1 Introduction

1.1 The problem of aerodynamic drag

Dlaczego badamy oraz wzór na opór aerodynamiczny. Że bazujemy na modern exterior balistics i jakieś inne z literatury bo to łądnie brzmi.

1.2 Methodology of the present work

For simulations, two programs were chosen to compare the results. The first program, Solidworks Flow Simulation, was used for both CFDs and model preparation. The second program utilized was Ansys Fluent.

Initially, the models were prepared in Solidworks and subsequently exported to .step (214) file format for importation into Ansys. Within Ansys, Fluent with Meshing was used to prepare the mesh, followed by the execution of simulations. Solidworks Flow Simulation was also employed for mesh preparation and simulation execution, enabling subsequent comparison with results obtained from Ansys Fluent.

Parametric studies/sets were conducted for all models, encompassing nine different velocities ranging from 0.1 to 1.0. Subsequently, resulting graphs depicting the drag coefficient versus Mach number were analyzed and compared.

1.3 Tested models

R6-Endcone, R6-No-Endcone, PrawieR5

For each set of simulations, computational domain mesh setting and graph of velocity and pressure for 0.6 mach will be shown.

2 Initial study

The work was initiated with the remodeled R5 model, which had been prepared in Solidworks and featured an endcone, a modification in comparison to the original R5 model. Subsequent testing of the model was conducted using Solidworks Flow Simulation. However, this model was solely utilized for comparing the results of the older model with the new one. The results can be observed here

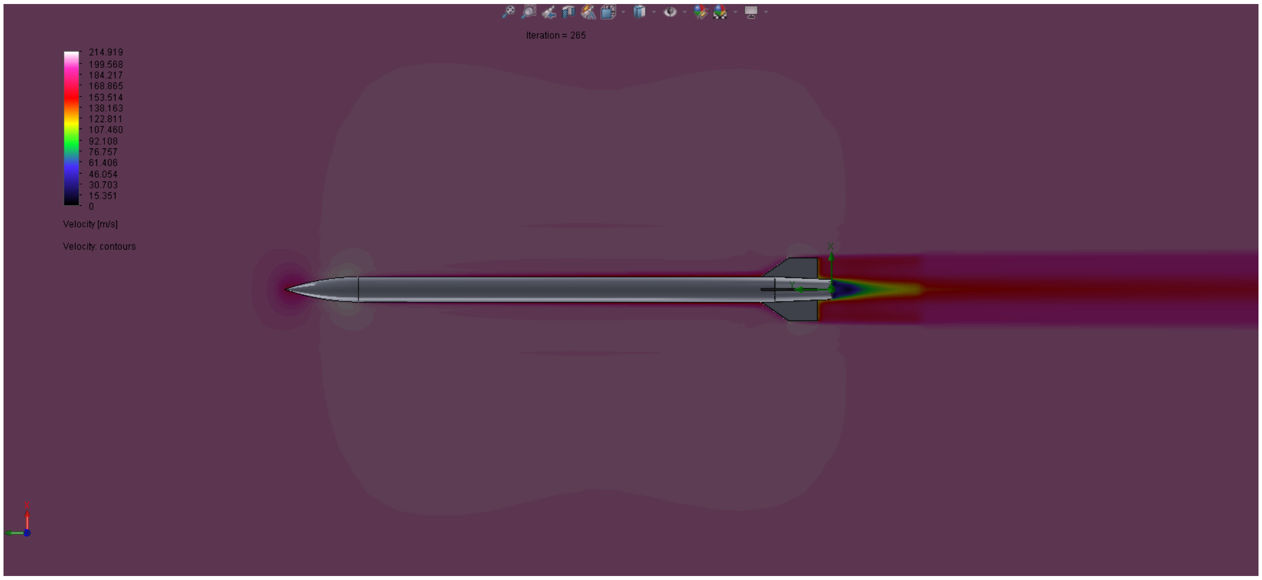

Figure 1: Velocity graph for PrawieR5 model at Mach 0.6

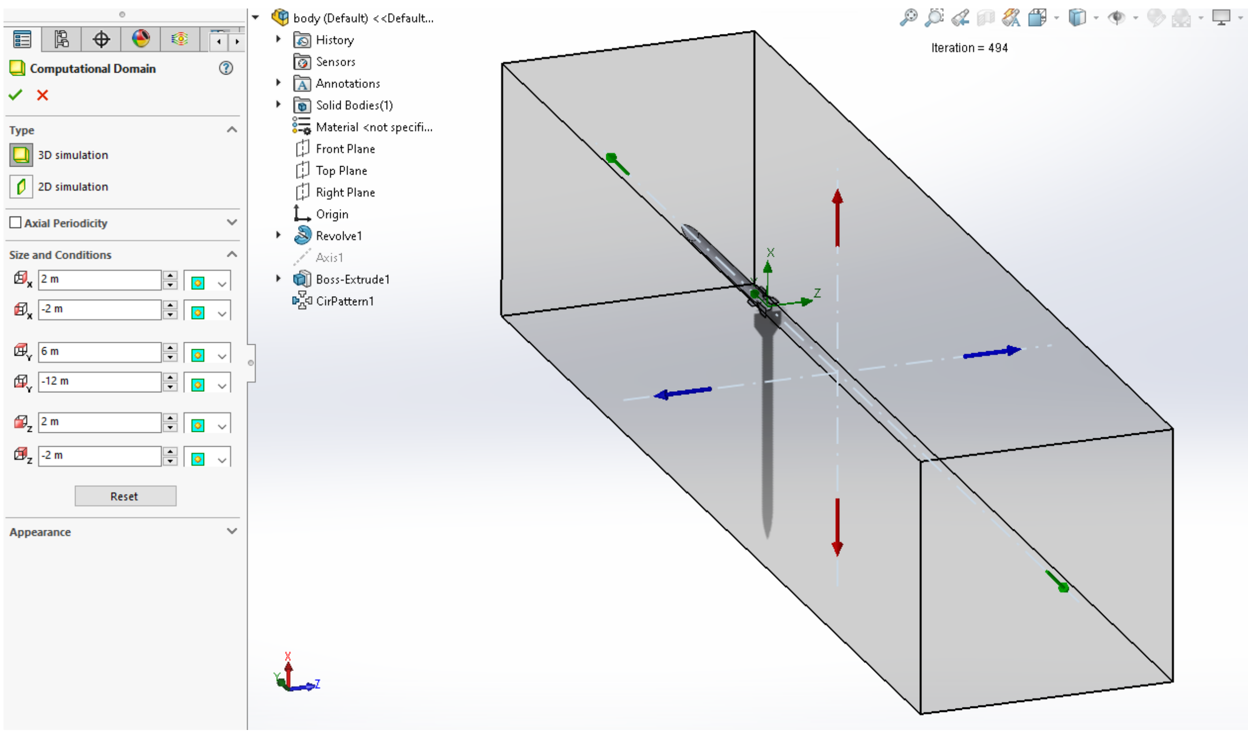

Figure 2: CD graph for PrawieR5 model at Mach 0.6

3 Preliminary research of endcone effect in Solidworks

3.1 R6 Endcone

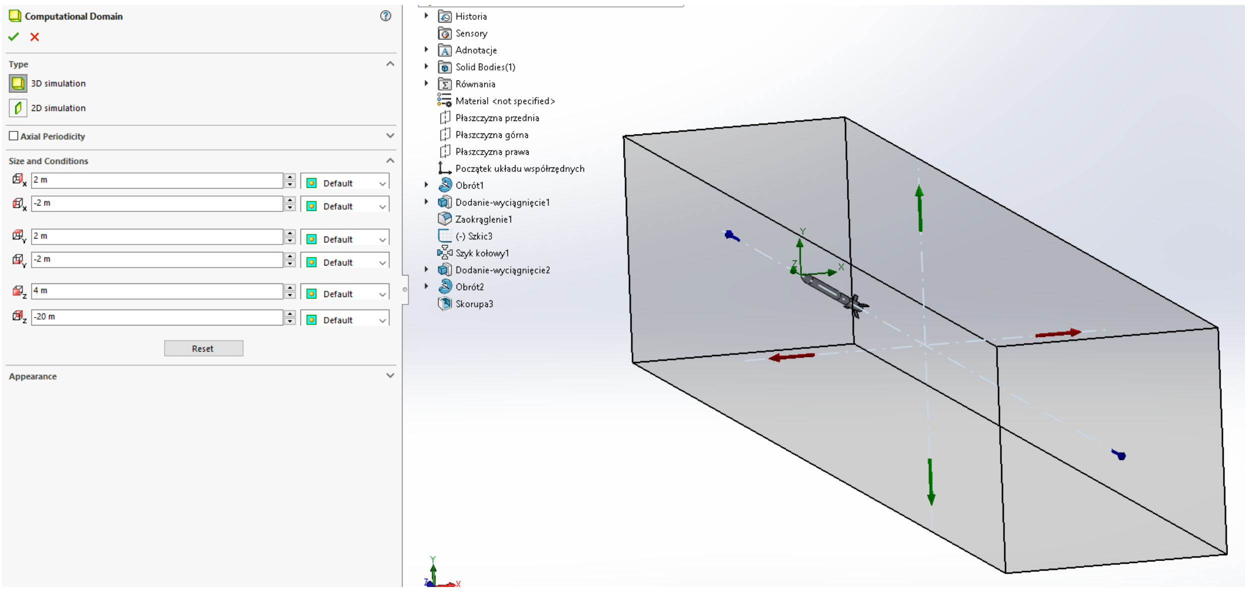

Figure 3: Computational domain for R6-Endcone model

Total cells	351,913
Fluid cells	351,913
Fluid cells contacting solids	51,217

Figure 4: Cell number for R6-Endcone model

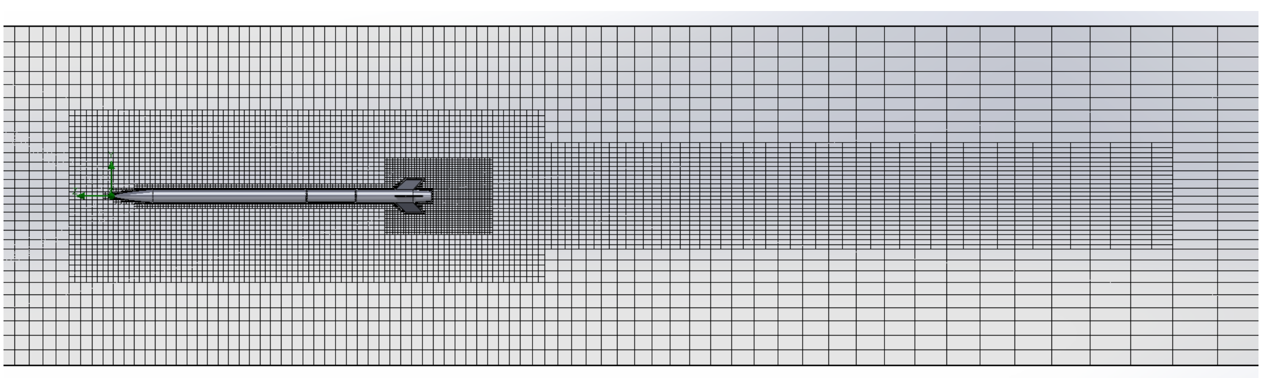

Figure 5: Mesh for R6-Endcone model

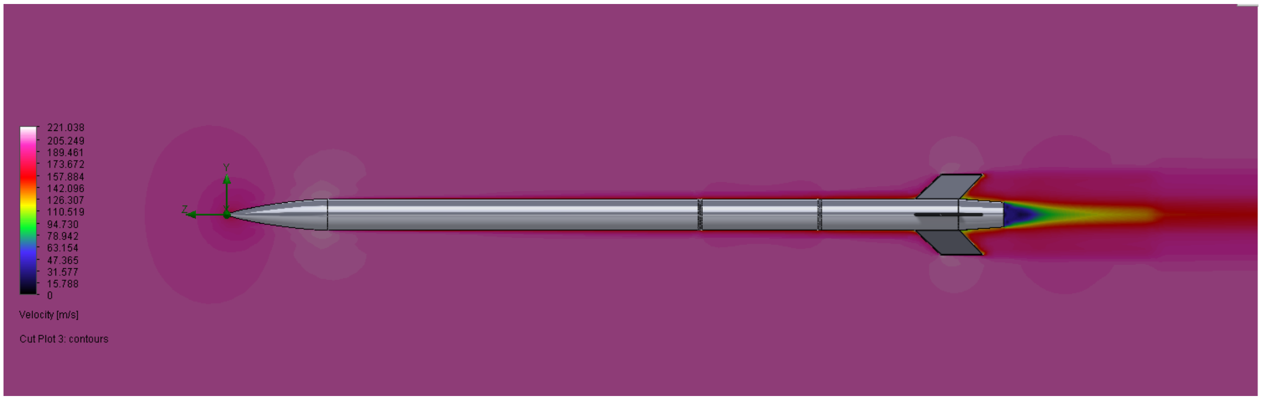

Figure 6: Velocity graph at 0.6 Mach for R6-Endcone model

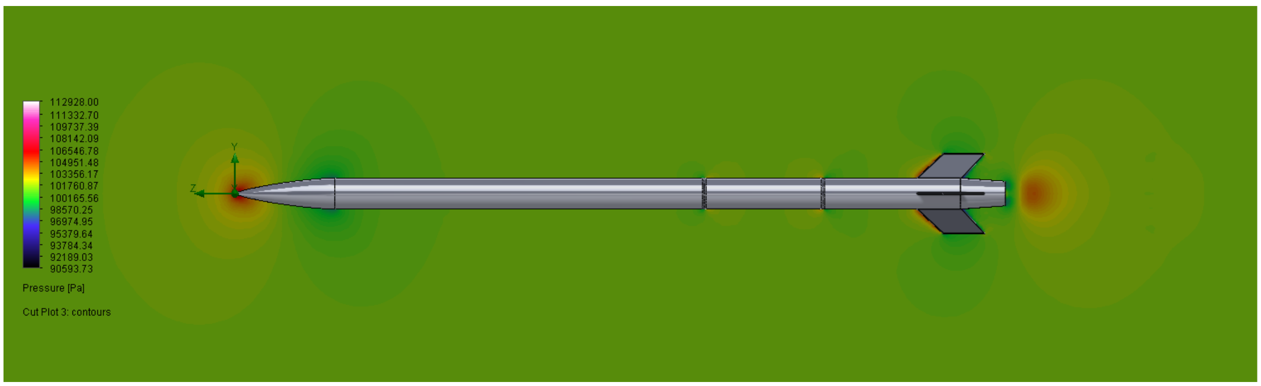

Figure 7: Pressure graph at 0.6 Mach for R6-Endcone model

3.2 R6 No Endcone

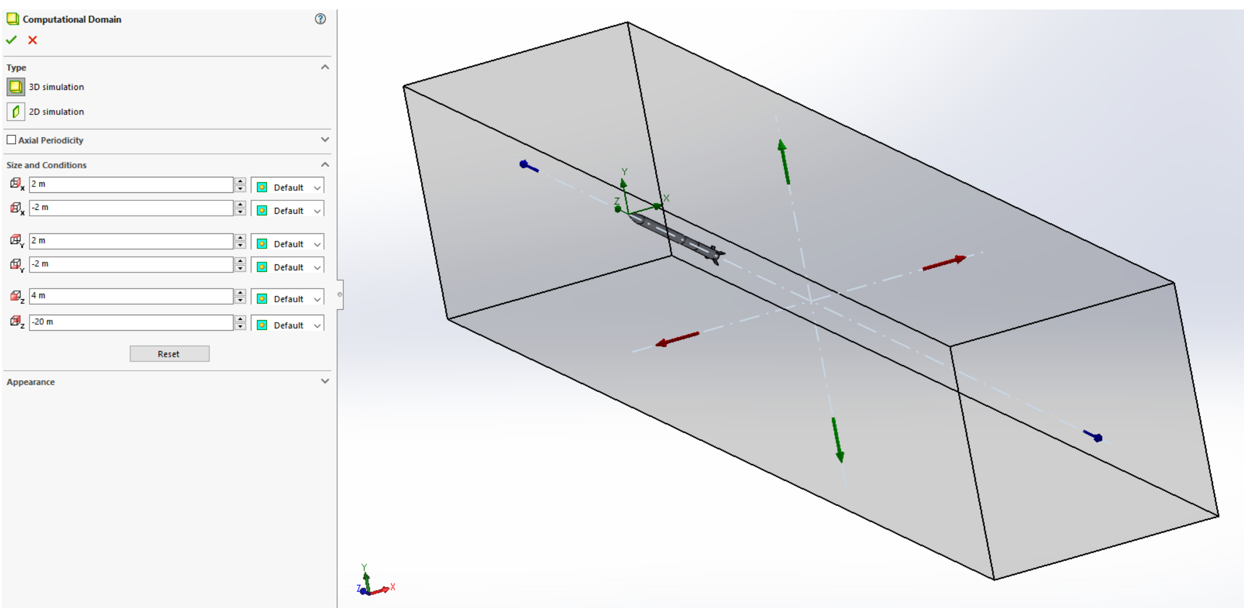

Figure 8: Computational domain for R6-NoEndcone model

Total cells	475,197
Fluid cells	475,197
Fluid cells contacting solids	74,456

Figure 9: Cell number for R6-NoEndcone model

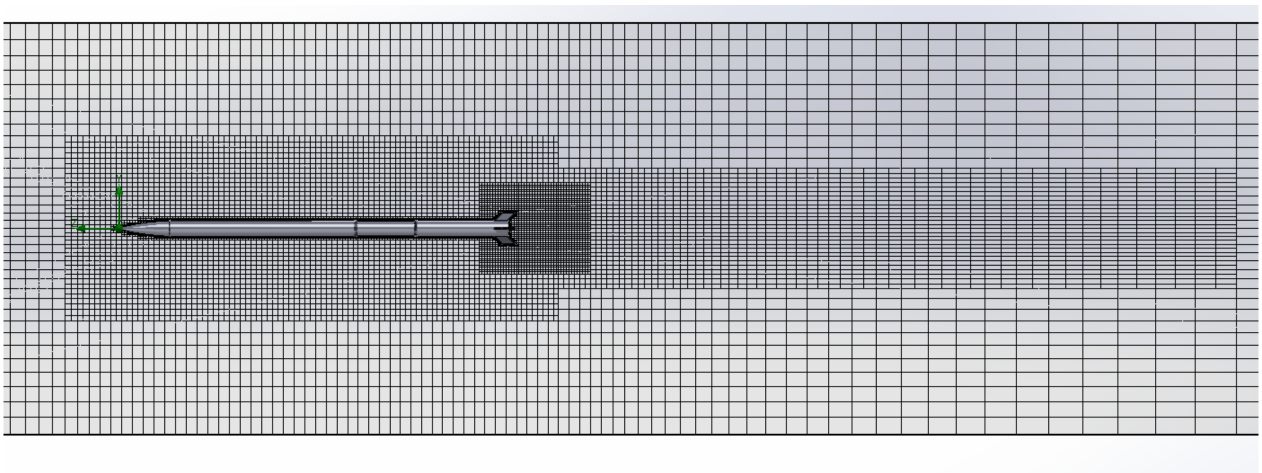

Figure 10: Mesh for R6-NoEndcone model

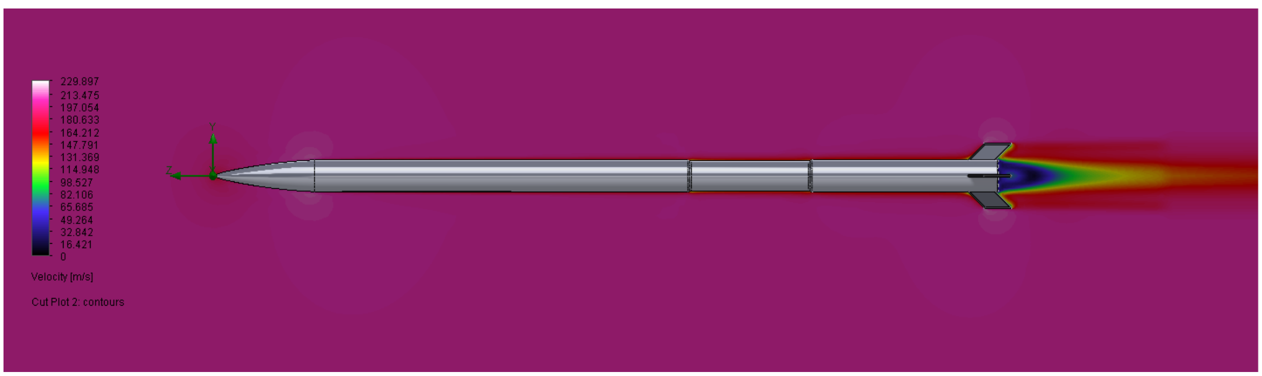

Figure 11: Velocity graph at 0.6 Mach for R6-NoEndcone model

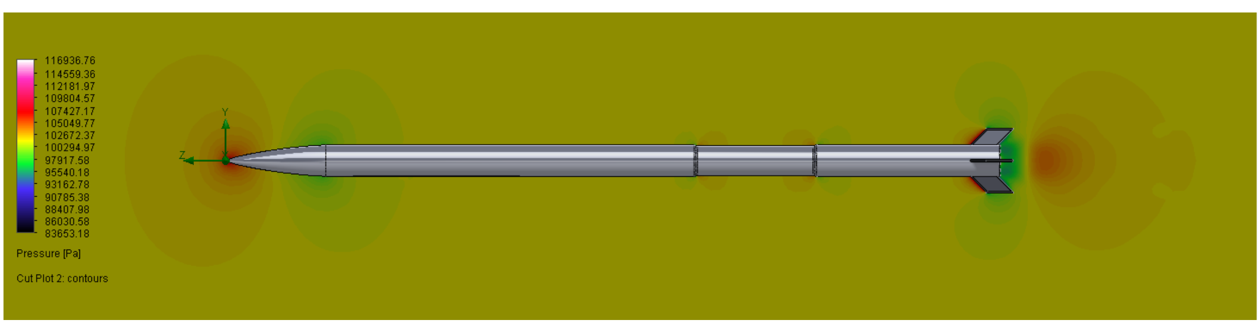

Figure 12: Pressure graph at 0.6 Mach for R6-NoEndcone model

3.3 Results of the preliminary research

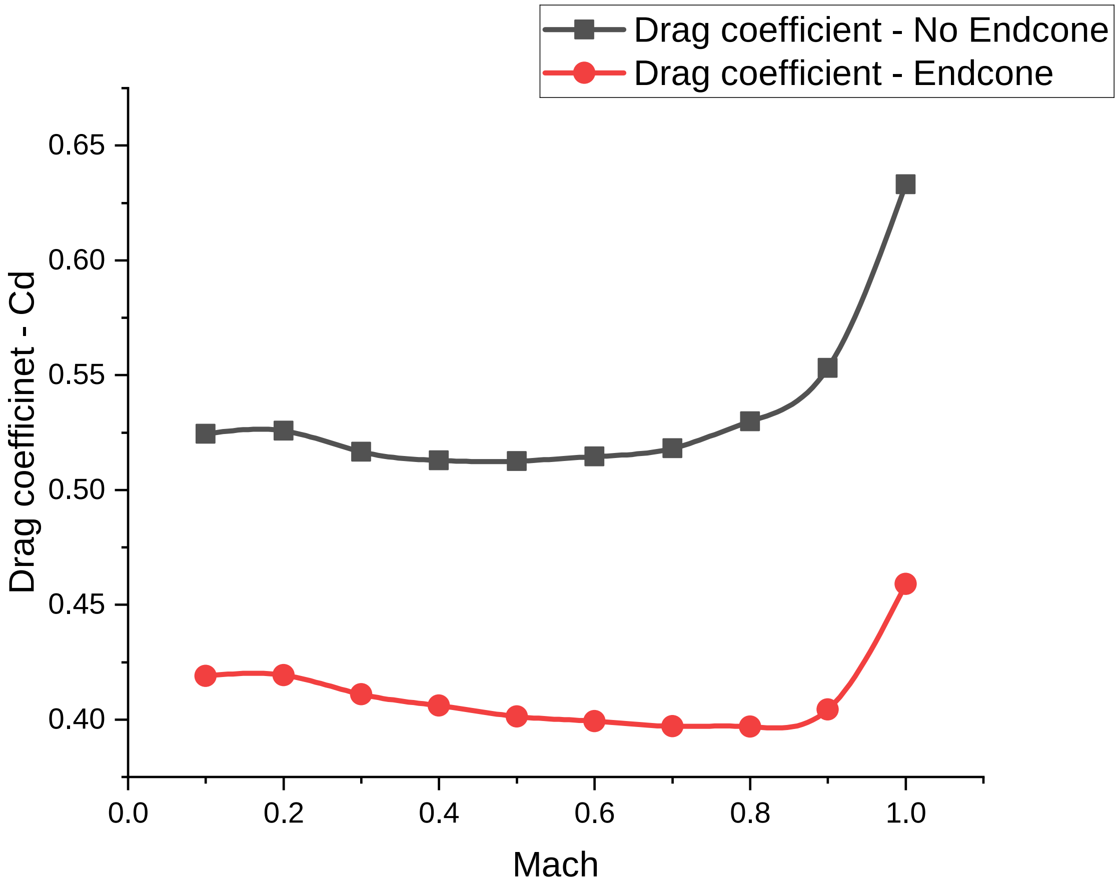

Figure 13: CD graph of R6-Endcone and R6-NoEndcone models

Preliminary research indicates that the endcone model exhibits significantly lower drag coefficient for 8 degrees endcone angle, while keeping trends of change on the chart. Even more, for endcone model the trans sonic spike starts later compared to no endcone model. This would be very beneficial for the range of 0.6-0.9 Mach.

Table 1: Average values and differences

	R6 Endcone	R6 No Endcone	Difference	% Difference
0.1 - 1.0 Mach	0.411	0.534	0.123	29.8%
0.1 - 0.6 Mach	0.409	0.518	0.108	26.5%

For a range of 0.1 to 0.6 Mach, the endcone model exhibited a 26% lower drag coefficient in comparison to the no endcone model. This is a significant difference, indicating that the endcone model is much more aerodynamically efficient.

4 Oplitmalization of the endcone in Solidworks

4.1 Range and goal of this study

The goal of this study was to find a minimum of the average drag force function, depending on the endcone angle, which was coupled to the lenght of the endcone. The range of the study was from 0 to 15 degrees, with a step of 1 degree. For each angle, simulations were preformed for 0.1 to 0.6 Mach, with a step of 0.1 Mach. In total 96 simulations were made.

Finding minimum of the average drag force function is crucial for the optimalization of the rocket since that would allow to reduce the drag force acting on the rocket, which would result in overall better performance of the rocket.

4.2 Results and discussion

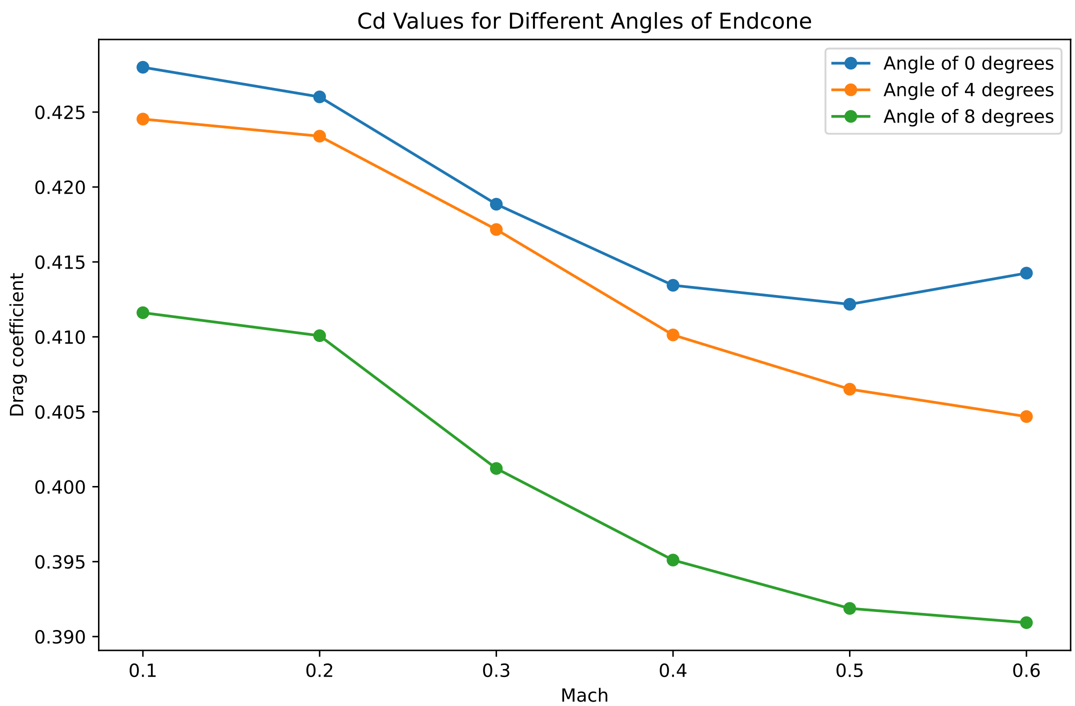

Figure 14: Example of CD graphs for different endcone angles

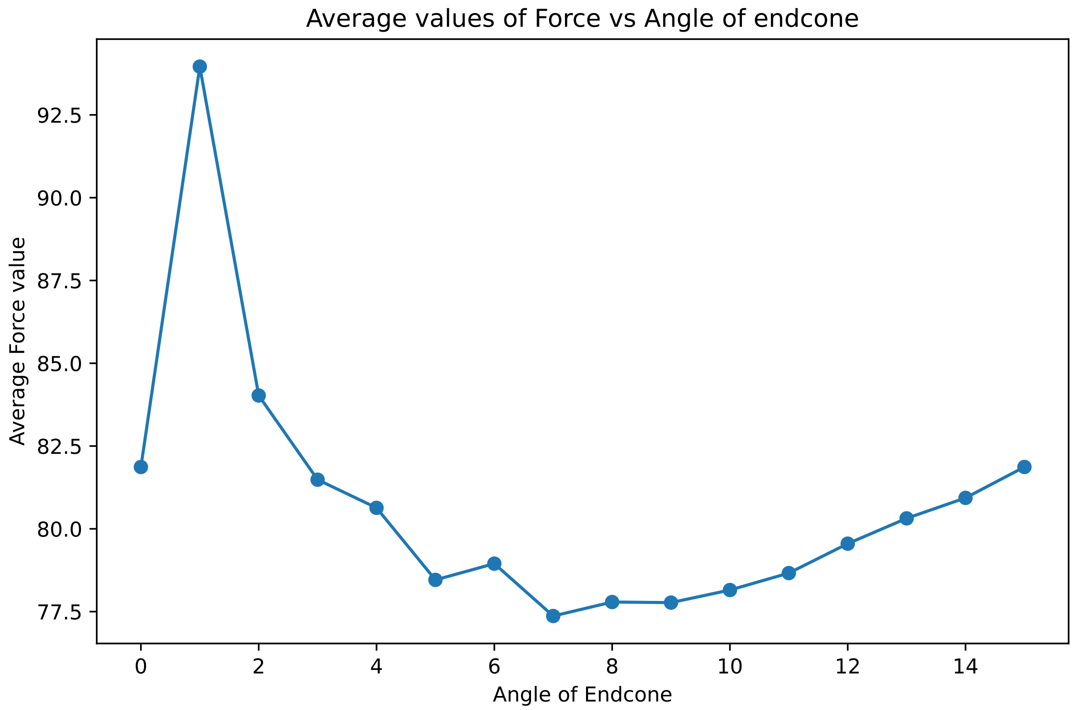

Figure 15: Average Force vs Angle graph

As we can see, the minimum of the average drag force function is at 7 - 9 degrees. We can also observe a trend of the function, which is decreasing for the range of 1 to 7 degrees and increasing for the range of 9 to 15 degrees.

Spike at 1 degree is also worth mentioning, it may be true value at this point or just a result of the simulation error. This would require further research to determine the true value, however it is not crucial for the optimalization of the rocket, since it is very unlikely that minimum could be found there.

5 Optimalization of the endcone in Ansys Fluent

1. What we did - optimalization depending on angle - 0.1 - 0.6 Mach and 1 or 2 degree step for some range.
2. Stability changes depending on angle - Graph from OpenRocket
3. Domain and Mesh, Speed and Pressure graphs for 0.6 Mach
4. Results and discussion - mention that endcone is 4 degrees because of manufacture.

6 Optimalization fin sweep angle in Ansys Fluent

1. What we did - optimalization depending on angle - 0.1 - 0.6 Mach and 1 or 2 degree step for some range. This all for 4 degree endcone angle.
2. Stability changes depending on angle - Graph from OpenRocket
3. Domain and Mesh, Speed and Pressure graphs for 0.6 Mach - BEST SAME AS BEFORE
4. Results and discussion, mention that the final results can be

7 Summary and discussion

Results were great success, unlukcy with endcone being 4 degrees, but still great.