

DRAG REDUCTION IN INDIAN LOCOMOTIVE USING AERODYNAMIC FAIRING

Submitted in partial fulfillment of the requirements for the award of
Bachelor of Engineering degree in
Aeronautical Engineering

by

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**DEPARTMENT OF AERONAUTICAL ENGINEERING
SCHOOL OF MECHANICAL ENGINEERING**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

**Accredited with Grade "A" by NAAC | 12B Status by UGC | Approved by AICTE
JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI - 600 119**

MARCH - 2021



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DEPARTMENT OF AERONAUTICAL ENGINEERING_

BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of YOKESH VEJAY. K. R (Reg. No. 37260051) and SUBHASH. P. KUMAR (Reg. No. 37260044), who carried out the project entitled "**DRAG REDUCTION IN INDIAN LOCOMOTIVE USING AERODYNAMIC FAIRING**" under our supervision from December 2020 to March 2021.

-

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DECLARATION

We, YOKESH VEJAY. K. R (Reg. No. 37260051) and SUBHASH. P. KUMAR (Reg. No. 37360044), hereby declare that the Project Report entitled “**DRAG REDUCTION IN INDIAN LOCOMOTIVE USING AERODYNAMIC FAIRING**” done by us under the guidance of Mr. G. MADHAN KUMAR is submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering degree in Aeronautical Engineering.

DATE:

PLACE:

SIGNATURE OF THE CANDIDATE

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ABSTRACT

Aerodynamics has an important role in high-speed locomotives in comparison to low-speed locomotives. As upgrades are underway in improving the high-speed locomotive engine's output like power to increase its speed, but as speed increases so do the aerodynamic factors like drag. Drag is one of the main factors influencing the fuel consumption of an engine. Hence, there is a necessity for the reduction of drag. Any changes to be made will be dependent on the design of the locomotive to make it aerodynamically efficient. This holds for manufacturing new locomotives however not for the ones that are already manufactured or which are in commission. This project proposes an emphasis on the improvement of aerodynamics to reduce energy consumption by making components called aerodynamic fairings that can be attached or fixed to the locomotive to make it aerodynamically efficient. The drag coefficient is immense while considering Indian locomotives. This is because of their block-like structure. This structure is used since it is compact, easily coupled, and can be attached at different positions. One of the most frequently used passenger locomotive engines of the Indian Railways is the WAP-7. Therefore, the project aims to develop a suitable aerodynamic fairing on the locomotive of WAP-7 which can reduce total drag and in turn reduce energy consumption. This fairing can be removed during the coupling process. Hence, the coupling advantage is not omitted. Along with this, the project aims at converting the existing models thereby decreasing the cost for manufacturing. This experiment is carried out using CFD analysis to optimize fairings design followed by Wind tunnel tests. This component is estimated to reduce total drag and energy consumption in a more economic approach. This translates into better fuel savings annually per train retrofitted with the fairings.

Keywords: Aerodynamics, Aerodynamic fairings, Drag, Design, WAP-7, Fuel savings, Energy Consumption

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CHAPTER 1

INTRODUCTION

1.1 AERODYNAMIC FAIRINGS

Aerodynamic fairings are structures that are used or fitted in vehicles like trains, aircraft, cars, bicycles, and motorcycles for reducing drag and improve appearance.



Fig 1.1 Aircraft wheel fairing

1.2 AERODYNAMICS

Aerodynamics is the study of the properties of moving air and the interaction of moving air with solid bodies. It is used in various fields like automotive, aeronautical and also in sports like racing and ski jumping.

1.3 AERODYNAMICS IN VEHICLES

Aerodynamics is the study of the flow of gases over moving bodies. The gas that we encounter the most is air. It mainly focuses on the forces of drag and lifts, which are caused by air flowing over and around solid bodies.

Aerodynamics is being studied and implemented in designing vehicles both high-speed vehicles such as bullet trains and low-speed vehicles like cycle, bike,

trucks. As engines became more powerful and faster, engineers realized that wind resistance significantly

hindered their speed and fuel consumption. This wind resistance is termed as aerodynamic drag which directly influences a vehicle's speed and fuel consumption.

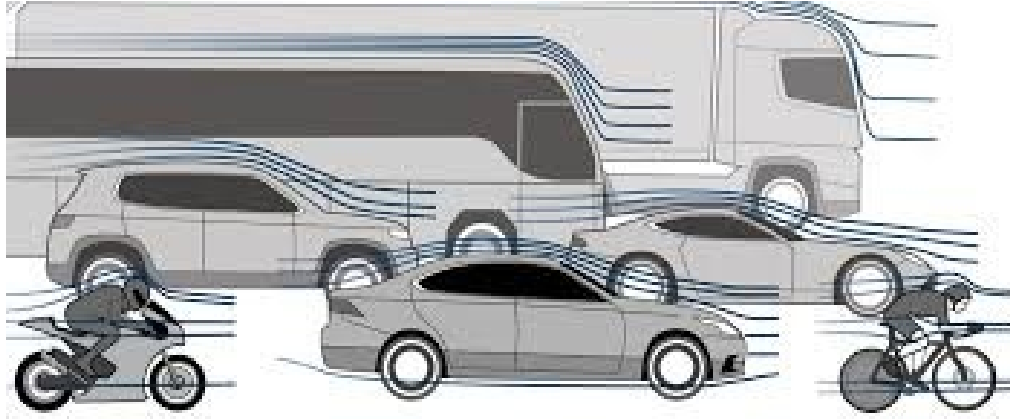


Fig 1.2 Flow over Vehicles

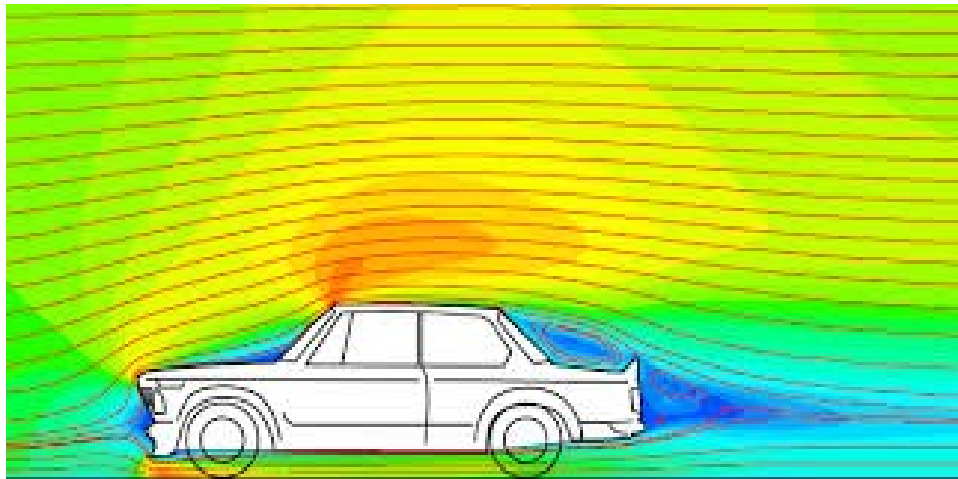


Fig 1.3 Flow over a car

1.4 AERODYNAMICS IN RAILWAYS/ LOCOMOTIVES

Railways have seen major changes right from the steam-powered engines to engines that run at 320 km/hr. This can be pointed to successful modifications of design that make trains aerodynamically efficient. Railways in India dates back to 1853, where a steam-powered locomotive was used. However, it was not until 1957 that a diesel engine was manufactured based on a block-like structure and since then not too many major modifications have been made to the design from

an aerodynamic point of view. Many efforts to speed up the train has to date been invested in the improvement of the

electric motor that runs the locomotive, rather than understanding the flow around the train which is a major problem due to the block-like structure that puts up with the majority of the wind resistance causing more drag. This has led to large energy losses in the form of drag and deterioration in performance. With the drastic developments in engines, speeding up trains causes many engineering problems which have been neglected in low-speed trains, the important one being the aerodynamic drag. Air drag is proportional to speed. Since the speed in trains are being increased with every new model, changes have to be made in the design to make the train aerodynamically efficient.

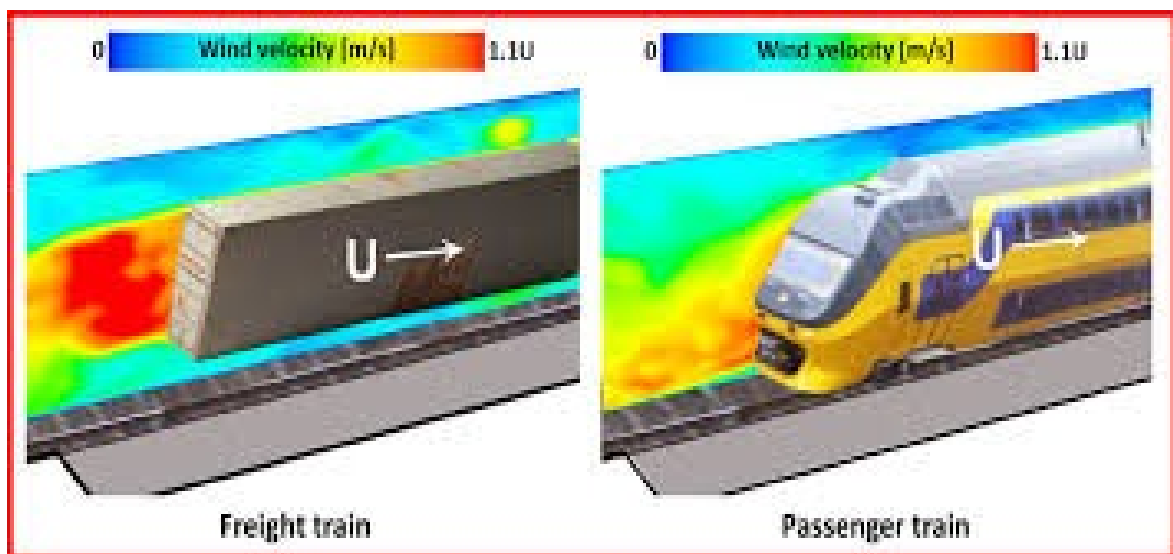


Fig 1.4 Flow over freight and passenger train

1.5 INDIAN LOCOMOTIVE WAP-7

The Indian locomotive class WAP-7 is a class of 25 kV AC electric locomotive developed in the year 1999. The model name WAP refers to the 7th Generation (W) broad gauge, (A) AC Current, (P) passenger traffic engine, which went into operation in the year 2000. There have been a total of 1210 WAP-7's built to date. It is one of India's most famous locomotive engines of Indian railways having operated passenger trains for more than 20 years. It has a maximum speed rating of 140 km/hr. It has the highest acceleration figures while hauling mail/express trains. It has a continuous 6,125 hp (4,567kW) continuously with regenerative braking as one of its standout features.

It is expected to become the most frequently used passenger locomotive in the near future. Upgrades are in the works to improve power output and top speed. On February 28, 2019, the first High-Speed version of WAP-7 HS Loco (Loco No 30750) was unveiled, capable of reaching 180 km/h and weighing 14 tons less than its predecessor.

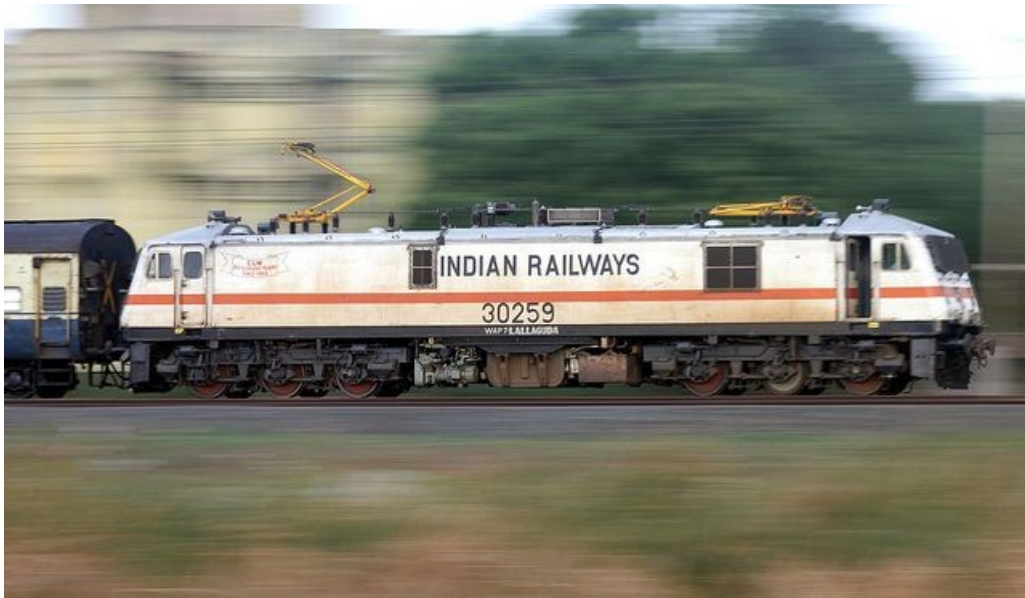


Fig 1.5 Indian Locomotive WAP-7



Fig 1.6 Indian Locomotive WAG-9

CHAPTER 2

LITERATURE SURVEY

Bhargav Goswami , 2018 published a paper in Optimization for Aerodynamic elements of Indian Locomotive of passenger train. The main goal of the paper was to use a multi-objective optimization technique to optimize the WAP-5 Indian Locomotive's aerodynamic factors. The aerodynamic properties of randomly generated train shapes have been determined. The model with the best results was chosen, and any necessary adjustments were made using an evolutionary algorithm. A model crossover is performed in order to improve optimization. The nose shape of the WAP-5 locomotive was numerically analyzed, and its viability was demonstrated using pressure variations around the frame. It can be assumed that the WAP-5 locomotive's aerodynamic elements have been optimized, a better nose shape configuration has been selected, and the aerodynamic drag has been reduced.

Chad L. Stucki, 2018, studied the fuel efficiency of freight trains in the paper titled. Aerodynamic design of locomotive nose fairing, under the study, it was found that at cruising speeds the largest contributing factor to the consumption of fuel was an aerodynamic drag, due to the air stagnation at the front of the train and substantial flow separation at the end of the train, hence the front and last railcars experience the greater drag than intermediate railcars. They designed a fairing using numerical analysis creating 140 different nose shape designs and found the most optimized design to reduce drag by 17.4% at the front of the locomotive. By this paper, it can be concluded that the flow at the last car should also be considered for reducing the drag.

Kyler Tolman, 2018 studied the aerodynamics of locomotives and observed that there are not as efficient compared to ground vehicles. Hence concluded that the design had to be changed to make it aerodynamically efficient. Proposed the use of origami-inspired aerodynamic fairing that can be folded and unfolded whenever necessary. The design was done by CFD analysis and multi-dimensional

polynomial regression. Both the small-scale model and full-scale model fitted with this design

were conducted. Hence concluded that an aerodynamic fairing attached to a diesel freight locomotive can help reduce drag. By doing this it was observed that there was an improvement in drag reduction, approximately 17%, and saved close to 25000 liters of diesel per year per train.

Zhen Feng WU, 2018, investigated the most efficient method to achieve aerodynamic efficiency. It was concluded that the most effective aerodynamic design is achieved only if the head of the train is streamlined to reduce the pressure drag acting upon the locomotive. This research shows that a high-speed train with a large-scale streamlined head car will minimize running aerodynamic drag and save energy, and it aims to provide technical support for the high-speed train head car's subsequent process design and production control.

Leifur T. Leifsson, 2017 studied the computational investigation of crosswinds on locomotives. The main reason for fuel consumption being drag due to wind resistance was the main reason to find ways of reducing aerodynamic resistance. An investigation was conducted using computational analysis, Reynolds Navier stokes equation and one-half wind-to-train-speed ratio was used with a crosswind angle of up to 30 degrees. When the results were compared to the Davis Peters equation, it was discovered that the locomotive is responsible for 75% of the overall drag in straight-on flow. As the crosswind angle gradually rose to 30 degrees, the percentage of drag decreased to 40% thus remaining the dominant source. An unsteady vertical structure was also discovered to be acting on the locomotive.

Giampaolo Mancini, 2014 published a paper investigating the effects of bogie fairings on high-speed trains. Experiments were conducted on a reduced and full-scale model of ETR 500 high-speed train that reaches speeds up to 300km/hr. It was observed that these fairings that were attached to the bogie of high-speed trains had shown a decrease in total drag experienced by the train. It was stated that the drag reduction achieved by the fairing design was aimed for the aerodynamic optimization and not only for the retrofitting on the bogies, thus proving that the optimization of external surface in the bogie area can strongly affect the aerodynamic drag of a high-speed train. The reduction was found to be close to a 10% reduction of the total drag

Mehrdad Rabani, 2014 investigated the effects of headwinds on passenger trains. It was done both numerically and experimentally, the model had one engine and one wagon behind it. At various points, pressure tabs were done to study the effects of airflow velocity. For the numerical simulation verification, the numerical results of pressure coefficients were compared to experimental values. The effect of wagon number on train drag coefficient and air pressure distribution on the train's symmetry plane has been numerically investigated. The drag coefficient increased by 1.2336 for a locomotive and seven wagons linked behind it. According to the results, there is a correlation behind it. It, but there is no discernible difference in the drag coefficient in the airflow. Each intermediate wagon's averaged drag coefficient was found to be 0.1321.

Hee-Min Noh 2013, studied the noise reduction in high-speed trains by using fairings in the gangways. It was observed that the increase in noise as the trains moved in through the tunnels was due to the air circulating between the gangways, more space, increased noise was recorded. Hence the reduction of noise by using fairings or side barriers was proposed. Thus it was found out that directly blocking the inflow between the cars section is an effective method to decrease noise.

CJ Baker, 2008 analyzed the slipstreams of high-speed passenger trains and freight trains. Unsteady gusts produced in the train boundary layer are a growing concern at high speeds, and wakes become a greater danger to passengers waiting on the platform and trackside staff. The flow characteristics vary depending on the train type, measurement distance from the train, and height above ground in each area. The division of slipstream and wake into several flow regions was verified through numerous wind tunnel and real-time tests. There is a localized velocity peak in the upstream/nose region, and its magnitude is less than that in general. Slipstream velocities rise as the platform surface reaches in the boundary layer for passenger trains. The data shows a strong ensemble-averaged velocity peak in the close wake area. The trackside, where the flow is most affected by the unshielded wheelsets, has the highest peak of gusts.

Erik Lindgreen, 2005 published a paper on railroad train driving resistance. Physical configurations have an effect on performance, such as wagon size and

layout, which affects aerodynamic resistance and, as a result, power requirements.

These driving resistance parameters can be calculated by examining the effects of wagon type and loading. The information provided here is intended to serve as a starting point for evaluating values for the ARTEMIS rail energy consumption and emissions model. The resistance of wagon side stakes can be decreased by 24 percent by lowering side stakes, according to real-time tests and computational analysis. To minimize air resistance in wagons, it's best to fill the room with empty containers. By covering the unloaded vehicles, open wagon resistance can be decreased by up to 25%.

JM Copley, 1987 studied the three-dimensional flow over train and developed a computer program to predict the forces and moments of steady winds over train. This calculation method was tested against measurements made on an idealized wind tunnel model of a rail train in a crosswind. It was observed that the vortex in the wake on the lee-side of the train has a large effect on the pressure distribution over the model. For an idealized model of the train with no wheels, the vortex wake is like a three-dimensional Karman Vortex Street, with vortex shedding from successive points on the roof and underside of the train. Developing a program that is modified to account for these effects and apply to a more realistic flow field. The method developed predicts the overturning moments in the cross-section.

CHAPTER 3

AIM AND SCOPE

3.1 PROBLEM STATEMENT

Many advancements have been made to make trains aerodynamically efficient, but in India, not many changes have been made, many engines still derive their primary block-like design which has limited the power capacities. The aerodynamic effects have led to the following problems:

- ❖ Increase in drag at higher speeds, hence limiting the speed of the train.
- ❖ Increase in overall fuel consumption, and loss in performance.

3.2 AIM AND OBJECTIVE

- ❖ To improve the Aerodynamics of locomotive WAP-7 in a more efficient manner using Aerodynamic Fairings.
- ❖ From previous studies, it has been found that close to 17% of the total drag can be eliminated and in turn reduce fuel consumption saving close to 24,000 liters of diesel per year.
- ❖ Even though the power output of WAP-7 is 6350 hp, Aerodynamic effects during high cruising speeds cause a loss in performance. Hence design and fabricate an aerodynamic fairing to reduce these aerodynamic effects.

3.3 SCOPE OF THE INVESTIGATION

In this project, the analysis of the existing model will be done. Modeling of the fairings is done on CATIA modeling software. Different designs of the fairings will be done. Analyzing the current situation lays the groundwork for determining the consequences of proposed adjustments and selecting the best options. The computational analysis is done on STAR CCM + analysis software. The results will be compared to the test done in a wind tunnel with the fabricated model.

CHAPTER 4

DESIGN OF AERODYNAMIC FAIRING

4.1 METHODOLOGY

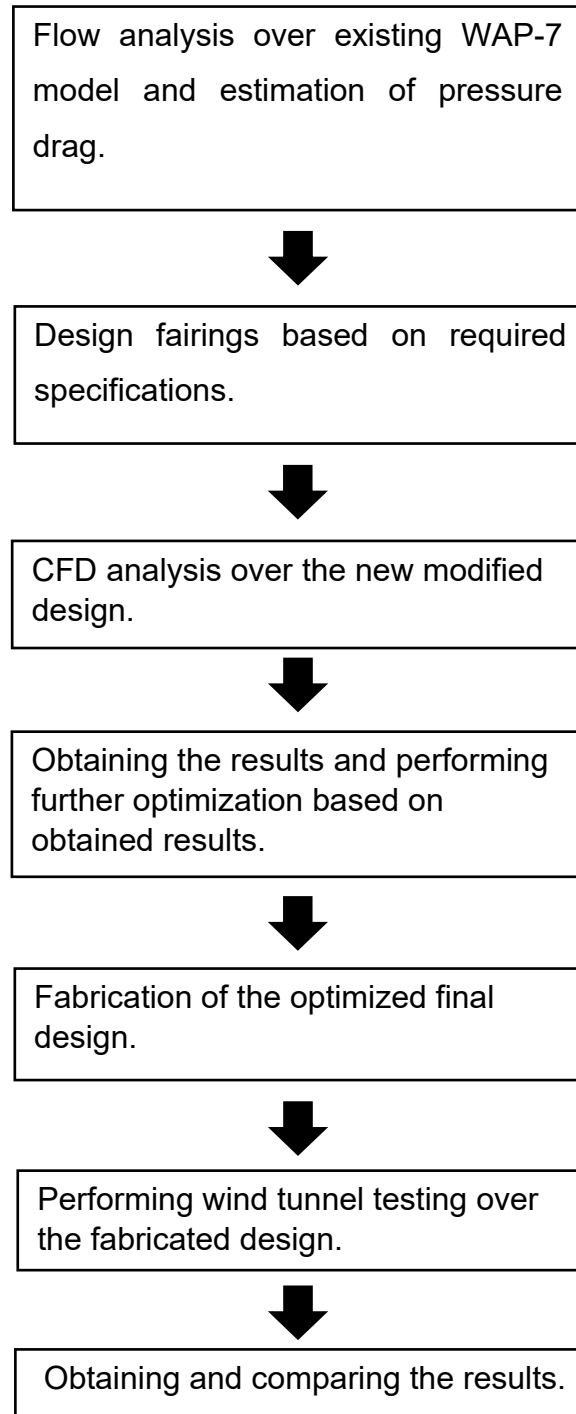


Fig 4.1

Methodology

4.2 WAP 7 MODEL

The WAP 7 Locomotive is the most commonly used locomotives in passenger trains. The model is designed in modeling software CATIA (V5) according to the dimensions specified in Table 4.1 in the scale of 1:1.

Table 4.2 Dimensions of WAP-7 Model

SI No	Parameter	Dimensions(mm)
1	Length	40000
2	Width	3100
3	Height	3895

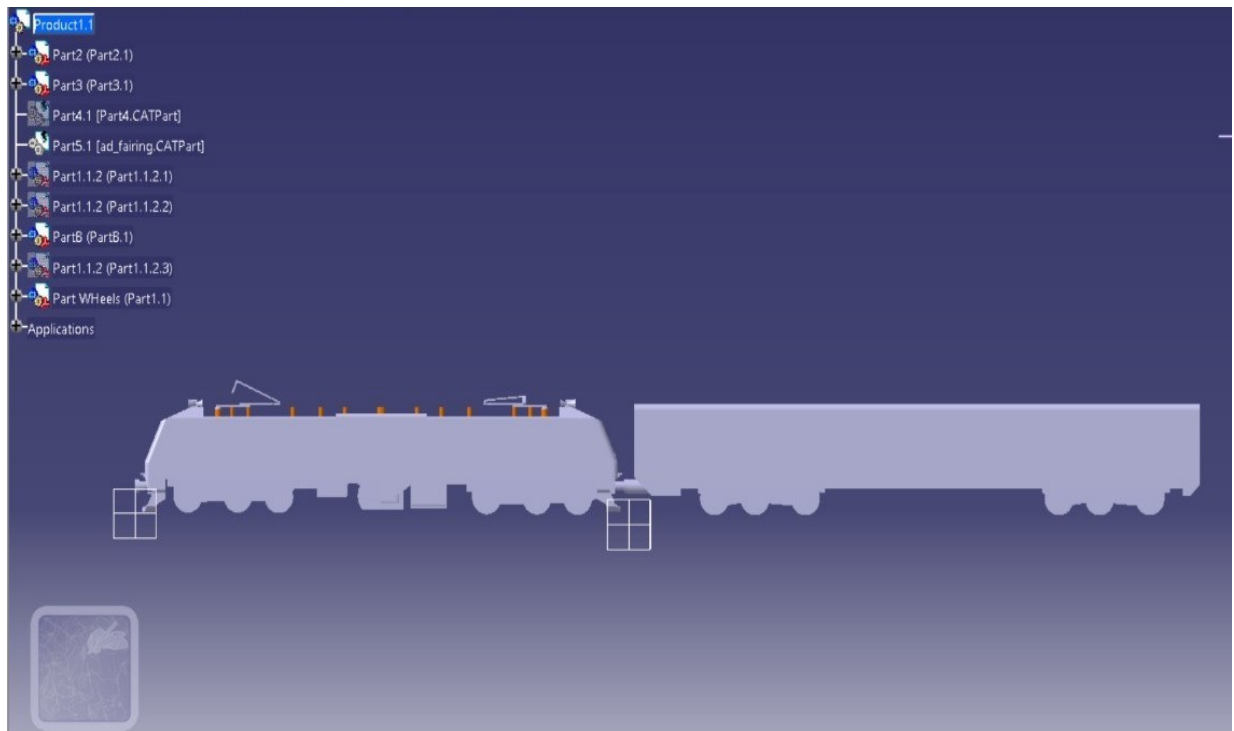


Fig 4.2 Side View of Indian Locomotive WAP-7 model in CATIA V5

The above Fig 4.2 depicts the model of the Indian Locomotive WAP-7, connected with one bogie compute the pressure, velocity and, drag coefficient needed for the design of aerodynamic fairings according to the specifications, the side top view of the model is as shown in Fig 4.3.

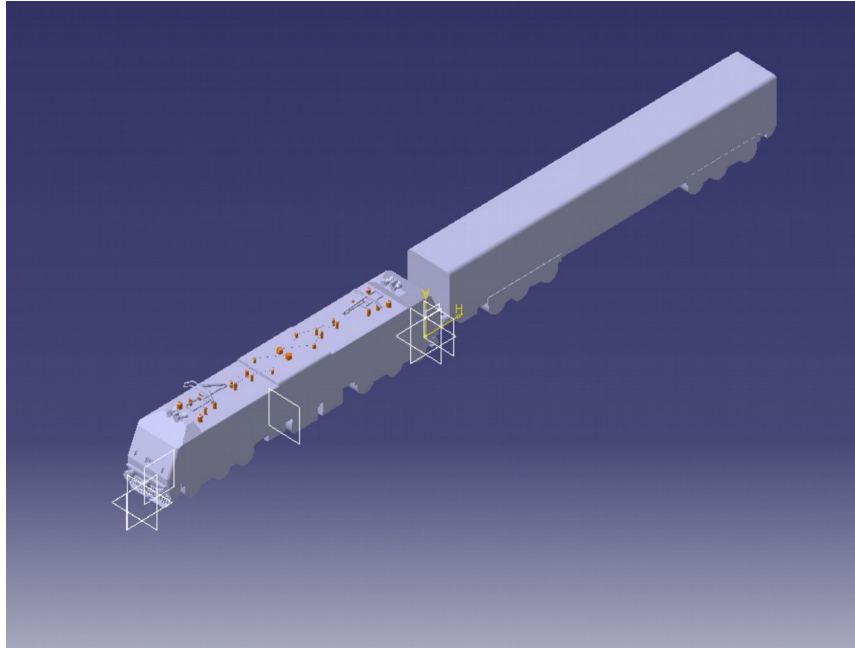


Fig 4.3 Top view of WAP -7

To obtain a more optimized result, we have considered making three designs of aerodynamic fairings and the design that is better suited to the reduction in drag will be considered for fabrication and experimental verification.

4.3 AERODYNAMIC FAIRINGS DESIGN

For this project, we will design three different aerodynamic fairings and choose the one which has the best possible results before stepping into the fabrication process they will be named as per,

1. Model A
2. Model B
3. Model C

Each fairing will differ concerning its design and characteristics that will help in the reduction of pressure drag and drag coefficient. All these components have been designed in CATIA V5 modeling software.

4.3.1 Model A

The Fairing for this model is designed based on the beak of a bird. This design theoretically helps in making the incoming air flow smoothly over the front face of

the engine thereby decreasing the onward drag force caused by the flow. This can considerably decrease the drag. Here at the end of the bogie, there will be a converging type of airfoil shape fairing. This is done to make the flow at this point detach and to flow smoothly instead of turbulent.

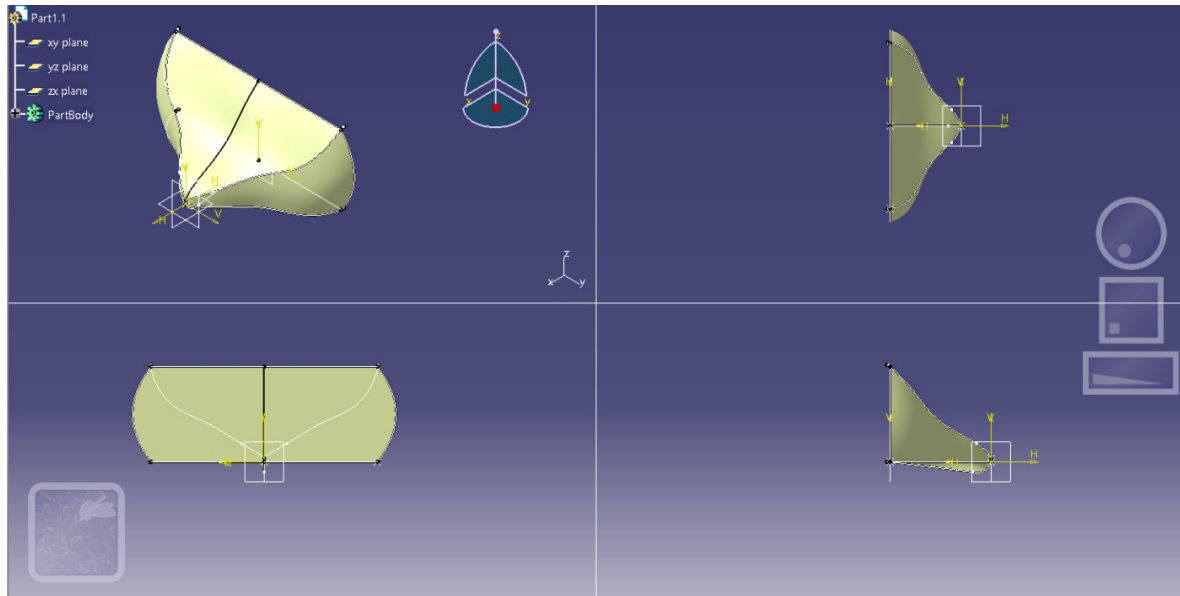


Fig 4.4 Four views of Front fairing for Model A

As seen in the Fig 4.4 the front fairing has been designed in such a way that it has many curves that converges at the lower center. This is done in order to pierce through the incoming wind and make the air flow smoothly over the surface to the upper part of the train.

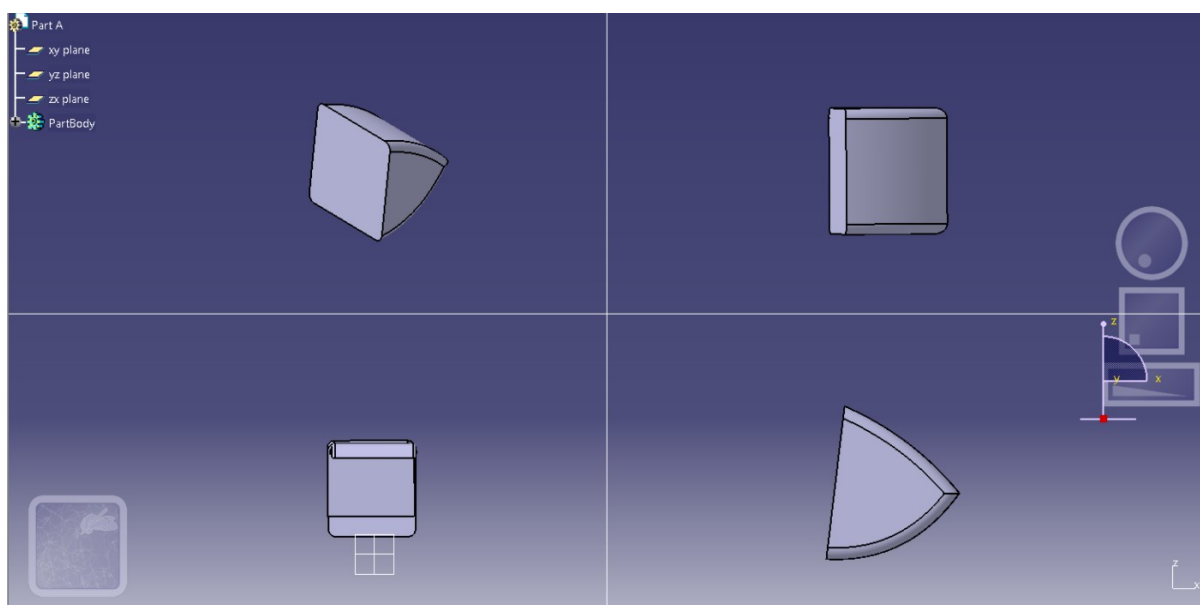


Fig 4.5 Four views of Back fairing for Model A

The Fig 4.5 shows the four views of the fairing that will be attached at the end of the bogie. This is designed to be a converging airfoil type trailing edge design so that the flow detaches at the surface eliminating the formation of the vortex at the fairing and exits as a laminar flow.

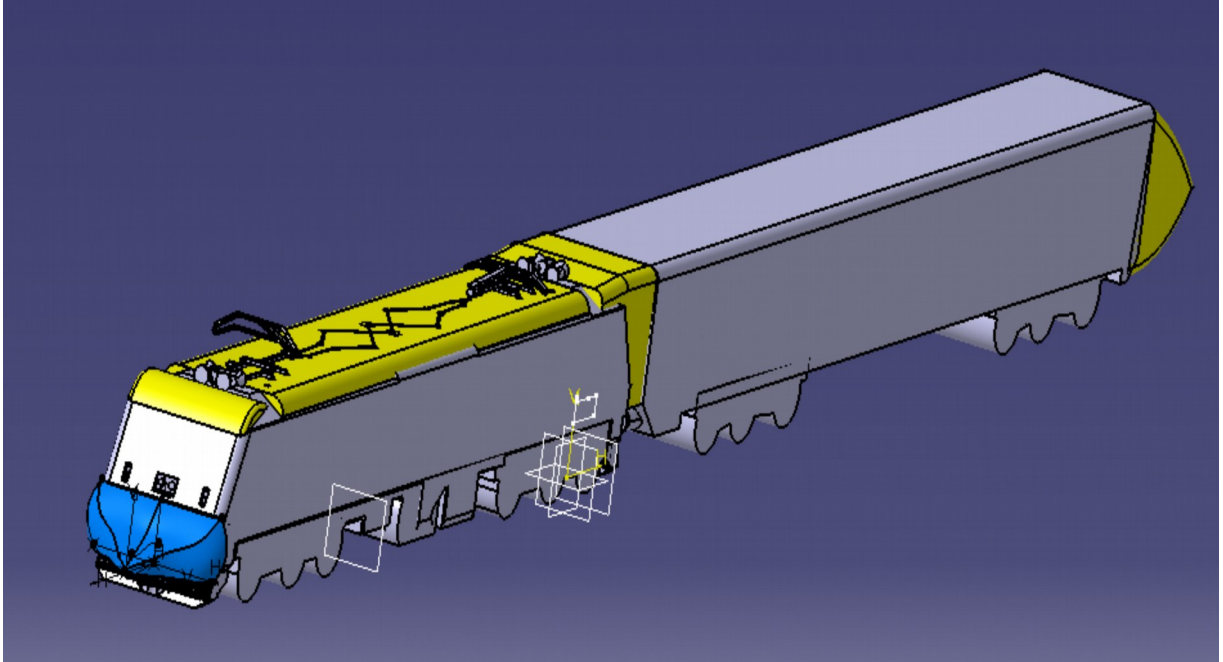


Fig 4.6 Front views of Model A

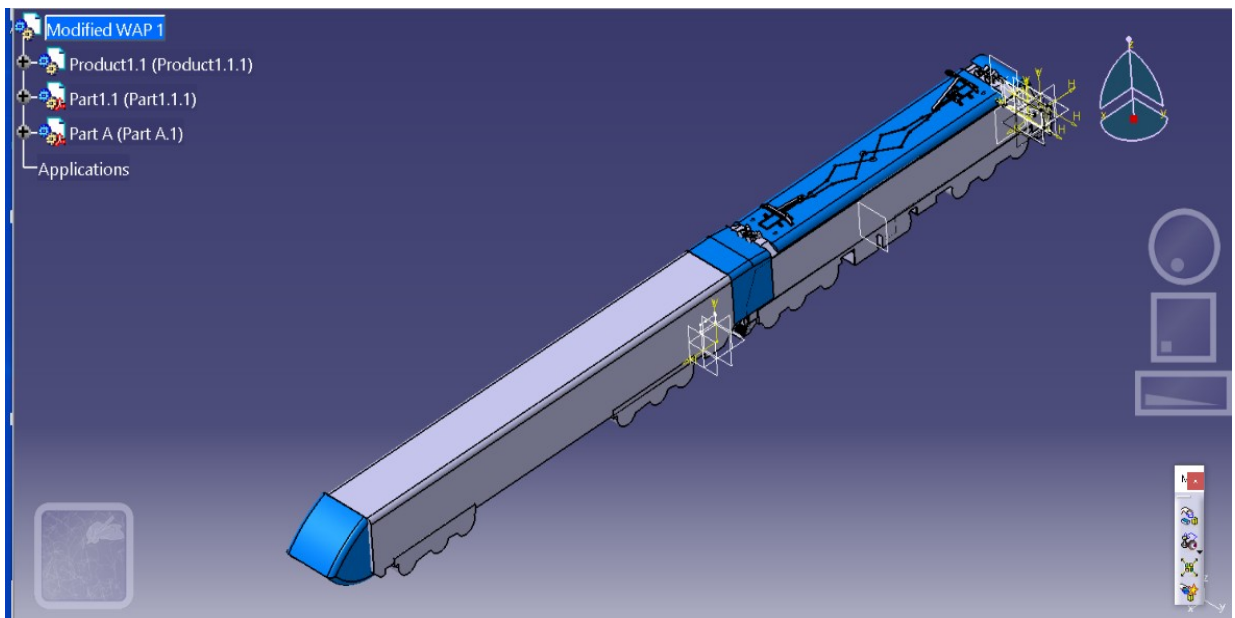


Fig 4.7 Back views of Model A

The Fig 4.6 and 4.7 show the fairings attached to the front and back of the WAP-7 model.

4.3.2 Model B

This design of fairing for Model B is derived from the design of fairing of Model A, but the main difference is that for the front fairing the curves are set into straight-line converging at the low center so that the fairing can still pierce through the incoming air. Also, the back fairing does have the same converging type airfoil design but is slightly modified by placing ridges into the fairing.

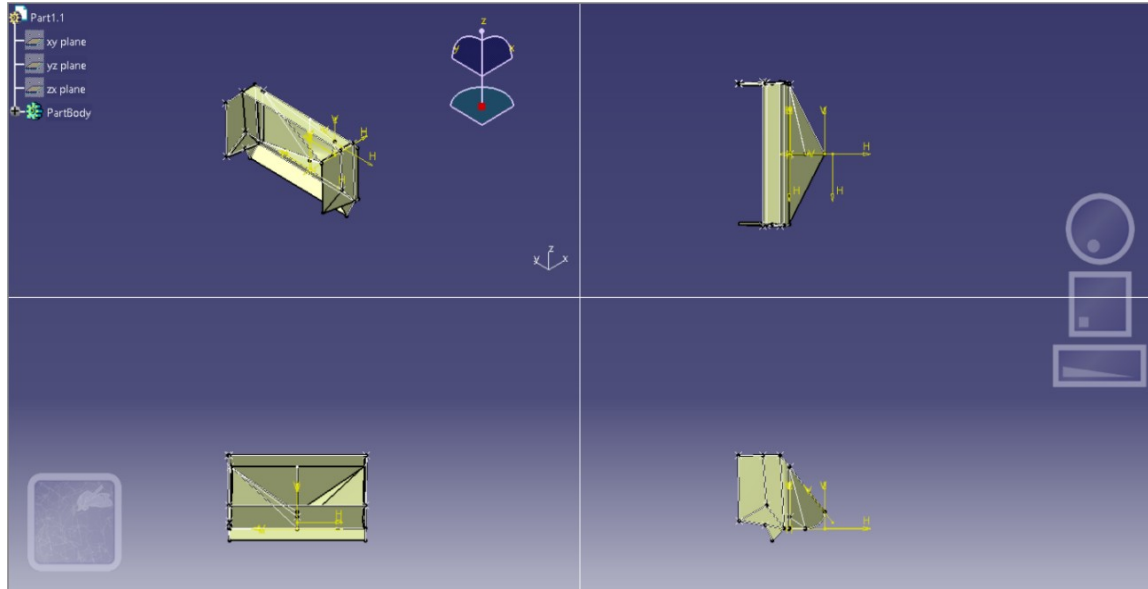


Fig 4.8 Four views of Front fairing for Model B

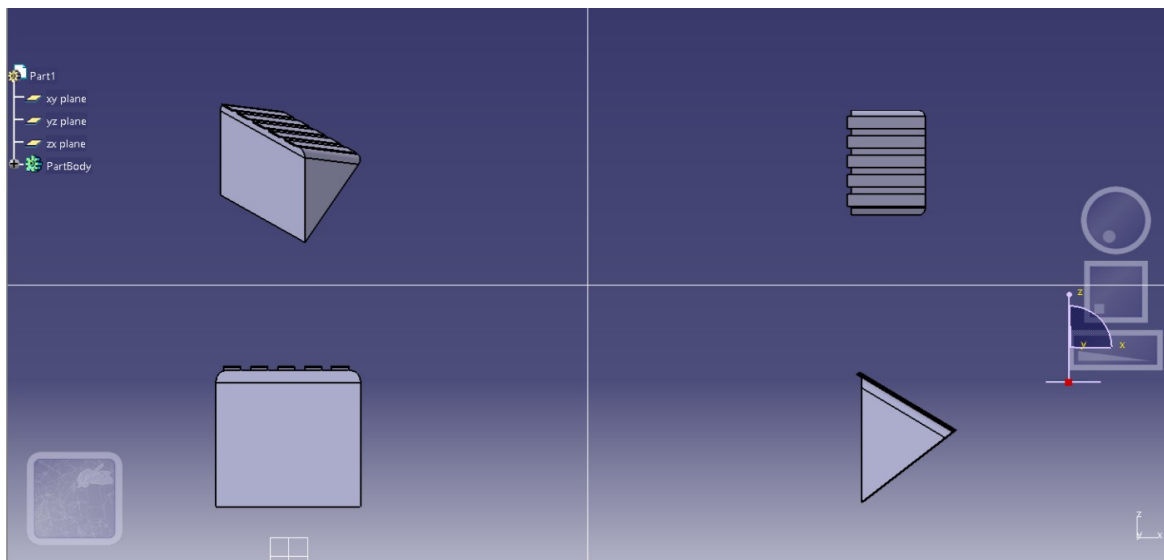


Fig 4.9 Four views of Back fairing for Model B

The two Fig 4.8 and 4.9 shows the four view of the fairings that will be attached to the front and back end of the WAP-7, clearly showing slight variation in

design compared to the fairing of Model A. Here the back fairings have ridges so that the flow gets attached to the surface, forming a vortex, and exits the fairing more efficiently compared to the fairing of Model A.

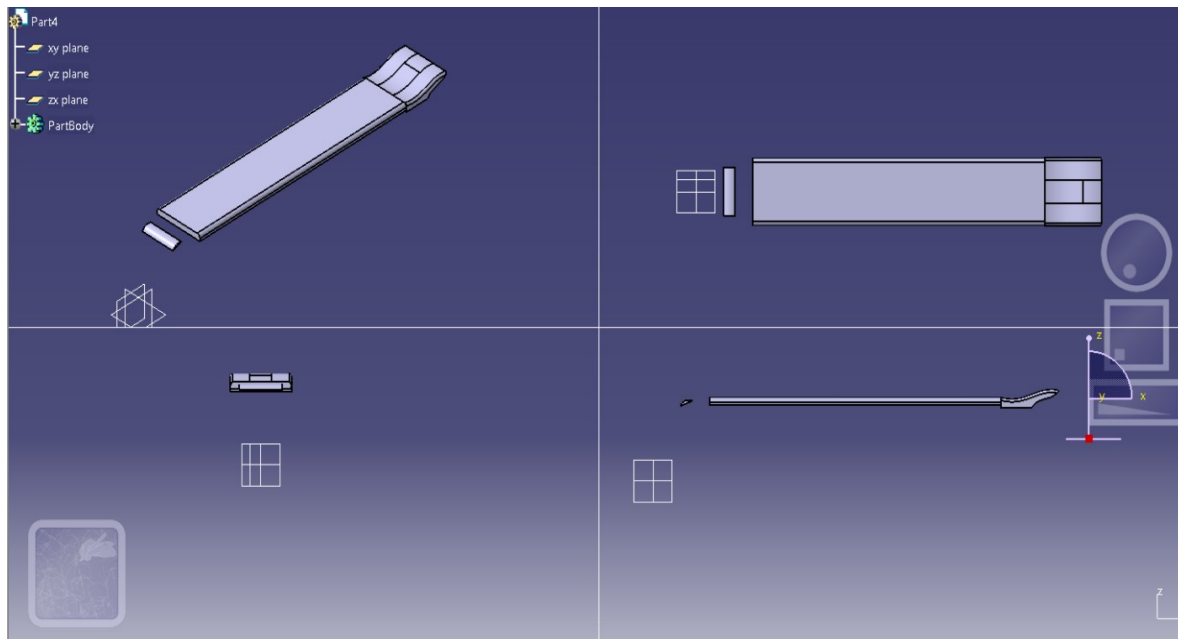


Fig 4.10 Four views of the Top fairing for Model B

As seen in Fig 4.10, considering the flow on the upper surface of the train we have decided to design an upper fairing that will be fixed at the top of the engine to smoothen the flow over the train.

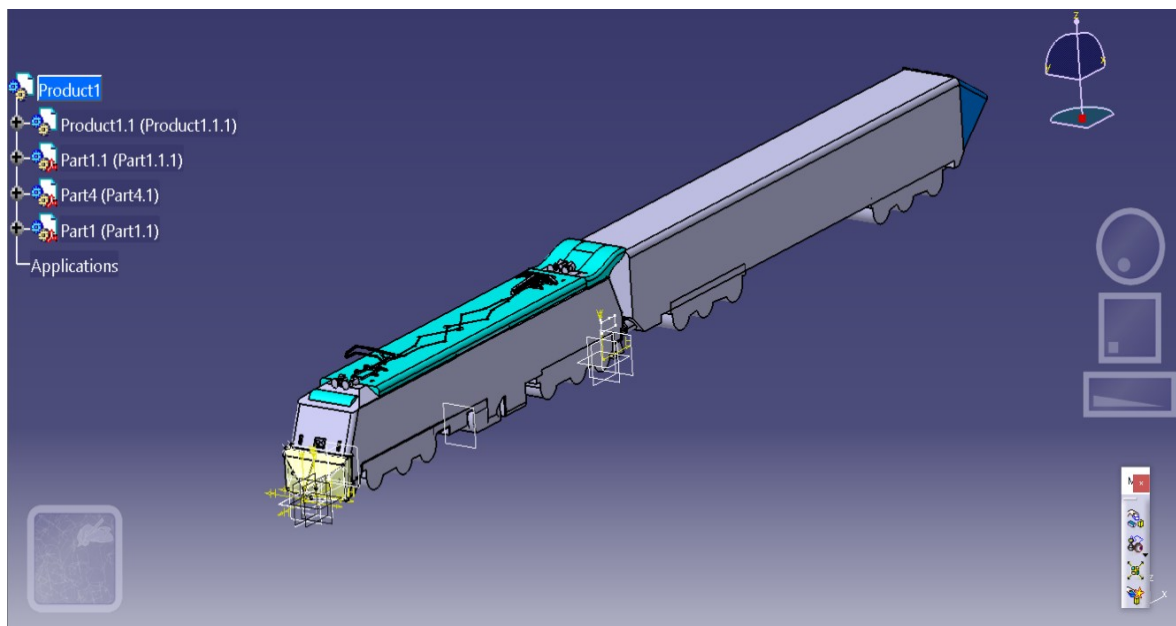


Fig 4.11 Front view of Model B

The following Fig 4.11 and 4.12 show the fairings attached to the front and back of the WAP-7 model. Also, we can see the difference in design compared to Model A.

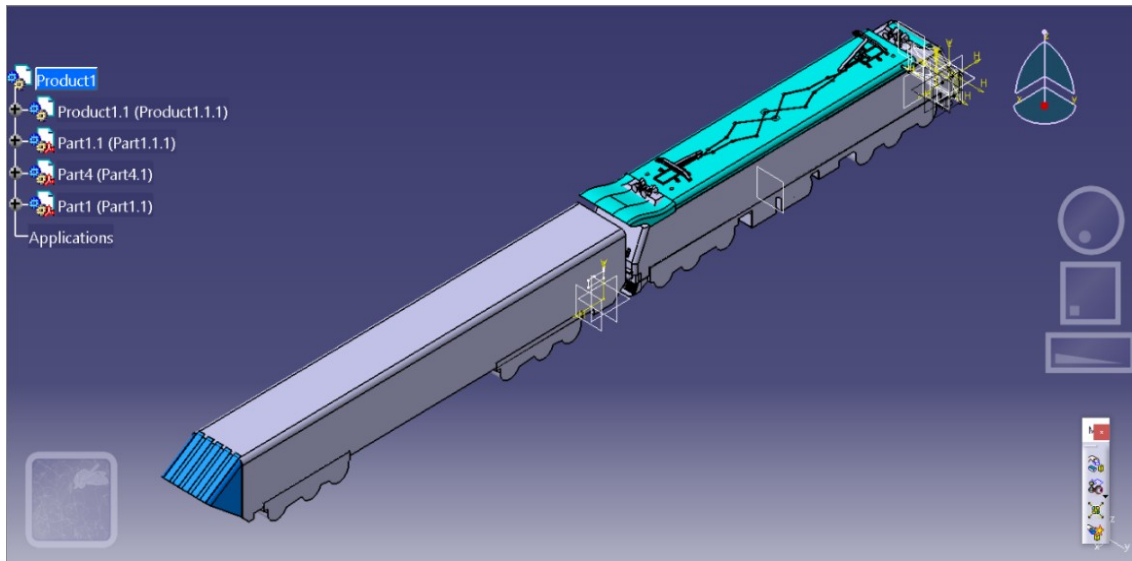


Fig 4.12 Back view of Model B

4.3.3 Model C

This design of fairing for Model C is completely different compared to the previous two designs. The front fairing is derived from the design of snow clearing trucks that are used to clear snow accumulated on the roads. The back fairing is derived from the shape of a pyramid i.e. lines converging to the center of the corners of the back end of the bogie.

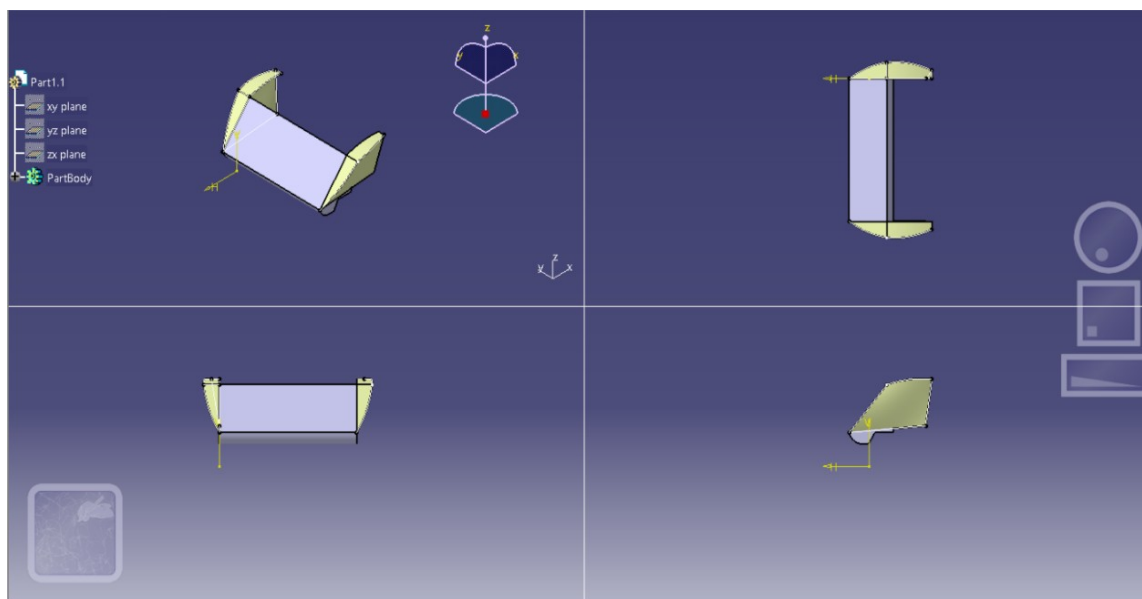


Fig 4.13 Four views of Front fairing for Model C

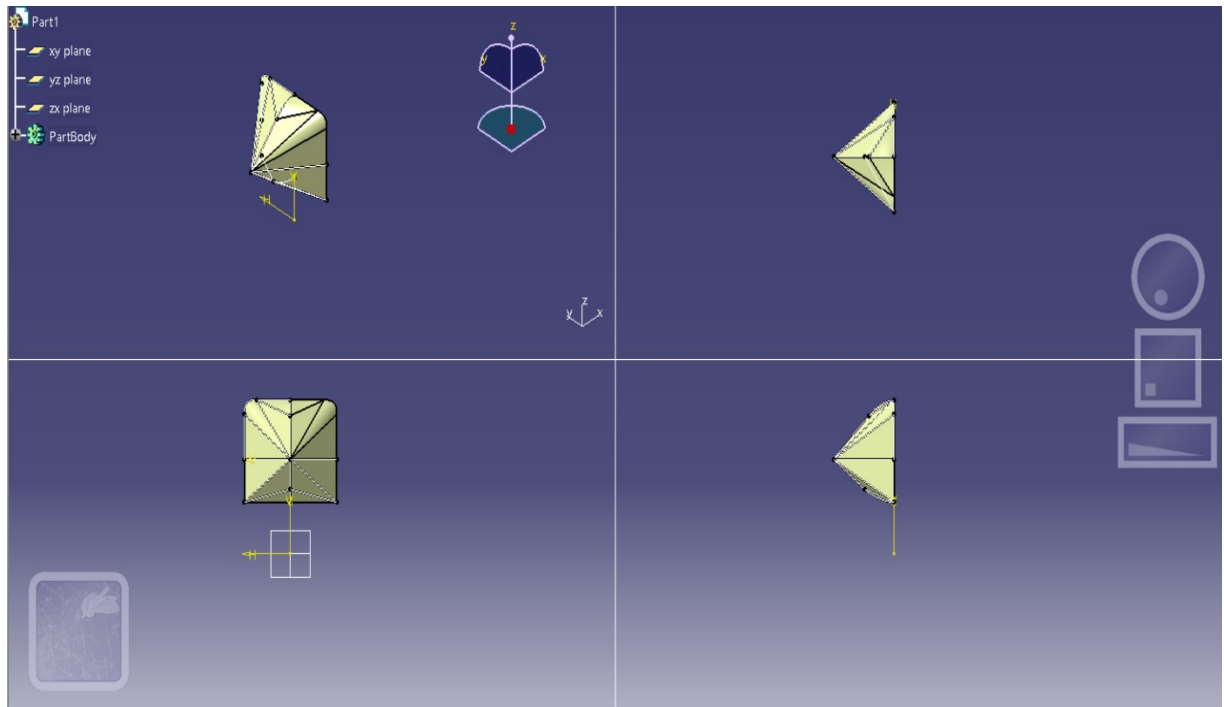


Fig 4.14 Four views of Back fairing for Model C

The two Fig 4.13 and 4.14 show the four view of the fairings that will be attached to the front and back end of the WAP-7, clearly showing the difference in design compared to Mode A and B. The back fairings are converging to a center point. Here the flow gets detached at the end.

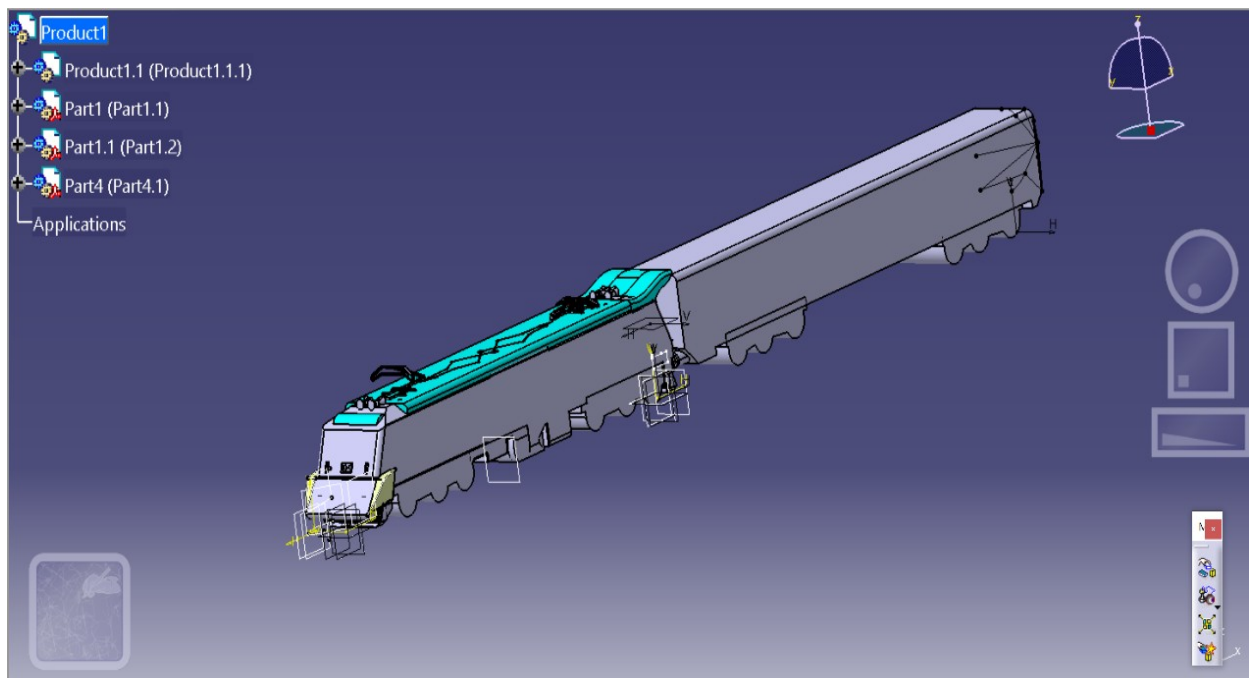


Fig 4.15 Front view of Model C

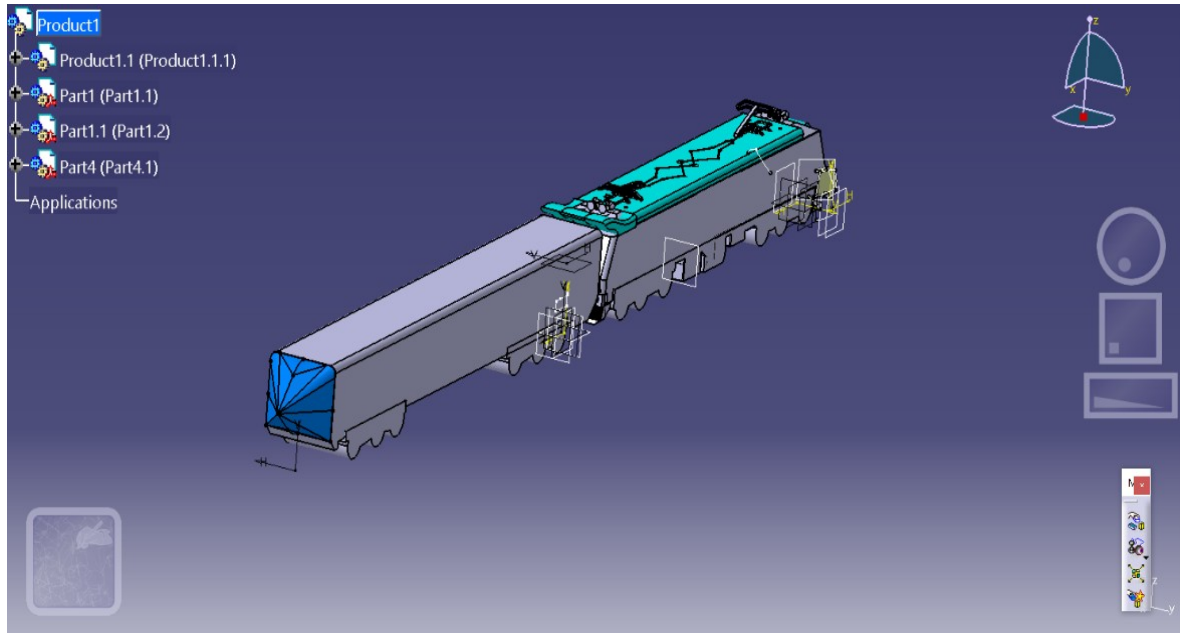


Fig 4.16 Back view of Model C

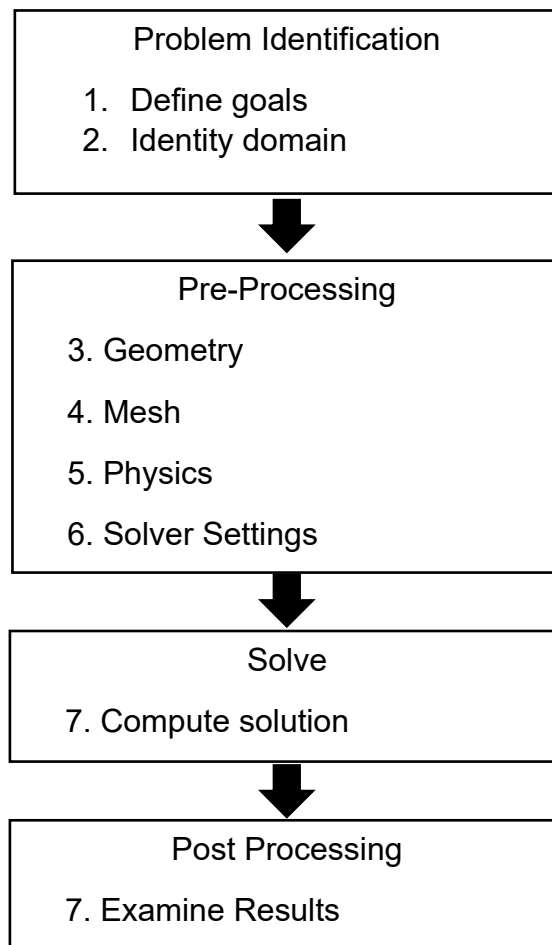
The above Fig 4.15 and 4.16 shows the fairings attached to the front and back of the WAP-7 model.

After the modelling and attaching the fairings to the front and back of each model. The next step in the process is to import the models into STAR CCM + computational analysis software and perform the analysis for each individual model. The steps and settings for the analysis is discussed in the next chapter.

CHAPTER 5

COMPUTATIONAL ANALYSIS

Any computational analysis consists of the following steps, preprocessing, Defining boundary conditions, and solver setting followed by post-processing. The initial problem identification has been made and subsequent steps are carried out.



5.1 PRE PROCESSING

5.1.1 Meshing

In Finite Element Analysis, meshing is the first step toward solving a problem. The domain is discretized (divided) into substantive divisions known as "Elements" in this case. These elements serve as the foundation for specifying boundary conditions and external effects. This process of discretizing the entire domain into

small elements into a finite region and point where two elements join is called NODE.

Hence the numerical calculations are carried out in these nodes alone. Finer the elements and nodes, the more accurate the results will arrive. As we increase the number of nodes and elements the computational time also increases and it requires high-speed computers. Based on available resources we have chosen an optimum number of nodes and elements. There are different types of meshing techniques and strategies but only a particular element suits a particular problem. A brief description of the type of elements and their usage is given below.

5.1.2 Mesh elements types

Tetrahedrons can be made easily, automatically, and for a variety of geometries. To capture gradients in one direction, isotropic refinement is used; the mesh is established in all three directions, and cell counts rapidly increase. The inflation layer aids refinement normal to the wall, but in 2D it is still isotropic (Surface Mesh). For most CFD applications, fewer elements are needed to overcome physics. This hexahedral mesh has half the number of nodes as a tetrahedron mesh and has the same flow physics resolution. Different types of 2D and 3D mesh elements are shown in Fig 5.1.2(a) Prism meshes are used to capture boundary layer flow when the unstructured mesh is used.

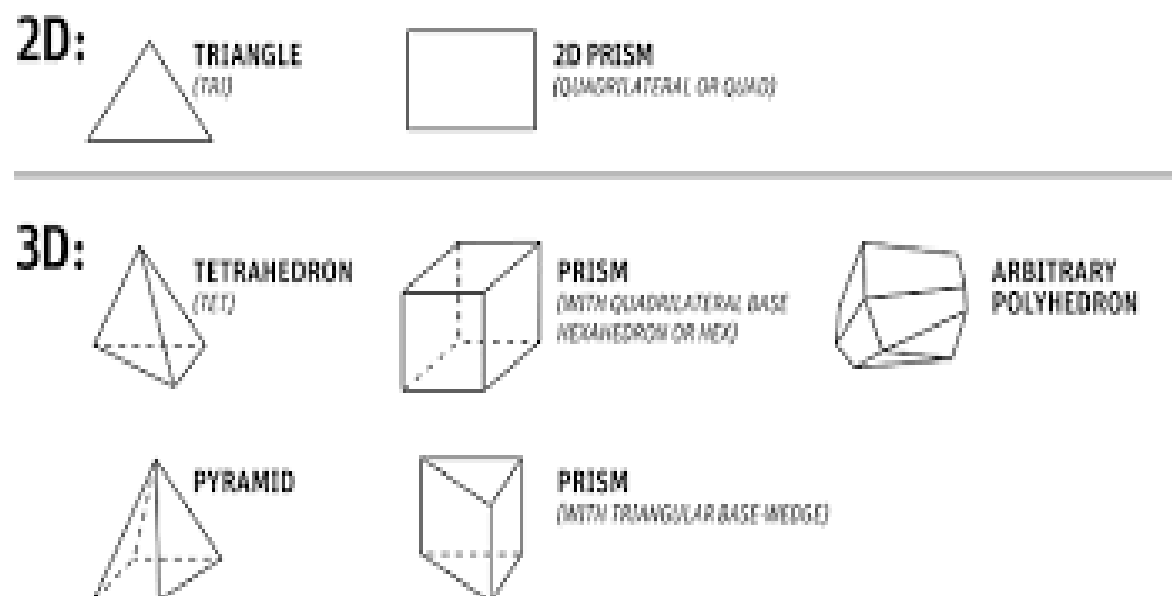


Fig 5.1 2D and 3D Elements

A computational domain is considered for the analysis. Mesh refinement. The computational analysis for the models will be done in STAR CCM+ analysis software. Meshed model of WAP-7 is as shown in Fig 5.2.

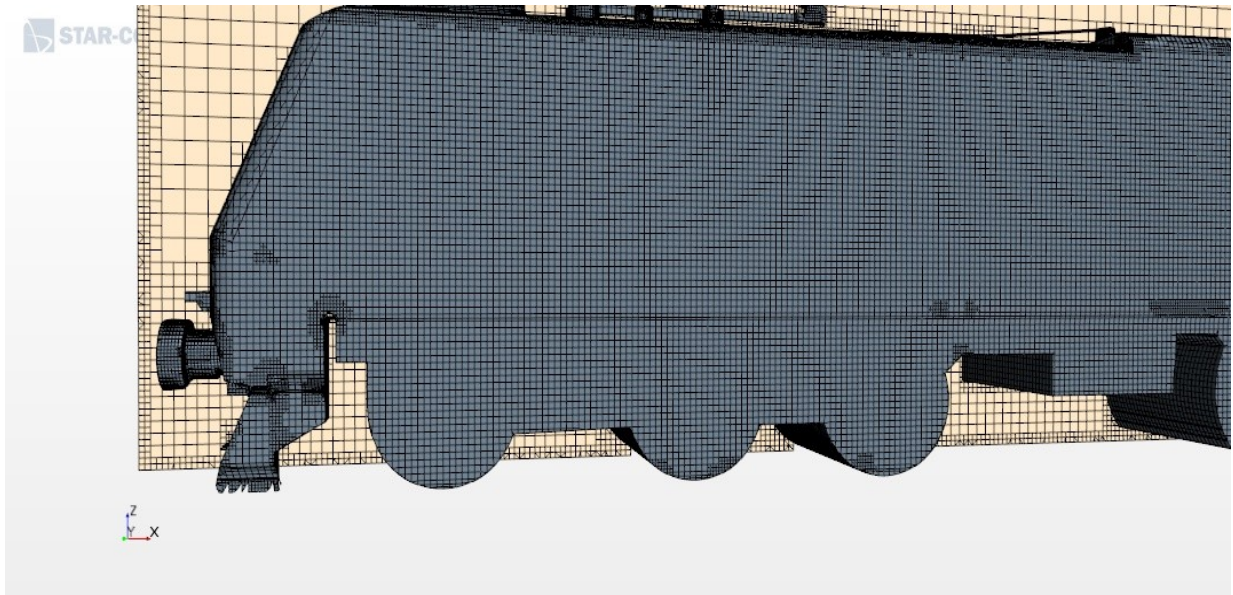


Fig 5.2 Meshed Model Of WAP-7

Table 5.1 Mesh Details

SI No	Detail	Count
1	Cells	3458093
2	Faces	10323807
3	Vertices	4950633

Now we will consider the above-meshed model of the existing WAP-7 for the analysis and then compare it to the fairings that have been designed to reduce the drag.

5.2 BOUNDARY CONDITIONS

The boundary conditions should be given correctly to obtain better results. The following combinations of boundary conditions are all valid configurations commonly used in commercial packages. They are listed in Table 5.2.

Table 5.2 Boundary Conditions

SI No	Boundary Details	Boundary Condition
1	Inlet	Velocity Inlet
2	Outlet	Pressure Outlet
3	Boundary	Wall

Velocity inlet and Pressure outlet are the Inlet and Outlet boundary conditions, respectively, whereas the sides are set as wall boundary.

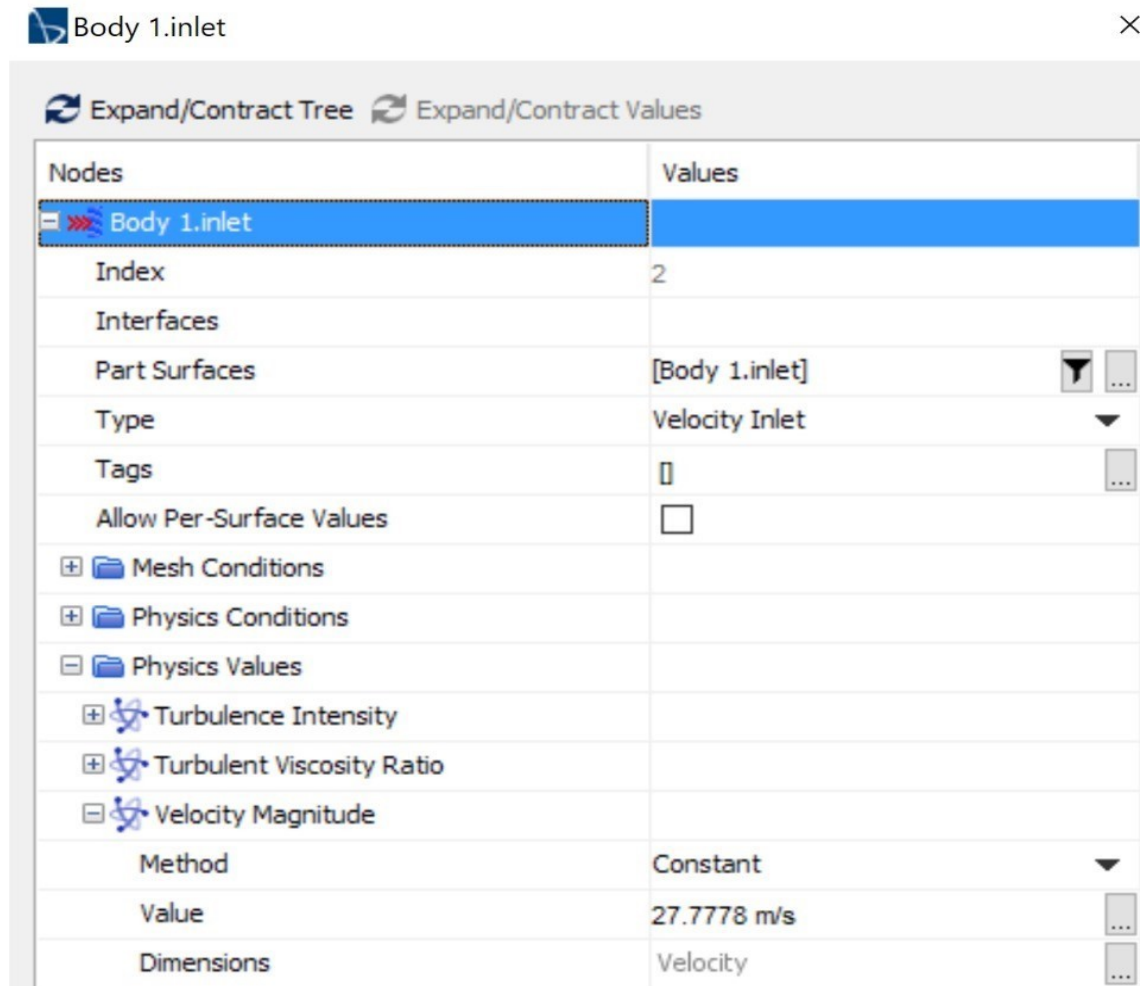


Fig 5.3 Velocity Inlet Setting

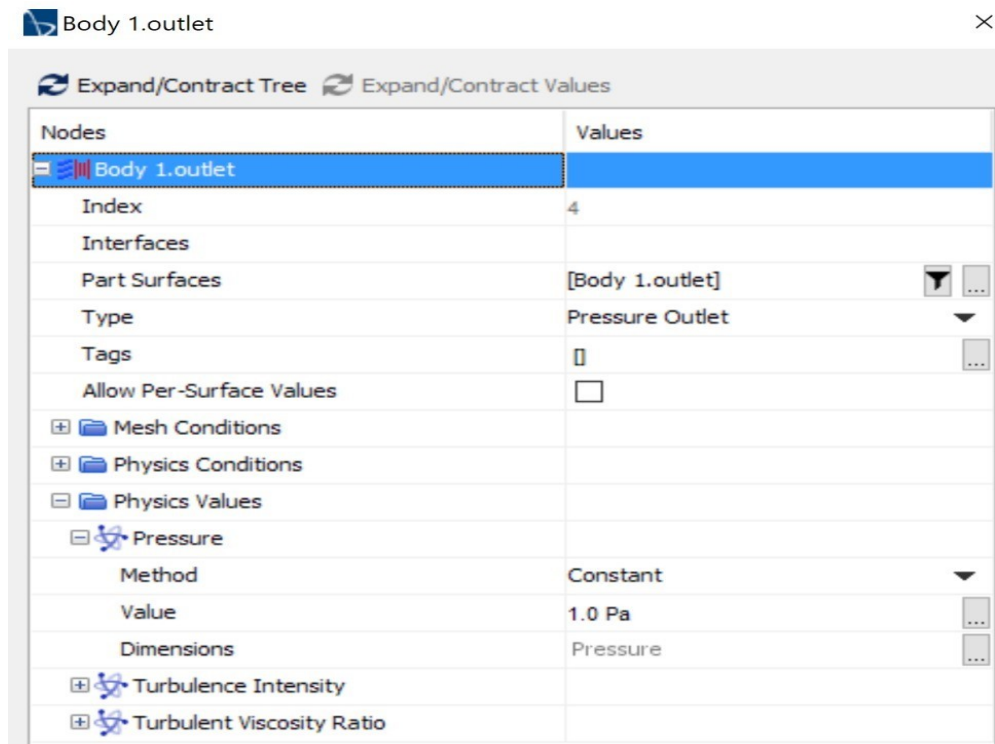


Fig 5.4 Pressure Outlet Setting

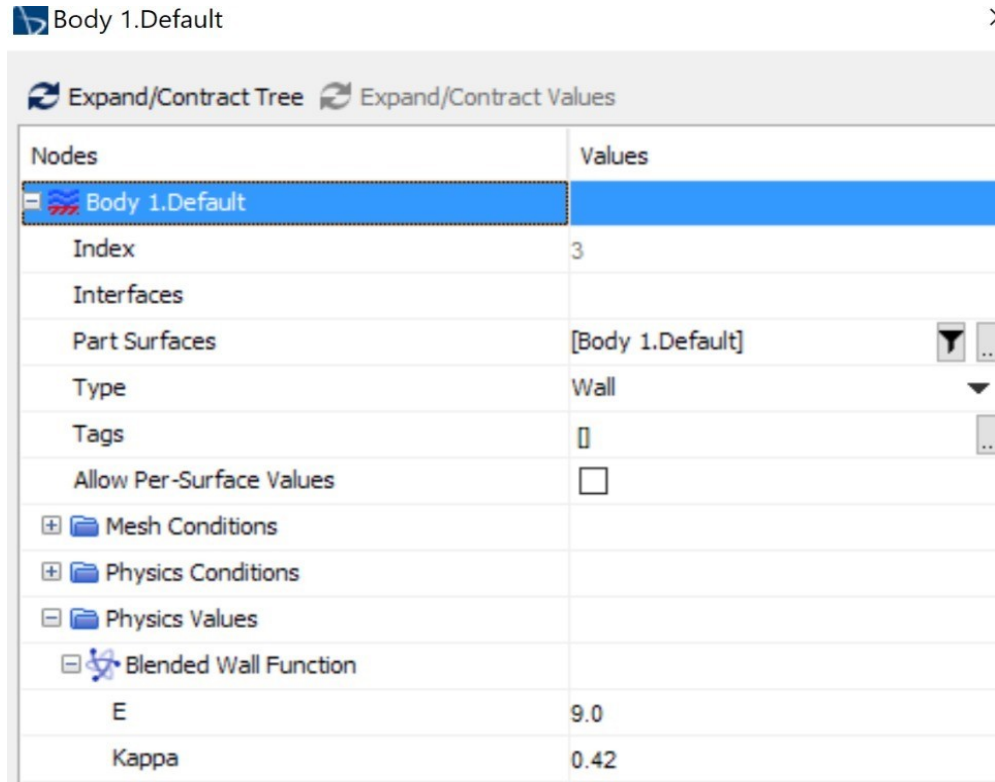


Fig 5.5 Wall Boundary Setting

5.3 CFD RESULTS

After defining the boundary conditions we will analyze the flow over the existing WAP-7 model and obtain the pressure contour along with the drag coefficient.

5.3.1 Existing Model Analysis Results

The results of the analysis are studied from the analysis with respect to pressure, and drag coefficient. The CFD analysis in Fig 5.5 shows the pressure contour of the model (Front view) and it can be observed that the maximum pressure is experienced at the lower center where it is close to 2911 pa of pressure.

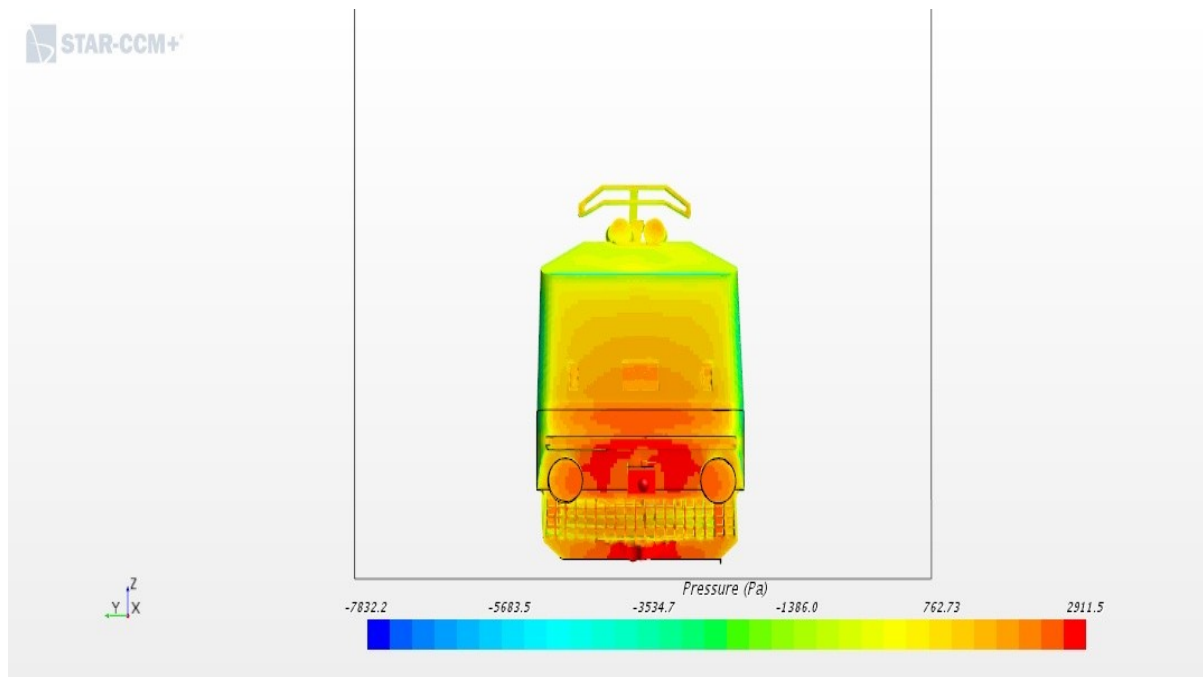


Fig 5.6 Pressure contour of existing model (Front view)

Fig 5.7 shows the side view of the pressure contour where blue represents the least pressure and red represents the maximum pressure. It can be observed that there is an accumulation of maximum pressure at the front, approximately 2857 pa at the front end due to the absence of an aerodynamic fairing. Next in the scale is the side of the train frame which experiences lesser pressure compared to the frontal area of the engine.

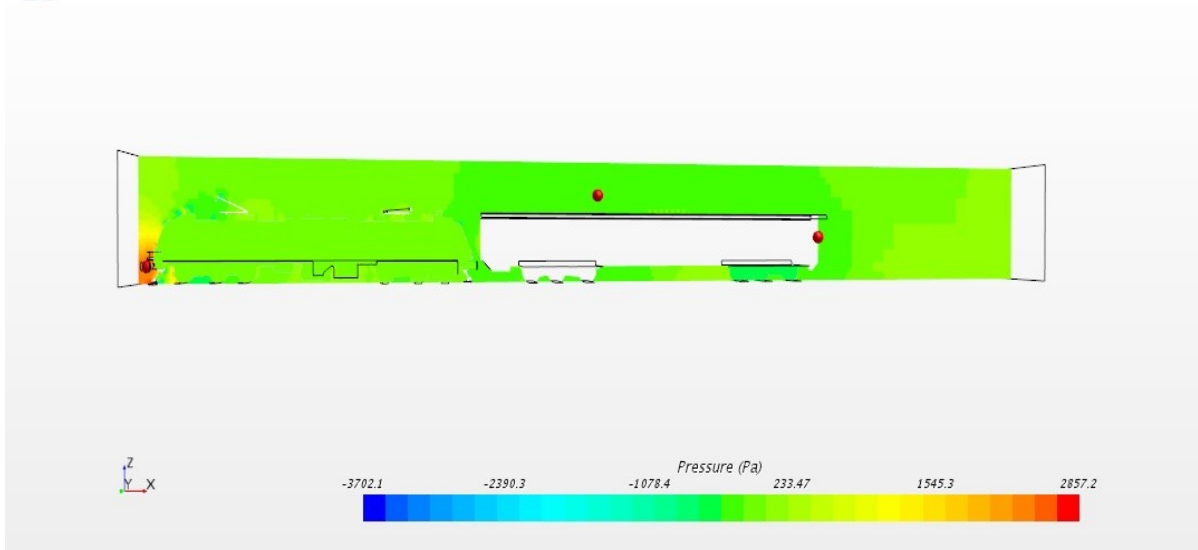
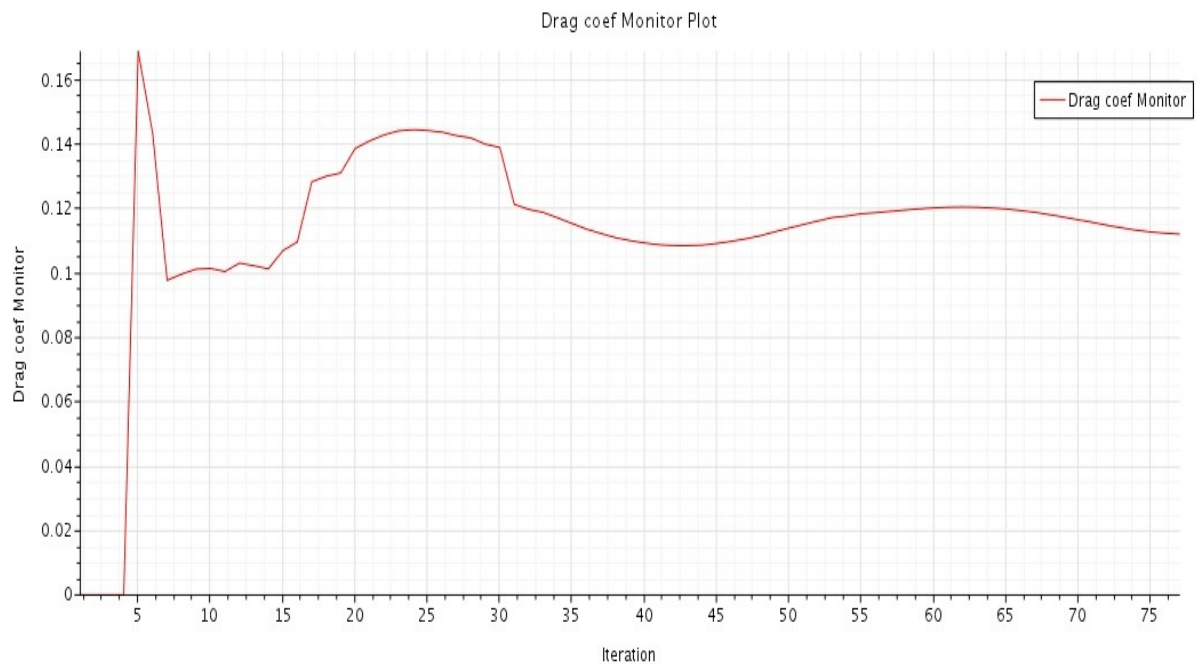


Fig 5.7 Pressure contour of existing model(Side view)



5.8 Drag coefficient plot of existing model

The drag coefficient is plotted against the number of iterations in Fig 5.8. As seen in the graph, the x-axis represents the number of iterations and y-axis represents the drag coefficient. Here we can observe that the drag rises steeply to about 0.17, drops to 0.1, and then maintains steadily. The enormous drag coefficient is due flat frontal area along with the absence of a fairing at the front of WAP-7.

5.3.2 Model A Results

The boundary conditions and solver settings remain the same for this analysis. The proposed fairing is attached to the WAP-7 model and analyzed.

The Fig 5.9 depicts the front view pressure contour of Model A. The pressure is the wind resistance acting on the front of the model. It can be observed that the maximum pressure is reduced to 1553 pa compared to 2911 pa of the model without a fairing. There is a reduction of 46% in pressure.

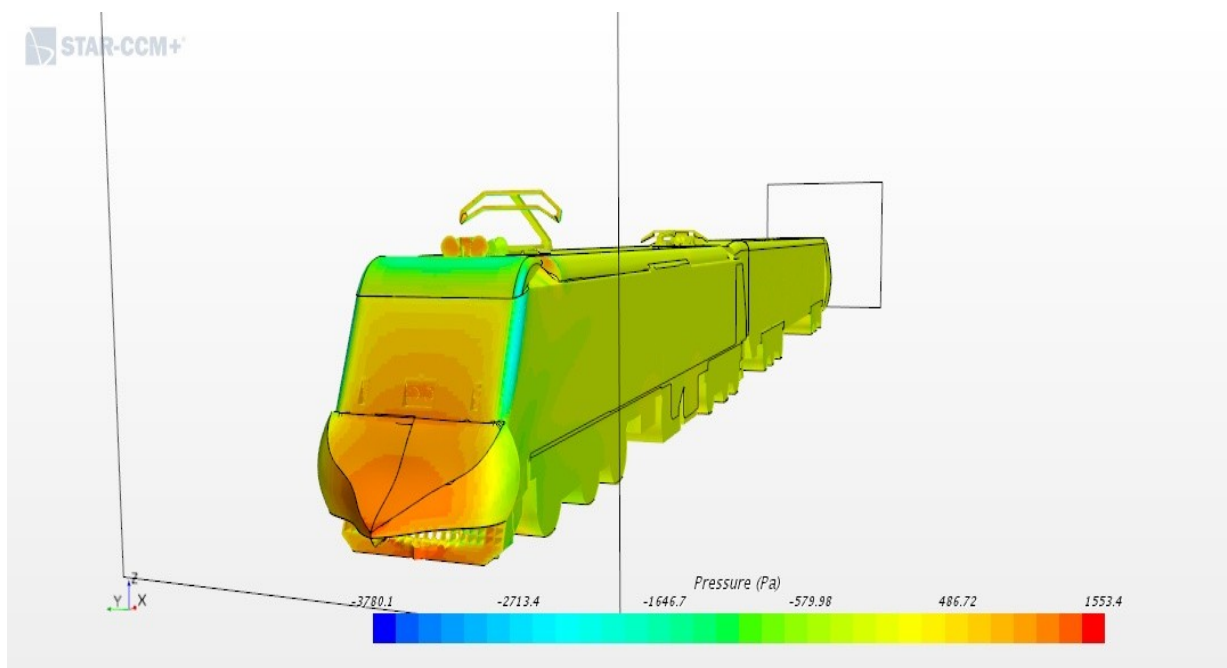


Fig 5.9 Pressure contour of Model A (Front view)

Fig 5.10 depicts the graph plotted drag coefficient against a number of iterations. The x-axis represents the number of iterations and y-axis represents the drag coefficient for each iteration. There is a steady increase from 0.069 to 0.07 followed by a decrease to 0.06 and maintains 0.064 as the number of iterations increases. It can be observed that there is a decrease from 0.16 (Existing model) to 0.07 (Model A). Along with a steady drag of 0.1 (Existing model) to 0.064 (Model A) as the number of iterations increases. Hence we can state that there is an improvement in drag reduction from the existing model of WAP-7 to the proposed Model A.

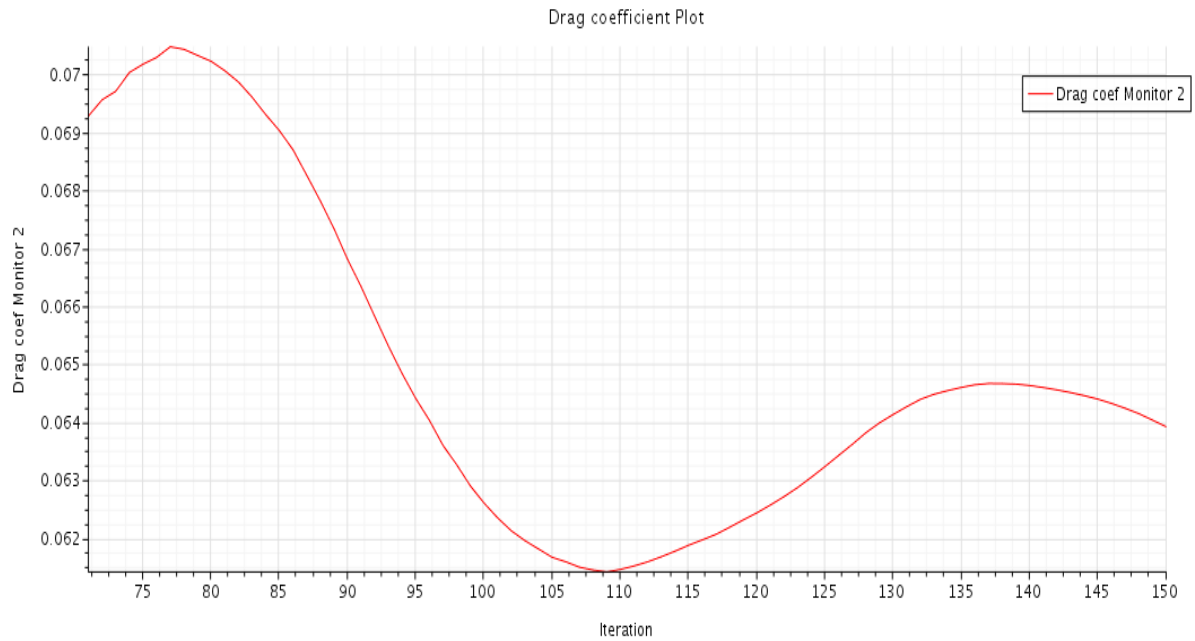


Fig 5.10 Drag coefficient plot of Model A

5.3.3 Model B Results

The boundary conditions and solver settings remain the same for this analysis. Model B is imported into STAR CCM + software for computational analysis.

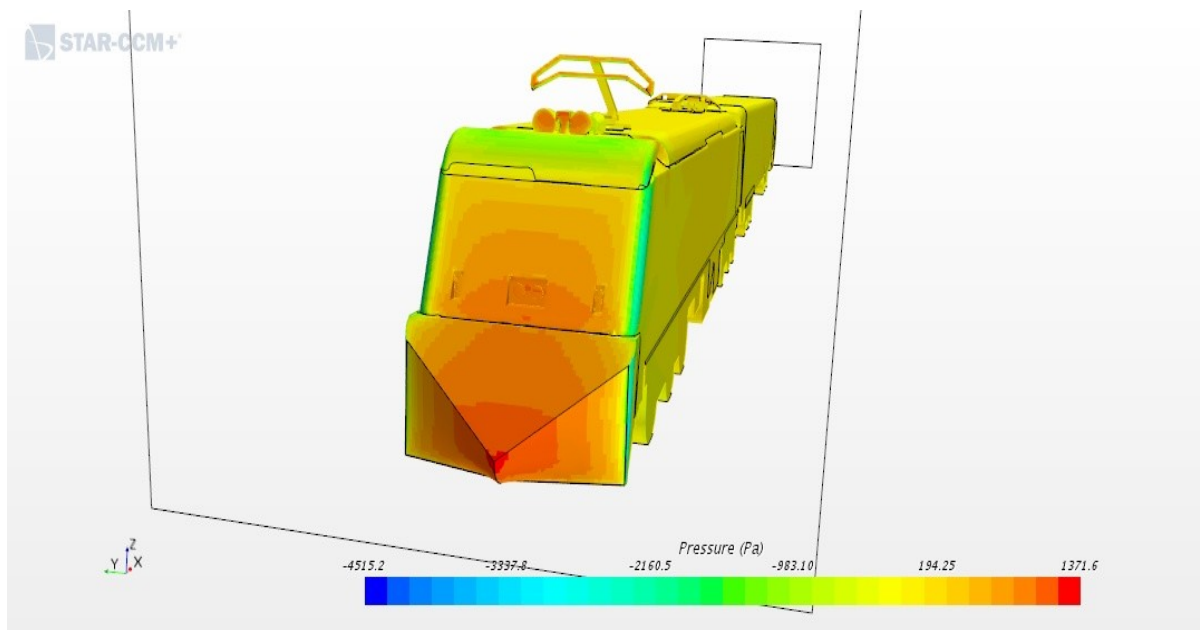


Fig5.11 Pressure contour of Model B(Front view)

Fig 5.11 and Fig 5.12 show the front view and side view of the pressure contour of the proposed model C. In this analysis, we can see another 13% reduction in pressure compared to Model A and approximately 60% reduction in pressure compared to the existing WAP-7 model without an aerodynamic fairing.

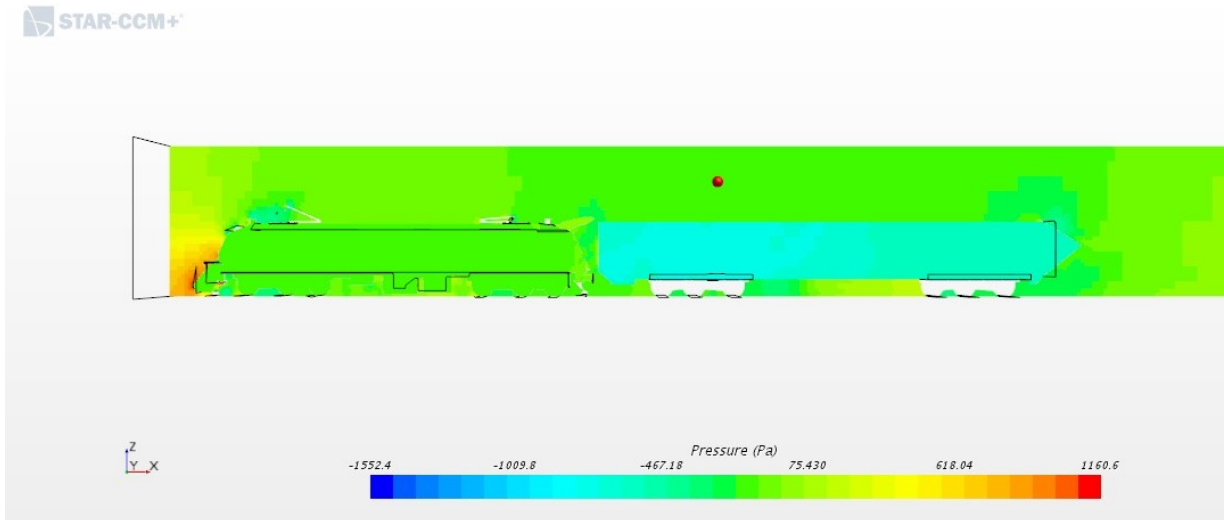


Fig 5.12 Pressure contour of Model B(Side view)

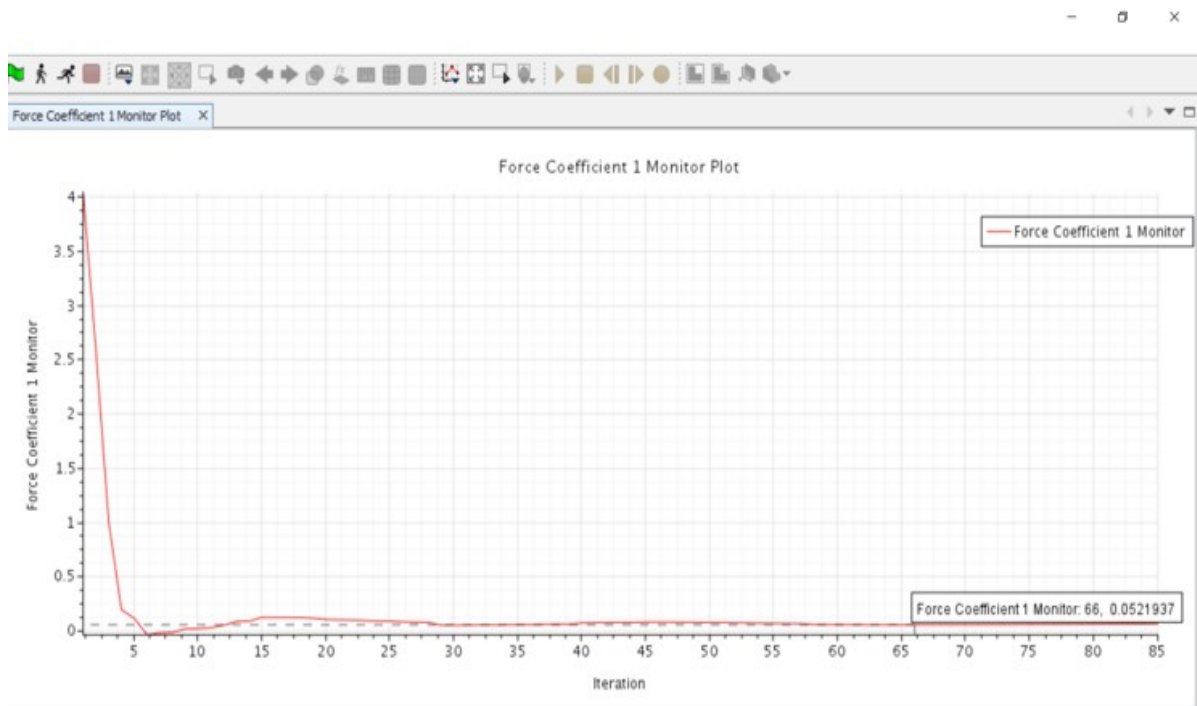


Fig 5.13 Force coefficient plot of Model B

Fig 5.13 depicts the force coefficient also called as drag coefficient plot against a number of iterations. It can be observed that the force or drag is reduced

significantly from 4 to 0.052 as the number of iterations increases. One of the reasons is the

additional top fairing that is attached to the model. Compared to 0.064 of Model A, Model B has a further reduction of 0.012. A 60% reduction in drag coefficient compared to the existing model.

5.3.4 Model C Results

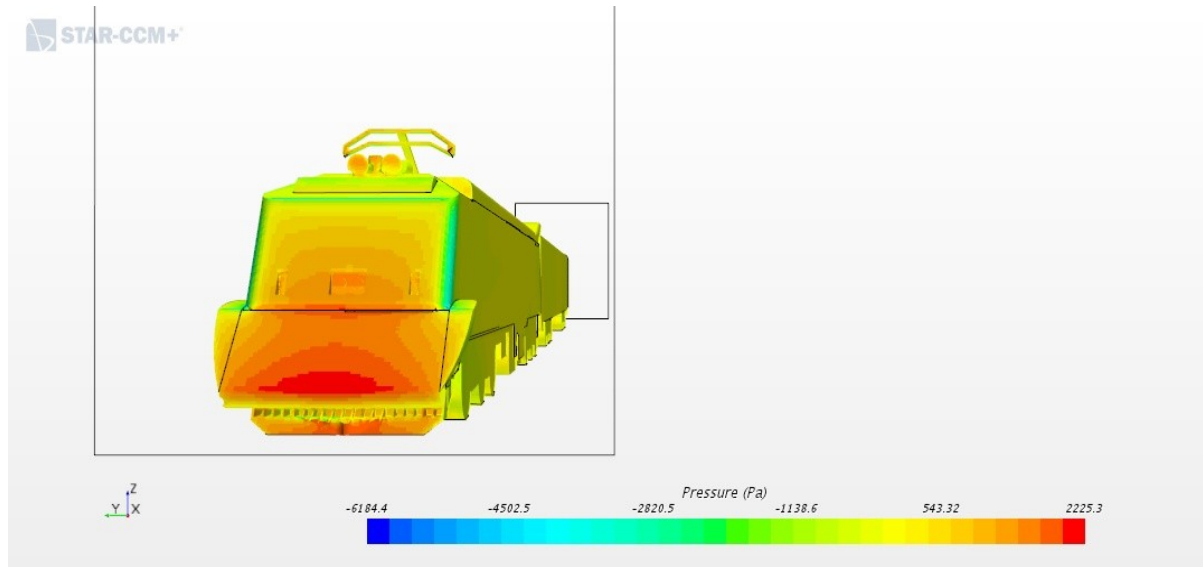


Fig 5.14 Pressure contour of Model C(Front view)

Fig 5.14 depicts the pressure contour of Model C. It can be observed from the figure that the maximum pressure is 2225.3 pa, which is a 23% reduction from the existing model. Compared to Model A and Model B, the maximum pressure is high and hence cannot be chosen as an alternative to the existing model.

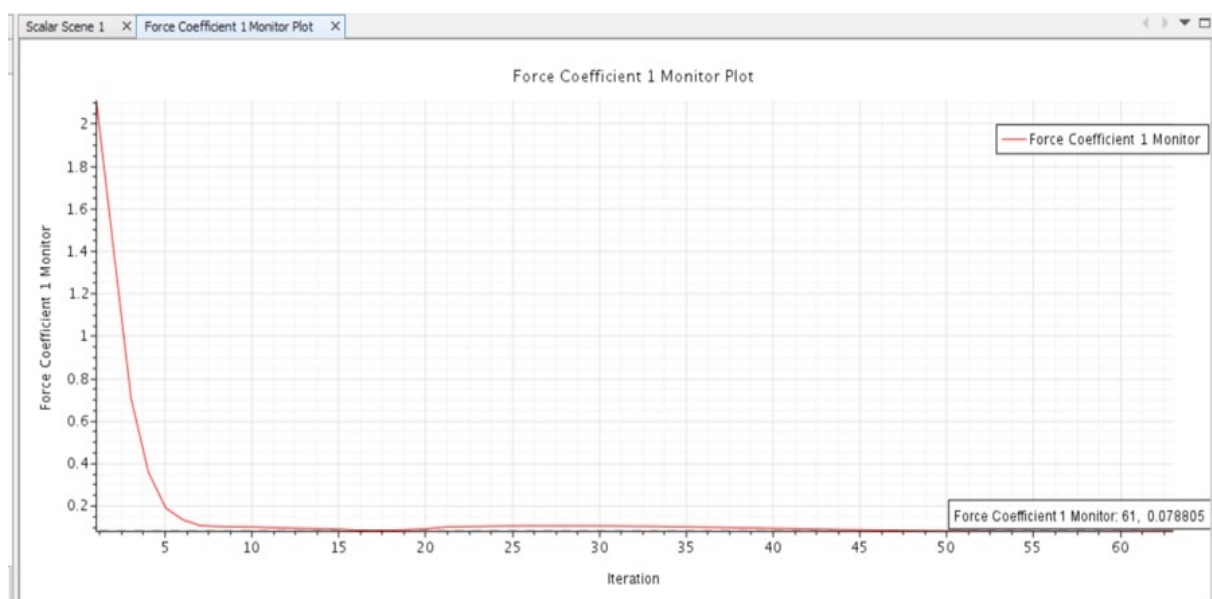


Fig 5.15 Force coefficient plot Model C

Fig 5.15 depicts the graph plotted force coefficient against a number of iterations for Model C. It can be observed that the Force coefficient or drag coefficient is 0.078. This is higher than both Model A and B. So this proposed model cannot be chosen as the best alternative considering both pressure and drag coefficient results.

5.4 COMPARISON OF COMPUTATIONAL RESULTS

The pressure and drag coefficient values of each proposed model and existing model are plotted and compared to choose the best alternative. The chosen model will then be fabricated and tested in a Wind tunnel.

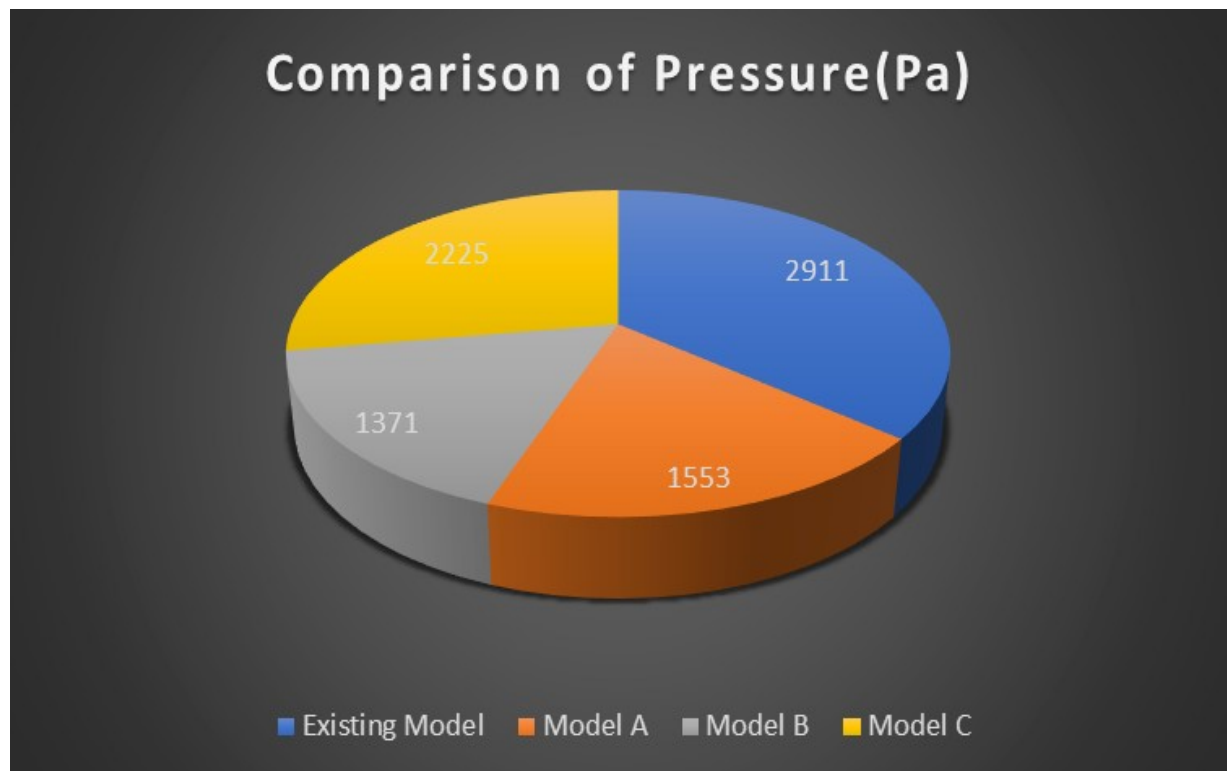


Fig 5.16 Comparison of Pressure for each model

From the comparison of pressure as shown in Fig 5.16. The best alternative model would be Model B as the maximum pressure is the least compared to all other models, 1553 pa compared to 2911 pa of the existing model. A reduction of 46% is observed. From the comparison of Drag coefficient values of each model as shown in Fig 5.17. The model with the least drag coefficient is model B which is 0.052

compared to 0.11 of the existing model and better than model A and C respectively. A reduction of 52% is observed in drag.

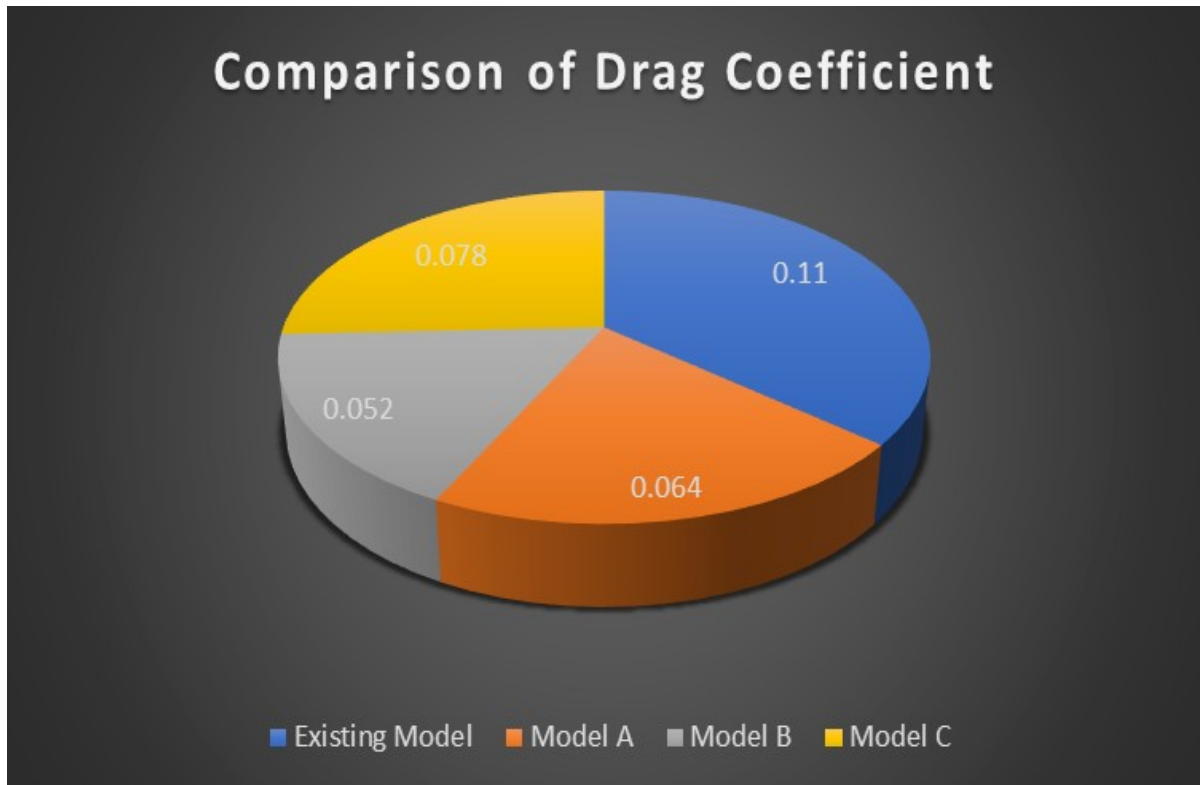


Fig 5.17 Comparison of Drag Coefficient for each model

Therefore after comparing both the Pressure and Drag coefficient of all models, we can conclude that Model B which has maximum pressure of 1553 pa and drag of 0.052 is the best alternative model to the existing model and hence will be fabricated and further testing will be done in a Wind tunnel for experimental validation of results.

CHAPTER 6

EXPERIMENTATION

6.1 FABRICATION OF THE MODEL

The material selection, working methodology is explained in this chapter.

6.1.1 Material Selection

For this experiment we have decided to use wood for the bogie and engine of the model, mainly owing to its rigid nature and easy carving. The front fairings and back fairings have been 3D printed using PLA (Polylactic acid) due to the complicated design.

6.1.2 3D Printing

3D printing or additive manufacturing is the construction or fabrication of a three-dimensional model from a CAD model. Here the model is imported from CATIA into 3D printing software where it programs the printer to heat the PLA (Polylactic acid) wire and deposit layer by layer to create the model.

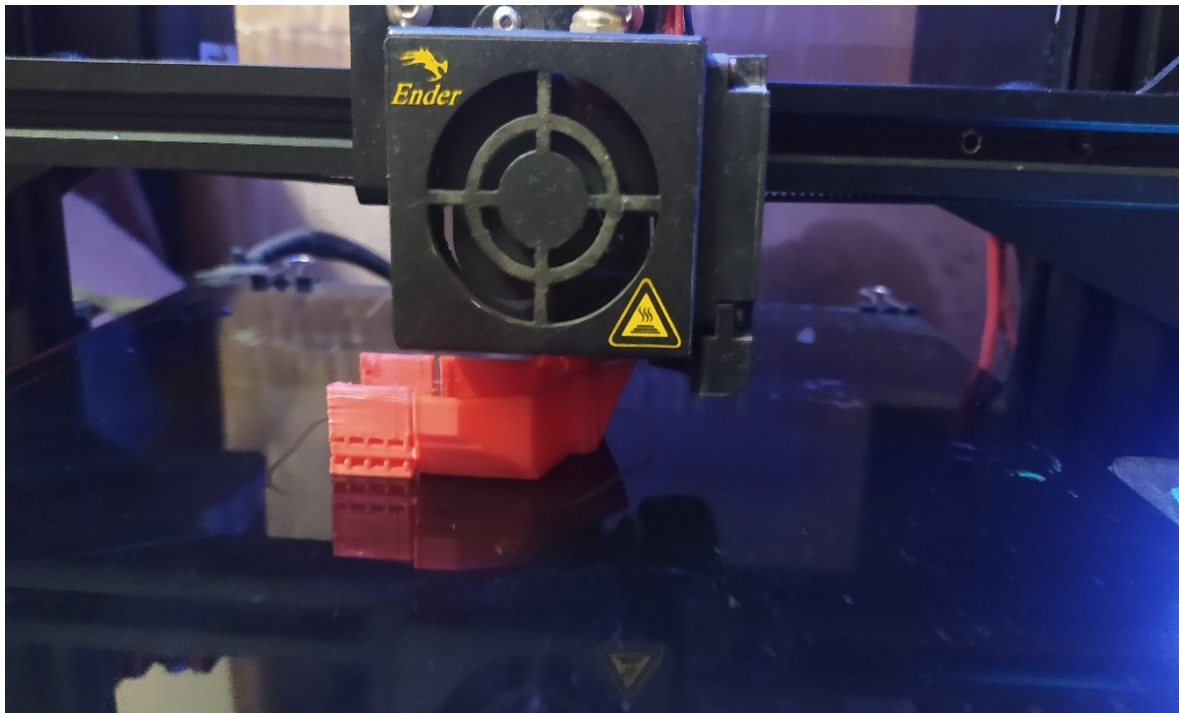


Fig 6.1 3D printing the modified model

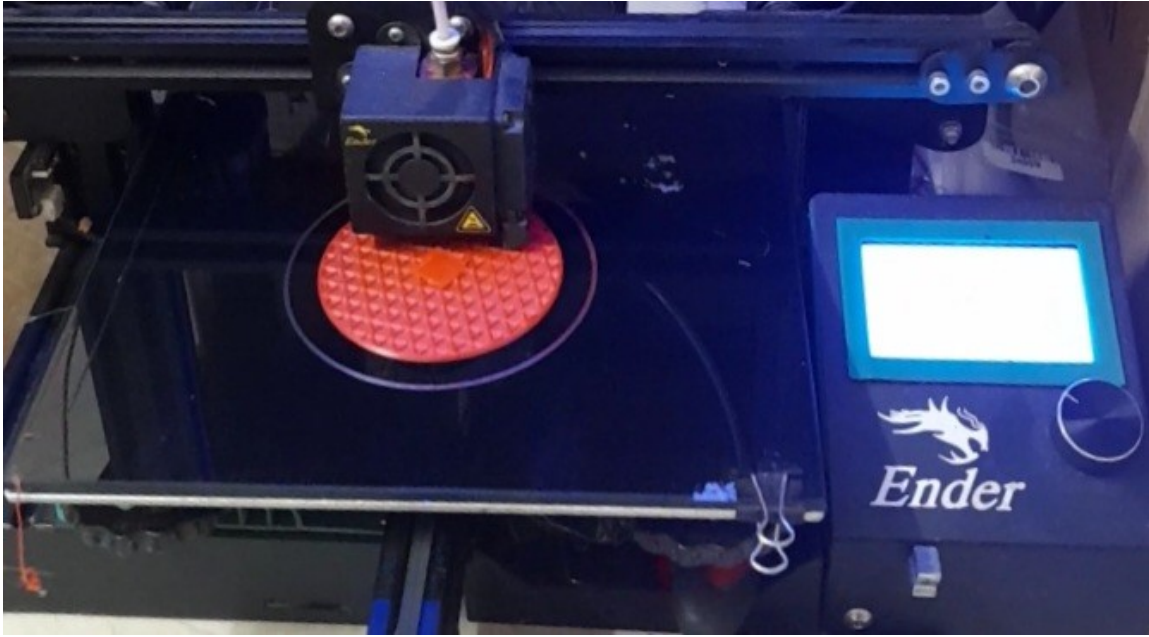


Fig 6.2 3D printing load cell and model connector

The existing model and the modified model are 3D printed owing to their complicated design. Also, the Load cell and model connector are 3D printed as well.



Fig 6.3 Load cell and model connector

The load cell and model are attached via load cell and model connector shown in Fig 6.3. This helps in fixing the model to the base of the test section while also obtaining the real-time readings during the test.

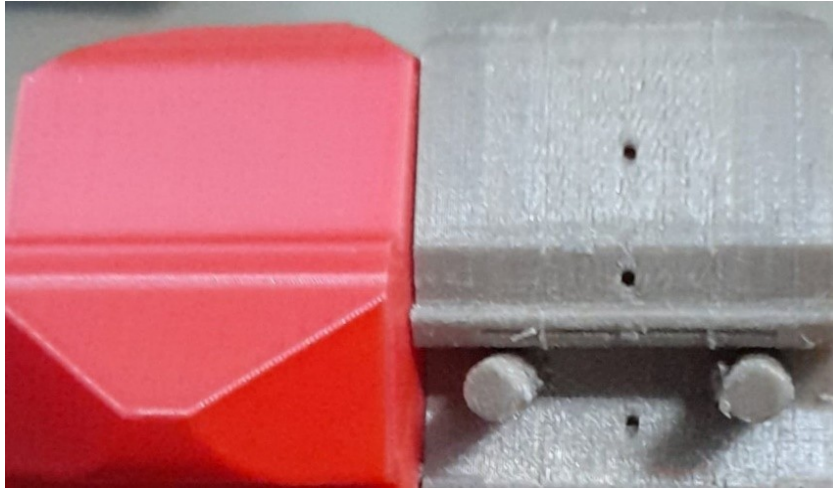


Fig 6.4 3D printed Modified Model (Left) and Existing model (Right)



Fig 6.5 Modified fairings attached to the body of the model

The fairings which have been 3D printed are glued to the wooden body acting as the engine and the bogie. After which surface finishing is done using paint and sandpaper to smoothen the surface of the wood. The surface finished model is as shown in Fig 6.6.



Fig 6.6 Surface finished modified model

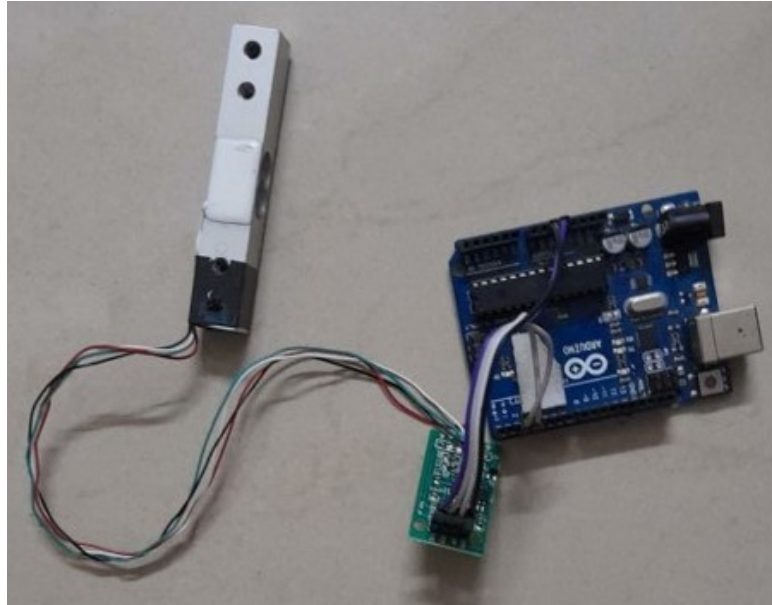


Fig 6.7 Load cell

The above Fig 6.7 shows the load cell that will be fitted with the model and connected to the laptop through an Arduino board. The Arduino board is loaded with the program that is calibrated to show zero drag as reading when the model is placed in the wind tunnel that is switched off.

6.2 EXPERIMENTAL SETUP

The experimentation requiring external flow can be done using a wind tunnel based on regime subsonic. This experiment involves testing at speeds less than 40 m/s hence it is done in Low subsonic wind tunnel. The testing is done in Aerodynamics Lab in the Aeronautical department of Sathyabama Institute Of Science and Technology, Chennai.

Table 6.1 Wind tunnel specifications

SI No	Parameters	Details
1	Wind tunnel type	Open circuit low speed
2	Test section	600mm X 600mm
3	Max speed	1400 RPM
4	Max velocity	40 m/s
5	Contraction ratio	9:1

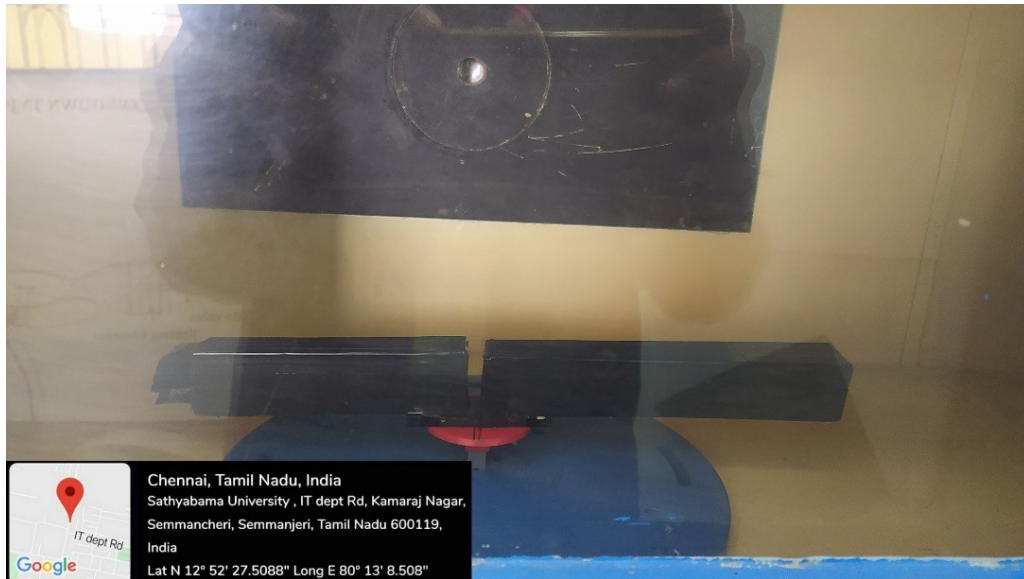


Fig 6.8 Existing model placed inside the test section

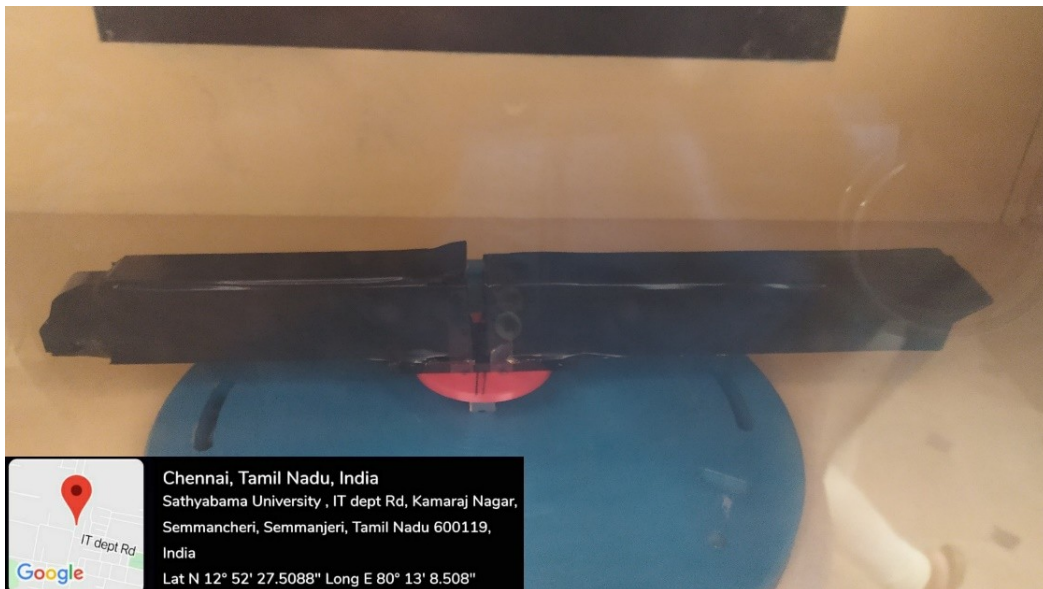


Fig 6.9 Fabricated modified model placed inside the test section

The model along with the load cell is placed in the test section as shown in Fig 6.8 and Fig 6.9. External connections are made from the load cell to a Laptop to obtain the readings during the test.

6.3 TESTING

The testing is done in a low subsonic wind tunnel (in Aerodynamics lab at Aeronautical department of Sathyabama Institute of Science and Technology, Chennai). The wind tunnel calibration is done to find out the velocity of RPM. The base plate is removed from the Test section. The model is fixed rigidly to the base

With the help of a connector. A load cell that is calibrated with the help of an Arduino board is fixed to the base plate and a laptop where the readings will be noted. The load cell and model connector is fixed, so that the model and load cell are fixed together to obtain the drag force acting on the model. The base plate is fixed to the test section, and the wind tunnel is switched ON. The RPM is set at specific intervals ranging from 0 to 250 RPM during which the load cell records the readings into the serial monitor of the Arduino interface. The readings are then plotted. The model is replaced with the modified model with aerodynamic fairings and the process is done from start. The graphs are plotted for drag against time and compared. The comparison between the existing model and modified model results are as shown in Fig 6.10 and 6.11. It can be observed that the maximum drag in the existing model is close to 0.20 whereas for the modified model it reaches 0.10, therefore there is approximately a 50% reduction in drag from an existing model to the modified model.

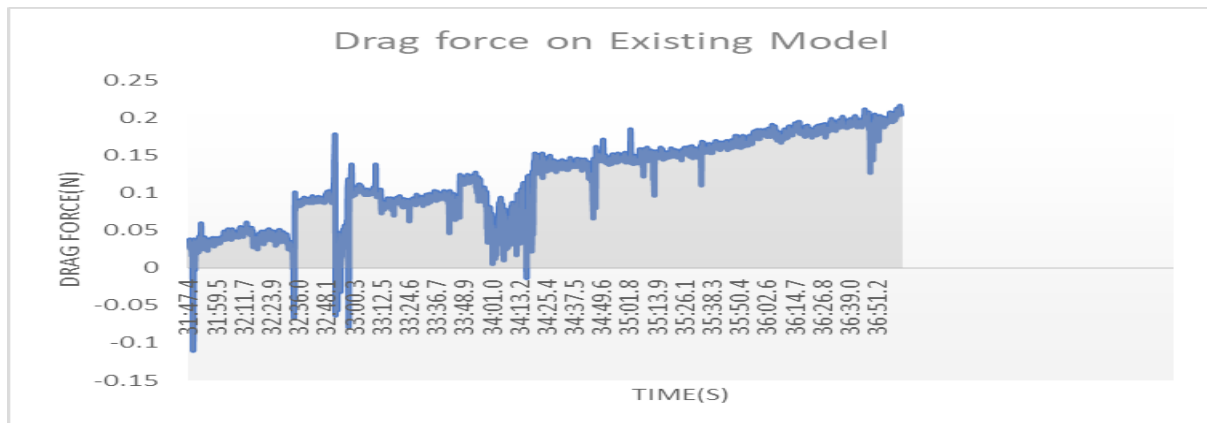


Fig 6.10 Drag force reading plot of Existing model

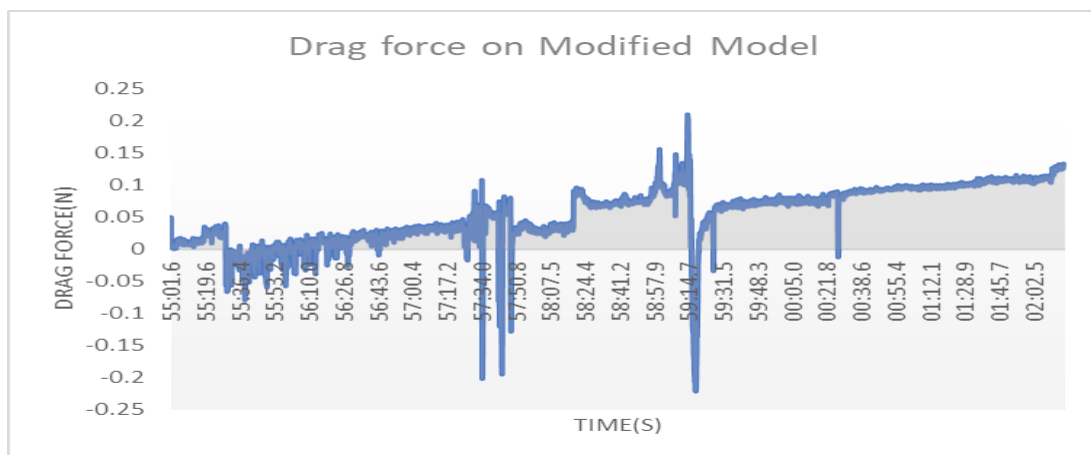


Fig 6.11 Drag force reading plot of the modified model

CHAPTER 7

SUMMARY AND CONCLUSION

7.1 SUMMARY

Firstly the specifications of the WAP-7 model is studied. Analyzing the current situation lays the groundwork for determining the consequences of proposed adjustments and selecting the best options. The CATIA model of the engine along with one extra bogie is made with the dimensions mentioned in the blueprint and scaled to 1:1. A CFD analysis of the model is carried out using a commercially available CFD package (STAR CCM +). A number of preliminary designs for the front and back fairings are sketched. From among them Three different designs for the aerodynamic fairings which would favour the reduction in drag are chosen. They are modeled in CATIA modeling software, then computational analysis of each models is performed. After comparing the Drag coefficient plot from the computational analysis of three different proposed designs of fairings with the existing model. The model which is a better alternative to the existing model is fabricated as modified model, along with the existing model (for comparison of results) for the experiment. The existing model and the modified model are fabricated by 3D printing using PLA (Polylactic acid) and with the help of wood. The CFD results are validated through the experiment in wind tunnel available in the Aerodynamics lab at the Aeronautical department of Sathyabama Institute of Science and Technology, Chennai. The models are fixed rigidly to the base with the help of a connector and is placed inside the test section of the Wind tunnel. For various RPM ranging from 0 to 250 is set and the readings are noted with the help of load cell that captures the real time readings. Various readings are obtained during the experiment and then the graph is plotted. The comparison of the drag is compared between the existing model and the modified model. From the graph plotted, it is observed that there is a reduction in drag of about 50%. Further tests and improvements can be done with a scaled up model to optimize the results.

7.2 CONCLUSION

The proposed model is tested against the existing model in the Wind tunnel at the Aerodynamics lab in Aeronautical Department of Sathyabama Institute Of Science and Technology, Chennai. In Fig 7.1 It was observed in computational analysis of the Existing model and Modified model where x-axis is the number of iterations and y-axis represents drag coefficient, As observed, for the existing model the drag increases to 0.15 and steadily maintains 0.12. For the Modified model the drag coefficient increases to 0.15 at the start and maintains steadily at 0.052. Hence there is a reduction of 52%.

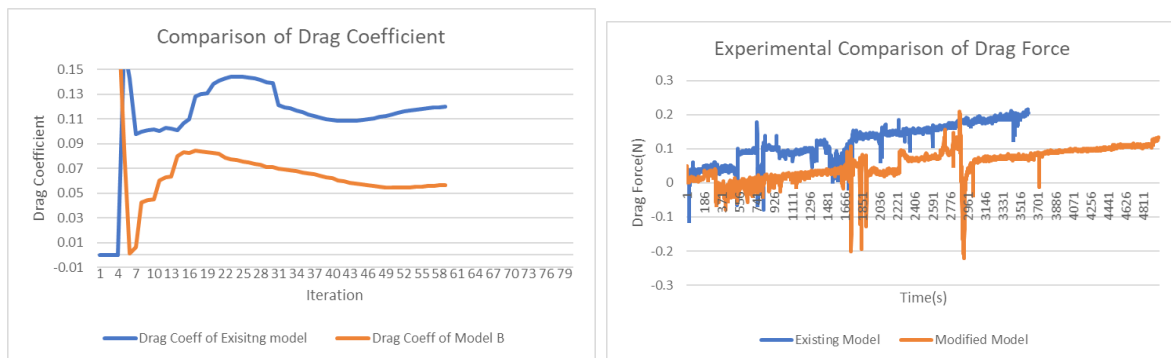


Fig 7.1 Computational Result

Fig 7.2 Experimental Results

The computational results are validated by experimenting in Wind tunnel. Fig 7.2 shows the graph of the experimental results. Where the x-axis represents Time in seconds and y-axis represents Drag Force in Newton. As observed, for the Existing model the drag rises steadily for different RPM set in the wind tunnel, the drag reaches a maximum of 0.2, this is due to the dissipation at the edge of the bogie increasing the turbulence which in turn increases the drag. For the Modified model the drag rises steadily and reaches a maximum of 0.1, the reduced drag is due the flow attachment to the surface, therefore, there is reduced turbulence. Hence there is a reduction of 50% experimentally. This reduction is due to the addition of aerodynamic fairings attached to the front and back of the train.

The comparison graphs of experimental results and computational analysis results are as shown in Fig 7.1.(a) and (b). From the above two graphs, we can conclude that the proposed model has an improvement in the reduction of drag to about 50% compared to the existing model of WAP-7.

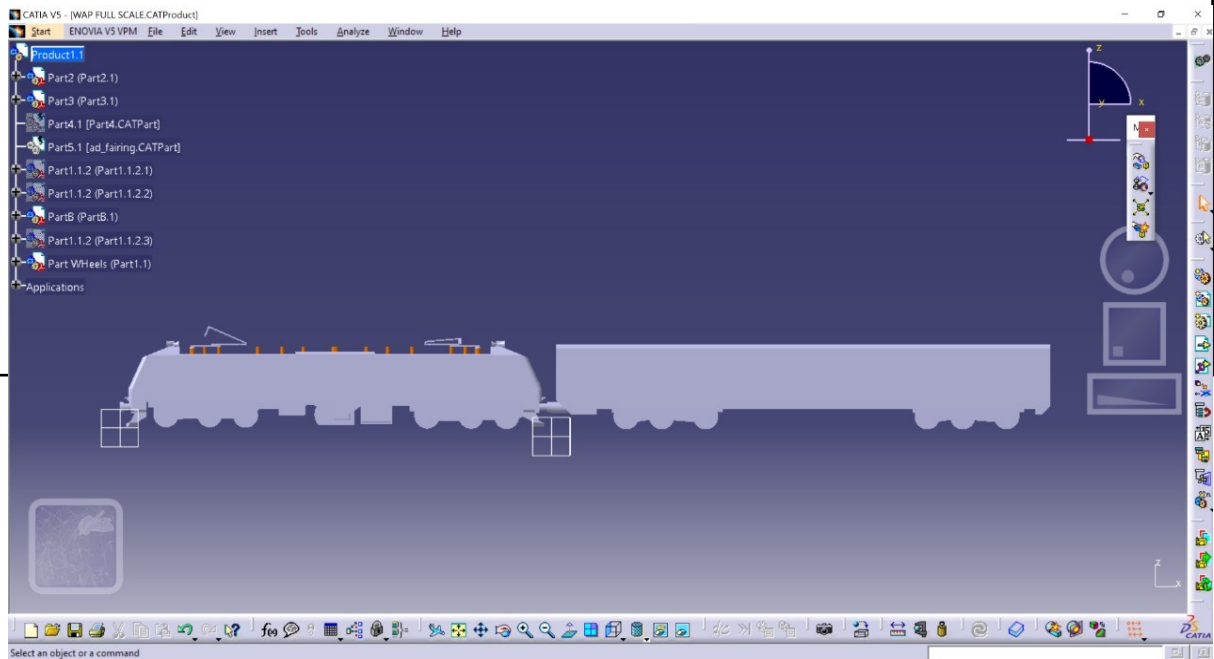
REFERENCES

- [1] Tolman, K., Crampton, E.B., Stucki, C., Maynes, R.D., Howell, L.L., Design of an Origami-Inspired Deployable Aerodynamic Locomotive Fairing” Origami7, Vol. 3, pp. 669-684, 2018, Proceedings of the 7th International Meeting on Origami in Science, Mathematics and Education.
- [2] Piotr Lukaszewicz. Running resistance-results and analysis of full-scale tests with passenger and freight trains in Sweden. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit 221:2 pp 183-193. 2007.
- [3] C. L. Stucki and R. D. Maynes. Aerodynamic Design of a Locomotive Fairing. In Proceedings of the 2nd Thermal and Fluid Engineering Conference.
- [4] S. Watkins, J.W. Saunders, and H. Kumar. Aerodynamic drag reduction of goods trains. Journal of Wind Engineering and Industrial Aerodynamics, pp 147-178, 1991.
- [5] Gao, G., Li, F., He, K., Wang, J., Zhang, J., & Miao, Investigation of bogie positions on the aerodynamic drag and near wake structure of a high-speed train. Journal of Wind Engineering and Industrial Aerodynamics, pp 41–53. 2019.
- [6] Saunders, J. W., Watkins, S., & Cassar, R. J. Vortex optimization of slotted tops and cavities of two different open rail wagons. Journal of Wind Engineering and Industrial Aerodynamics, 49(1-3), 421–430. 1993.
- [7] Palli S, Koon R, Sharma RC, Muddada V .Dynamic analysis of Indian railway integral coach factory bogie. Int J Veh Struct Syst 7(1):16–20, 2015.
- [8] Sharma RC, Recent advances in railway vehicle dynamics. Int J Veh Struct Syst 4(2):52–63, 2012.
- [9] W.F.M. Gross, Atmosphere resistance to the motion of railway trains, The Engineer 1898.
- [10] Peter P Wegene, Aerodynamic Drag, What makes Airplane fly, pp 101-126, 1997.
- [11] McCallen, R., Browand, F., Ross, J. (eds.): The Aerodynamics of Heavy Vehicles: Trucks, Buses, and Trains. Springer, New York, 2004.

- [12] Giovanni Solari, Wind and Aerodynamics , Wind Science and Engineering, pp 441-558,2019.

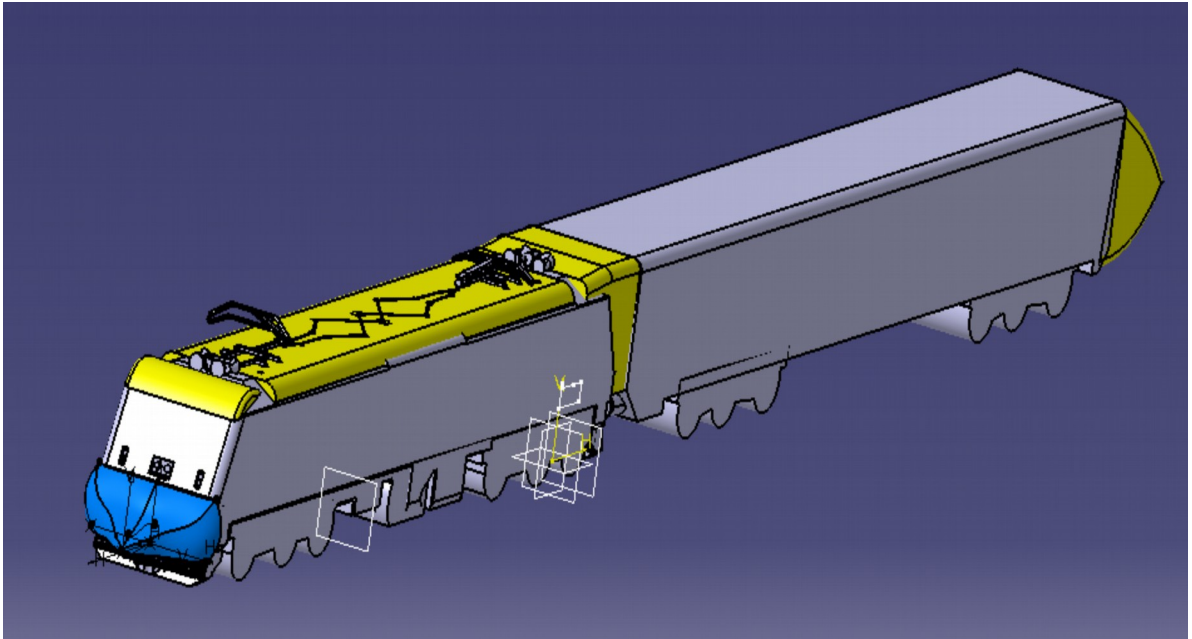
APPENDIX

SIDE VIEW OF WAP-7 IN CATIA V5

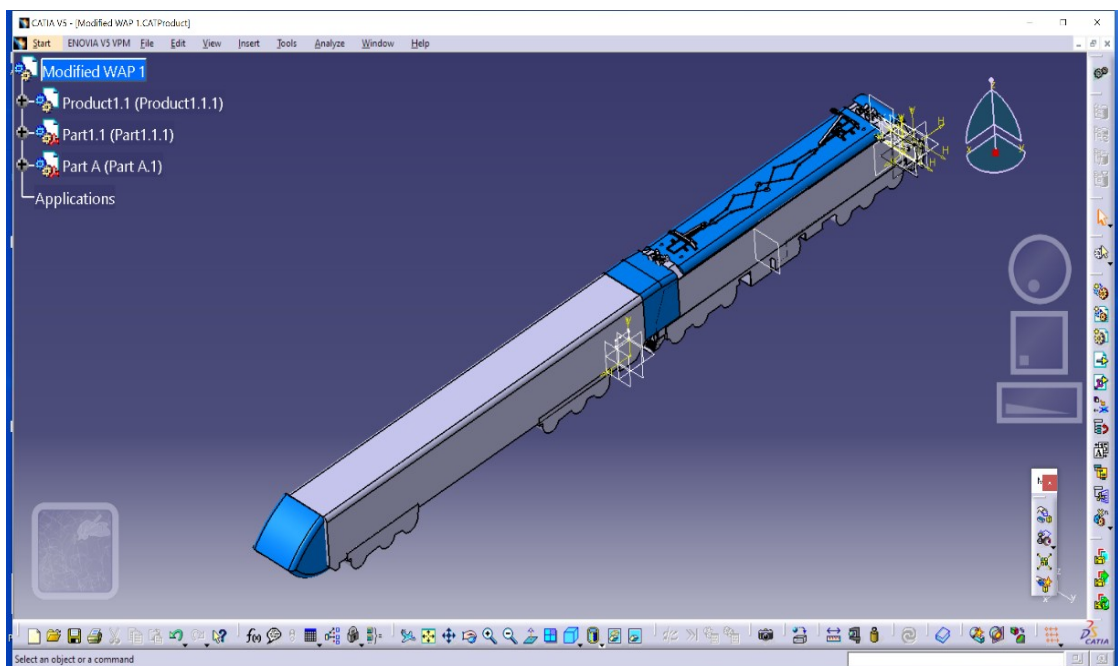


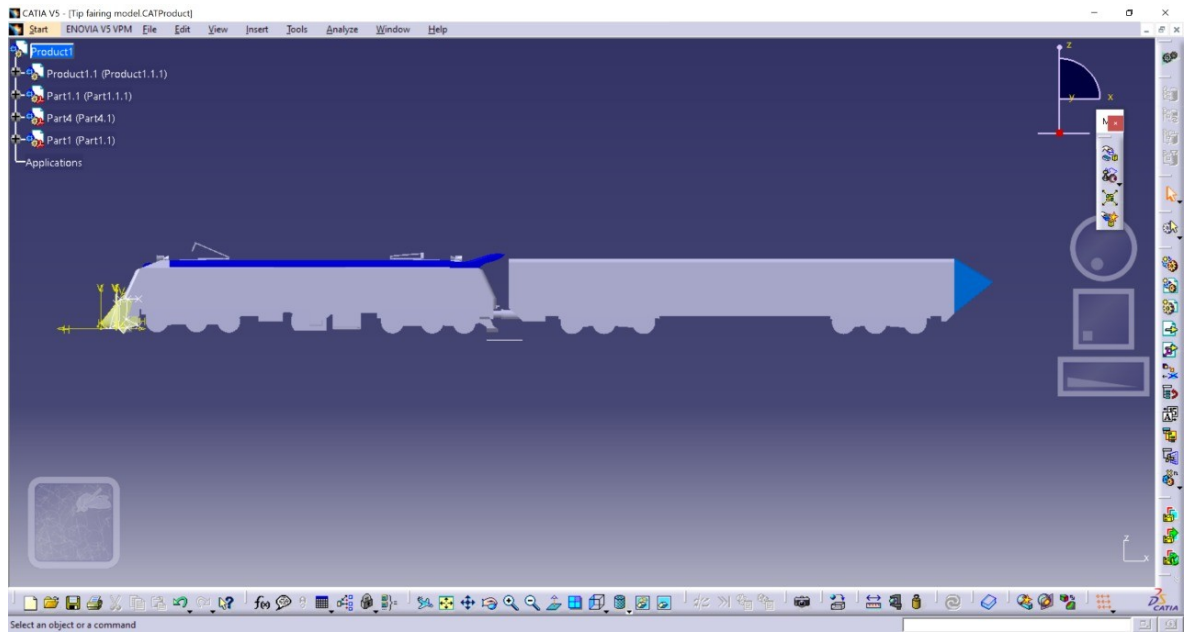
SIDE VIEW OF MODEL B IN CATIA V5

FRONT VIEW OF MODEL A

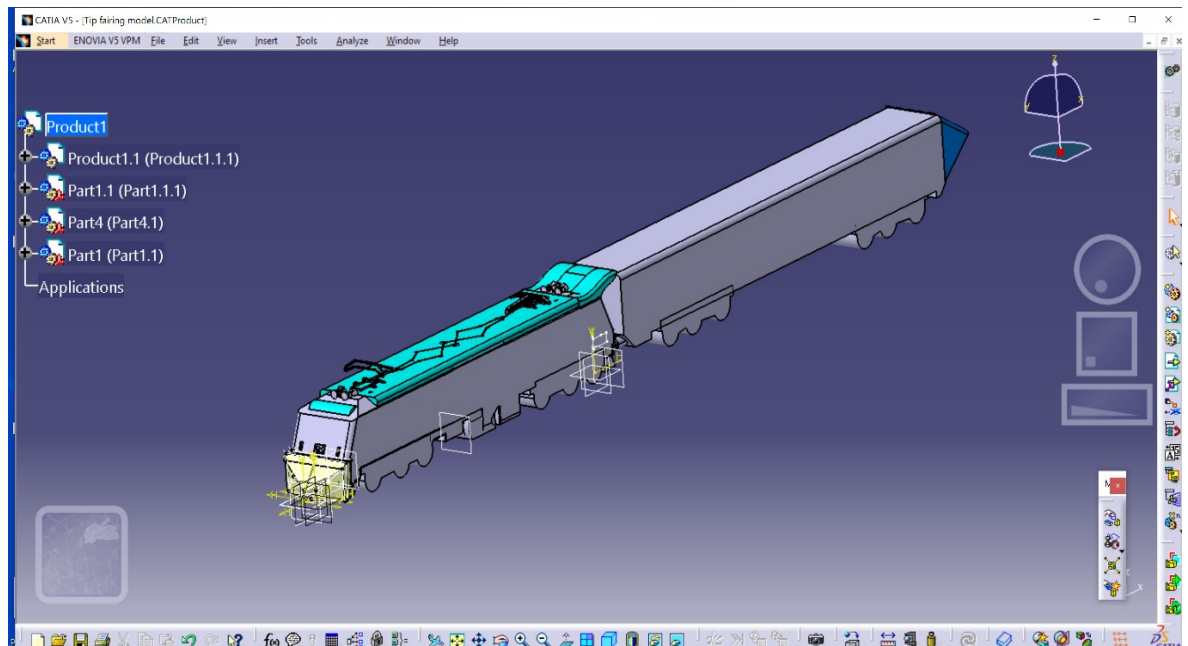


BACK VIEW OF MODEL A

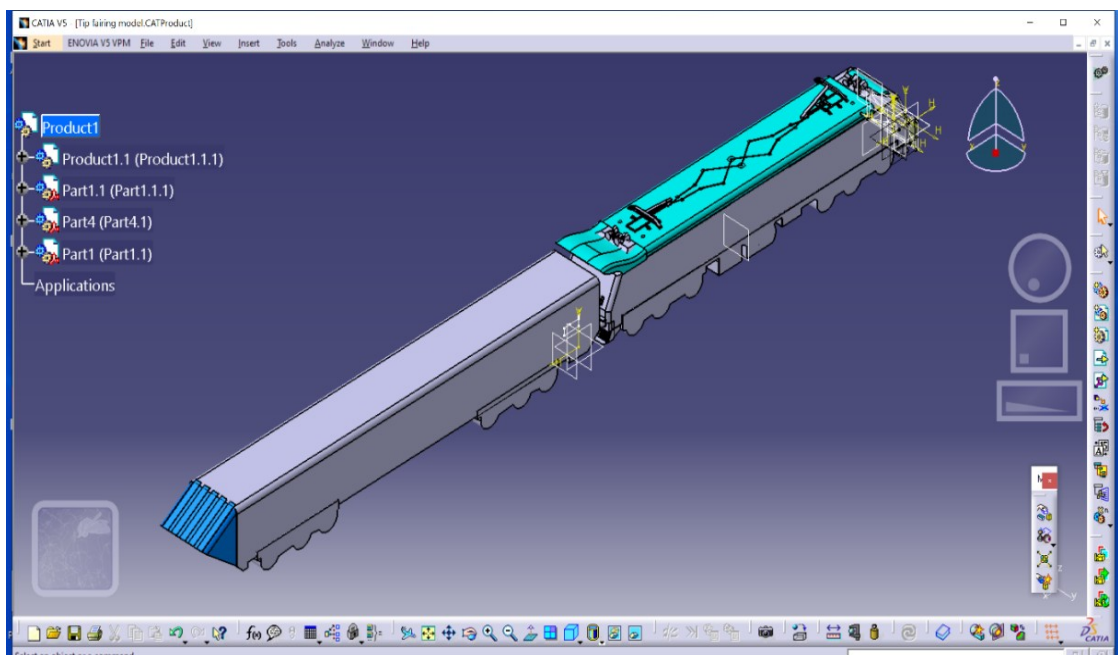




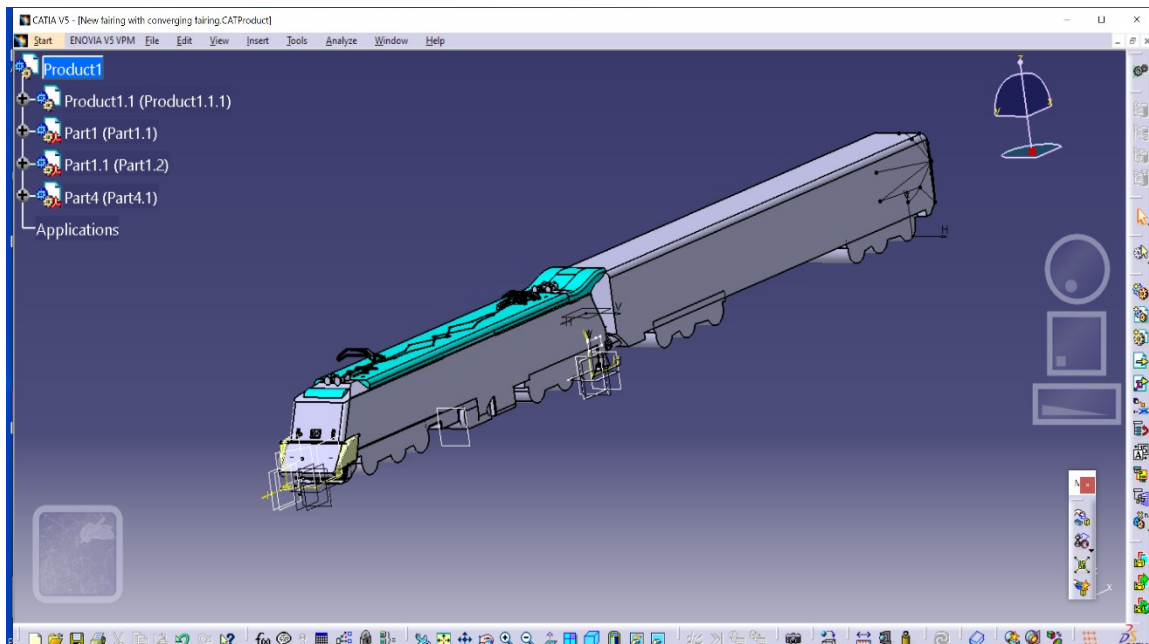
FRONT VIEW OF MODEL B



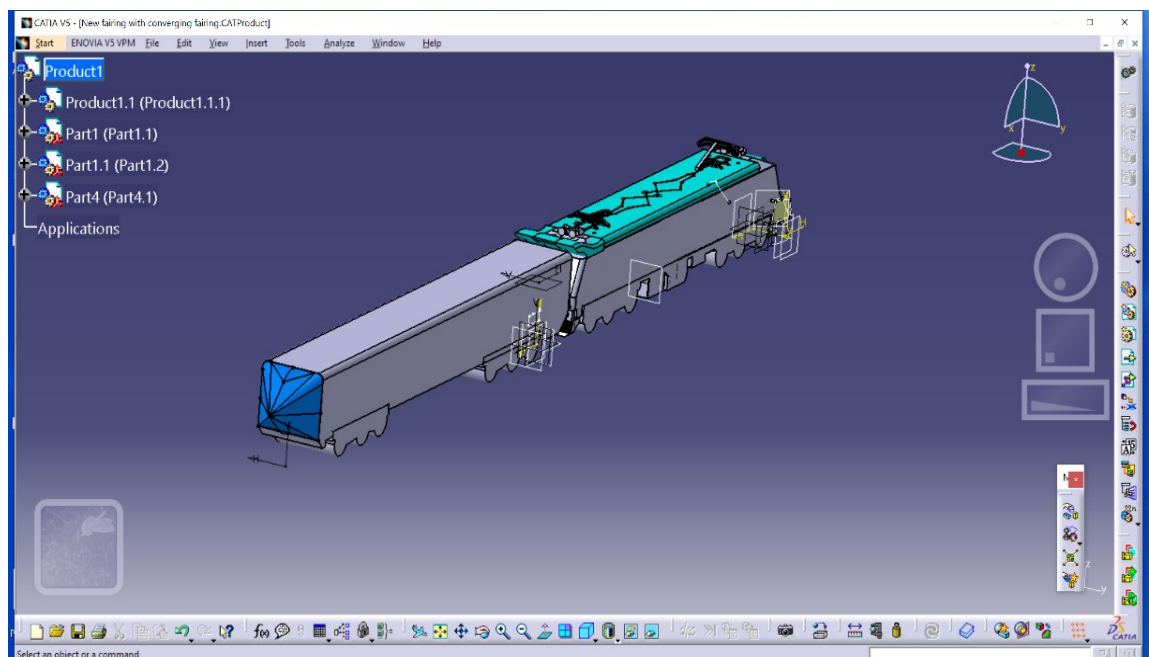
BACK VIEW OF MODEL B



FRONT VIEW OF MODEL C



BACK VIEW OF MODEL C



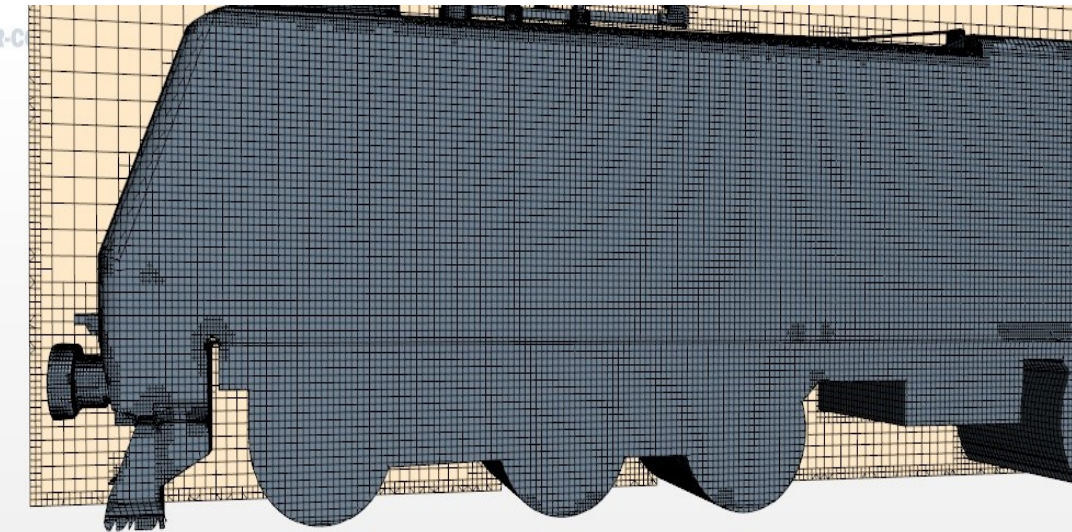
MESHED MODEL OF WAP-7

STAR-CCM+



MESHED MODEL OF WAP-7(ZOOMED IN)

STAR-CCM+



MESHED MODEL B

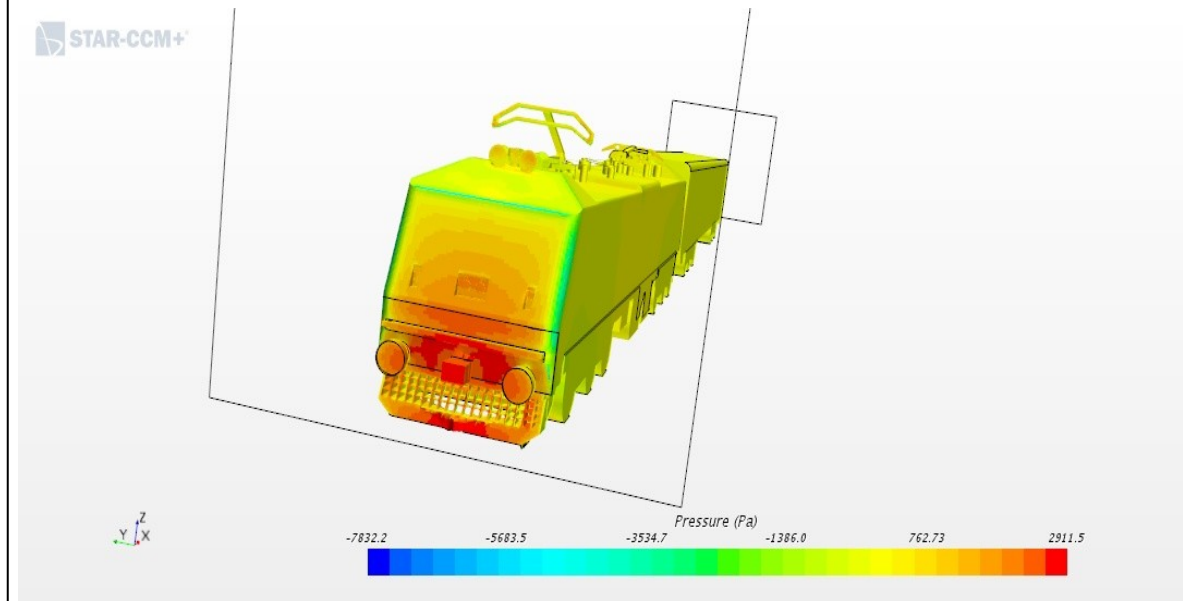
STAR-CCM+



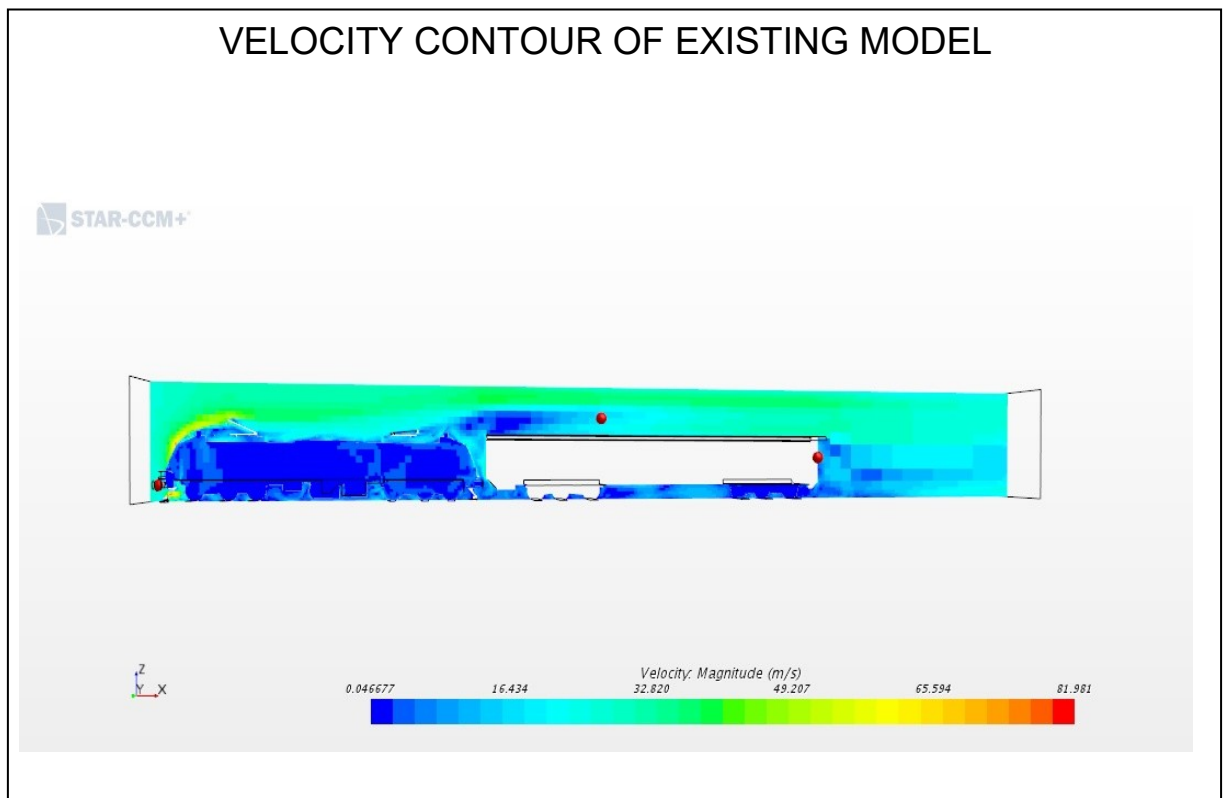
MESH DETAILS OF MODEL B

Details	Count
Cells	3766237
Faces	11230106
Vertices	5394758

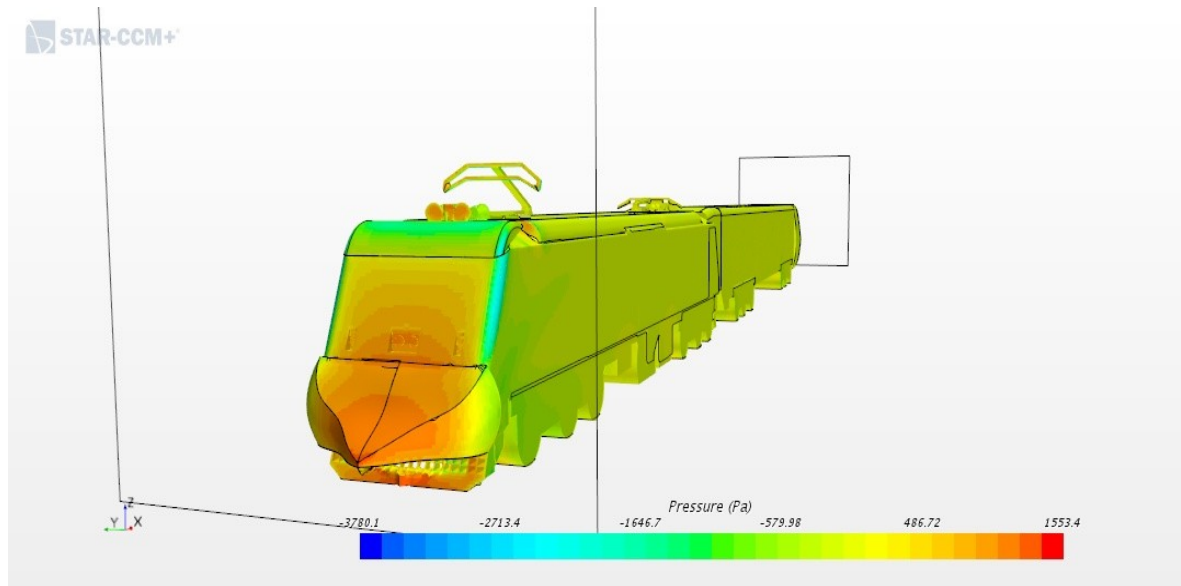
PRESSURE CONTOUR OF EXISTING MODEL



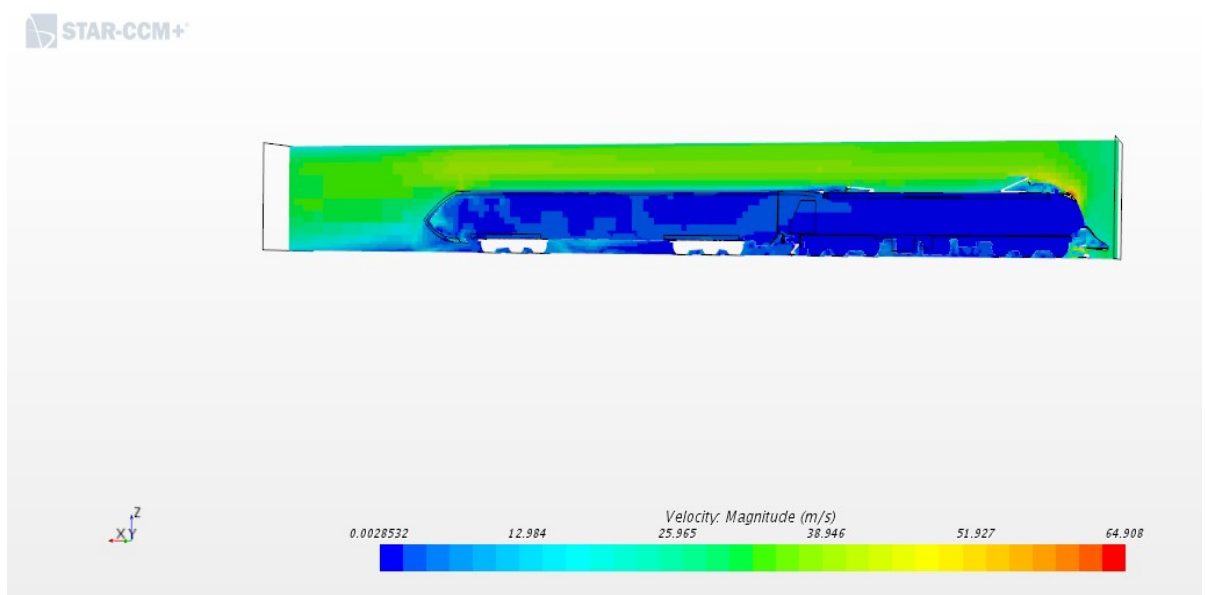
VELOCITY CONTOUR OF EXISTING MODEL



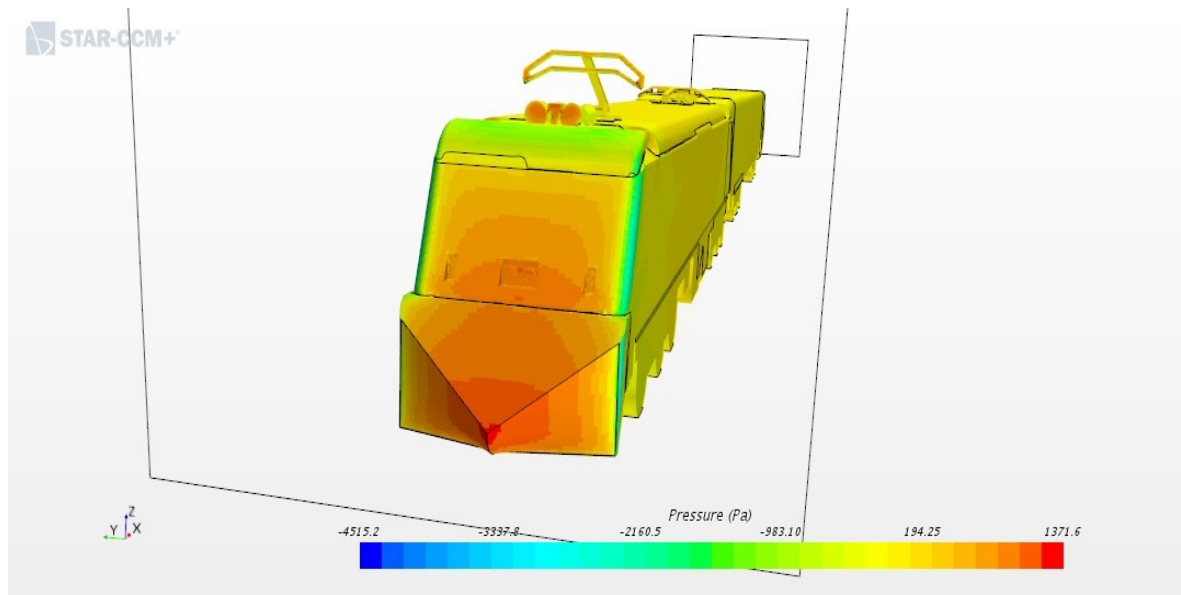
PRESSURE CONTOUR OF MODEL A



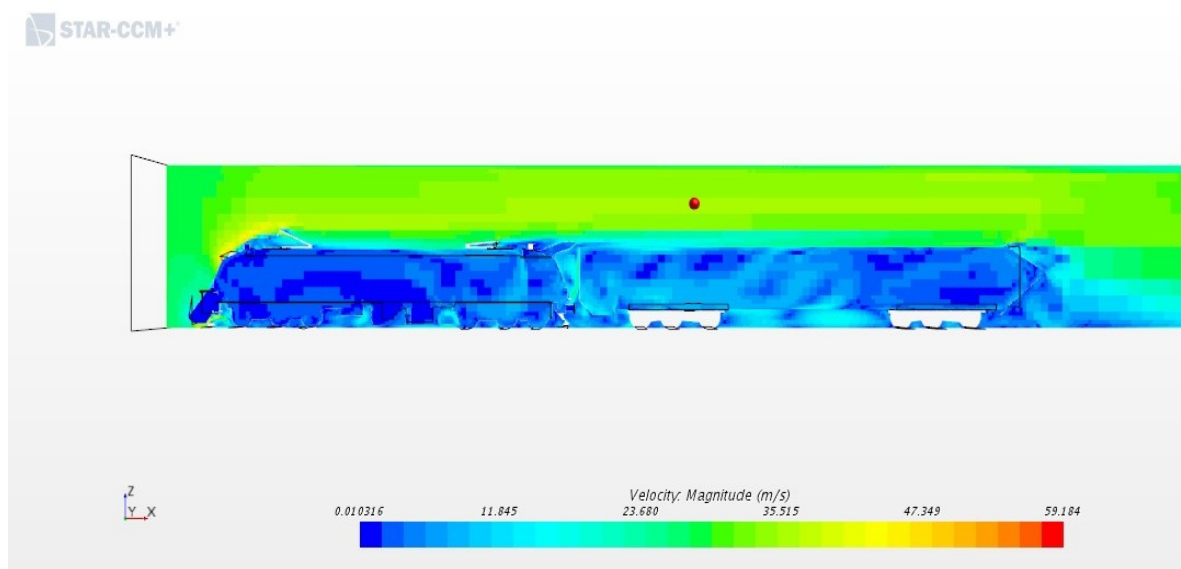
VELOCITY CONTOUR OF MODEL A



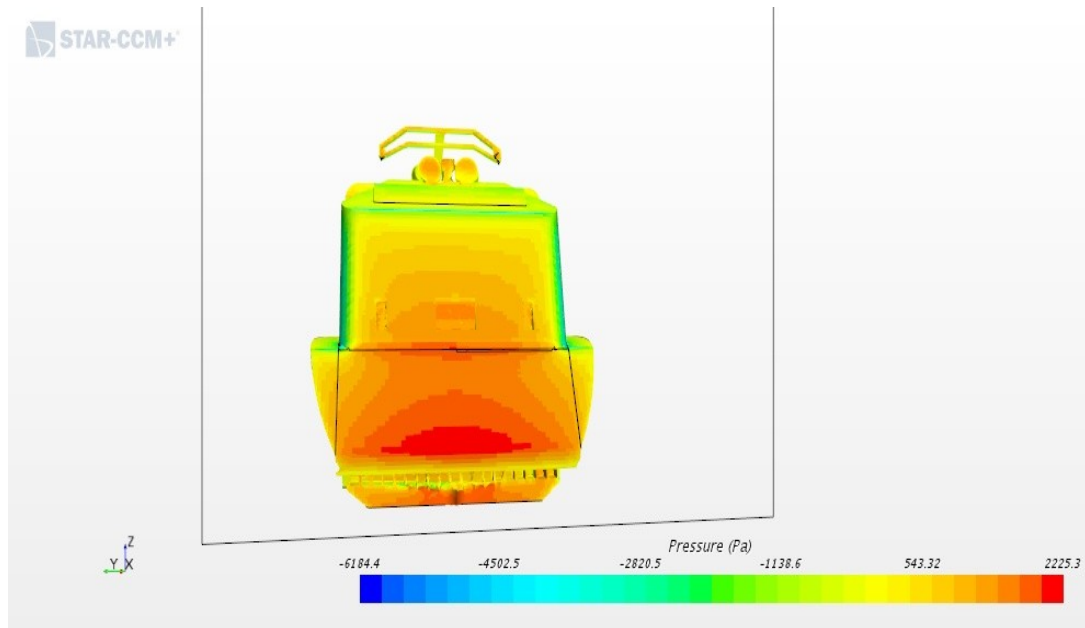
PRESSURE CONTOUR OF MODEL B



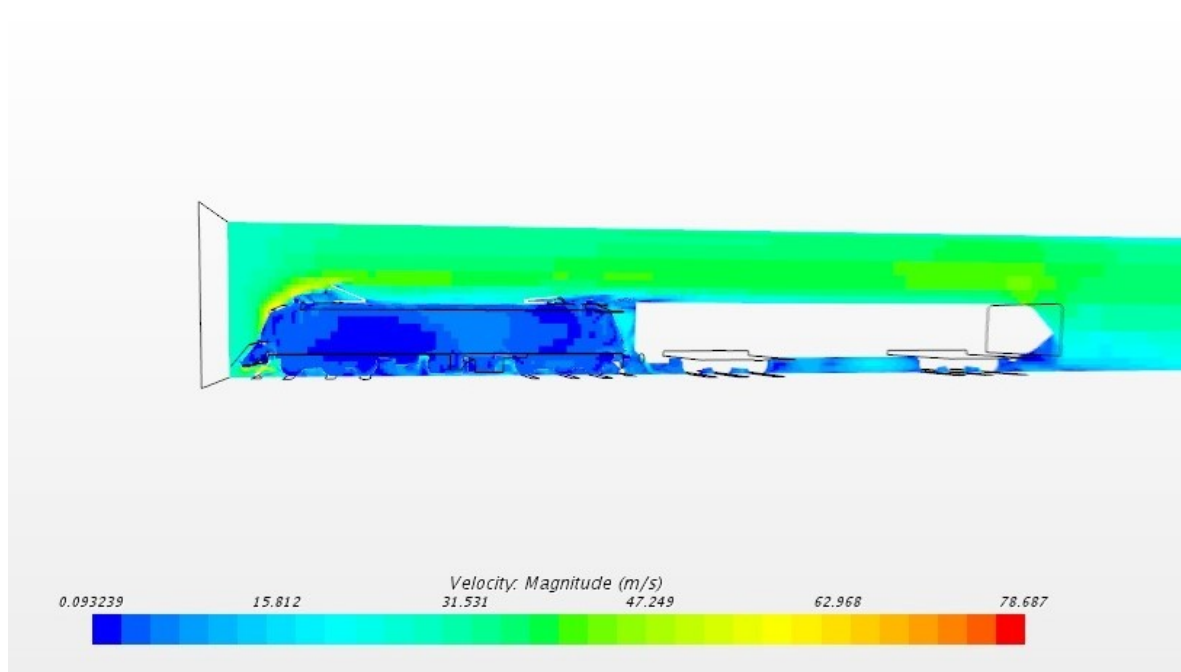
VELOCITY CONTOUR OF MODEL B



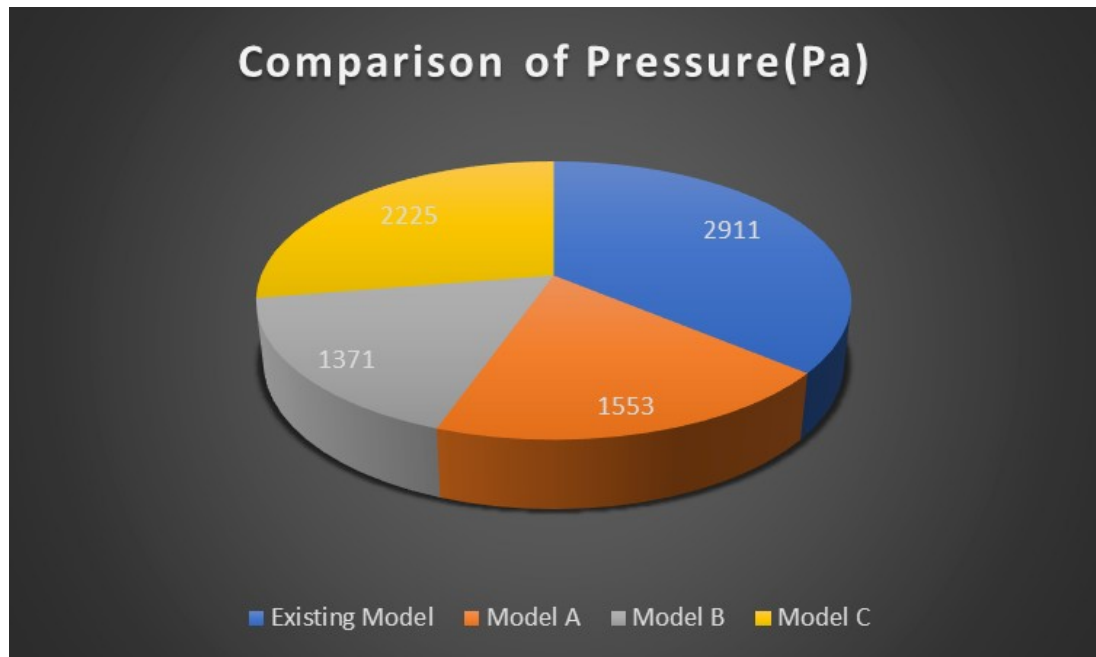
PRESSURE CONTOUR OF MODEL C



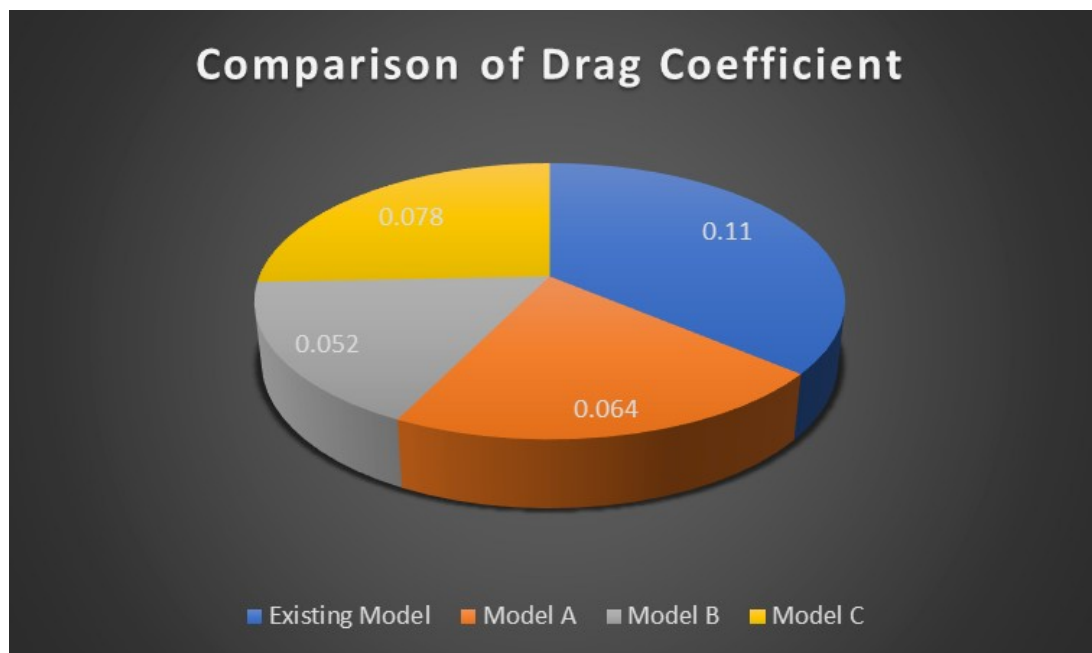
VELOCITY CONTOUR OF MODEL C



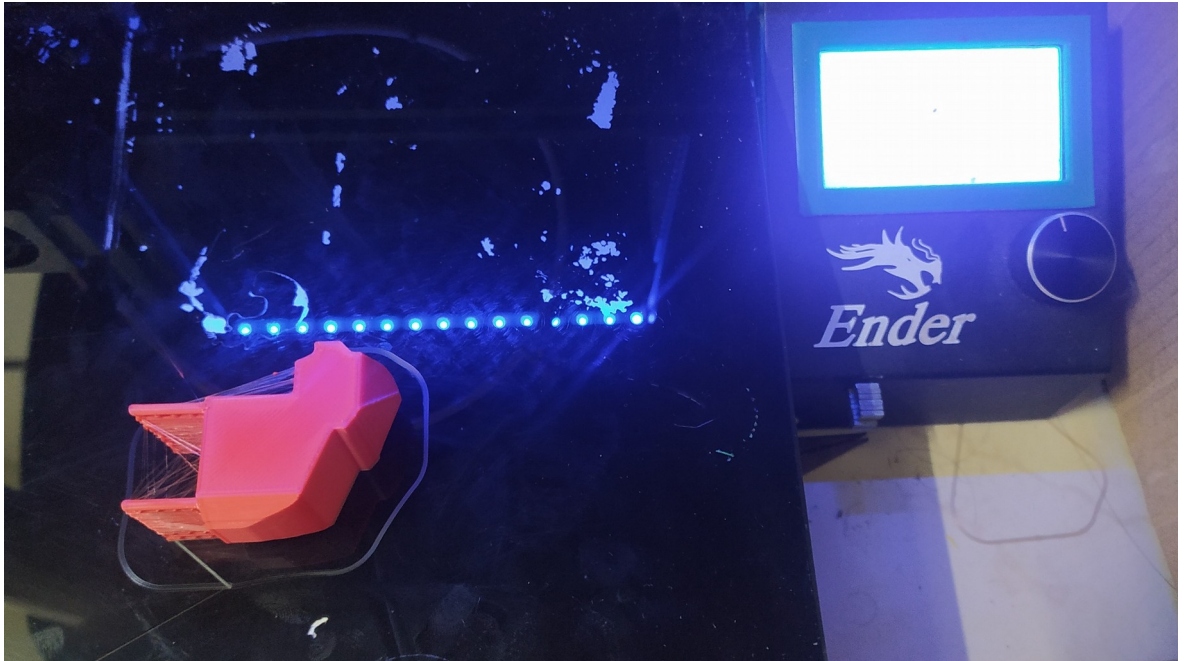
COMPARISON GRAPH FOR PRESSURE OF MODELS



COMPARISON GRAPH FOR DRAG COEFFICIENT OF MODELS



3D PRINTED MODIFIED MODEL



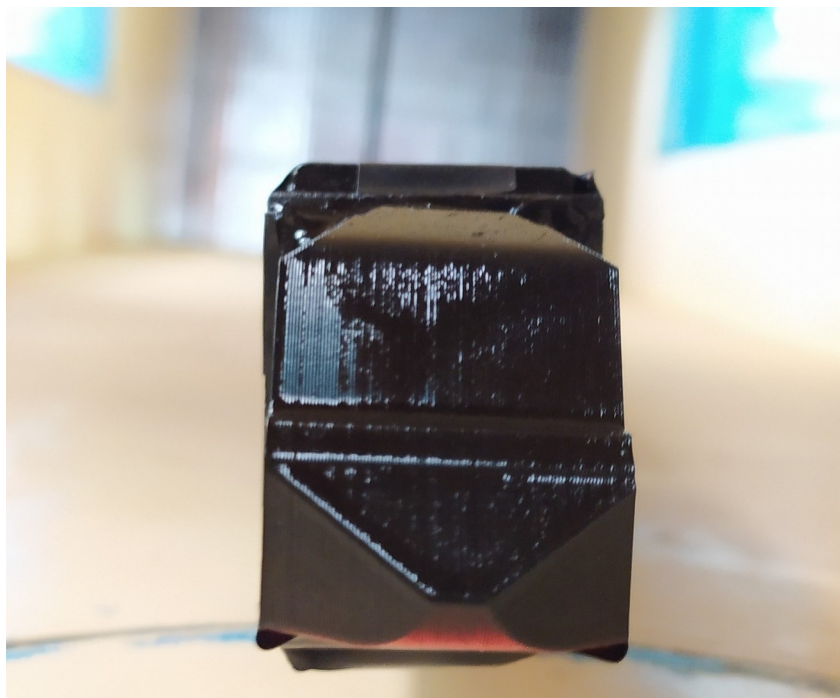
EXISTING MODEL



FRONT VIEW OF EXISTING MODEL



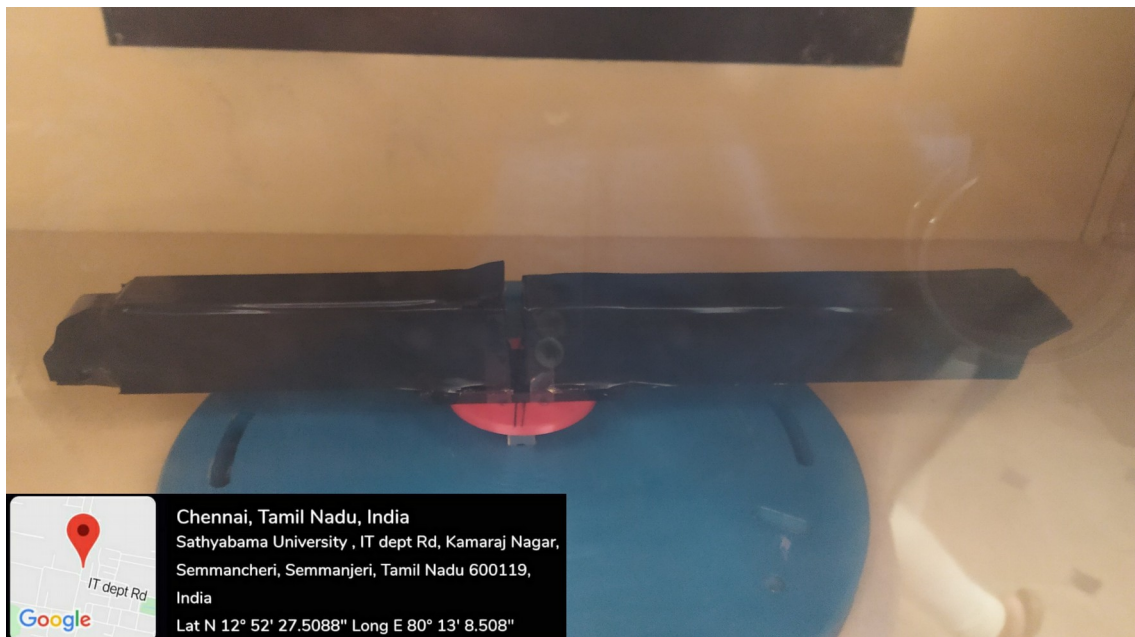
FRONT VIEW OF MODIFIED MODEL



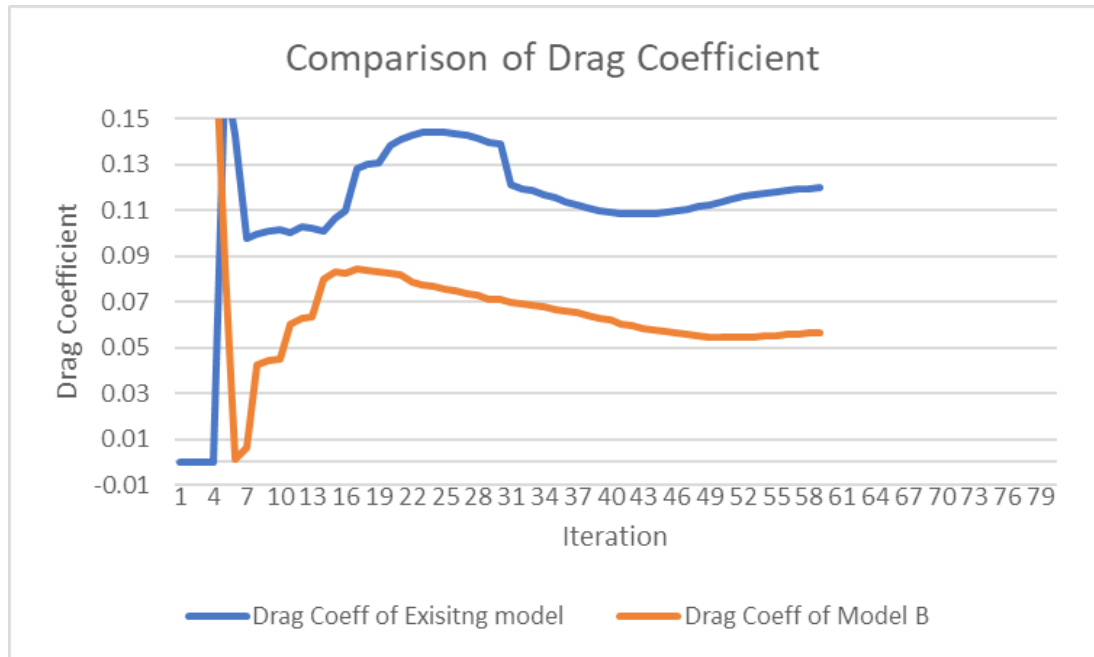
EXISTING MODEL PLACED INSIDE THE TEST SECTION



MODIFIED MODEL PLACED INSIDE THE TEST SECTION



DRAG COEFFICIENT COMPARISON (COMPUTATIONAL)



DRAG COEFFICIENT COMPARISON (EXPERIMENTAL)

