Ram-Acceleration Enhancement through Projectile and Staging Design

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Abstract
Experimental investigations were conducted in a 25-mm-bore ram accelerator using open-base projectile, which was designed to obtain higher acceleration by reducing the mass. Single stage operations were conducted in a reliable starting mixture, $2.8CH_4+2O_2+5.7N_2$. Depending on the entrance velocity, delayed start was observed. The immediate successful start was obtained with entrance velocity over 1.3 km/s.

Introduction
A ram accelerator is a device that can launch a relatively heavy projectile.[1] Various investigations have been conducted to achieve a high muzzle velocity in this device.[1-6] A long ram acceleration tube and a high acceleration rate can increase the muzzle velocity. However, in practice the facility length is often limited. Therefore, in order to achieve high muzzle velocity, the present paper tries to increase the acceleration level.

Bruckner et al.[7] discussed the effect of unsteadiness in calculating thrust. They evaluated unsteady terms in each conservation equation and concluded that the effect of the projectile acceleration, which was lower than 4×10^4 g, on the thrust could be negligible. Thus, quasi-steady-state analysis has often been used to predict thermally choked ram accelerator performance. However, operational characteristics at higher acceleration have not been well studied, thereby requires further investigations.

Investigation of high acceleration operation using reduced mass projectile is in progress at Shock Wave Research Center.[8,9] In this paper starting characteristics of reduced mass projectile will be presented.

Experimental facilities
Figure 1 shows the schematic of the ram accelerator (RAMAC25) at Shock Wave Research Center (SWRC), Institute of Fluid Science, Tohoku University. The inner diameter and the length of the ram acceleration section were 25 mm and 6 m, respectively. A single-stage powder gun was used as the pre-launcher, where a projectile was accelerated up to about 1.3 km/s. Single-base smokeless powder (NY-500, Nippon Oil & Fats Co. Ltd.) was used as the gun propellant.

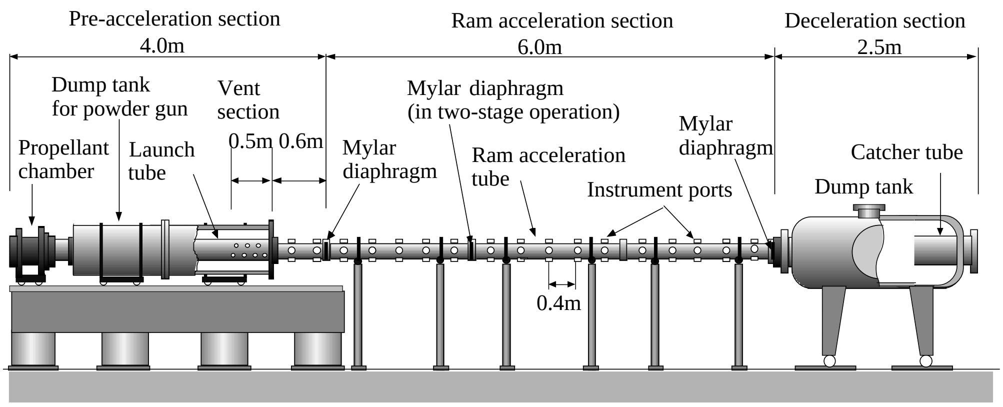

Fig. 1 Schematics of 25-mm-bore ram accelerator.

The configuration of the projectile used in these experiments is shown in Fig. 2. The projectile was manufactured with aim of significantly decreasing the projectile mass. The base of this projectile was pierced to greatly reduce the pressure difference between its inside and outside. Inner shape of this one-piece projectile was lathed from the base so that the wall has uniform thickness. The projectile was made of magnesium alloy (AZ31(F)) and aluminum alloy (A7075-T6). The mass of the magnesium projectile and aluminum projectile was about 10 g and 9 g, and the wall thickness was 2 mm and 1 mm, respectively.

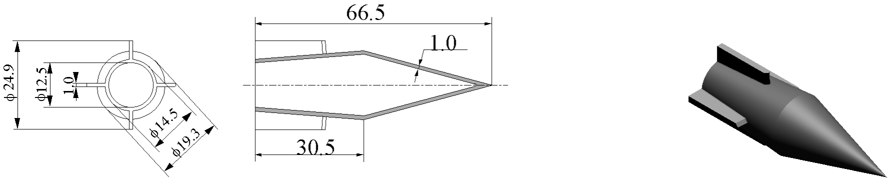

Fig. 2 Design of open-base projectile.

Results and discussion

Reliable starting mixture, $2.8CH_4+2O_2+5.7N_2$, was employed throughout the present operations. The initial fill pressure was 3.5 MPa. Fig. 3 shows the velocity profiles with different entrance velocities.

The solid circles represent the velocity profile of magnesium projectile. The entrance velocity was 1.2 km/s. In this experiment first 2-m stage was filled with the starting mixture and next 4-m stage was filled with $4.7CH_4+2O_2+4.7He$. Immediately after entering the first stage the projectile was slightly accelerated due to obturator and obturator-driven shock wave. Then the projectile decelerated slowly, which indicated that the shock wave and combustion system fell-off from the aftbody of the projectile (so-called 'wave fall-off'[10,11]). The combustion front, however, caught up with the projectile and finally overtook it (so-called 'wave unstart'[10,11]). Before the wave unstart, a positive transient thrust was maintained for about 1.5 m.

Experiments were also conducted with aluminum projectile instead of magnesium projectile under the same operation conditions. Although the entrance velocities were failed to measure, it supposed to be slightly higher than those of magnesium projectile due to reduced mass. Measured velocity profiles were plotted with open diamonds in Fig.3. In both cases, similar delayed start process was observed, and it was shorter than that of magnesium projectile case. The difference in the length to establish the successful ram acceleration suggested that this experimental condition is marginal.

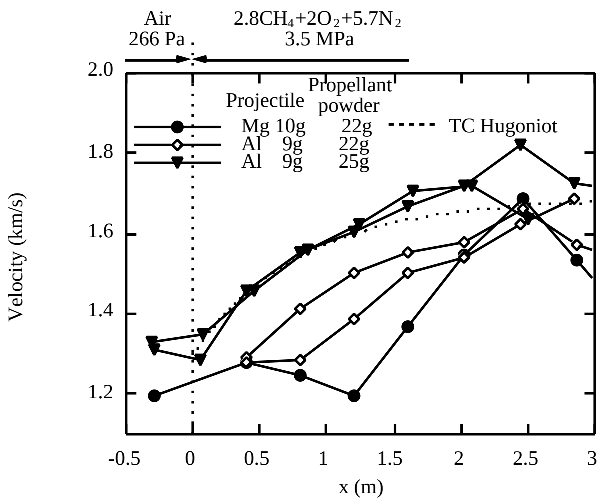

Fig. 3 Velocity profiles measured with different entrance velocities.

Further experiments were conducted at higher entrance velocity. The entrance velocity was increased up over 1.3 km/s by increasing the amount of the mass of the propellant powder. In these cases, successful immediate starts were obtained. Measured velocity profiles were plotted with solid triangles in Fig.3. Corresponding thermally choked Rankine-Hugoniot relation was also plotted with broken line.

Throughout these experiments, it is obvious that the higher entrance velocity prevent delayed start. This characteristic might be explained in this way; the reduced mass projectile is helpful to gain high acceleration so that the mixing time of propellant gas is not enough to obtain immediate start. The higher entrance velocity increases the pressure and temperature of stagnation region in front of the obturator, at which combustion starts, which leads to decrease of induction time of the mixture and hence prevent, delayed start.

Conclusion

Starting experiments were conducted with reduced mass open-base projectile. In this series of experiments, it was found that the entrance velocity was a critical parameter. Delayed start appeared at lower entrance velocity. Successful immediate start was achieved at entrance velocity over 1.3 km/s.

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Reference

1. Hertzberg, A., Bruckner, A. P. and Bogdanoff, D. W., “Ram Accelerator: A New Chemical Method for Accelerating Projectiles to Ultrahigh Velocities,” AIAA J., Vol. 26, No. 2, 1988, pp. 195-203.
2. Elvander, J. E., Knowlen, C. and Bruckner, A. P., “High Acceleration Experiments Using a Multi-stage Ram Accelerator,” *Ram Accelerators*, Springer-Verlag, Heidelberg, 1998, pp. 55-64.
3. Kruczynski, D. L., “High Performance Ram Accelerator Research,” *Ram Accelerators*, Springer-Verlag, Heidelberg, 1998, pp. 97-104.
4. Giraud, M., Legendre, J. F. and Henner, M., “RAMAC in Subdetonative Propulsion Mode: State of the ISL Studies,” *Ram Accelerators*, Springer-Verlag, Heidelberg, 1998, pp. 65-77.
5. Seiler, F., Patz, G., Smeets, G, and Srulijes, J., “Presentation of the Rail Tube Version II of ISL’s RAMAC30,” *Ram Accelerators*, Springer-Verlag, Heidelberg, 1998, pp. 79-87.
6. Sasoh, A., Hamate, Y., Utsunomiya, G. and Takayama, K., “High acceleration ram accelerator operation,” AIAA paper 99-2262, 1999.
7. Bruckner, A. P., Knowlen, C., Hertzberg, A. and Bogdanoff, D. W., “Operational Characteristics of the Thermally Choked Ram Accelerator,” AIAA Journal of Propulsion and Power, Vol. 7, No. 5, 1991, p.828.
8. Hamate, Y., Sasoh, A. and Takayama, K, “Ram accelerator operations at acceleration level up to 6×10^4 g,” Journal de Physique IV, Vol. 10, PR-11, 2000, pp. 3-9
9. Hamate, Y., Sasoh, A. and Takayama, K, “RAMAC25 Multi-Stage Operation,” AIAA paper, 2000-3232.
10. Schultz, E., Knowlen, C. and Bruckner, A. P., “Overview of the Subdetonative Ram Accelerator Starting Process,” *Ram Accelerators*, Springer-Verlag, Heidelberg, 1998, pp. 189-203.
11. Sasoh, A., Hamate, Y., Takayama, K., “Significance of Unsteadiness in Operation of the Small Bore Ram Accelerator,” AIAA paper, 98-3446.