Numerical Simulations of Two Blasts by a Supersonic Projectile Discharged from a Tube

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Abstract. This paper describes a numerical study on wave interactions following
the emergence of a supersonic projectile released from the open-end of a shock
tube into ambient air. The Euler equations, assuming axisymmetric flows, were
solved using a dispersion-controlled scheme implemented with moving boundary
conditions. The numerical results show that not only does the leading shock due
to the second blast overtake the projectile but also the gas behind the projectile
does so when the initial pressure ratio behind and ahead of the projectile is high.
Subsequently, the projectile will overtake them again. The second blast becomes
tightly coupled with the first.

1 Introduction

A supersonic projectile moving in a tube, like a piston, drives a precursor
shock wave ahead of it. The precursor shock wave will discharge from the
open-end of the tube first, which leads to shock-wave diffraction with an
associated starting vortex and a jet flow. Later, the projectile itself moves
out of the tube, and interacts with this diffracting shock system and the jet
flow. Meantime, the high pressure gas behind the projectile expands out of
the tube and the second blast is generated. The second blast may overtake
the projectile and will be overtaken again later by it. This topic is similar
to a gun-firing muzzle blast, usually termed the transitional or intermediate
ballistic regime. The discharge of firearms spawned a great deal of research
in the past, but most of the pioneer work devoted to experimental flow vi-
ualization or modeling of physics in the region far from the jet in terms of
well-established theories for spherical blast waves [Baker (74); Schmidt et al.
(75); Erdos et al. (75)]. Considering that the muzzle blast flowfield is char-
acterized by two blast waves and the shock-wave/moving-body interaction, a
numerical study was recently reported by Jiang et al.(98). The more detailed
understanding of shock wave phenomena was gained from their work, espe-
cially for that in the vicinity of the muzzle and the projectile where two blasts
are closely coupled, which can be neither visualized experimentally because
of dusty propellant gases, nor modelled with classic blast theory because of non-linearity and complex interactions of shock waves. However, the friction between the projectile and the tube was neglected in their work so that the second blast is much weaker than it should be in a real problem. This study aims at behaviors of the second blast wave by considering the friction between the projectile and the tube, i.e. the pressure behind the projectile is higher than that ahead of it. The interaction between the second blast and the projectile was also emphasized in the present work.

2 Numerical methods

Assuming axisymmetric flows, a hyperbolic system of conservation laws for a perfect gas in cylindrical coordinates was accepted in the present study. The dispersion controlled-scheme proposed by Jiang (93) was applied for solving the governing equations. In order to simulate a flying projectile, the surfaces of the projectile are traced step by step while the projectile is moving in the fixed main mesh system so that the moving boundary conditions consistent with the Euler equations can be applied on the surfaces of the projectile. Detailed descriptions of the governing equations, numerical methods, the moving boundary conditions and the computational domain can be found in the paper by Jiang et al. (98).

![Fig. 1. Validation of numerical methods and moving boundary conditions](image)

To validate numerical methods, two test cases were conducted. The first case is the diffraction of a shock wave discharged from the open-end of a shock tube into ambient air. Its geometry is thus the same as that in the present study but without that projectile. From numerical solutions, a computational interferogram was constructed with consideration of the axisymmetric density distribution, and compared directly with an experimental result as shown in Fig. 1a. Another case, designed for verification of the moving boundary conditions, is a projectile flying in open space at a supersonic speed, and thus similar to the present study but without the tube. This case was calculated using both moving and fixed boundary conditions so that a comparison could be made for verification (see Fig. 1b). From the results of these two cases it