AEE 558 - CFD

FLOW OVER AHMED BODY

CFD SIMULATION

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Final Project

TABLE OF CONTENTS

INTRODUCTION

A well-known CFD benchmark for external aerodynamics is flow around the Ahmed body [1] presented the Ahmed body as a generic automotive model. All ground vehicles are bluff bodies because they move near to the road surface. The examined body is capable of capturing the flow characteristics that distinguish modern automobiles. The Ahmed model is often used in experiments as a representation of the motor vehicle due to its simple geometry and the ease of varying a number of important parameters. An example where the Ahmed body is deemed useful is in the automotive industry, where it is important to determine the aerodynamic effects of the spacing between adjacent motor vehicles.

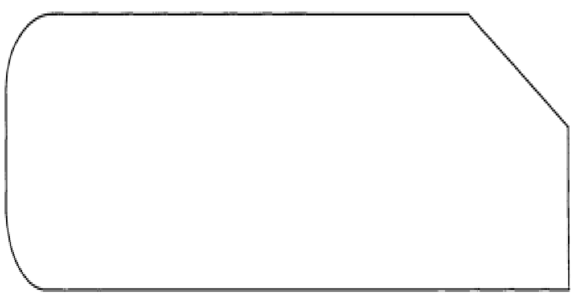


Figure 1 Geometry of Ahmed Model

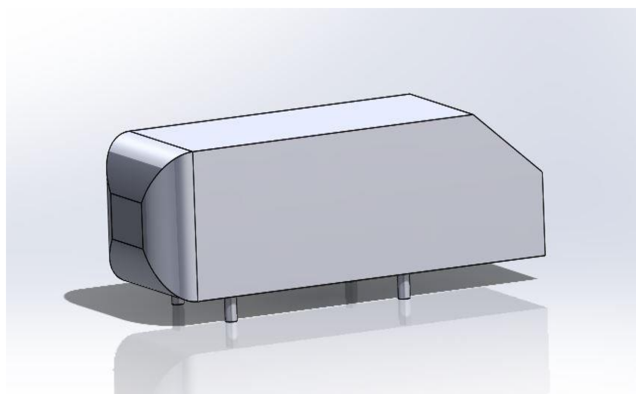


Figure 2 3-d Geometry of Ahmed Model [2]

In this Project we consider an Ahmed configuration to perform air simulations over it in Cradle CFD software. First, an outer domain is constructed over a single body to obtain and observe the desired flow characteristics. At the inlet of the Domain the velocity taken is 40.5m/s with respect to the given Reynolds number (i.e. $2.3 * 10^6$) which is proportional to the characteristic length.

Turbulence kinetic energy i.e. k = 0.797 is calculated from the assumed turbulence intensity given as 1.8%.

This project begins with the consideration of a single model case, wherein we have different meshes generated with different turbulent models to determine the flow over the model. Also, a second trailing car is considered with spacings to determine the flow characteristics between the spacings and impact it has on the models.

Below are the Constructed models and domains used in this project for the determination of Aerodynamics/Flow characteristics. 1) Single Model 2) Two models with 1characteristics length spacing 3) Two models with 1.5 Characteristic length spacing.

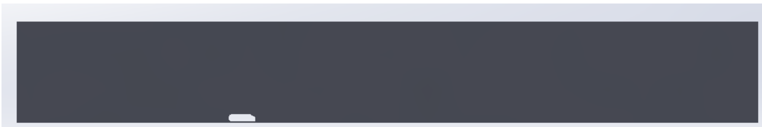


Figure 3 Single model with domain

Figure 4 Two models with 1 body length spacing

Figure 5 Two models with 1.5 body length spacing

SINGLE MODEL

A domain is constructed over a single Ahmed model using SOLIDWORKS and then exported to Cradle CFD for analysis. The process begins with applying the flow analysis conditions such as the velocity, density, Turbulence kinetic energy (TKE), pressure etc. as the boundary conditions for the model. Following that we create an octree wherein we obtain different meshes to determine the accurate flow analysis.

Since the drag force is broken down into pressure and viscous component, we calculate the pressure and viscous force on the surface of the cylinder.

While creating the mesh we concentrate the mesh refinement over the cylinder as to get a much accurate result.

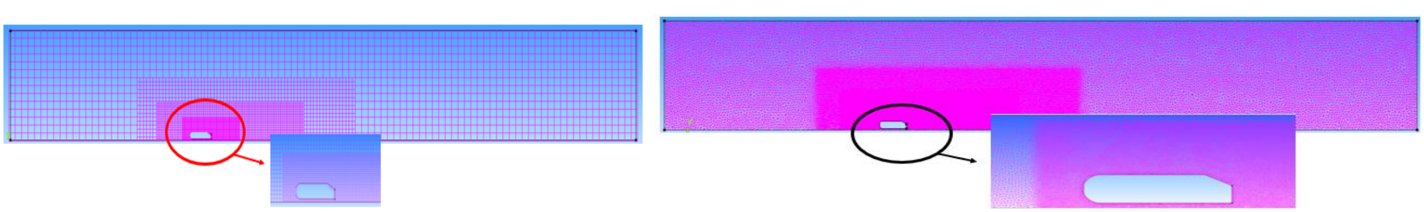


Figure 6 1) Octree for single body and 2) an example of fine mesh with prism layers

Typically, three meshes are chosen 1) Coarse mesh 2) Medium mesh and 3) Fine mesh. According to the y+ calculator with the given data my estimated wall distance was suggested to be taken as $1.1e^{-5}$, so this value is being considered for my estimated wall distance used in the coarse mesh. To obtain a medium and fine mesh an option called global refinement is used once for medium and twice for fine mesh which gives a factor of four times the nodes between each mesh levels.

Similarly, the estimated wall thickness for the medium and fine mesh, 1/3 rd of the minimum octant size is taken. The variation rate of thickness and number of layers have the value of 1.1 and 10, which remains same for all the types of meshes, only the thickness of the first layer changes with respect to the octant size.

To calculate the Cd and Cl we instigate pressure and viscous force over the model, in the output control. The total drag D = ($F_{p\ (axial)} + F_{v(axial)}$) and total lift L = ($F_{p\ (normal)} + F_{v(normal)}$).

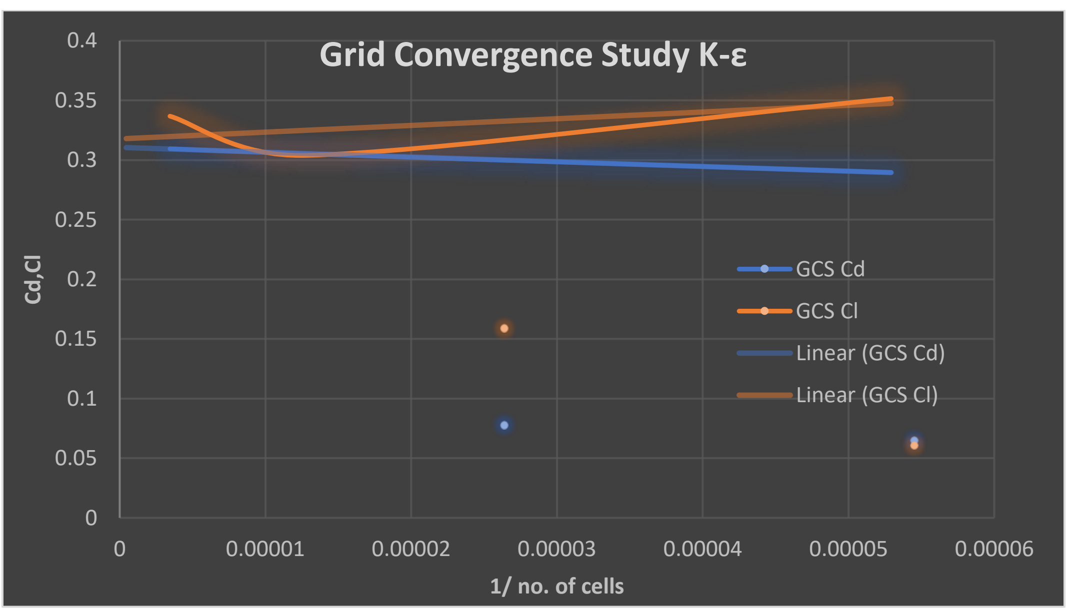
The coefficient of lift Cl = $2L/(\rho V^2 A)$ and coefficient of drag Cd = $2D/(\rho V^2 A)$.

For this model two different turbulence models are considered.

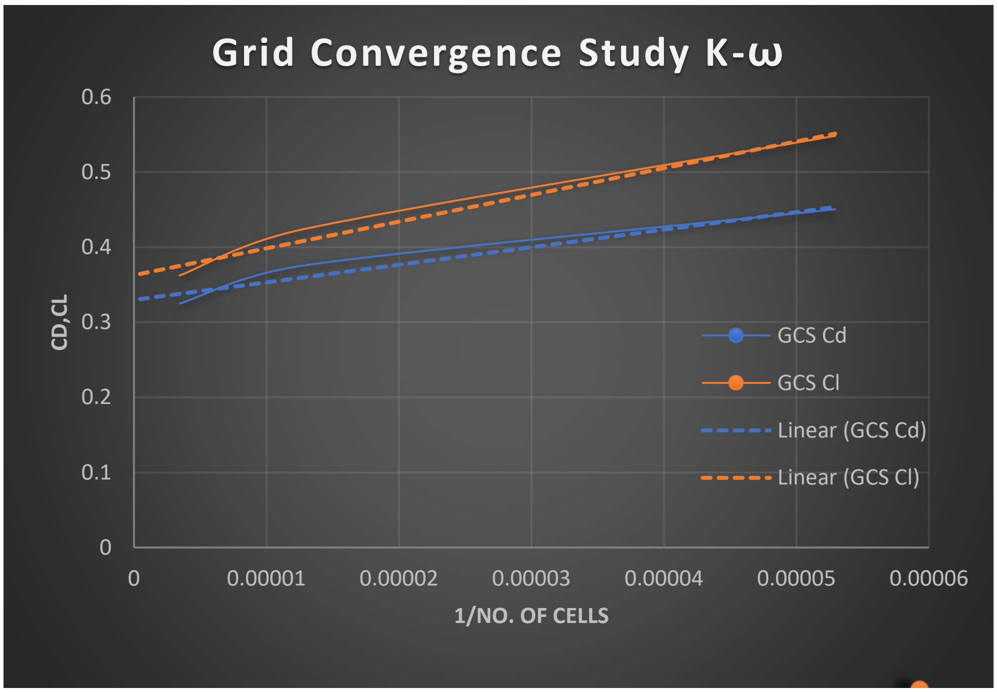
1) Standard K-ε turbulence model, and
2) Standard K-ω turbulence model

And the type of turbulent flow considered is RANS. The calculated values for three different mesh resolutions are shown below in the table.

K-ε model							
	1/Cells	Fpx	Fvx	Cd	Fpy	Fvy	Cl
Coarse Mesh	5.29297E-05	0.00026	0.00003403	0.289501	0.000355	1.99E-06	0.351492
Medium Mesh	1.28052E-05	0.00028	0.00003	0.305225	0.00029	1.86E-05	0.303857
Fine Mesh	3.44956E-06	0.000293	0.00002124	0.3094	0.00032	2.20E-05	0.336733



K-ω model							
	1/Cells	Fpx	Fvx	Cd	Fpy	Fvy	Cl
Coarse Mesh	5.293E-05	0.000381	0.0000765	0.450454	0.000589	-3.22E-05	0.548224
Medium Mesh	1.2805E-05	0.000343	0.0000385	0.375624	0.000409	2.19E-05	0.423968
Fine Mesh	3.4496E-06	0.00032	0.00001	0.324917	0.000319	0.000049	0.362332



Since we do not have the exact error values we use $N^{-p/d}$ for nodes in our grid convergence study, where cradle is second order so p=2 and the dimension d=2.

After Richardson's extrapolation we can see that the Drag coefficient Cd = 0.31 approx. and Lift coefficient Cl = 0.35 approx.

Figure 7 Cp over Ahmed model

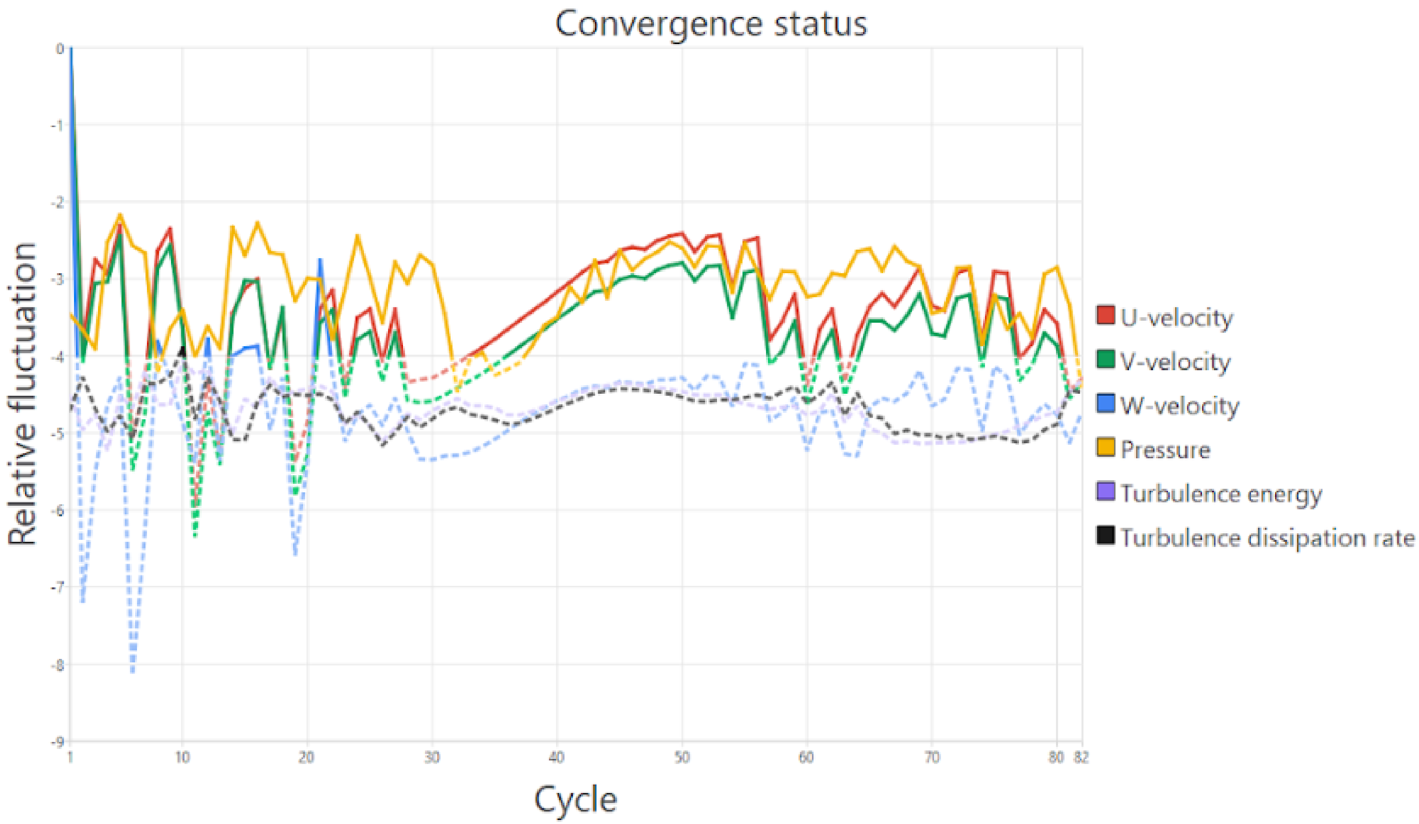


Figure 8 Convergence history for single model

It is noticed that the streamlines formed by the turbulent flow below the Ahmed configuration is varying and in front of the model is somewhat a stagnation point since it is observed that there is a huge pressure difference right in front of the model.

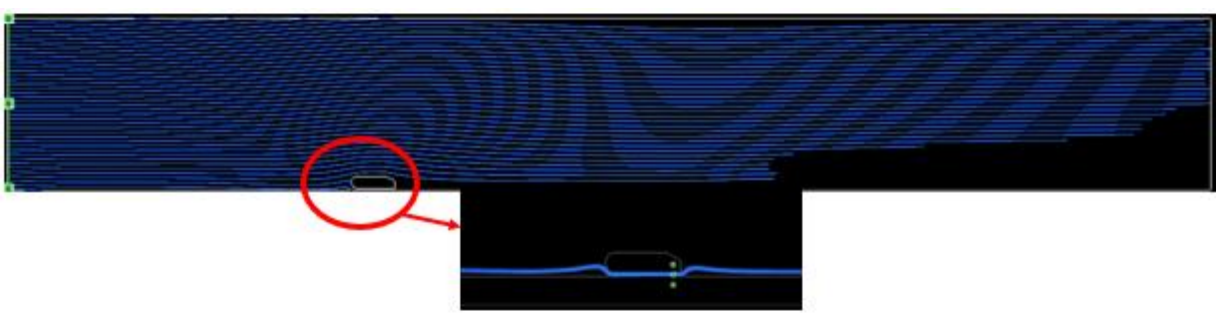


Figure 9 Streamlines over Ahmed model

The pressure forces are 9/10 times and the viscous forces are 1/10 times the drag force.

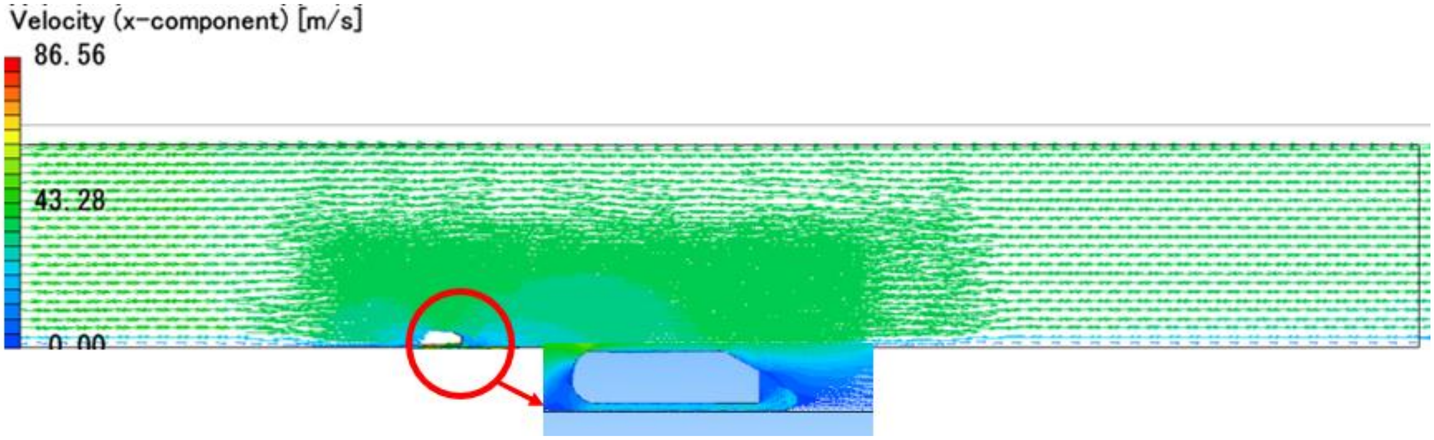


Figure 10 Velocity and its vector field over Ahmed body

Above plots are some plots where we can visualize and understand the behavior of the turbulent flow over the Ahmed Model. We also notice a wake structure with some small vortices behind the model.

1 LENGTH SPACED MODEL

1 length spaced model is just another Ahmed model added to the domain, it can either be a leading model or trailing model. The distance between the model is measured in terms of the characteristic length of the Ahmed model.

So, this model is 1 characteristic length away from the leading Ahmed model. Also, in this project we consider the possible flow characteristics affecting the trailing model as well as the leading car. The process is similar to that of a single model but we should be biased in which model to refer or select.

Trailing model:

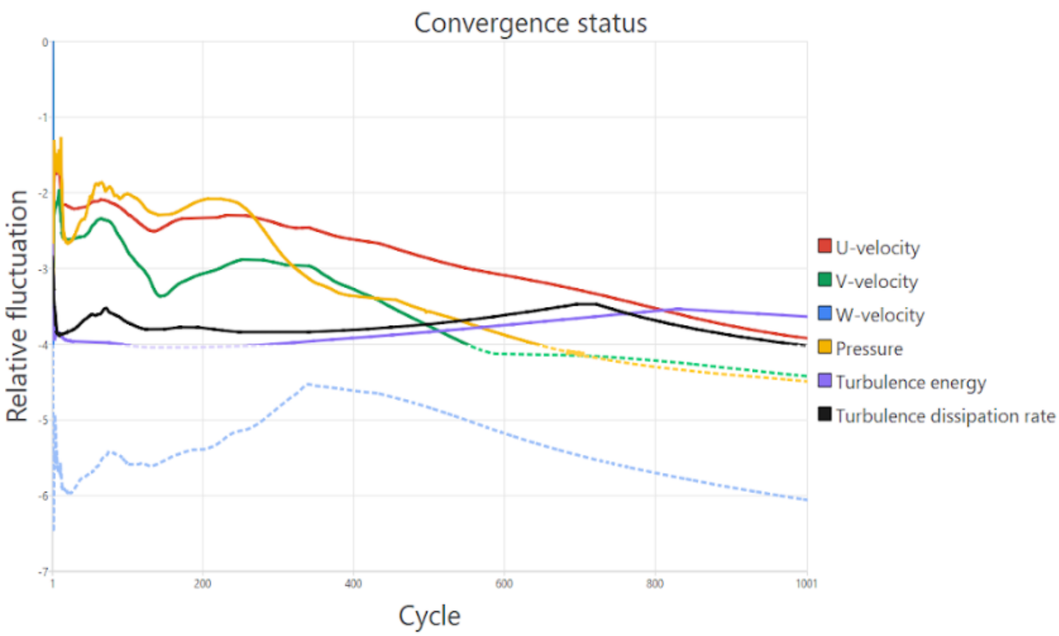


Figure 11 Trailing 1L spaced model Convergence history

Figure 12 Cp Distribution

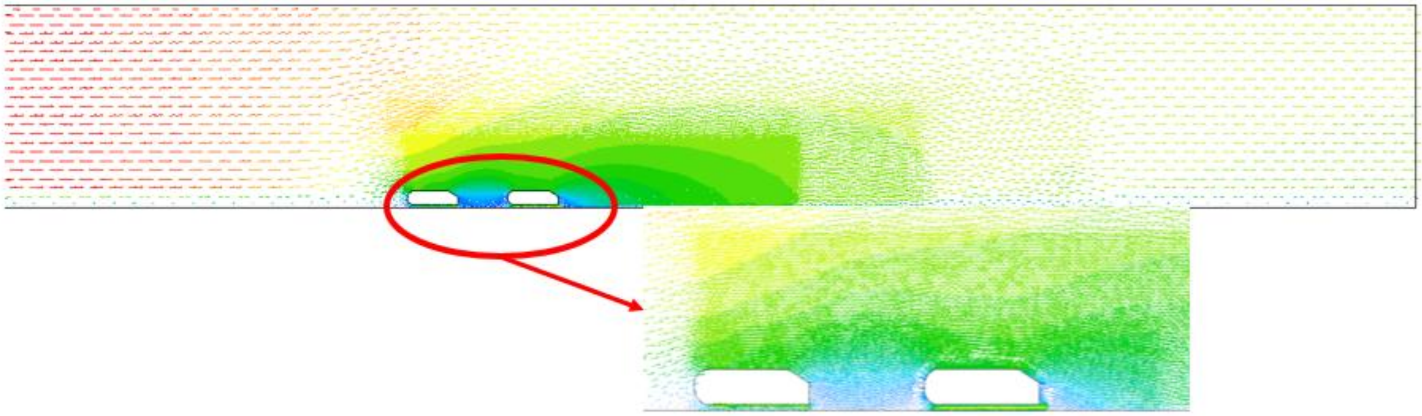


Figure 13 Velocity vectors over the models

For trailing model both turbulent models were consider. The calculated Cd and Cl are shown below in the Table.

K-ε model							
	1/Cells	Fpx	Fvx	Cd	Fpy	Fvy	Cl
Medium Mesh	3.51531E-05	0.000952	8.78E-05	1.023771	0.000332	-1.87E-06	0.32505
Fine Mesh	2.81362E-06	0.0036	0.0000429	3.586793	0.0004	2.56E-06	0.39636

K-ω model							
	1/Cells	Fpx	Fvx	Cd	Fpy	Fvy	Cl
Medium Mesh	1.6061E-05	0.0029	0.0000385	2.893242	0.000569	-5.32E-05	0.507856

Even after multiple tries and extending the cycles to 5000cycles the velocities were not converging and varied results were observed.

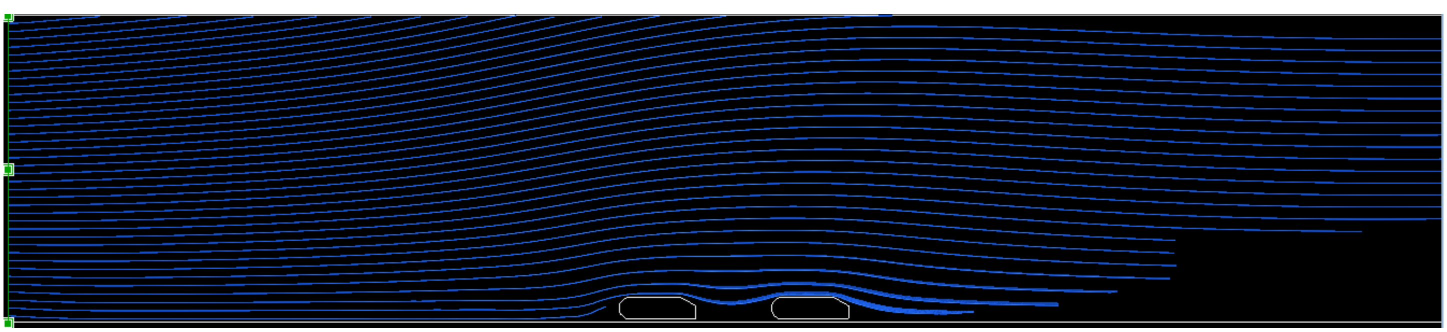


Figure 14 Streamlines observed while biasing the trailing model

Leading model:

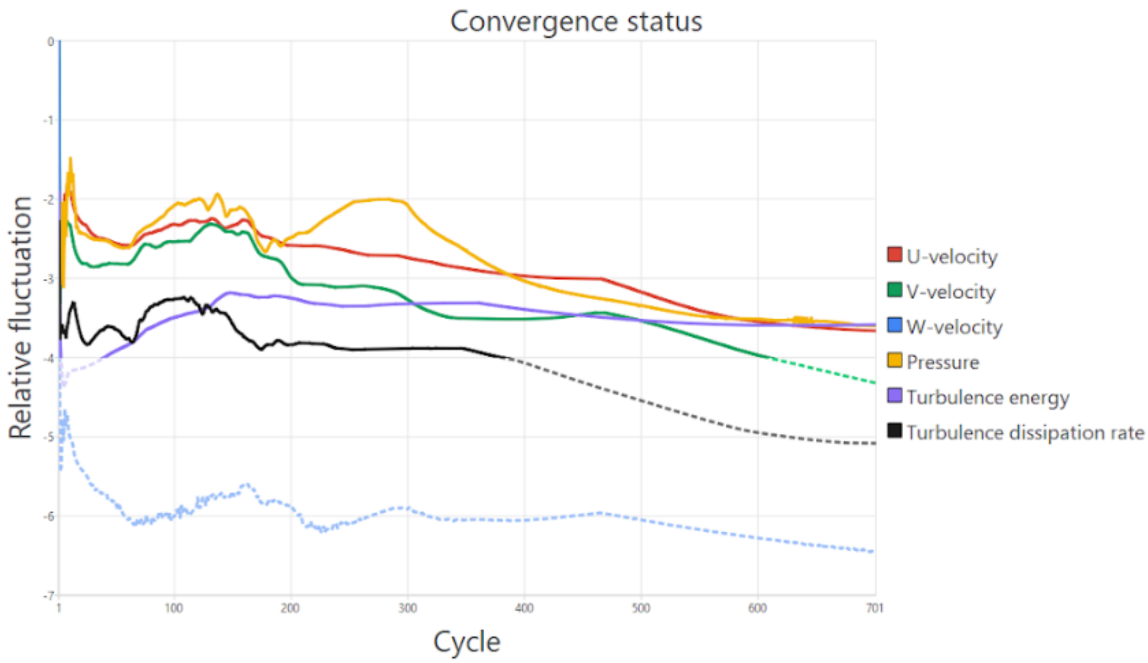


Figure 15 Leading 1L spaced model Convergence history

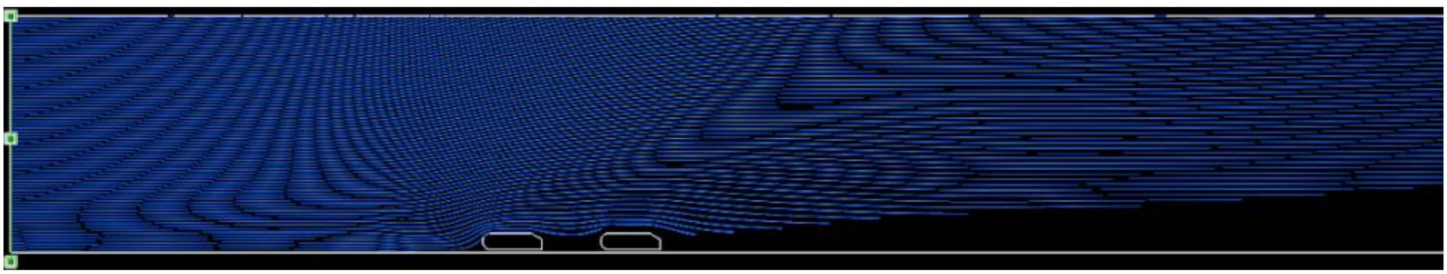


Figure 16 Streamlines observed while biasing the Leading model

K-Ɛ model and K-ω turbulence model is used for the leading model's flow analysis with different meshes.

K-ε model							
	1/Cells	Fpx	Fvx	Cd	Fpy	Fvy	Cl
Medium Mesh	2.37209E-05	1.83E-04	7.20E-05	0.251073	0.000239	4.30E-06	0.239947
Fine Mesh	5.54754E-06	0.000528	0.000068	0.58682	0.000566	3.13E-06	0.560364

K-ω model							
	1/Cells	Fpx	Fvx	Cd	Fpy	Fvy	Cl
Medium Mesh	1.6061E-05	0.0014	0.0022	3.544553	0.003041	4.47E-04	3.43418

Leading Model also had the same convergence problem with varying values even after many trials.

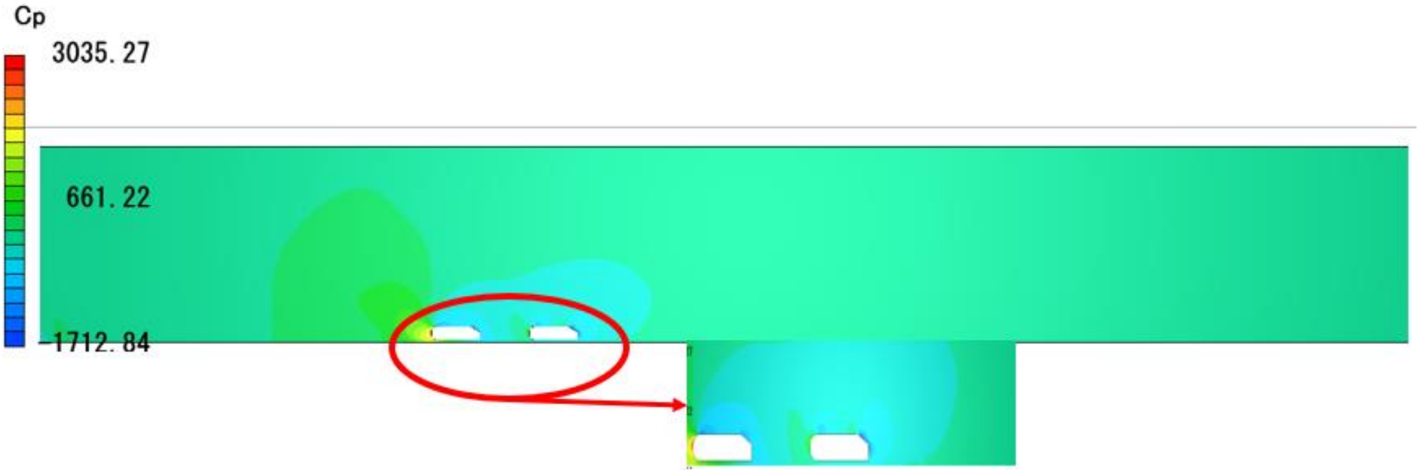


Figure 17 Cp distribution

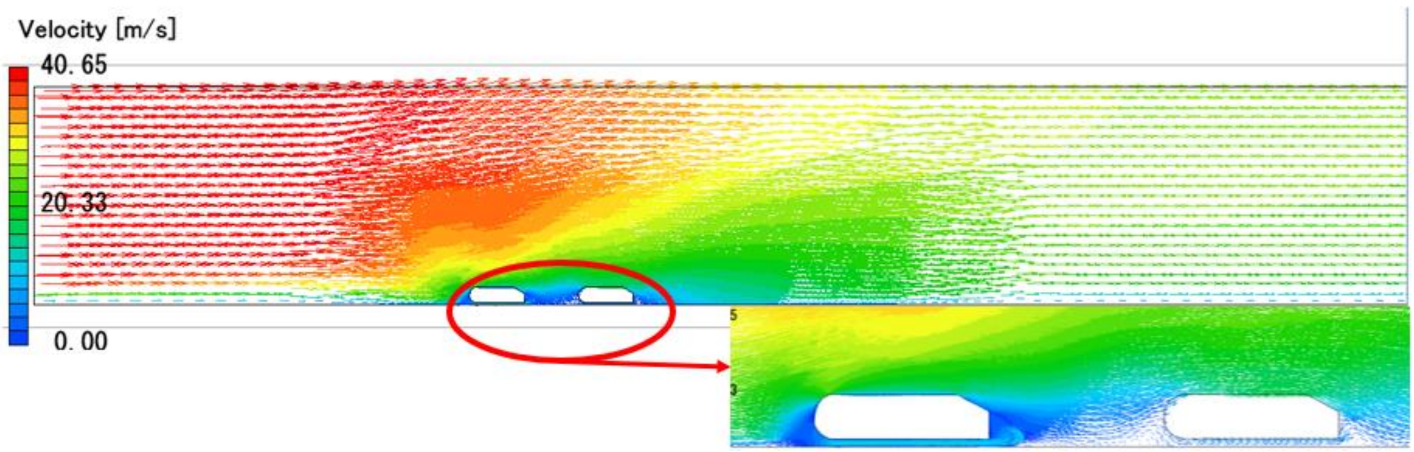


Figure 18 Velocity and its vector field over 1L spaced models

1.5 LENGTH SPACED MODEL

1.5 length spaced model is just another Ahmed model added to the domain, it can either be a leading model or trailing model. The distance between the model is measured in terms of the characteristic length of the Ahmed model.

So, this model is 1.5 characteristic length away from the leading Ahmed model. Also, in this project we consider the possible flow characteristics affecting the trailing model as well as the leading car. The process is similar to that of a single model but we should be biased in which model to refer or select as primary model.

Leading model:

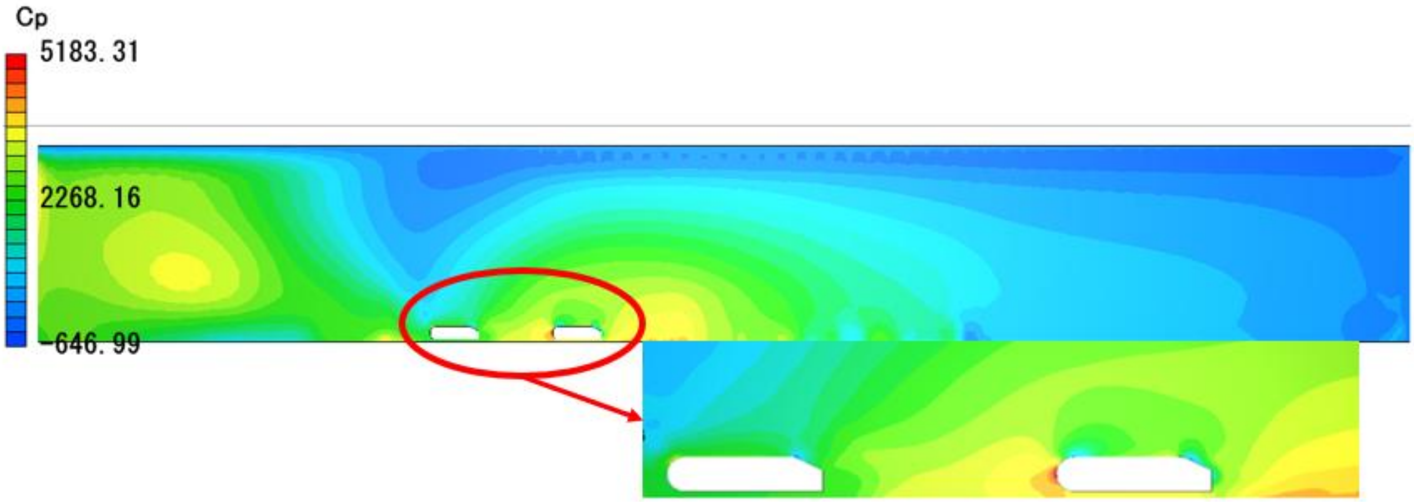


Figure 19 Cp distribution over 1.5L spaced models

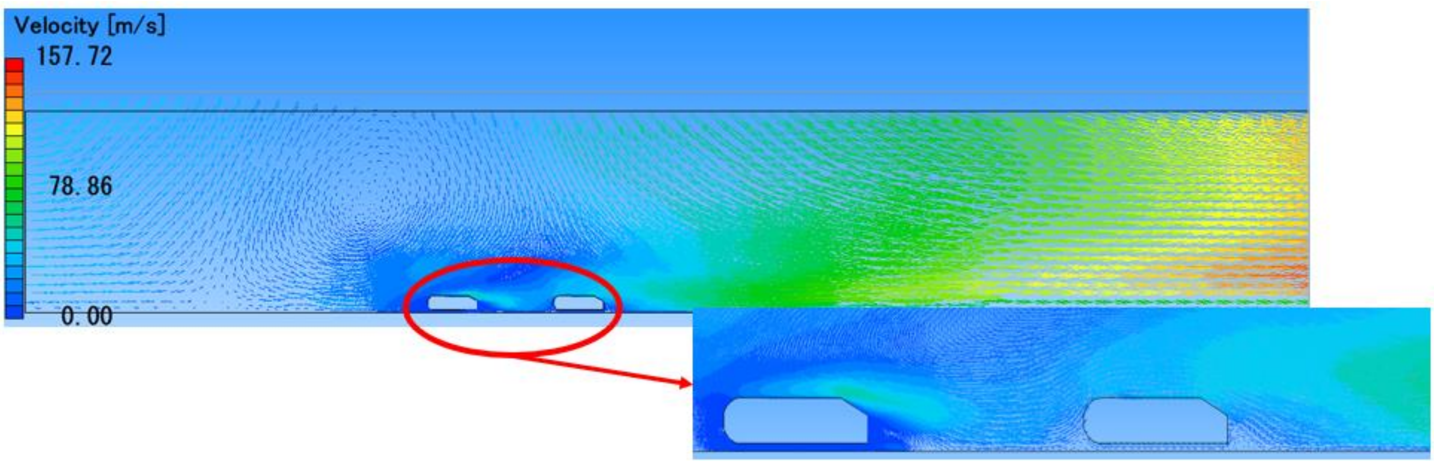


Figure 20 Velocity and its vector field over 1.5L spaced models

K-Ɛ model and K-ω turbulence model used for 1.5L space Ahmed models' results are shown in table.

K-ε model							
	1/Cells	Fpx	Fvx	Cd	Fpy	Fvy	Cl
Medium Mesh	2.10137E-05	2.13E-04	3.12E-05	0.240537	0.000213	-1.55E-07	0.21001
Fine Mesh	4.94057E-06	0.003657	0.00096	4.54589	0.0015	3.92E-05	1.515444

K-ω model							
	1/Cells	Fpx	Fvx	Cd	Fpy	Fvy	Cl
Medium Mesh	2.3217E-05	0.0265	0.00331	29.35087	0.084	4.28E-04	83.12765

Trailing model:

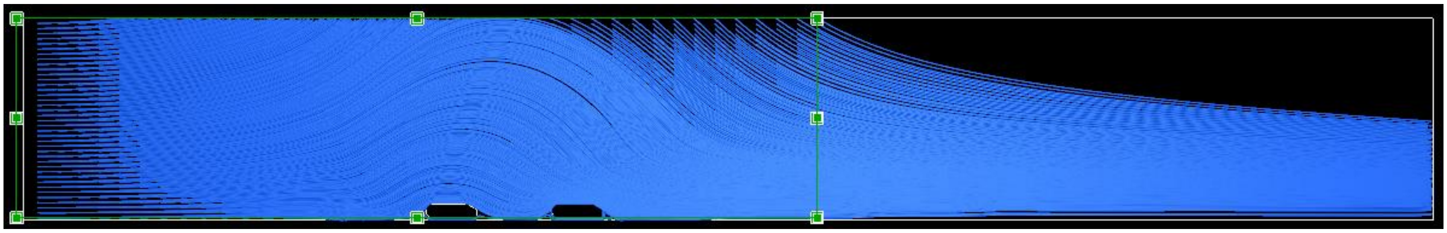


Figure 21Streamlines observed while biasing the Trailing model

Figure 22 Cp distribution over 1.5L spaced models (Trailing model)

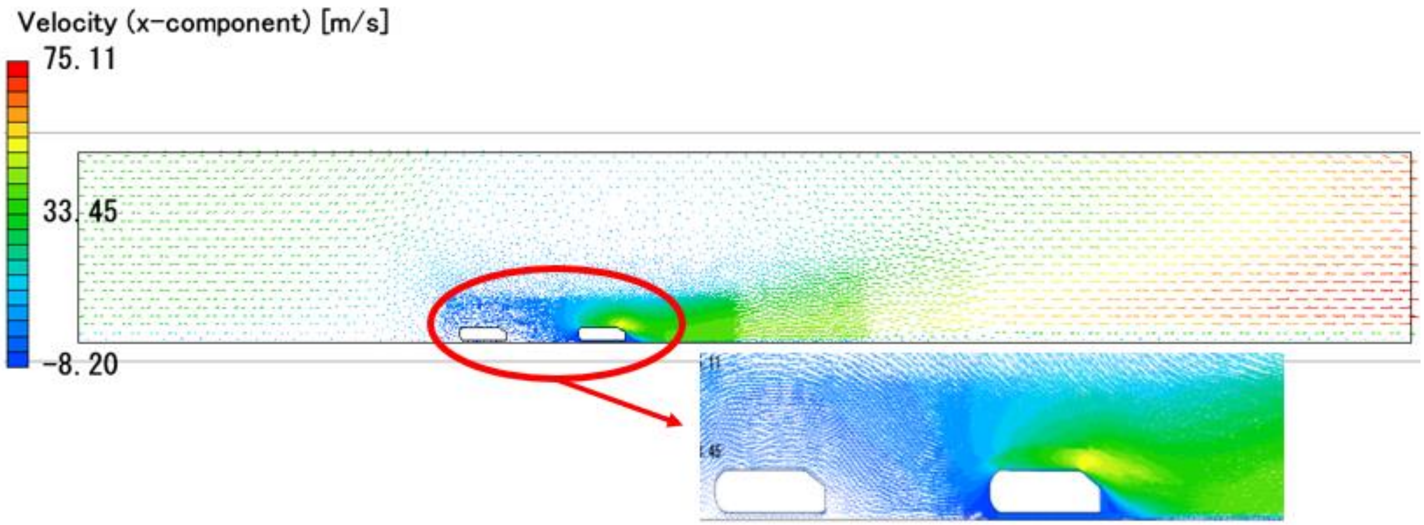


Figure 23Velocity and its vector field over 1.5L spaced models (Trailing model)

K-ε model							
	1/Cells	Fpx	Fvx	Cd	Fpy	Fvy	Cl
Medium Mesh	2.0605E-05	2.14E-04	5.62E-05	0.266029	5.48E-06	-2.12E-06	0.003308
Fine Mesh	5.55065E-06	0.000201	0.000206	0.400731	0.0322	2.33E-04	31.93347

K-Ɛ model and K-ω turbulence model used for 1.5L space Ahmed models' results are shown in table.(with selected model as trailing model for analysis)

K-ω model							
	1/Cells	Fpx	Fvx	Cd	Fpy	Fvy	Cl
Medium Mesh	2.2938E-05	0.002355	0.00048	2.791336	0.000408	1.85E-05	0.419931

CONCLUSION

It has been observed that the slant portion of the Ahmed model makes the flow to stick to It and when it reaches the end the flow is disturbed into vortices, which might cause a separation bubble.

Also, from the flow characteristics we can note that when considering coefficient of drag, and while considering two models; the closer the models get the more drag(0.3 -0.4) the leading model suffers whereas the trailing model as its drag reduced. This happens until the distance between the models is less than 1.5 characteristic length.

For coefficient of lift, when the models are close to each other the lift on the trailing model is higher than that of the leading model and when a distance of 1L between the models is observed the lift (0.2 – 0.5 abrupt increase) acts more on the leading model rather than the trailing model.

REFERENCES

1. S.R. Ahmed, G. Ramm and G. Faltin, Some Salient Features of the Time-Averaged Ground Vehicle Wake, SAE Technical Paper 840300, 1984
2. Google Image "https://www.google.com/url?sa=i&url=https%3A%2F%2Fgrabcad.com%2Flibrary%2Fahmed-body4&psig=AOvVaw1U9jx9sxLb_t8viOYTKGb&ust=1651893900109000&source=images&cd=vfe&ved=0CAwQjRxqFwoTNipssf2yfcCFQAAAAAdAAAAABAD"