Drag coefficient as a function of Mach number for PrawieR5 rocket

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Abstract

This paper presents the results of flow simulations conducted in Solidworks for the PrawieR5 rocket model. The ensuing drag coefficient graphs, as a function of Mach number, are analyzed and compared with Moder exterior ballistics. Additionally, the document discusses the utilized meshes and presents futher information about few choosen simulations.

Nomenclature

ρ	Density of Air
A	Area of cross-section of rocket
C_d	Drag coefficient
k	Specific heat ratio
M	Mach number
p_0	Total pressure
p_d	Dynamic pressure
p_s	Static pressure
v	Relative velocity

1 Problem of drag coefficient

$$\rho + 2 \cdot \sigma = 2568 \pm 46 kg/m^3$$

This basic study does not take into account the complex nature of aerodynamic drag and simplifies drag effect to a one minimal equation for geometric and friction forces. The aim is to establish a singular drag coefficient, treated as a function of Mach number. This study seeks to produce plot resembling those found in Modern Exterior Ballistics for projectiles.

1.1 Basic physics used in study

This study will focus on one drag coefficient, which in this case will be determined with usage of the equation from Modern exterior ballistics[1], which is showed bellow.

$$F_d = C_d \cdot A \cdot \frac{\rho_{air} v^2}{2} \tag{1}$$

1.2 CFD model

As mentioned previously, simulations were conducted using Solidworks Flow Simulations. Initial conditions of simulation:

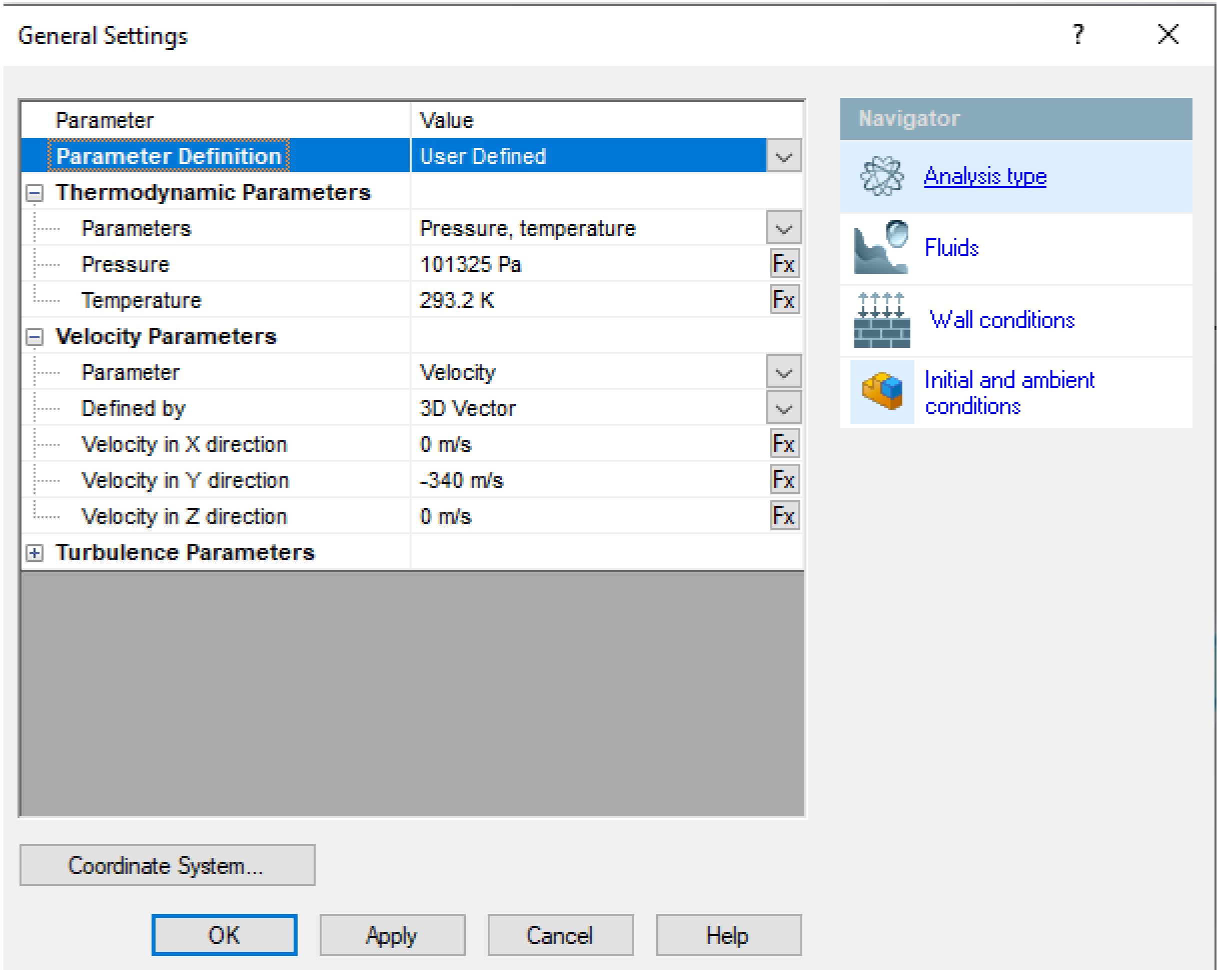

Figure 1: Initial conditions

Mach number change was dependant only on changes in velocity. Depending on the simulation, different meshes were applied for parametric studies at low and high Mach numbers. For high Mach parametric studies (Mach number greater than or equal to 3), the high Mach flow option in Solidworks settings was utilized.

2 Initial studies

2.1 General observations

Initial studies dealt with problem of choosing correct settings for simulations. Most important highlight of this part is that high mach number setting should be choosen only when flow speed is close to Mach 3 or greater. Other big highlight is that Solidworks gives a warning for supersonic flows, but there is nothing we can do about it. It just gives a warning, there seem to be no setting that would get rid of it.

In this sections images of velocity and pressure graphs for high mach setting on will be shown, which later can be compared to high mach setting off, which is correct setting for those speeds. Bellow, reader can find mesh visualization for following simulations.

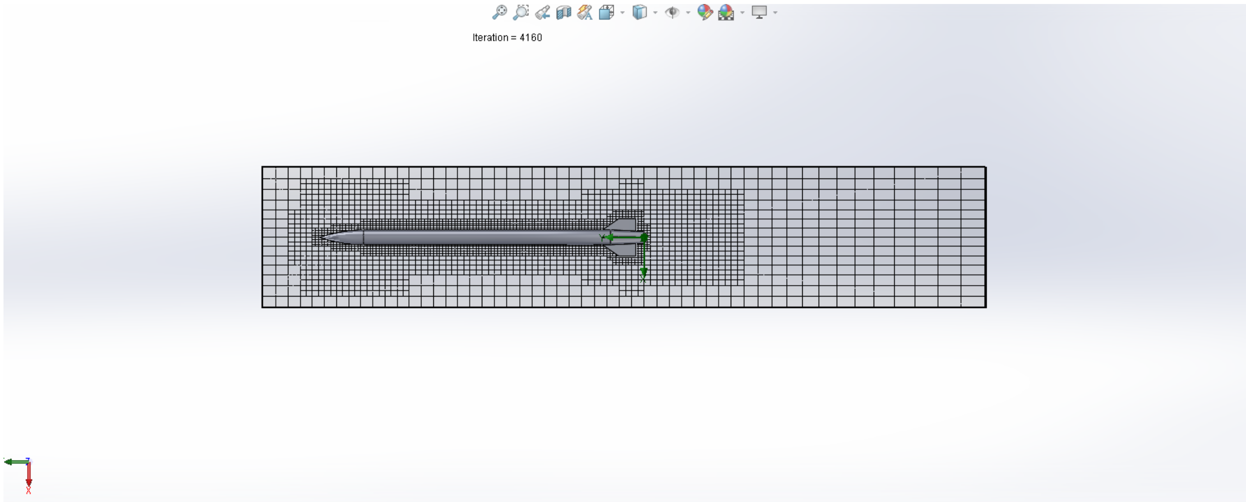

Figure 2: Mesh visualisation

2.2 High mach setting on for Mach 0.8

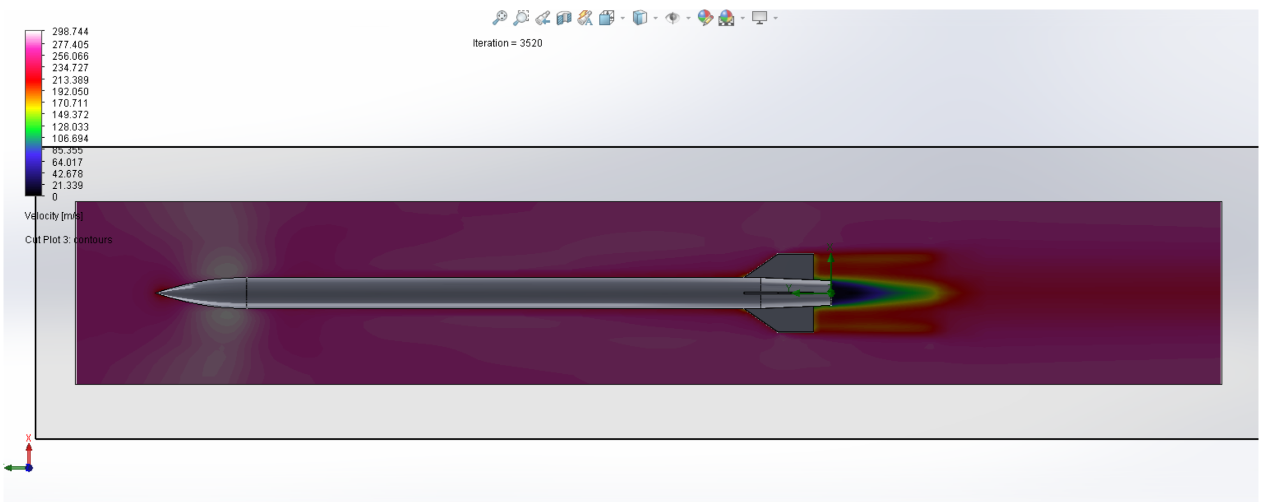

Figure 3: Mach 0.8 velocity graph

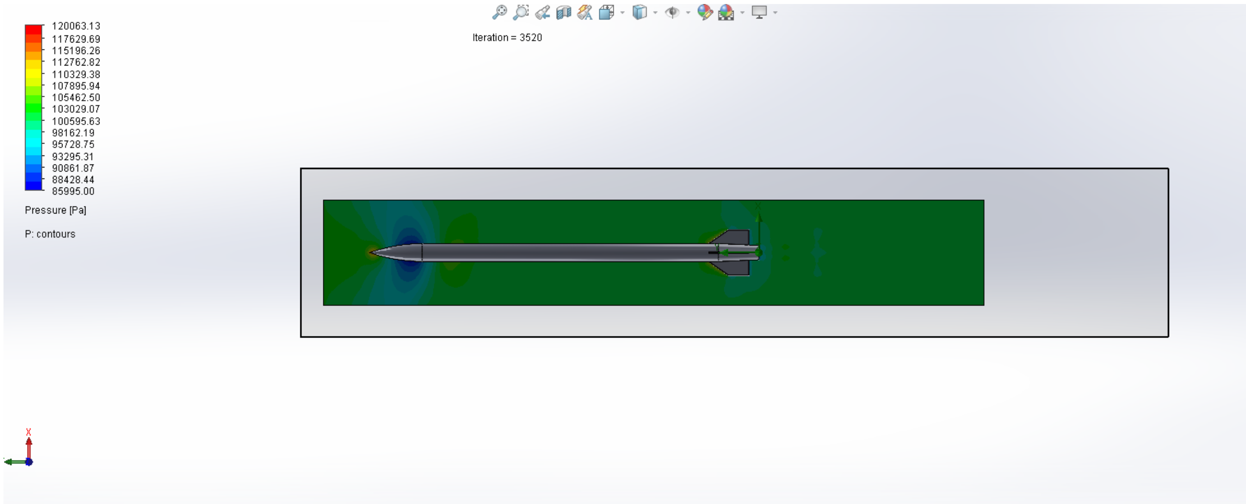

Figure 4: Mach 0.8 pressure graph

2.3 High mach setting on for Mach 1

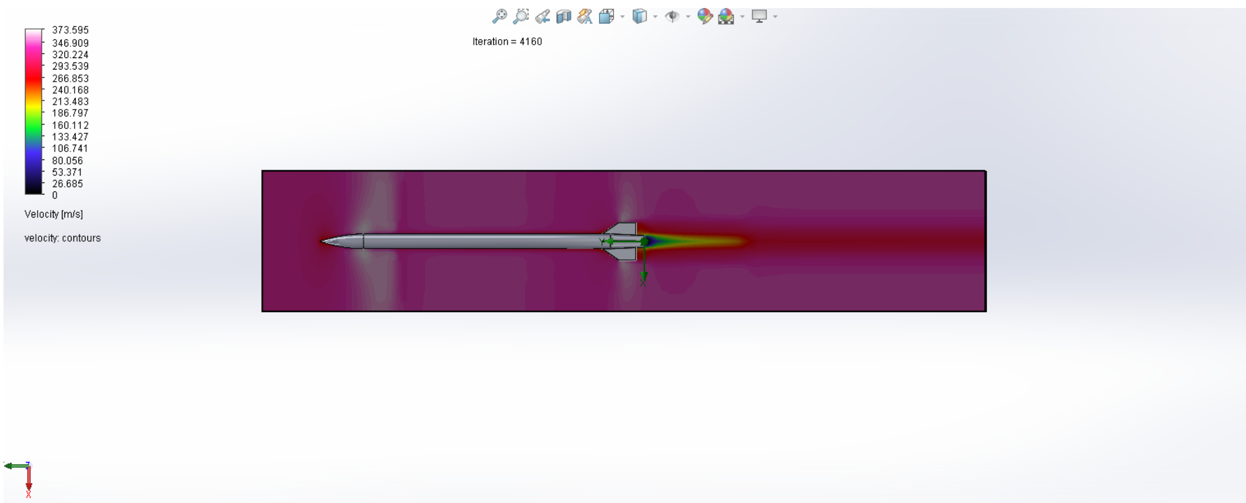

Figure 5: Mach 1 velocity graph

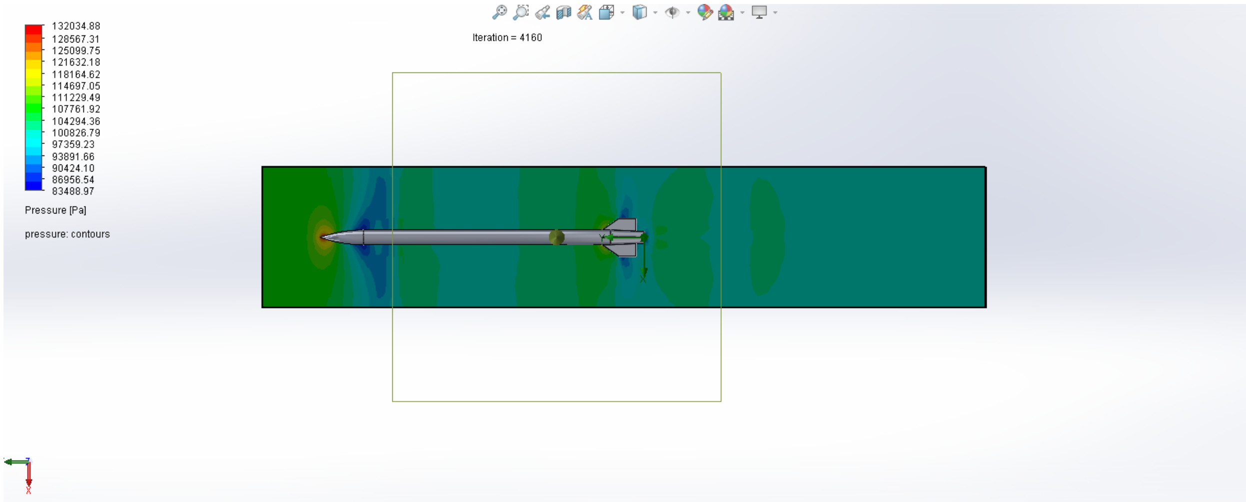

Figure 6: Mach 1 pressure graph

3 Parametric study for low mach

3.1 General information

After testing phase final simulations were conducted. For Range of 0 - 2.5 Mach high mach setting was turned off and new mesh was prepared. Since computational power avaible for the study was relativly small, parametric study was conducted for values of 0.2 - 1.6 Mach with step 0.1 Mach. Two additional points for study were used which were 2.0 and 2.5 Mach.

3.2 Mesh settings

Info

Parameter	Value
Status	Mesh generation finished normally.
Total cells	149,847
Fluid cells	149,847
Fluid cells contacting solids	24,596

Figure 7: Number of cells

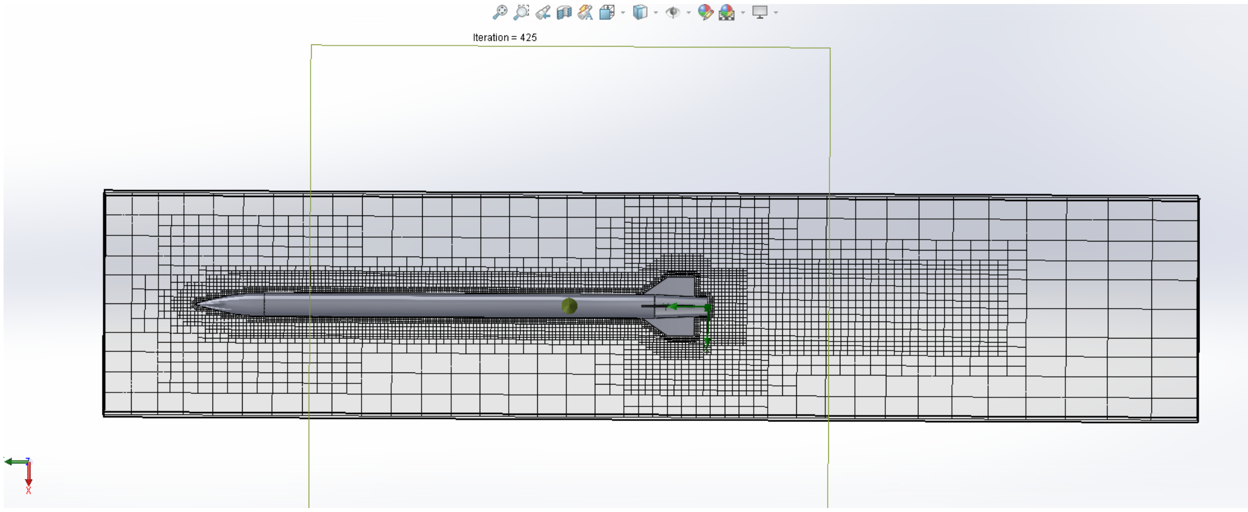

Figure 8: Mesh visualisation

3.3 Mach 1 flow

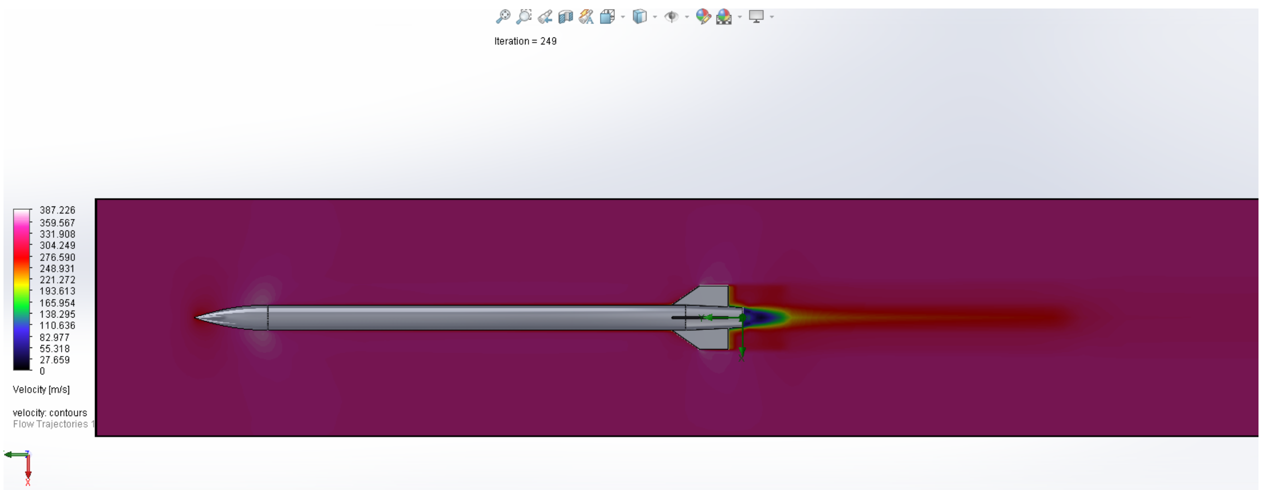

Figure 9: Mach 1 velocity graph

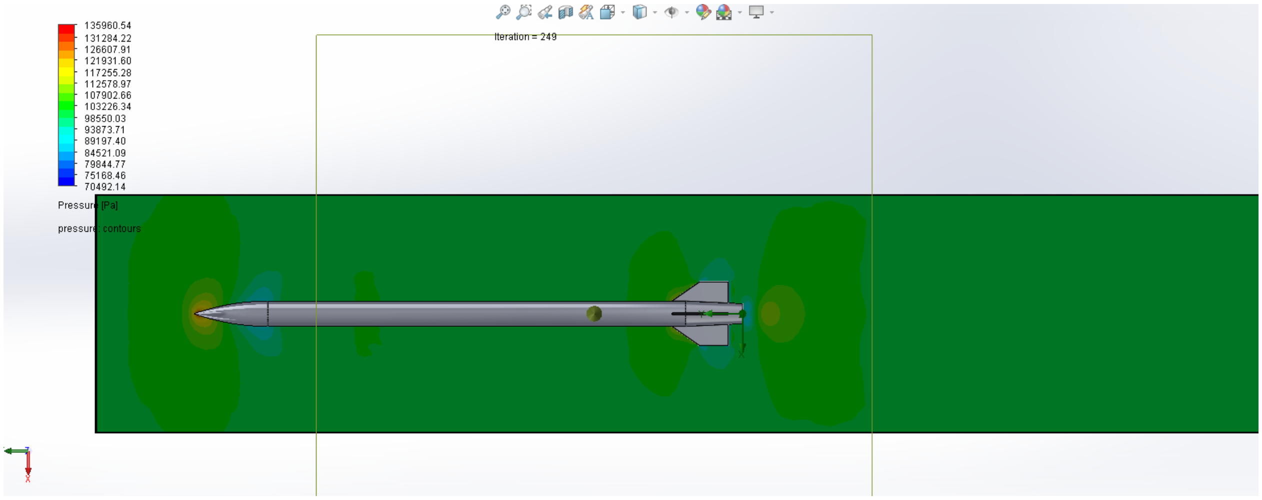

Figure 10: Mach 1 pressure graph

3.4 Mach 1.6 flow

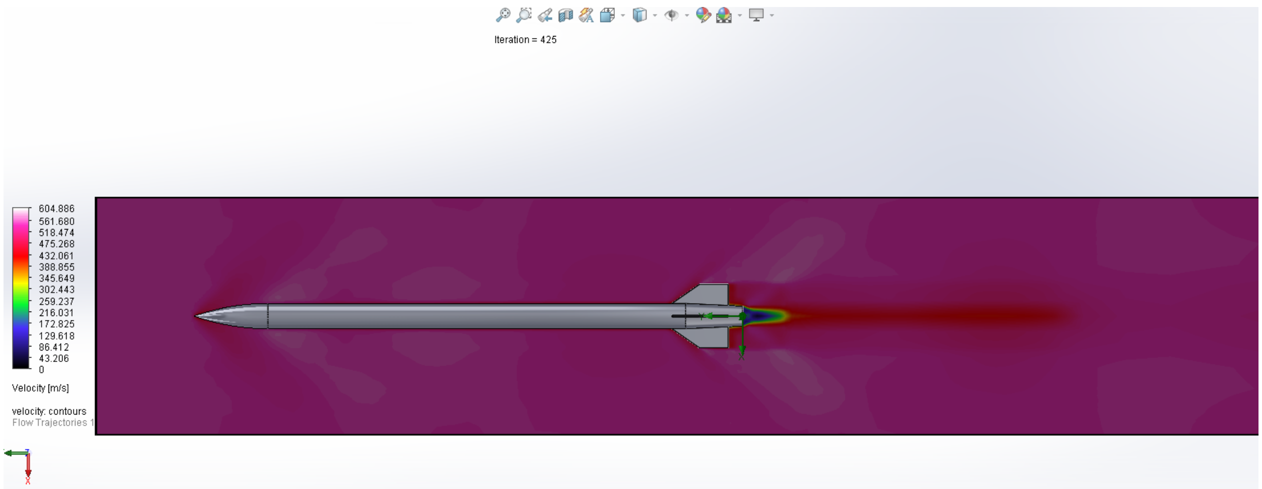

Figure 11: Mach 1.6 velocity graph

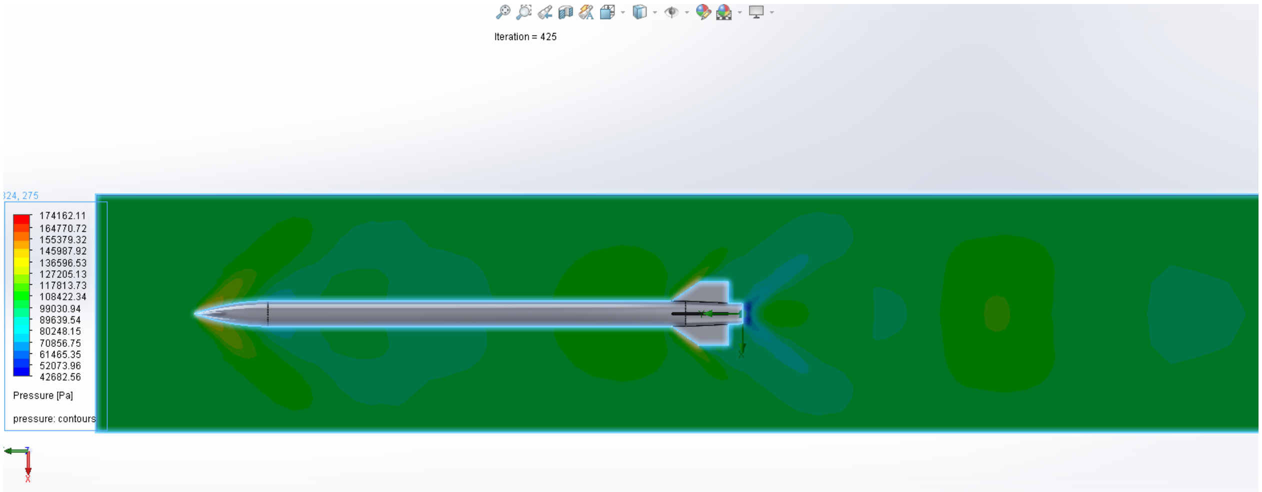

Figure 12: Mach 1.6 pressure graph

3.5 Mach 2.5 flow

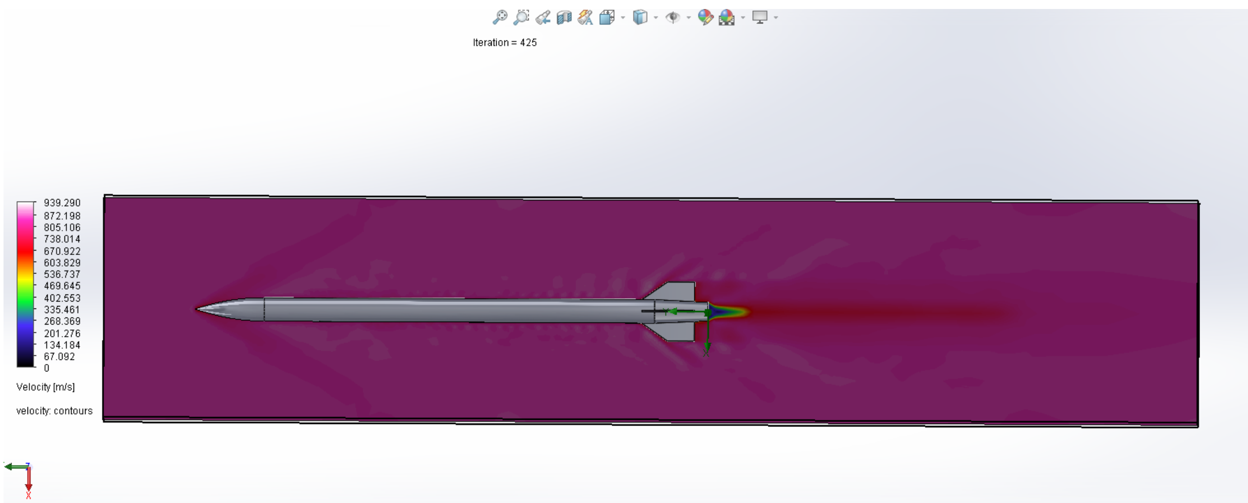

Figure 13: Mach 2.5 velocity graph

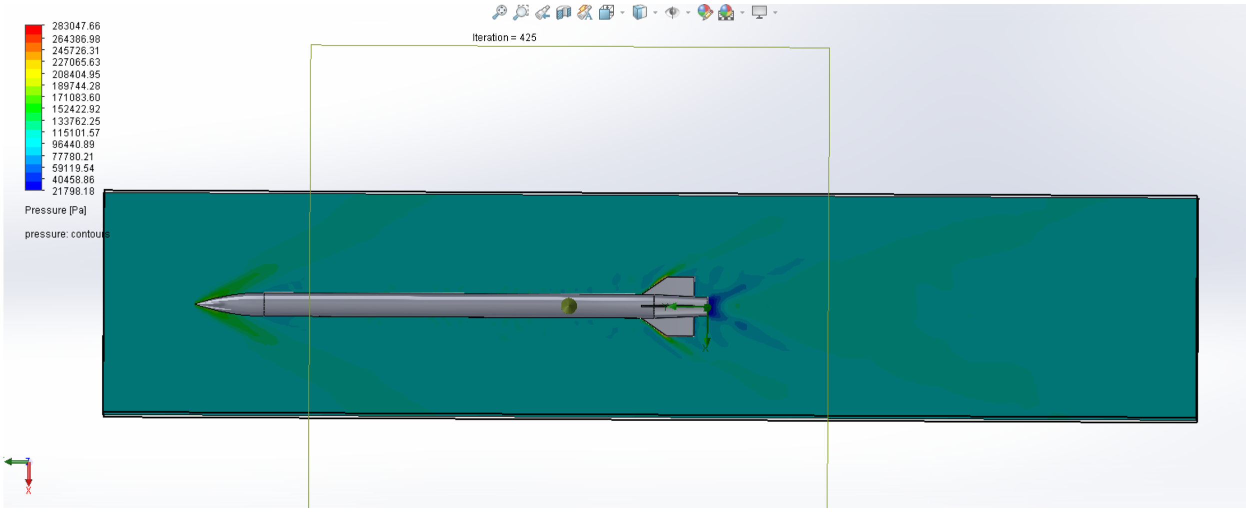

Figure 14: Mach 2.5 pressure graph

4 Parametric study for high mach

This parametric study was once again conducted for limited set of Mach values, starting from 3.0 to 5.0 with step equal to 0.5 Mach. The high mach setting was on for this series of simulations.

4.1 Mach 5 flow

5 Results

5.1 General information

As a result of the parametric studies, tables of data were obtained. You can find them in Tables folder in repository. Later, from those tables drag coefficients were calculated and using OriginPro plots of data were obtained. You can find those beneath.

5.2 Analysis of results

Final graph for values of 0.2 to 5 Mach is very similar to graph for computed rocket type projectile in Modern exterior ballistics[1]. Differences in values of our study to study there are insignificant and could be attributed to slight differences in geometires of those projectiles. It's especially visible for 0.2 to 0.8 Mach range, where graph for PrawieR5 rocket is more similar to graphs of projectiles with similar nose cone.

However simulated data of this study has two unexpected values, one is for Mach 1.3 and other for Mach 2.5. In this points odd fluctuation can be seen, which could be most likely attributed to Soliworks Fluid Simulations miscalculations or is some kind of characteristic value for this specific geometry.

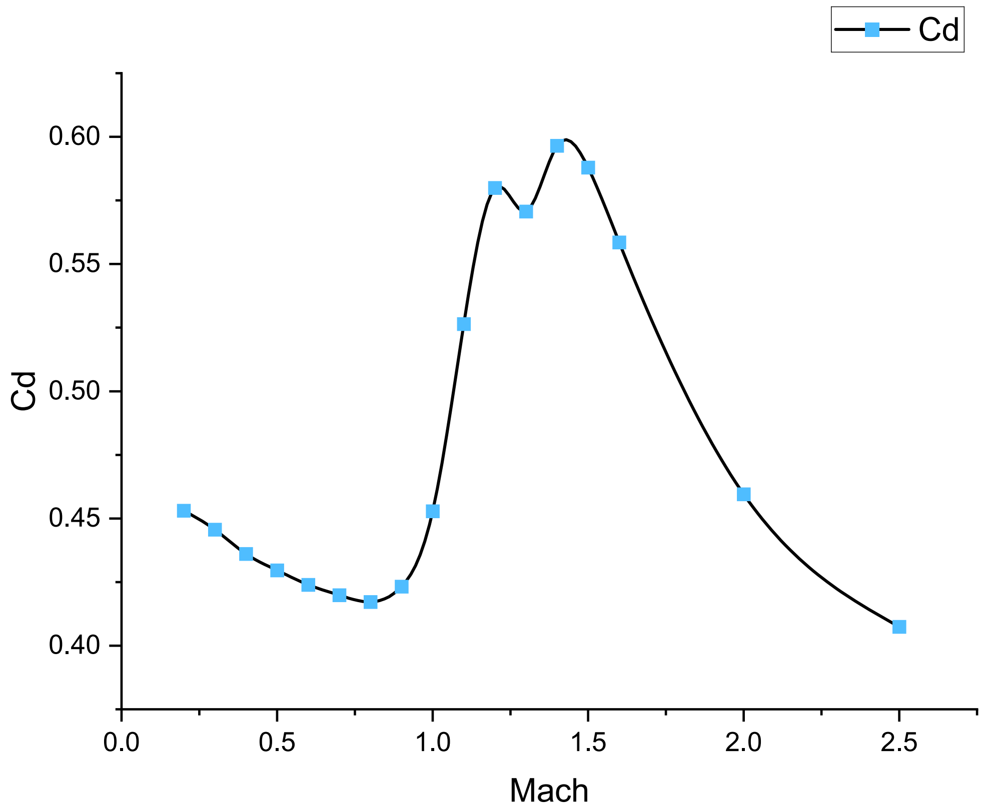

Figure 15: Graph of drag coefficient for range of 0.2 - 2.5 Mach

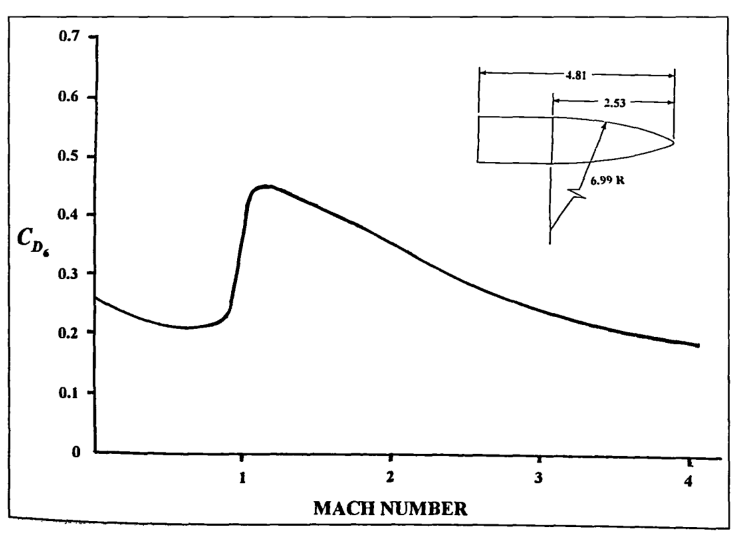

Figure 4.3 Drag Coefficient versus Mach Number for Projectile Type 6.

Figure 16: Graph of drag coefficient for projectal with similar noze cone geometry[1]

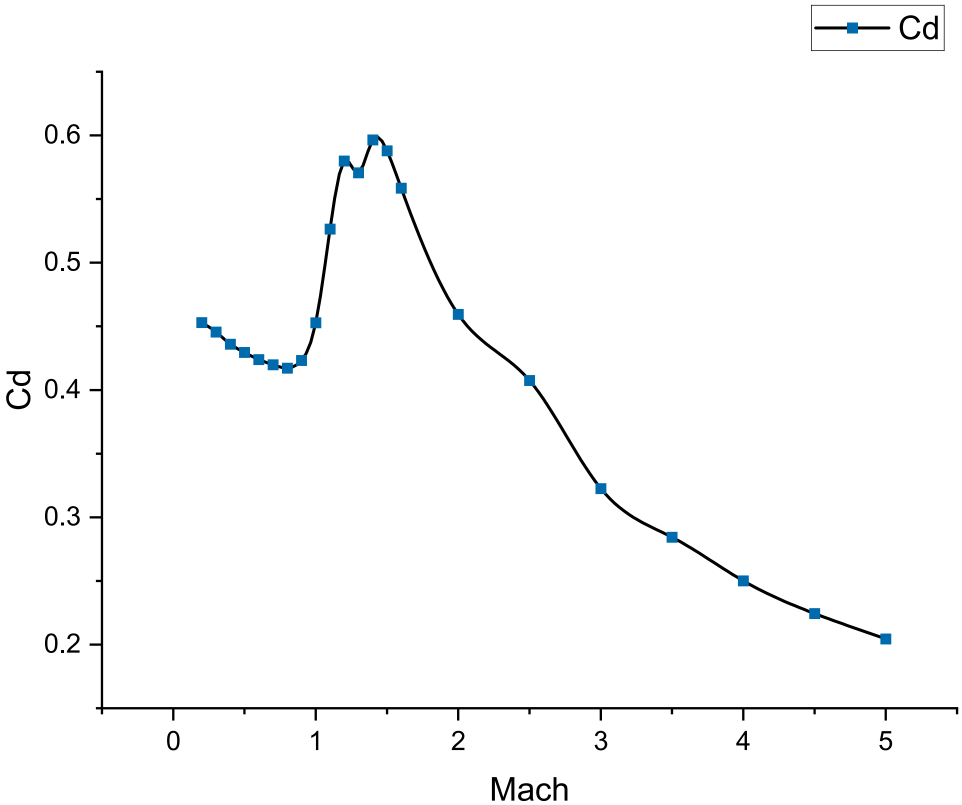

Figure 17: Graph of drag coefficient for range of 0.2 - 5 Mach

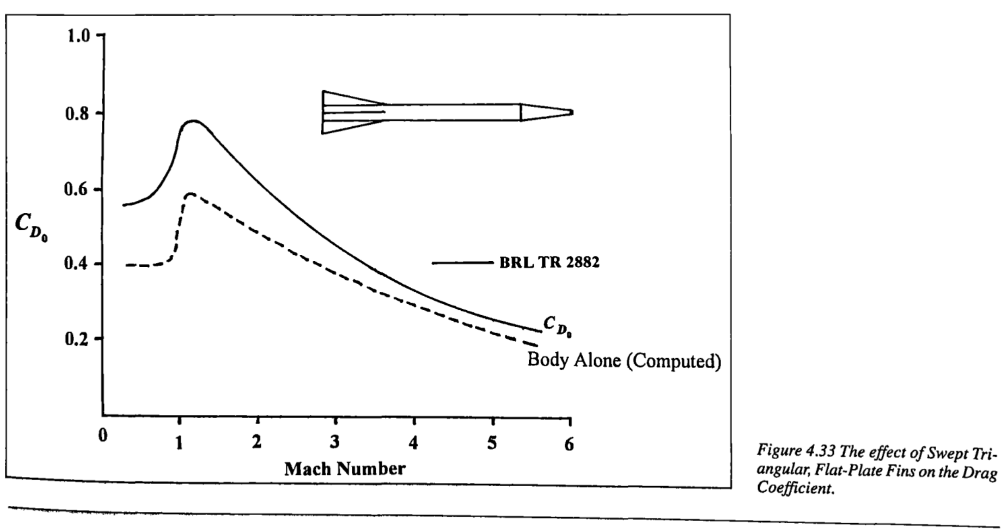

Figure 18: Graph of drag coefficient for rocket type projectal[1]

References

[1] Robert L. McCoy (1999) Modern Exterior Ballistics: The Launch and Flight Dynamics of Symmetric Projectiles, Schiffer Military History