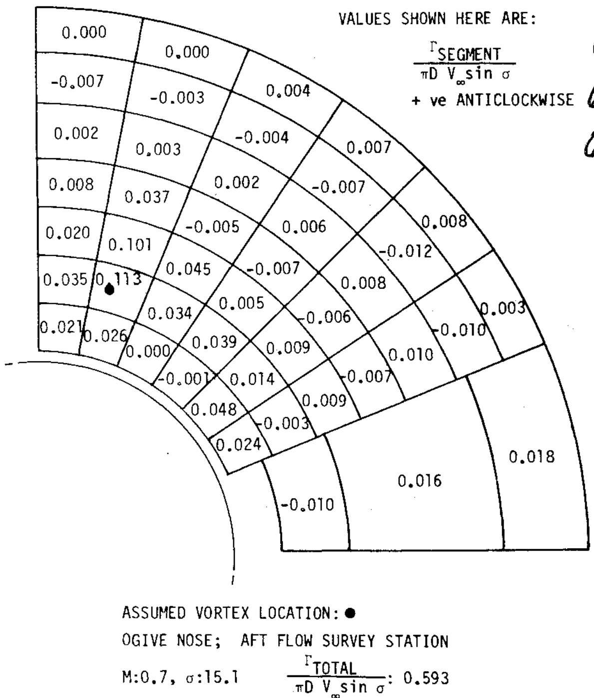

Fig. 3 Distribution of circulation within leeside wake.

information, the relative importance of core and feeding sheet in the leeside quadrant.

Circuit integrations for the ogive nose at $M = 1.15$ and $\sigma = 15.1$ and 20.7 deg have shown that the vortex feeding sheet can contain 21-35% of the circulation in the leeside area under these conditions for the aft flow survey location. This percentage may be compared with values of 40-60% from tests[1] at higher supersonic Mach numbers. Other results are given in Table 2. Most of the data for Γ_s/Γ_t lie in the range 0.21-0.35. (Subscripts s and t refer to sheet and total values.) The values are more reliable for the aft flow survey location since at that point the development of the flow pattern into a core and feeding sheet was more easily observed. Changes in flow condition are seen to have little systematic effect on the ratio Γ_s/Γ_t.

Concluding Remarks

As part of an effort to improve prediction methods for the aerodynamic characteristics of missiles, flow survey tests have been performed which contribute some new information on the characteristics of symmetric body vortex systems at transonic speeds. The test program has included experiments on a tangent ogive forebody with a high nose semiapex angle and also a body with an ellipsoidal nose.

Values of vortex strength, and vertical and lateral location have been deduced from the velocity vector information obtained in the leeside wake of the body. The relative importance of the feeding sheet and vortex core has been assessed. It was found that the former can contain 21-35% of the circulation in the leeside quadrant.

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Ignition Delay Studies on Hybrid Propellant Grains

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Introduction

IN hybrid rockets, the propellant grain consists of a mixture of ground solid fuel, finely divided metal powder, fractional percents of additives used for increasing the burn rate, and a polymer as binder. In the past, several hypergolic hybrid fuels associated with nitric acid have been developed and their ignition delays measured as a function of physical and chemical factors.[1-4] However, not much effort was given to the simulation of actual rocket conditions by embedding the hypergolic solid fuels in a binder and measuring the ignition delays. Recently, solid amines[5] have been used with various binders in hypergolic hybrid propellant grains. The hypergolic combustion of propellant grain containing a mixture of tetraformal trisazine and OH-terminated polybutadiene with HNO_3 has recently been reported.[6] The use of several other fuels and binders has been reported in the literature.[7-9]

In the present investigation, the ignition delays of some of the hydrazones embedded in a polymer matrix have been measured as a function of: 1) weight of the propellant grain, 2) polymer binder type, 3) polymer binder loading, and 4) metal loading.

Experimental

Materials

Furfuraldehyde pehnylhydrazone (FPH) was prepared following the procedure described earlier.[2] Formaldehyde phenylhydrazine polymer (FORPH) was prepared by reacting phenylhydrazine with a little excess of formaldehyde solution. The yellow solid mass (polymer type) was separated from the beaker, washed with an alcohol-water mixture and dried in vacuum. Commercially available phenolformaldehyde (PF) was used in the present study. The nitric acid having 91% HNO_3, 7% NO_2, and 2% H_2O by weight was used in all experiments.

Propellant Grains

The polymeric binder, formaldehyde phenylhydrazine or phenolformaldehyde, was melted and mixed with fuel powders until a homogeneous mixture resulted. The mixture was then transferred into a test tube and allowed to solidify at 5°C for three days. The cured propellant grains were cut to size and used in the form of a tablet for measuring ignition delays (ID). The grains are easily processed and have good physical properties. All ID's were measured by using the setup described in Ref. 4.

Results and Discussion

The experimental results showing the minimum ignition delays for furfuraldehyde phenylhydrazone and benzaldehyde phenylhydrazone taken in the polymer matrix are given in Table 1. The FPH/FORPH-HNO_3 system gave the least ID at 300 mg weight of the propellent grain using 0.55 ml of nitric acid.

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Index categories: Fuels and Propellants, Properties of; Solid and Hybrid Rocket Engines: Combustion Stability, Ignition, and Detonation.

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Table 1 Effect of binder type on ignition delay

Sample	Average minimum ID, ms
Furfuraldehyde phenylhydrazone (FPH)[a]	40
Benzaldehyde phenylhydrazone (BPH)[a]	102
Formaldehyde phenylhydrazine polymer (FORPH)[a]	167
Phenolformaldehyde (PF)	No flame
FPH (70%) + FORPH (30%)	160
FPH (95%) + PF (5%)	490
BPH (70%) + FORPH (30%)	632

[a]Taken in the form of powder; amount of oxidizer = 0.55 ml.

Table 2 Effect of weight percent of aluminum in propellant grain on ignition delay

	Average ID, ms				
	Percent Al by weight				
Sample	0	5	10	15	20
Furfuraldehyde phenylhydrazone (70-50%) + formaldehyde phenylhydrazine (30%)	160	243	280	316	347
Formaldehyde phenylhydrazine polymer[a]	652	749	768	836	...

[a]Taken in the form of pellet; amount of oxidizer = 0.55 ml.

In order to elucidate the effect of binder type on the extent of hypergolicity of propellant grains, binders that are inert and active toward nitric acid have been used. Several combinations are possible: active fuel-active binder, active fuel-inert binder, inert fuel-active binder, etc. The formaldehyde phenylhydrazine polymer, which was found to be hypergolic with nitric acid, can be considered as an active binder, whereas phenolformaldehyde gave no perceptible reaction with nitric acid. The experimental results are given in Table 1. In the system where fuel and binder are active toward the oxidizer, e.g., FPH/FORPH-HNO_3, small ignition delays were observed (Table 1). In this case, the nature of the flame and reproducibility of the results were excellent. However, if the binder is inert toward nitric acid, for instance, a FPH/PF-HNO_3 system, a large ID was observed and the ignition behavior was not so good. Also, in the third case where the fuel was less reactive (inert) toward nitric acid, a larger ID was obtained, although ignition was consistent. It is interesting to note that the polystyrene and CTPB-based propellant grains underwent decomposition with smoke evolution but not ignition under similar conditions. It is clear from the experimental results (Table 1) that the binder influences the hypergolic nature of a propellant to a greater extent. It can be concluded that the binder should not only provide structural integrity to the grain but also be hypergolic with the oxidizer in order to get full advantage of hypergolic fuels.

The amount of polymer used in the propellant grain depends upon the required energetics, ID, and physical properties. In one of the propellant grains, FPH/PF, the percentage of phenolformaldehyde was varied and the ID was measured as a function of its weight. The results are plotted in Fig. 1. It is seen from Fig. 1 that the ID increases with the weight percent of binder in the grain. At 30% and above by weight of the binder, the grain gave inconsistent ignition. At a lower percentage of the binder, the grain was brittle; whereas at a higher percentage, the physical properties of the grain were good at the expense of the ignition characteristics.

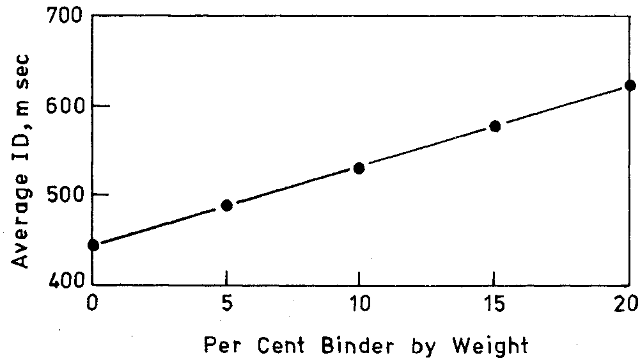

Fig. 1 Plot showing the effect of percent binder in the grain on ignition delay.

It is known that the performance of hybrid propellant rocket motors can be improved by adding metal powders such as aluminum to the propellant grain.[10] It is believed that the ID of a propellant grain may also be changed in the presence of metal. In the present investigation, the ID's of FPH/FORPH and formaldehyde phenylhydrazine polymer were measured at various weight percents of Al in the grain. The results are tabulated in Table 2. With the increase of Al percentage, the ID's were increased in both cases. Aluminum, which does not react with nitric acid, acts as a diluent, thereby causing larger ignition delays. The grains, however, in the presence of Al burnt with a white dazzling flame. The same grains when used with RFNA having 24% NO_2 gave inconsistent ignition.

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