# 이동충격파를 추월하는 발사체의 공기역학

G. Rajesh* · 김희동** ·

# Aerodynamics of the Projectile Overtaking a Moving Shock Wave

G. Rajesh* · H. D. Kim** ·


## ABSTRACT

The aerodynamics of a projectile overtaking a moving shock wave is analyzed using a chimera scheme. The flow field characteristics for various shock wave Mach number and projectile masse are investigated. the unsteady forces acting on the projectile for both supersonic and impossible overtaking conditions are computed in order to analyze the aerodynamic characteristics of the projectile. It is seen that the projectile Mach number significantly affects the flow fields for both supersonic and impossible overtaking. Unsteady drag is influenced by the overtaking conditions. The unsteady drag coefficient is the highest for the impossible overtaking condition.


Key Words: Projectile(발사체), Overtaking(추월), Moving shock wave(이동 충격파), Aerodynamics (공기역학), Chimera scheme(키메라 방법)

## 1. Introduction

The aerodynamic characteristics of projectiles passing through moving shock waves are extremely complicated due to the complex wave interactions around the projectile. The projectile experiences drastic changes in the aerodynamics forces as it moves through the shock wave form a high-pressure region to a low pressure region. Such rapid changes in the aerodynamics force characteristics makes the trajectory of the projectile unstable, consequently leading to loss of projectile stability and the control efficiency. d Such flow fields are usually encountered near the vicinity of the launch tube exit of a ballistic range facility, thrusters, retro-rocket firings, silo injections, shock tunnel discharges, missile firing ballistics, etc. Many of the earlier works on projectile aerodynamics field deal with the calculation of flow fields theoretically [1, 2] and experimentally[3, 4]. Numerical works were also carried out for shock wave diffractions over stationary cylinders[5]

Recently, Watanabe, et. al[6] analyzed the subsonic and supersonic overtaking of a projectile using a numerical technique. Significant differences were observed in flow fields and drag coefficients on the projectile for both the cases. In another work done by Ahmedika, et al.[7], transonic and supersonic

* Doctoral Student, School of Mechanical Engineering, Andong National University
** Professor, School of Mechanical Engineering, Andong National University
E-mail: kimhd@andong.ac.kr

overtaking were studied. They concluded that the projectile drag coefficient variations in transonic overtaking are more predominant than in supersonic case and projectile stability might also be affected.

The projectile Mach number ($Mp_2$) relative to the unsteady flow behind the blast wave is a major factor which determines the overtaking conditions.

$$M_s = \frac{u_s}{a_1}, \quad M_{p1} = \frac{u_p}{a_1}, \quad M_{p2} = \frac{u_p - u_2}{a_2}$$

Where, $u_s, u_p, u_2, a_1$ and $a_2$ are the velocities of moving shock wave (blast wave), projectile, flow downstream of the moving shock wave, waves upstream and downstream of the moving shock wave, respectively. For supersonic and subsonic overtaking, $M_{p2} > 1$ and $M_{p2} < 1$, respectively. In Fig.1, the projectile Mach number $M_{p1}$ is plotted against the shock wave Mach number $M_s$. The solid line indicates the minimum condition for the projectile to catch up the moving shock wave ($M_{p1} = M_s$) and below this line, overtaking is impossible. The dashed line ($M_{p2} = 1$) demarcates the supersonic and subsonic overtaking zones.

In the present work, Two cases of supersonic overtaking and an impossible overtaking is analyzed as shown in Fig.1. The drag histories for supersonic overtaking are qualitatively the same, while the impossible overtaking condition shows a randomly fluctuating projectile drag coefficient. Subsonic overtaking case is also being analysed and the results will be presented soon.

## 2. Numerical Model

A commercial software CFD FASTARN is used to analyse the projectile flow fields. It uses a chimera scheme 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.

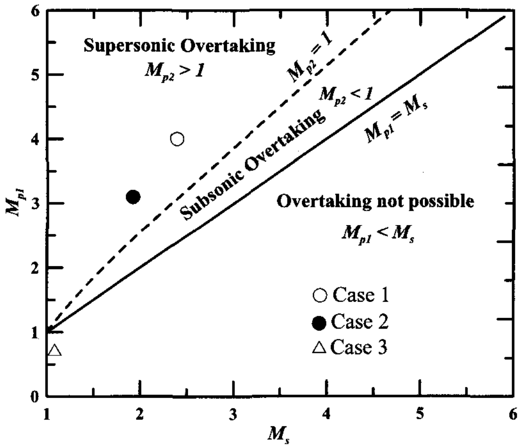



Fig. 1 Flow regimes analyzed in the present work

### 2.1 Computational Conditions

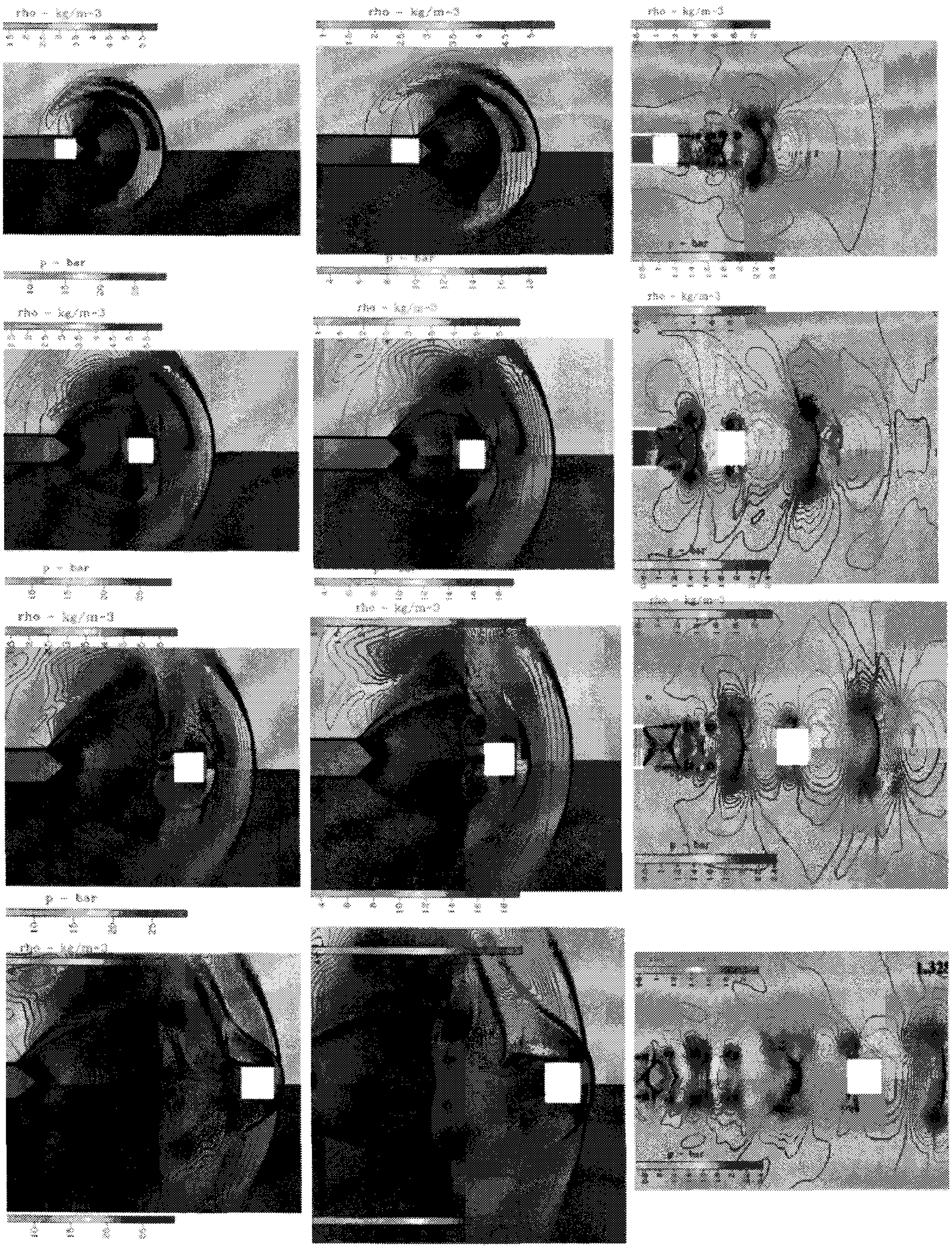
A moving shock wave is assumed at the exit of the launch tube where th projectile is kept inside . The projectile and the flows ahead and behind the projectile are in the same condition of that of the "post-shock flow"of the moving shock wave which is at the exit of the launch tube when the computation starts. Table 1 shows the conditions used in the present work

Table 1. Computational cases analyzed

| Initial shock Mach number | Projectile Mach number | Shock Mach number when projectile exits from launch tube | Nature of overtaking |
|---|---|---|---|
| 5 | 4 | 2.4 | Supersonic |
| 4 | 3.13 | 1.96 | Supersonic |
| 1.5 | 0.7 | 1.02 | Impossible |

## 3. Results and Discussion

Fig.2 shows the iso-picnics on the upper part of the flow field and isobars on the lower part of the flow



a) $M_s$=2.4, $M_{pi}$=4.0
Supersonic overtaking

b) $M_s$=1.95, $M_{pi}$=3.12
Supersonic overtaking

c) $M_s$=1.1, $M_{pi}$=0.7
Overtaking impossible

Fig. 2 Flow fields for various cases

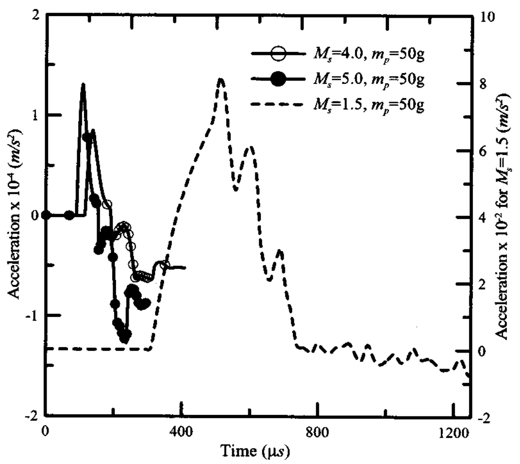



Fig. 3 Acceleration histories of projectile

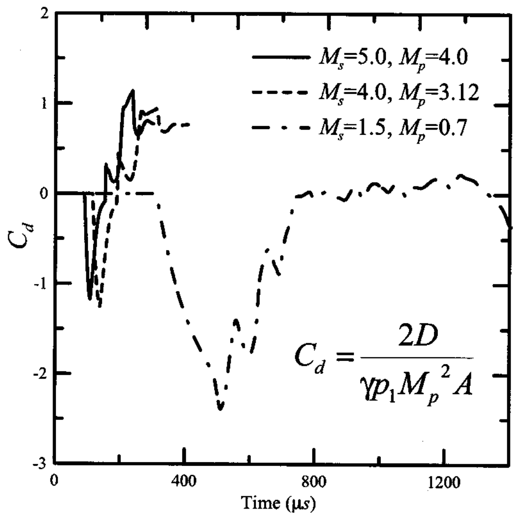



Fig. 4 Variation of unsteady drag coefficients

fields for all the three cases considered. The flow fields are shown according to the appearance of various flow structures. It is seen that the flow fields for both the supersonic overtaking case are qualitatively the same.

Fig.3 and 4 show the acceleration and drag coefficient histories for various cases considered. It is seen that the accelerations of the projectile are qualitatively same for both supersonic and subsonic while it changes in random fashion for the impossible overtaking case. The unsteady drag also follows the same trend. It is noted that the drag coefficient in the impossible overtaking case is qualitatively and quantitatively different from the other two and is the highest among the three.

## 4. Conclusions

A computational fluid dynamics method which uses the chimera scheme has been employed for analysing the aerodynamics of a projectile overtaking a moving shock wave. Two supersonic overtaking and one impossible overtaking cases have been analysed. The flow fields in the supersonic cases are significantly different from that of the impossible overtaking. The unsteady drag coefficient shows random fluctuations in the impossible overtaking, and is the highest among the three.

## References

1. Erdos, J. I., and Del Guidice, P. D., 1975, "Calculation of Muzzle Blast Flowfields," AIAA Journal, Vol.13, pp.1048-1057.
2. Merlen, A., and Dyment, A., 1991, "Similarity and Asymptotic Analysis for Gun-Firing Aerodynamics," J. Fluid Mechanics, Vol.225, pp.497-502.
3. Glass, I. I., 1974, "Shock Waves and Man", The University of Toronto Press, Canada.
4. Schmidt, E., and Shear, D., 1975, "Optical Measurements of Muzzle Blast," AIAA Journal, Vol.13, pp.1086-1096.
5. Watanabe, R., Fujii, K. and Higashino, F., 1995, "Numerical Solutions of the Flow around a Projectile Passing through a Shock Wave," AIAA paper 95-1790-CP.
6. Ahmadikia, H. and Shirani, E., 2001, Transonic and Supersonic Overtaking of a Projectile Preceding a Shock Wave. ICTP Report-IC/2001/48.