which the present measurements were made, did not change significantly when the spacing was approximately doubled.[1,3] However, because the present data were obtained at particle Mach numbers exceeding the critical value for a sphere, it may be possible that significant interference, other than that due to wake effects, arose from the shock wave system that would exist in such cases. Unfortunately, no information could be found to determine how, in this situation, the drag on a single particle would be affected.

Data scatter

The second term on the right side of Eq. (2) is essentially a correction for the effects of cloud nonuniformity. However, when the drag coefficient is evaluated by finite difference methods (as done here) the calculated coefficient, C_{DFD}, is not completely corrected for such effects. If, as was reasonably true in the present case, one assumes that, over the data reduction time interval, 1) each particle cloud element underwent a constant acceleration, 2) the particle displacement was much less than the "wavelength" of the nonuniformity, and 3) the change in cloud density was small compared to the initial density, then[5]

$$C_{DFD} \approx C_D[1 - 0.5\delta(u_s - u_c)\Delta t] \tag{3}$$

where

$$\delta \equiv -(1/u_c)(1/\rho_{p1})(\partial \rho_p/\partial t) = (1/\rho_{p1})(\partial \rho_p/\partial x|_1)$$

Substitution of typical maximum values of the variables on the right side of Eq. (3) ($\delta_{max} \approx \pm 6$ ft^{-1}, $u_s - u_c \approx 2000$ fps and $\Delta t_{max} \approx 100$ μsec) into that equation demonstrates that maximum errors in C_{DFD} of $\pm 60\%$ were possible because of the cloud nonuniformity effects. This result seems to agree with the scatter limits in Fig. 1.

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Burning Rate Acceleration Sensitivity of Double-Base Propellant

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A NUMBER of investigators[1–7] have considered the effects of acceleration on the burning rates of solid propellants. Analytical investigations[1,3,8,9] and most experimental investigations have been made for composite solid propellants. Recent studies at the Naval Postgraduate School have considered the effects of acceleration on the burning rates of double-base propellants with and without an aluminum additive.

The research discussed herein was conducted at the Naval Postgraduate School Rocket Test Facility with a centrifuge mounted combustion bomb. Details of the test facility and centrifuge are presented in Refs. 1, 4, and 10. All tests were conducted utilizing propellant strands. The strands were two inches in length and $\frac{1}{2}$ in. $\times$ $\frac{1}{2}$ in. in cross section. The acceleration force was directed normal and into the propellant surface and the strands were inhibited on all surfaces except the surface normal to the acceleration force. The large centrifuge radius (3 ft) and bomb/surge tank volume (1565 in.^{3}) allowed tests to be conducted with less than 6% variations in pressure and acceleration. Average burning rates were determined from the known strand lengths and the total burn times obtained from the pressure-time history in the combustion bomb/surge tank system.

Two typical double-base propellants were employed in this investigation. Propellant formulations are presented in Table 1.

The propellants were practically identical except that propellant DBNA was nonaluminized and propellant DBA had 5.3% aluminum. Both propellants had lead and copper additives.

Tests were conducted at pressures of 265, 500, and 1000 psia and with accelerations to 1000*g*. The data are presented in two forms; burning rate augmentation vs acceleration and postfire residue weight per unit of original strand volume vs acceleration. Burning rate augmentation is defined as $\dot{r}/\dot{r}_0$ where $\dot{r}$ is the burning rate at a given acceleration and pressure and $\dot{r}_0$ is the burning rate at the same pressure with the centrifuge at rest. The lines drawn through the experimental data points were made only to help visualize the trends in the data.

The data obtained for propellant DBNA are presented in Figs. 1 and 2. The burning rate augmentation is observed to decrease with decreasing pressure and increasing acceleration. Postfire residue data were taken for the 265 psia runs. Comparing Figs. 1 and 2 it can be seen that the augmentation began to decrease at approximately the same acceleration level that postfire residue began to appear.

The residue was in the form of pieces and/or partial layers of lead and/or copper. The residue forms are indicated in

Table 1 Double-base propellant formulations

Propellant designation	Weight % nitro-cellulose	Weight % nitro-glycerin	Wt % monobasic cupric salicylate	Wt % monobasic lead	Wt % Al
DBA	45.0	41.7	2.5	2.5	5.3
DBNA	48.0	44.5	2.5	2.5	...

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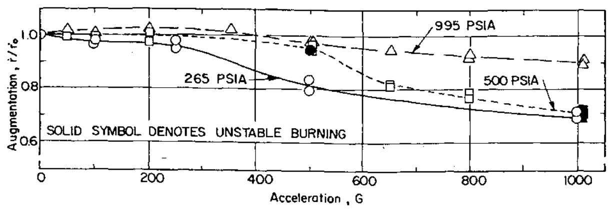

Fig. 1 Effect of acceleration on augmentation of propellant DBNA.

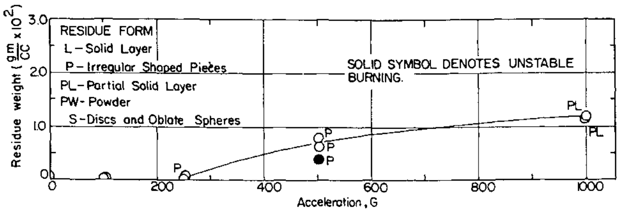

Fig. 2 Effect of acceleration on postfire residue of propellant DBNA at 265 psia.

Fig. 2. The lead has a low melting point and at high accelerations probably forms a partial "flood layer" of molten metal on the surface of the burning propellant—thereby decreasing the burning rate.[1,3] Several 500 psia tests and one 265 psia test exhibited unstable burning at high accelerations as indicated in Fig. 1. The bomb pressure would oscillate in a low-frequency sinusoidal motion. The instability could be the result of periodic flooding and unflooding of the propellant surface.

The data obtained for the aluminized double-base propellant DBA are presented in Figs. 3 and 4. The burning rate augmentation increased with pressure at high accelerations. At 503 psia, augmentation increased slightly with acceleration and then decreased to less than one at 1000*g*. One test at 503 psia and 1000*g* exhibited unstable burning. At 1000 psia the augmentation remained practically constant at all accelerations.

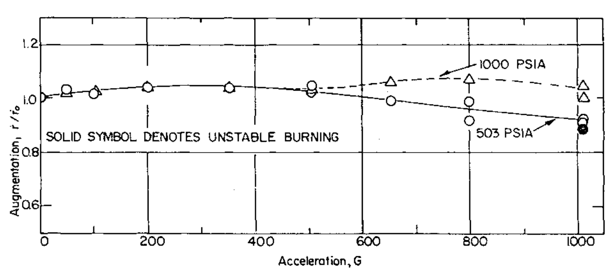

Fig. 3 Effect of acceleration on augmentation of propellant DBA.

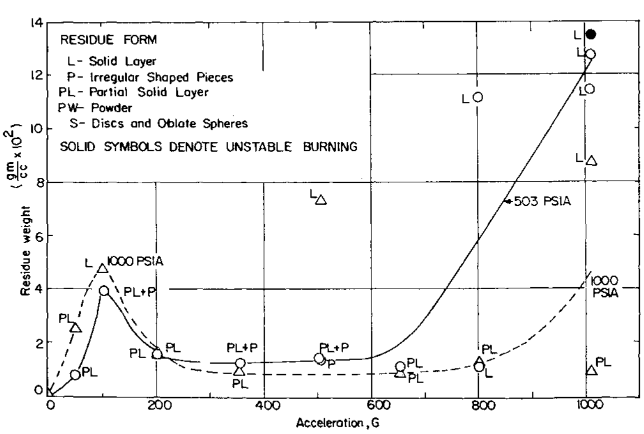

Fig. 4 Effect of acceleration on postfire residue of propellant DBA.

The postfire residue form and weight are practically the same to 600*g* for both pressures. Above 600*g* the residue weight varied considerably from run to run at fixed acceleration, and pressure. A general trend was observable. At high accelerations, increasing pressure decreased residue weight and increased augmentation. The postfire residue consisted of aluminum and/or aluminum oxide in addition to lead and/or copper. Comparison of Figs. 1 and 3 indicates that the presence of aluminum enhanced the augmentation at high accelerations.

It appears that lead (and possibly copper) additives tend to flood the propellant surface and decrease augmentation at high accelerations and may cause unstable burning. Addition of aluminum increases the augmentation[1,3] but the lead and/or copper additives prevent significant acceleration induced burning rate augmentation.

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Prevention of Flare-Induced Separation by Boundary-Layer Bleed

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THE theoretical and experimental investigation of hypersonic flow over blunt-nosed bodies with a flare are of interest in aeronautics and astronautics.[1] Calculated inviscid flows on a flare hemisphere cylinder could not be com-

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