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

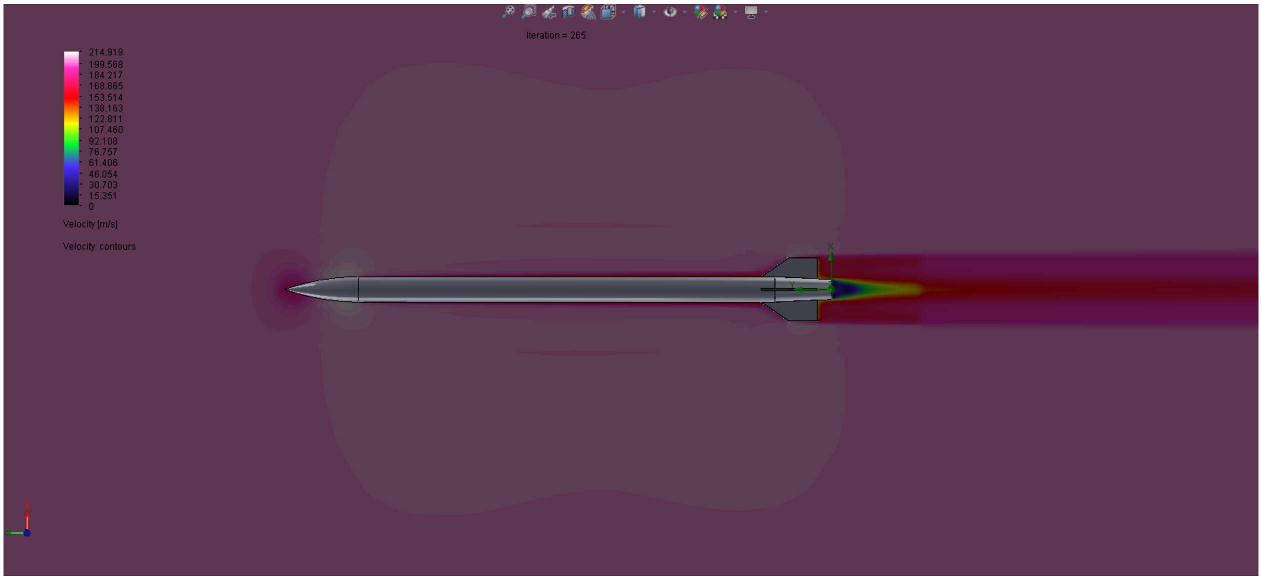

Figure 1: Velocity graph for PrawieR5 model at Mach 0.6

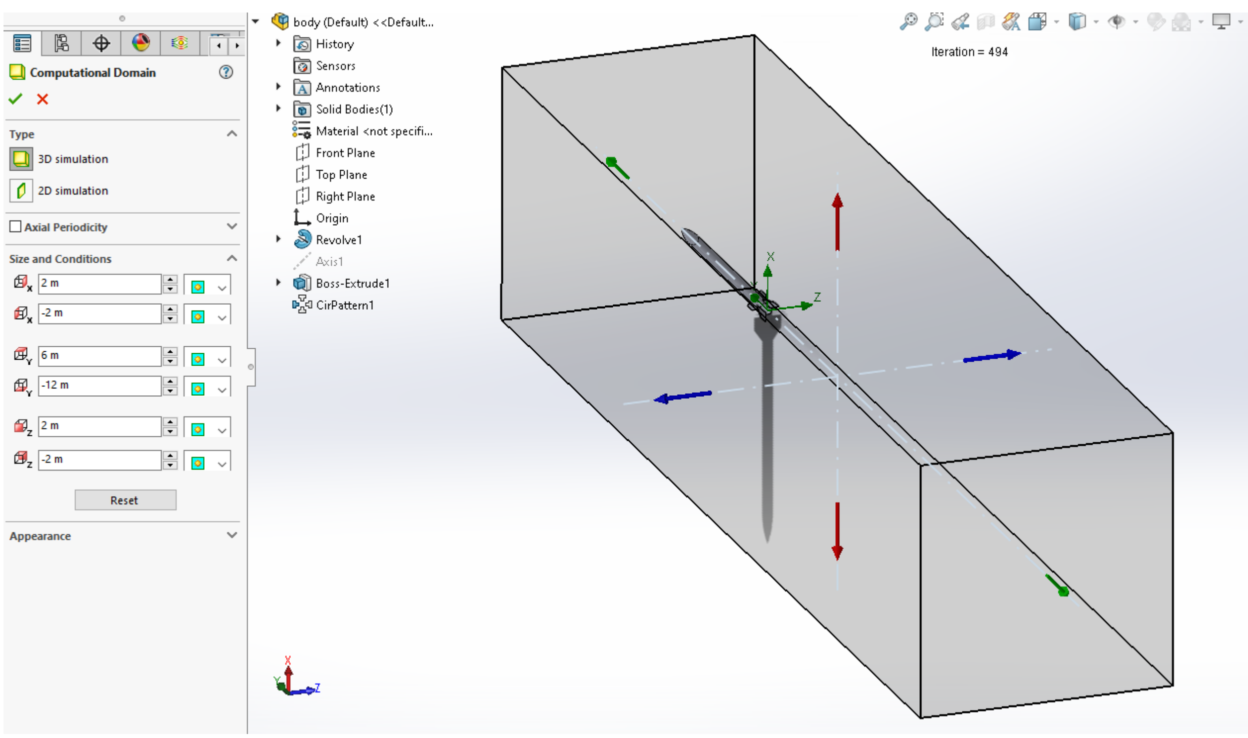

Figure 2: CD graph for PrawieR5 model at Mach 0.6

3 Preliminary research of endcone effect in Solidworks

3.1 R6 Endcone

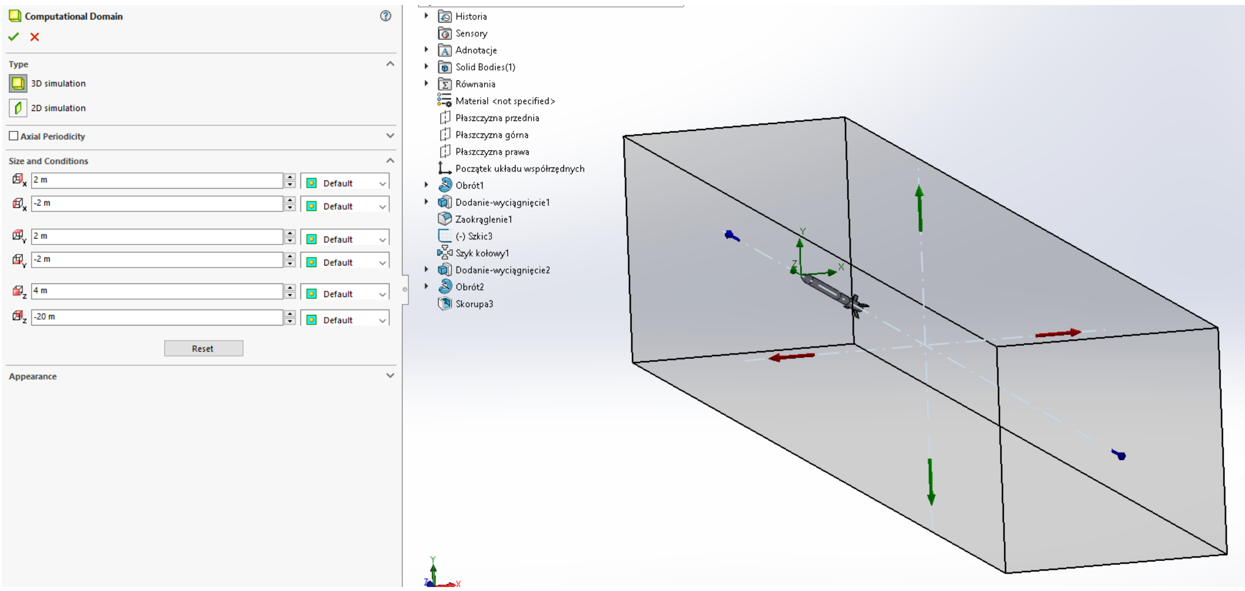

Figure 3: Computational domain for R6-Endcone model

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

Figure 4: Cell number for R6-Endcone model

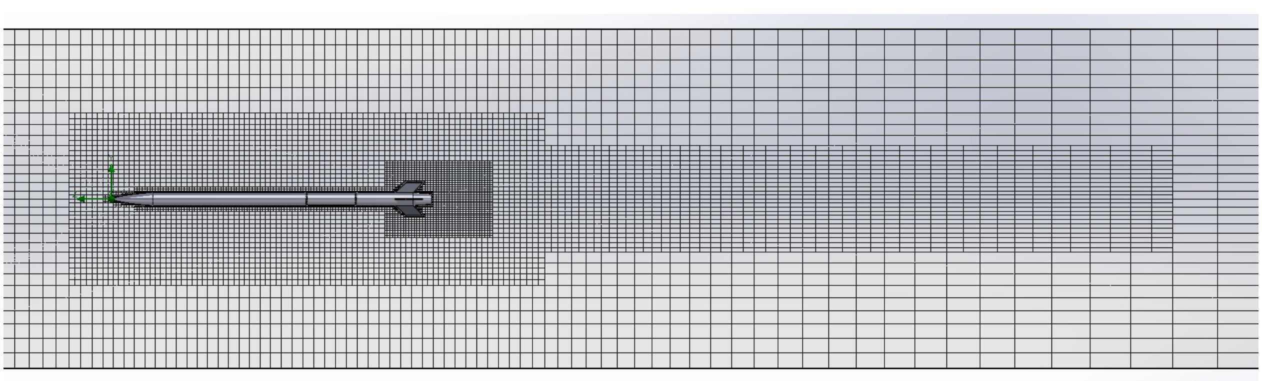

Figure 5: Mesh for R6-Endcone model

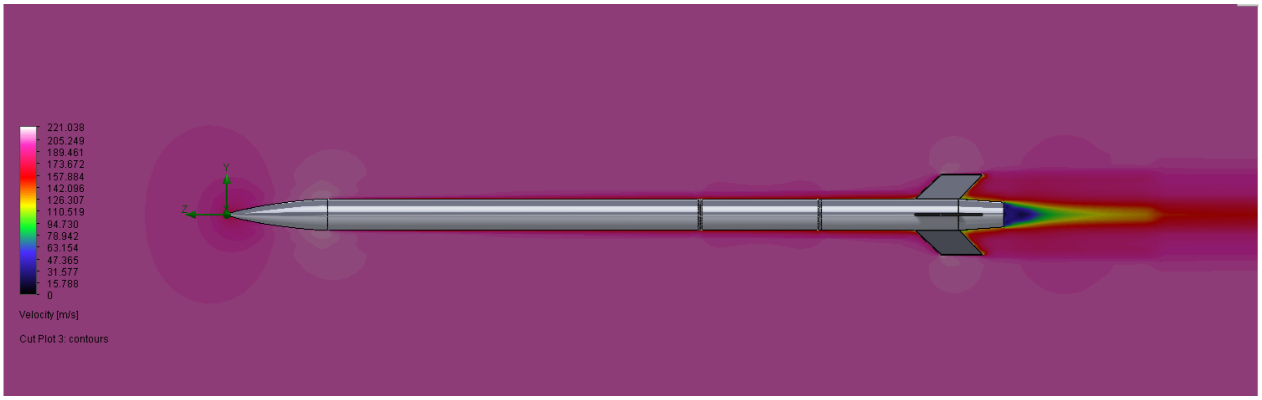

Figure 6: Velocity graph at 0.6 Mach for R6-Endcone model

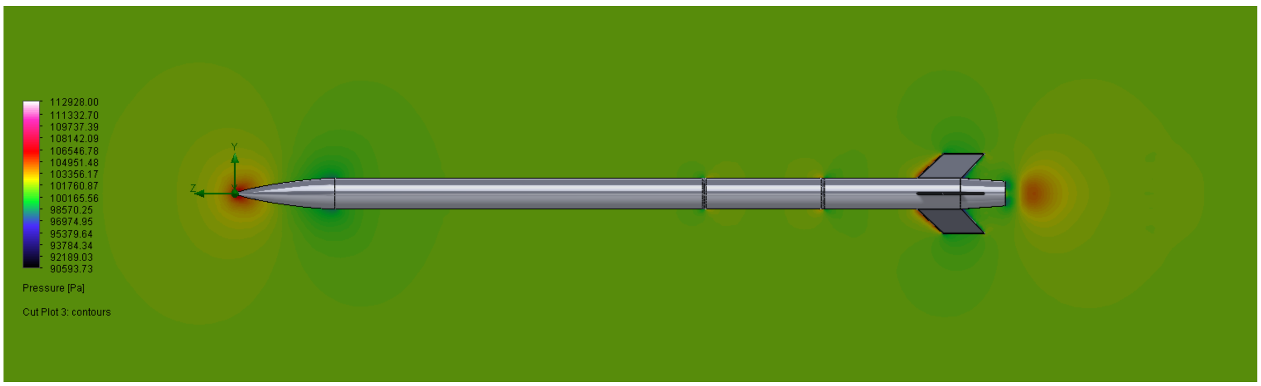

Figure 7: Pressure graph at 0.6 Mach for R6-Endcone model

3.2 R6 No Endcone

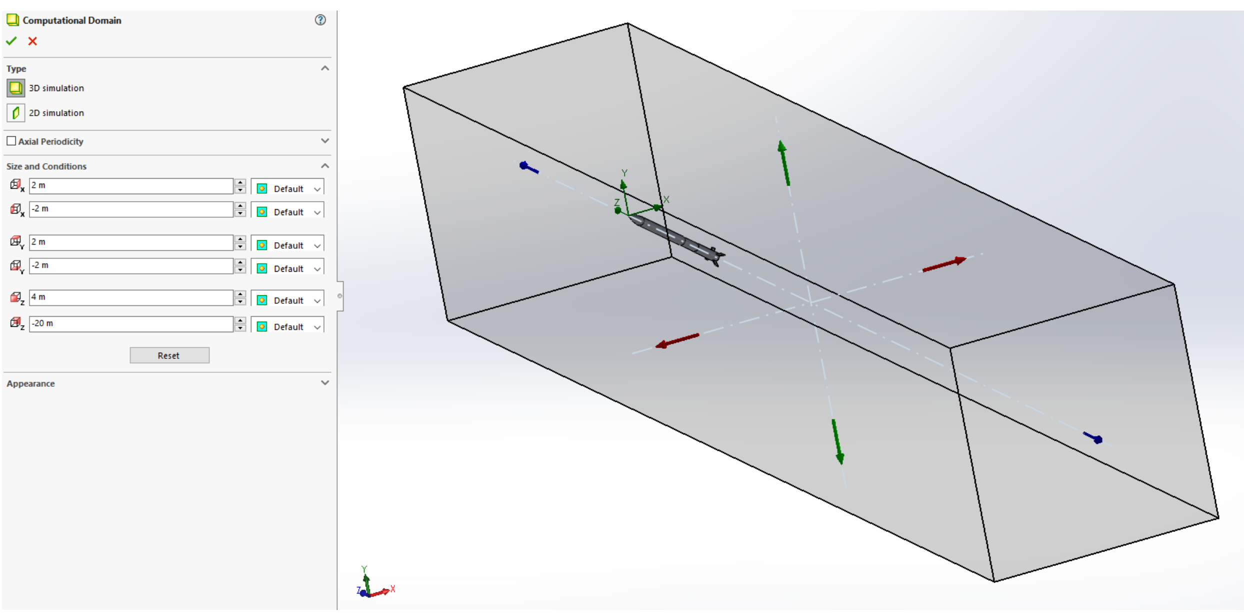

Figure 8: Computational domain for R6-NoEndcone model

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

Figure 9: Cell number for R6-NoEndcone model

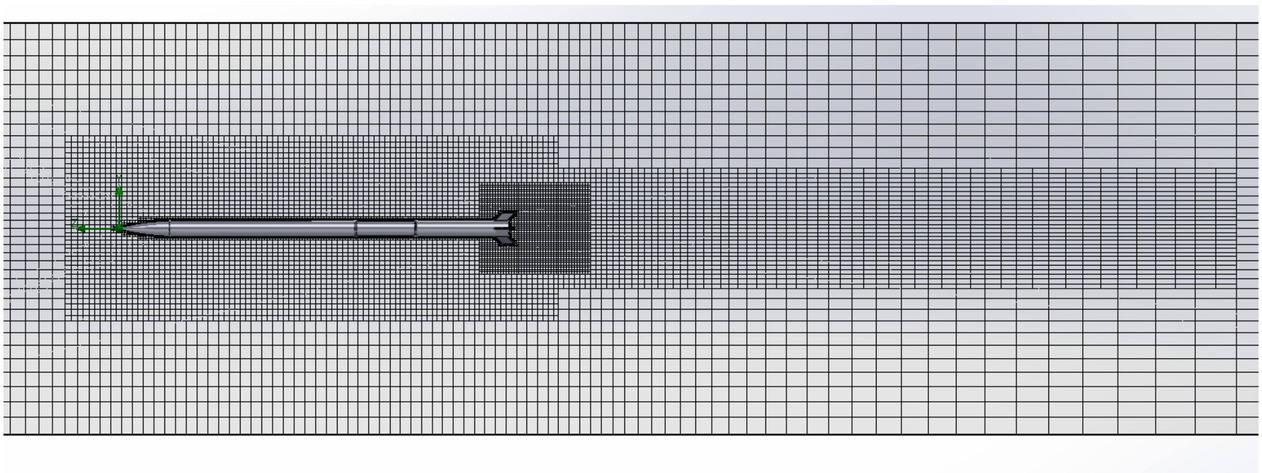

Figure 10: Mesh for R6-NoEndcone model

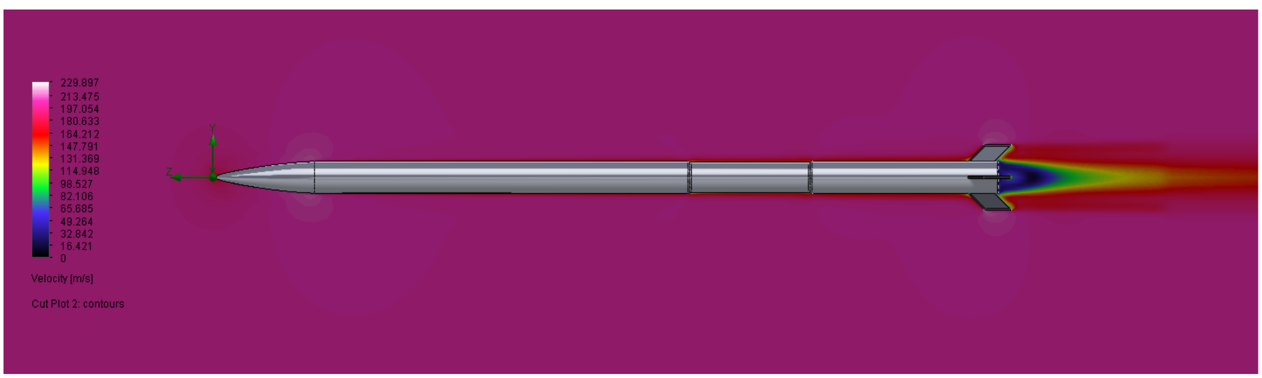

Figure 11: Velocity graph at 0.6 Mach for R6-NoEndcone model

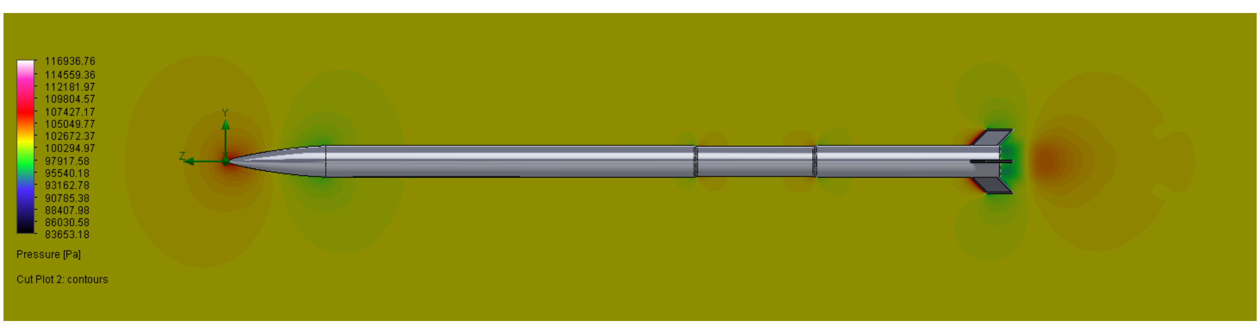

Figure 12: Pressure graph at 0.6 Mach for R6-NoEndcone model

3.3 Results of the preliminary research

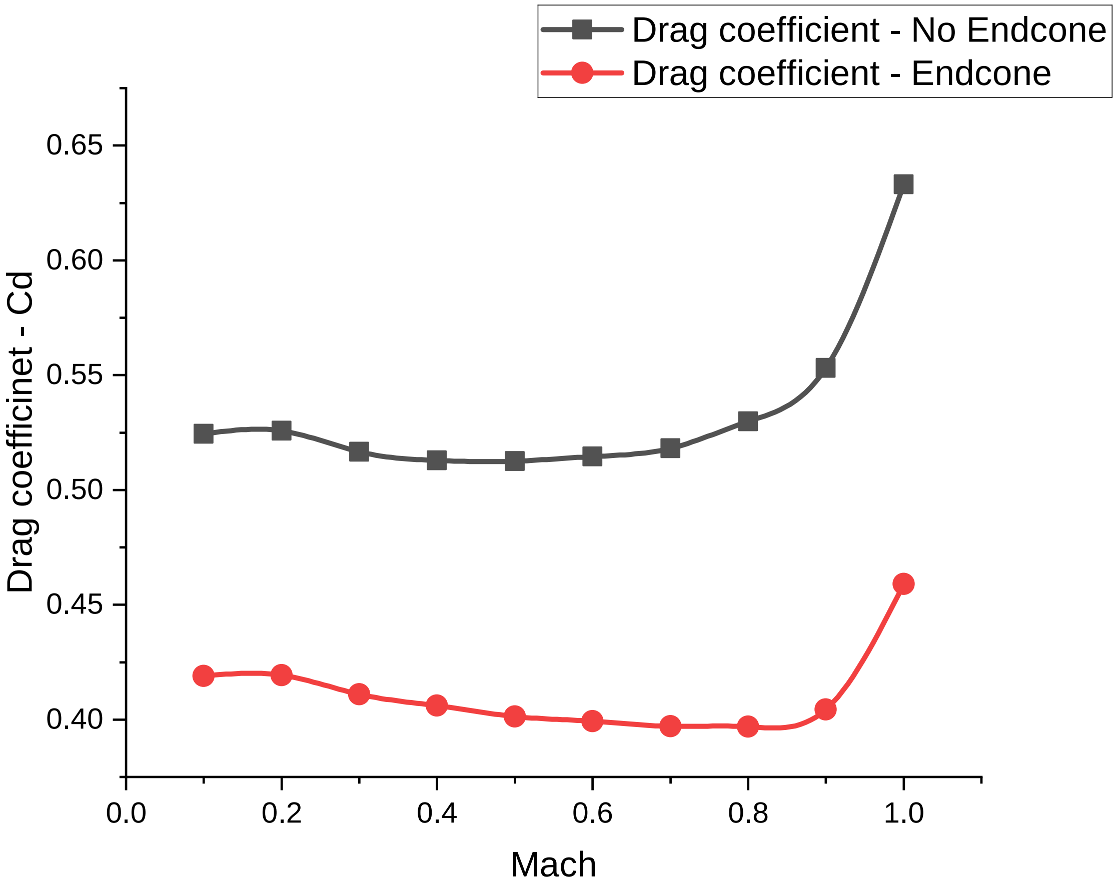

Figure 13: CD graph of R6-Endcone and R6-NoEndcone models

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 3 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, however it since lenghts of encone for angle values of 0 - 3 were too big, those where deleted from study.

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.

Function of drag coefficient for different Mach number depending on the endcone angle is also shown in the graph. It allows to determine the optimal angle for the endcone for specific velocity and can be compared with existing literature.

Mesh and domain settings for following simulations are the same as in the preliminary research for R6-Endcone model. Cell count changed slightly with the change of the endcone angle, but it was negligible.

4.2 Results and discussion

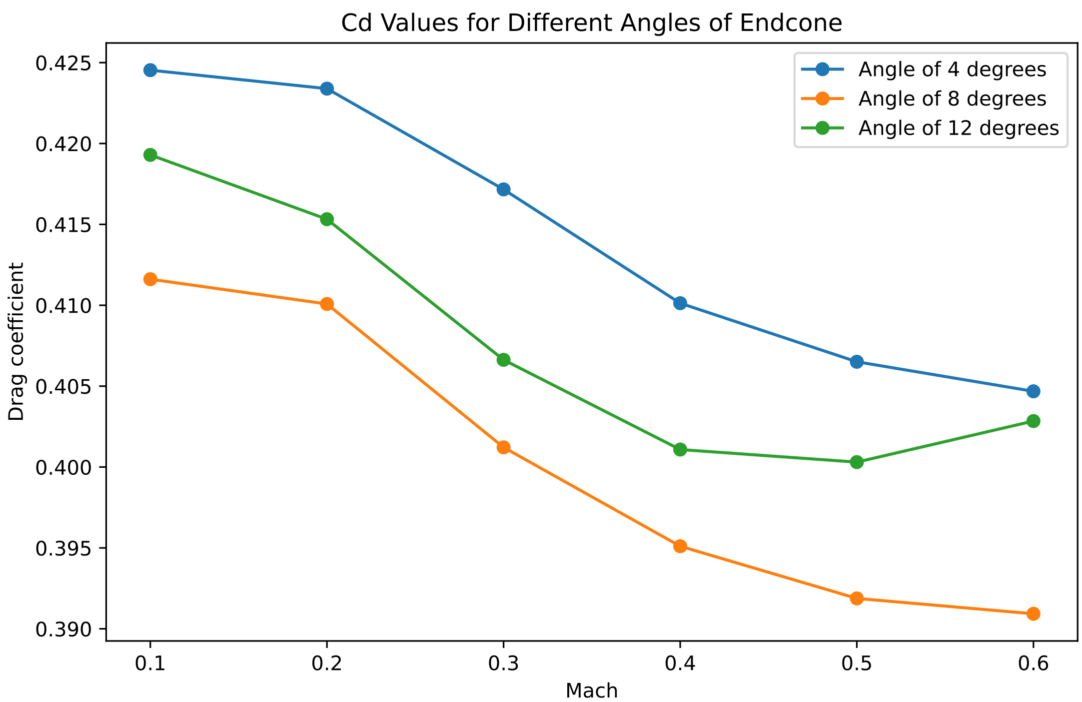

Figure 14: Example of CD graphs for different endcone angles

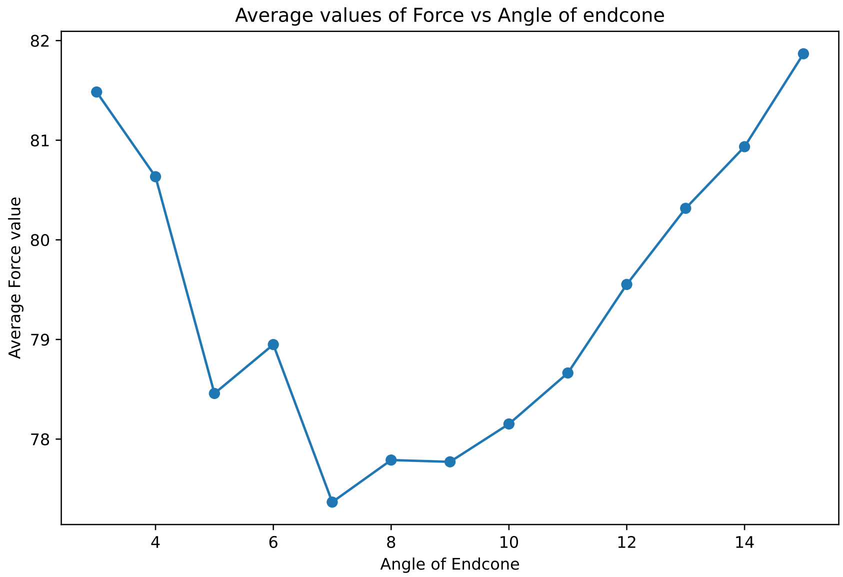

Figure 15: Average Force vs Angle graph

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 3 to 7 degrees and increasing for the range of 9 to 15 degrees.

Spike at 6 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 validity of this spike, however it is not crucial for the optimalization of the rocket, since it is much higher than the minimum of the function and it's unlikely that noise of simulation was that high.

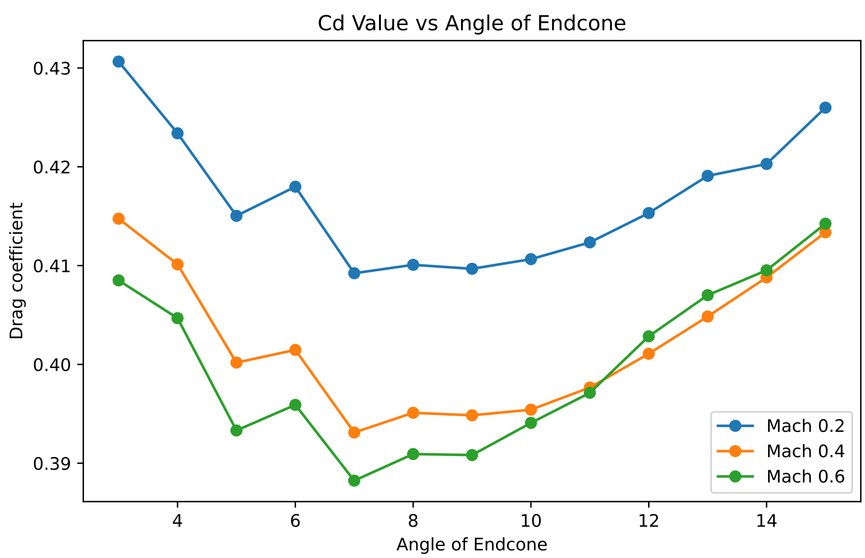

Figure 16: Drag coefficient vs Angle graph

4.3 Shift of upward trend of transonic spike

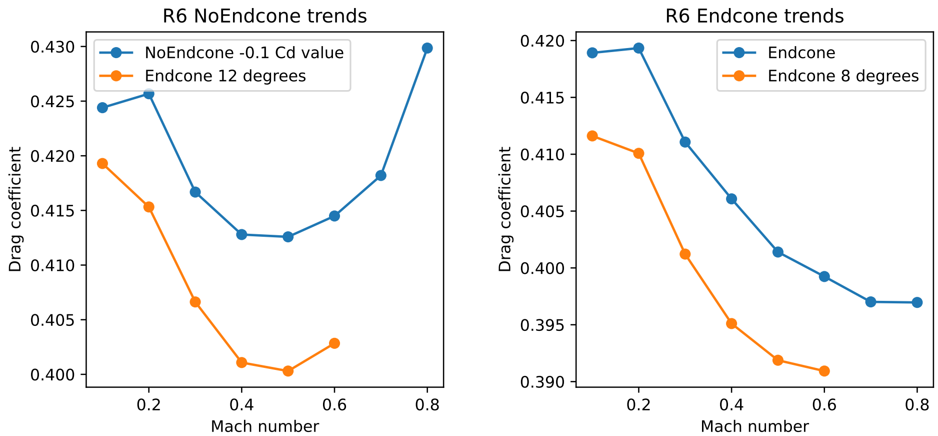

Figure 17: Comparison of Drag coefficient vs Mach graph trends for different endcone angles

Concluding observation is that the transonic spike starts later for the endcone model with optimal endcone angles, which is very beneficial for the range of 0.6 to 0.9 Mach. This is a very important finding from the perspective of future rocket projects, where the rocket will be operating in this range of Mach. For such rockets, optimal endconoe angle could generate significant savings in energy.

This observation could be already noticed in the preliminary research, where the Endcone model exhibited decreasing trend of drag coefficient for the range of 0.6 to 0.8 Mach, while the NoEndcone model exhibited a significant increase trend from 0.5 Mach forwards.

5 Optimalization of the fins in Solidworks

5.1 Range and goal of this study

The goal of this study was to find the most optimal sweep angle of the fins for the R6 model. Only parameter was 90 degrees minus sweep angle, the lenght of top of fin, lenght of bottom of fin and height of fin were kept constant. The range of the study was from 30 to 90 degrees, with a step of 5 degree. For all sweep angle values, simulations were preformed for 0.1 to 0.6 Mach, with a step of 0.1 Mach.

Mesh and domain were kept the same as in prior simulations. Cell count changed slightly with the change of the sweep angle, similiar to the endcone study, it was negligible.

Endcone angle this time was kept at 4.29 degrees, since the physical model of it was already made.

One important note is that for the rest of this study, we will call the angle 90 degrees minus sweep angle just sweep angle.

5.2 Results and discussion

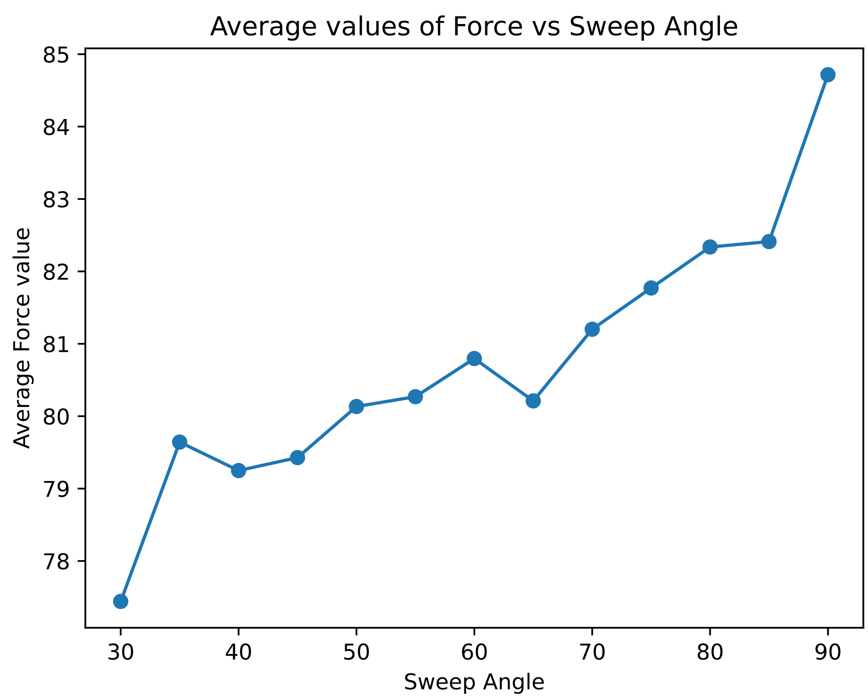

Figure 18: Average Force Value vs Sweep Angle

As shown in the graph, the minimum of the average drag force function is at 30 degrees. The function is increasing for whole tested range, with relatively small local extremums at 35 and 65 degrees. This means that the optimal sweep angle for the fins is 30 degrees. It could be also assumed that the trend will continue to decrease for the range of 30 to 0 degrees, however too small sweep angle would be impractical for the rocket, so it was not tested.

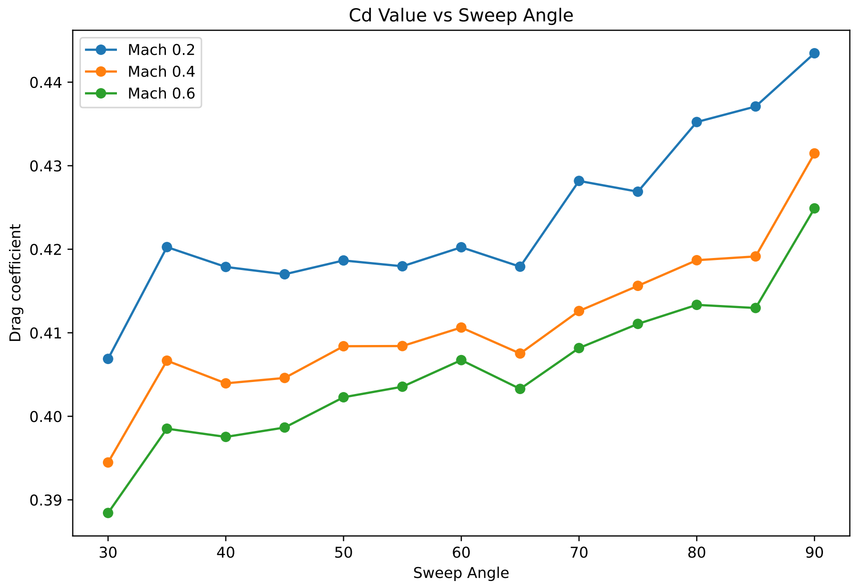

Figure 19: Drag coefficient vs Sweep Angle

Drag coefficient vs sweep angle graph shows the same trend as the average drag force function, but also confirms the existence of characteristic local extremums at 35 and 65 degrees. This is a very important finding from the perspective of the optimalization of the rocket, since when desinginig the rocket, there was a prefered range of sweep angle. This study now clearly shows that when deling with the range of the sweep angle from 55 to 90 degrees, most aerodynamicly efficient point likely to be close to 65 degrees.

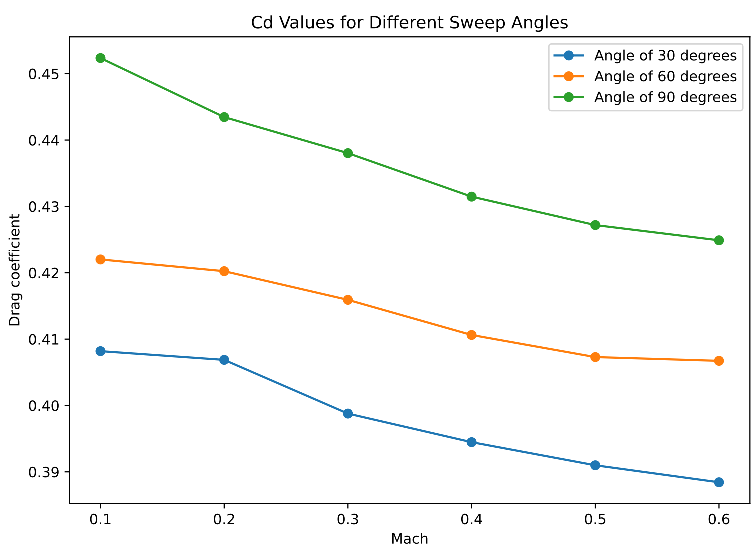

Figure 20: Similarity of curves of drag coefficient vs Mach for different sweep angles

6 Summary

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