Ballistic Range의 작동과정에 대한 수치 해석적 연구

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Computational Study of the Operating Processes of a Ballistic Range

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ABSTRACT

A computational study has been performed using a chimera scheme to study the various operating processes inside a ballistic range. The compression flow fields in the pump tube and projectile motion in the launch tube are captured for various piston masses and diaphragm rupture pressures. The effect of a shock tube in between the pump tube and launch tube is analyzed. The results are compared with available experimental data. It is noted that, by adding a shock tube in between the pump tube and launch tube, the peak pressure in the ballistic range can be reduced without appreciable reduction in the velocity of the projectile.

Key Words: Ballistic range(발리스틱 레인지), Piston(피스톤), Projectile(발사체), Moving shock wave (이동 충격파), Chimera scheme(키메라 방법)

1. Introduction

The ballistic range is a fluid dynamic device that can accelerate a projectile to high-supersonic or hypersonic speeds. Unlike supersonic or hypersonic wind tunnel in which the model under aerodynamic test is fixed at the test section, a projectile in ballistic range is accelerated to very high-speeds through a shock compression. Ballistic range has extensively been used in hyper-velocity impact engineering, supersonic and hypersonic projectile aerodynamics and aeroballistics. Recently much interest has been concentrated on creating an extremely high-pressure state over several tens to hundreds thousand atmosphere using such a ballistic range [1-2]. In this case, the projectile speed has been known to be more than ten kilometers per second.

The ballistic range is often called "a two-stage light-gas gun", as the projectile attains energy in two stages. Energy of the high-pressure gas is first transferred to the light-gas in the pump tube through an isentropic compression process and then

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to the projectile through an unsteady shock wave.

In the present study, a CFD method has been applied to predict the compressible flow field which is driven by the motion of piston inside the pump tube of the ballistic range. The 3-D, unsteady, compressible Euler equations were numerically solved using a fully implicit finite volume method. The chimera scheme was employed for simulating the moving piston in the pump tube and the motion of the projectile in the launch tube. Many parameters such as mass of the piston and pump tube diameter have been varied to study the compression process in detail. The computational results are validated with experimental data available.

The effect of adding shock tube in between the pump tube and the launch tube has also been analyzed. The operating processes are analyzed and it is shown that with the addition of the shock tube, significant performance enhancement is obtainable in terms of the kinetic energy of the projectile and reductions in both maximum pressure in the device and peak pressures at the base of the projectile.

2. Numerical Model

A commercial software CFD FASTARN is used to analyse the projectile flow fields. It uses a chimerascheme which allows the overlapping of one zone over the other. The data are interpolated between the overlapping grids as the solution progresses. The code solves the 3-D Euler equations using a finite volume method. A 3-D symmetric model is used in all the cases for reducing the computational time.

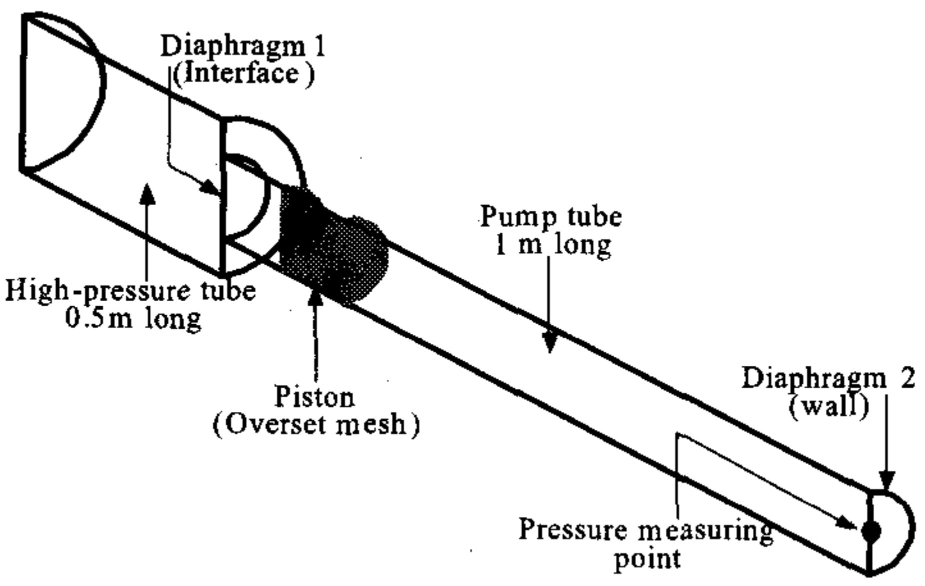

Fig. 1 computational conditions

2.1 Computational conditions

Fig.1 shows a half section of the computational domain for the pump tube and the piston. During the simulation of the piston motion, the lengths of pump tube and of high-pressure tube are taken as 1m and 0.5 m respectively. Though diameters of both the tubes are varied, the ratio of cross sectional area of high-pressure tube to that of pump tube is kept constant at 6.25. The high-pressure tube pressure and rupture pressure of diaphragm 2 are maintained constant at 20bar and 80/100 bar respectively.

3. Results and Discussion

In Fig.2, computational result for the pump tube pressure history is compared with that of the experimental one. The agreement seems to be very good except at some places . This is because in the experiment, the gases in high-pressure tube and pump tube were air and helium respectively,

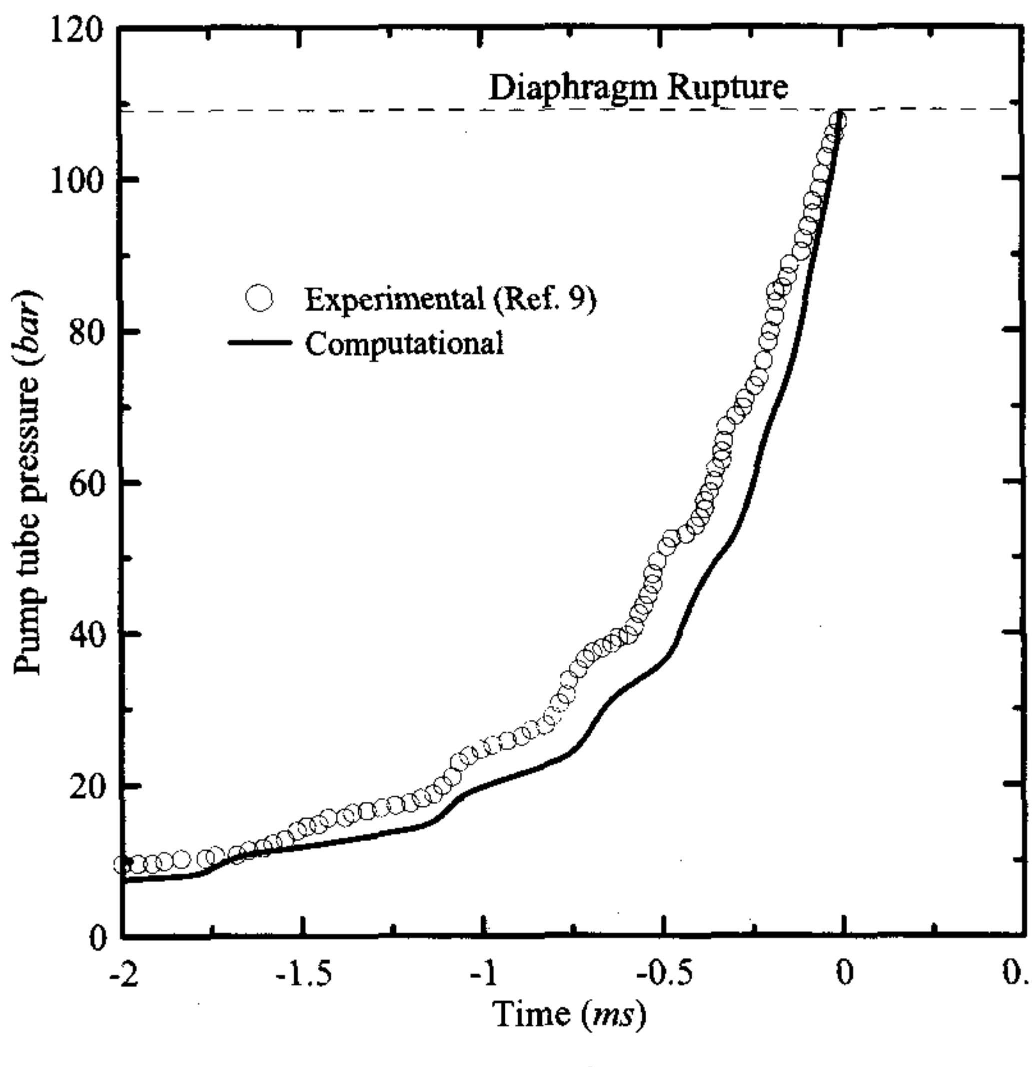

Fig. 2 Comparison of piston velocity

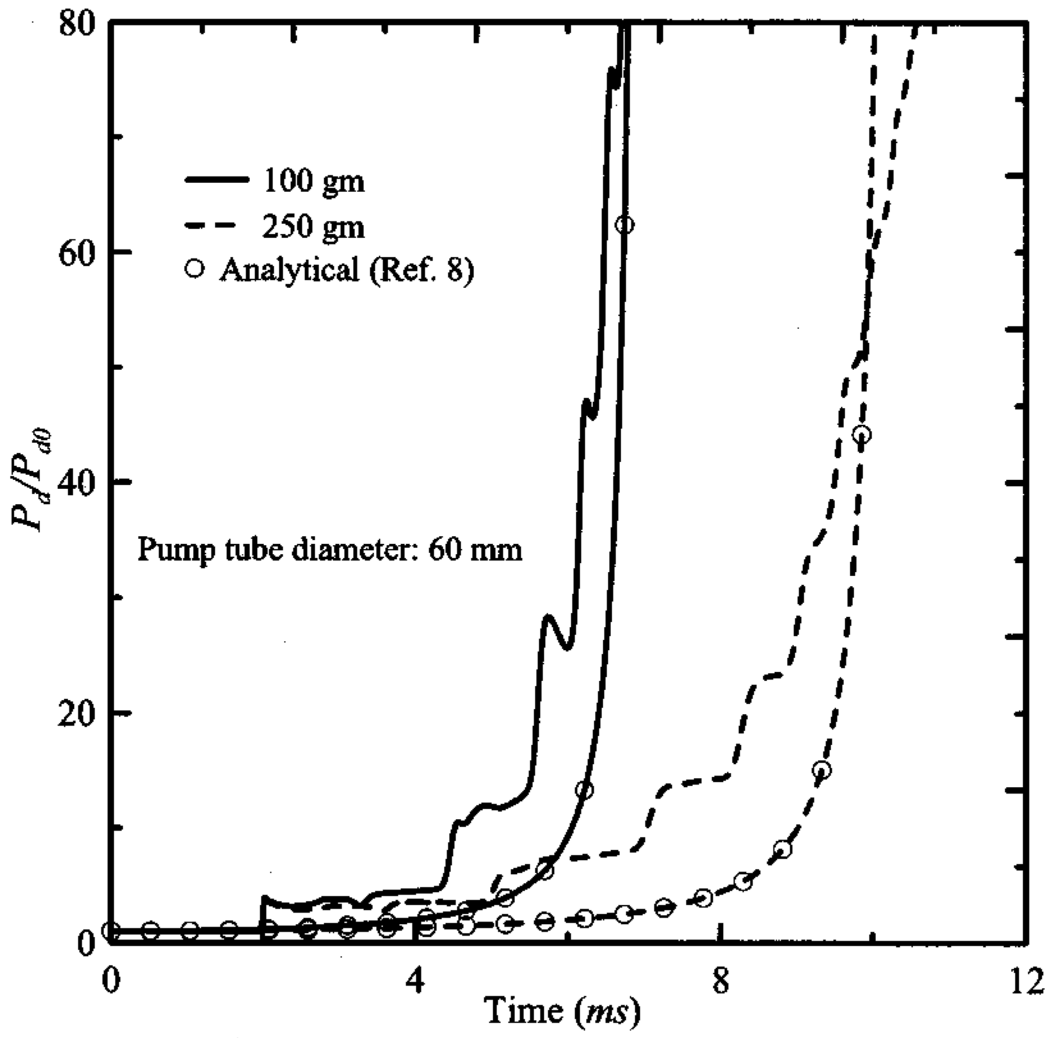

Fig. 3 Pump tube pressure history-piston mass effect

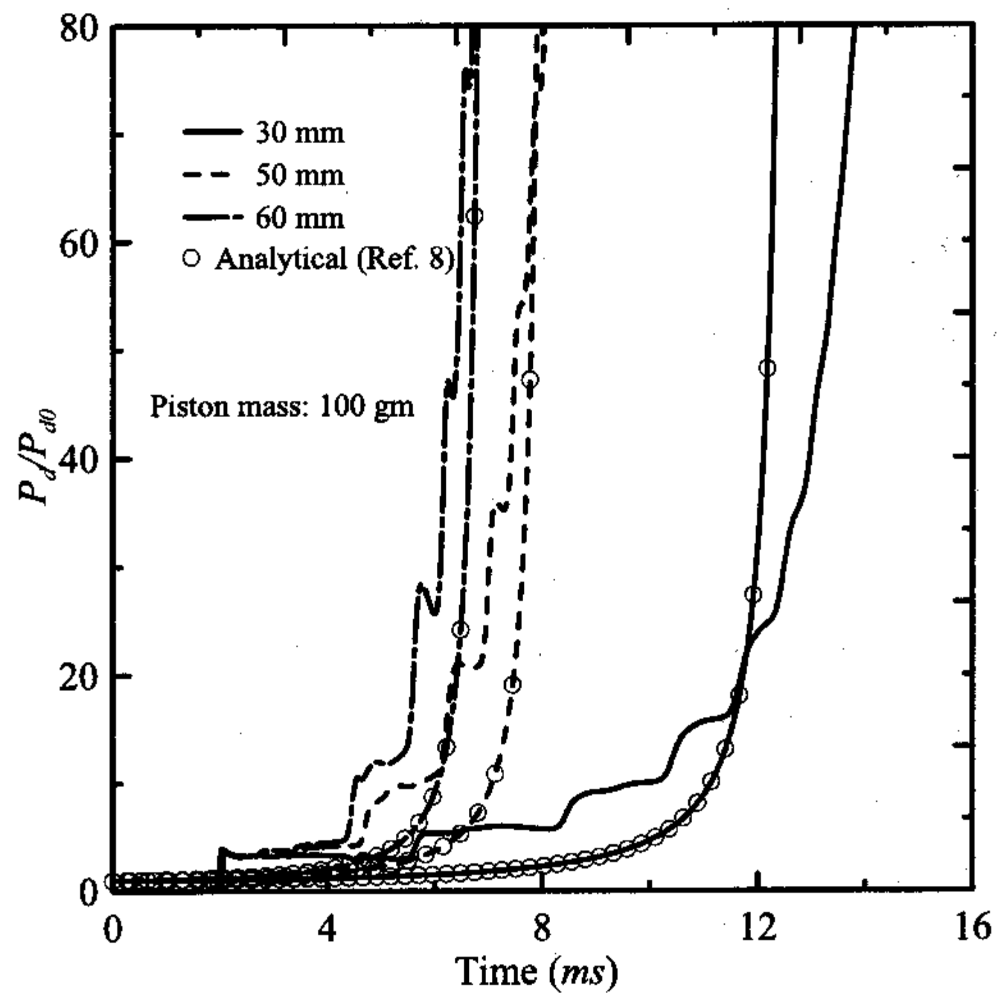

Fig. 4 Pump tube pressure history- diameter effect

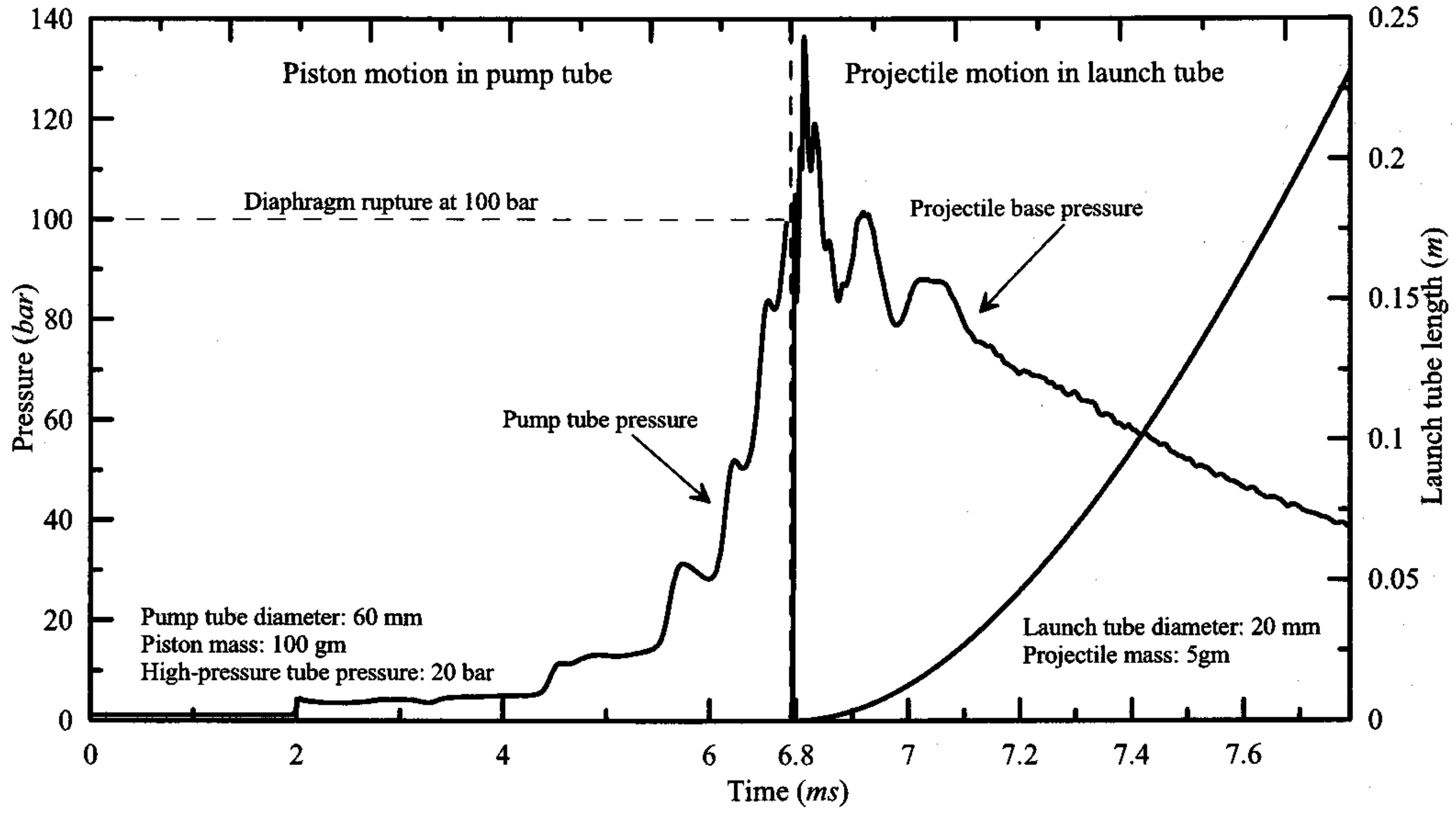

Fig. 5 Operating processes of ballistic range

while in the computations, these have been taken to be helium only.

In Fig.3, the pump tube pressure histories are plotted for various piston masses. The computational results are compared with the analytical ones [8]. P_d/P_{d0} denotes the ratio of the pump tube pressure at anytime to the initial pump tube pressure at $t=0$. It is seen that the heavier is the piston, the more will be the time taken to build up the pressure as expected. In the case of 100gm piston, computation predicts a faster build-upof pressure in the pump tube over the analytical results, while for the 250gm piston, the latter somewhat over-predicts the pressure build up.

Fig.4 shows the pump tube pressure histories for various pump tube diameters. It is known from the graph that the smaller is the pump tube, the more will be the time taken by the piston to build up the required pressure. In a smaller pump tube, the force difference across the piston at a particular time will be less than that in a larger pump tube in the direction of motion owing to a small cross sectional area, while all other parameters remaining the same. This makes a smaller piston move at a smaller velocity as compared to a larger one, requiring larger time for pressure build-up.

The total operating processes of the ballistic range are detailed in Fig.4. After the rupture of the pump tube diaphragm, the pressure at the base of the projectile increases sharply, due to the reflection of the unsteady shock wave moved into the launch tube. This peak pressure at the base of the projectile is very much significant as far as the projectile stability is concerned. A major problem of projectile deterioration, often called, "projectile fly out", in ballistic ranges is attributed to this peak pressure experienced by the projectile.

4. Conclusions

A computational fluid dynamics method which employs the chimera scheme is used to simulate the compressible flow driven by a piston in a ballistic range. Complex flow fields produced by the compression of the driving gas in the pump tube of the device have very well been captured by the present method. The flow fields were analyzed for various piston masses and the pump tube diameters. The heavier is the piston, the more will be the time taken to achieve the required diaphragm rupture pressure. For smaller diameter pump tubes, the time take to reach the required diaphragm rupture pressure will be more, owing to a reduced piston velocity. The flow fields reveal the presence of many compression waves and their reflections on both the piston and the pump tube diaphragm.

Significant performance enhancement is achieved with the addition of the shock tube in between the pump tube and the launch tube. Further computational study is also in progress to study the shock tube effect on the ballistic range performance.

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