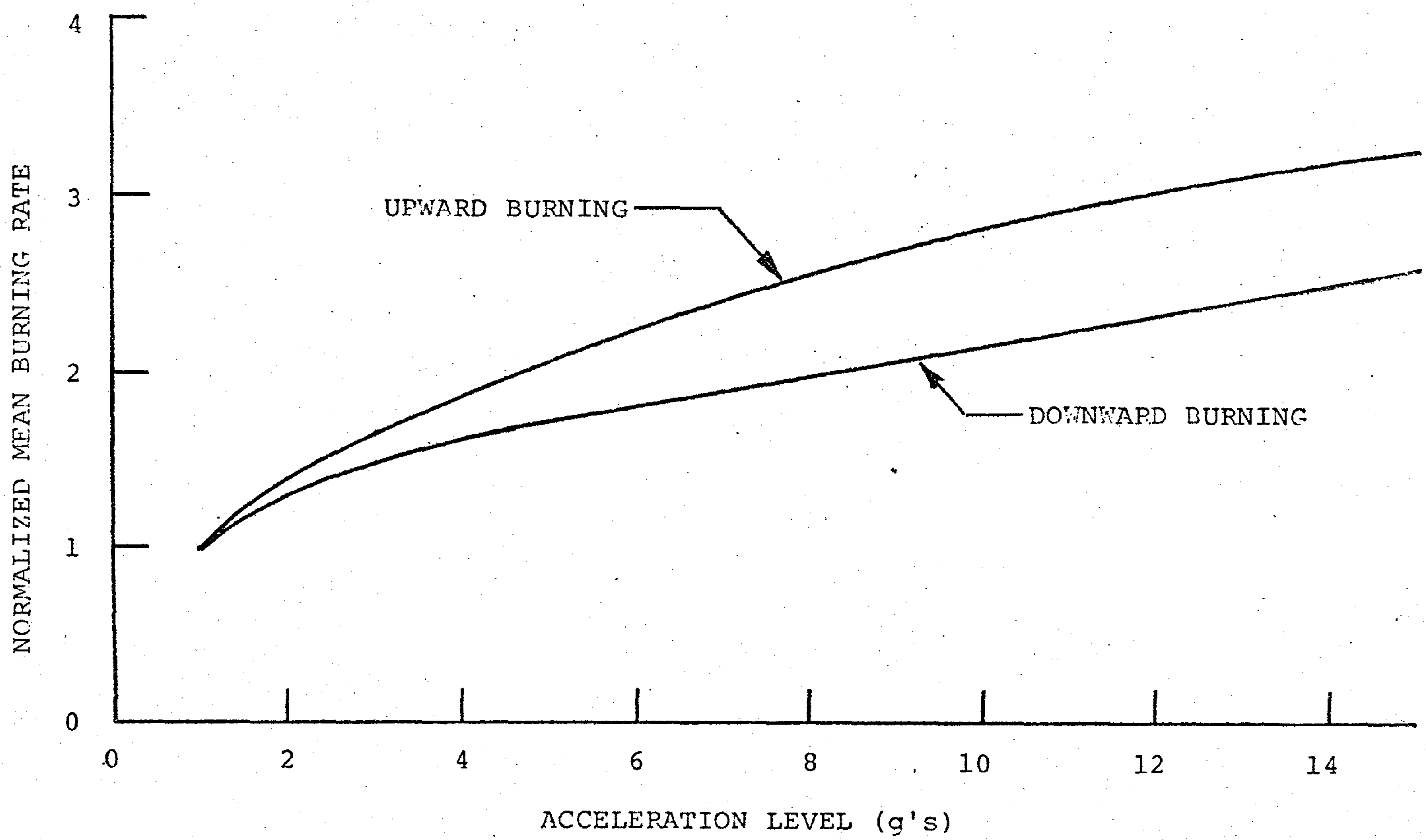

FIGURE 2

EFFECT OF ENVIRONMENT ON THE VARIATION
OF THE NORMALIZED MEAN BURNING RATE WITH
THE ACCELERATION LEVEL
FOR UPWARD BURNING

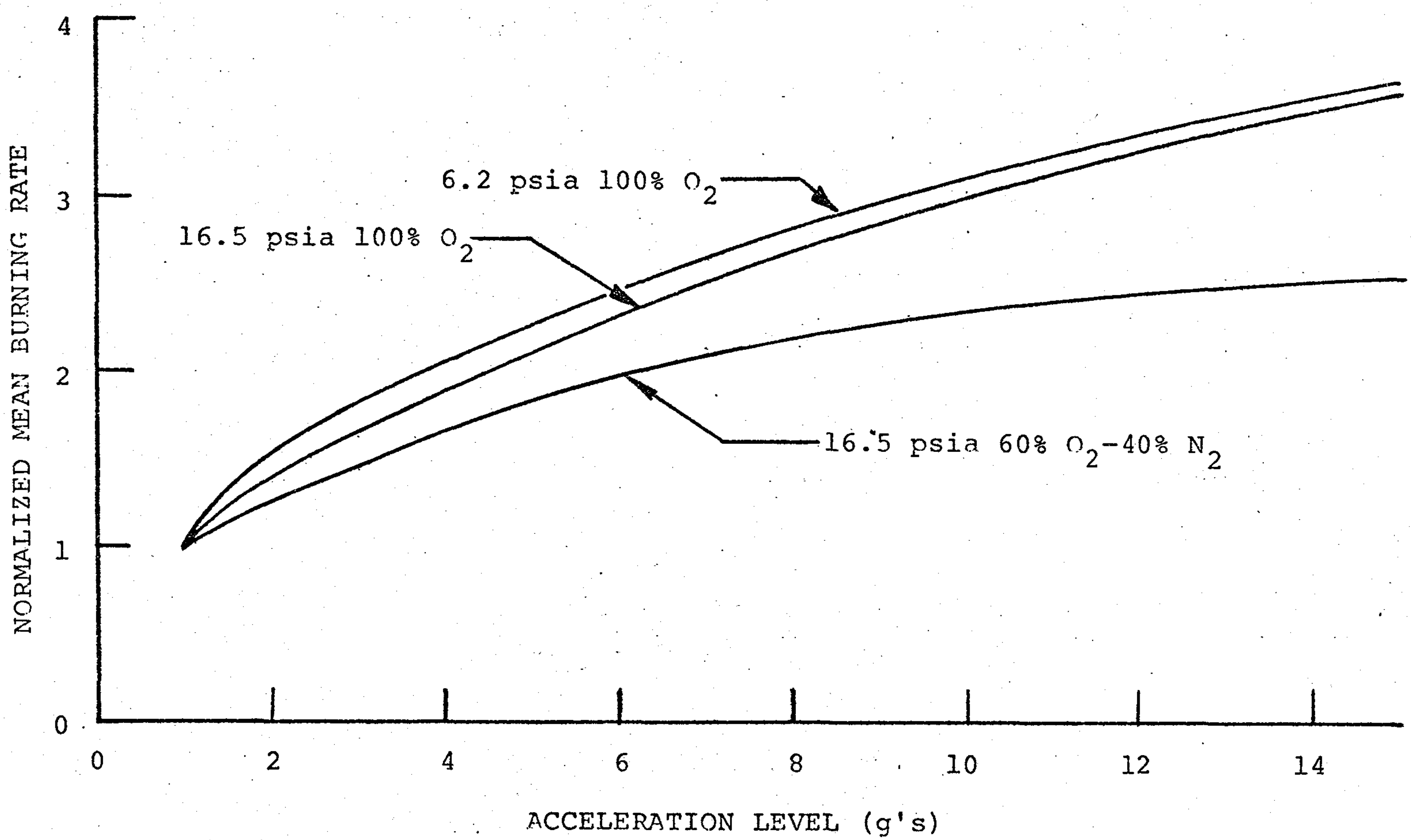

FIGURE 3

EFFECT OF THE ENVIRONMENT ON VARIATION
OF THE NORMALIZED MEAN BURNING RATE WITH
THE ACCELERATION LEVEL
FOR DOWNWARD BURNING