ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF MECHANICAL, CHEMICAL AND MATERIALS ENGINEERING

Body shape optimization using CFD: A case of locally built Isuzu passenger bus

A thesis submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in Automotive Engineering

By

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MECHANICAL SYSTEMS AND VEHICLE ENGINEERING PROGRAM

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CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in the thesis entitled “Body shape optimization using CFD: A case of locally built Isuzu passenger bus Adama Endalk garage Ethiopia” in partial fulfillment of the requirements for the award of the degree of Master of Science in Automotive Engineering is an authentic record of my own work carried out from October 2016 to January 2017 under the supervision of N. RAMESH BABU Department of Mechanical and Vehicle Engineering, Adama Science and Technology University, Ethiopia.

The matter embodied in this thesis has not been submitted by me for the award of any other degree or diploma. All relevant resources of information used in this thesis have been duly acknowledged.

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief. This thesis has been submitted for examination with my approval.

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Approved by board of Examiners

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External Examiner	signature	Date

Dedication

To my beloved family for their immeasurable support, encouragement, and patience.

ACRONYMS AND ABBREVIATIONS

A_D	Drag Area
A_L	Lift Area
BEM	Boundary Element Method
CAD	Computer Aided Drafting
CFD	Computational Fluid Dynamics
C_L	Lift Coefficient
CPU	Central Processing Unit
C_p	Coefficient of Pressure
C_d	Drag Coefficient
DNS	Direct Numerical Simulation
D_p	Pressure Drag
D_f	Friction Drag
F_L	Lift Force
F_d	Drag Force
Kmph	kilometer per hour
FVM	Finite Volume Method
FEM	Finite Element Method
G	gravity
M	moment
M_P	pitching moment
M_r	rolling moment
M_y	yawing moment
M_{pr}	pitching resistance moment
Mrr	rolling resistance moment
M_{yr}	yawing resistance moment
ρ	Density
P	power
RANS	Reynolds-Averaged Navier-Stokes
T	Temperature
μ	Viscosity

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ACRONYMS AND ABBREVIATIONS

A_D	Drag Area
A_L	Lift Area
BEM	Boundary Element Method
CAD	Computer Aided Drafting
CFD	Computational Fluid Dynamics
C_L	Lift Coefficient
CPU	Central Processing Unit
C_p	Coefficient of Pressure
C_d	Drag Coefficient
DNS	Direct Numerical Simulation
D_p	Pressure Drag
D_f	Friction Drag
F_L	Lift Force
F_d	Drag Force
Kmph	kilometer per hour
FVM	Finite Volume Method
FEM	Finite Element Method
G	gravity
M	moment
M_P	pitching moment
M_r	rolling moment
M_y	yawing moment
M_{pr}	pitching resistance moment
Mrr	rolling resistance moment
M_{yr}	yawing resistance moment
ρ	Density
P	power
RANS	Reynolds-Averaged Navier-Stokes
μ	Viscosity

ABSTRACT

Nowadays with increase in competition in automobile sector, External aerodynamics is becoming an important field of study in recent years. This is because of its effectiveness in the study of visibility, stability and performance. The bus transportation is cheaper and easier to use than other means of transportation. However, buses have some disadvantages such as air pollution due to engine exhaust. This study was an attempt to reduce the gas emissions from buses by reducing the aerodynamic drag for fuel economy. Investigating C_d reduction, driving characteristic such as stability, applied to achieve this goal including slight modification of the outer shape of the Isuzu passenger bus. Rotating moment due to location of difference between C.G and C.P, due to center fugal force when the vehicle corner at high speed, thus situation can create rolling, yawing and pitching moment on the vehicle during operation on the road this will cause problems on the performance of car model like driving instability, also structural strength. This project starts with observing locally built bus garage Adama Ethiopia. Data collection was by measuring the real locally built Isuzu passenger bus body. A simulation of a bus model dimensions 7.7m × 2.8m × 2.3m was conducted thus, the CAD models of Isuzu passenger bus bodies of their aerodynamics CATIA software to model, CFD PHOENICS VR 2015 for simulation and analyzed, ansys workbench15 for structural strength analyses used. Input Velocity given to the CFD phoenics analysis was 60kmph, 80kmph, 100 kmph, and 115 kmph respectively. The respect to model 1 which existed bus its speed 60km/h, 80kmph, 100 kmph, and 115 kmph, the % drag coefficient reduction of the model 2 was 31.8, 29.1, 18.6, 11.9 and model 3 was 13.7, 40.6, and 39.3,15 respectively. The model 3 Isuzu passenger Bus driving stability was guaranteed when driving from 60km/h up to 100km/h with 12 m/s side wind for all speeds. But when the model Bus driving at the speed of 115km/h the value of (M_{rr}) was less than ($M_{rolling}$), therefore the model Bus's driving stability was not guaranteed when driving at the speed of 115km/h which is due to the side wind and at the high speed. The structural strength analysis was investigated Total deformation was 0.83903mm, equivalent elastic strain 0.1282mm/m, equivalent vonmisses stress was $2.5213x\times10^7$pa,normal elastic strain was 3.509×10^5mm/m, maximum shear elastic strain was 0.1717mm/m, maximum shear stress was 1.3208×10^7pa .

Key words: *aerodynamic drag, shape optimization, cross wind stability, structural strength.*

1. INTRODUCTION

Throughout the history of the motor car there have been individual vehicles that have demonstrated strong aerodynamic influence upon their design. Until recently their flowing lines were primarily a statement of style and fashion with little regard for the economic benefits. It was only rising fuel prices, triggered by the fuel crisis of the early 1970s, that provided a serious drive towards fuel-efficient aerodynamic design. The three primary influences upon fuel efficiency are the mass of the vehicle, the efficiency of the engine and the aerodynamic drag. Only the aerodynamic design will be considered in this section but it is important to recognize the interactions between all three since it is their combined actions and interactions that influence the dynamic stability and hence the safety of the vehicle[7].

Buses are the major mode of mass transportation all over the globe, despite of the rail network. Buses are inefficient in term of fuel consumption, thus in order to decrease the fuel consumption of vehicles, improvement in the aerodynamics of bus shapes will add to the value. It becomes essential to thoroughly design a vehicle for its aerodynamics, as it directly relates to the fuel economy and resisting forces, which further this, become a parameter for mankind to purchase the vehicle. More precisely the reduction of their drag coefficient becomes one of the main topics of the automotive research. Decreased resistance to forward motion allows higher speeds for the same power output or lower power output for the same speeds.

Aerodynamics being the aid to form a body shape that maximizes the down force, the negative lifts and minimizes the force that opposes the forward movement and the drag forces. The aerodynamically efficient design of the bus reduces the drag force improving the fuel efficiency. In a moving vehicle, the engine power is used to overcome tractive resistance, which is the combination of rolling and aerodynamic resistance. The rolling resistance will be dominant over the aerodynamic resistance at lower speeds [25].

The design of the internal bus skeleton structure is the basis of various bus developments in the bus industries. It contains the framework of tubes with various cross sections are arranged within specified shapes based on the design philosophy. The bus body structure have six main components the left and right frame side, the front and back frame side, the top and bottom frame side. In that the top frame side is sometime called roof frame side. The bottom frame side is also called floor frame side [56].

1.1BACK GROUND OF STUDY

Automotive engineering development

To the layman, the most obvious aspects of progress are technical innovations and styling changes, but from a professional engineering viewpoint, the major achievements lie as much in the areas of refinement and systems of manufacture. Innovations can be important in giving manufacturers a competitive advantage, but new ideas often make their debut many decades before they are widely adopted. It is the processes of refinement and production development that make new technical features reliable and cheap enough for use in mass-produced vehicles [7].

Innovations and inventions

Engineering history is bedevilled by rival and sometimes false claims to particular inventions. In reality, innovative developments have often been the work of several different engineers working in parallel but quite independently, and the recognized inventor is simply one whose Name is well known, or who has been championed for nationalistic reasons. Many apparently new inventions are, in any case, simply adaptations from different technologies. The differential Mechanism, for example, was used by watchmakers before being adapted for automotive purposes.

It is frequently difficult to trace the earliest examples of the use of a particular device or mechanism. J. Ickx, 1992, describes how the Bollées (father and two sons) invented or adapted an amazing array of devices in the late 19th century, including all-round independent suspension, and power steering (originally applied to steam-powered vehicles). In 1894, the younger Amédée Produced a gas turbine, and later went on to invent fuel injection, supercharging, and hydraulic valve lifters. All these devices are usually ascribed to other, later inventors.

The first major technical breakthrough

It is a little surprising that road vehicle transport lagged so far behind the development of the Railways. Steam locomotives appeared early in the 19th century and by the time the first really Practical road vehicles emerged over half a century later, rail transport had become a mature Technology with large networks covering many countries. The problem of road transport Development lay in the combination of the heavy cumbersome steam engine and poorly surfaced roads. By the end of the 19th century, significant developments of the steam engine had taken place such as the use of oil or paraffin instead of coal as the fuel, and the development of the lighter more compact 'flash' boiler system in which steam was generated by passing water through heated tubes rather than boiling it up in a pressure vessel. Practical steam-powered road vehicles started to appear in small numbers, and indeed for commercial vehicles, the line of development was not finally terminated until the 1950s. Some impression of the level of refinement of steam cars may be drawn from the elegant 1905 Stanley shown in Figure 1.1. Two major drawbacks to automotive steam propulsion were the long start-up time required, and the high rate of water consumption.

Figure 1.1 A Stanley steam car of 1905.

This elegant vehicle is far removed from the lumbering smoky traction engines that nowadays chug their way to nostalgic steam rallies. Steam cars were much quieter and smoother-running than their petrol engine contemporaries, but took some time to fire up. They also needed frequent intakes of water.

The development of the world motor industry

The motor industry originated in small workshops producing hand-built vehicles tailor-made to the customers' specification, but Henry Ford's mass production techniques were soon copied by others. Throughout the 1920s and 1930s, small low volume manufacturers of coach built vehicles were able to co-exist with the large mass production companies such as Ford, Chrysler, Morris and Fiat. The smaller firms were, however, gradually forced to merge or to be swallowed up by the large companies, or to simply disappear. After the Second World War the trend accelerated, until by the 1970s, only a few specialist companies such as Rolls-Royce remained.

The process of absorption brought its own problems. Large organizations that bought up a failing company often found that they had bought its weaknesses as well. All too often, there was a failure to rationalize. A good example was the British Motor Corporation (BMC) which was formed from the merging of the two major British Motor manufacturers Austin and Morris, and a number of smaller companies such as MG. At one stage in the 1950s this resulted in its trying to cope with having to stock over 100 000 different components. A further series of mergers resulted in the formation in 1968 of British Leyland (BL), which comprised nearly the whole British motor industry, and was the fifth largest motor manufacturer in the world. Lack of rationalization resulted in its having 46 different models at one time. Similar mergers took place elsewhere, and by the 1980s, most European countries had only one or two major native motor manufacturers, and these were often kept alive by being nationalized and subsidized. In Britain, the Conservative Government removed the protection of nationalization, and a few years later, the Rover Group, a late manifestation of the BL empire, was sold to BMW. After a few years of disastrous performance, it was returned to British ownership, becoming the MG Rover Group. Apart from this company, the British motor industry now comprises several large plants belonging to multi-national manufacturers, and a number of major component suppliers. The demise of the native British car assemblers is well described by Wood (1988).

American manufacturers also had to rationalize, but were in a rather different position, as a significant part of their operations was carried out in subsidiary plants abroad. This was the Result of their attempting to overcome import barriers that had been erected in the early days, When the success of Ford and Chrysler had threatened to overwhelm the European industry. The American conglomerates discovered the advantages of moving parts of their operations around the globe to take advantage of local conditions. Japanese manufacturers faced with similar restrictions on their exports, developed the same strategy. Nowadays most of the major manufacturers operate as multi-national organizations, producing vehicles for a world market, and making use of facilities and suppliers throughout the world. Ford now operates several design offices in different countries, each one concentrating on a particular class of vehicle.

Construction development

Most early car manufacturers adopted the construction methods of horse-drawn carriages for the upper bodywork, but bicycle technology was also used to some extent, and the wire-spoked cycle type wheels eventually replaced the wooden-spoked carriage wheels. The construction of horse-drawn vehicles was of necessity light. Above a wooden chassis, sat a light wooden framework that was covered with a skin of sheet metal, wood or fabric. The largely wooden construction was less suitable for motor vehicles that travelled at much higher speeds, thereby giving rise to higher shock loads. The motor vehicles also had to sustain the loads and vibrations of the engine and transmission, and therefore, a much more substantial metal chassis frame was usually employed. For many years, the upper bodywork retained the wooden framework, usually in ash, but the wooden or fabric skinning soon gave way to sheet metal. A few fabric and wooden bodied vehicles were still produced as late as the 1930s by specialist coachbuilders, but this was mainly because the antiquated style conveyed an air of past elegance. The combination of steel chassis, wooden framework and sheet metal skinning was used for most vehicles, whether mass produced or coach built, until the late 1930s, with aluminium often being used for the more expensive and high-performance vehicles (Figure 1.2). Aluminium has a lower density than steel and produced a lighter body with better resistance to corrosion. It was however, more expensive, and was more difficult to weld, particularly in the higher strength alloys. It also tends to stretch when dented, making minor repairs more difficult. After the Second World War, the wood frame and metal skin form of construction became restricted to specialist coach built Vehicles, and indeed it is still used for the Morgan sports cars.

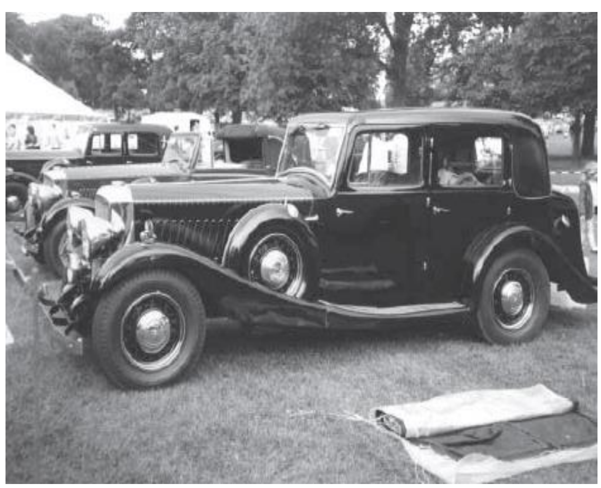


Figure 1.2 This 1935 Railton Carbodies saloon combines classic features of both American and British design.

The engine is a Hudson unit with a three-speed crash gearbox. Sixteen-inch American size wheels are used, but the hand-built coachwork with ash frame, aluminium panelling and steel wings is typically British. The long bonnet is actually justified in this case, because of the straight-eight 4.2 litre engine.

Note the small boot, which had only recently evolved from a separate trunk. Windscreen wipers had been standard for several years, but the flat front screen could still be hinged open. In the 1930s, increasing use was made of pressed-steel skin panels in place of flat sheets or Hand beaten or wheeled panels.

Sheets of steel were pressed in moulds to produce complex shapes with multiple curvature. This process enabled the economic production of the bulbous styling forms that became popular, particularly in the USA. The multiple curvatures also made the panels much stiffer, and the skin could then take a significant part of the loads. Some manufacturers began to dispense with the wooden frame, and to use either a metal frame or even no framework at all, relying on the panels and formed sheet steel stiffening elements to provide all the rigidity necessary for the upper body.

A substantial lower chassis frame was initially retained, but the separate chassis began to disappear, being replaced by a stiff floor 'pan' that was fabricated from welded (usually spot welded) shaped sheet elements. The floor pan was welded to the upper shell, and much of the stress could then be carried by the upper body shell. By the 1950s, this 'unitary' type of construction had been almost universally adopted for mass-produced cars. In recent years, the shell construction has been refined to produce a smooth aerodynamically optimized shape with a minimum of protrusions or gaps. More recently, attention has been paid to the contouring of the underside.

A great disadvantage of early unitary construction was the problem of severe corrosion that rapidly developed around the welds and in inaccessible areas. It took some time for really effective anti-corrosion treatments to be developed, and even longer for some manufacturers to shake off their belief in the advantages of built-in obsolescence. Composite construction, originally in fiber glass and resin was developed soon after the war. It has a number of advantages including the lack of corrosion, and the ability to produce complex shapes cheaply. The tooling costs of composite construction are very much lower than for pressed steel, making composites attractive for small-scale manufacture or short production runs. The techniques of composite vehicle body construction have been developed notably by Lotus, and applied to their sports cars. Disadvantages of the material include the difficulty of attaching metal components, and high material costs. Increasing use is being made of composite and plastic materials for body components, but their use for the main shell is generally restricted to specialist high-performance vehicles (Figure 1.3).

Figure 1.3 Composite material construction of the main bodywork shell has been highly developed by Lotus for its specialist low production volume sports cars.

At first, luggage was usually strapped to the rear of the vehicle on an external rack, a feature that was still found on popular European cars in the early 1930s. The racks were eventually replaced by an integral trunk or boot, and thus the basic three-box saloon or sedan form became established as the standard arrangement. Initially, the rear box was quite small (Figure 1.3), but in the ’fifties, ’sixties and ’seventies, rear trunks of extraordinary size complemented the equally exaggerated engine covers on popular American vehicles (Figure 1.4).

Figure 1.4 Post-war American exaggerated styling.

By the end of the 19th century, steam-powered lorries and buses had begun to appear, but these were immediately challenged by petrol-engined vehicles that were developed concurrently with the motor cars. Steam engine technology was particularly highly developed in Britain, and steam lorry manufacturers such as Foden and Sentinel were loath to abandon their expertise and experience. By the 1930s, Sentinel was producing highly sophisticated steam lorries, but nevertheless fighting a losing battle. In Britain, coal-fired steam propulsion did have one significant advantage over petrol or diesel power in that coal was an indigenous fuel, and relatively cheap.

The historical development of commercial vehicles including buses is well described by Nicholas Faith, 1995. Apart from its contribution to the evolution of road haulage, the internal combustion engine facilitated the development of motor buses (Figure 1.5) which rapidly ousted their horse drawn rivals. By the 1950s, buses had also almost completely displaced the electric tram and the later

Figure 1.5 A 1911 London B-type bus.

Petrol-engined buses soon displaced the earlier horse drawn vehicles. Note how the driver and upper deck passengers are totally exposed to the weather. The tyres are solid rubber. (From the collection of the London Transport Museum.) Electric trolley bus. In addition to having a major impact on urban public transport, buses were able to fill the gaps in the rail network, particularly in rural districts.

The building of the Autobahns in Germany in the 1930s encouraged a new form of passenger transport: the long-distance high-speed coach service. Taking advantage of the wide dual carriageway roads, special fast streamlined buses were built. The combination of streamlining and high-powered engines resulted in vehicles with top speed of well over 100 km/h (62 mph).Refinements such as toilets were also incorporated. The buses were operated by the German state railway company, with integrated bus and rail services. At the same time in

America, long distance bus services were also expanding rapidly and challenged the railroads which were suffering from the expense of track and rolling stock maintenance. The Greyhound Bus Company developed a nation-wide network by a process of absorption and collaboration with competitors. After the Second World War, the combination of road and air transport in America threatened the very survival of the railways which did not traditionally have the protection of nationalization. By the 1960s, long-distance American buses incorporated tinted windows, toilets, air-conditioning and pneumatic suspension, and were able to cruise comfortably at the legal speed limit [7].

Aerodynamics was born as a science at the end of the 19th and beginning of the 20th Century. Styling has existed from early times. However, the terms ‘stylist’ and ‘styling’ originally came into common usage in the automotive industry during the first part of the twentieth century [18].

Nowadays, the waste of energy and the environmental pollution are some of the major global concerns for all science disciplines especially engineering. There are a lot of researchers who studied the aerodynamic behavior around vehicles and tried to control their harmful emissions. Thus, they considered how to find out a better way to improve the vehicle performance by modifying the shape and weight of the vehicle.

Buses are one type of the heavy vehicles that consume much fuel. They are road vehicles designed to carry passengers in different applications. The smaller loads are carried by midi-buses and minibuses. Coaches are used for longer distance services. Bus manufacturing is increasingly globalized with the same design appearing around the world. Buses may be used for scheduled bus transport, scheduled coach transport, school transport, private hire, tourism, etc. Promotional buses may be used for political campaigns and others are privately operated for a wide range of purposes [1].

The external aerodynamics plays an important role in the development process of modern automotive. The vehicle’s performance, its stability is influenced by aerodynamic loads. Furthermore, the driver’s comfort and the driver’s visibility depend on the external flow field. The automotive industries apply wind tunnel experiments and computational fluid dynamic (CFD) simulations to study the aerodynamic loads on their vehicles. With increasing of automobile speed, people begin to pay attention to dynamic performance of automobiles. Due to increasing of oil price, high demands bring forward to automobile design, especially to aerodynamic characteristics of automobiles. The aerodynamic characteristics directly affect driving characteristics, stability, operation, oil consumption and safety of automobiles [2].

Nowadays the automotive industry is one of the challenged sectors on the market. The company has to fulfill the current regulations commissioned by the International Standards in means of the environmental field like the pollution, emission and safety for the passengers or manufacturing. Products have to meet the expectation of the customers on the market in every possible aspect from the comfort to performance or simply the fame in certain occasions. These conditions lead to high quality standards, what cannot be maintained without development of the current state. High demand needs investment and manufacturers are doing Research & Development projects in various fields of engineering in order to accomplish their goals. Automotive industry is a collaboration of all mechanical engineering discipline from thermodynamics to solid and fluid dynamics through material science. In these fields the Computational Fluid Dynamics can be applied as an ancient tool in the Research and Development projects.

As the CFD software packages are getting more common, and become reliable and rapid, it can be applied in multiple tasks. Automotive flows can be separated into internal and external category.

The current economic growth trend in India predicts the number of vehicles on road to increase rapidly in the next 15 years. Such a growth, however, would also increase the CO2 emissions considerably which would have drastic effects on the environment. Automobile manufacturers are therefore, looking for new ways and developing new technologies to reduce fuel consumption and improve vehicle efficiency.

In terms of vehicle efficiency, drag is an important factor which is why vehicle aerodynamics is such an active area of research for automobile manufacturers. While wind tunnel testing was the most profound way of testing vehicle aerodynamics in the 20th century, recent growth in the available computational power has led to more and more adaptation of numerical simulations. Computational Fluid Dynamics (CFD) helps study the flow behavior without having to create a physical model and thus helps reduce costs while simultaneously saving time [3].

During a car displacement, wheels' rotation is responsible of about 25% of the aerodynamic drag of passenger cars. To control the flow and then to achieve drag reduction, a better physical understanding of the flow mechanism is first needed [4].

Aerodynamic styling of a car is one of the most crucial aspects of car design-a highly complex phenomenon, encompassing the task of an artful integration of advanced engineering and stylish aesthetics. A lot of emphasize is laid on the aerodynamics in car design as an aerodynamically well designed car spends the least power in overcoming the drag exerted by air and hence exhibits higher performance- cruises faster and longer, that too on less fuel[5].

Directional stability: At high speeds, the yawing moment caused by aerodynamic forces during turning or because of a crosswind can be quite significant.

In the early years of the automobile era (up to the 1920s) car performance and road quality Limited the top speeds. Therefore, there was little correlation between aerodynamics and yawing moment. However, as car performance and road quality improved, the aerodynamic yawing moment became increasingly important [61].

More recently within last 10 years, computational fluid dynamics (CFD) has matured sufficiently as a technology to enable it to calculate such quantities as drag and lift for a road vehicle without resort wind tunnel testing. However, the computational models are very large and even with state-of the-art processor it may take several day of CPU time to gain a solution. In order to reduce this to a time scale which is acceptable to vehicle designer within a day, it is necessary to use a simplified computational technic and adopt a model to describe the mean effect of turbulence. Unfortunately, simple turbulence models often fail to calculate the flow properly e.g. the position of flow separation on rear slant is crucial in Determining the aerodynamic drag but it is extremely difficult feature to calculate using a simple turbulence model. Hence, to road vehicle manufacturer, CFD is currently a subject to research rather than a design tool, and the key to understand vehicle aerodynamic is still the wind tunnel [6].

Fig1.6suzu passenger vehicle locally built Adama Ethiopia

Due to the global climate change of today the automotive industry invests significantly in reducing the fuel consumption of their products. The companies are, at first hand, pushed by the Governments and legislations to reduce the emissions of their vehicles. There are many approaches to reduce the emissions and all of them are of importance for the automotive industry [17].

The stakeholders on the nowadays automotive market have started to tackle with a design process that takes advantage of various non-ferrous materials available on the market, exploiting Their specific properties. The main outcome of a multi-material design is a significant mass Reduction and enhancements in structural mechanical properties e.g. increased stiffness of Crash worthiness. The motivation for weight minimization comes from the fact that the mass of new vehicles has been growing steadily for the last four decades, exhibiting 1.1% of an annual increase. Despite the fact that load bearing components are the subject of structural optimization approaches, the mass increase takes place due to the intensive use of auxiliary systems like air-conditioning, electronics or additional gas tanks. Moreover, from the economical point of view, lower curb weight result in decrease of operational costs. This is particularly important in the case of the mass transport (e.g. buses or coaches), for which the annual mileage is very high.45 these mechanical performances along with the weight minimization were the subject of many Optimization attempts.

The same authors in presented a study on enhancing the bus rollover resistance. They identified the components that exhibited high internal energy level and applied on them Structural modifications that were obtained by means of a simple one-variable regression based Optimization process, Similar studies were presented by Su et al. in in which the authors [32].

Our society's increasing requirements for mobility with simultaneously growing environmental sensitivity is a big challenge for the traffic policy makers and the transport corporations including private fleet operators. Consequently, it is also indispensable for the manufacturers of light and heavy passenger vehicles and the body builders to adapt to the ecologically motivated requirements, which becomes more and more important without compromising on basic minimum requirements of safety and comfort. [33].

Buses are generally believed to be very safe [34]. Most of bus accidents are caused by rollover as statistics showed which set up rules aimed at enhancing the upper structures of buses [35].

1.2 Problem statement

Isuzu passenger bus is currently popular in Ethiopia. Many government and private organizations are using the bus as a service and public transport. Nowadays with increase in competition in automobile sector, vehicle aerodynamics characteristics, shape optimization and manufacturing processes of body plays an important role.

External aerodynamics is becoming an important field of study in recent years .This is because of its effectiveness in the study of visibility, stability and aerodynamic body shape optimization.

At present, the bus transportation is cheaper and easier to use than other means of transportation. However, buses have some disadvantages such as air pollution due to engine exhaust. This study

- An attempt to reduce the gas emissions from buses. by reducing the aerodynamic drag reducing the carbon dioxide emissions,
- Improvement of driving characteristics visibility
- Rotating moment due to location of difference between C.G and C.P, due to centrifugal force when the vehicle corner at high speed, thus situation can create rolling, yawing and pitching moment on the vehicle during operation on the road this will cause problems on the performance of car model like instability.
- Check of driving stability at corner with side cross wind for best model.

1.3 objectives of the study

1.3.1 General Objective of the Study

The general objective of this thesis is to optimise the aerodynamic body shape of locally built Isuzu passenger bus using CFD.

1.3.2 Specific Objectives of the Study

The specific objectives are:-

- To study the details of the Isuzu bus.
- To model and analyse the body by using CATIA and CFD respectively.
- To modify the body shape for reducing drag.
- To check the effect of body modification on stability and structural strength of the bus

1.4 Scope of the study

The work is delimited to the analysis of the c_d reduction, stability and structural strength with the minor modifications made on locally built Isuzu bus. The softwares like CATIA, CFD phoenics VR 2015 and ANSYS are used for this purpose. The amount of fuel saved also estimated

1.5 Limitations

Limitation: Time given to complete the thesis

1.6 Significance of the Study

Isuzu passenger is currently popular in Ethiopia. Many government and private organizations are using the bus as a service and public transport. This works help in

- Improving the aerodynamic design of locally built bus.
- Reducing the fuel consumption.
- Reducing the environmental pollution.
- Creating the job opportunities by increasing the industrial activities.

  The local industries, the community, the country as a whole get benefit out of this work.

1.7 Structure of the report

This report consists of five chapters. The first chapter is introduction about the research study. It includes the background of study, problem statement, objectives, scopes, significant of the study and the structure of report. Next chapter focuses on the literature review based on the previous aerodynamic experiments and structural strength. Chapter three describes the methodology of the procedures of this research which was done. Methods and procedures are described in general. Besides that, the details of used simulation settings and boundary conditions are briefly described. The results and discussions are presented in chapter four. The final chapter of this thesis consists of conclusion and recommendation of this research study. The overall conclusion with finalized details is discussed with some recommendation.

2. LITERATURE REVIEW

2.1 Bus aerodynamics

Buses are the major mode of mass transportation all over the globe, despite of the rail network. Buses are inefficient in term of fuel consumption, thus in order to decrease the fuel consumption of vehicles, improvement in the aerodynamics of bus shapes will add to the value. It becomes essential to thoroughly design a vehicle for its aerodynamics, as it directly relates to the fuel economy and resisting forces, which further this, become a parameter for mankind to purchase the vehicle. More precisely the reduction of their drag coefficient becomes one of the main topics of the automotive research. Decreased resistance to forward motion allows higher speeds for the same power output or lower power output for the same speeds.

Aerodynamics being the aid to form a body shape that maximizes the down force, the negative lifts and minimizes the force that opposes the forward movement and the drag forces. The aerodynamically efficient design of the bus reduces the drag force improving the fuel efficiency. In a moving vehicle, the engine power is used to overcome tractive resistance, which is the combination of rolling and aerodynamic resistance. The rolling resistance will be dominant over the aerodynamic resistance at lower speeds [25].

Aerodynamic resistance (drag) amounts for more than three fourth of total engine power while operating at higher speeds, since the drag increases as the square of the speed. Thus the maximum power generated by the engine is utilized to overcome the aerodynamic resistance. Due to this the engine load increases substantially which further raises the fuel consumption rate.

Aerodynamics is the study of a solid body moving through the atmosphere and the interaction which takes place between the body surfaces and the surrounding air with varying relative speeds and wind direction [12].

Aerodynamics makes it major impact on modern vehicles through its contribution to road load. Aerodynamic forces interact with the vehicle causing drag, lift, lateral forces, and moments in roll, pitch, yaw and noise. This impact on fuel economy and handling, the flow around the vehicle not only leads to drag but also causes aerodynamic forces and moments which are components of resulting wind force this affects driving stability. The airflow pattern resulting from the forward motion of the vehicle produces lift and pitching moment this affects traction. Due to the lateral side force the yawing moment and rolling moment results. To control the stability of the vehicle these aerodynamic forces can be used positively by producing the needed negative lift that is the down force to give more traction to the driving wheels [16].

The constant need for better fuel economy, greater vehicle performance, reduction in wind noise level and improved road holding and stability for a vehicle on the move, has prompted vehicle manufacturers to investigate the nature of air resistance or drag for different body shapes under various operating conditions [12].

Aerodynamic styling of a car is one of the most crucial aspects of car design-a highly complex Phenomenon, encompassing the task of an artful integration of advanced engineering and stylish Aesthetics. A lot of emphasize is laid on the aerodynamics in car design as an aerodynamically well designed car spends the least power in overcoming the drag exerted by air and hence exhibits higher performance- cruises faster and longer, that too on less fuel[8].

The present study and research work was aimed to deliver an aerodynamically improved bus design with user oriented exterior styling and interior comfort [18].

The reduction of coefficient of drag through proper tuning of the exterior and reducing the frontal projected area are two viable options for reducing the aerodynamic drag of road vehicles [2].Buses are one type of the heavy vehicles that consume much fuel. Modifications of the external body and/or surface of the bus to reduce the aerodynamic drag are proposed [1].

Buses are one type of the heavy vehicles that consume much fuel. They are road vehicles designed to carry passengers in different applications.

The vehicle should project its performance and comfort capabilities through its exterior design. Finding harmony with the aerodynamic requirements and customer oriented styling will lead to a successful vehicle with low fuel consumption [2].

2.2 Aerodynamic forces

Aerodynamic research initially focused upon drag reduction, but it soon became apparent that

The lift and side forces were also of great significance in terms of vehicle stability. An unfortunate side effect of some of the low drag shapes developed during the early 1980s was reduced stability especially when driven in cross-wind conditions. Cross-wind effects are now routinely considered by designers but our understanding of the highly complex and often unsteady flows that are associated with the airflow over passenger cars remains sketchy. Experimental techniques and computational flow prediction methods still require substantial development if a sufficient understanding of the flow physics is to be achieved.

The aerodynamic forces and moments that act upon a vehicle are shown in coefficient form In Figure 2.1 the force and moment coefficients are defined respectively as

$$C_f = \frac{F}{\frac{1}{2}\rho v^2 A} \qquad C_m = \frac{M}{\frac{1}{2}\rho v^2 Al}$$

Where: F is force (lift, drag or side),

M is a moment,

ρ is air density,

v is velocity,

A is reference area and

l is a reference length.

Since the aerodynamic forces acting on a vehicle at any given speed are proportional to both the appropriate coefficient and to the reference area (usually frontal area) the product C_fA is commonly used as the measure of aerodynamic performance, particularly for drag [7].

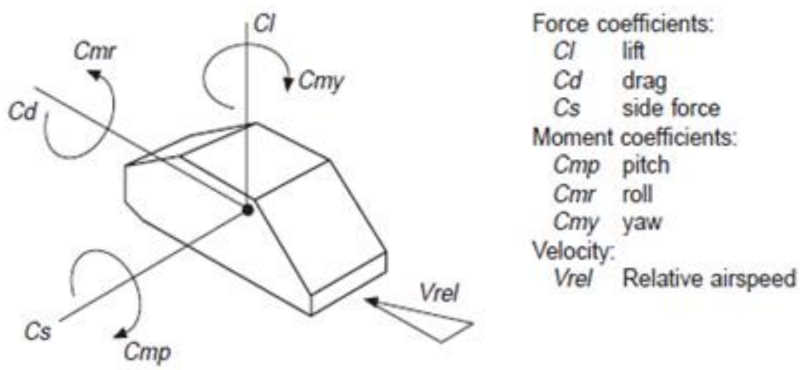


Figure 2.1 lift,drag,side force and moment axes

The forces may be considered to act along three, mutually perpendicular axes. Those forces are the drag, which is a measure of the aerodynamic force that resists the forward motion of the car, the lift which may act upwards or downwards; and the side force which only occurs in the event of a cross-wind or when the vehicle is in close proximity to another. The lift, drag and pitching moments are a measure of the tendency of those three forces to cause the car to rotate about some datum, usually the centre of gravity. The moment effect is most easily observed in cross-wind conditions when the effective aerodynamic side force acts forward of the centre of gravity, resulting in the vehicle tending to steer away from the wind. In extreme, gusting conditions the steering correction made by the driver can lead to a loss of control. Cross-wind effects will be considered [8].

Aerodynamics drag force is the force which opposes the forward motion of the vehicle when the vehicle is traveling. The aerodynamics drag force acts externally on the body of a vehicle. The aerodynamics drag affects the performance of a car in both speed and fuel economy as it is the power required to overcome the opposing force. Because air flow over a vehicle is so complex, it is necessary to develop semi empirical models to represent the effect.

1. Therefore, aerodynamic drag force is characterized by,

   D = ½ ρ v2 CD A

   Coefficient of drag is defined as how the aerodynamic the shape is to the incoming air. C_D is determined empirically for the car.

2. It is possible to have an aerodynamic drag coefficient greater than 1 if the air is pushed outward such that the effective area of the air movement is greater than the area of object facing the air [21].

Drag force acting on the vehicle also depends on frontal projected area and the coefficient of drag value of the vehicle [23].

Drag is an aerodynamic force that opposes a vehicle's motion through the air, caused by interaction and contact of a solid body with a fluid. Unlike other resistive forces, such as dry friction, which are independent of velocity, drag forces depend on velocity. Drag depends on the density of the air, the square of the velocity, the size and shape of the body and a variable known as the drag coefficient. The drag force of a vehicle is represented as; (the density of air at 250 C is 1.184kgm-3). Benson suggested that the reference area to be used for computing the drag of a vehicle should be the frontal area which is perpendicular to the flow direction of the fluid [61].

As a car moves along, it pushes the air that surrounds it away. As a result the car is subjected to drag. Drag, also known as air resistance or fluid resistance refers to forces that oppose the motion of the vehicle [62].

When a body is in motion a drag force is created which opposes the motion of the object so thrust can be the force produce in opposite direction to drag that is higher than that of drag so that the body can move through the fluid. Thrust is a reaction force explained by Newton's second and third laws, The total force experienced by a system accelerating in mass "m" is equal and opposite to mass "m" times the acceleration experienced by that mass[49].

2.3 Factors affecting the aerodynamics forces

The aerodynamic forces acting on a body in motion in a fluid depend not only on the geometry Of the body but also on the fluid and the interface between the fluid and the body. The two Major types of forces acting on such a body are the pressure forces and the frictional forces. It is Important to have boundary layer attached to the surface so as to avoid excessive wake Formation. Aerodynamics is an indispensable aspect of automotive industry with benefits in all spheres such as improving the fuel efficiency, emission reduction, increased directional stability and better ride quality[23].

The important aspects of aerodynamic studies are the reduction of aerodynamic drag, reduction of the side force and the yaw moment, which have an important influence on stability, handling and reduction of aerodynamic noise.

Similarly an important issue for acoustic comfort, the reduction of dirt deposited on the windows and lights when driving on wet road also plays a major role in this aspect. While focusing for safety, this aspect can be extended to the creation of spray wakes that can reduce visibility for other vehicles following or passing the vehicle under study [5].

Lift force

The force a flowing fluid exerts on a body in the normal direction to the flow that tends to move the body in the direction of the fluid flow is called lift. It is caused by the components of the pressure and wall shear forces in the direction normal to the flow. The lift coefficient is given by CL

$$CL = (2 * FL) \,/\, \rho V^2 A$$

Where, CL = Coefficient of lift,

FL = Lift force,

ρ = Density of the air,

V = Velocity of the air,

A = Frontal area (Area projected on a plane normal to the direction of flow).

There are various methods to reduce the drag of a vehicle by use of the passive devices. Some of the examples are, front screens, rear screens, structural elements that localize the area Of flow, spoilers, bumpers and diffusers [33].Lift is a component of force that is perpendicular to the direction of flow of the air stream [38].

The lift force dependent on the overall shape of the vehicle. At zero wind angle, lift coefficient normally fall in the range of 0.3 to 0.5 for modern passengers car, but under crosswinds conditions the coefficient may increase dramatically reaching value of 1 or more [16].

2.4 Bluff body aerodynamics

In aerodynamics, a bluff body is one which has a length in the flow direction close or equal to that perpendicular to the flow direction. This spawns the characteristic that the contribution of skin friction is much lower than that of pressure to the integrated force acting on the body. Even a streamlined body such as an airfoil behaves much like a bluff body at large angles of incidence. A circular cylinder is a paradigm often employed for studying bluff body flows.

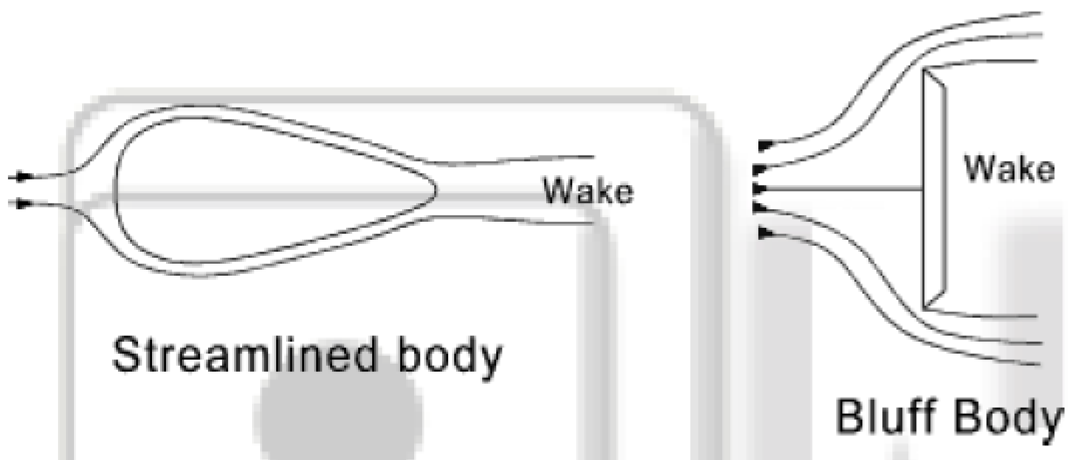


Fig.2.2:- The wake creates by streamlined and bluff body [49].

The term bluff body is devised for aerodynamic bodies where the total drag consists of mainly pressure drag and the friction drag is a small portion of the total drag. Flow separation plays an important role in the total drag of bluff bodies since pressure drag is a result of flow separation.

Most automotive applications are concerned with bluff body aerodynamics, even in the cases where streamlining is applied the flow still separates and the drag is dominated by pressure drag

Vortex structure

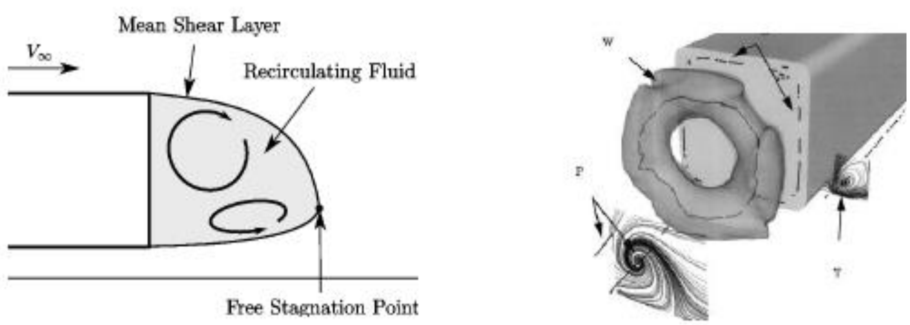
The GETS model is a bluff body, where flow separation occurs only at the back of the model.

The front edge radius is chosen such that the flow remains attached and the boundary layers can develop on the surfaces of the model. The boundary layers on the side top and bottom reach the base of the model and separate on the aft edge of the model forming free shear layers. These shear layers curve towards each other and close in the free stagnation point, see figure 2.1(a).

The shear layers enclose a region of recirculating air, called the wake and this structure of the recirculating air in the wake is an unsteady three dimensional process.

The recirculating fluid in the wake forms a vortex, with a continuous vortex core and which is described as a ring vortex. In figure 2.3(b) an instantaneous representation of the vortex core is shown obtained by LES simulations from. This vortex imposes a pressure field on the base of the trailer responsible for the suction force acting on the base. The vortex ring and the shear layers encapsulating is not a steady process however, small eddies develop in the shear layer and are convected downstream while growing in size. The larger vertical structures separate from the shear layer at a shedding frequency causing the wake to decrease in size and the free stagnation point to move upstream closer towards the base as is displayed in figure 2.3.

This vortex shedding and moving of the free stagnation point is called bubble pumping and is an Unsteady effect in the recirculation region. The fluid shed from the recirculation region in the form of a vortex is equal to the average amount of fluid which is entrained in the recirculation region



(a) Bluff body showing shear layers (b) Instantenious ring vortex in wake

Figure 2.3: Near wake visualization and ring vortex

Through the shear layers, this continuous process of fluid entrainment through the shear layers and the periodic shedding of vortices causes the flow behind the truck to be unsteady.

The development of the small eddies in the shear layers which leads to the eventual shedding of vortices in the wake requires a modeling approach capable of capturing the small size eddies, which is not practical for conceptual engineering projects. Furthermore as this unsteady process is not fully understood, it remains a subject of research. The unsteady behavior of the shear layers is not treated in this thesis and a time-averaged flow field is evaluated in order to obtain the overall force balance on the model.

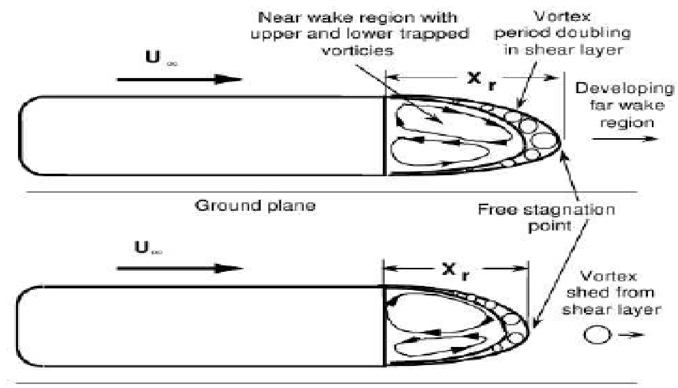


Figure 2.4: Vortex shedding in near wake [62]

The design concepts were introduced to a high speed coach ,a streamlined design of the front side of the vehicle to reduce profile or pressure drag and rear-spoiler to minimize the turbulent kinetic energy formed at the rear of it

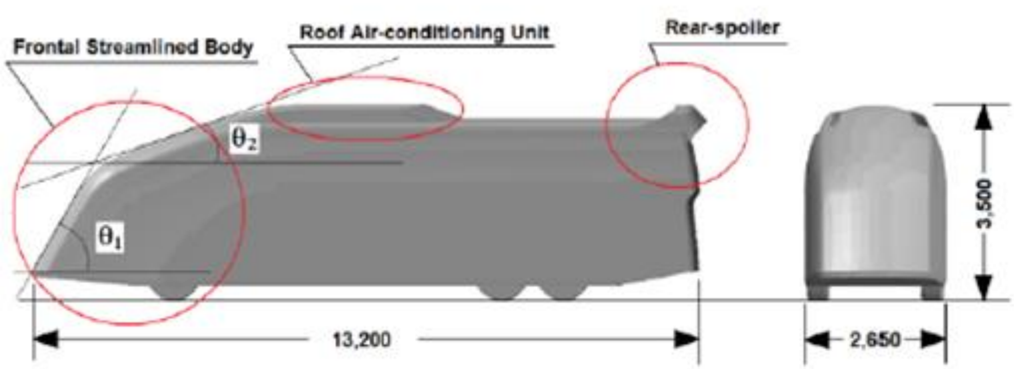


Fig: 2.5-dimentional view of streamline design designed coach with general shape of rear spoiler.[53]

2.5 Ahmed Body

The Ahmed body was first defined and its characteristics described in the experimental work of Ahmed et al. (1984).[60]

Ahmed et al. designed a simple model for a car as shown in Fig-2.6 and this constituted of nose shaped front and a movable slant plane at the rear to conduct experiments at different rear angles to study the flow pattern. The nose and the slant plane was connected by a rectangular box. Wake separation flow behind the Ahmed body is the main contributor to the drag force, therefore its accurate prediction is important..

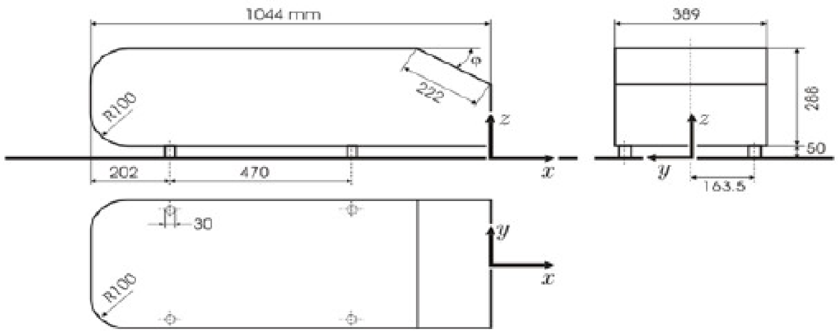


Fig 2.6: Geometry of the Ahmed Body [24]

2.6 Aerodynamic Design of Ahmad Body

Aerodynamics analysis is used in the design of car to reduce drag coefficient. The investigation has obtained the behaviour of newly developed turbulence models for complex geometry cases, a simplified car model, known as the Ahmed body, has been tested by Ahmed. The Ahmed body is made up of a round front part, a moveable slant plane placed at back part of the body to study the coefficient of drag and separation phenomena at different angles, and a rectangular box, which Connects the front part and the rear slant plane. As the wake separation flow behind the Ahmed body is the main contributor to the drag force, accurate prediction of the separation process and the wake flow are the key to the successful modelling of this case. Many researchers have made use of CFD techniques to perform numerical simulations related to automobile. Several numerical simulations were performed to analyse the pressure field, velocity vector field, and aerodynamic force prediction related to a passenger car. The external surface of the car is very Important in aerodynamics aspects of vehicles such as stability, comfort and fuel consumption at high speeds. The total weight and modification of the external surfaces of the car are the most important to improve the aerodynamics characteristics of the car. These characteristics are Helpful to improve the cruising conditions, greater stability of navigation, and lower fuel consumption [6].

A road vehicle has also aerodynamic properties that are specific to this kind of vehicles.

Due to its geometry, it can be considered a bluff body, which means that drag is mainly due to the pressure acting on it. Skin friction, caused by viscous shear forces on the surface of the vehicle, has only a small contribution to the drag. Flow separation occurs in the back of the body, creating large recirculation regions in the near wake, resulting in a lower pressure on the back surfaces, see figure (2.7).

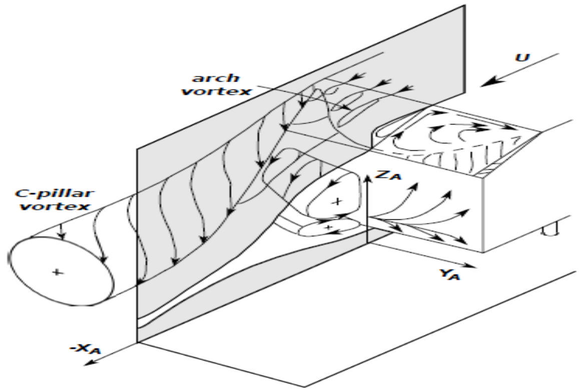


Figure 2.7: Vortex system behind a road vehicle (Ahmed et al., 1984) [41].

Total Resistance Fr = (0.015+0.00016V) W [63]

Power Required P = FtV/ηt

Ft = Fd+Fr

Fd - Drag force
Fr - Rolling resistance

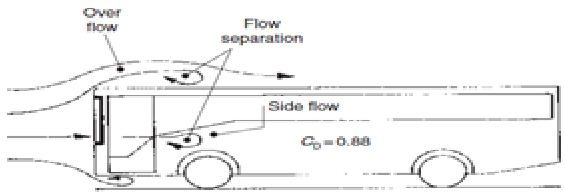
Drag Coefficient Reduction [64]

$$\Delta C_D\% = \frac{C_{D\,modified} - C_{D\,with\,out\,modifiction}}{C_{D\,with\,out\,modification}} \times 100$$

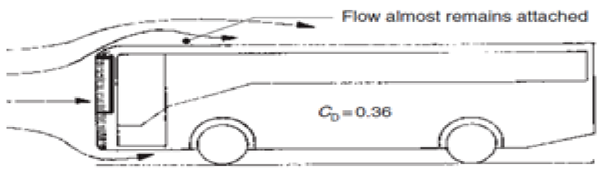
Some Ethiopian areas which are meteorology station wind speed has been recorded [65]. Gode station observed wind velocity 11.34 m/s.

The effects of rounding sharp front cab body edges

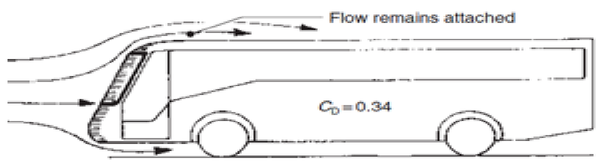
A reduction in the drag coefficient of large vehicle buses, coaches and trucks can be made by rounding the front leading edges of the vehicle. Fig2.8 (a-d)



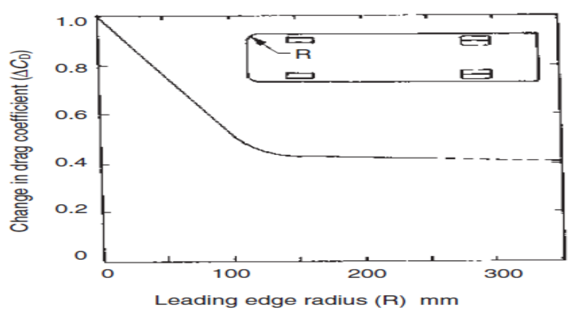
(a) coach with sharp leading edges



(b) coach with rounded leading edges



(c) Coach with rounded edges and backsloping front



(d)The effect of rounding vehicle edges up on the aerodynamic drag

Fig 2.8: The effects of rounding sharp front cab body edges [12].

The external surface of the car is very important in aerodynamics aspects of vehicles such as stability, comfort and fuel consumption at high speeds. The total weight and modification of the external surfaces of the car are the most important to improve the aerodynamics characteristics of the car. These characteristics are helpful to improve the cruising conditions, greater stability of navigation, and lower fuel consumption [6].

2.7 Heavy vehicles

In vehicle body development, reduction of drag is essential for improving fuel consumption and driving performance, and also the aerodynamically refined body is aesthetically attractive, it will contribute much to increase the vehicle's capacity.

The aerodynamic drag of heavy road vehicles participates significantly on the overall energy of vehicles efficiency and thus represents a challenge for its optimization. Although the Aerodynamic development of passenger and sport cars has seen much growth, it can be same for commercial heavy vehicle. The aerodynamic design of heavy vehicle tractor trailer still needs more development for minimum fuel consumption. Heavy vehicle are aerodynamically inefficient compared to other ground vehicle due to their larger frontal area and bluff bodies shape. It is estimated that a 40-tons articulated truck travelling at 60 mph consumes about 34 Litters of fuel to overcome drag across a 100-mile high way stripe ; an average car would consume four time less under similar condition**.** More energy is consumed in overcoming aerodynamic drag as the vehicle speed up. Reducing fuel consumption for heavy vehicles can be achieved by altering truck shapes to decrease the aerodynamic resistance (drag). It is conceivable that present-day truck drag coefficients might be reduced by as much as 50%,this reduction in drag would represent approximately a 25%reduction in fuel use at highway speeds, an estimated total savings of $1.5 billion per year can be recognized in the United States alone for just a 6% reduction in fuel use .This reduction represents 1% of all fuel use in the united states. Heavy tractor trailer geometry may have many aspects geometrical configuration that contributes to drag force and can be articulated as source of drag. These drag source can present as follows:

1-Tractor geometry.

2-Gap between the tractor and trailer.

3- Under body drag.

4- Wheel aerodynamic.

5- Rear base of trailer.

6- Side mirror.

The schematic of fig 2.9 depict the dominant percentage drag regions on a tractor-trailer truck which are the tractor front face, tractor trailer gap, undercarriage/wheels, and trailer base [54].

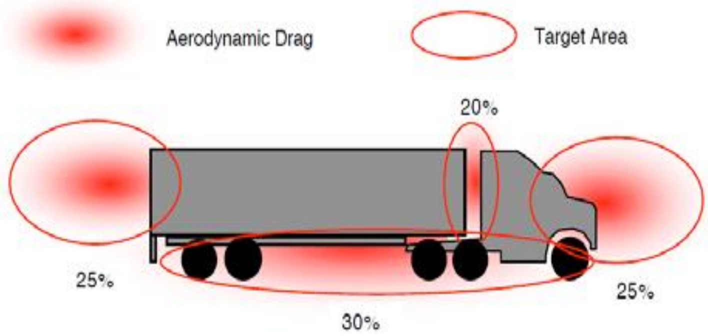


Fig.2.9 Graphic depicting the distribution of aerodynamic drag for a heavy vehicle tractor-trailer truck [54].

A significant effort was made by researchers over the decade to develop various fuel saving devices for commercial vehicles, there is still scope to further reduce the aerodynamic drag.

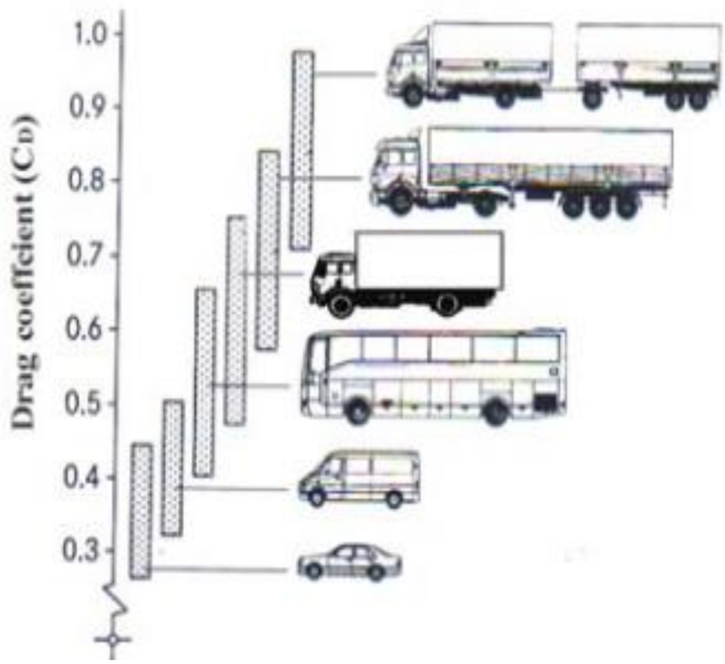


Fig. 2.9.1 Drag coefficients of different commercial vehicles

2.8 Aerodynamic boat-tail

An aerodynamic boat-tail, also called boat-tail plates, was evaluated at Nasa Ames Research Centre. The configuration is described by figure 2.9.2. The idea is to trap a vortex or eddy in the corner between the rear of the trailer and boat-tail plates. The dimensions of the truck is not given in the report but is assumed to be of standard dimensions**.**

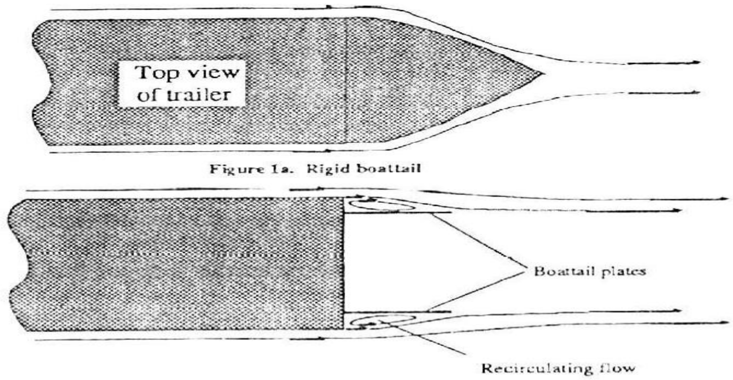


Figure 2.9.2: The configuration of aerodynamic boat-tail compared to ordinary rigid boat-tail [48].

The eddy turn the flow inwards as it separates from the rear of the trailer and creates a virtual Boat-tail and thus increase the base pressure acting on the rear of the vehicle and reduce the net aerodynamic drag of the vehicle.

2.9 Drag Characteristics in a Car Model Boundary Layer

Air has viscosity, that is, there is internal friction between adjacent layers of air, whenever there is relative air movement and consequently energy is dissipated. When air flows over a solid surface a thin boundary layer is formed between the main airstream and the surface. Any relative movement between the main airstream and the surface of the body, then energy dissipation takes place within this boundary layer via the process of shearing of adjacent layers of air. When air flows over any surface, air particles would be in intimate contact with the surface and attach themselves to the surface so that relative air velocity at the surface becomes zero as shown in

Figure 2.9.3.The relative speed of the air layers adjacent to the attached air surface film is very low; however, the next adjacent layer will slide over an already moving layer so that its relative speed would be higher. Hence the relative air velocity further out from the surface rises progressively until it attains the unrestricted free air stream speed.

2.9.1 Flow Separation and Reattachment

The stream of air flowing over a car's body tends to follow closely to the contour of the body unless there is a sudden change in shape as shown in Figure 1. The front bonnet (hood) is usually slightly curved and slopes up to wards the front windscreen. From here there is an upward windscreen tilt (rake) which is, followed by a curved but horizontal roof. The rear windscreen then tilts downwards where it either merges with the boot (trunk) or continues to slope gently downwards until it reaches the rear end of the car. An example of flow separation followed by reattachment can be visualized with air flowing over the bonnet and front windscreen as shown in Figure 1. If the rake angle between the bonnet and windscreen is large, the streamline flow may separate from the bonnet and then reattach itself near the top of the windscreen or front end of the roof. The space between the separation and reattachment can be occupied by circulating air which is referred to as a separation bubble, and if this rotary motion is vigorous a transverse vortex would be established. Thus, the drag characteristics of a car is nothing but the resistance force of air (fluid) which is offered to the car (vehicle) to reduce its speed. The study of these characteristics of drag leads to implementation of modern techniques to reduce the resistance and to increase the speed of the vehicle there by increasing fuel efficiency and economy.

Vortex Generators as Passive Control Device

Vortex generators are aerodynamic surface, consisting of a small vane or bump that creates a vortex. Vortex generator can be found on many devices, but it is often used in aircraft design. Vortex generators delay flow separation and hence are found on the external surfaces of vehicles where flow separation is a potential problem. They are typically rectangular or triangular in shape, about 80% as tall as the boundary layer. Vortex generators have many geometrical parameters like general shape, height, length and angle to the main flow direction. Further, it is necessary to specify the chord wise position and span wise spacing on the blade. Wake reduction can be done by passive control device as well as flow control device. The passive flow

Control method is chosen in this work to minimize the wake region behind the vehicle. Vortex generators are Chosen as passive device which creates vortices, where the laminar flow gets converted into turbulent flow and so the boundary layer separation gets delayed. Due to this, the wake region behind the vehicle is minimized [19].

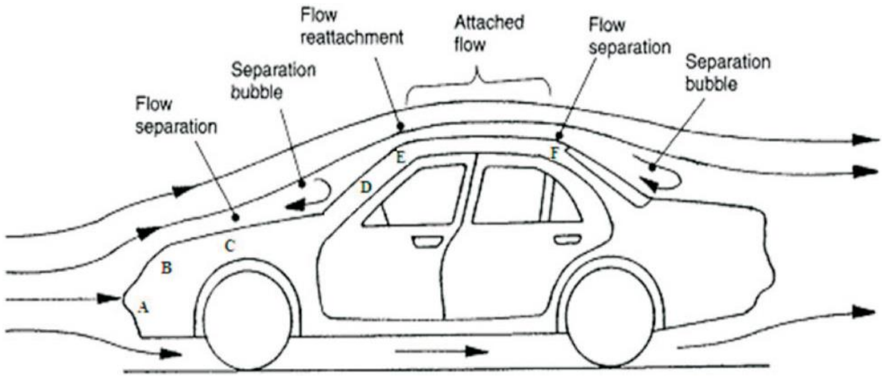


Figure 2.9.3: Transition from laminar to turbulent with respect to velocity (speed) [19].

There are two components of drag that affect a moving object:

Pressure drag is the component of drag that acts in the direction of motion as a result of the pressure forces acting on the body. Behind the vehicles, there is a steep pressure gradient, which leads to the separation of the flow separation in viscous flow. The front part of the flow field shows high-pressure value, whereas on the rear part flow separates leading to a high suction in the area. As we integrate the force component created by such high change in pressure, the resultant is called as 'Pressure Drag'. This factor is affected by the height of the vehicle as well as the separation of the flow field [2].

This is the drag that is generated by the resolved components of the forces due to pressure acting normal to the surface at all points. It may itself be considered as consisting of several distinct contributions:

(i) ***Induced*** drag (sometimes known as vortex drag);

(ii) ***Wave*** drag; and

(iii) ***Form*** drag (sometimes known as boundary-layer pressure drag) [44].

The study of pressure distribution over the body of the bus model is important as the pressure distribution data can be analyzed in order to calculate the form drag, lift forces and side forces. The data of pressure distribution over any surface of the bus model is presented using the pressure coefficient (cp) which is a normalized way of expressing static pressure. The pressure coefficient is calculated from the following equation [45].

Friction drag is the component of drag that acts parallel to a surface as a result of shear and viscous effects in the flow adjacent to the body surface. Every material or wall has a distinct friction, which resists the flow of fluids. Due to molecular friction, a stress acts on every surface of the vehicle. The integration of the corresponding force component in the free stream direction leads to a friction drag. If the separation does not occur, then friction drag is one of the main reasons to cause overall drag [1].

In principle, automotive aerodynamics comprises the drag, lift, and side force coefficients, in Conjunction with the rolling, yawing, and pitching moment coefficients. In real-world situation, the aerodynamic forces and moments which act on a vehicle are of transient nature. However, development of vehicle aerodynamics to date has mainly been focused on the steady-state components, particularly the drag coefficient, *Cd*. This coefficient can only be used to evaluate performances related to fuel efficiency and top speed, and provides no indication in regard to the Vehicle performance in terms of stability [20].

The forces and moments can be attributed to the pressure distribution and to the wall shear stress distribution. The pressures and shear stresses can be characterized by the pressure and local friction coefficients: c_p and c_f: [53].

Inertia is the resistance to change the direction or velocity of a body in motion.

Pitch–the force felt in acceleration or braking movement around (Horizontal axis) of vehicle

Roll–the force felt in cornering, side to side movement (Lateral axis) of the vehicle

Yaw–the force felt in a spin movement around (Vertical axis) of the vehicle [11].

Crosswind is rarely sustained. Atmospheric turbulence can be seen as a noisy background signal peppered with discrete powerful events known as gusts.

- Gusts are sudden and last a short time. The response of cars to gusts is different to the response to sustained crosswinds the former is dynamic, the latter is static.
- Gusts excite the yaw dynamics of the car and can cause oscillations to occur [61].

Computational fluid dynamics (CFD) is a branch of fluid mechanics that, with the help of computers, uses numerical methods to solve and analyze problems involving fluid flows [10].

2.9.2 Structural body strength

A bus in any country is a kind of industries which is connected directly to the prosperity and maintains the stability of this state. After two years of completion of the security and sociality Stability of the welfare states, it stopped immediately in case of any defects in the stability. The design of the internal bus skeleton structure is the basis of various bus developments in the bus industries. It contains the framework of tubes with various cross sections are arranged within specified shapes based on the design [30].

Our society's increasing requirements for mobility with simultaneously growing environmental sensitivity is a big challenge for the traffic policy makers and the transport corporations including private fleet operators. Consequently, it is also indispensable for the manufacturers of light and heavy passenger vehicles and the body builders to adapt to the ecologically motivated requirements, which becomes more and more important without compromising on basic minimum requirements of safety and comfort [28].

It is found that the young's modulus, which is a measure of stiffness, is high for structural steel. Also the load bearing capacity is higher for structural steel. Hence structural steel is selected as the material for analysis. The behavior of the structure under different load conditions like static, cornering etc. are also analyzed. The scope of this project is to provide a light weight design which will reduce the weight as well as improve the stability under all the driving conditions. Cornering

In case of cornering, the major part of cornering load is acting on the side frames. When the vehicle turns a left turn most of the weight shifts to the right side in lateral direction. Hence a portion of load is applied on to the right side frame and Von-Mises stresses are evaluated 40

With the growing concerns on energy conservation and vehicle emission it is increasing pressure on vehicle manufacturers internationally to provide lighter weight components for vehicles. In order to minimize energy consumption, lightweight has become a critical issue because, weight is a key factor for the fuel consumption. The lighter the vehicle more will be the fuel efficiency [29].

Buses are transport means for which in Europe the regulation is not at the moment so hard as for cars. The high cost of the single vehicle makes the manufacturers unwilling to perform full vehicle tests like car crash-tests. Every year in the EC approximately 20.000 buses are involved in accidents. The statistics report about 300.000 injured and 150 fatalities per year due to these accidents. These data show that the bus is one of the safest vehicles, safer than the aeroplane, safer than the train and the car. Nevertheless the few accidents are often so disastrous to capture the attention of the public opinion. In particular in rollover event serious consequences for the occupants are nearly in evitable [31].The crash process of energy absorption can be reflected from view of the acceleration of mass center and crash time, while the velocity of mass center and crash time are determined by the height of center of gravity. Therefore, the height of the center of gravity should be lowered to the greatest extent to improve the bus rollover security [35].

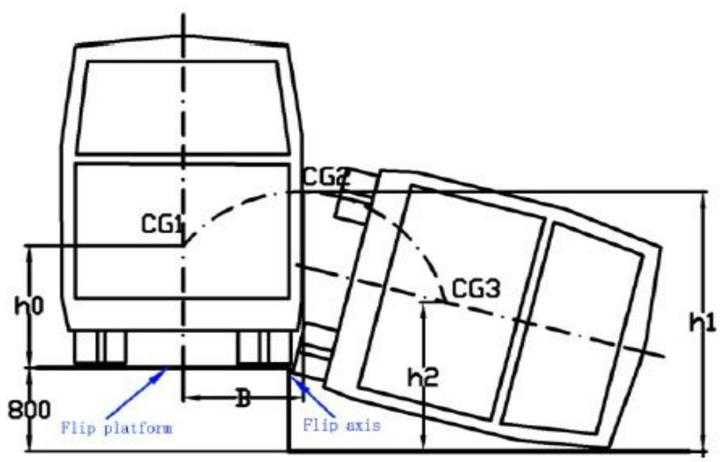


Fig. 2.9.6: Changes for the center of gravity during bus rollover

2.9.3 Force and moment measurements

With the model mounted on a force balance, one can measure lift, drag, lateral forces, yaw, roll, and pitching moments over a range of angle. This allows one to produce common curves such as lift coefficient versus angle of attack. The force balance itself creates drag and potential turbulence that will affect the model and introduce errors into the measurements. The supporting structures are therefore typically smoothly shaped to minimize turbulence [26].

Sudden spike in fuel prices and concern of greenhouse gas emissions, automotive design engineers are facing a new challenge for introducing more aerodynamic design vehicles. The ineffective aerodynamic shape results in excessive drag which leads to increased fuel consumption rates. The main cause of vehicle aerodynamic drag is due to pressure drag or form drag. Pressure drag on vehicles due to flow separation constitutes more than 80% of the total aerodynamic drag [5], while frictional drag constitutes for the remaining 20%. Thus, reducing aerodynamic drag is significant for the fuel consumption efficiency. In United States, the ground vehicles consumed about 77% of all (domestic and imported) petroleum; 34% is consumed by automobiles, 25% by light trucks and 18% by large heavy duty trucks and trailers. It has been estimated that 1% increase in fuel economy can save 245 million gallons of fuel per year. Additionally, the fuel consumption by ground vehicles accounts for over 30% of CO_2 and other greenhouse gas (GHG) emissions. Moreover, most of the usable energy from the engine goes into overcoming the aerodynamic drag (53%) and rolling resistance (32%); only 9% is required for auxiliary equipment and 6% is used by the drive-train. 15% reduction in aerodynamic drag at highway speed of 55mph can result in about 5–7% in fuel saving . Thus, research on vehicles aerodynamic drag reduction have been carried out for a few decades [21].

CFD or Computational fluid dynamics is a branch of fluid mechanics that, with the help of computers, uses numerical methods to solve and analyze problems involving fluid flows. Computers are used to carry out calculations using an iterative procedure wherein the solution accuracy improves with every iteration. The underlying equations that are solved in CFD problems are the Navier-Stokes equations.

In the laminar regime, the flow of the fluid can be completely predicted by solving the steady-state Navier-Stokes equations, which predict the velocity and the pressure fields. As the flow begins its transition to turbulence, it is no longer possible to assume that the flow is invariant with time. In this case, it is necessary to solve the problem in the time domain. As the Reynolds number increases, the flow field exhibits small eddies, and the timescales of the oscillations become so short that it is computationally unfeasible to solve the Navier-Stokes equations. In this flow regime, a Reynolds Averaged Navier-Stokes formulation can be used, which is based on the observation that the flow field over time contains small, local oscillations that can be treated in a time-averaged sense.

A. Rans

The Reynolds Averaged Navier-Stokes equations (also known as RANS equations) are equations used to predict the fluid flow using a time averaged formulation. The primary concept applied is Reynolds decomposition which involves decomposing an instantaneous quantity into its time averaged and fluctuating quantities. The time averaged nature of its equations makes it an attractive choice while simulating turbulent flows. Considering certain approximations based on the knowledge of properties of turbulent flows, these equations can be used to give time averaged solutions to the Navier–Stokes equations.

B. k-epsilon model

The k-epsilon model is one of the most commonly used turbulence models. It is a two equation model that employs two extra transport equations to represent the turbulent properties of the flow. This allows a two equation model to account for history effects like convection and diffusion of turbulent energy. This model, however, does not perform well in cases of large adverse pressure gradients.

C. Realizable k epsilon model

The realizable k-epsilon model addresses the well-known deficiencies of the traditional k-epsilon model by incorporating:

- ❖ A new eddy-viscosity formula involving a variable Cμ originally proposed by Reynolds.
- ❖ A new model equation for dissipation based on the dynamic equation of the mean square velocity fluctuation.

This model makes it possible to achieve good results in terms of integral values (eg. Cd) which are within 2-5% of the actual value. It is also very stable and converges quickly.

D. Non-equilibrium wall function (NWF)

For high Reynolds number flows, such as in external flow around vehicles, resolving the near wall region down to the wall is not practical. To overcome this, wall functions are used. NWF takes into account the effects of local variation in the thickness of the viscous sub layer, when computing the turbulent kinetic energy budget in wall adjacent cells. Besides this, NWF is also sensitized to adverse pressure gradients which are common in flow around vehicles. Compared to traditional wall functions, NWF provide more realistic predictions of the behaviour of the turbulent boundary layers, including flow separation, and they do so without a significant increase in either CPU time or dynamic memory [3].

3. METHODOLOGY

The external aerodynamics plays an important role in the development process of modern automotive. The vehicle's performance, its driving stability and structural strength are influenced by aerodynamic loads. Furthermore, the driver's comfort and the driver's visibility depend on the external flow field. The automotive industries apply computational fluid dynamic (CFD) simulations to study the aerodynamic loads on their vehicles. With increasing of automobile speed, people begin to pay attention to dynamic performance of automobiles. Due to increasing of oil price, high demands bring forward to automobile design, especially to aerodynamic characteristics of automobiles and the aerodynamic characteristics directly affect driving characteristics, stability, operation, oil consumption and safety of automobiles.

In this work, first of all models of the Isuzu passenger car were prepared using CATIA software and this generic model is imported into the PHOINICS VR 215 to simulate wind tunnel test using Phoenics VR 2015 FLUENT model for analysis of coefficient of drag. After this the meshing is generated on the surface of the passenger ISUZU car. Aerodynamic evaluation of air flow over an object can be performed using analytical method or CFD approach. On one hand, analytical method of solving air flow over an object can be done only for simple flows over simple geometries like laminar flow over a flat plate.

Steps of Analysis

- Selecting the models
- Formation of Base Line Model: Designing of model in CATIA with proper dimensions & parameters.
- Baseline passenger car CFD method and setup: Apply the boundary conditions.
- Generate the wind tunnel for simulation by CFD.
- Simulation & Testing of base line passenger car for drag coefficient and lift coefficient.

Also structural strength were tested using Ansys work bench 15 software

In this study setting the baseline model Isuzu passenger vehicle is the first task. This baseline model is one of the models of buses which currently popular in Ethiopia.

Isuzu passenger bus was bench marked for the study. It is manufactured in Ethiopia. This bus model was used to carry out CFD analysis to find aerodynamic parameters such as, pressure and velocity distribution around the body, Cd, and contribution of various exterior parts on the overall drag coefficient of the vehicle.

Fig 3.1 existing Isuzu passenger bus

Justification for the selection of Isuzu passenger bus for aerodynamic study

Isuzu passenger busses with a seating capacity of 29 are being manufactured in Ethiopia, particularly in Adama. It became very popular bus in Ethiopia for city to city public transport. Due to poor aerodynamic shape, it has very bad fuel economy, with fuel consumption up to 18-22 litres per 100km.so this model is selected for improving its aerodynamic shape and to study the aspects like stability, structural strength.

3.1 Isuzu passenger Bus specification

The following table shows bus specification used in the analysis. The Endalk garage uses Isuzu truck to build the Isuzu passenger bus.

Table 3.1 Bus specification

Overall Dimension	Width = 2.3 m
	Length = 7m
	Height = 2.8 m
Capacity	29 Passengers
Wheel Base	4.66m
Maximum Speed	121km/h
Fuel Tanker Capacity	200L
Model :Isuzu f series 550	6HK1-TCN
Engine type	Turbocharged and inter cooled
Number of cylinder	6
Maximum Torque(Nm@r/min)	706@1450
Maximum Horse Power(hp@r/min)	236@2400

3.2 Geometry Generation

Three dimensional model of the baseline model(7700mm, 2300mm, 2800mm), model 2, and model 3 and model of the modified structure were created using CATIA V5R19

- Model 1

This model is the baseline model that means the actual existing Isuzu passenger cross-country bus model design.

- Model 2

These models are the modified models of baseline model. The models are designed under the consideration of aerodynamic aspects and parameters. Modified aspects are Frontal area, Roof shape air conditioning unit added, at the corners curves.

- Model 3

Designed under the consideration of aerodynamic aspects and parameters. Modified aspects are Frontal area, and Roof add air conditioning unit and Rear spoiler added .

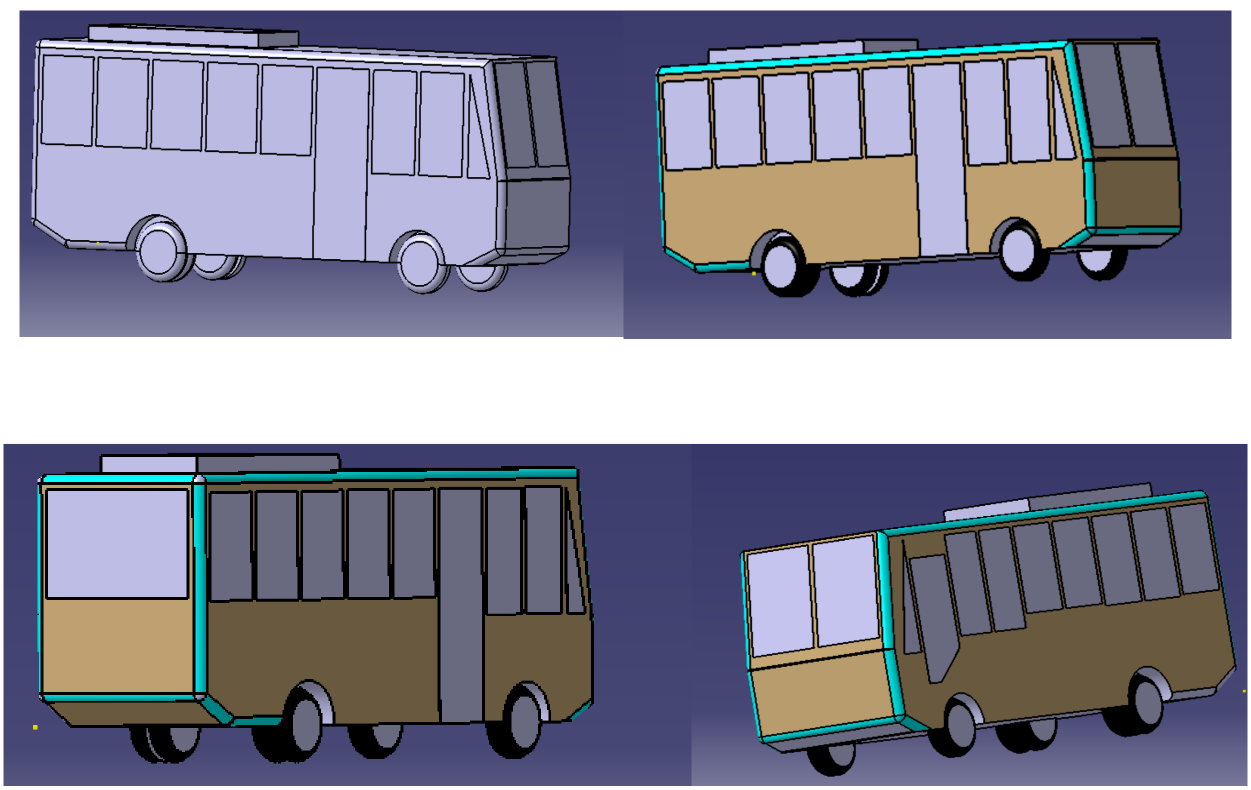


Figure 3.2: Existing Isuzu passenger bus Model 1

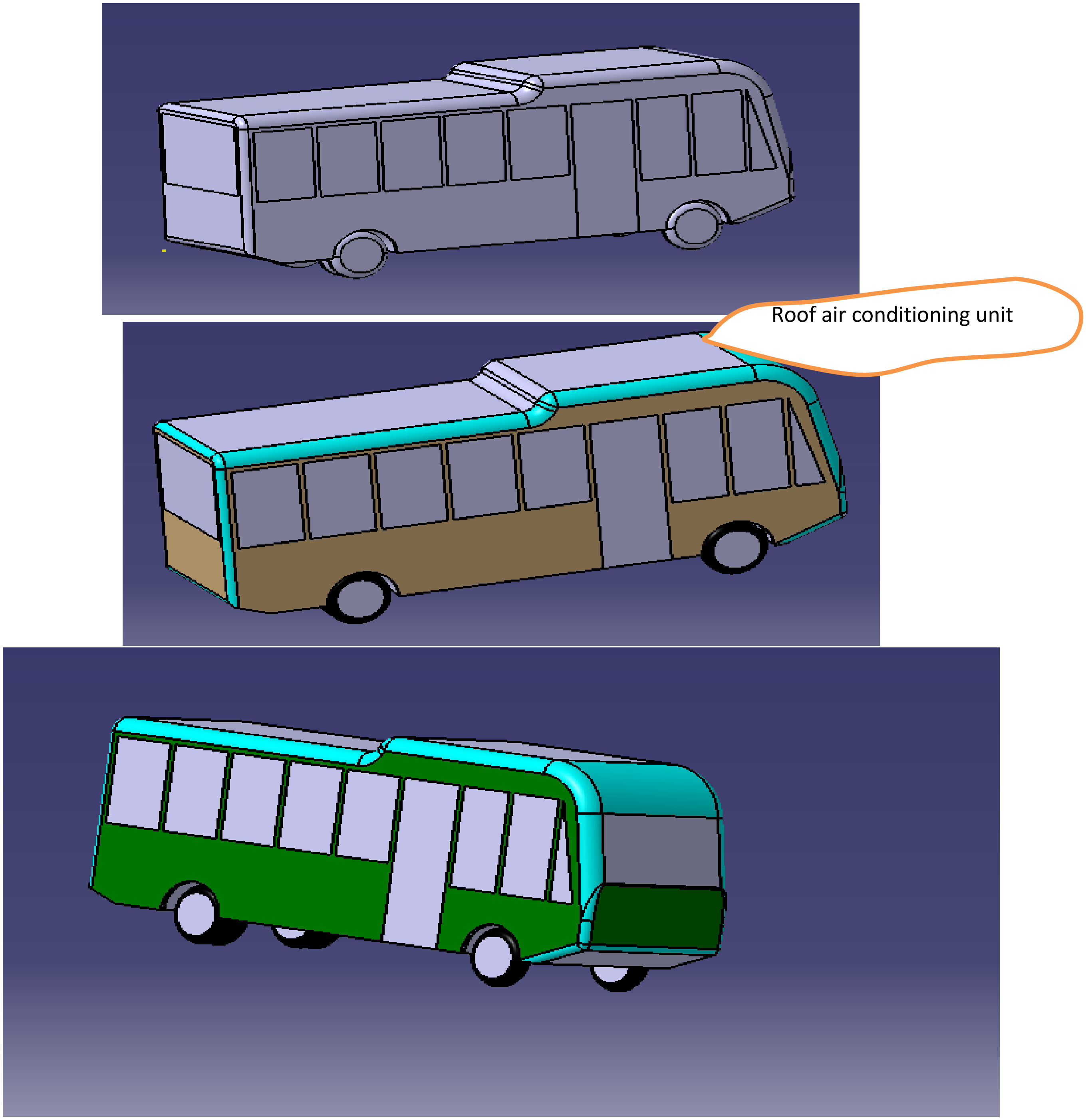


Figure 3.3: Isuzu passenger bus Model 2.

The major modifications in model 2 are: roof air condtioning unit,at the corner curves diamentions are changed,at the front area is changed ,also at the top roof the load added place is changed compared to the existed model.

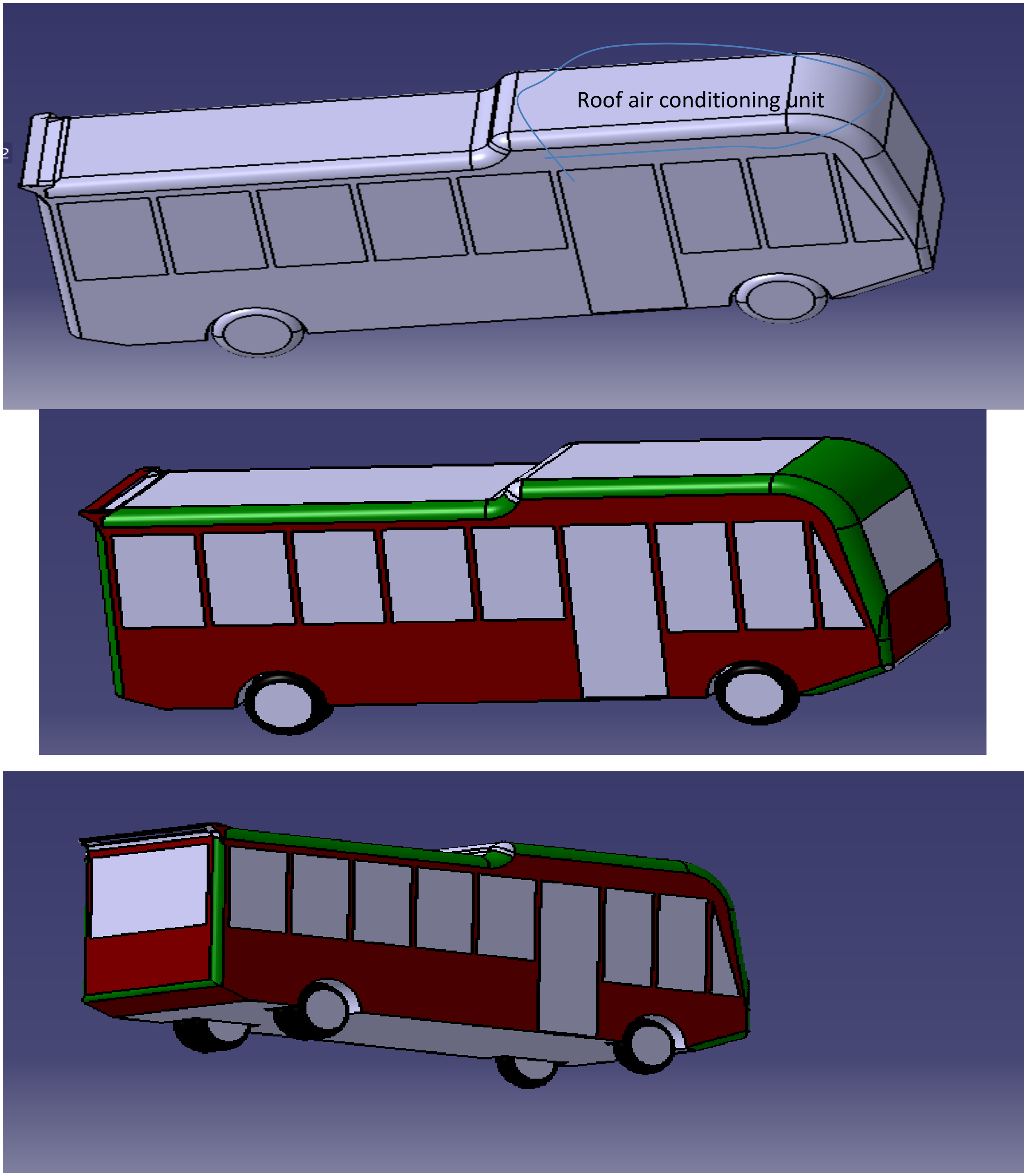


Figure 3.4: Isuzu passenger bus Model 3.

The major modifications in model3 are:at roof air condtioning unit,at the corner curves diamentions are changed,at rear top spoiler is added , at the front area is changed ,also at the top roof the load added place is changed compared to the existed model.

Computer aided design and analysis has great significance to study vehicles structure property and investigating the vehicle structure. The vehicle structure strength can easily be found using this CFD tool. Simulation is useful to study and examine the behaviour of a body under different operating scenarios without the need of physical test of the actual. Further, simulation results can be used to demonstrate and communicate the reliability of the vehicle to the authority approving the certification. This procedure will have an advantage both to the manufacturers to have confidence on what they do and the country at large that benefits from reliable locally built vehicles.

3.3 Modelling of bus structure

The modeling of the Isuzu passenger bus structure is made with data collected from Adama Ethiopia Endalk garage Isuzu passenger bus body builder. Before measuring the structure, drawing of the bus structure is made. This helps for easy placement of the measured length on the corresponding members on the drawing. During the data collection of the structure, all members of the structure are measured with length measuring tape. The modelling of the bus structure is made with CATIA V5R19 software. The bus structure is made with steel beams of rectangular hollow section, with different size. The sizes of rectangular hollow section used are 70x50x3 mm, 50x30x3 mm and 40x40x2.5mm. This model Isuzu passenger bus has a capacity of 29 passengers.

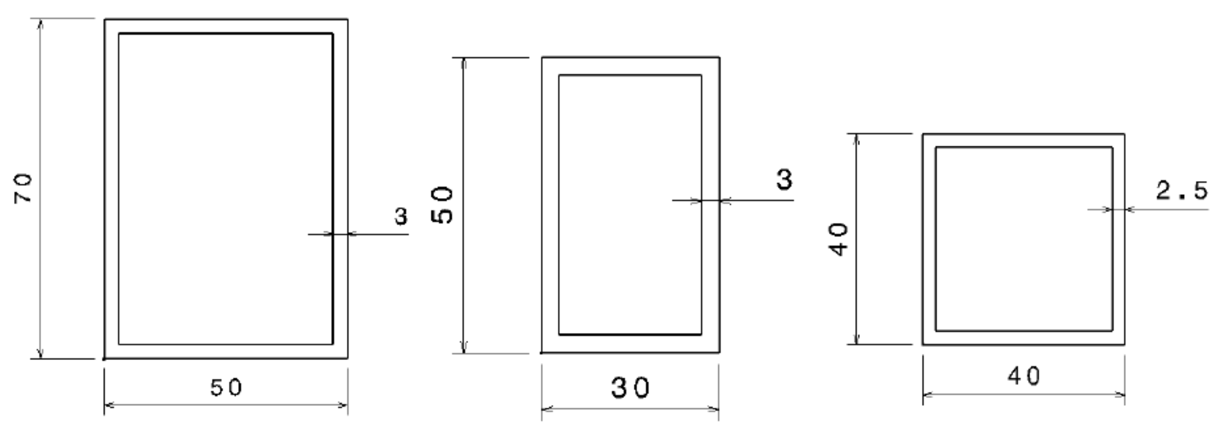


Figure 3.5 rectangular hollow section profiles employed (dimensions in mm)

(Rectangular Hollow Section) steel is used to build the Isuzu bus structure. The steel used in this analysis is standard of St 37.2 with material property given in table 3.2.

Material Property	Structural steel(st 37.2)
Tensile yield strength	360 MPa
Compressive yield strength	360 MPa
yield stress	220 MPa
Density	7850 kg/m3
Young’s modulus	200 GPa
Elongation in 50mm gauge $5.65\sqrt{a^x}$ length	25

Table 3.2 Material property of rectangular hollow section used [51].

Before going to the finite element analysis, the modeling of the Isuzu bus structure should be made.

The figure given below shows the model 3 of the Isuzu passenger bus made in CATIA V5R19 window. The structure parts are made with the real profile and dimension used in Endalk garage Adama Ethiopia. but its front and roof parts are modified

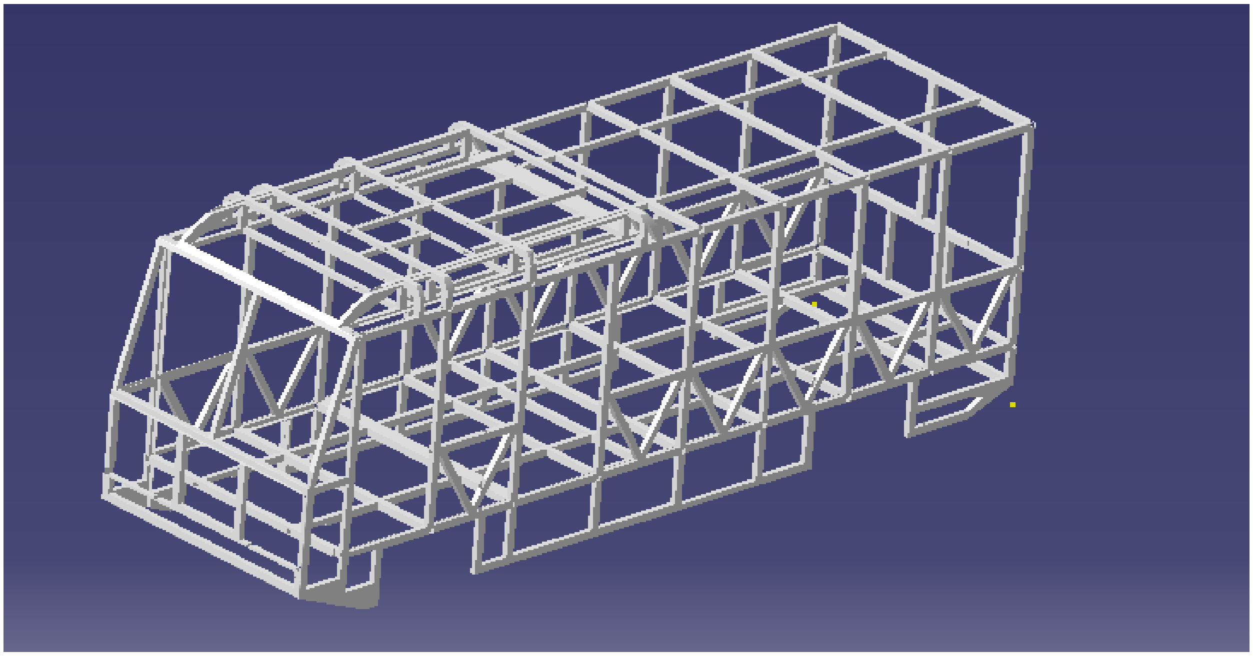


Figure 3.6: Model Structure modified Isuzu passenger bus

3.4 Procedure: for CFD phoenics VR simulation

Boundary Conditions

Arrange domain of the experiment

- ❖ Size of the domain region is X= 80m, Y= 16m, Z= 32m.
- ❖ By boundary conditions of the domain using inlet, outlet and ground plate
- ❖ Importing Isuzu bus model size at scale of 1:1 and the dimensions are W(X)= 2.33m, L(Y)= 7m, H(Z)=2.8m.
- ❖ Make boundary palates like inlet, outlet, and ground plate.
- ❖ Set initial condition wind velocity is V=115km/h,100Km/h,80km/h,60km/h
- ❖ Set the position of sensor in the domain at X= m , Y= m , Z= m as shown
- ❖ Calculate momentums of total force at Xpo ,Ypos,and Zpos
- ❖ Calculate drag coefficient from total forces at the reference density of 1.189kg/m^3, reference area in x, y and z is 6.44m^2.
- ❖ The current domain material treated at air at 20°c, 1atm
- ❖ For solution of pressure and velocity distribution
- ❖ Turbulence model is KECHEN standard
- ❖ Using question formulation ELLIPTIC STAGGERED
- ❖ Total number of iteration is 1000
- ❖ Global convergence criterion is 0.01
- ❖ Tolerance is 0.001

Probe Location

The probe location defines the location in the model domain which will be used to monitor the progress of the solver solution. It is represented visually in the domain as. The probe location dialog allows the user to locate the probe either using physical units within the domain or via cell location.

Settings –Isuzu bus or New Object

There are five options:

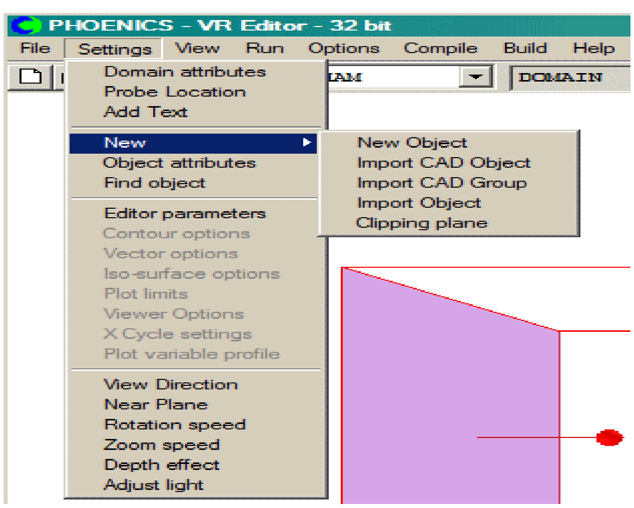


Figure 3.4.1 probe location

New Object: creates a new object and displays the object dialog for the newly-created object. It is equivalent to clicking on 'Object – New – New Object' on the Object Management Dialog reached from the button on the hand-set or the O icon on the toolbar.

Import CAD Object: creates a new object and opens the CAD Import dialog for it.

Settings - Object Attributes

This brings up the object dialog box for the currently-selected object. It is equivalent to double-clicking on an object. If no object is already selected, the Object Management Dialog showing a list of all objects will be displayed.

Settings - Find Object

This brings up the Object Management Dialog. The selected object (if any) becomes the current object, and is high-lighted in the list of objects.

Settings - Editor Parameters

The VR Editor Parameters menu sets the Increment size, and Scale factors.

Settings - View Direction

This option leads to the Reset View Parameters dialog which is described in the section **Reset View Parameters** below.

Settings - Near Plane

Parts of the image closer than the **near plane** are not visible. The default setting ensures that the entire image is visible. The near plane can be moved interactively by sliding the slider on the dialog box. The dialog can remain open without interrupting other activities. **Reset** restores the default value.

Run - Pre processor

The Preprocessor sub-menu contains the following items

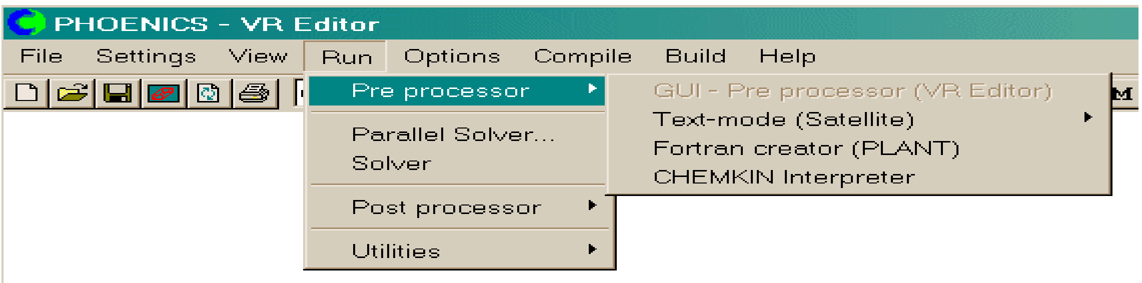


Figure 3.4.2 Run - Pre processor

Run - Solver

This will run the PHOENICS Earth solver on the local computer, using the EARDAT file in the current directory. VR-Editor will write out a new Q1 and EARDAT before starting the Earth run.

Run - Post processor

The Post processor sub-menu contains the following items:

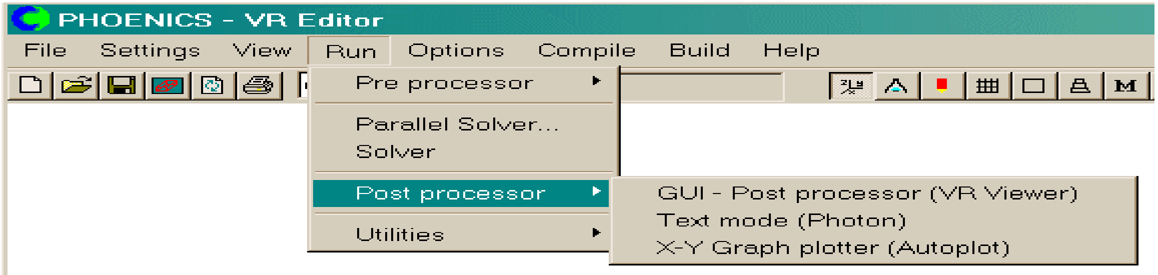


Figure 3.4.3 Run - Post processor

Object 'General' Page

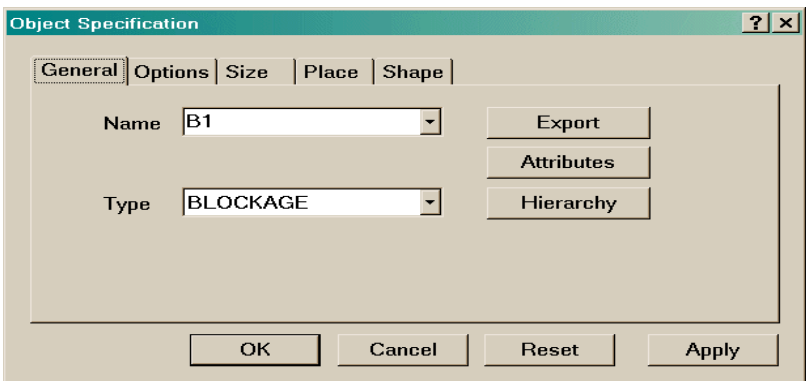


Figure 3.4.4 Object 'General' Page

Object 'Place' Page

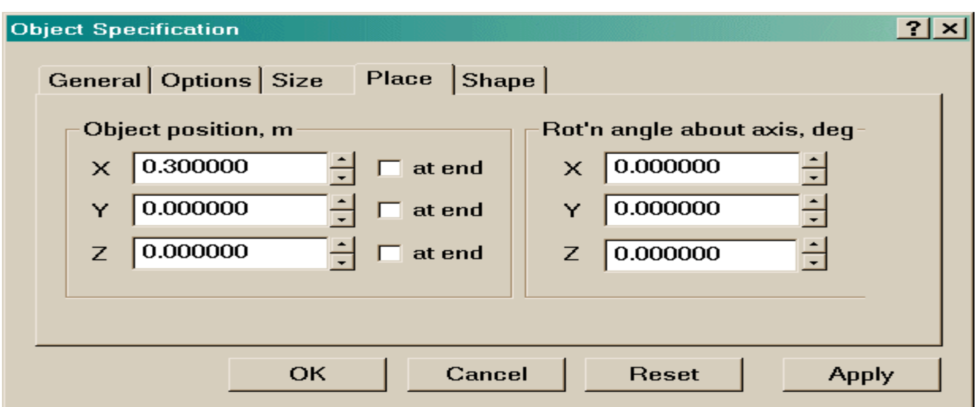


Figure 3.4.5 Object 'Place' Page

Object 'Shape' Page

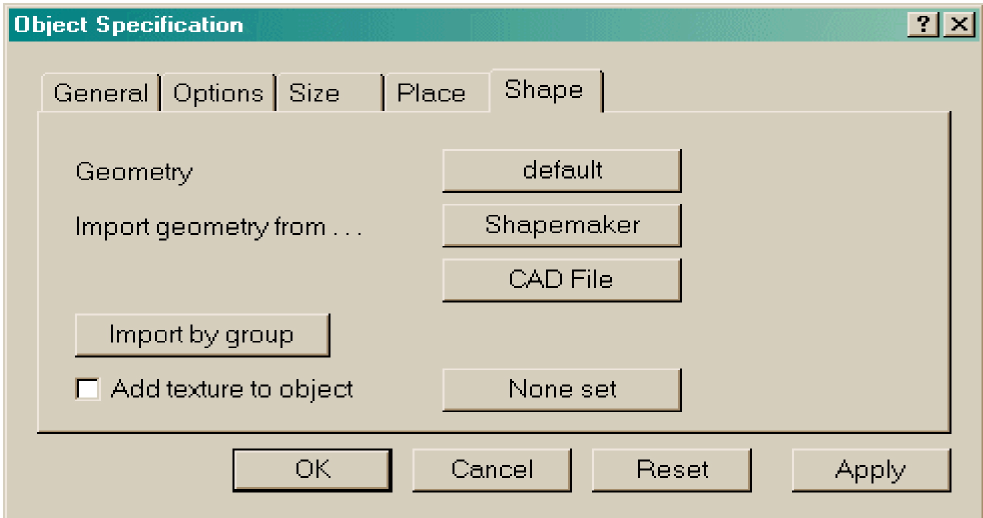


Figure 3.4.6 Object 'Shape' Page

Within the bounding box of an object, the true shape is determined by the geometry file associated with that object. The shape is defined by quadrilateral facets, which are defined in the geometry file. A large selection of geometry files is supplied as a standard part of the installation. A description of the data file format is given in **'Creating the geometry of a Virtual-Reality object'**. All the geometry files have a .dat extension.

The default object shape is a rectangular block, which completely fills the object bounding box. Other shapes can be imported from the **Geometry** dialog box, imported from CAD or made in Shapemaker[59].

The allowable object Types are shown in the pull down list:

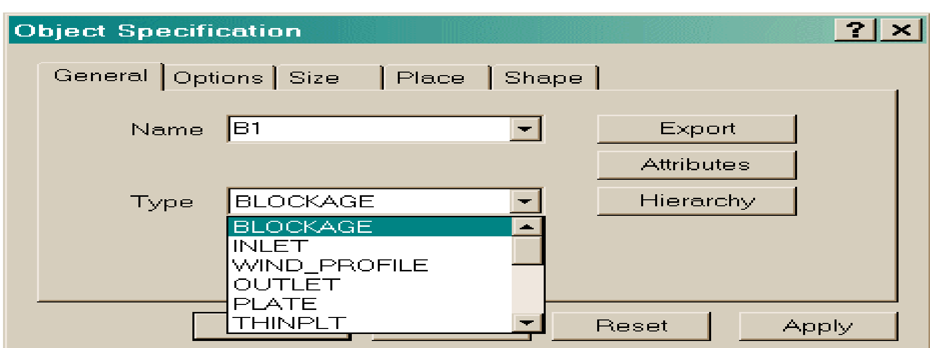


Figure 3.4.7 object specification

Object Type	Brief Description
BLOCKAGE	3D, solid or fluid. Can apply heat and momentum sources.
INLET	2D, fixed mass source.
ANGLED-IN	3D, fixed mass source.
WIND	3D, whole domain, applies wind profiles at domain boundaries
WIND_PROFILE	2D, fixed mass source following atmospheric boundary layer.
OUTLET	2D, fixed pressure.
ANGLED-OUT	3D, fixed pressure.
PLATE	2D, zero thickness obstacle to flow. May be porous.
THINPLT	2D, nominal thickness for heat transfer.
FAN	2D, fixed velocity
POINT-HISTORY	single cell transient monitor point.
FINE_GRID_VOL	3D region of fine grid.
USER_DEFINED	2D or 3D, for setting user-defined sources (PATCH/COVAL).
NULL	2D or 3D. Used to cut the grid for mesh control.
PRESSURE_RELIEF	single cell fixed pressure point.
DRAG_LIFT	3D, region over which momentum imbalance (force) will be calculated.

The full list for PHOENICS 'Core' is:

Blockage Slide Velocity
This option only appears for solid blockages, but not for blockages made from a fluid. By default the surfaces of the blockage are stationary. It is possible to set a non-zero surface velocity. The options for Cartesian grids are:

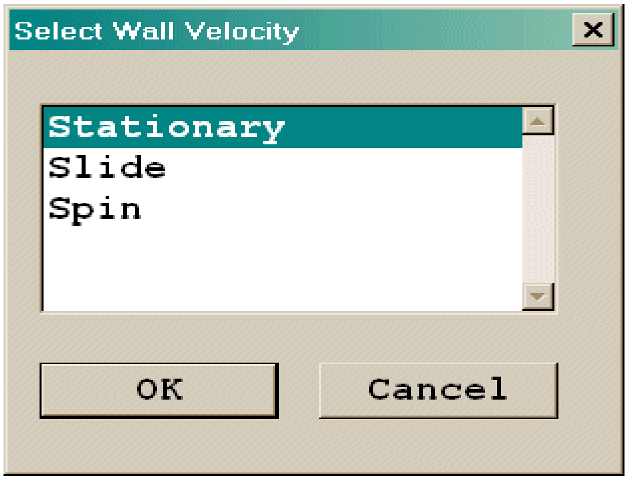


Figure 3.4.7 selection wall velocity

Stationary - the surfaces do not move.

Slide - the components of the surface velocity vector can be set.

Spin - the object is treated as if it were spinning about the X, Y or Z axis. The coordinates of the rotation axis are taken to be the same as the object rotation centre. Positive rotation speeds produce clockwise rotations when viewed along the rotation axis toward the origin. For polar grids, the options are[59].

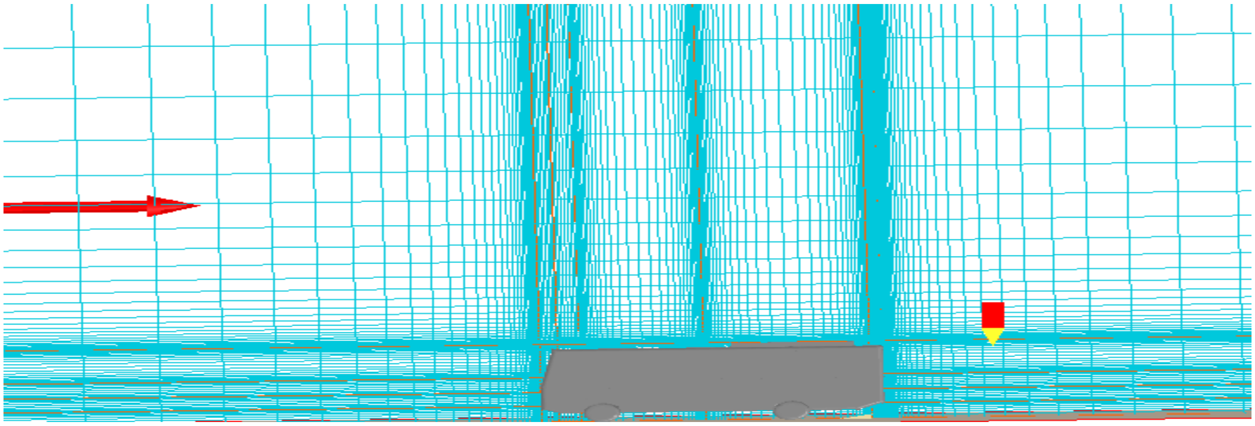


Figure: 3.4.8 grid generation model 1

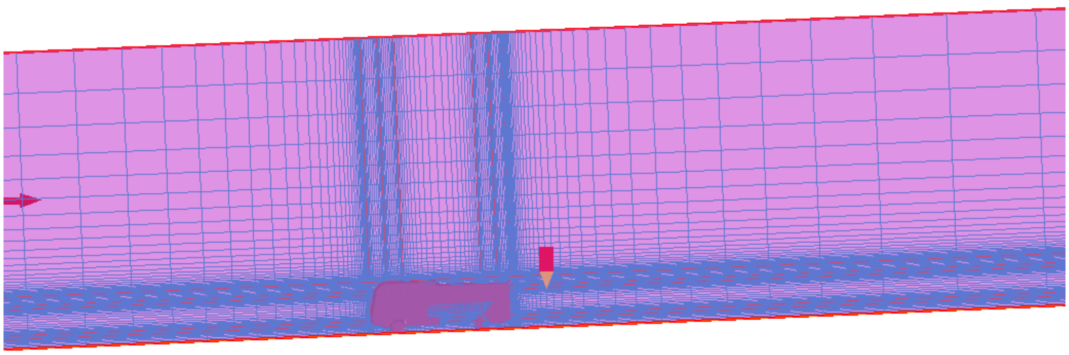


Figure: 3.4.8.1 grid generation model 2

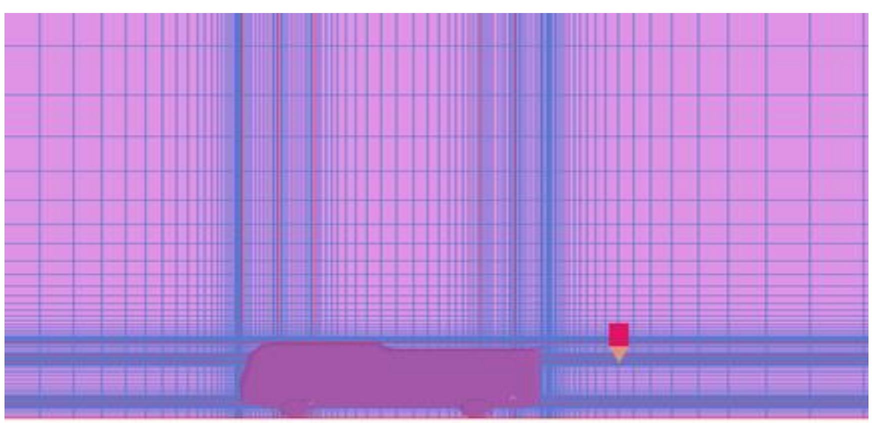


Figure: 3.4.8.2 grid generation model 3

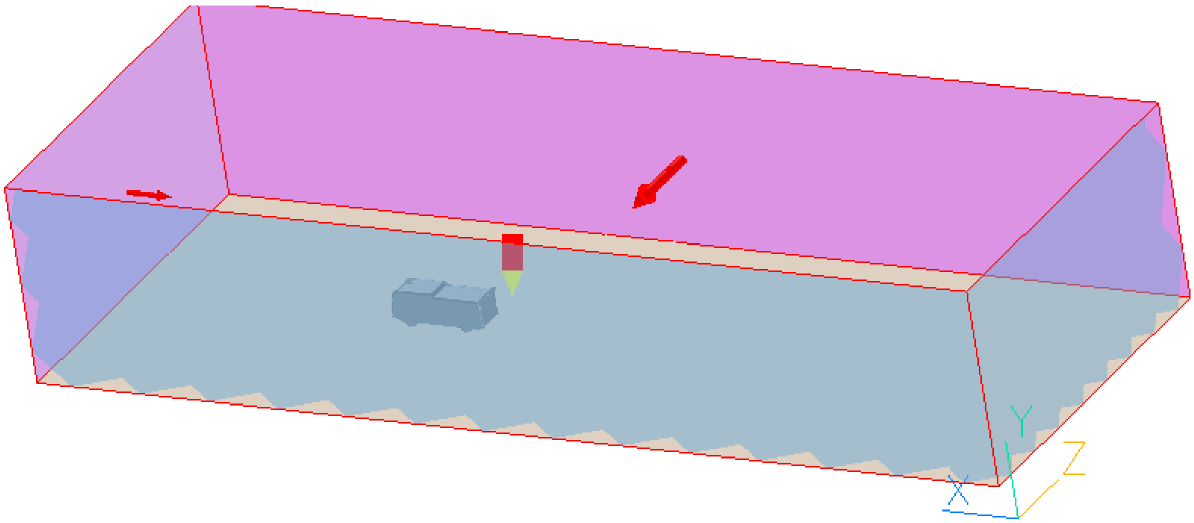


Figure: 3.3.1 domain size model3

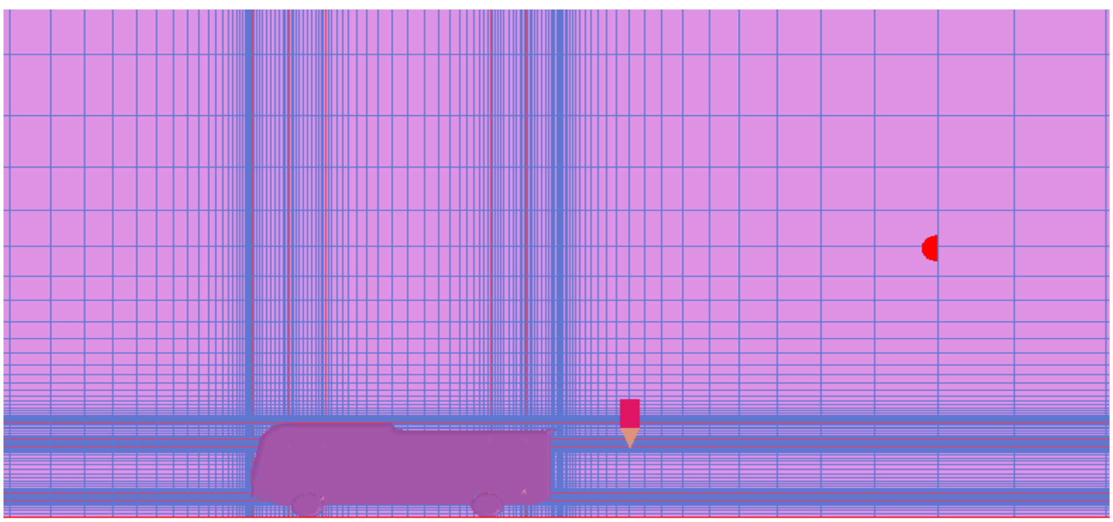


Figure: 3.3.12: grid generation model 3

3.5 Methodology for driving stability

Calculation of rotational moment at each axis

1. **X-axis moment (Rolling)**

$$MX = F_Y \text{ x } d_z - F_z \text{ x } d_y$$

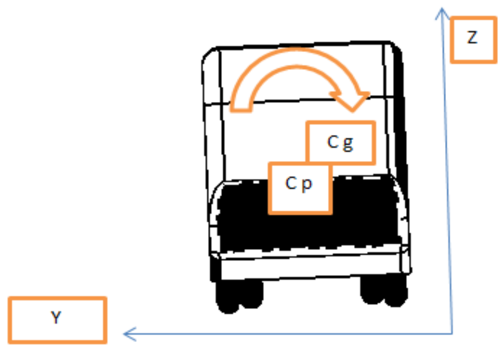


Fig.3.4 Front view of ISUZU passenger model Bus.

2. **Y-axis moment (Pitching)**

$$MY = F_Y \text{ x } dx - F_X \text{ x } d_z$$

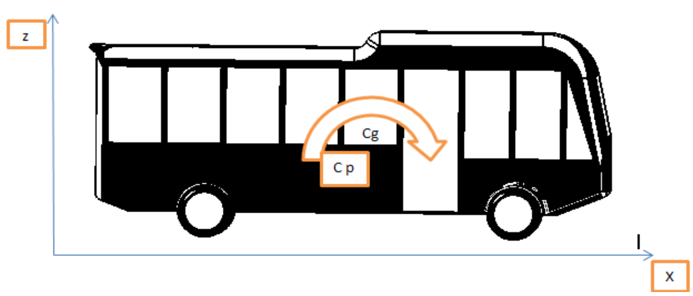


Fig.3.4.1 side view of Isuzu Bus Model to show pitching moment

3. **Z-axis moment (Yawing)**

$$Mz = F_X \text{ x } d_y - F_Y \text{ x } d_x$$

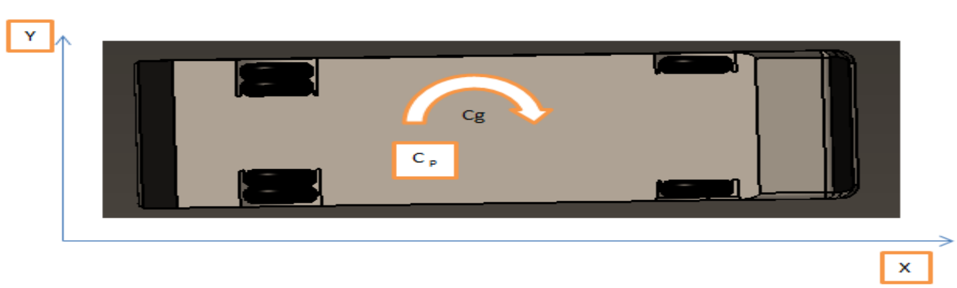


Fig3.4.2 Top view of Isuzu Bus model

4. **Yawing Resistance moment(M_{yr})**

$$\mathbf{M_{yr} = F_1 \times L_1 + F_2 \times L_1 + F_3 \times L_2 + F_4 \times L_2}$$

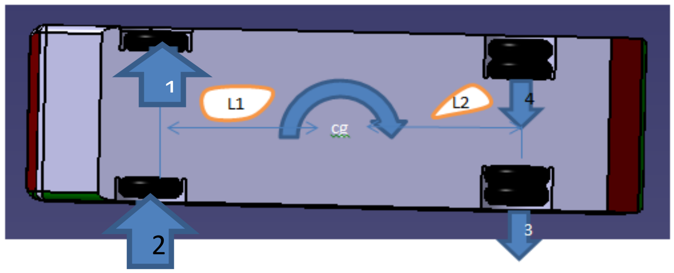


Fig3.6. bottom view of Isuzu Bus model Yawing resistance moment shown.

5. Rolling Resistance momentum (Mrr)

M_{rr1} = W x c and M_{rr2} = W x b

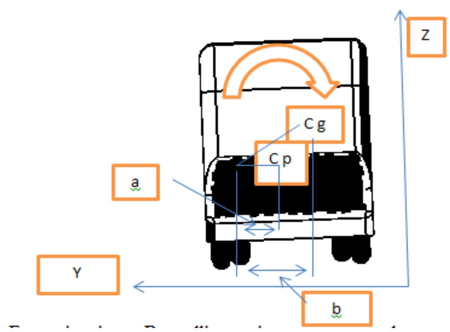


Fig: 3.7 Front view Isuzu Bus rolling resistance moment shown.

5. **Pitching Resistance moment (Mpr)**

Mpr = W x a and M_{Pr} = W x b

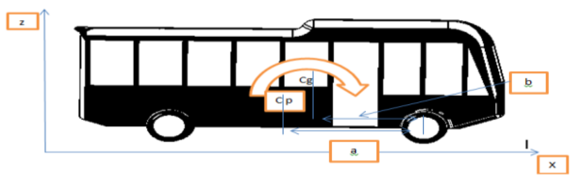


Fig.3.8 side view of Isuzu Bus Model to show pitching moment

3.6 Structural strength

FEA has become a solution to the task of predicting failure due to unknown stresses by showing problem areas in a material and allowing designers to see all of the theoretical stresses within. This method of product design and testing is far superior to the manufacturing costs which would accrue if each sample was actually built and tested. In practice, a finite element analysis usually consists of three principal steps:

a) Pre-processing: The user constructs a model of the part to be analyzed in which the geometry is divided into a number of discrete sub regions, or elements," connected at discrete points called nodes." Certain of these nodes will have fixed displacements, and others will have prescribed loads. These models can be extremely time consuming to prepare, and commercial codes vie with one another to have the most user-friendly graphical “pre-processor" to assist in this rather tedious chore. Some of these pre-processors can overlay a mesh on a pre-existing CAD file, so that finite element analysis can be done conveniently as part of the computerized drafting-and-design process.

b) Analysis: The dataset prepared by the preprocessor is used as input to the finite element code itself, which constructs and solves a system of linear or nonlinear algebraic equations $K_{ij}U_j = f_i$ Where u and f are the displacements and externally applied forces at the nodal points. The formation of the K matrix is dependent on the type of problem being attacked, and this module will outline the approach for truss and linear elastic stress analyses. Commercial codes may have very large element libraries, with elements appropriate to a wide range of problem types. One of FEA's principal advantages is that many problem types can be addressed with the same code, merely by specifying the appropriate element types from the library.

c) Post processing: In the earlier days of finite element analysis, the user would pore through reams of numbers generated by the code, listing displacements and stresses at discrete positions within the model. It is easy to miss important trends and hot spots this way, and modern codes use graphical displays to assist in visualizing the results. A typical postprocessor display overlays colored contours representing stress levels on the model, showing a full field picture similar to that of photo elastic or moiré experimental results. Solving any problem analytically, you need to define (1) your solution domain, (2) the physical model, (3) boundary conditions and (4) the physical properties. You then solve the problem and present the results. In numerical methods, the main difference is an extra step called mesh generation. This is the step that divides the complex model into small elements that become solvable in an otherwise too complex situation. Below describes the processes in terminology slightly more attune to the software.

Finite element modelling

Finite element modelling is made with ANSYS 15 Workbench. The structure model made by CATIA V5R19 software is imported to ANSYS 15 workbench. In order to import the CATIA made model to ANSYS 15 window, both software run at the same time. The model in CATIA is opened. Then with the import option found in ANSYS workbench, the modelling is imported. Figure shows the model of the bus structure in ANSYS workbench window

3.7 Build Geometry

Construct a three dimensional representation of the Isuzu passenger body structure to be modeled and tested using the work plane coordinate system within ANSYS.

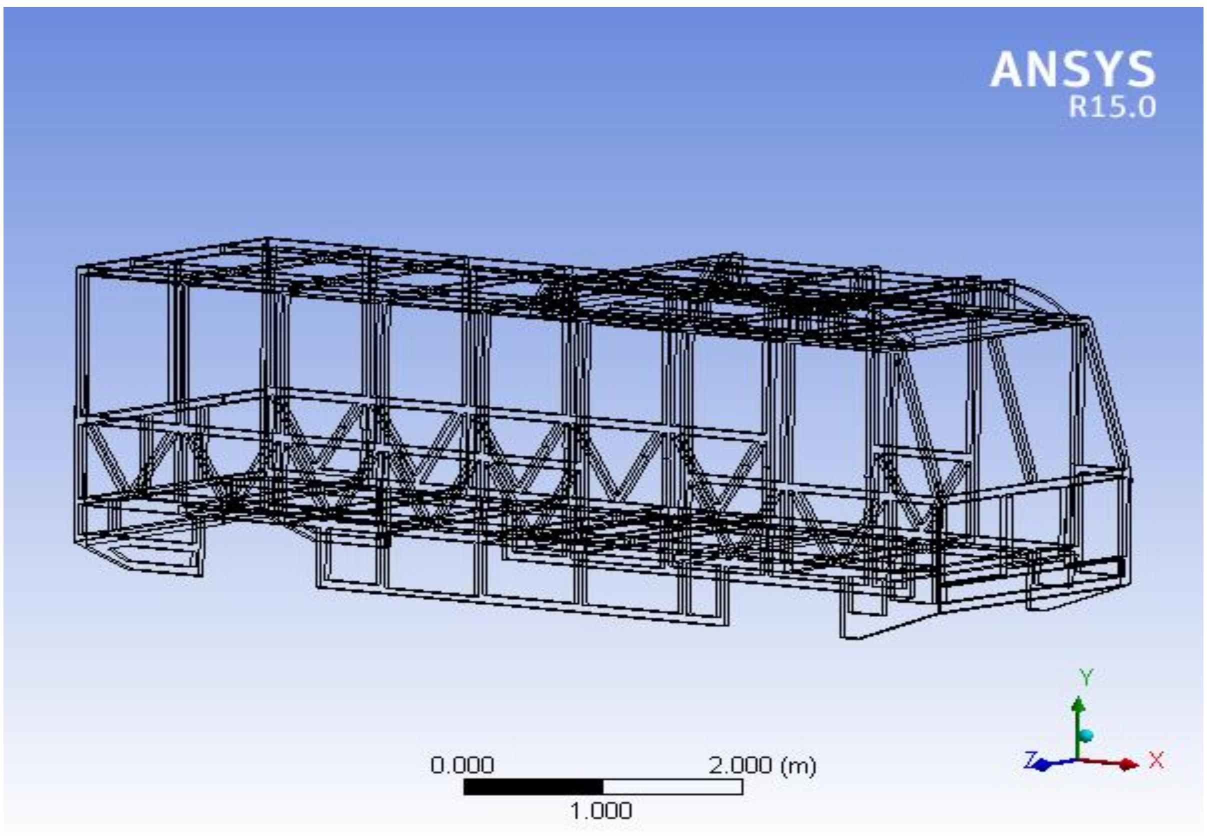


Figure 3.9: Frame structure for Modified Isuzu passenger bus ansys window

Finite element meshing of the bus

Finite element meshing is made with ANSYS 15 workbench. Meshing is an integral part of the computer-aided engineering (CAE) simulation process. The mesh influences the accuracy, convergence and speed of the solution. Furthermore, the time it takes to create a mesh model is often a significant portion of the time it takes to get results from a CAE solution. Tetrahedral mesh elements are used in meshing of the bus structure

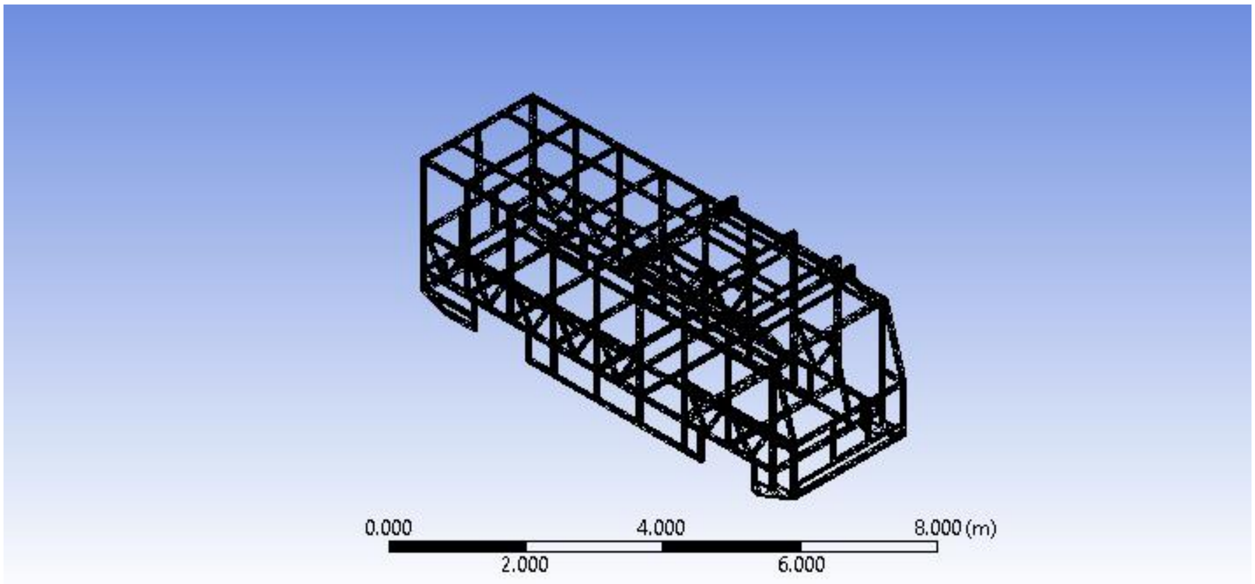


Figure3.10. Generate Mesh

3.8 Inputs for Finite Element Analysis

The inputs for the finite element analysis are all the loads carried by the bus. These loads Carried by the bus during operation are self-weight of bus=17tone, passenger weight=65kg assumption times the number of passengers, fuel weight is 200kg. There are different loading cases that act on the bus structure such as aerodynamic load 15,852.6N. But the two main loading cases are bending load due to the weight and torsional stiffness due to the relative vertical movement of the wheels.

4. RESULTS AND DISCUSSION

4.1 Pressure and velocity distribution

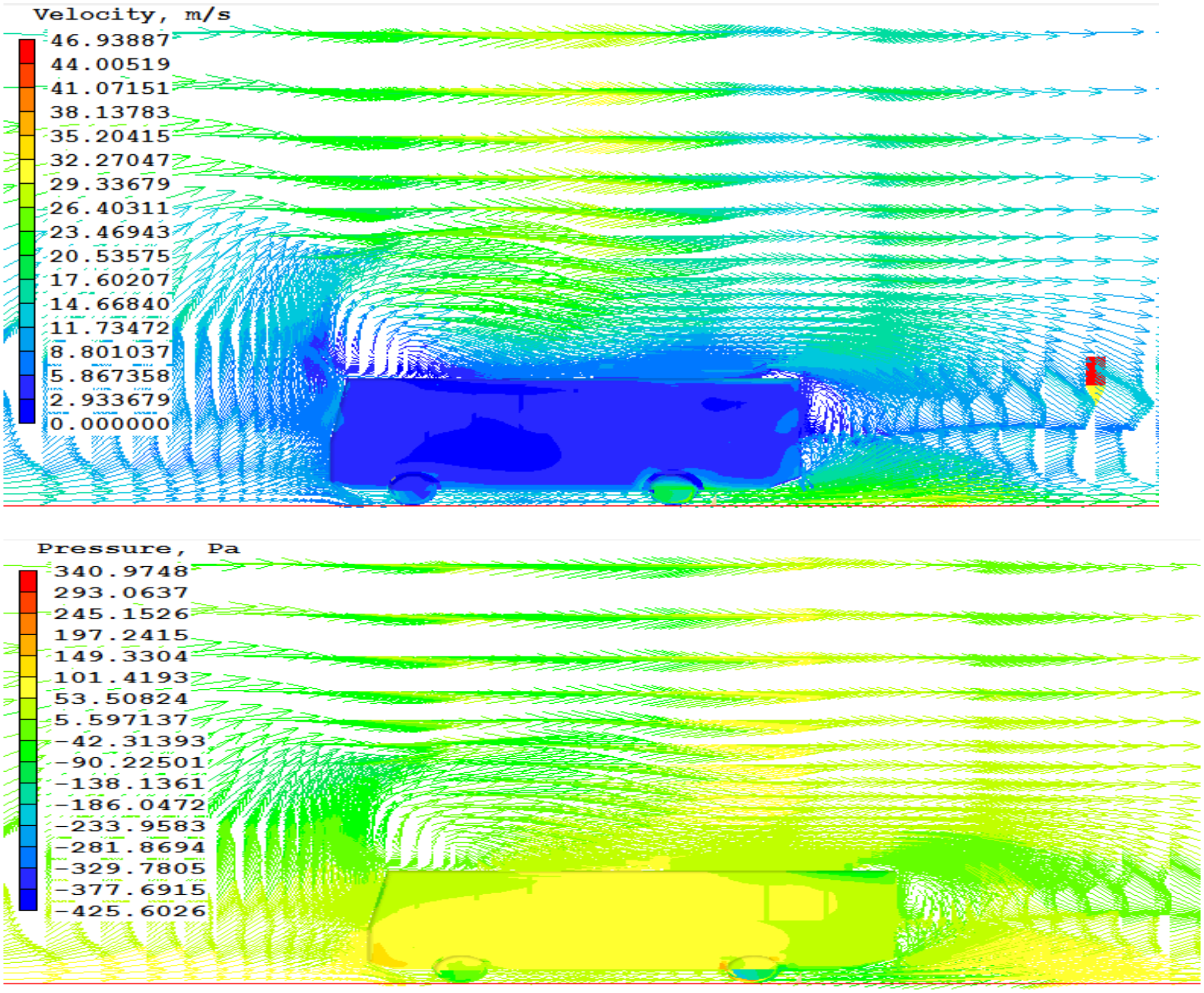


Figure 4.1: model 1 velocity and pressure distribution, velocity 60kM/h

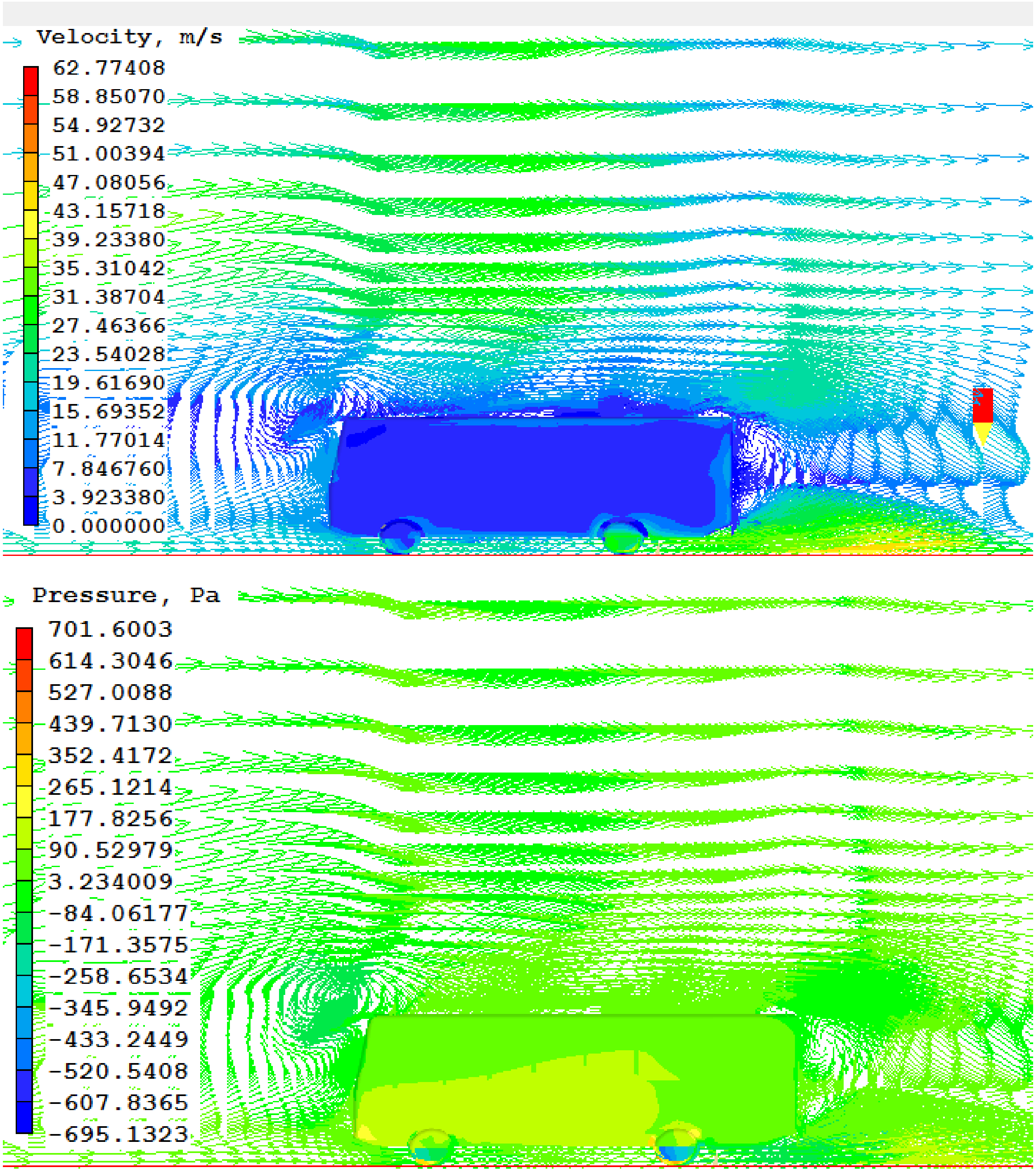


Figure 4.2: model 1 velocity and pressure distribution when velocity 80KM/h

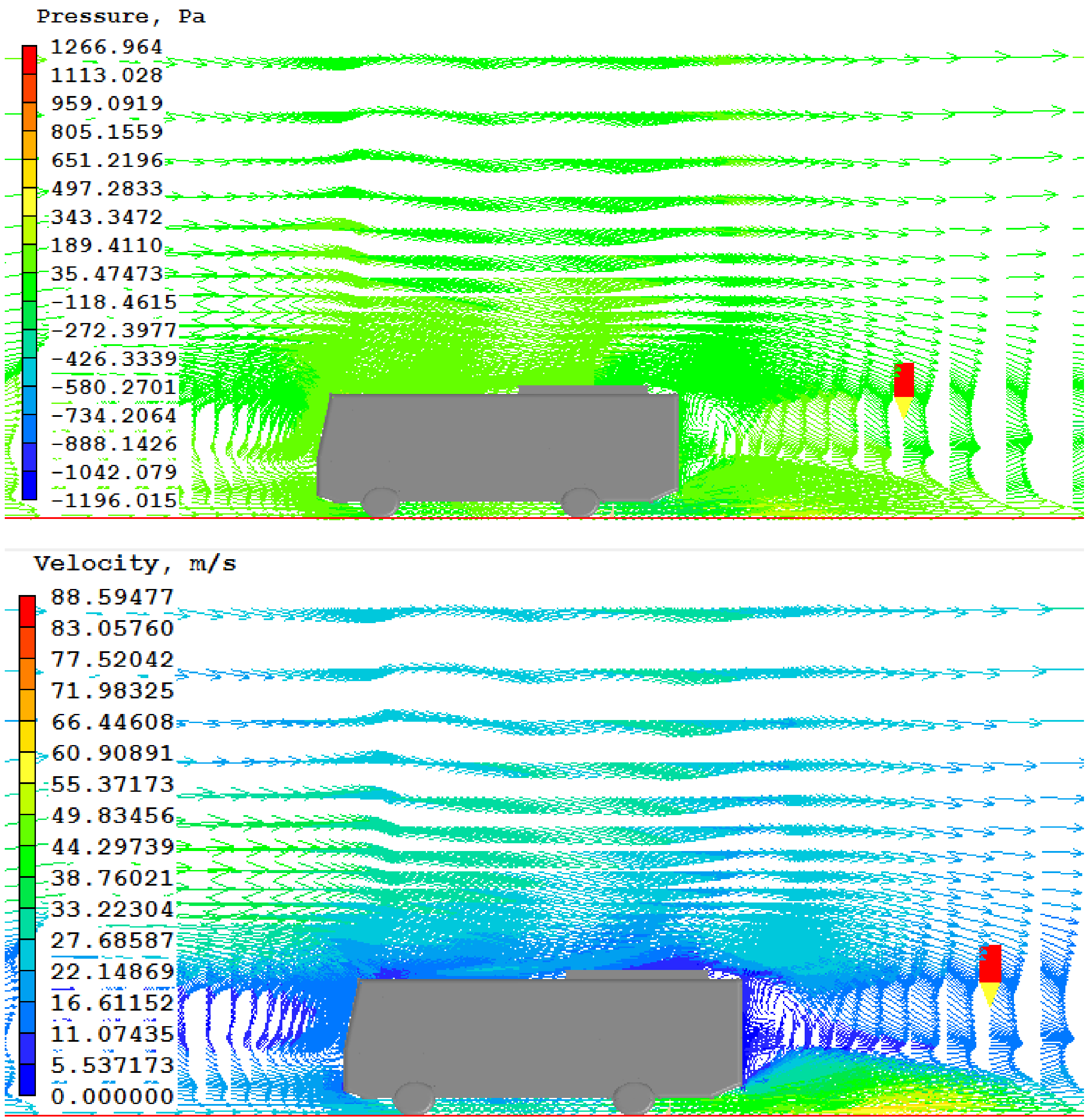


Figure4.3: model 1 velocity and pressure distribution when velocity 100kM/h

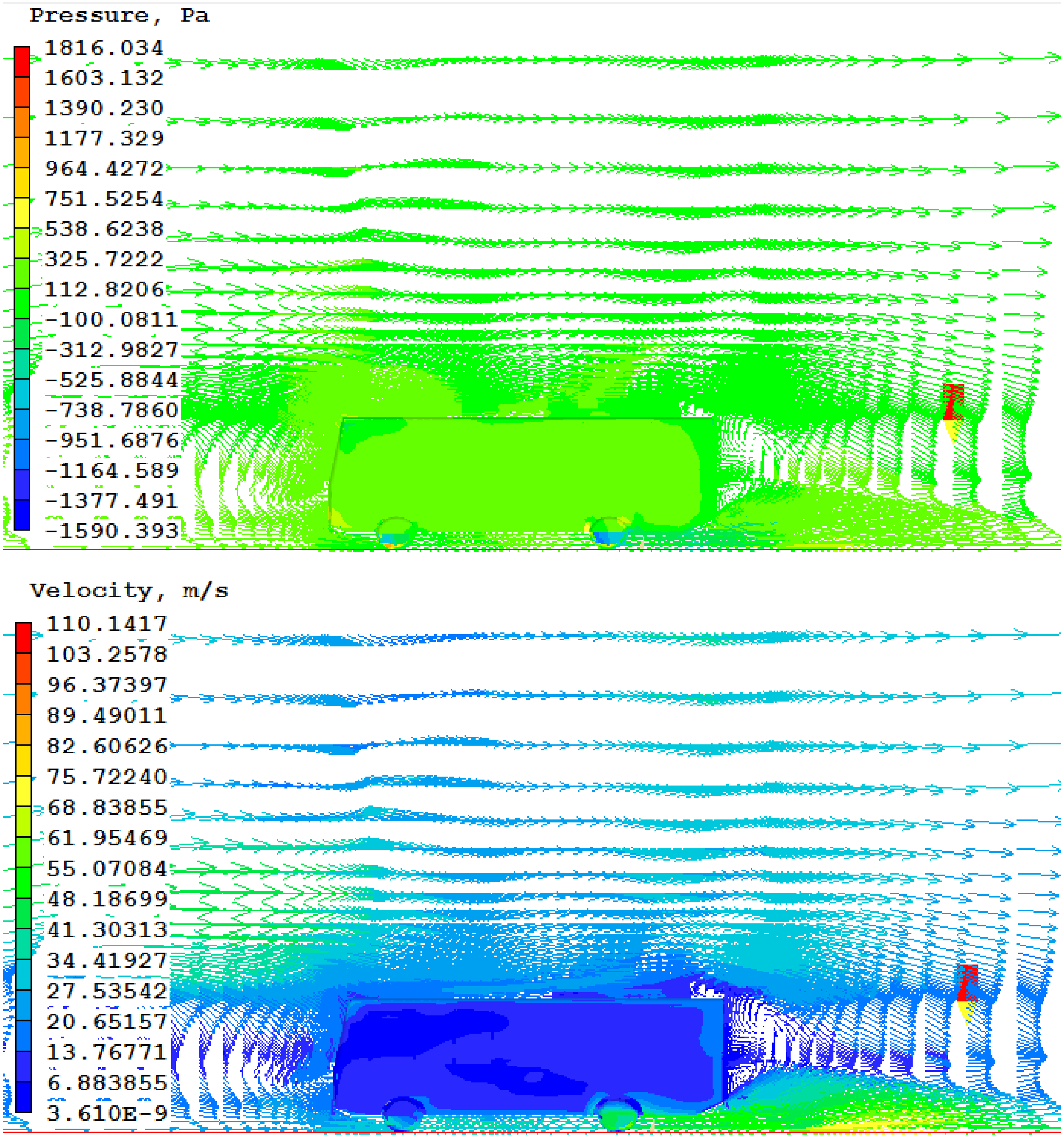


Figure4.4: model 1 velocity and pressure distribution when velocity 115 kM/h

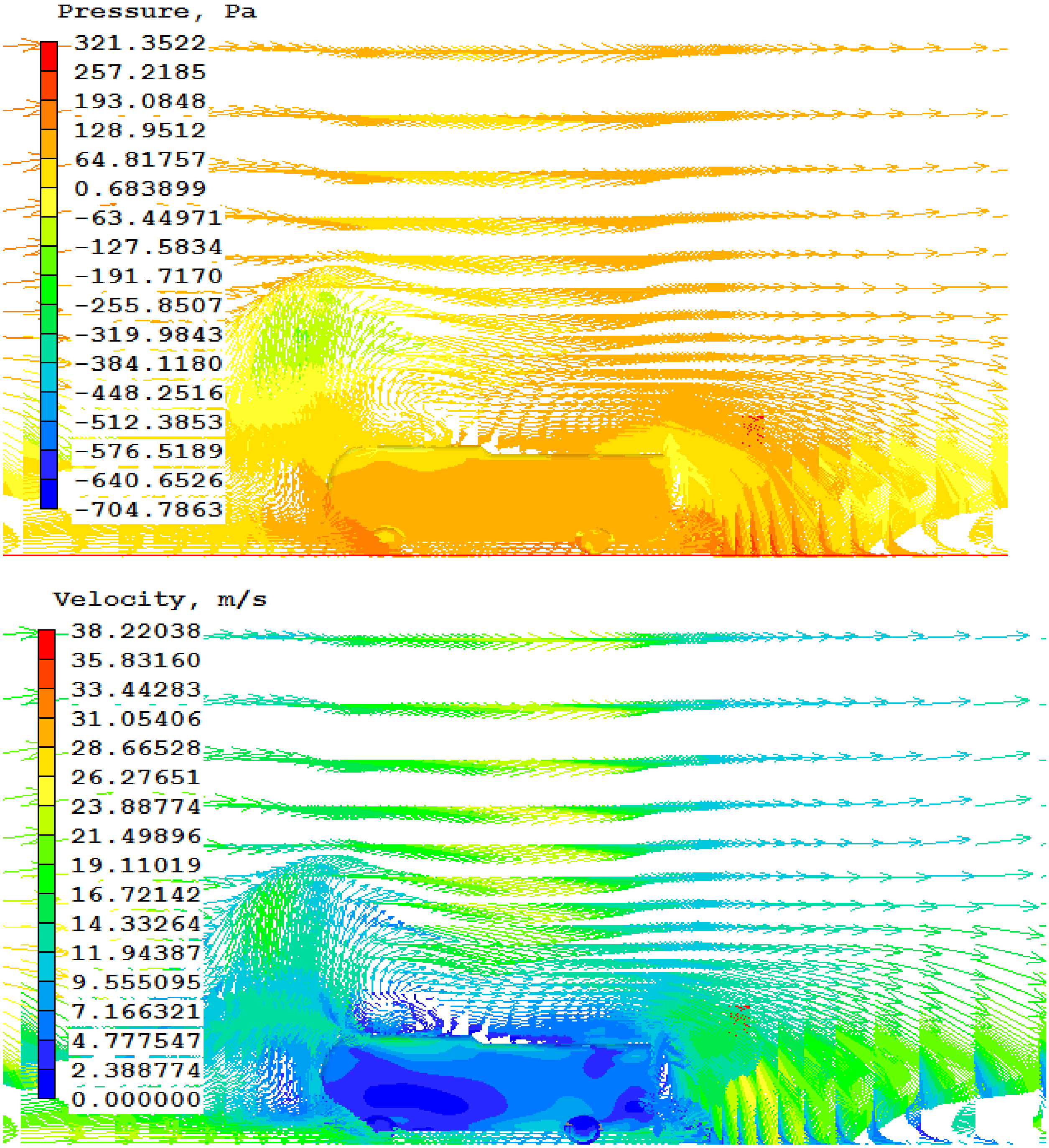


Figure4.5: model 2 velocity and pressure distribution when velocity 60kM/h

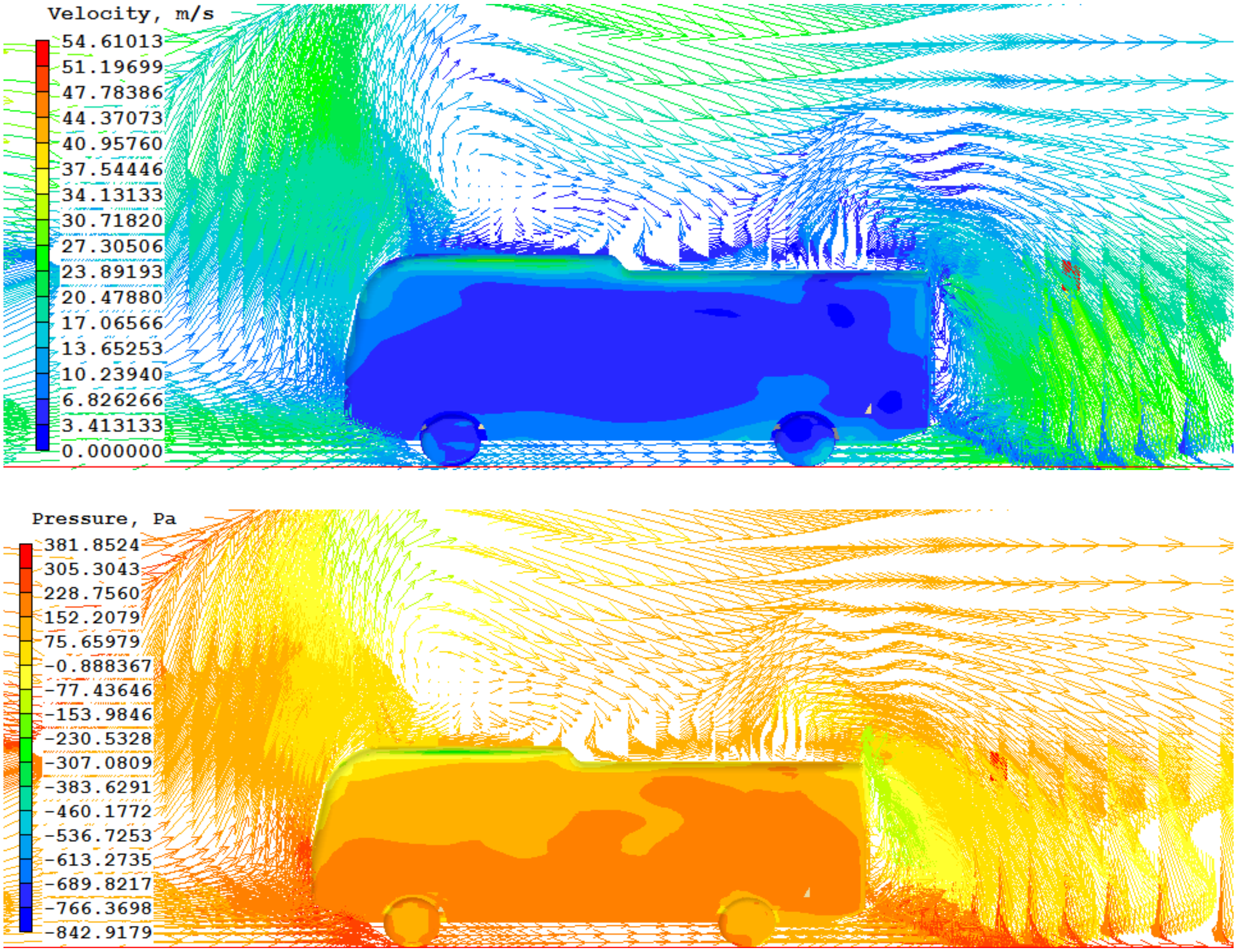


Figure4.6: model 2 velocity and pressure distribution when velocity 80kM/h

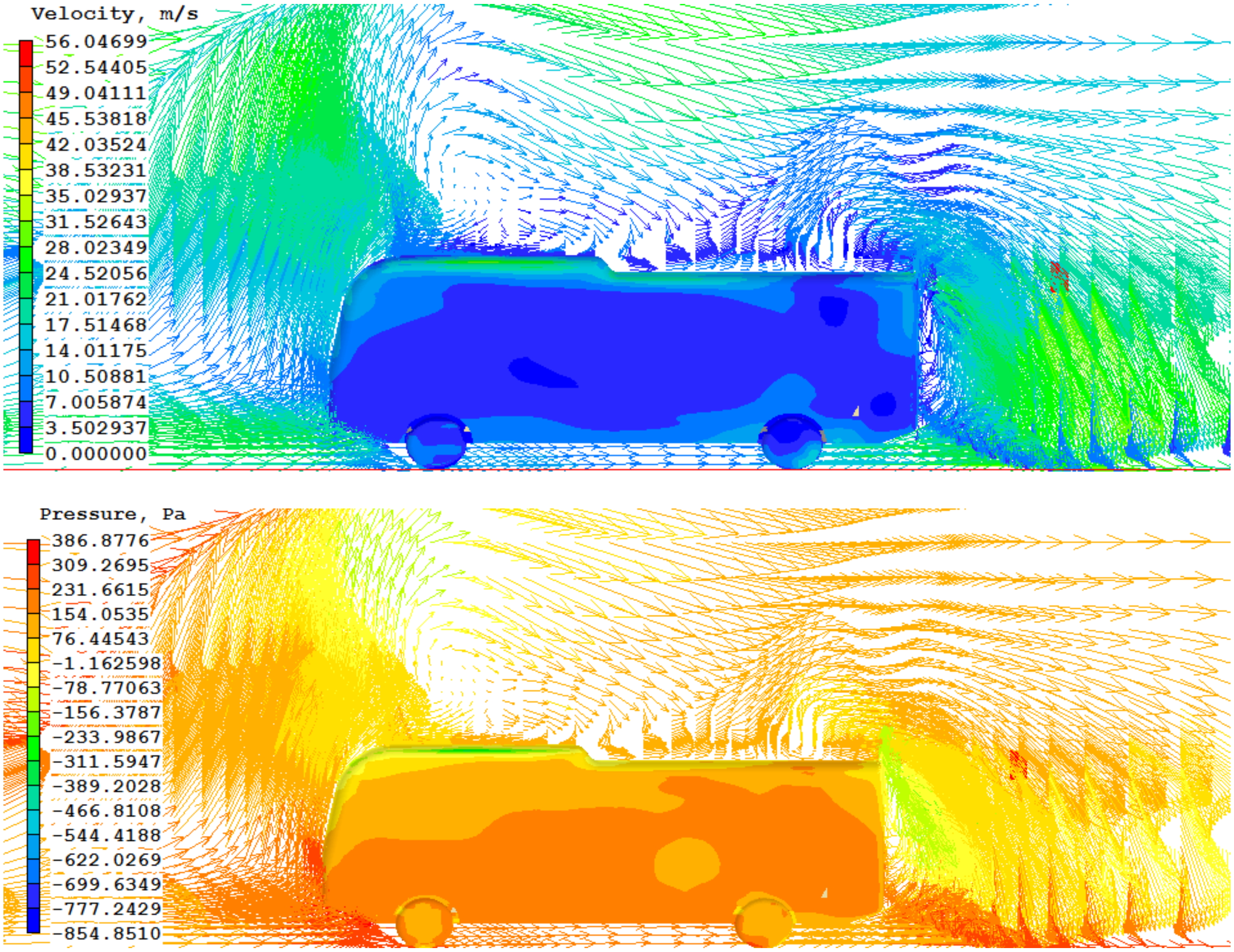


Figure4.7: model 2 velocity and pressure distribution when velocity 100km/h

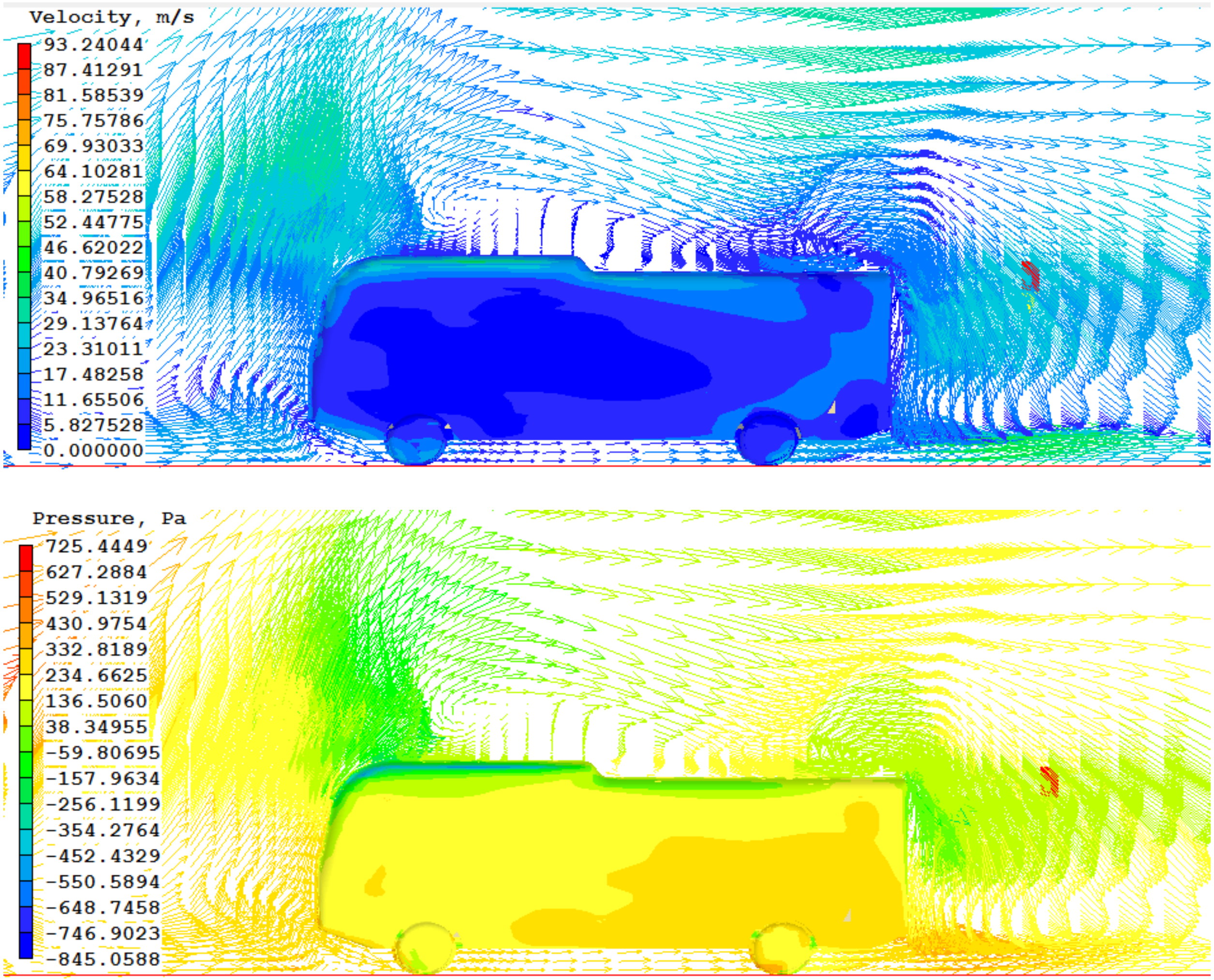


Figure4.8: model 2 velocity and pressure distribution when velocity 115km/h

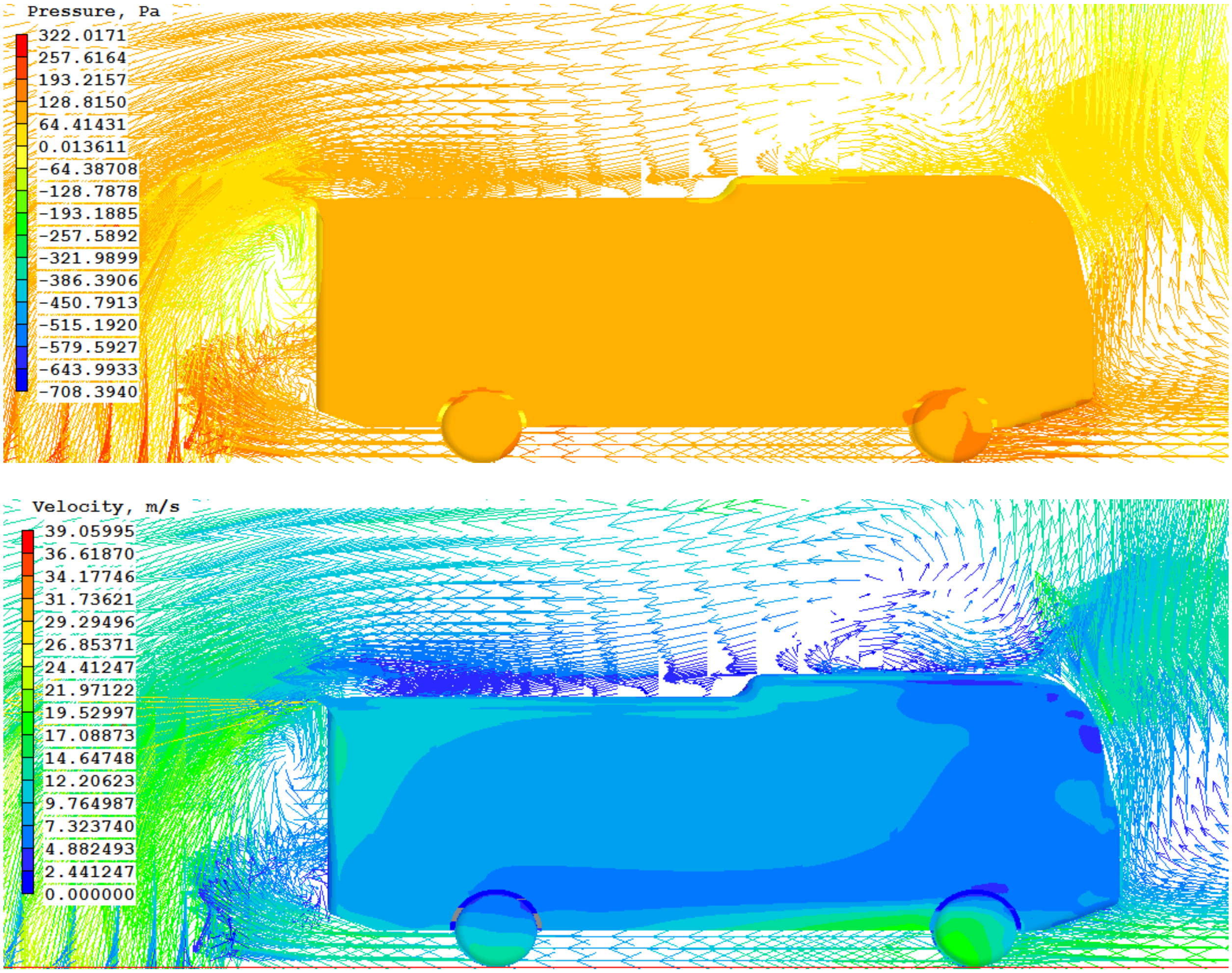
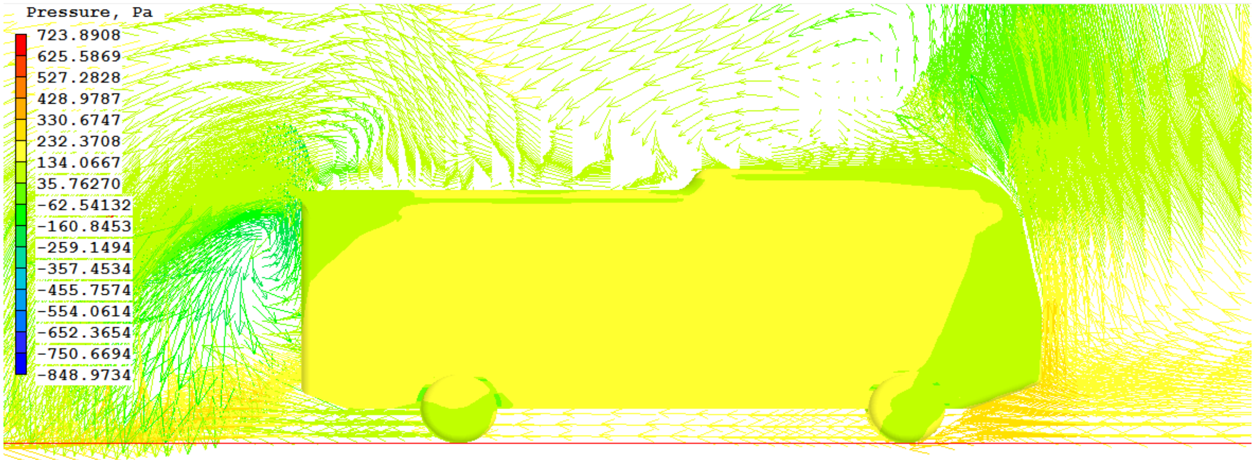


Figure4.9: model 3 velocity and pressure distribution when velocity 60km/h



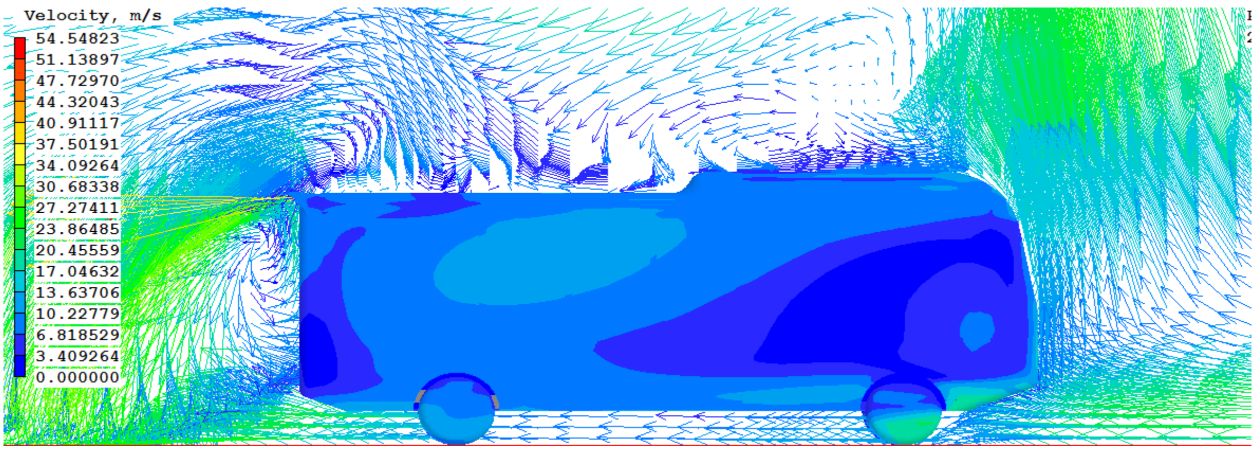


Figure4.9.1: model 3 velocity and pressure distribution when velocity 80km/h

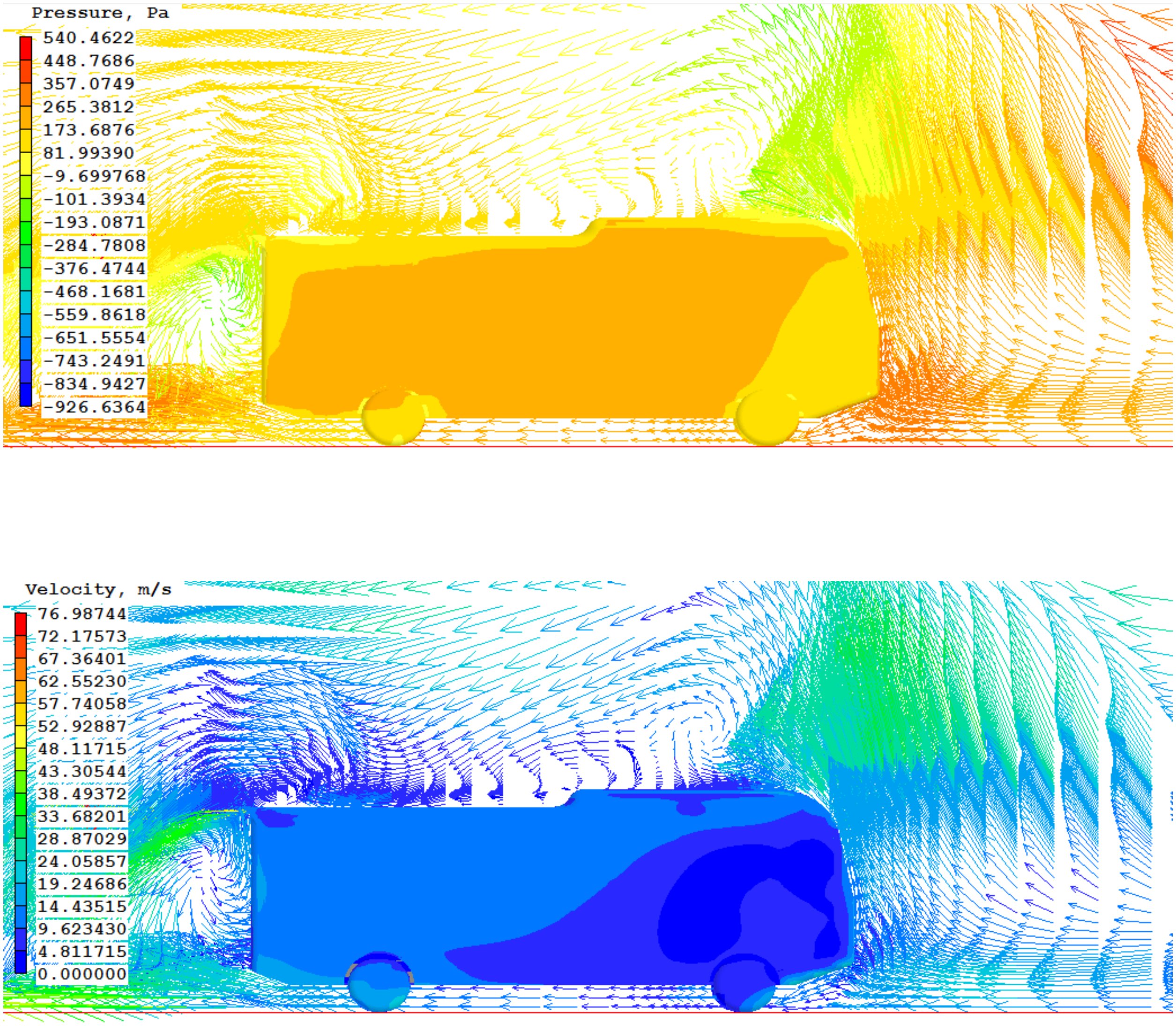
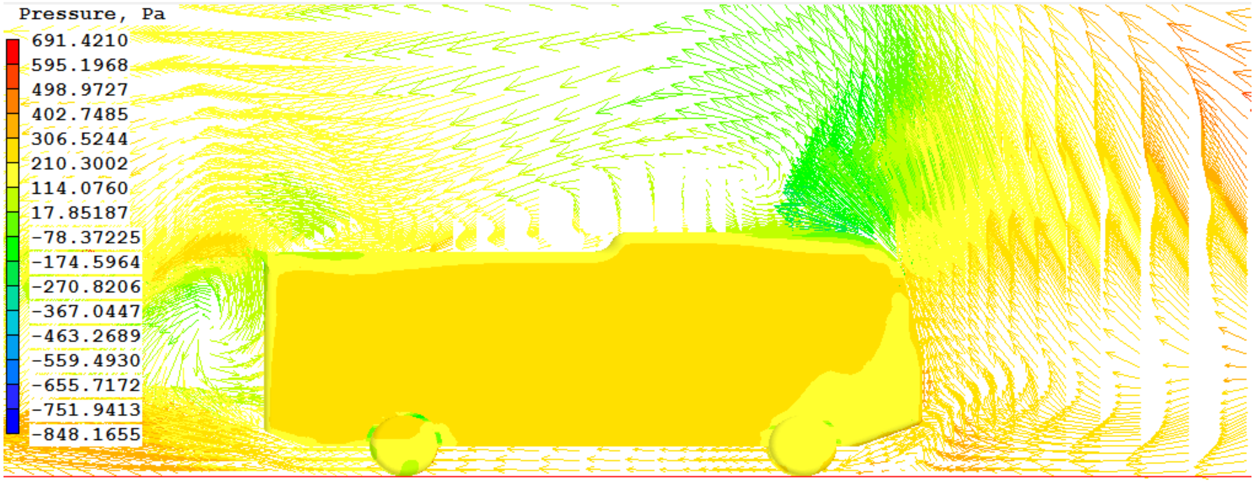


Figure4.9.2: model 3 velocity and pressure distribution when velocity 100km/h



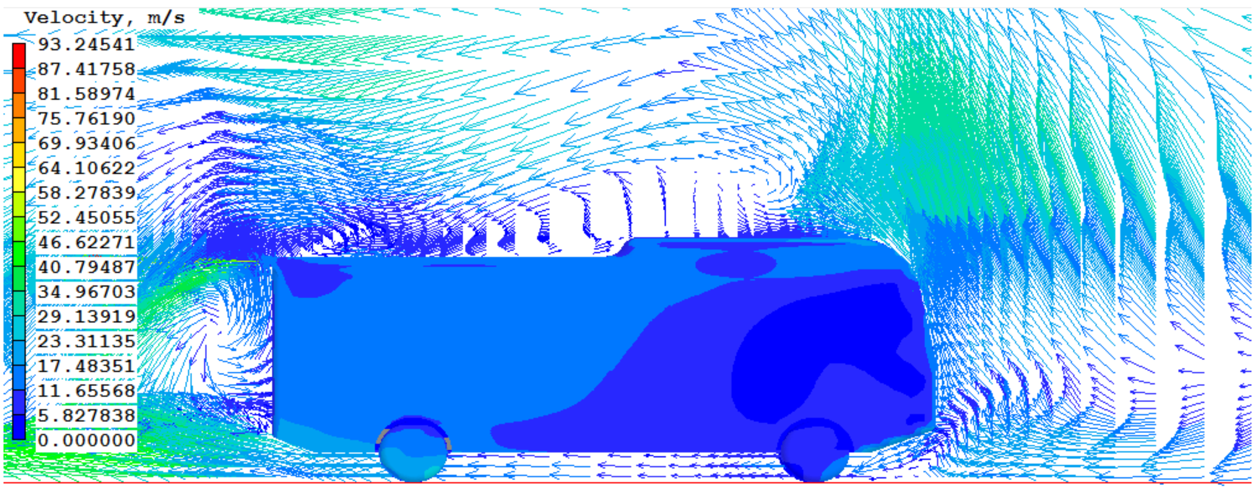


Figure4.9.3: model 3 velocity and pressure distribution when velocity 115 km/h

4.2 Stability at side wind 12m/s

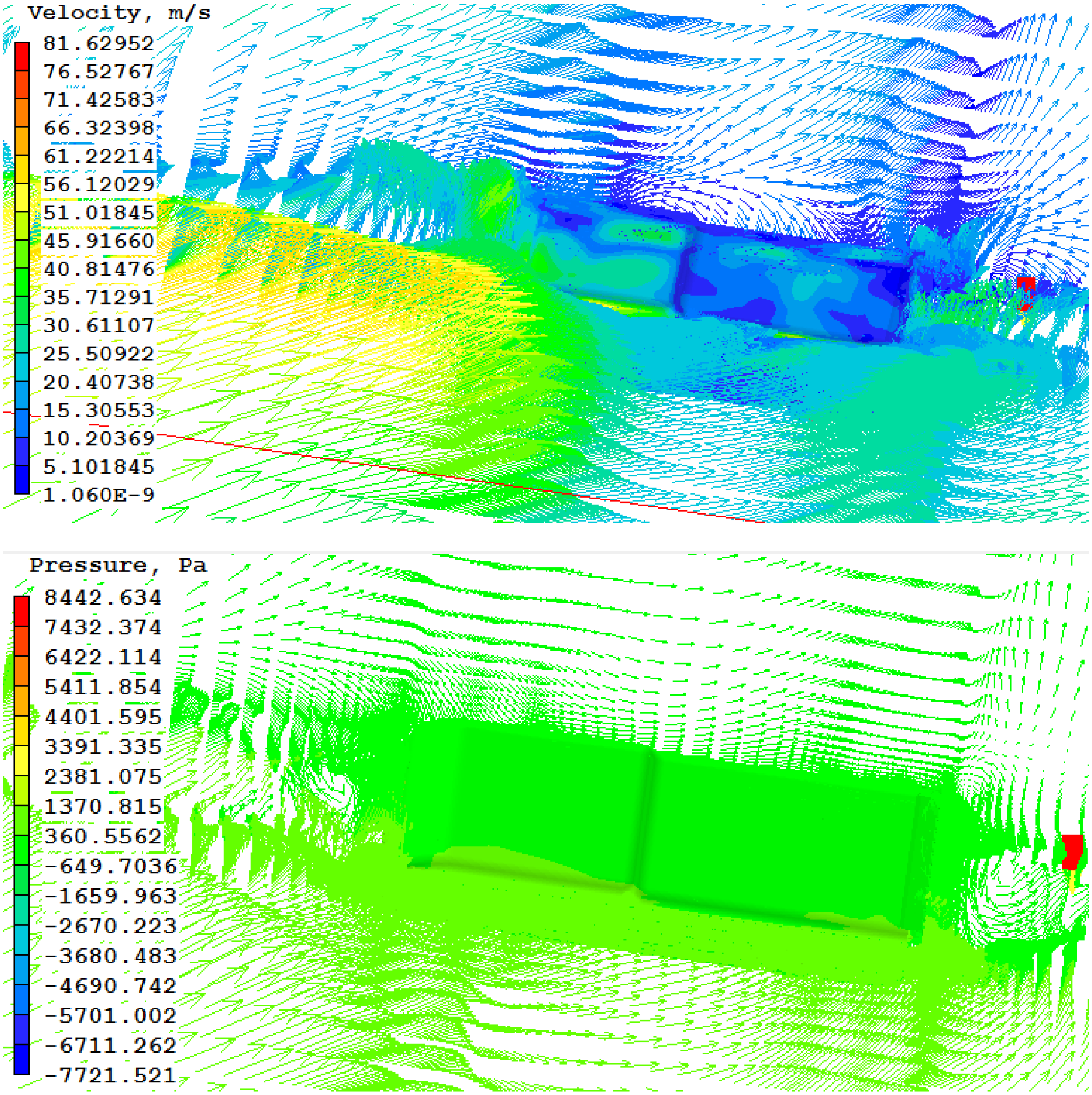
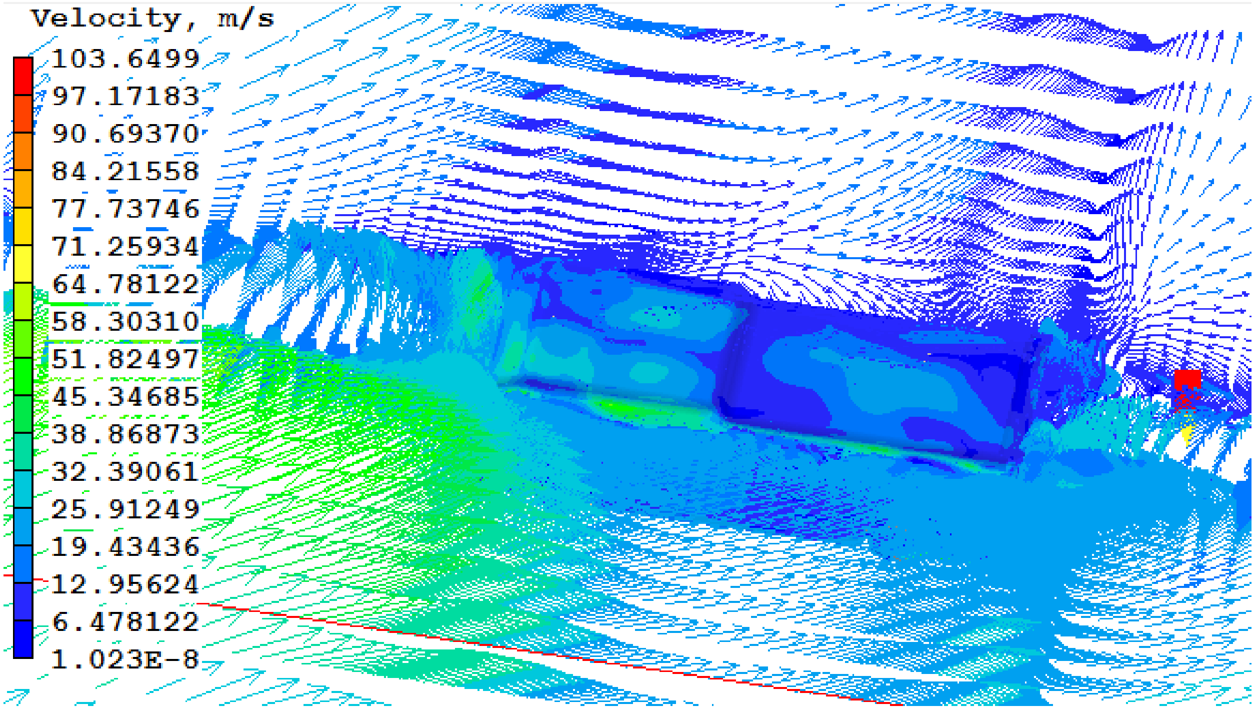


Figure4.9.4: velocity and pressure distribution in model 3 at velocity 60km/h and side wind 12km/h



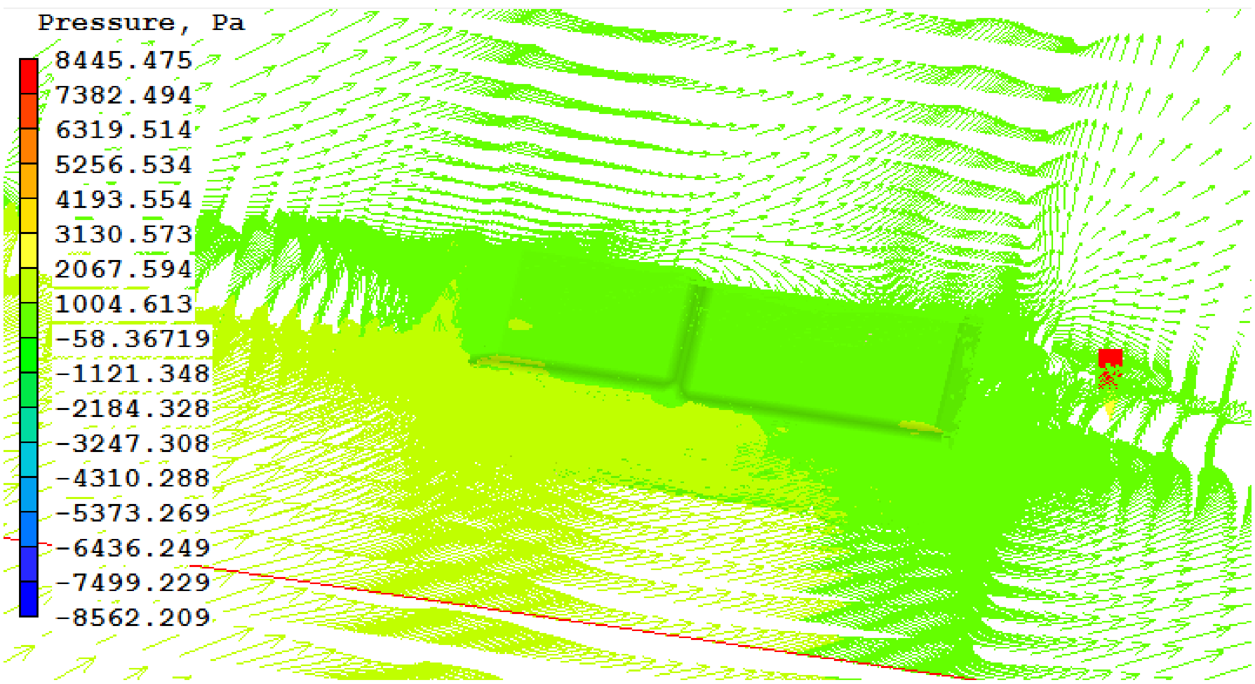


Figure4.9.5: velocity and pressure distribution in model 3 at velocity 80km/h and side wind 12km/h

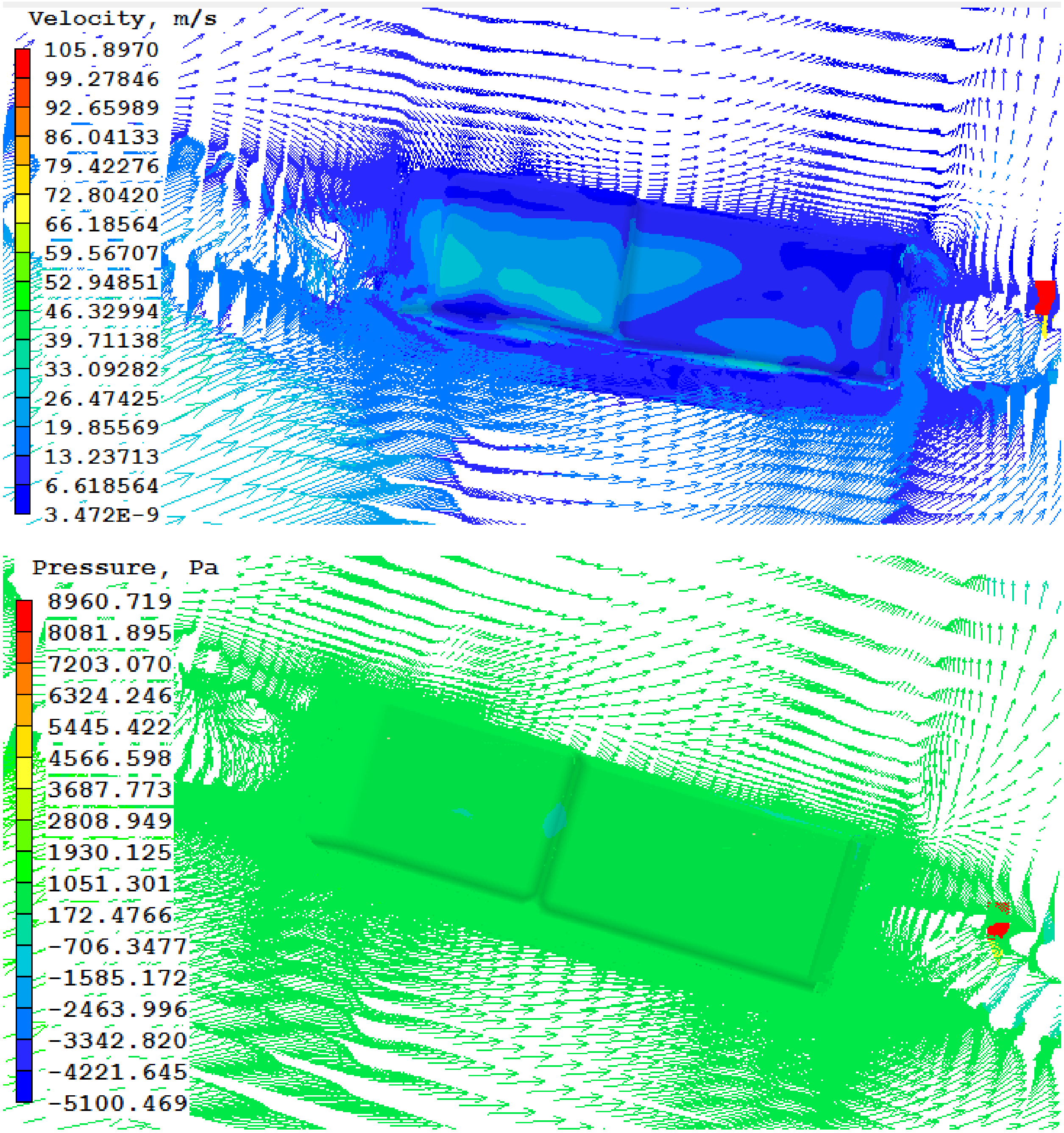


Figure 4.9.6: velocity and pressure distribution in model 3 at velocity 100km/h and side wind 12km/h

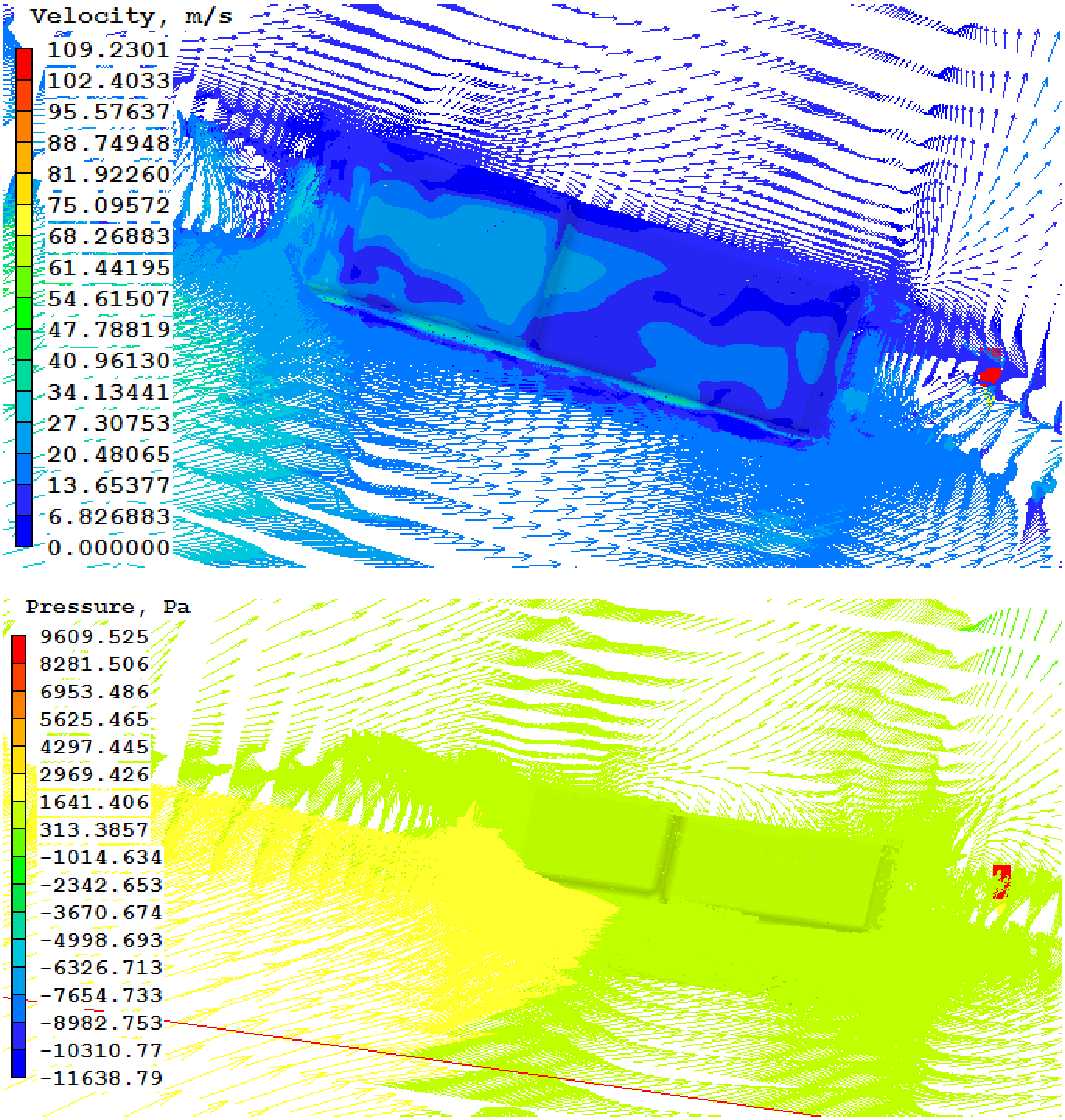


Figure4.9.7: velocity and pressure distribution model 3 at velocity 115km/h and side wind 12km/h

Table4.1: C_d at different Speed km/h

Vehicle model	C_d at different Speed km/h			
	60 km/h	80 km/h	100 km/h	115 km/h
Model 1	3.46137E-01	4.83771E-01	5.13323E-01	5.81342E-01
model 2	2.35930E-01	3.42421E-01	4.17607E-01	5.12201E-01
model 3	2.03644E-01	3.28505E-01	4.011871E-01	5.04519E-01

Table 4.2 redaction of C_d in percent

Isuzu passenger models	Speed variation km/h	Drag coefficient	Cd redaction in percent
Model 1	60	3.46137E-01	--
	80	4.83771E-01	--
	100	5.13323E-01	--
	115	5.81342E-01	--
Modified model 1	60	2.35930E-01	31.8
	80	3.42421E-01	29.2
	100	4.17607E-01	18.6
	115	5.12201E-01	11.9
Modified model 2	60	2.03644E-01	41.2
	80	3.28505E-01	32.1
	100	4.011871E-01	21.8
	115	5.04519E-01	13.2

From table 4.1, it is observed that the drag coefficient is increasing with increase in speed in all the models. Table 4.2 shows the percentage of c_d reduction in each model compared to baseline model at various speeds

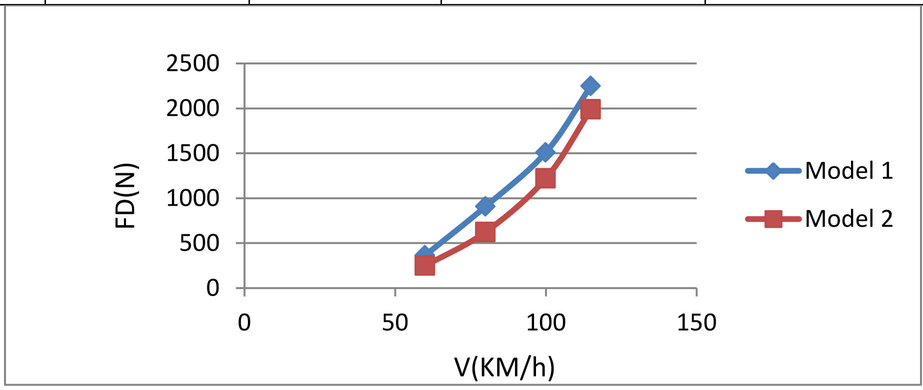
Drag force

Using the formula

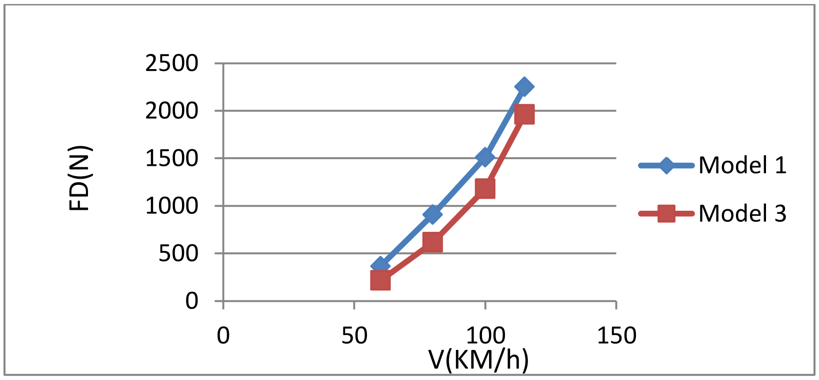
$$F_d = C_d x 1/2(\rho \text{ x } A \text{ x } V^2)$$

Table 4.3 Drag force (N) models vs speed

Velocity km/h	Velocity m/s	Model 1	model 2	model 3
60	16.67	365	249	215
80	22.22	908	642	616
100	27.78	1510	1220	1180
115	31.94	2250	1990	1960



Graph 4.1 variations of drag force model 1 and model 2



Graph 4.1.1 variations of drag force model 1 and model 3

Rolling Resistance (N)

Using the following formula we calculated the resistance force due to rolling

Rolling Resistance (N)

Fr = (0.015+0.00016V) W

Table 4.4 Rolling Resistance (N)

Velocity km/h	Velocity m/s	Model 1	model 2	model 3
60	16.67	300.3424	300.3424	300.3424
80	22.22	315.4384	315.4384	315.4384
100	27.78	330.5616	330.5616	330.5616
115	31.94	341.8768	341.8768	341.8768

Total Resistance (N)

Adding the resistance forces together will give us the total resistance force.

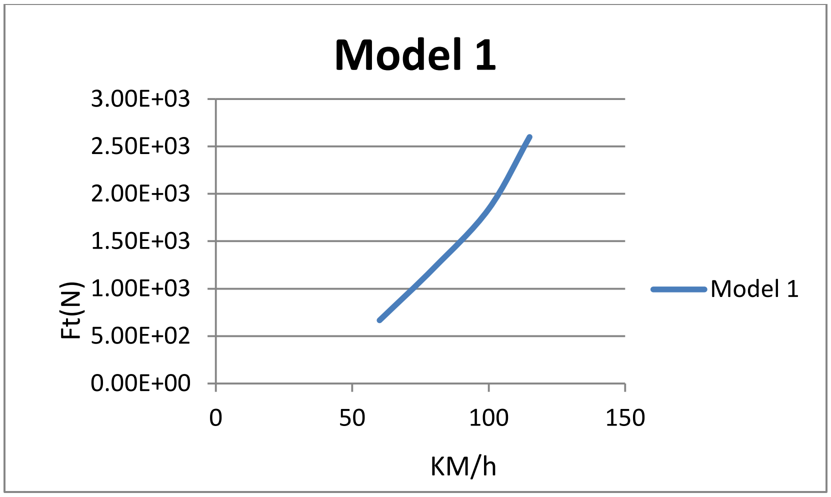
$$F_t = F_d + F_r + F_g$$

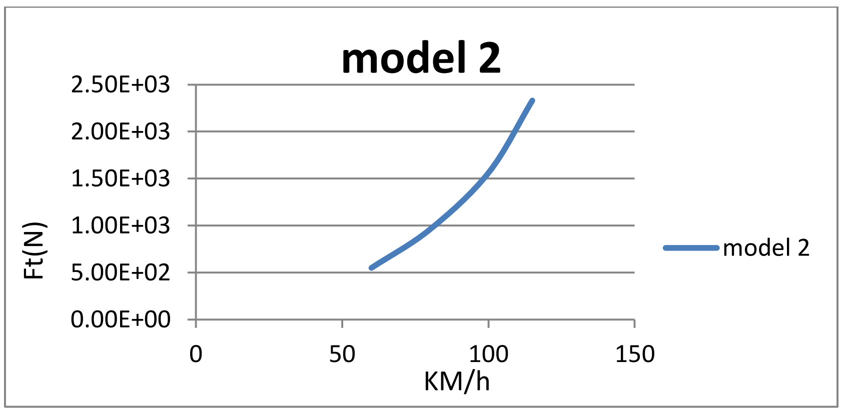
Where, F_d - Drag force, F_r - Rolling resistance, F_g - Gravitational force but,

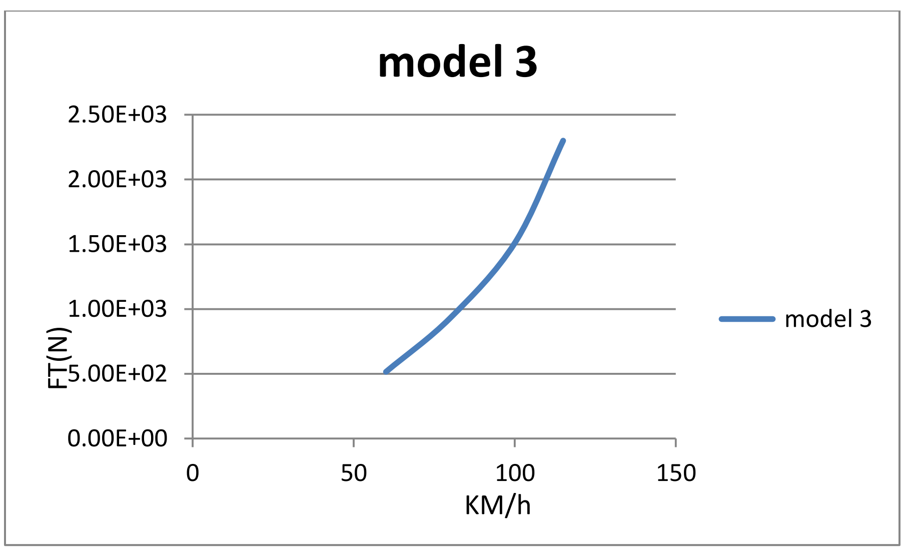
$$F_g = 0 \text{ (considering level road which is the inclination angle } = 0^o) = W \sin\theta = 0$$

Table4.5 .Total resistance (N)

Velocity km/h	Velocity m/s	Model 1	model 2	model 3
60	16.67	6.66E+02	5.49E+02	5.15E+02
80	22.22	1.22E+03	9.58E+02	9.32E+02
100	27.78	1.84E+03	1.56E+03	1.51E+03
115	31.94	2.60E+03	2.33E+03	2.30E+03







Graphs 4.2: Total resistance

4.3 Power Requirements

The power required to pull the bus against the resistance in a leveled surface is calculated and their corresponding values for different speeds are given below

$P = F_t V/\eta_t$ Where, P = Power

F_t = Total Resistance

V = Vehicle Speed

η_t = Transmission efficiency taking

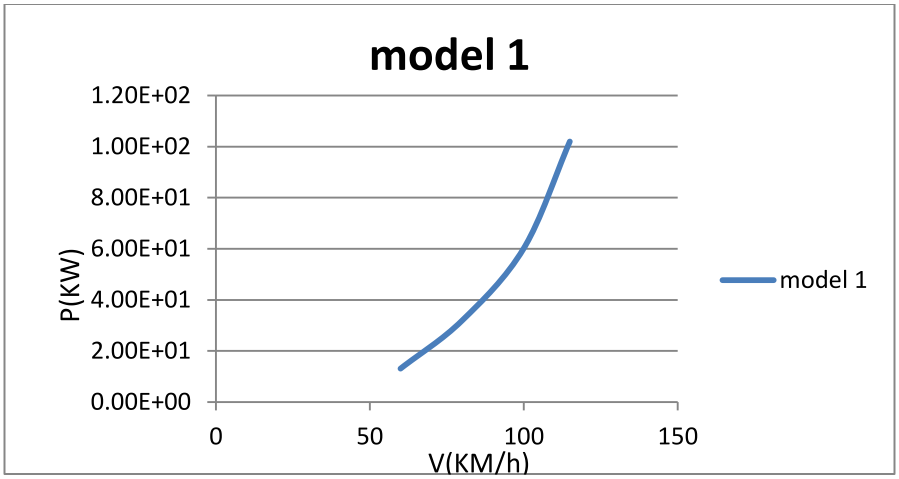
Parameters required for calculation of the power are given in table 4.6

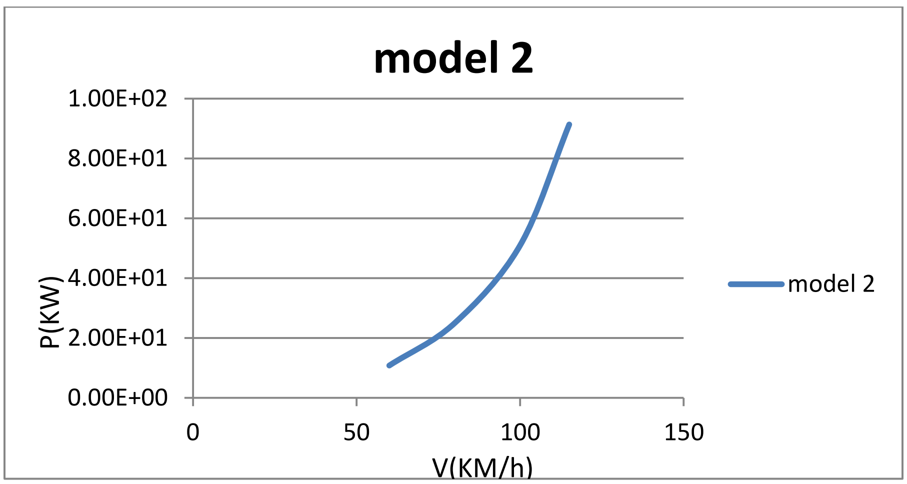
Table 4.6: parameters

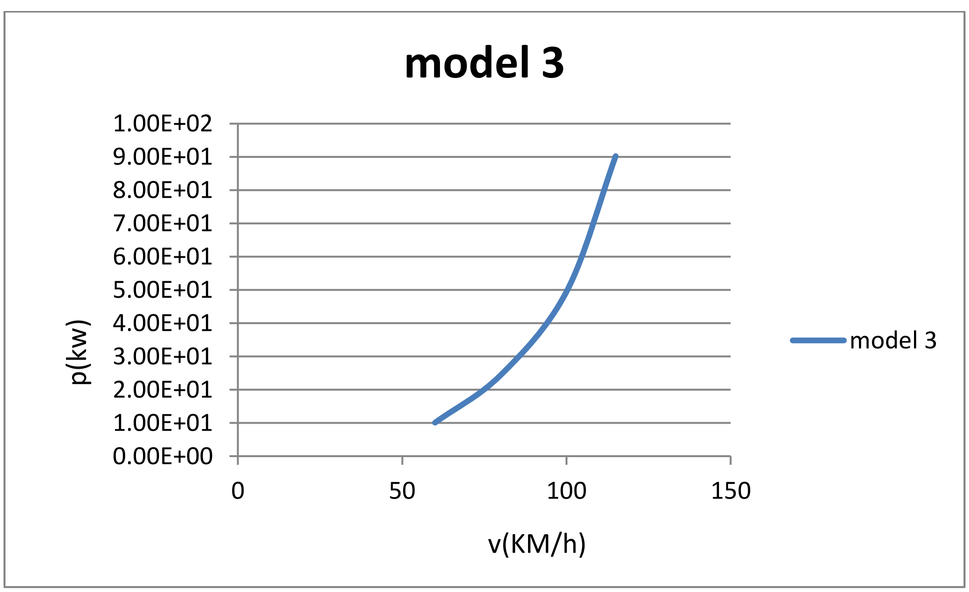
Parameter	Model 1	Modified Model 1	Modified Model 2
Air density(kg/m^3)	1.18	1.18	1.18
Frontal projected area (m^2)	6.44	6.44	6.44
Weight (kg)	17000	17000	17000
Transmission efficiency(η_t)	0.85	0.85	0.85

Table 4.7: the total power required (kW)

v(m/s)	model 1	model 2	model 3
16.66667	13.1	10.8	10.1
22.22222	31.9	25.0	24.4
27.77778	60.1	51.0	49.4
31.94444	102	91.4	90.2







Graphs4.3: power vs speed

Generally the power required by model 1 is greater than both model 2 and model 3.The power required in Model 3 is slightly less than model 2. Which means model 1 consumes more fuel than the two models. Similarly model 2 consumes more power than model 3.

Calculation of Fuel Consumption

Fuel consumption has the relation with the percentage reduction of coefficient of drug [57].

Percentage reduction of fuel consumption = 3/5× [percentage total drag reduction]

Table 4.8: Reduction of fuel consumption

Isuzu passenger models	Speed variation km/h	Drag coefficient	Cd redaction in percent	%fuel reduction
Model 1	60	3.46137E-01	--	
	80	4.83771E-01	--	
	100	5.13323E-01	--	
	115	5.81342E-01	--	
model 2	60	2.35930E-01	31.8	1.91E+01
	80	3.42421E-01	29.2	1.75E+01
	100	4.17607E-01	18.6	1.12E+01
	115	5.12201E-01	11.9	7.14E+00
model 3	60	2.03644E-01	41.2	2.47E+01
	80	3.28505E-01	32.1	1.93E+01
	100	4.011871E-01	21.8	1.31E+01
	115	5.04519E-01	13.2	7.93E+00

Knowing the percentage reduction of fuel consumption, amount of fuel saved in a year can be calculated .the bus travels every day to different destination from one city to the other like from Addis Ababa to Dire Dawa or Jimma e.t.c

Assuming on an average the bus is given for 10 hrs for 340 days in a year. the fuel consumption is around 18-20 liter per 100 km distance. Taking 19 liter per 100 km, amount of fuel saved can be calculated as follows.

The amount of Fuel saved lit/100km = fuel consumption× percentage fuel reduction /100

= 19lit/100km× (% fuel reduction)/100

Table 4.9: fuel saved in lit/100km

Isuzu passenger models	Speed variation km/h	Drag coefficient	Cd redaction in percent	%fuel reduction	Fuel savage L/100km
Model 1	60	3.46137E-01	--		
	80	4.83771E-01	--		
	100	5.13323E-01	--		
	115	5.81342E-01	--		
model 2	60	2.35930E-01	31.8	1.91E+01	3.63E+00
	80	3.42421E-01	29.2	1.75E+01	3.33E+00
	100	4.17607E-01	18.6	1.12E+01	2.13E+00
	115	5.12201E-01	11.9	7.14E+00	1.36E+00
model 3	60	2.03644E-01	41.2	2.47E+01	4.69E+00
	80	3.28505E-01	32.1	1.93E+01	3.66E+00
	100	4.011871E-01	21.8	1.31E+01	2.49E+00
	115	5.04519E-01	13.2	7.93E+00	1.51E+00

Fuel saved lit/year = fuel consumption X (percentage of fuel reduction /100) X maximum working hours X vehicle speed

=19lit/100km × (% fuel reduction)/100 (10hr × 340days) × V km/hr

Table 4.9.1 Fuel saved for single vehicle per year (lit).

Isuzu passenger models	Speed variation km/h	Drag coefficient	C_d redaction in percent	%fuel reduction	Fuel saved lit/100km	Fuel saved for single vehicle per year. (lit)
Model 1	60	3.46137E-01	--	--	--	--
	80	4.83771E-01	--	--	--	--
	100	5.13323E-01	--	--	--	--
	115	5.81342E-01	--	--	--	--
model 2	60	2.35930E-01	31.8	1.91E+01	3.63E+00	7.40E+05
	80	3.42421E-01	29.2	1.75E+01	3.33E+00	9.06E+05
	100	4.17607E-01	18.6	1.12E+01	2.13E+00	7.23E+05
	115	5.12201E-01	11.9	7.14E+00	1.36E+00	5.30E+05
model 3	60	2.03644E-01	41.2	2.47E+01	4.69E+00	9.57E+05
	80	3.28505E-01	32.1	1.93E+01	3.66E+00	9.95E+05
	100	4.011871E-01	21.8	1.31E+01	2.49E+00	8.47E+05
	115	5.04519E-01	13.2	7.93E+00	1.51E+00	5.89E+05

4.4 Stability

Rotating moment generated on the Isuzu passenger bus body due to the location difference between C.P and C.G. its result obtained from CFD simulation.

Table 4.92 Specification of model vehicle

Model dimension	Geometric
Overall length (m)	7.7
Over all width (m)	2.30
Body height (m)	2.8
Curb weight (ton)	14
Weight of loaded car (ton)	17
Clearance (m)	0.4
Frontal area (m^2)	6.44
Side area (m^2)	21.56
C.G height (m)	1.4
C.G Location (m) longitudinal	10.78

Table 4.93 Intial and bounder condition for calculation

Inlet 1	Velocity boundery $v_{vehicle}$ = 115km/hr
Inlet 2	Velocity boundery for side-wind $v_{side-wind} = 12m/s$
Outlet 1	Pressure boundery with fully deloped condition $P_{out} = 1atm$
Outlet 2	Pressure boundery with fully deloped condition $P_{out} = 1atm$
Surface of model vehicle	No slip condition
Low wall	Slip boundery with inlet air velocity
Radius of gyration	100m
Domain size Grid number	X: 80m Y: 16m Z: 30M 150x106x109

Centrifugal force and moment

Centrifugal force: - $F_c = \frac{mv^2}{R}$ and this force forms a Centrifugal moment $M_c = \frac{mv^2 h}{R}$ $or\ F_c \times h$

$F_c\ at\ R = 100m$

$$F_c = \frac{17 \times 1000 \times 31.94^2}{100} = 173.42\text{KN And } M_c = 173.42\text{kN} \times 1.4\text{m} = 242.78\text{kNm}.$$

Table 4.9.4: F_c and M_c with in radius of gyration 100m

MODEL 3	v(m/s)	Fc when Radius of gyration =100m	M_c when Radius of gyration =100m
	16.67	47.24111kg	66137.56Nm
	22.22	83.93383kg	117507.4Nm
	27.78	131.1938kg	183671.4Nm
	31.94	173.4278kg	242798.9Nm

Moment generated on the vehicle body

Yawing moment assuming running on dry asphalt road surface during turning

And take average tire friction coefficient $\mu = 0.9$. $L_1 = 2.33$m and $L_2 = 2.4$m

$M_{yr} = F_1 \times L_2 + F_2 \times L_2 + F_3 \times L_1 + F_4 \times L_1$ Take CCW as positive

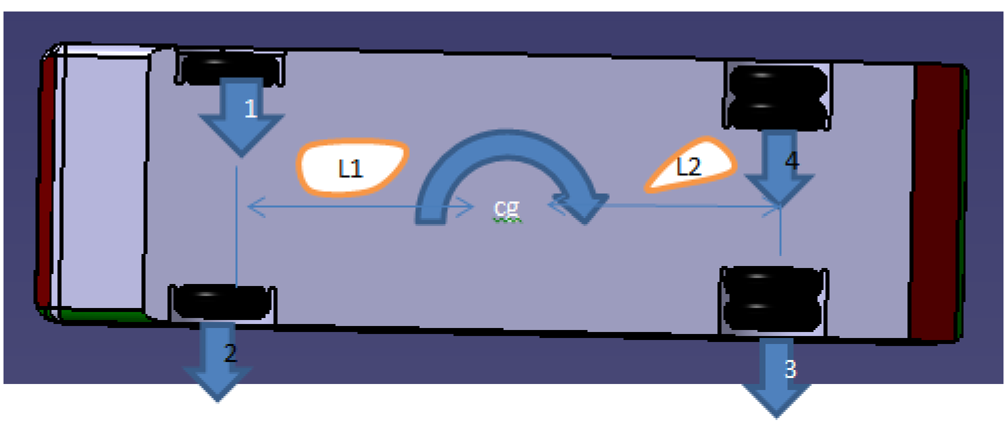


Fig. 4.9.8.1 Free body diagram

Rolling resistance moment M_{rr}

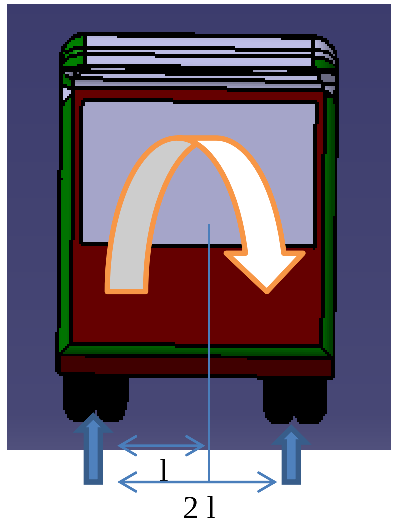


Fig. 4.9.8.2 Rolling resistance moment

Tire section width is 285mm or 0.285m roll resisting force acting at the center of tire or 0.2852/2 = 0.1425m so, L = width of bus minus 0.1425m i.e. (2.33m – 0.1425m)/2 = 1.09375m.

$$M_{rr} = l \times W$$

Pitching resisting moment (M_{pr}).

For this case L = 2.33m from C.G location to front tire center.

$$M_{pr} = w \times L = .$$

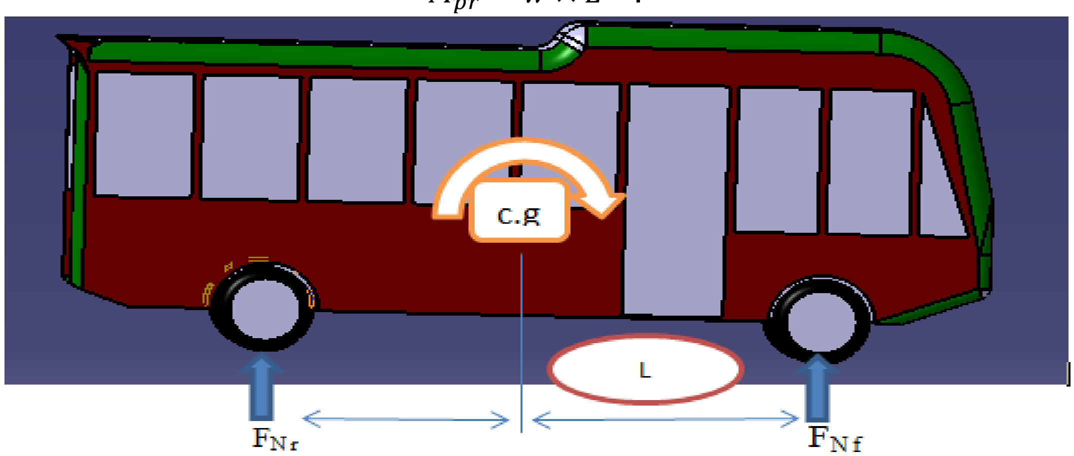


Fig. 4.9.8.3 Pitching resisting moment

Table4.95: moments about user coordinate

Isuzu passenger Bus Speed and 12m/s side wind	Moments about user coordinate(N/m)		
	$M_{rolling}$	$M_{pitching}$	M_{yawing}
60km/h	2.722993×10^{4}	3.105816×10^{3}	1.1182139×10^{5}
80km/h	1.182058×10^{4}	4.239615×10^{3}	7.618870×10^{4}
100km/h	4.286549×10^{3}	6.643904×103	7.106413×10^{4}
115km/h	2.389189×10^{4}	8.581624×10^{3}	8.027312×10^{4}

Table4.96 : moments about origin or rolling

Bus Speed And 12m/s side wind	Moments about origin or rolling Center(N/m)		
	M_{rr}	M_{pr}	M_{yr}
16.67m/s	3.62452×104	5.391×103	4.022108×10^{5}
22.22m/s	5.2451×104	6.56×103	7.146126×10^{5}
27.78m/s	6.1261×104	9.093×103	1.116984×10^{6}
31.94m/s	1.8346×104	9.836×104	1.476564×10^{6}

The objective of this study is the investigation of the stability of moving model of Isuzu passenger bus model 3 at 60km/h, 80 km/h, 100km/h and 115km/s speed and 12m/s side crosswind. The study of effect of forces and moment which is acting on the center of pressure is one of the most important moving stability.

CFD analysis of flow over the modified Isuzu passenger bus is carried for the speed from 60km/h up to 100km/h and side wind is 12m/s for yawing moment (Myawing), rolling moment(Mrolling) and pitching moment(Mpitching) .the values of Mr,My and Mr less than respective resistance moments M_{rr},M_{yr} and $M_{pr.}$ Therefore the model Bus's driving stability is guaranteed when driving from 60km/h up to 100km/h with 12 m/s side wind for all speeds.

But when the model bus driving at the speed of 115km/h the value of rolling moment resistance (Mrr) is less than rolling moment (Mrolling). Therefore the model Bus's driving stability is not guaranteed when driving at the speed of 115km/h which is due to the side wind and at the high speed.

4.5 structural analysis of the bus

the structure model constitutes assemblies of individual members to form the whole structure. When the model is imported in to ANSYS 15 workbench, the ANSYS 15 workbench automatically recognizes the members in contact. The contact surfaces in reality are the places where welds are found. But to in incorporate the weld effects in to the analysis, we need to use ANSYS 15 workbench weld representative element. Therefore, in ANSYS 15workbench, there are two ways of considering welded assemblies. The first one is contact element where it is used when we have a solid model. The other one called spot-weld connection is used when we have model of surface bodies assembled together [52].

4.6 structural analysis of model 3 Isuzu passenger bus

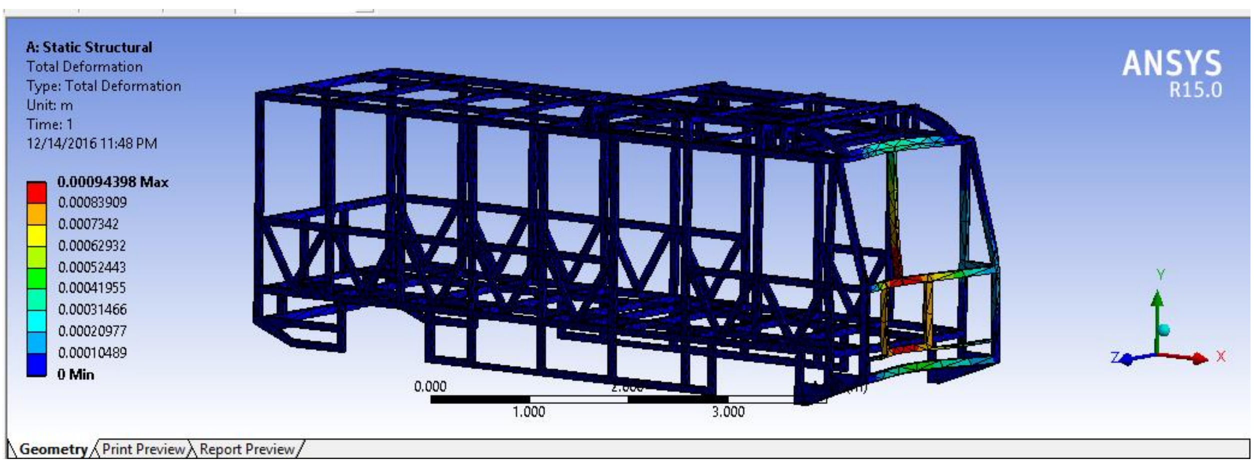


Figure 4.9.8.4 Deformation

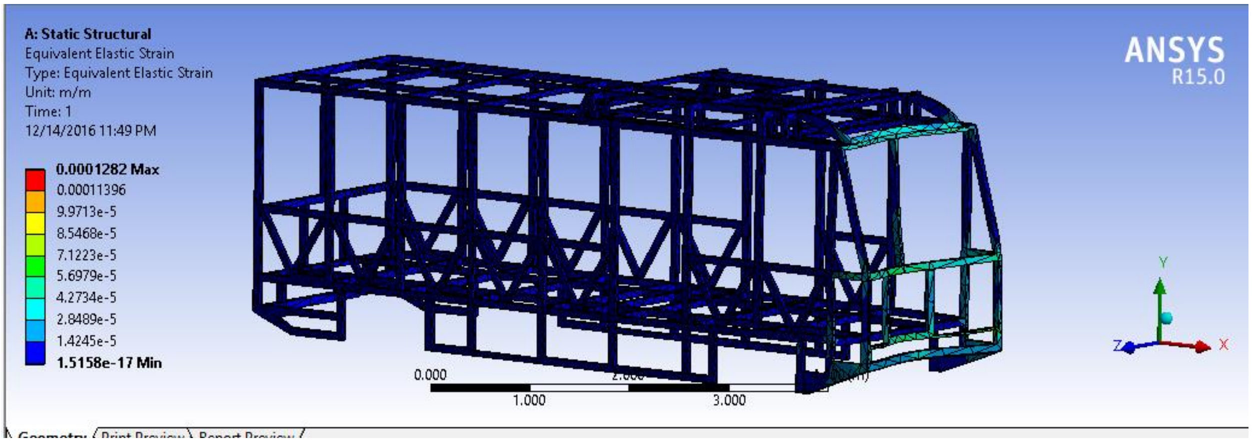


Figure 4.9.8.5 equivalent elastic strain

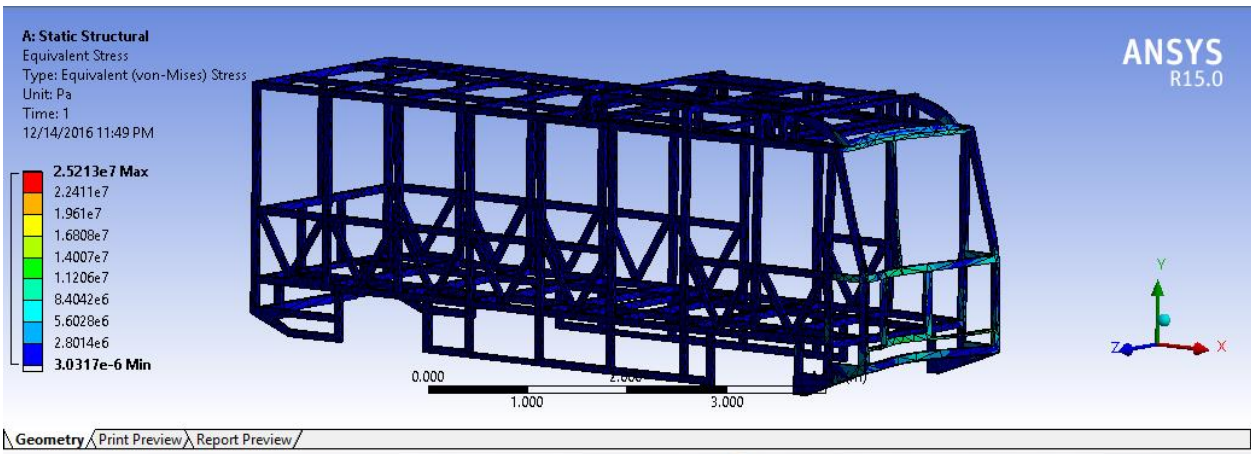


Figure 4.9.8.6 von- mises stress

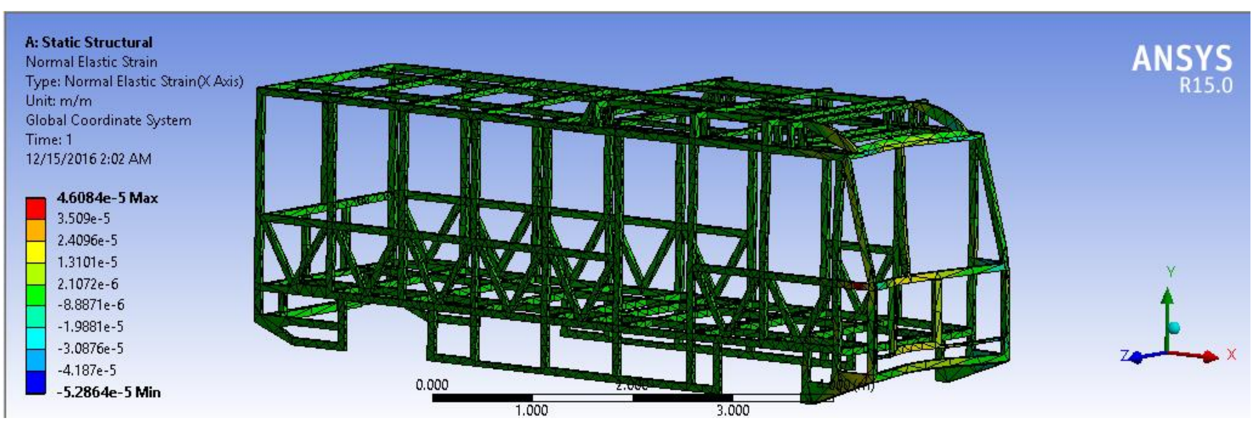


Figure 4.9.8.7 Normal elastic strain

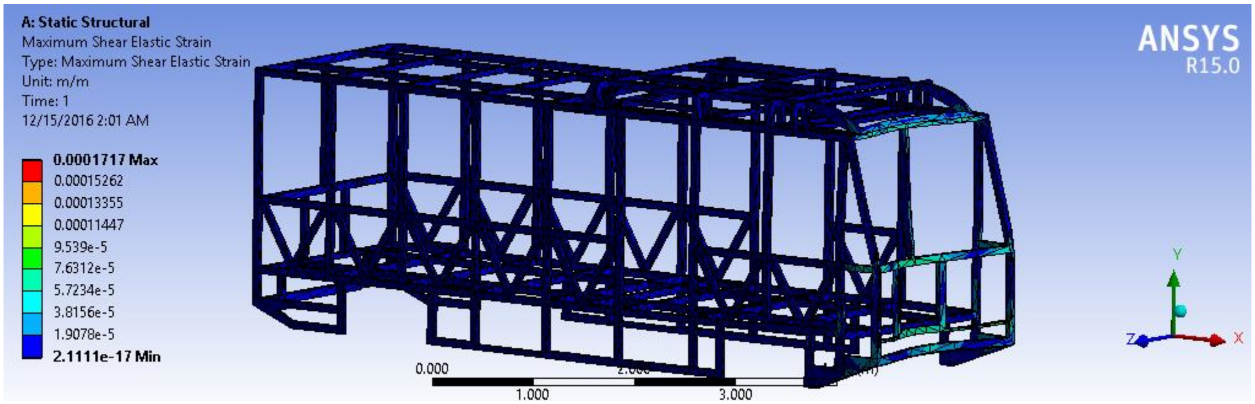


Figure 4.9.8.8 shear elastic strain

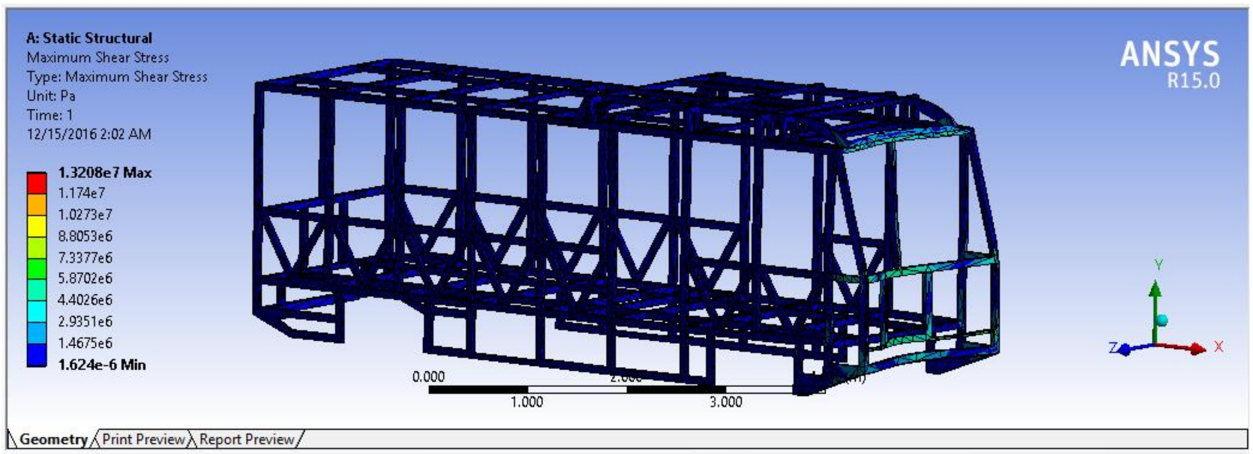


Figure 4.9.8.9: shear stress

Objective was to investigate the structural strength of modified Isuzu passenger bus. In this project, a model 3 Isuzu passenger bus body structure is designed and modeled in 3D modeling software CATIA VR19 and ansys work bench15. The dimensions of the body structure are taken from Endalk garage Adama Ethiopia. The original body is as it is but at the front small modification and at roof air conditioning unit. The structural strength analysis Total deformation is 0.83903mm, equivalent elastic strain 0.1282mm/m, equivalent (Von-mises) stress is 2.5213×10^7pa, normal elastic strain was 3.509×10^5mm/m, maximum shear elastic strain is 0.1717mm/m, maximum shear stress was 1.3208×10^7pa.the results are shown in table 4.1.5

Table 4.97: The result of FEM analysis

	St 37.2
Total deformation	0.83903mm max
Equivalent elastic strain	0.1282mm/m max
Equivalent (von- mises) stress	2.5213×10^{7}pa max
Normal elastic strain	3.509×10^{5}mm/m max
Maximum shear elastic strain	0.1717mm/m max
Max shear stress	1.3208×10^{7}pa max

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The aerodynamic design of bus is an area where a lot of improvements will appear in the near future, in concern of drag reduction. In general that can be implemented in most modern road going vehicles; Smooth bus shape, rounded corners, high rake angle for the windscreen, tapered rear end. The aerodynamics of buses has been described in order to get notions about how to reduce drag resistance. However, design has to deal with a whole lot of other performance, functionality and styling issues which sometimes, and not so few, still tend to rule when meeting incompatibilities with aerodynamic ones.

Analysis was completed successfully in 3-D by using CFD phoenics VR 2015 software. by taking in account the boundary conditions; velocity, pressure, density of air and the frontal area of the bus. New models are designed by the help of drag reduction techniques like rear spoiler, roof air conditioning unit etc. Thus it is possible to produce the bus body shape with optimum shape that will offer less aerodynamic resistance.

Models of Isuzu passenger body busses have been modeled for performing numerical analysis using CFD phoenics software. The Bus model1 is the existing model, Bus model.2 is the existing model with the front, taper corners and roof air conditioning unit end modified. Bus model 3 is the existing model with the front, corners, rear spoiler and roof air conditioning unit end modified.

Input Velocities used for the CFD phoenics analysis is 60kmph, 80kmph, 100 kmph, and 115 kmph. With respect to model 1 at speeds 60km/h, 80kmph, 100 kmph, and 115 kmph , the % drag coefficient reduction for model 2 is 31.8, 29.1, 18.6, 11.9 and for model 3 are 41.2,32.1,21.8,13.2 respectively. The % reduction of Fuel consumption with respect to model 1 at speeds 60km/h, 80kmph, 100 kmph, and 115 kmph, model 2 are 19.1, 17.5, 11.2, and 7.4 and for model 3 are 24.7, 19.3, 13.1, and 79.3 respectively. Hence the modifications made to the body shape lead to considerable reduction in drag coefficient and there by reduction in fuel consumption without negatively affecting the stability vehicle.

CFD analysis of flow over the modified Isuzu passenger bus is carried for the speed of from 60km/h up to 100km/h and side wind is 1.2m/s for yawing moment (M yawing), rolling moment (Mrolling) and pitching moment (M pitching) values are smaller than each value of rotational resistance moment (Mrr), yawing resistance moment (Myr), Pitching resistance moment (Mpr) for the variable speed of model bus. Therefore the model Bus's driving stability is guaranteed when driving from 60km/h up to 100km/h with 12 m/s side wind for all speeds.

But when the model Bus driving at the speed of 115km/h the value of rolling moment resistance (Mrr) is less than rolling moment (Mrolling). Therefore the model Bus's driving stability is not guaranteed when driving at the speed of 115km/h which is due to the side wind and high speed.

The structural strength of modified Isuzu passenger bus was investigated. In this thesis work, a model 3 Isuzu passenger bus body structure is designed and modeled in 3D modeling software CATIA VR19 and ansys work bench15. The dimensions of the body structure are taken from Endalk garage Adama Ethiopia. The structural analysis was made on body structure after making slight modification in front and roof air conditioning unit. The structural strength analysis results are as follows: total deformation is 0.83903mm, equivalent elastic strain 0.1282mm/m, equivalent von-mises stress is 2.5213×10^{7}pa, normal elastic strain was 3.509×10^{5}mm/m, maximum shear elastic strain is 0.1717mm/m, maximum shear stress is 1.3208×10^{7}pa.

5.2 Recommendations for future work

- By using CFD with time-dependent inflow boundary conditions, it is possible to optimise the body shape with respect to the transient yaw moment. However, today this requires a large computational effort. When computational power allows the co-simulation of an un steady crosswind acting on detailed vehicle models, together with detailed models and representative driver models, it will be possible to optimise the crosswind performance of the complete vehicle system efficiently. The potential improvement of the crosswind performance by using an adaptive steering feel requires a steering system with the possibility of quickly altering the steering ratio and servo assistance. Such systems are today available for passenger cars and will probably be available for Isuzu passenger vehicles in the future. In order to take the full advantage of an adaptive steering feel, a steer-by-wire system will probably be needed. This will also require fast and reliable methods for detecting a crosswind disturbance for input to the adaptive steering system.
- The design of air conditioning unit for Isuzu passenger bus in order to reduce suffocation.
- Comparing the structural strength of existed one with slightly modified one by changing materials in order to have light weight and stronger.

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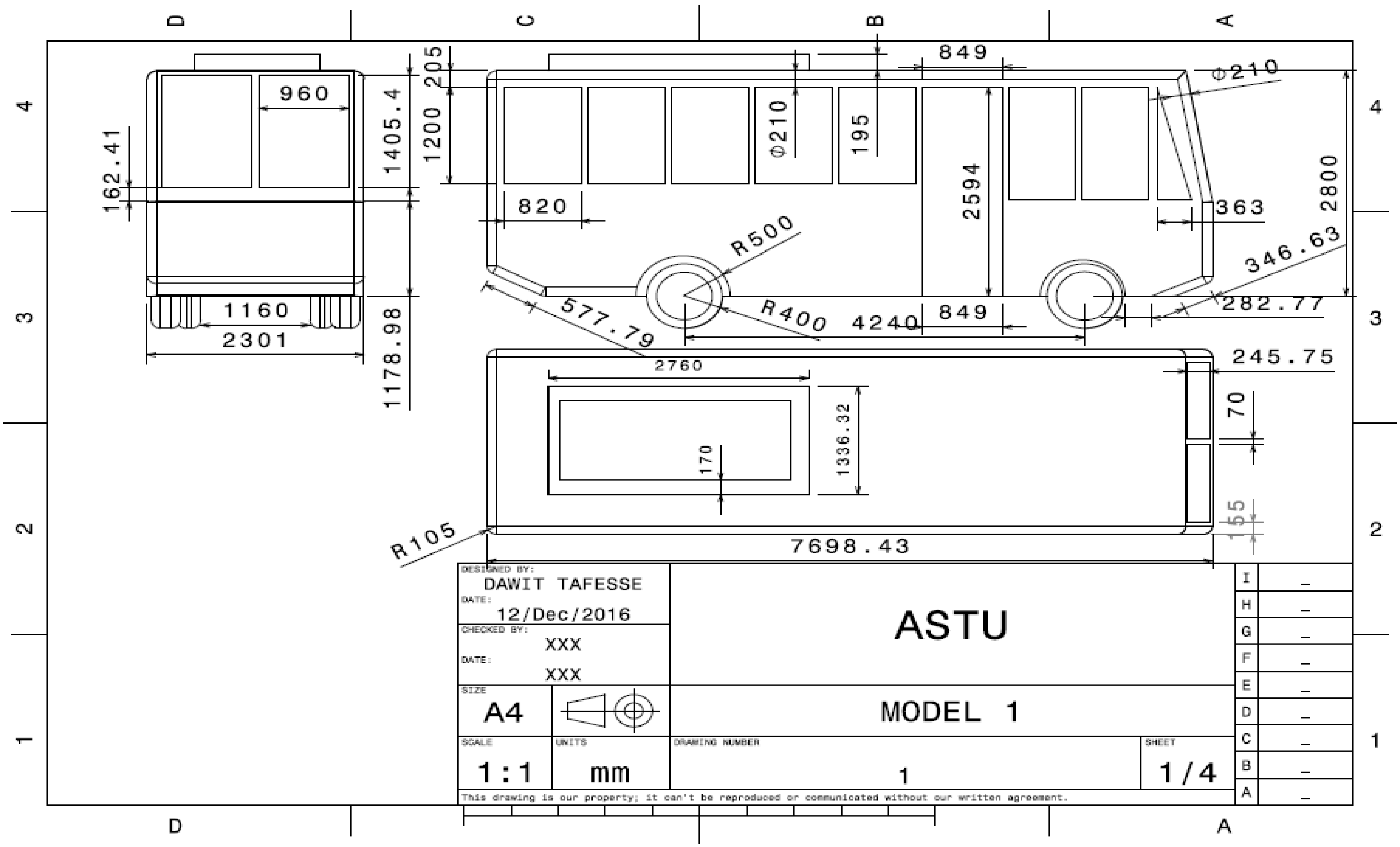
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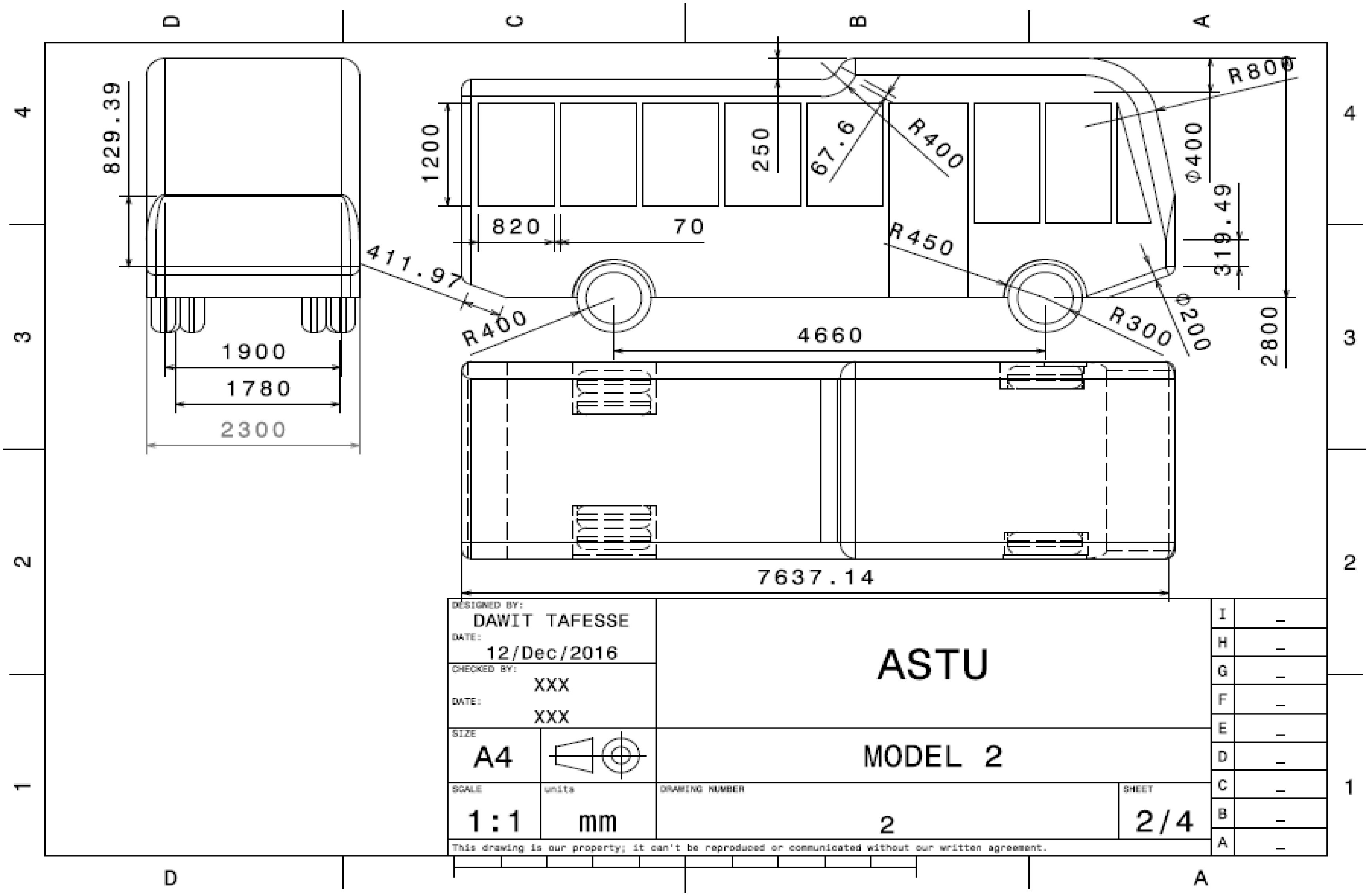
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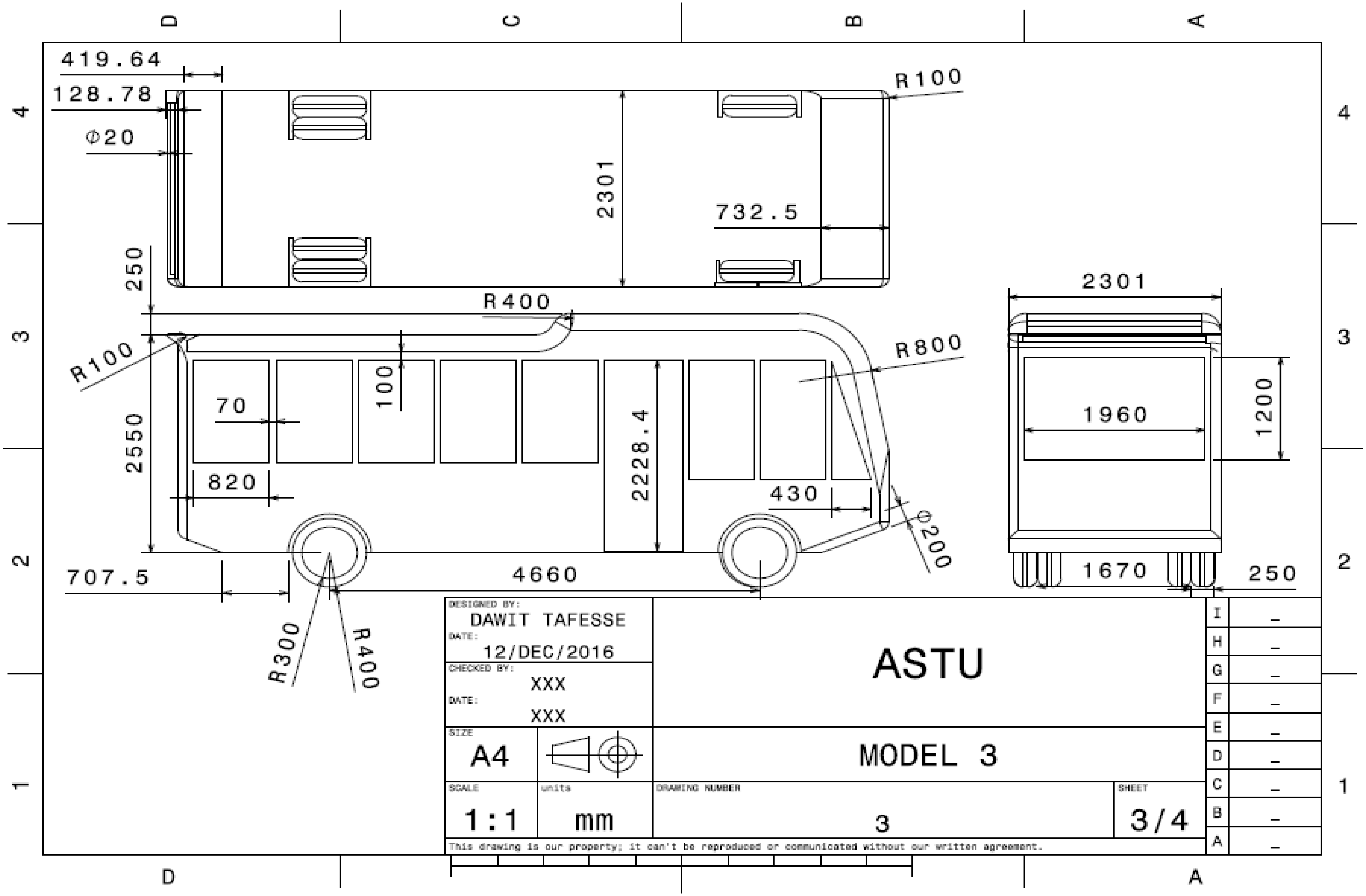
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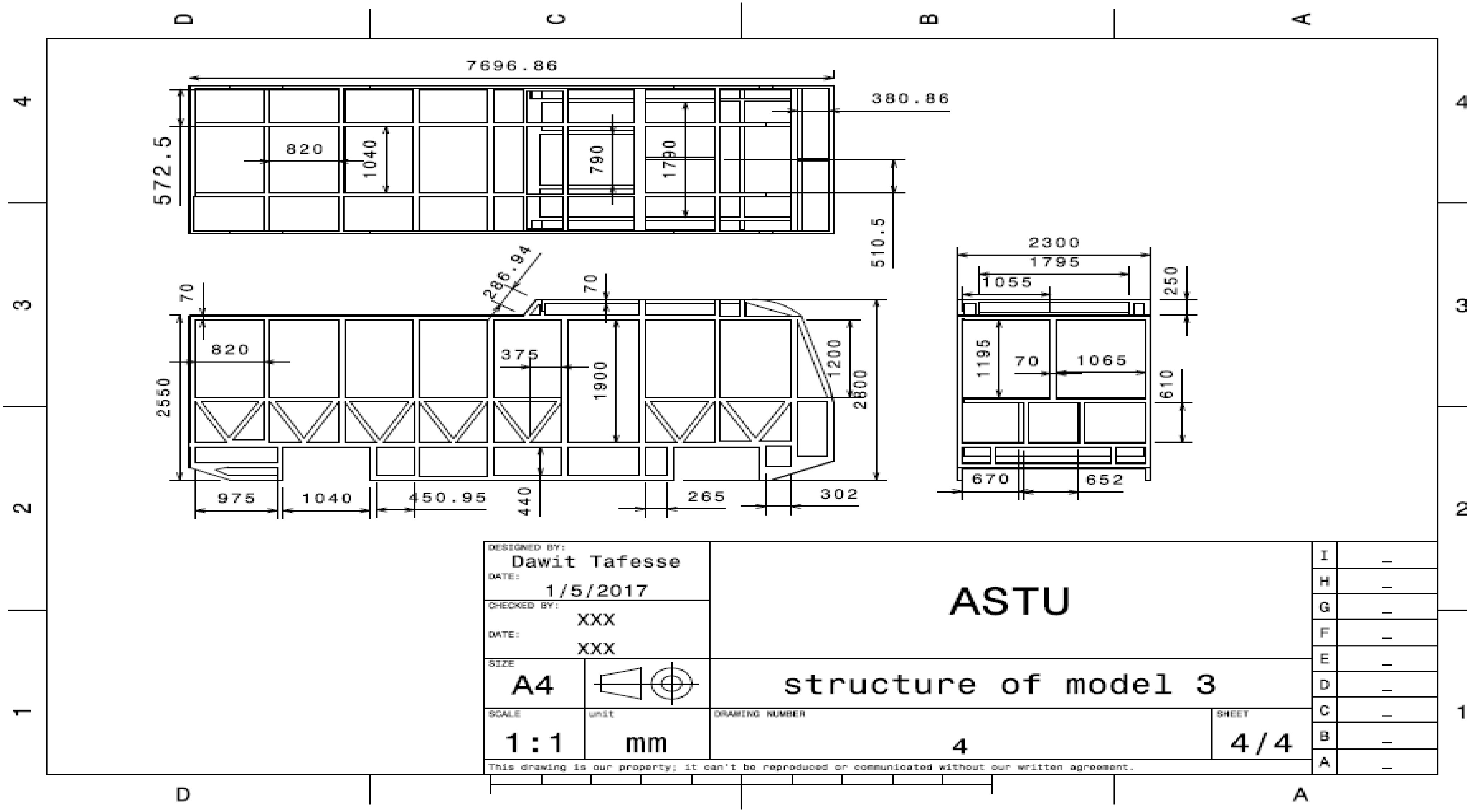
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