The Impact of Projectile Geometry on Ram Accelerator Performance

by

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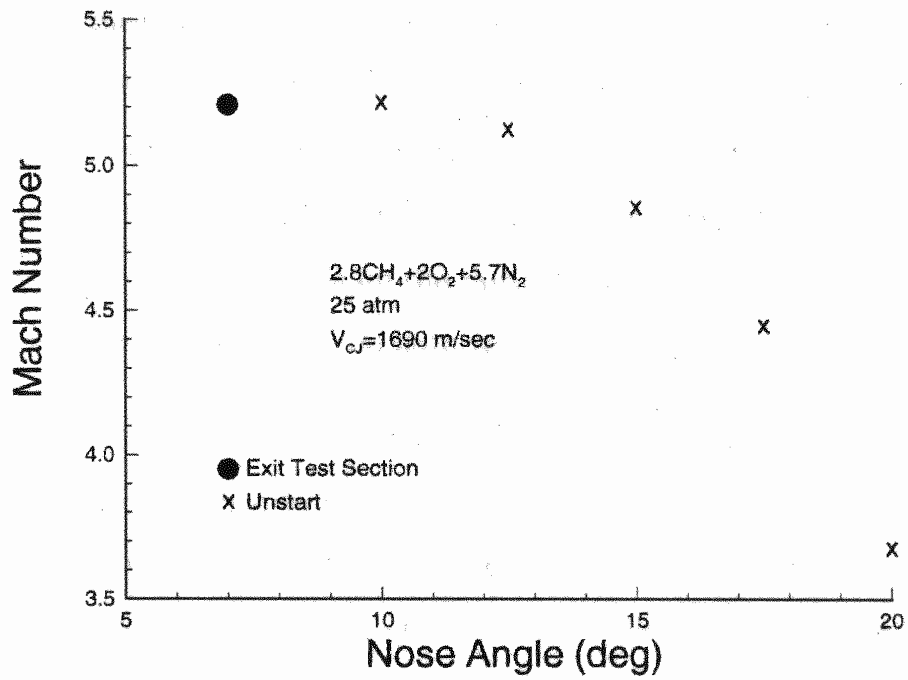

Fig. 4.15 Nondimensional peak velocity as a function of nose cone angle.

4.2.3 Body Length

The body is the heaviest element of the projectile, making it the most important component to refine. If the body length could be cut in half, the overall projectile mass would decrease by 40%, yielding a 67% increase in acceleration.

There are two mechanisms which could set a lower limit to the length of the body. The primary function of the body is to stabilize a shock system caused by the heat release. If the body becomes too short, then the shock system would be disgorged into the diffuser, unstarting the projectile. The other possible mechanism is a stability bound. As the body becomes shorter, there is less fin length to keep the projectile centered within the tube. Eventually, the body may become so short that the fins cannot resist the perturbations which force the projectile against the tube wall. Since the center of gravity (C.G.) depends on the mass distribution of the projectile, stability considerations depend on both the nose and the body.

To explore these questions, two sets of four-fin bodies were made from a magnesium alloy. The bodies were systematically shortened from a nominal length of 71 mm to 35 mm in 9 mm increments (Fig 4.16). One set was configured with a 10° nose cone angle, and the other with a 15° nose angle. All the projectiles had the same throat diameter, base diameter and fin thickness.

The velocity-position profiles of these experiments are shown in Fig. 4.17. The projectiles showed the expected increase in acceleration as the body length decreased; however, the projectile unstarts displayed very interesting trends. Fig 4.18 compares the unstart Mach number with the body length. One important observation is that the stability of the projectile is a second-order effect. The longer 10° nose cones exacerbate the projectile's stability problem by moving the center of gravity further forward than 15° noses. The C.G. condition was most extreme when a 10° nose was mated with a 35 mm long body, yet all of the 10° nosed projectiles unstarted at higher velocities than their counterparts with 15° noses. If stability were a first order effect, projectiles with 10° noses should have unstarted at lower velocities than the projectiles with 15° noses.

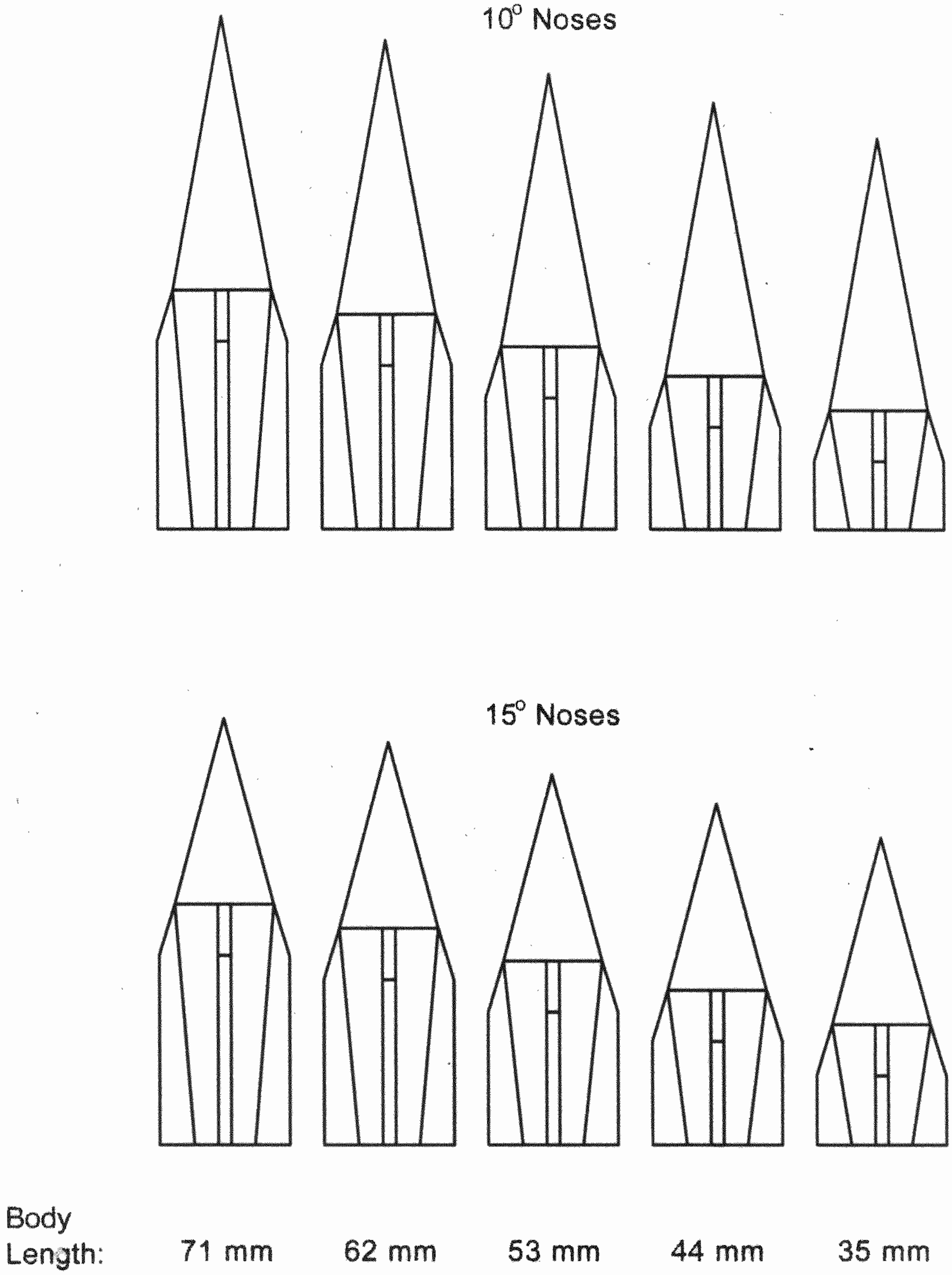

Fig. 4.16 Projectiles used to investigate the effects of body length.

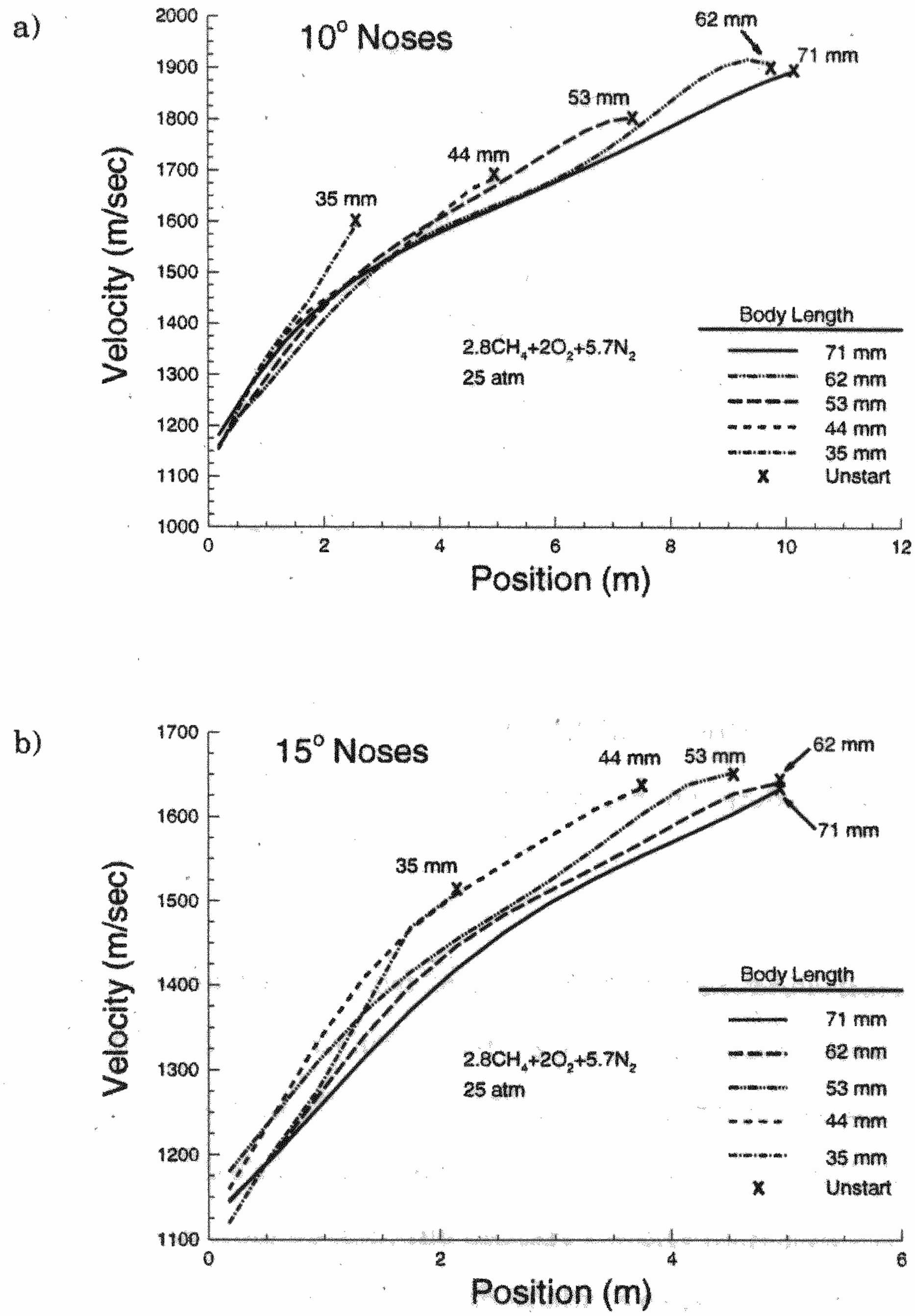

Fig. 4.17 Velocity-position data for projectiles with different body lengths and nose cone angles.
a) Projectiles with 10° noses.
b) Projectiles with 15° noses.

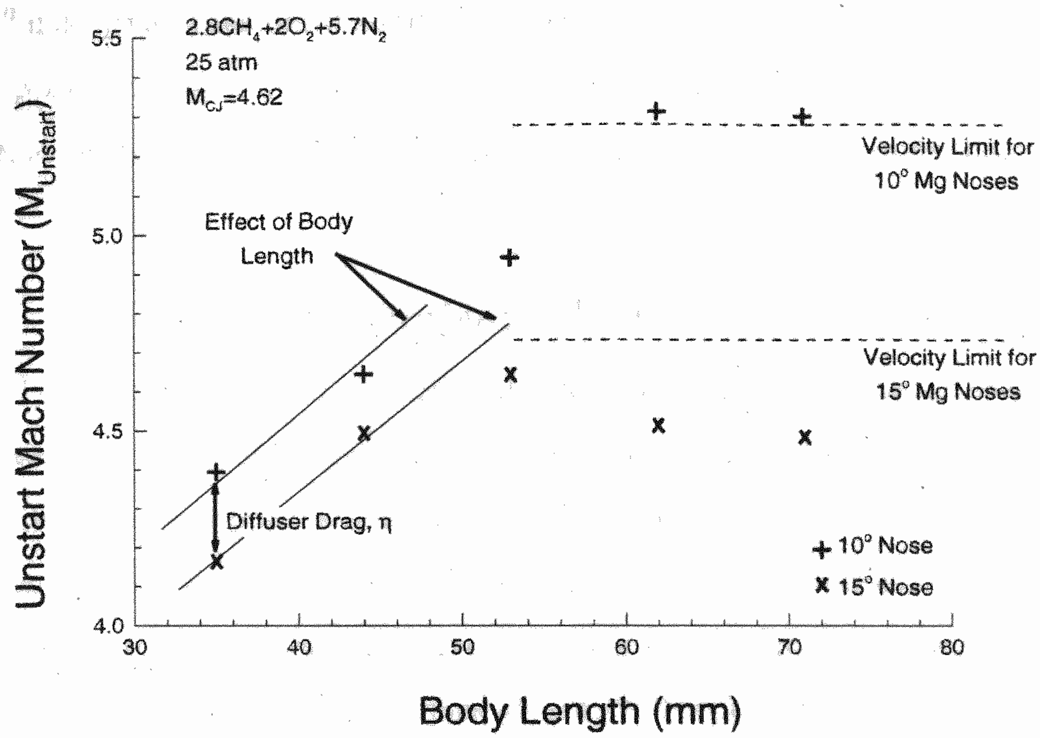

Fig. 4.18 The unstart pattern formed by projectiles with different body lengths.

While the unstart pattern does not indicate that projectile stability is a first order effect, the length of the body is still important to the ultimate velocity of the projectile. The effect of the body length can be seen in the figure as parallel lines having a positive slope. As the projectile bodies increase in length from 35 mm, the unstart velocity increases. The positive slope of the unstarts is consistent with unstarts caused by shock structures on the body. A model for this mechanism will be discussed in more detail in the next chapter. The small difference in height of these lines may be the effect of the increased drag or decreased diffuser efficiency of 15° nose cones. The progression of unstarts for projectiles with 10° noses has a sharp break at

M=5.3, beyond which the body length has no effect. The pattern of unstarts for 15° nose projectiles has a similar character. It should be noted that these break points correspond to the velocity limits found in the nose angle variation series, and probably represent a limitation of the nose cone, not the body.

4.2.4 Projectile Material

The methane dilution experiments, described earlier, mapped the Q-M envelope for a $H_2/O_2/CH_4$ mixture.[27] These experiments revealed a limit on projectile velocity at approximately 115% V_{CJ}, similar to the outcome of the nitrogen dilution series (Fig. 3.7). Other studies indicated that as the projectile approaches transdetonative velocities at high fill pressures, melting and ablation of the nose cone becomes severe.[26,28,29] To confirm the observed restriction as a structural limitation, a projectile was fabricated identical to those used in the methane dilution series, except that the nose cone was made of a titanium alloy. If the limit were purely gasdynamic, then the titanium-nosed projectile would unstart at 115%V_{CJ}, like the aluminum projectiles. However, if the limit was related to nose cone integrity, then projectiles with titanium components would be able to operate at higher velocities than standard all-aluminum projectiles.[30]

The titanium-nosed projectile was injected into a test mixture which duplicated the conditions of a prior experiment (where the projectile was all-aluminum). This projectile operated beyond the velocity limit for all-aluminum projectiles and exited the test section still accelerating (Fig. 4.19).