AERODYNAMIC DESIGN OF A ROOF FAIRING FOR TRUCKS

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DECLARATION

I certify that this thesis was written entirely by myself and that it has never been presented, in whole or in part, in any previous degree application. The work presented is completely my own, unless otherwise stated by references or acknowledgements.

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LIST OF ABBREVATIONS

NASA	National Aeronautics and Space Administration
WHO	World Health Organization
IPPC	The Intergovernmental Panel on Climate Change
GHG	Greenhouse Gas Emission
MyCAC	Malaysian Climate Change Action Council
CO_2	Carbon Dioxide
CRF	Cab Roof Fairing
CFD	Computational Fluid Dynamics
LHDC	Long Haul Driving Cycle
NEDC	The New European Driving Cycle
FEA	Finite Element Analysis
SST	Shear Stress Transport
SAS	Scale Adaptive Simulation
PLA	Polylactic Acid

ABSTRAK

Pelepasan karbon dioksida ialah pelepasan karbon ke atmosfera yang juga dikenali sebagai pelepasan gas rumah hijau merupakan penyumbang utama kepada perubahan iklim di dunia ini. Di Malaysia, sektor pengangkutan menyumbang kira-kira 28% daripada jumlah pelepasan karbon, di mana 85% daripada pengangkutan jalan raya (Mustapa & Bekhet, 2016). Oleh itu, adalah penting untuk mengurangkan pelepasan GHG untuk melambatkan perubahan iklim dan juga meningkatkan kualiti udara. Peranti pengurangan seret boleh membantu mengurangkan rintangan udara kenderaan, oleh itu daya yang bertindak ke atas kenderaan akan memindahkan lebih banyak kuasa yang dihasilkan oleh enjin ke dalam pergerakan. Oleh itu, tujuan tesis ini adalah untuk mengkaji bagaimana kelakuan aliran udara yang dikenakan ke atas lori dengan halaju 20 m/s secara simulasi. Selain itu, terowong angin digunakan untuk memerhati seretan yang bertindak pada trak model 3D yang dipilih. Halaju berbilang digunakan dari 1 m/s hingga 15 m/s untuk memerhati seretan. Hasilnya menunjukkan bahawa CRF yang mempunyai tepi bulat di hujung boleh membantu mengurangkan seretan aerodinamik. Dalam simulasi, dapat dilihat bahawa jurang antara trak dan treler telah mewujudkan kawasan tekanan rendah yang turut menyumbang kepada seretan aerodinamik. Oleh itu, penggunaan CRF dalam eksperimen, seretan aerodinamik dikurangkan kira-kira 5.86% pada halaju 15 m/s.

ABSTRACT

Carbon emission is the release of carbon into the atmosphere also known as greenhouse gas emissions is the main contributor to climate change in this world. In Malaysia, the transportation sector accounts for around 28% of total carbon emission, of which 85% comes from road transport (Mustapa & Bekhet, 2016). Therefore, it is important reduce the greenhouse gas (GHG) emissions to slow the climate change and also improve air quality. Drag reducing devices can help to decrease air resistance of a vehicles, thus the forces acting on the vehicles will be transfer more of that power produced by the engine into movement. Therefore, the purpose of this thesis is to study how the air flow behavior imposed on the truck with 20 m/s of velocity by simulation. Moreover, wind tunnel is used to observe the drag acting on the 3D model truck that are selected. Multiple velocities is used from 1 m/s to 15 m/s to observe the drag. The result shows that a cab roof fairing that has rounded edges at the end could help to decrease the aerodynamic drag. In the simulation, the gap between the truck and trailer has created a low-pressure area which also contribute to the aerodynamic drag. Therefore, the use of cab roof fairing in the experiment, aerodynamic drag is reduced for about 5.86% at the velocity of 15 m/s.

CHAPTER 1 INTRODUCTION

1.1 Overview of Climate Change

According to National Aeronautics and Space Administration (NASA), climate change is a change in the usual weather found in a place (Sandra May, 2017). Earth’s climate is constantly changing such as the changes of rate of the rain in over a year. However, it is observed that the Earth’s climate has been warmer which is a warning as every degree of warming matters. Global warming is defined as the unusually rapid increase in Earth’s average surface temperature over the past century primarily due to the greenhouse gases that is released. The global average surface temperature rises about 0.6℃ to 0.9℃ between 1906 and 2005. Due to that, the rate of temperature had rapidly increases nearly doubled in the last 50 years. With the rapidly increasing Earth’s temperature, global warming will likely cause bigger destructive phenomena such as extreme weather that will affect ecosystems, people and damaging environment and more (Holli Riebeek, 2010)

Climate change is no longer merely a concern of the environment or development as it endangers human health. The risk of contagious diseases such as malaria due to climate changes might affect the developing countries hard due to short medicine supply and more (Renee Cho, 2014). The case of contagious diseases such as malaria and dengue fever cases are expected to increase rapidly due to high temperature. According to the World Health Organization (WHO), between 2030 and 2050, climate change is expected to cause approximately around 250,000 additional death per year due to malnutrition, malaria, diarrhoea and heat stress (World Health Organization, 2021). Therefore, it can be concluded that climate change is one of the biggest health and life threat that facing humanity and all living things. The Intergovernmental Panel on Climate Change known as the IPCC stated that around 95% to 100% global warming occurs due to humans. United States fourth national climate assessment found that between 93% to 123% of observed from 1951 to 2010 warming happens due to human activities (Hausfather Zeke, 2017). The dangerous effect of climate change that result in global warming might not be seen now, but the scientist around the world are worried that the Earth’s life span might shorten over years as the climate changes and temperature are rising as they predicted.

1.2 Overview of Greenhouse Gas Emission (GHG) Policies

Carbon emission is the release of carbon into the atmosphere also known as greenhouse gas emissions is the main contributor to climate change in this world. Thus, during U.S. Climate Summit in April 2021, United States of America President Biden encouraged and pressured countries to speed up the carbon neutral pledges to reduce carbon emission (Omri Wallach, 2021). Therefore, Malaysia’s aim to be carbon neutral by 2050 as announced by the Prime Minister of Malaysia Datuk Seri Ismail Sabri Yaakob, is an affirmation of the nation’s commitment to accelerate the growth of a green economy and ensure long-term energy sustainability.

The Paris Agreement is a legally binding international agreement on climate change that seeks to boost the global response to the threat of climate change, according to the United Nations Climate Change. The agreement's objective is to encourage the global response to climate change by limiting global temperature rises 2℃ above pre-industrial levels to pursue efforts to limit the temperature increase even further to 1.5℃ (United Nations Climate Change, 2015). Therefore, by being a signatory of the Paris Agreement, Malaysia has vowed allegiance towards the worldwide common commitment of cutting climate-altering pollution (Toh Zhee Qi, 2020).

Malaysian Climate Change Action Council (MyCAC) is established by Tan Sri Muhyiddin Yassin who served as the eighth prime minister of Malaysia to discusses the climate change issues. The member of the council will set policy direction in climate change mitigation and adaption strategies and actions to drive green economic growth and low carbon level. Moreover, the members will discuss to set the direction, discussing climate change policies and actions (Bernama, 2021). Malaysia has committed to reduce the Greenhouse Gas (GHG) emission by 45% by 2030 in relation to the 2005 GDP during the 2015 United Nations Climate Change Conference. However, Malaysia is on the track to the race of zero net of greenhouse gas emissions as it has 29% reduction of carbon emission. (Charmaine Wong, 2021).

1.3 Statistics of Carbon Dioxide Emission

In 2010, around 14% of carbon emissions are from the transportation sectors. It is observed that the statistic of carbon emission is increasing rapidly since 1900 as it has increased up to 90% in 1970 (United States Environmental Protection Agency, 2022). In the United States of America, transportation sectors contribute around 26% of carbon emissions by sector and medium and heavy-duty trucks contributed 23% of carbon emissions in 2014 according to Epa et al., (2016). According to the European Union, the transport sector is responsible for 28% of carbon dioxide emissions (CO_2) with more than 70% of CO_2 emissions due to road transport in 2019 (Crippa et al., 2019). Malaysia's carbon emissions increased to 250.3 million tonnes last year, up from 241.6 million tonnes in 2017.

According to BP Statistical Review of World Energy, transportations, and garbage were the main sources of emissions (Ethel Khoo, 2019). In 2020, carbon emission per capita was 7.98 tons of CO_2 per capita. The statistics kept increasing from 1.33 tons of CO_2 per capita in 1971 to 7.98 tons CO_2 per capita in 2020 (Knoema, 2021). In Malaysia, the transportation sector accounts for around 28% of total carbon emission, of which 85% comes from road transport (Mustapa & Bekhet, 2016). Malaysia's transportation industry produced 42.43 million metric tonnes of carbon dioxide, accounting for 22.9 percent of the country's total carbon dioxide emissions.

1.4 Problem Statement

Every year, about half of the 10 billion tons of carbon emitted into the atmosphere from human activities remains temporarily stored, in about equal parts, in the oceans and plants. While rising carbon dioxide concentrations in the air can be beneficial for plants, it is also the chief culprit of climate change. The gas, which traps heat in Earth's atmosphere, has been increasing since the industrial age due to the burning of oil, gas, coal and wood for energy and is continuing to reach concentrations not seen in at least 500,000 years. The impacts of climate change include global warming, rising sea levels, melting glaciers and sea ice as well as more severe weather events (Reiny, 2016).

However, with the increasing carbon emission in the world, $\mathrm{CO_2}$ emissions are directly linked to drag and fuel consumption. One of the factors that influences carbon emissions and fuel consumption is aerodynamics. When aerodynamic drag increase, vehicles especially trucks movement through the air is accelerates forward. Thus, the stronger the aerodynamic drag acting on the truck, the more energy requires to move. Therefore, the main objective of the thesis is to design cab roof fairing that will help to reduce the aerodynamic drag imposed on the truck.

1.5 Objectives

The main objectives of the study are:

1. To design a roof fairing of a truck that has an excellent aerodynamically structure that can help to increase fuel efficiency and reduce carbon emission.
2. To examine whether the shaped of cab roof fairing will affect aerodynamic drag or not.

1.6 Scope of Work

This project focused on the design of the cab roof faring on a truck to observe whether it will affect drag or not. The 3D model will be tested using certain parameters that has been set. The simulation will be done as it requires an understanding of the truck aerodynamic shapes. There will be six different designs of roof fairing that will be tested by using Ansys CFD. The drag values obtained from the simulation will be compared between all the model.

Furthermore, based on the values of drag obtained from the simulation, two models will be printed by using a 3D printer. The selected two models will the basic truck design and the best truck with cab roof fairing design. After finished printing, the two models will be tested using wind tunnel with various speed from 441 RPM to 1206 RPM and the velocity from 0 m/s to 15 m/s. The objectives of the experiment are to measure the aerodynamic forces that are being imposed on each of the model. Therefore, the values obtained from simulation and experiment will be compared.

CHAPTER 2 LITERATURE REVIEW

2.1 Overview of the Simulation using Computational Fluid Dynamics (CFD)

Sanda-Mariana et al., (2019) journal focused on the required standards of automotive manufacturing that involves complex studies with the purpose of fuel and noise reduction. Therefore, the automotive must be built with a more laminar distribution based on the shape of the automotive. Thus, the aim of this study is to determine the airflow distribution and minimize the drag coefficient of the truck by using a deflector which is also known as roof fairing. By using CFD, an advanced study can be performed by highlighting the advantages of each component of the truck body structure. Theoretically, the significant roles of the truck dynamic are tested by the aerodynamic shape of the body. It is because when the front air of the vehicles is compressed, the air pressure will increase but decrease at the rear of the body. The simulation experiment is done in two situations. The first version used the basic geometry of the truck without any element added to reduce the airflow. On the other hand, in the second simulated version, a truck with a better and improved truck body model is used. Therefore, from the simulation experiment, it can be concluded that the second version of the truck model that also equipped with upper part deflector proved a better laminar distribution. Therefore, it resulted in the decreasing of drag force as it has achieved a better aerodynamic shape.

Monica T et al., (2017) stated that the squared edges and bluff body shapes have become one of the main problems faced by heavy vehicles such as trucks. To improve fuel economy, heavy trucks should have an aerodynamic design. The low and high-pressure regions of the trucks will lead to the formation of the drag due to the air that passes through the surface of the trailer thus, automatically reducing the fuel consumption. In this study, different trucks with different aerodynamic shapes have been studied by using CATIA V5 R20 and simulated by using ANSYS CFX solver software. The aim of this study is to observe the airflow around the truck as in different shapes and external drag-reducing devices. Therefore, based on this study, the angled base flaps at the rear side known as roof fairing of the vehicle does maximize the benefit of drag reduction compared to the blunt body.

The purpose of this researched by Kulkarni et al., (2015) is to analyse the drag coefficient and fuel consumption based on the existing Tata 1613 trucks modelled in Ansys Fluent. The original truck was modelled in CATIA V5. There are two situations used in the simulation which is in stationary air and moving object or moving air and a stationary object. In this world, better aerodynamically trucks will be expensive, thus the objective of this study is to improve the truck design by minimal modification but still can reduce drag force, lift force and increase fuel performance. The paper proved that the fuel consumption can be saved around 2.4 litres by changing the shape of the wooden board. In conclusion, it has been proven that the drag coefficient can be reduced approximately 43.32% and decrease the fuel consumption by 43%.

Using Ansys Fluent, Chilbule et al., (2014) performed a numerical study on a basic vehicle model that included a trailer. The Shear Stress Transportation (SST) Turbulence Model is utilised to carry out the simulation. The base truck's modified model features a wind deflector and six vortex trap panels, each of which contributes to a decrease in drag that is five and three percentage points more than the original. It is estimated that there was a reduction in drag of 21% in total. The findings of Roy & Srinivasan, (2000) demonstrate that the results obtained with a crosswind speed of 30 miles per hour show that with a better aerodynamic design B, which is a modified model. However, on the other hand, the drag reduction of over 30% is achieved in design A. It is predicted that this will result in a savings of roughly 35% in gasoline. These findings provide more evidence that adjusting the shape of the vehicle may greatly enhance fuel economy.

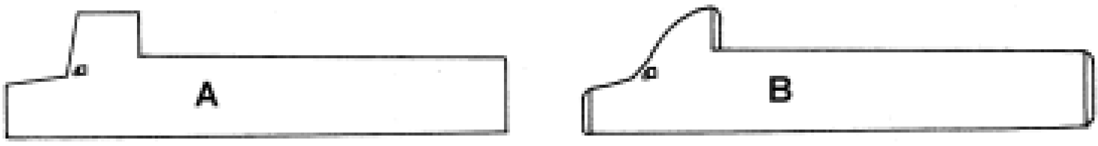

Figure 2.1 Truck design A and B used for simulation. (Roy & Srinivasan, 2000)

2.2 Overview of Experiment by using Wind Tunnel

Vaghela, (2013) study presents the optimization of aerodynamic drag force created in heavy-duty vehicles since the air exerts two types of forces on a moving truck known as drag force and lift force. A huge truck's drag force is caused by its large frontal area; hence, a reduced frontal area will assure a favourable aerodynamic design. As a result, the goal of this study is to recommend an optimal angle to minimise aerodynamic force and hence fuel consumption. In this experiment, a wind tunnel is utilised to create a quick stream of air through the test objects, allowing researchers to analyse the aerodynamic and structural impacts by replicating the air through the objects. A honeycomb bent to provide smooth flow can be included in wind tunnels to assure even flow. The experiment is carried out in a wind tunnel, with tape measuring the pressure differential at each place on the vehicle body. Finally, with a deflector angle of 17.5^o, the velocity of the cab and trailer increases with pressure at the nose of the cab. As a result, it is demonstrated in this study that the deflector on the cab reduces pressure and improves vehicle aerodynamic performance.

Kim, Lee, et al., (2017) conducted an experiment inside of a wind tunnel to compare the effectiveness of a standard cab roof fairing to that of a modified cab roof fairing in terms of their ability to reduce drag. The wind speed in the wind tunnel ranges anywhere from 5 metres per second to 75 metres per second. The wind tunnel test with a low turbulence intensity is carried out to compare the impact of various additional devices on the reduction of drag. Three designs of cab roof fairing are tested in this study which is 2D cab roof fairing based on the streamlined curvature, 2D cab roof fairing with rounded edges also known as 3D cab roof fairing and modified cab roof fairing. The modified cab roof fairing is designed with a simple curvature and additional rounding on the side edges of the 2D cab roof fairing. When compared to the 3D cab roof fairing, which boosts drag reduction by 15.97%, the data demonstrates that the 2D cab roof fairing decreases the drag coefficient by 15.05 percent less than the 3D cab roof fairing. On the other hand, considering that the redesigned cab roof fairing displays a drag reduction of 18.6% at Reynolds number of 9.1×10^5, one may draw the conclusion that it is the most effective.

2.3 Overview of Add-ons and the Placement on the Vehicles.

According to the study by Chowdhury et al., (2012), various kinds of add-ons are intended to show that the overall projected frontal area will be increased, and the value of the drag coefficient will also increase depending on the positioning of the add-ons. The primary purpose of the research is to investigate the effect that various vehicle add-ons have on overall energy usage as well as GHG emissions. There are a variety of vehicle add-ons that are used, including police sirens, taxi signs, advertising signs, roof-racks, and roof loads of ladders and barrels. These vehicle add-ons were developed and built to be attached to the 25% scale of base model of the automobile to ensure that the airflow is practical. The test is done with a speed of 40km/h to 120 km/h under four different yaw angles of $0°, 10°, 20°$ and $30°$.

According to the results of the research, the frontal area of the car models rose by around 5% points when the barrel was installed as opposed to when the police sirens were. Finally, the findings demonstrate that the drag caused by the taxi sign is growing by around 5%, whereas the drag caused by the barrel is nearly 40%. Based on the results of this experiment, the baseline model with the barrel connected has the highest values for the drag coefficient when compared to the other four add-ons. The reason for this is that the barrel has a larger surface area, thus the frontal area that was projected became larger. It is possible to draw the conclusion that the size of the add-ons will influence the rise in drag, which in turn will influence fuel consumption.

Based on the study by Kumar et al., (2018), it investigates the effect of dimensions and placement of a flat cab roof deflector on the aerodynamic performance of the truck. From the simulation made by using Ansys, it is set that the drag force is minimum of the width of the deflector at the rear is maximum. Thus, the position of the deflector must be maximum or equal to the trailer width. It is important to not misplace the cab roof fairing as it will increase the total drag up to 2.9%. An optimum design of the rear and front width of the deflector can reduce the drag up to 7.8% and 3% respectively. In conclusion, it is proved that the proposed dimensions and positions of the cab roof fairing prove that it can reduce the total drag of the truck by approximately 12%.

According to Salati et al., (2017), one of the add-ons that may assist in lowering the amount of resistance that a heavy truck experiences is a front-rear trailer system that is separated into four sections: the top, the side, the front, and the rear. The underbody area and the back of the trailer are where the main of the trailer's drag is produced. The study of the experiment is carried out using a wind tunnel test conducted out on a scale model of 1:10. According to the results of the study, the greatest reduction in drag that can be achieved by installing both the front and the rear device on the truck is around 9.5%. The length of the device should ideally be at about 45 centimetres in length. This device is also a useful approach for minimising the aerodynamic forces operating on a container, which is important because the shear stress and the sources of drag are significantly larger on a container than they are on a normal trailer.

In the author's earlier studies by Salati et al., (2015), to reduce the influence of drag vortices formed in the back of the model, the Airbag is used. The rear model's vortices will be influenced by the fin's presence. To control the trailer's back wake, the boat's tail geometry was developed. As a final resort, the trailer's front-to-rear geometry was created to raise the separation on that side just over the trailer's surface for optimal visibility. As a result of its small size and placement, it may have only a little influence on trailers' ability to park and store their payloads. When there is no crosswind, the study found that the vehicle's total drag may be reduced by up to 12%, resulting in a 4% fuel savings. The front-rear trailer system improves the aerodynamics of big trucks in both crosswinds and front winds. Any truck, regardless of brand, may have this device fitted without affecting the vehicle's operation. Though the boat-tails are a viable method of lowering drag, there are safety concerns for other cars in the event of an accident when this equipment is in use.

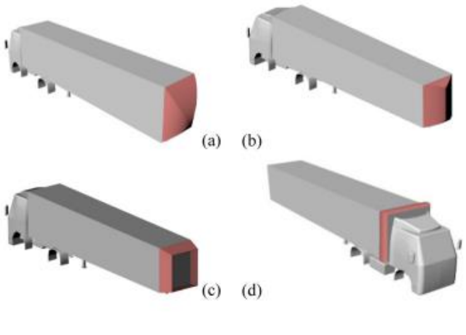

Figure 2.2 Devices installed on the trailer. Airbag geometry (a), fin geometry (b), boat tail (c), front trailer device (d). (Salati et al., 2015)

According to the study by Hariram et al., (2019), it observed the different aerodynamic solutions regarding tractor and semi-trailers used in European countries. The aim of the research is to propose aerodynamic measures for a wide range of formats to reduce carbon emissions. By introducing innovative and energy-efficient trucks and load carriers, the focus is to enhance load efficiency by 25%. Some of the solutions that have been considered are by using front and underbody deflectors, rear diffusers and more. Each of them can do works as it can reduce the drag friction. Therefore, one of the key innovations presented in this paper is to demonstrate a mission-based configurable aerodynamic truck-trailer design to optimize the drag coefficient. If the roof fairing is not adjusted and placed in the right way, the leading edge will be sharp thus, it will disturb the airflow. The air flow again will be disturbed when it flows along the trailer roof and at the back of the trailer. Therefore, with the help of correctly installed roof fairing, drag can be reduced and reduced fuel consumption. A cab roof fairing is a stiff and sophisticated shaped wedge on the cab's roof top that directs wind around the trailer from the tractor's front. An adequately sized cab roof deflector is sometimes integrated to adapt the trailer's varied heights which means that the roof fairing must be adjusted to the trailer's roof height.

Chowdhury et al., (2013) has conducted a study to investigate the aerodynamic impact of fuel-saving technologies in a tractor-trailer. This experiment is conducted in a wind tunnel using a model vehicle scaled at 1:10. This research employs several external attachments, including front fairing, side skirting, and gap filling. Therefore, all external attachments will be evaluated at various vehicle speeds and yaw angles. Aerodynamic drag was measured in this study using a wind tunnel with a maximum speed of 145 km/h. During the experiments, four separate yaw angles of 0°, 5°, 10°, and 15° were utilised. The test findings revealed that minimising aerodynamic drag was dependent not only on the front fairing, but also on the filling of various gaps in other body components. Clearly, the amount of surface area covered by the exterior fairing has a substantial effect on drag reduction. Results suggested that partial gap filling can improve drag reduction performance, however full gap-filling indicates the best results. Lowering the drag by covering the exterior attachments, is feasible to reduce both drag and fuel use. In conclusion, this research shows that the front fairing may reduce the amount of drag by up to 17%, while the addition of aerodynamic fairings in other portions of the vehicle can reduce the amount of drag by up to roughly 26%.

2.4 Overview of the Difference between various Designs of Cab Roof Fairing

The aim of this study by Kim, Hong, et al., (2017) is to focus on the reduction of the aerodynamic drag of heavy vehicles by prepared three cab roof fairing with different materials. This study had prepared three various kinds of roof fairing which are created from basic material, bio-inspired material and advanced bio-inspired material. On the side surfaces of the vehicle models, the bio-inspired CRFs considerably decreased the areas of split shear flow and turbulent kinetic energy levels. According to the research work, cab roof fairing can lower the drag coefficient of a 40-foot trailer type by 30 percent at 65 mph. One of the design cab roof fairings in this research is influenced by the form of sea lions' heads. This is because sea lions are one of the fastest animals that can swim in the ocean, reaching speeds of around 10 metres per second. In this study, the curvature inspired by sea lions were being simplified to match with the cab roof fairing with a hope that it can control the flows on both sides surfaces of the vehicles.

The aerodynamic drag exerted on the car model was measured using a seven-component external balance, and the measurement accuracy of the drag force was within the error margin of 0.2%. The vehicle model was put on the balance by attaching the front and rear wheels to the four contacts of the balance. By spinning the turntable supporting the vehicle model and the balance to adjust the yaw angle from 0° to 15°, the influence of crosswind on the aerodynamic forces exerted by the vehicle was determined. Experiment results indicate that the advanced bio-inspired cab roof fairing may successfully lower the drag coefficient by roughly 20% for 15-ton heavy vehicle models and 23%t for 5-ton models. The study by (Markina et al., 2020) has prepared a set of different shapes of cab roof fairing to be tested on the KAMAZ heavy truck to study the aerodynamic drag coefficient. A 3D model of KAMAZ-65117 car with a mass of 24,000 kg was built. The present investigation is based on a few presumptions, the most important of which is that the built model includes only the primary and largest structural elements, and that all gaps and transitions between the surfaces of the body parts that are smaller than 30 millimetres in width are disregarded. From the simulation, it is concluded that the model with cab roof fairing shows a streamline air flow. Therefore, it is concluded that t the using of cab fairings on KAMAZ heavy truck can significantly reduce the force of aerodynamic drag by reducing the drag of the trailer.

It also stated in the study that the drag force has been reduced about 19.1% with the use of cab roof fairing. For fuel consumption, it is decreased by 5.1% which is about 1.54 litre for a fully loaded truck at a speed of 60 km/h. Moreover, with the help of fairings, skirts and deflector on the truck, 9.31% decreased on fuel consumption which makes it save around 3.15 litre at a speed of 90 km/h.

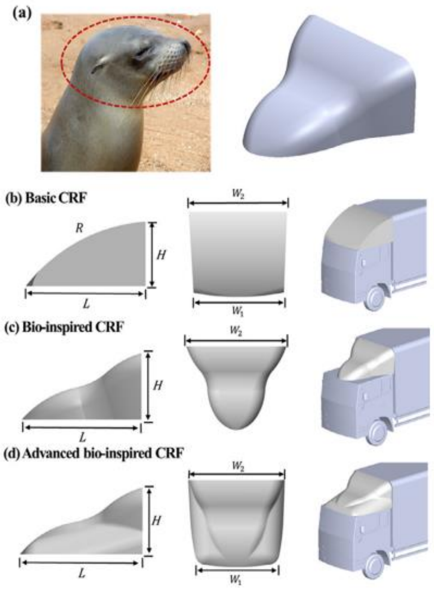

Figure 2.3 Three designs of cab roof fairing prepared in the study by (Kim, Hong, et al., 2017)

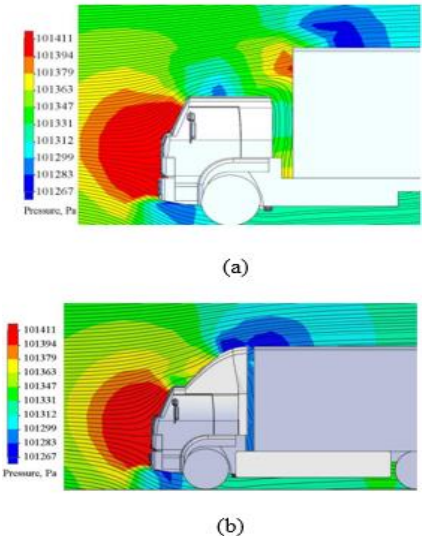

Figure 2.4 The streamline for flow over KAMAZ cabin with and without cab roof fairing. (Markina et al., 2020)

2.5 Overview of the relationship between Yaw Angle and Aerodynamic Drag

According to the study by Chowdhury et al., (2012), a rise in the yaw angles of advertising signs would result in an increase in the value of drag because of the higher projected frontal area. The rising yaw angles of the roof rake, on the other hand, led to a decrease in the amount of drag and friction as the roof became more streamlined. It has been concluded in the study, that the baseline vehicle that does not have any add-ons will always have the lowest number for the reduction in the amount of drag, regardless of the yaw angle. On the other hand, yaw angle has different effects on different combination of the baseline model. From Figure 2.6, the aerodynamic drag decreases with the increase of yaw angles for configuration a, e and f whereas the aerodynamic drag and yaw angle respectively increases for configurations b, c and d. Therefore, the study concluded that there are about 17.6% and 26.1% of aerodynamic drag reduction in ‘configuration a’ and ‘configuration b’ respectively.

According to Salati et al., (2017), nevertheless, the tractor-trailer gap on the sides of the vehicle needs to be carefully built, and this is especially important when the vehicle is operating in a circumstance where there is a crosswind. It is possible for free-stream wind to enter between the driving cab and the trailer if the yaw angle, which is the angle formed by the speed of the vehicle and the direction of the wind, becomes significant. In this scenario, the drag of the vehicle is equal to the total of the drag of its two distinct bluff bodies, in contrast to the front wind condition, in which it is often lower. Side fairings are fitted onto the driving cab in order to circumvent this issue and maintain control over the flow-field that exists between the two bluff bodies. On the other hand, the fact that there was no moving ground during the experiment had an effect on the flow field in the underbody of the vehicle. This particular aspect is most noticeable at the zero-yaw angle, which is the location where the numerical computations and wind tunnel tests revealed the greatest disparities from one another. The separation over the leading top edge of the trailer has the greatest impact on the flow field around the vehicle when the yaw angle is increased where the underbody has much less of an effect.

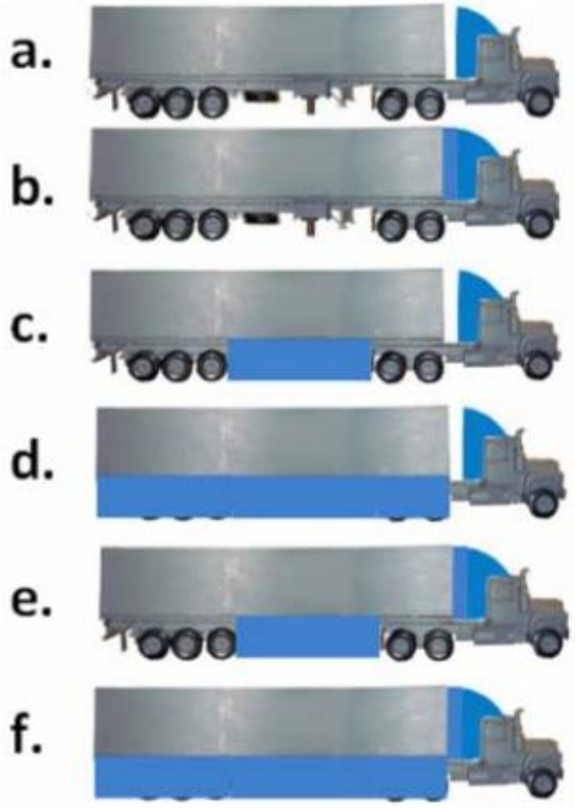

Figure 2.5 Different combinations of fairing on the baseline semi-trailer truck model. (Chowdhury et al., 2012)

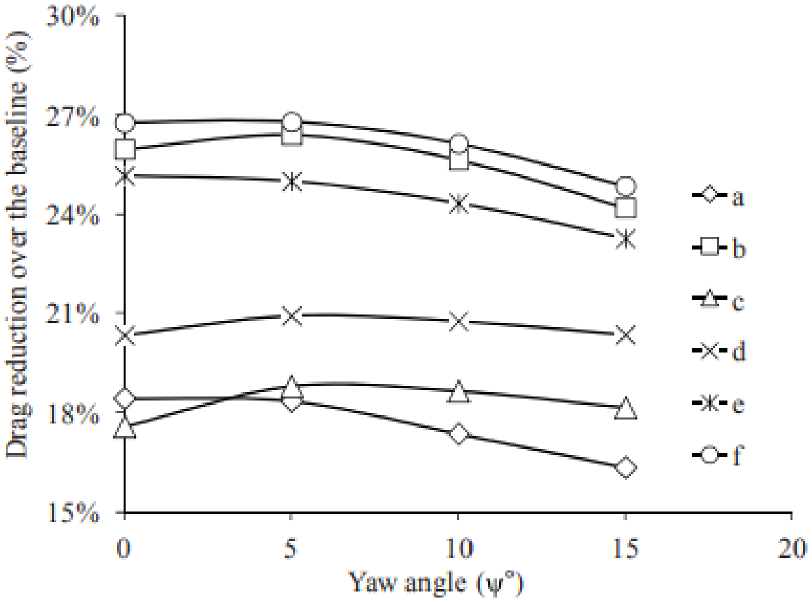

Figure 2.6 Drag increase over base vehicle in percentage as a function of yaw angle. (Chowdhury et al., 2012).

2.6 Overview on the Aerodynamic Drag and Fuel Consumption

The research work by Sivaraj et al., (2018) has compiled data on the overall aerodynamic performance of road cars and how to counteract the increase in drag force in order to determine the optimal placement for a car's base bleed. Theoretically, the overall aerodynamic drag force may be reduced by minimising the wake region at the back of the vehicle and decreasing the pressure in front of the vehicle by delaying flow separation. In this study, a subscale model of a hatchback automobile with several base bleed locations throughout the front and rear of the vehicle is tested in a wind tunnel. The low-pressure region is created due to the flow separation. The study demonstrated that fuel consumption may be reduced by improving the aerodynamics of a vehicle, as the optimal placement of base bleed on the front and back sides of a vehicle reduced the drag coefficient by 6.188%. This lowered fuel consumption by up to 4.33% in an actual 70 km/h hatchback automobile. According to Heinz Heisler, (2002), this is because the airflow on a moving hatchback automobile generates a larger wake zone, which can increase the amount of drag at the rear of the vehicle.

Khosravi et al., (2016) had carried a comparison study to determine whether it is possible to improve the aerodynamic performance of trucks to increase their fuel economy by utilising the most efficient design of extra devices. The results of a study of airflow contours and an optimization technique show that two plates at the sidewalls of a gap with optimal length and installation angle can achieve a 20% and 10% decrease in drag force and fuel consumption, respectively. It is possible to accomplish this aim by optimising the plate length as well as the installation angle. According to the analysis done on the data, it was determined that the coefficient of drag could be powered to 20%, which would result in a reduction of between 4 and 10% in the amount of fuel that would need to be used annually. Rajendran et al., (2015) has studied the numerical model based on the Computational Fluid Dynamics on small vehicles to obtain the flow structure around the passenger car with tail plates. From the experiment, the drag coefficient is reduced up to 3.87% due to the use of tail plates. The objective is to reduce aerodynamic drag acting on the vehicle and thus improve the fuel efficiency of passenger car.

Moreover, Kulkarni et al., (2015) also mentioned in its own study that 2.4 litres fuel can be saved by changing the shape of the wooden board which is used on the truck which decrease the fuel consumption for about 43%. According to Rose, (1981), the maximum observed reduction in drag coefficient, 36 percent, was achieved by combining two devices, resulting in a 16% fuel savings at a constant 80 km/h and a 13% fuel savings at a constant 50 km/h. On a 365 km road test route, utilising one of the most fuel-efficient single devices, further tests revealed a 13.2% fuel savings under moderate driving conditions. It is estimated that a 40-tonnes articulated truck travelling at 60 mph consumes around 34 litres of fuel to overcome the drag caused by travelling the length of a 100-mile highway strip, but an ordinary automobile would consume fuel at a rate that is four times lower under comparable conditions.

Next, according to Mohamed-Kassim & Filippone, (2010), heavy vehicles, in comparison to other ground vehicles, have poor aerodynamic efficiency due to the enormous frontal surfaces and bluff-body forms of their bodies. According to the study, long-haul driving cycles are called LHDC whereas NEDC is The New European Driving Cycle created to resemble European urban driving. According to the research work, urban distribution uses 13 percent more fuel than LHDC. In the NEDC instance, accelerating from repeated stops requires more gasoline. Less than half the 45,600 litres consumed yearly is used to counteract drag. The main reason for this is that more fuel is needed to accelerate the truck from frequent stops in the NEDC case. Only 14.7% of the 45,600 L consumed yearly is utilised to counteract drag, less than half on a long-haul travel. 43% of gasoline is used for acceleration. If the truck's load weight is lowered, fuel used for tyre resistance and acceleration drops proportionally but drag stays the same. For 20 tonnes, NEDC truck fuel efficiency is enhanced by 41% compared to original weight. Under LHDC, weight reduction increases fuel economy by 27 percent. The NEDC and LHDC examples utilise 27,000 and 30,000 L yearly, respectively. Aerodynamic drag dominates fuel use in LHDC, especially when cargo weight is lowered, but in NEDC, most fuel is needed to accelerate the vehicle, especially with heavy loads.

CHAPTER 3 RESEARCH METHODOLOGY

Aerodynamic contributes 50% to overall fuel economy, therefore it is one of the main problem that is needed to be solve by designing a vehicle that can reduce aerodynamic drag (International Trucks, 2013). A poorly designed roof fairing will cause the airflow to hit the flat front of the trailer, thus increasing the aerodynamic force. Due to this, the trucks will use more fuel that will lead to high fuel consumption to move against the increasing aerodynamic force that hit the front of the trailer.

In order to finish the experiment, there are two phases that need to be done, and those processes are the simulation and the experimental technique. To begin, Ansys Fluent is the software that is used to carry out the simulation. Ansys is a programme for engineering simulation on 3D design that can give product modelling solutions with an unequalled scalability and a full multi-physics. Ansys was developed by Dassault Systems. Because of this, Ansys is able to assist both individuals and businesses in the development of new products and the validation of existing ones (Ansys, 2014).

Ansys Fluent is a type of software for simulating fluids that operates on the basis of computational fluid dynamics (CFD), a method that has shown to be of great assistance when coping with situations that occur in the real world. Ansys Fluent provides task-based pre-processing workflows that may be adjusted to assist speed up the process of building a high-quality CFD-ready mesh. These workflows can be accessed using the Ansys Fluent user interface (Simutech Group, 2021). Therefore, it is important to show that a truck with roof fairing can and definitely will decrease the fuel consumption and carbon emission compared to the trucks that do not use roof fairing. In conclusion, trucks with better aerodynamic shapes and add-ons can improve fuel efficiency. Therefore, it is important for a truck to have roof fairing within the right place to reduce fuel consumption and carbon emissions.

3.1 Simulation

There are six models used in the simulation to prove whether cab roof fairing really can help to reduce the aerodynamic drag on a truck. Certain of the models are inspired by a real-life design that can be seen on the road. Design 3 and Design 4 are bioinspired by the dolphin head however the difference between these two designs are the height difference. Figure 3.1, shows the real-life cab roof fairing that is used as inspiration in the simulation.

Figure 3.1 The example of cab roof fairing used on lorry that can be seen on the road

3.1.1 2D Design of the Cab Roof Fairing

In order to make sure that the simulation done will be much more accurate, the test enclosure sections dimensions are not changed, thus it has the same dimensions for all the cases with the truck model at the middle. Below show the dimensions of the enclosure section.

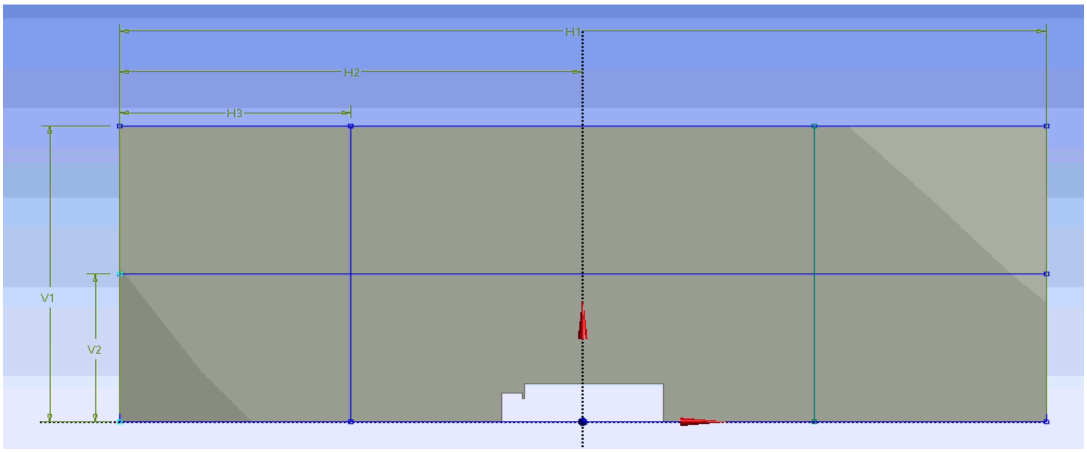

Figure 3.2 Test enclosure section

Table 3.1 Dimensions of the test enclosure sections

Dimensions Label	Dimensions (m)
H1	80
H2	40
H3	20
V1	30
V2	15

3.1.2 Design Model 1

To put it another way, the cab roof fairing was not included in the vehicle in its model 1 version. It is because, this model will be used as the baseline and will be compared with other design. Based on the Figure 3.3, the width of the truck head is labelled as H7 is 1.80 m while the height of the truck is 2.90 m.

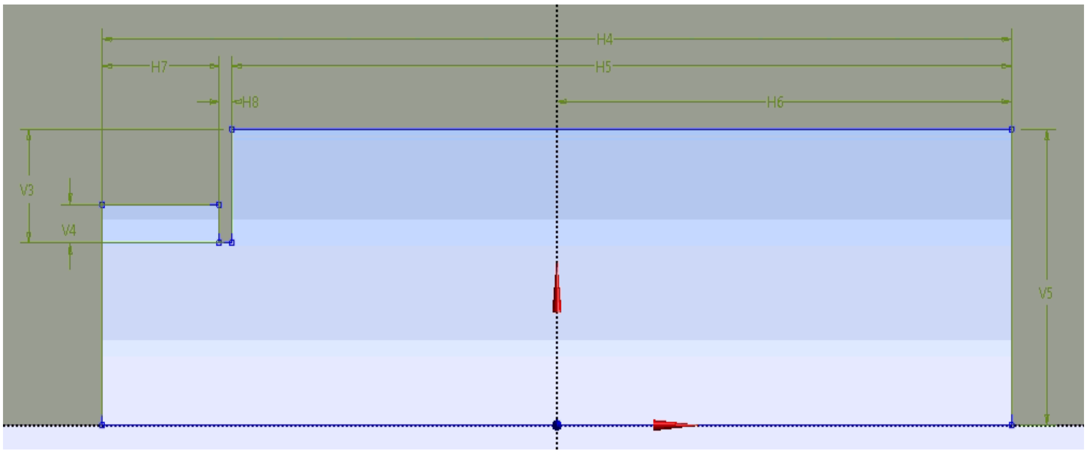

Figure 3.3 Design Model 1 with dimensions labelled

Table 3.2 Dimensions of Design Model 1

Dimensions Label	Dimensions (m)
H4	14.00
H5	12.00
H6	7.00
H7	1.80
H8	0.20
V3	1.50
V4	0.51
V5	3.89

3.1.3 Design Model 2

Truck in Design Model 2 is installed with the first design of cab roof fairing. The height of the cab roof fairing is set at 0.99 m while the length is 1 metres. The cab roof fairing is designed sharp so that the air flow can be observed through simulation. The design of the cab roof fairing installed is shown in the Figure 3.4.

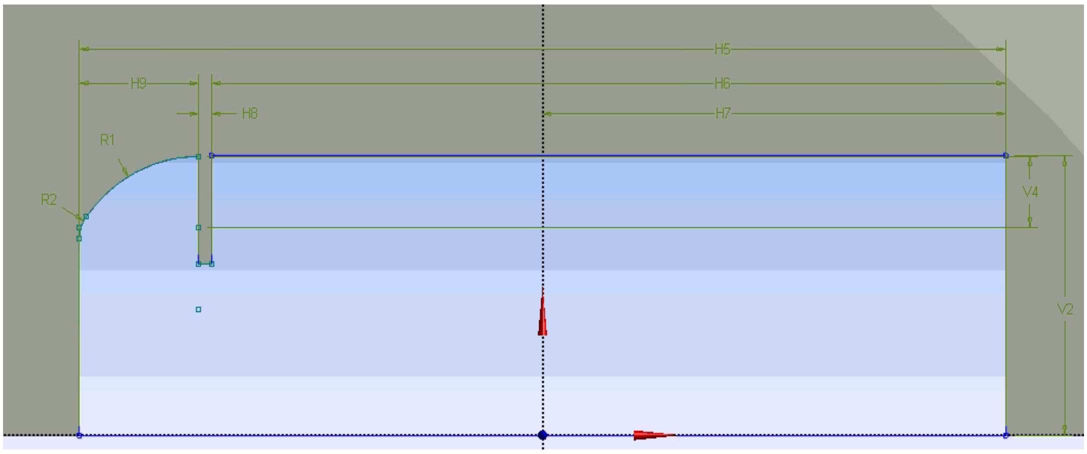

Figure 3.4 Design Model 2 with dimensions labelled

Table 3.3 Dimensions of Design Model 2

Dimensions Label	Dimensions (m)
H5	14.00
H6	12.00
H7	7.00
H8	0.20
H9	1.80
V2	3.89
V4	0.99
R1	2.13
R2	0.50

3.1.4 Design Model 3

The cab roof fairing has a height of 0.99 metres and is fitted at the same height as the truck cabin. Therefore, the simulation will be used to determine whether or not the height of the cab roof fairing will influence the aerodynamic drag.

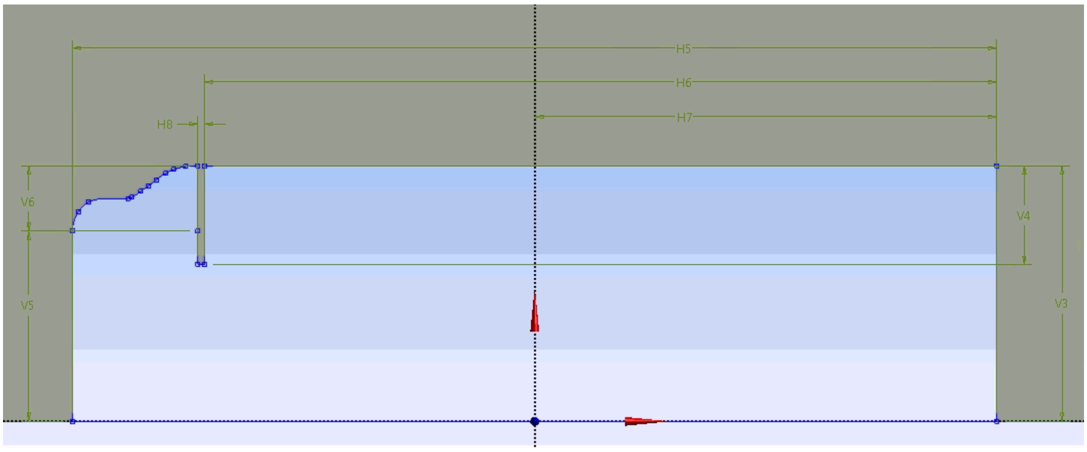

Figure 3.5 Design Model 3 with dimensions labelled

Table 3.4 Dimensions of Design Model 3

Dimensions Label	Dimensions (m)
H5	14.00
H6	12.00
H7	7.00
H8	0.20
V3	3.89
V4	1.50
V5	2.90
V6	0.99

3.1.5 Design Model 4

It is clear by looking at the shape of the cab top fairing in this design that this design is fairly identical to Design Model 3. However, the height of the cab roof fairing is just 0.74 metres, which means that it will be significantly lower than the truck cabin. The design of the curve may be altered by making manual adjustments to the bezier curve. A Bezier curve is a mathematically defined curve that is utilised in visual application that only deal with two dimensions. The curve is defined by four points: the starting point, the ending point, and two independent locations in the centre that are referred to as handles. The central points of the Bezier curve can be adjusted by manually in order to produce a variety of different shapes. (Tech Target Contributor, 2005).

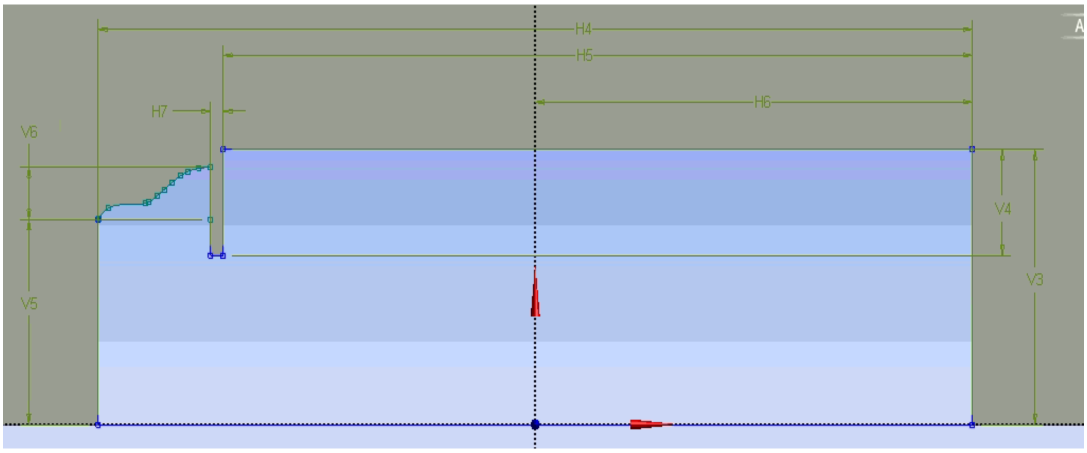

Figure 3.6 Design Model 4 with dimensions labelled

Table 3.5 Dimensions of Design Model 4

Dimensions Label	Dimensions (m)
H4	14.00
H5	12.00
H6	7.00
H7	0.20
V3	3.89
V4	1.50
V5	2.90
V6	0.74