ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

School of Mechanical, Chemical and Materials Engineering

A Numerical study on the Effect of Aerodynamic Devices on the tractor –trailer Sino Truck(model 321) :A Case study of Mesfine Industrial Engineering PLC.

A thesis submitted in partial fulfillment of the requirements for the award of

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Master of Science

In

Automotive Engineering

By

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Advisor: Prof. Chul-Ho Kim

Mechanical systems and Vehicle Engineering program

January, 2017:Adama

CANDIDATE'S DECLARATION

I hereby declare that the study thesis work which is being presented in the paper entitled "A Numerical study on the Effect of Aerodynamic Devices on the tractor –trailer sino Truck(model 321):A Case study of Mesfine Industrial Engineering PLC.in partial fulfillment of the requirements 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 Prof. Chul-Ho Kim, Department of Mechanical and Vehicle Engineering, Adama Science and Technology University, Adama, Ethiopia.

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

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DEDICATION

This thesis is dedicated to all my family members and my sincere friends.

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TABLE OF CONTENTS

Table of Contents **Page**

ACKNOWLEDGEMENTS..........i

TABLES OF CONTENTS..........ii

LIST OF TABLES..........Vii

LIST OF FIGURES iX

ACRONYMS AND ABBREVATIONS..........Xii

ABSTRACT..........xiii

1.**INTRODUCTION**..........1

1.1 Background of the study..........1

1.2 Statement of problem..........5

1.3 Objectives of the study..........7

1.3.1 General objective..........7

1.3.2 The specific objectives of the study..........7

1.4 Research question..........7

1.5 Significance of the study..........7

1.6 Scope of the study..........8

1.7 Limitation of the study..........8

1.8 Organization of the study..........8

2. **LITERATURE REVIEW** 10

2.1 Overview..........10

2.2 What are Aerodynamic Devices?..........10

2.3 Aerodynamic Drag for a Heavy vehicle tractor-trailer truck..........11

2.4 Tractor-trailer gap affect..........17

2.5 Aerodynamic characteristic Air Flow ground Truck..........18

2.6 Tractor Aerodynamic Devices..19
2.7 Drag Reduction through Attach Add-on Devices...,20
2.8 Air flow at the Rear of the trailer..22
2.8.1 Taper tails/extension panels...23
2.9 Factors contributing to flow field around truck 26
2.9.1 Separation:...26
2.9.2 Boundary layer...27
2.9.3 Friction Drag...27
2.9.4 Pressure drag...28
2.10 Shape changes affecting drag 28
2.11 Models Applied in CFD Simulation for Truck 30
2.12 Side Wind Performance 31
2.12.1 Trailer yaw..34
3. MATERIALS AND METHODS..38
3.1 Methodology..38
3.1.2 Model Geometry Specifications and Considerations...38
3.1.3 Sino Truck Model321 Technical Specification...39
3.1.4 Specifications of existing Sino Truck 39
3.1.5 Experimental range of operating parameters of the model sino truck32...........................40
3.2 Selected Case...40
3.2.1 Reference(Original Model321)..40
3.2.2 Gap treatment...41

3.2.3 Base treatment Sino Truck model 321..42

3.2.4 Undercarriage treatment..42

3.2.5 Aerodynamic Trailer..43

3.3 Baseline Model to the modified Model..44

3.3.1 Reducing Drag with Aerodynamic Device...46

3.4 Boundary and initial Conditions for CFD Calculation..48

3.5 Sino Truck Aerodynamics: Numerical Evaluation Methods.......................................48

3.6 Aerodynamic Simulation Sino Truck Methods..49

3.7 Case description &CFD Simulation Setup...50

3.8 Sino truck model test in with different velocity..52

3.9 Total Drag Force of Sino Truck Calculation..52

3.9.1 Drag..53

3.9.2 Drag coefficient (C_d) calculation performance analysis of Sino truck model32.............52

3. 9.3 Calculation of Power Requirements and fuel consumption..54

3.9.4 Fuel Consumption..54

3.10 Forces and Moment on the Sino Truck...55

3.11 Calculation of rotational moment at each axis 55

3.11.1X-axis moment (Rolling)..55

3.11.2 Y-axis moment (Pitching)...56

3.11.3.Z-axis moment (Yawing)..56

3.11.4 Yawing Resistance moment(My)..57

3.11.5 Rolling Resistance momentum (Mrr)......57

3.11.6 Pitching Resistance moment (Mpr)......58

4. RESULTS AND DISCUSSION......59

4.1Results and Analysis......59

4.1.1 Optimamum grid test use velocity and pressure 60

4.1.2 Comparing air movement with and without a cab roof deflector......61

4.1.3 Air flow underneath the Trailer......67

4.1.4 Side Plate......70

4.1.5 Base plates......70

4.1.6 Rear of the Trailer......71

4.1.7 Frame extension......72

4.2 Aerodynamics Performance Analysis of Sino Truck(Model321)......74

4.2.1 Drag coefficient at different speeds......74

4.2.2 Total Drag Force at different speeds......75

4.2.3 Total resistance Force......76

4.2.4 Power requirement......77

4.2.5 Fuel Consumption......79

4.3 Stability of Side Wind......81

4.3.1 CFD calculation output Of the Modified Sino Truck......81

4.3.2 Centrifugal Force and Momentum......82

5. CONCLUSION AND RECOMMENDATION 90

5.1 Conclusion......90

6.2 Recommendation.....91

REFERENCES.......92

APPENDIX.....97

Appendix – A- Mesh Settings by Part.....97

Appendix –B-Drawing..... 99

.

LIST OF TABLES

Table 1: Comparison between several widely used turbulence Model for truck..........................31

Table 2: Aerodynamic general Specifications sino truck model 321..38

Table 3: Technical specification...38

Table:4 Specifications and detail dimension of Sino Truck model321......................................39

Table 5: Experimental range of operating parameters of the Model sino truck321.....................40

Table 6: Selected cases..40

Table 7: Different Model Modification...47

Table 8: Boundary Condition Settings...48

Table 9: Grid Test..60

Table 10: Drag Coefficient at different speeds 74

Table 11: Drag Force versus Speed..75

Table 12: Total Resistance..76

Table 13:Power requirement 77

Table 14:Fuel reduction..79

Table 15: Fuel saved in lit/80km...80

Table 16: Specifications of Sino truck model 321...*81*

Table 17: Boundary condition settings for stability from CFD..82

Table 18 :Centrifugal Force and Mc...83

Table19: Moments coordinates from CFD result..85

Table 20: Moments about origin or rolling center...85

Table 21: Grid test (existing Sino truck (model 321)model testing in the domain..................97

Table22 :Mesh settings for the tractor Sino truck (model 321)...97

Table 23: Mesh settings for the trailer of sino truck(model 321)..98

Table 24: Mesh settings for the Devices...*98*

LIST OF FIGURES

Figure 1: Critical Flow region for the Drag 6

Figure 2: Distribution of Aerodynamic drag for a Heavy vehicle tractor trailer truck..................12

Figure 3:Gap region and Gap flow fields for a typical tractor-trailer truck..................................17

Figure 4: Trailer bluff base and base flow field of a tractor-trailer truck.....................................23

Figure 5:Cross flow vortex trap gap over front face...24

Figure 6: Different flow topology due to tractor streamlining...26

Figure 7: Complete set of Forces acting on a Truck..29

Figure 8 :Side Force acting on Sino Truck...32

Figure 9: Side wind motion Around Tractor-Trailer, plus wake region.......................................36

Figure 10:The baseline (Model1 Sino truck321)...41

Figure 11:Model 2 sino truck321..41

Figure 12:Vortex stabilize..41

Figure 13:Base treatment..42

Figure 14:Undercarriage treatment...43

Figure 15: Teardrop...43

Figure 16 :Baseline model 1 (Existing model of sino truck 321)..44

Figure 17:Optimal (Modification model321)..45

Figure 18:A Tractor-Trailer without Aerodynamic devices...46

Figure 19: Tractor-Trailer with Aerodynamic Devices installed produces less Drag 46

Figure 20:Optimum of Grid mesh……………………………………………………………………………51

Figure 21:Frontal view of Sino Truck Model321...55

Figure 22:Side view Sino truck Model to show Pitching...56

Figure 23: Top view of Sino Truck Model321...*56*

Figure 24:Bottom view of Sino Truck Model321...57

Figure25:Front view Sino truck Sodel321 Rolling resistance Moment...57

Figure 26: Grid convergence Test...60

Figure 27:Model 1 velocity and pressure distribution (64kM/h)..61

Figure 28:Model 1 Velocity and Pressure distribution (80kM/h)..62

Figure 29:Model 1 Velocity and Pressure distribution (96kM/h)..63

Figure 30: Velocity and Pressure distribution over Sino truckMode2(64km/h).....................64

Figure 31: Velocity and Pressure distribution over Sino truck Mode2(80kM/h)....................65

Figure 32: Velocity and Pressure distribution over Sino truck Mode3(64kM/h)....................67

Figure 33: : Velocity and Pressure distribution over Sino truck Mode3(80km/h*)...................67*

Figure 34: Velocity and Pressure distribution over Sino truck Mode3(96kM/h*)......................68*

Figure 35: Total Pressure and Velocity contour for simulations at Y= 900mm.........................69

Figure 36: velocity magnitude displayed 600mm above ground baseline and original.........70

Figure 37: Velocity vectors displayed in a z-plane of side plate..70

Figure 38: Velocity vectors of the base wake displayed in the symmetry plane........................71

Figure 39:Velocity vectors displayed in symmetry plane rear trailer..71

Figure 40:Frame extension Pressure displayed in symmetry plane...72

Figure 41: Velocity magnitude displayed in symmetry plane..73

Figure 42 : Drag coefficient versus speed of models of Sino truck..75

Figure 43: Drag Force versus Speed of Models...76

Figure 44:Total resistance..77

Figure 45: Power requirement versus speed..78

Figure 46:Body diagram of yawing momentum..83

Figure 47: Rolling resistance momentum(Mrr)..84

Figure 48:Pressure and velocity distribution respectively(64km/h)..86

Figure 49: velocity and pressure distribution respectively(80km/h)...87

Figure 50 :Top view pressure and velocity distribution respectively 88

Figure 51 :Front view pressure and velocity distribution respectively.......................................89

Figure52: Side skirts...99

Figure 53:Teardrop – side view, measures...99

Figure 54: Side plates - side and top view, measures..... 100

Figure55: Reference trailer - top and side view, measures..100

ACRONYMS AND ABBREVATIONS

CFD	Computational Fluid Dynamics
LES	Large Eddy Simulations
CAD	Computer Aided Design
DC	Drag Counts
DNS	Direct Numerical Simulation
F_S	Fuel Saving
LBM	Lattice Boltzmann Method
PID	Property Identification
RANS	Reynolds Averaged Navier-Stoke
F_D	Drag force
A	maximum cross sectional area of tractor-trailer truck, m^2
C_D	Drag coefficient
G	Gap between tractor and trailer
HP	Horsepower
M_{yawing}	yawing moment
$M_{pitching}$	pitching moment
$M_{rolling}$	Rolling moment

ABSTRACT

Reducing the Fuel consumption of Sino Truck(model321) is one of the most great issues within the Automotive industry and other company. Together with the increased Fuel price, the development of more Fuel efficient Sino Truck has escalated. Fuel reduction for trucks showed that aerodynamic improvement is one of the most important technique when it comes to Fuel saving. Sino Truck(model321) has a well established aerodynamic focus in the product development process of the tractor and trailer aerodynamics. Different aerodynamic trailer devices and aerodynamically shaped tractor-trailers gap have been tested by means of Computational Fluid Dynamics, in order to investigate their influence on the flow around the Sino Truck. In addition, drag contribution from different regions are analyzing to see where it is possible to gain most drag. Finally, an evaluation was done to see if the results from the simulations could promote any possible aerodynamic profits of a mutual development between tractor and trailer manufacturers. Devices that are implemented in the undercarriage and base region presented the best results, which indicates that these regions are most susceptible for drag improvements. Devices placed at the rear face of the trailer improved the flow from the roof and the upper sides. The gap treatment improved the flow over the gap and along the trailer roof, although a larger gap clearance would probably have amplified the effect of these devices. Profits of such mutual development can for example be that the gap could be further reduced, and the interface and flow transition between the cab, the trailer, the tractor and the trailer undercarriage can be optimized. Sino Truck (model 321) subjected to 43.2kM/hr crosswind at the different speed from 64kM/hr up to 96kM/hr .The results of the driving CFD are compared with result of yawing moment(M_{yawing}),rolling moment($M_{rolling}$) and pitching moment($M_{pitching}$) values are smaller than each result of rotational resistance(Mrr), yawing resistance(Myr), Pitching resistance(Mpr).

Keywords: *Aerodynamics,CFD,drag reduction ,tractor- trailer, Fuel economy, stability*

1. INTRODUCTION

1.1 Background of the study

A Sino truck in motion is subjected to different aerodynamic forces such as drag, lift. The goal of aerodynamic design is to accurately and efficiently determine surface shapes that attain optimal aerodynamic performance. Although the focus is on aerodynamic design, it should be noted that optimal shape design problems, are the optimization of a performance criterion depends on the shape of a boundary, occur in many areas of engineering. Aerodynamic drag is the force that resists the movement of a body through a fluid medium. Aerodynamic drag varies with the square of the relative speed U_∞ between the truck and the surrounding air. When a truck travels through still air, doubling the heavy speed approximately quadruples the aerodynamic drag. In the presence of terrestrial winds that are not in-line with the truck motion, crosswinds generate a non-zero yaw angle of the wind relative to the sino truck travel direction. For heavy-duty sino truck, such as tractor-trailer combinations, the drag coefficient increases significantly with yaw angle [1].

Today, there are a large number of Class 8 sino truck tractor-trailer drag-reducing devices and technologies both in-use and under development. Many of these have been extensively studied, with the performance benefits well documented in the research press. These include roof deflectors, cab side extensions, trailer “boat tails” and trailer side skirts. The section will also describe some of the less well studied, and less commercially adopted technologies for improving aerodynamic efficiencies of tractor-trailer combinations [2].

New types of research are introduced in transportation industry, which is Sino truck aerodynamic. Since truck have transform from square design into smoother design, it improve the aerodynamic of the cargo truck. The aerodynamic of road Sino truck is very important due to reduction of fuel consumption, optimize performance also to improve stability and handling in term of safety. The road truck aerodynamic is important for increasing the performance of the Sino truck with less fuel consumption; furthermore, it also was improve drawing of the truck. Hence, by saving, the maintenance cost of the truck may reduce the transportation cost, one way of reducing maintenance cost is improve the aerodynamic of the truck, since truck is large and fast moving truck it is essential to have a good air flow around the truck. The flow of behavior Sino truck gap region affects directly the pressures on the back-face of the cab and the front face of the trailer, both of which are large surfaces perpendicular to the Sino truck motion and therefore strong contributors to the overall drag on the truck. When prevailing winds impinge on the tractor-trailer at even moderate oblique angles, the cross flow through the gap modifies the pressures on the cab and trailer faces resulting in an increase in overall truck.

Performance of tractor-trailer design over the last several decades reveals gradual aerodynamic improvements to the front of truck, namely from the front of the tractor to the front of the trailer, but very little has been done to improve the back of trailers. Tractors have benefited from tremendous improvements, such as the adoption of the aero-shield as an integrated part of the cab. The problem of the gap between tractor and trailer, which is an important source of drag, has been partly mitigated by the introduction of cab extenders that effectively reduce the size of the gap but do not eliminate it entirely. In contrast, trailers have seen little modification, aside from the rounding of their truck leading edges in the front. Shape that forming aerodynamic drag region on heavy trucks. A large amount of drag based on pressure drag is consisted on the front surface, the wheels, the gap between the truck and trailer and the rear of the trailer the fact that hard-shell trailers are designed to be loaded from the back makes the implementation of drag reduction devices in the back particularly challenging. Truck operators are extremely reluctant to deal with any type of physical device that may interfere with routine loading and unloading operations. Drag reduction on freight-trucks could lead to both environmental and economic benefits as the energy consumption is lowered. Since not much research has been done on these types of Sino truck, it is of great interest to conduct CFD analyses to make them more energy efficient. In this study it's been tried to study the aerodynamic characteristics and aerodynamic shape optimization Hence, even a small reduction in the aerodynamic drag could lead to substantial fuel saving. At the same time, the emissions of heavy trucks and concomitant fuel combustion can be significantly reduced. All in all, an improvement of a truck's configuration could decrease the drag coefficient (C_d), leading to a better fuel efficiency and a cleaner environment [2] [3].

It could be beneficial to consider the whole combination tractor and trailer in the continuing work of aerodynamic development. On today's market there exist different trailer shapes and several types of trailer devices to reduce drag, although they are not very commonly used on the roads. It is also possible to acquire an already aerodynamically shaped trailer, a so-called teardrop trailer [4].The effect of the gap clearance between the tractor and the trailer is very much dependent on how large the gap is. One of the drag contributing issues with the larger gaps is that air goes into the gap and hits the trailer front, which results in an increased pressure drag. This pressure becomes even greater if there is a height difference between the tractor and the trailer [5].During crosswind conditions more air is entering the gap which will increase the flow separation, and thereby turbulence, on the leeward side of the trailer. This will affect the drag and stability. For those configurations is the gap is large there are a number of devices to improve the aerodynamics. The main purpose of such devices, added on the trailer front, is to prevent uncontrolled circulation and cross-flow in the gap, improve the flow over the gap and to reduce the pressure acting on the trailer. Sino Trucks has a well establish aerodynamic focus in the product development process of the tractor, although there is no focus on trailer aerodynamics. Truck aerodynamics is generally aim at reducing the drag and improving the flow quality on the front end of the tractor, where as less attention is given to the aerodynamics of the trailer as the shape is modified for low cost and maximum loading capacity, the drag contribution of the trailer is between 50 to 60% [6].

The purpose of truck aerodynamic improvements is to minimize fuel consumption and also one of the aerodynamic drag reduction technology development activities was to design, develop, and demonstrate aerodynamic devices that would improve the fuel economy of tractor-trailer trucks under operational conditions. The effect of drag reduction and fuel consumption in operation with typical truck in typical driving condition the more fuel can save if coefficient of drag reduces. Aerodynamic drag force becomes important at higher speeds and vehicle performance and fuel consumption are significantly influenced. Because the aerodynamic drag force increases proportional to the square of the speed. The heavy truck performs cruising at high speed in intercity and take way too much over the years. The sino truck manufacturers invest aerodynamic studies in order to increase sino truck performance in the century where fuel source are depleting, it is essential that it reduce the usage of fuel. Since truck were used to transport goods, by reducing the fuel consumption was reduce the operating cost of the truck, hence directly was reduce the goods cost. Design activity has recently been initiated to explore advanced aerodynamic technologies to reduce trailer undercarriage drag. A large amount of drag based on pressure drag is consisted on the front surface, the wheels, the gap between the truck and trailer and the rear of the trailer and the undercarriage/wheels. Implying that reducing the aerodynamic drag of the trailer could lead to a significant reduction in fuel consumption. In this thesis a system is will be analyses which is a derivative of a lift producing device used in certain types of cargo truck [7].The increased trailer gap will also cause turbulence as well as increased sensitivity to side winds at highway speeds, much of the energy used to move a truck goes to pushing air out of its way. When a truck moves, the air exerts a force on the Sino truck that resists its motion, making it more difficult to move. The importance of aerodynamics on heavy truck fuel economy is further highlighted by the work of Tyrrell in 1987 that showed operational and environmental factors act to further increase the impact of aerodynamics on heavy truck fuel economy resulting in aerodynamic drag becoming the dominant resistance force for these classes of sino truck. These operational and environmental concerns include factors such as vehicle interference, atmospheric effects, and road conditions that must be addressed when developing aerodynamic based fuel economy improvement technologies for heavy truck. It is estimated that application of existing aerodynamic innovations to the tractor and trailer is increase the fuel economy by some percent. The heavy truck community has been slow to adopt the existing innovations due to their concerns related to operations and maintenance that is driven by device complexity. One of the forces acting on the sino truck is aerodynamic drag force. Aerodynamic drag force becomes important at higher speeds and truck performance and fuel consumption are significantly influenced. Because the aerodynamic drag force increases proportional to the square of the speed. The heavy truck perform cruising at high speed in intercity and take way too much over the years. The truck manufacturers invest on aerodynamic studies in order to increase truck performance [8].

1.2 Statement of Problem

The aerodynamic shape of a Sino is crucial, because it has a large impact on fuel consumption and important source of drag. It is found that Sino truck is the favorite heavy-duty truck and a bloodline of economic grows(backbone of one country). Sino truck has been used for container transportation, fire fighting, trip through cross country. Sino Truck(model321) have been choose because it is the latest model of class in Mesfine Industry Engineering.It transport goods from one point to the others . it manufactured in Ethiopia Mesfine Industrial Engineering plc. But the technology behind are not competitive with other truck manufacturer. Due to drag and tractor-trailer gap.

The great problem is:

- Author would not develop great shape for the resistance of drag , not considered tractor-trailer device. consequences affect in the circulation of the Sino truck and fuel consumption.
- The underbody flow encounters a large amount of disturbances due to irregular geometries with sharp edges underneath the tractor and the trailer. Together with other disturbances, such as rotating wheels, this results in a reduction of velocity in the flow.
- At the rear of the trailer, a dominant base wake is creating, containing unsteady turbulent flow. This is a result of a low-momentum flow along the top and the sides of the trailer that separates at the trailing edge of the trailer.

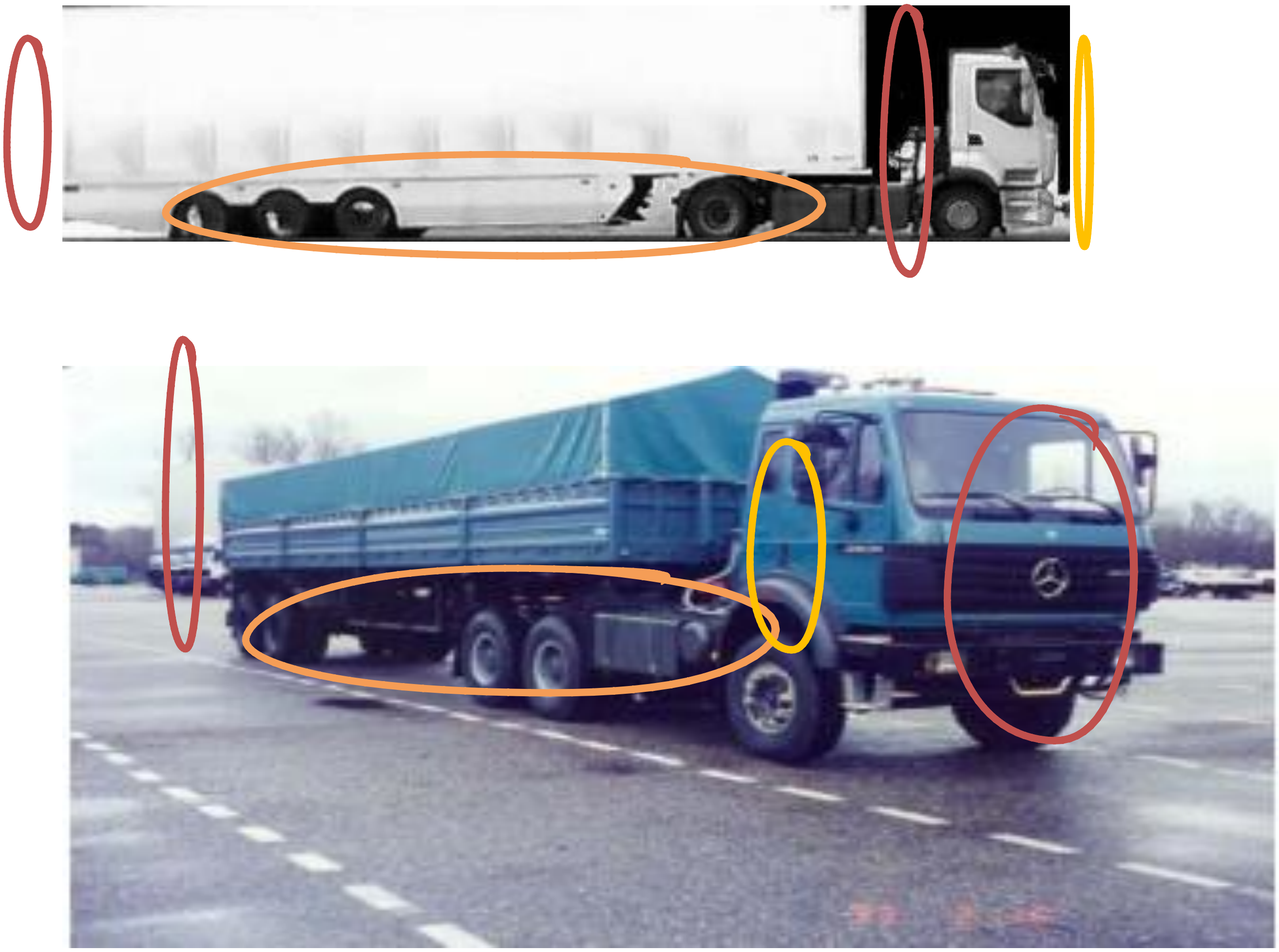


Figure 1: Critical flow region for the drag

1.3 Objectives of the study

1.3.1 General Objective

The general objective of this study A Numerical study on the Effect of Aerodynamic Devices on the tractor –trailer Sino Truck(model 321):A Case study of Mesfine Industrial Engineering**.**

1.3.2 The specific objectives of the study

The specific objectives are as follows:

- To study the specification and usage of Sino truck(model321)
- To prepare the model of Sino truck with different trailers device
- To compare the aerodynamics drag of different model
- To check the performance of the truck in cross wind.

1.4 Research question

So as to achieve the intended objectives stated above, the following research questions have been formulate and with the data and analysis of the simulations complete,

- Are there any un improvement aerodynamic areas on the sino truck?
- How much fuel can save by using aerodynamic?
- What are the differences in aerodynamic performance between the two?

1.5 Significance of research

This research uses different methods to improve drag coefficient and reduction of fuel consumption

- improve the flow over the gap and to reduce the pressure acting on the trailer
- Improved Sino truck appearance(Reducing frontal area)
- Reduce operating cost or fuel consumption to generate economy development.
- Reduce sensitivity to side winds.

1.6 Scope of the Study

In this thesis, the focus is on reducing the pressure near the truck front by shape optimization and increasing the back pressure with active flow control so that the aerodynamic pressure drag is reduce. Mainly on drag. CFD simulation, as the main part of the total aerodynamic resistance lies on the frontal part of the sino truck surface the main focus of the study is around the trailer and added on the tractor to guide the air over the cab gap. Develop a CFD model and perform the airflow study of the truck aerodynamic. The affect of gap between tractor-trailer ,adding devices and side wind performance Sino tuck with constant speed.

1.7 Limitation of the Study

This paper does not consider any costs of either production (manufacturing) or implementation of the Sino truck model(321) due to the financial. The Sino truck model(321)are only aerodynamically were evaluate and choice of material and applicability were not discusse.Furthermore; no consideration is taken to legislation about detail dimension of the internal part Sino truck. Due to time limitation Conduct a wind tunnel testing to validate the CFD simulation is restricted. Mean the simulations are compared to CFD conducted experiments and evaluated to verify their efficiency .

1.8 Organization of the Study

This thesis consists 5 chapters. The first chapter deals with the introduction and background of the study, of a numerical analysis of the drag reduction device and a comparison with the aerodynamic behavior of sino truck model and reduced of trailer-tractor. The second chapter focuses on the literature review. Third chapter includes Method and Materials, as the computational setup time is a dominant time constraint in engineering applications the modeling setup is automate to a large extent in order to be able to increase the amount of design iterations in At first the geometric model used to analyses the base drag aerodynamics and some background on base drag and existing drag reduction devices was revise discusses. The numerical background and computational setup of the computational fluid dynamics models where discusses in this chapter and, Fourth chapter deals with for the latter a separate dedicate as this is a fundamental aspect of CFD simulations results , a quality grid can influence the solution significantly. The results and the flow around the geometric base model are was discuss in.

Chapter 5 containing conclusions, recommendations, suggested future works, references and appendices was use in the study, Finalize this thesis in chapter.

2. LITERATURE REVIEW

2.1 Overview

In truck aerodynamic improvement, cab shape plays the most important roles in reducing drag. By referring to Richard, M.W. (2003), at low speed, the mass of the truck was influence the engine load of the truck, but as the truck speeding more than 80 KM/H, aerodynamic of the truck will influence the engine load. Since in highway, trucks were speeding until approximately 108KM/H it is essential that aerodynamic improvement need to be done to reduce operating cost. A Sino - Truck Aerodynamic Design Features done by Edwin J.S. and Robert R. Meyer, Jar, (1999). The report describe that the aerodynamic of the sino truck need to be done because of the fuel crisis that hunted the transportation industry [8].

Tractor streamlining, Management of airflow around the tractor-trailer gap, Management of airflow under the trailer, Management of airflow at the rear of the trailer. With the status of some current and emerging technologies, it is predicted that aerodynamic treatment to these key areas can lead to a reduction in fuel consumption. The effect of the gap clearance between the tractor and the trailer is very much dependent on how large the gap is. One of the drag contributing issues with the larger gaps is that air goes into the gap and hits the trailer front, which results in an increased pressure drag. This pressure becomes even greater if there is a height difference between the tractor and the trailer. In addition to the tractor front, the regions that represent the main drag-contributing areas around a truck are: the gap between the tractor and the trailer, the base wake behind the trailer and the undercarriage [9][8].

2.2 What are Aerodynamic Devices?

Aerodynamic devices improve the streamlining of the tractor-trailer. The devices reduce the surface area that the air hits, so less drag is produce, and consequently, less fuel is used. Research on aerodynamic devices has been improving fuel efficiency in tractor-trailers for many years. These older cab over engine still accurately show how the air movement changes when a streamlining cab roof deflector is added. Aerodynamic drag consists of two components; pressure drag (force acting normal to surface) and friction drag (force acting tangential to surface). Friction drag is due to shear stress between the fluid and the surface, whereas pressure drag is due to a pressure difference between the front and the rear of the body the truck. For a truck, and other blunt bodies, the pressure drag is the most dominating one and contributes to more than 90 percent of the total drag. In addition to the tractor front, the regions that represent the main drag-contributing areas around a truck are: the gap between the tractor and the trailer, the base wake behind the trailer and the undercarriage.

2.3 Aerodynamic Drag for a Heavy vehicle tractor-trailer Truck

To curb the impact of rising fuel costs the nations heavy truck community is exploring a number of advanced technologies that include aerodynamic drag reduction for both the tractor and the trailer. An assessment of on-road heavy truck energy consumption, for still air conditions, shows that the primary energy loses are due to drive-train, rolling friction, and aerodynamic drag[53].

It is well documented that as vehicle speed is increased the force required to overcome both aerodynamic drag and rolling friction increase, however, the rate of increase in aerodynamic drag with increasing vehicle speed is much greater than that for rolling friction such that at speeds greater than 45 miles per hour aerodynamic drag is the dominant resistance force. The importance of aerodynamics on heavy truck fuel economy is further highlighted by the work of [54]. that showed operational and environmental factors act to further increase the impact of aerodynamics on heavy truck fuel economy resulting in aerodynamic drag becoming the dominant resistance force for these class of vehicles. These operational and environmental concerns include factors such as vehicle interference, atmospheric effects, and road conditions that must be addressed when developing aerodynamic based fuel economy improvement technologies for heavy truck. It is estimated that application of existing aerodynamic innovations to the tractor and trailer is increase the fuel economy by 20 percent.

The heavy truck community has been slow to adopt the existing innovations due to their concerns related to operations and maintenance that is driven by device complexity, weight and cost To understand the technical challenge and economic payoff offered by aerodynamic drag reduction, it is important to understand the distribution of the drag between the tractor and trailer, see figure 2. The data used to develop the drag distributions depicted in figure 2 were obtained from a review of the available historical data, as represented by the data contained[55][56]. The schematic of figure 2 depict the dominant drag regions on a tractor-trailer truck are the tractor front face, tractor-trailer gap, undercarriage/wheels, and trailer base. The data show that under representative operational conditions a crosswind is present and the distribution of aerodynamic drag between the tractor and trailer is 35% tractor and 65% trailer. The drag of the trailer can be further qualified as having equal parts trailer front face drag, trailer base drag, and trailer undercarriage/wheel drag. To address the needs of the trucking community it is critical that aerodynamic drag reduction efforts address truck operations, maintenance, safety, weight, cost, stability and handling, braking, splash and spray, and tire wear[57].

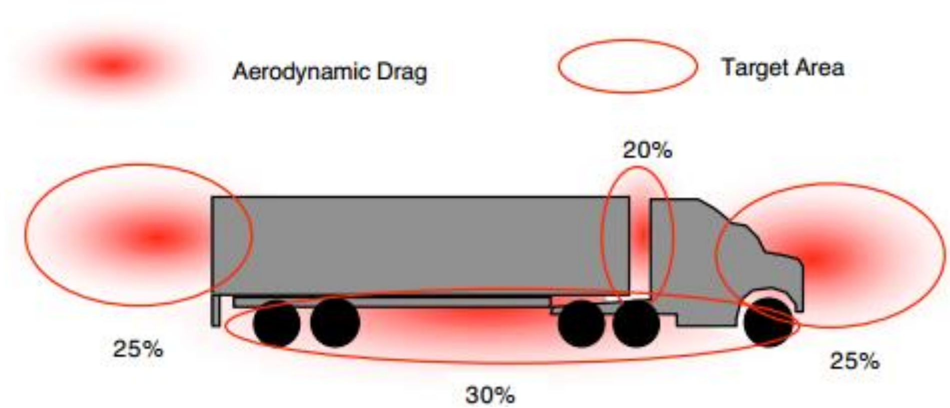


Figure 2: distribution of aerodynamic drag for a heavy vehicle tractor-trailer truck

Fuel consumption has always been one of the key issues in the truck business, not least in the last couple of years when environmental concerns have been increasing globally. Decreasing operating costs for the customers have been driving the development for many years whereby a lot of experiences in the fuel consumption field have been obtained. For economical reasons most of the improvements suggested have not been implemented, but now that governmental and customer demands are increasing, more drastic enhancements are to be adapted onto future trucks. Before new developments are applied, it is important to analyze which areas having the highest need of improvements. To be able to distinguish where upgrades are most effectively implemented, truck testing needs to be carried out. Presently there are three kinds of fuel consumption tests that are used for evaluating trucks at Volvo: driving on roads and measuring the fuel consumed during the cycle, driving the truck on a chassis dynamometer by adding the truck resistances at different speeds, to the moving ground.

If this is the situation, it is beneficial to use a roof deflector with an angle adjusted to the height of the trailer. The intent of the operational test program was to minimize the large number of factors that influence fuel economy, such as type and geometry of the tractors and trailers, the operational routes, the loads carried by the trucks, operator behavior, fuel quality, tire quality, rolling friction, and environmental concerns to name a few. Of greater importance to the fleet owner was the impact on operations and maintenance requirements. The test program included the operation of matching baseline trailer (i.e., no device installed) for each of the experimental trailers. Each of the baseline and experimental trailer pairs are pulled over the same route. Another variable considered in the test activity is the effect that the style/model of the tractor had on the results. The fleet owner had three different style/model tractors that were integrated in to the test activity. However, due to the concern of impacting fleet operation the organization and management of these variables was at the discretion of the fleet owner. The fleet owner minimized fuel related factors by ensuring that each tractor received fuel from the fleet owners fuel supply system and by using the same fuel fill procedures for all test data runs. To minimize the affect of tires the fleet owner ensured that each tractor and trailer involved in the test had similar tire types and tread depth. During cross-wind conditions more air is entering the gap which is increase the flow separation, and thereby turbulence, on the wards side of the trailer. This is affect the drag and stability. In order to reduce the drag due to the gap clearance there exist several different solutions of aerodynamic devices which can be implemented on the truck. Most common is the roof deflector and the side deflectors added on the tractor to guide the air over the gap. For those configurations where the gap is large, there are a number of devices to improve the aerodynamics[11].

Computational Fluid Dynamics, usually and from here on abbreviated to CFD, is a numerical method to compute the dynamics of a fluid. In brief, it is implemented by dividing a computational domain into small cells where the flow is modeled and flow equations are solved. Since almost all fluid flows are turbulent, different CFD methods are used in order to simulate turbulence. These can be divided in different categories where some of them are; Turbulence models for Reynolds-Averaged Navier-Stokes (RANS) equations, Large Eddy Simulation (LES), Direct Numerical Simulation (DNS) and Lattice Boltzmann method (LBM). The LBM differs from the other methods by simulating the movements of particles and aims at recover the hydrodynamics of the Navier-Stokes equation. RANS on the other hand, uses the Navier Stokes equations as a starting point and aims at solving them [10].

The drag created at the base of a trailer accounts for 29% of the total drag of a tractor-trailer so an improvement can make a large impact on fuel economy[10][11].

DNS does not use a turbulence model; it computes all the turbulent velocity fluctuations and therefore demands both small time steps and cells that require substantial computer resources. LES focus on the large eddies in the flow and requires quite large computer resources. However, the most common way to simulate turbulence is to calculate the time averaged properties of the flow, such as mean pressure, mean velocity and so on, which in most cases give sufficient information about the flow. This method has a modest computer demand and is conducted with RANS-models [13]. External aerodynamic simulations using computational fluid dynamics (CFD) are well-established tools in the product development process for the automotive and aerospace industries [14].

CFD simulation technique helps engineers to understand the physical phenomena-taking place in their design and provides an environment to optimize the performance with respect to certain design criteria. In the automotive domain for example, the aerodynamic forces, e.g. lift, drag and cross force, have a strong impact on the Sino truck's fuel efficiency and handling behavior. CFD can be leveraged to analyze these forces and to determine an optimal design. For the classic method of steepest descent. Alternatively, the gradient in conjunction with the objective function value can be used to approximate the "curvature" of the design space, which leads to the much more efficient quasi-Newton methods and conjugate gradient methods. In 1974, Hicks, Murman, were the first to apply gradient-based methods to aerodynamic shape optimization problems [15].

They used the method of feasible directions, which is based on conjugate gradients, to optimize airfoil shapes in transonic flow governed by the small-disturbance equation. Since this pioneering work, the application of gradient-based methods to aerodynamic shape optimization problems has been an active area of research. The undercarriage flow encounters a large amount of disturbances due to irregular geometries with sharp edges underneath the tractor and the trailer. Together with other disturbances, such as rotating wheels, this results in a reduction of velocity in the flow, so-called low-momentum flow, under the trailer with numerous separations and energy losses [16]. Different types of devices placed under the trailer can be used to improve the undercarriage flow by directing the flow along the side of the trailer. This is even more beneficial during crosswind conditions since it prevents cross-flow.

A smoother trailer bottom Heavy trucks use fuel to overcome rolling resistance and aerodynamic drag. Design optimization is a subject with less irregularity can also be a good adjustment to improve the undercarriage flow. Fuel efficiency is generally defined as the proportion of energy released by a fuel combustion process which is converted into useful work Numerical methods for optimization have also emerged that are able to optimize a certain performance index with respect to a specified set of parameters. As a result of these advances it is now possible to couple an analysis tool, such as CFD [17]. great interest in the transportation industry since optimization can lead to lighter, faster, and more fuel-efficient transportation vehicles. Due to the highly nonlinear nature of the Navier-Stokes equations, analytical aerodynamic solutions for air or ground transportation vehicle geometry needed for optimizing the objective values such as lift are not available. Hence, currently almost all practical aerodynamics problems are solved iteratively using specialized CFD software [20]. 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 [21]. 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 truck as well as the separation of the flow field [22].

Therefore, the design variables represent the deformations added to the original shape in order to create the new shape. This method is used in to optimize the shape of several airfoils in this period started to obtain special importance the aerodynamic of the Sino truck. The objective is reducing the drag resistance to reduce the fuel consumption. All the manufactures have arrived at the same equation of optimization. The drag coefficient (C_d) is useful when comparing the aerodynamic efficiency between different vehicles. It is related to the aerodynamic drag force (C_d), truck speed (V), frontal area (A) and the density (ρ), Aerodynamic drag, also called wind resistance, is a retarding force exerted on a vehicle by the air through which it moves. As a truck travels forward, it breaks up the flow of air, creating an area of low air pressure behind the body or trailer (the wake). The high pressure air surrounding the wake then moves into the low-pressure area, exerting a force that pulls the sino backwards. Low pressure areas created in the gap between the tractor and the trailer, and underneath the truck, similarly contribute to aerodynamic drag [23].

The amount of energy required to overcome aerodynamic drag is affected by three factors: The effective frontal surface area of the Sino truck, the shape of the Sino truck, the speed at which the vehicle is traveling. A cargo truck with less frontal surface area will have lower drag. Truck with a rounded or streamlined shape will also have lower aerodynamic drag since air flow separation will be less dramatic (i.e. reduced wake Aerodynamic drag on a tractor-trailer is affected by: the shape of the tractor cab, the transition between the back of the cab and the front of the trailer, the gap distance between the tractor and the trailer, the underbody of the truck, and the rear edge of the trailer will be design. However, the ultimate goal in CFD is to obtain model as flow as actual as possible. With the reduction on computational cost, aerodynamic simulation by using CFD, being run at a faster turnaround time will only be at a fraction of the cost. In this study aerodynamic simulation using RANS method is used [24].

2.4 Tractor-trailer gap affect

The pressure coefficient, the pressure normalized with the velocity, on the trailer front. In 0° yaw, large pressure peaks are observed at the upper corners and at the upper side edges of the trailer front. These high-pressure regions occur as air separates at the trailing edge of the tractor's roof- and side deflector and hits the trailer. This gives an indication of areas at the trailer front where the roof- and side deflectors work poorly. In 5° yaw these regions are relocated and accumulated at the left side of the trailer front where the wind is coming in.

Due to a bad aerodynamic affects to the need of a more power to move the truck,. The primordial objective of both aerodynamics is to reduce drag (air resistance).

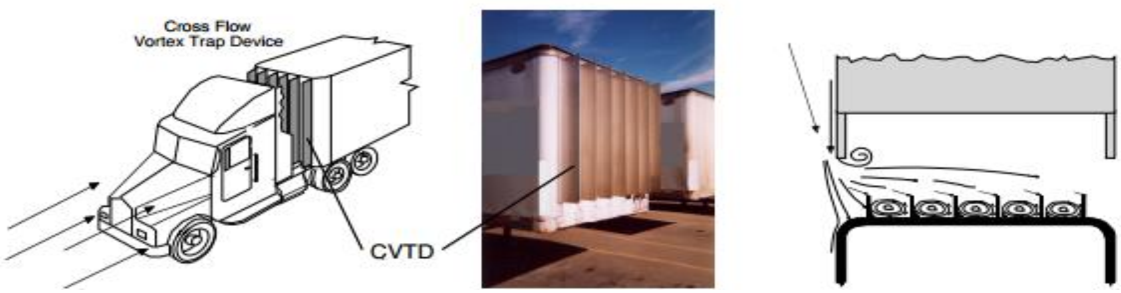


Figure 3:Gap region and Gap flow fields for a typical tractor-trailer truck

2.5 Aerodynamic characteristic Air Flow ground Truck

a, Speed

Aerodynamic devices affect fuel consumption at all speeds. However, the faster a truck travels the more energy it requires to overcome the forces of aerodynamic drag. Therefore, at typical highway speeds, the potential for fuel savings is especially large.

b, Initial aerodynamic design

The amount of fuel savings that result from adding aerodynamic devices is influenced by how aerodynamic your vehicle was before the devices were added. If you have an old tractor that is not aerodynamic (for instance it has square edges, a large grill and external exhaust), adding a cab roof fairing or deflector can result in 2 to 6 percent fuel savings Additional cosmetic components can increase the frontal area of the cab and increase aerodynamic drag on the vehicle [26].

c, Device installation

The aerodynamic equipment must been installed correctly to give you the best fuel savings. Your supplier can help you ensure that the equipment installation is doing correctly. Some dealers will Install the device.

d, Device breakage and maintenance

For aerodynamic devices to work at their maximum potential, the equipment must be in good working condition. An aerodynamic device that has cracks or fractures will not achieve the same level of performance and their effects on fuel savings were reduce. To reduce the risks of breakage, drivers need to be aware that new equipment may change the way they dock the trailer and turn in tight spaces. To achieve optimal fuel savings from the aerodynamic and angles up toward the trailer. It is widely used on trucks throughout North America and is provided by the original equipment manufacturer or as an add-on device cab roof fairing is the preferred device for tractors that haul box-style trailers of similar heights over long distances at highway speeds.

2.6 Tractor Aerodynamic Devices

Cab roof fairings and deflectors produce fuel savings by reducing air flow in the tractor-trailer gap. Depending on your trucking operation, one device may be more beneficial than the other. Cab roof fairings are typically offered as part of an aerodynamic package, which include cab extenders for additional fuel savings. These fairings are not adjustable after installation so they are suitable for tractors that always pull trailers of the same height. For operations that pull trailers of varying heights, adjustable cab roof deflectors may be a better choice. Cab roof fairing A cab roof fairing provides a 4 to 6 percent fuel savings by streamlining the air flow between the tractor-trailer gap. A three-dimensional mounding attaches to the tractor roof. The same operators do not always own trailers and tractors therefore; there may be reluctance on the part of trailer owners to pay for devices that were benefit the tractor owners. The results of aerodynamic testing on heavy-duty front bumpers have been scattered with some results showing modest reductions and some showing modest increases in fuel consumption. Similarly, modest aerodynamic improvements may be achieved with the use of wheel covers and slotted mud flaps. Super hydrophobic coatings could be used to reduce the likelihood that water and ice could build up on a trailer. However, this technology remains largely un-tested on road vehicles. Base bleeding has been shown to reduce drag in laboratory settings, however, the need for electrical devices (which then become an electrical drain on the charging system and thus a parasitic loss to the engine) to provide airflow and the need to tune the ducting of passive systems makes base bleeding a much less practical alternative to drag reduction.

Cab underbody treatments have been shown to decrease the aerodynamic drag of tractors, however, testing should be performed using a rolling road type wind tunnel to quantity these effects. Several manufacturers have commercial products for the gap regions on the market today that claim fuel savings on the order of 2%. The percentage savings are, however, highly dependent of the test procedure chosen, including initial gap size, and test speed. Numerous academic studies have investigated the potential fuel saving effects of tractor-trailer gap devices. It is; however, appropriate to first investigate the theoretical maximum benefit of completely closing the gap. Studies have suggested that the upper limit of aerodynamic improvement expected was in the range of a 7% drag reduction. At a typical speed of 55 mph, this would translate to an approximate 3.5% fuel saving. Recently, Mercedes introduced a concept trailer that is reported to provide an 18% reduction in drag for a full European tractor-trailer combination (consist of a cab-over tractor). Side skirts are used to prevent air flow from entering the under-trailer region. In recent years, these have been widely adopted and are commonly observed on many trailers. Fuel consumption reductions on the order of 3-7% have been reported. Side underbody boxes have also been shown to reduce drag by as much as 10% to 15% and can be used to store equipment that would normally be strapped to the outside of the tractor or the underside of the trailer. Side underbody boxes could also be used in place of traditional side guards. However, they add weight to the trailer and could also affect the break over angle as trailers pass over railroad tracks and other obstacles. Optimal for drag reduction purposes and typical length restrictions. As with side skirts, the interaction of boat tails with other devices is important for optimization.

Currently, limited evidence exists in peer-reviewed scientific sources to indicate that vortex generators have a significant impact on fuel savings for heavy vehicles. Retractable trailers (i.e. trailers whose height reduces by a wide margin) are being prototyped in Canada but testing has yet to be performed to quantify the potential for drag reduction. Aero-tractor models provide a reduction in aerodynamic drag, over the classic style, on the order of 30%. This is accomplished primarily through rounding of the front surfaces, the use of roof air deflectors, and the use of fairings over the fuel tanks between the steering axle and the drive axles.

2.7 Drag Reduction through Attach Add-on Devices

The use of aerodynamic add-on devices is the simplest but most effective approach to reduce the drag coefficient because the cost is relatively low and the current truck structures and designs do not need to be changed significantly. It has been proven by Munson [26] that the pressure difference were enlarged due to a pressure drop in the wake area behind the separation point, where vortices are generated. Specifically, the energy in wake were consumed in rotation, which cannot be transformed to potential energy immediately. This phenomenon were lead to the pressure difference surrounding the truck and result in an increased C_d. Therefore, various add-on devices designed to reduce aerodynamic drag have been tried over the past few decades, such as sealing the gap between tractor and trailer, covering exposed underbody structures, adding base flaps to reduce wake and flow separation, etc. Although these approaches are achievable through installing a roof cap, side skirts, tractor-trailer seal, and base-flaps, some of these solutions have not been fully adopted in the trucking industry due to their immature designs. For example, side skirts make the truck underside less accessible for maintenance; a full roof cap is a good solution for articulated trucks, but would increase the drag when trailers are detached [27]. Furthermore, it is very difficult to identify an optimal base flap design to address many uncertain factors, especially for the base flaps tail configurations they are use to prevent airflow from entering the under-trailer region. In recent years, these have been widely adopted and are commonly observed on many trailers. Fuel consumption reductions approximately 3-7% has been reported [30]. In addition, these devices have simple mechanical designs such that maintenance and reliability should not be a major concern. Some variants on side skirts have been proposed. Modified version of side skirts, wedge skirts and side wings [31] are claim to be optimized to enhance further the under-body aerodynamic Side skirts are used to prevent airflow from entering the under-trailer region.

In recent years, these have been widely adopted and are commonly observed on many trailers. Fuel consumption reductions on the order of have been reported. Underbody In a similar manner to side skirts, one approach to minimize under-trailer aerodynamics drag might be the development of lightweight underbody boxes, similar to those seen on commercial moving vans Drag reductions on the order of 10-15% have been shown for wind-tunnel tests using scaled models of such configurations aerodynamic There are operational issues that would need to be resolved, as well as significant weight penalties that may arise as well as changes to the break over angle of the trailer; however there are benefits as well. It is envisioned that these boxes could be developed for the stowage of binding straps, chains, spare tires and other accessories. Such boxes could offer side under-ride protection to vulnerable road users. Any such implementation would have to be well design to ensure that no ground clearance operability issue arose [32]Trailer side skirts provide a 4 to 7 percent fuel savings by minimizing the air fl own under the trailer and around the back axle. Trailer side skirts are a set of panels that run the length of the trailer to extend it closer to the ground. In addition to the fuel savings, drivers report better tractor-trailer stability in crosswinds with the use of trailer side skirts, and they have been shown to reduce tire spray, which can cause visibility issues for other drivers. Trailer side skirts should be use for box-style trailers that travel long distances at highway speed.

2.8 Air Flow at the Rear of the Trailer

Heavy truck trailers come in a variety of types and designs with the most common type trailer being described as a van type which is designed to be light weight load carrying container that is fitted with rear doors to provide efficient loading and unloading of freight. As a result of these operational dominant design requirements the trailer has a very poor aerodynamic shape that may be characterized as a bluff body. The aerodynamic behavior of bluff bodies is dominated by unsteady wake flows that result in high base drag. A graphic of a typical trailer after end region is shown in figure 4. The aerodynamic design challenge is to control the massively separated and unsteady wake behind the bluff base area in CVTD order to reduce the base drag and thereby increase the fuel economy. The schematics of figure 4 show top and side views of the dominant wake flow features behind a tractor-trailer truck The trailer base is one of the largest sources of drag for tractor trailers. Low pressure on the trailer face due to the aerodynamic wake, combined with the high pressure on the front face of the Truck, causes a net pressure differential that generates a force in the down wind direction. This front-to-back pressure differential is the primary source of drag for most heavy truck. Increasing the base pressure was reduce this differential and reduce the net drag on the truck. Therefore, many drag-reduction technologies for the trailer are aimed at increasing this back pressure. 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. 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[41].

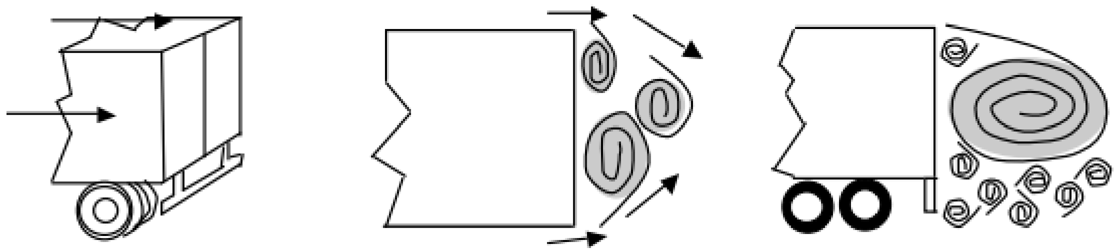


Figure 4: Trailer bluff base and base flow field of a tractor-trailer truck

2.8.1 Taper tails/extension panels

Tapering the back end of a long truck were increase its base pressure by providing pressure-recovery of the surrounding flow before it leaves the sharp back edges and forms a wake. This increased base pressure provides a lowered overall pressure difference from front-to-back of the tractor-trailer combination. Boat-tails, otherwise known as extension panels, is another technology that has been demonstrated to be effective to reduce the drag of tractor-trailer combinations, although various configurations are available [34][35].

Vortex generators are devices that, when placed on a surface, generate a vortex or array of vortices in the flow along the surface that can influence the flow-separation behavior further downwind. Several concepts for implementing such devices on the sides and tops of trailers have been proposed as a means to reduce the aerodynamic drag of heavy Truck. A small-scale wind[36].

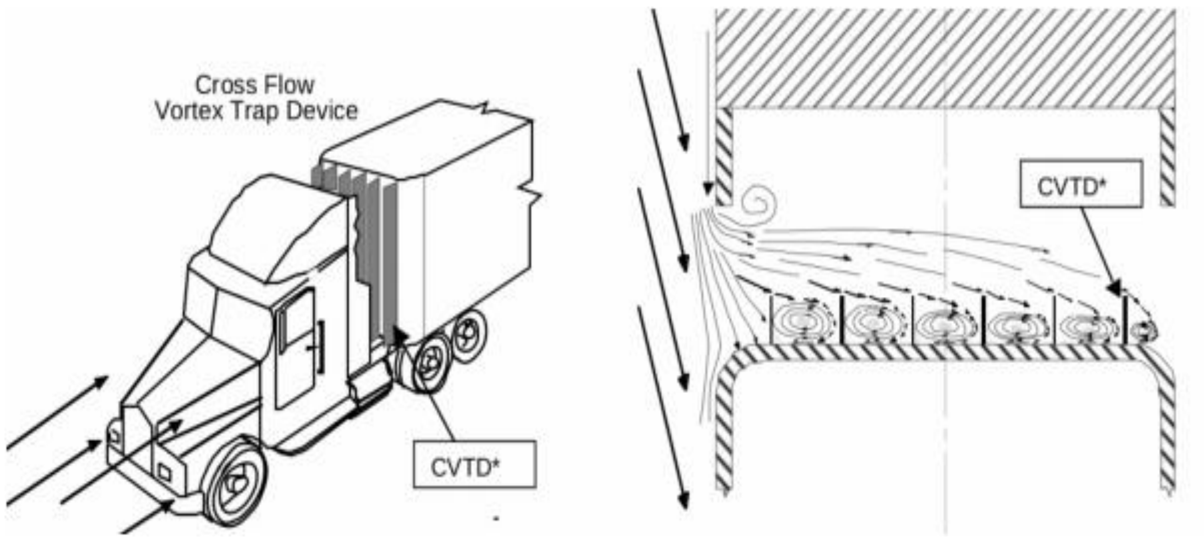


Fig 5:Cross flow vortex trap gap over front face

In their 2006 study, Leuschen and Cooper [37] attempted but were unable to find a vendor or concept developer available to have their vortex generator devices systematically tested on a full-scale of sino truck in a wind tunnel. Therefore, they developed their own prototype vortex generator for testing purposes, which was based on the vortex-strake concept studied in [37]. They found it provided a measurable increase in truck drag with an associated increase in fuel consumption greater than 1% for typical usage of long-haul sino truck. The Frontal area of a tractor-trailer of sino truck is dictated by the trailer and its cargo volume. To reduce the drag of a tractor-trailer combination when running with an empty trailer, Brad Bennett, a designer from British Columbia, has proposed a retractable trailer [38]. This technology also requires a retractable tractor fairing, in order to be effective. Numerous academic studies have investigated the potential fuel saving effects of tractor-trailer gap devices. It is however appropriate to investigate first the theoretical maximum benefits of completely closing the gap. Such a study [39] suggested that the upper limit of aerodynamic improvement expected was in the range of a 7% drag reduction. At a typical speed of 55 mph, this would translate to an approximate 3.5% fuel saving. Other studies, including [37], [49] have reported fuel savings of between 1% and 3% for typical gap closure devices. These are important findings, as they are in line with quoted manufacturers numbers. There does exist, however, a significant opportunity to refine and optimize the traditional gap treatment devices to attain the maximum possible fuel savings.

Additionally, little has been done to study the effects of towing a variety of trailers behind an aerodynamically streamlined cab. Since those studies were reported, some of the technologies have been introduced and are in use in the North-American transportation industry. Trailer side skirts are commonly observed on highway tractors-trailer combinations, and boat-tail technologies are coming to market and are being evaluated by trucking fleets. Details of these technologies will be discussed in later chapters of this report. A multitude of other proposed technologies are discussed in later sections as well, along with an evaluation of their potential impact to the transportation industry.

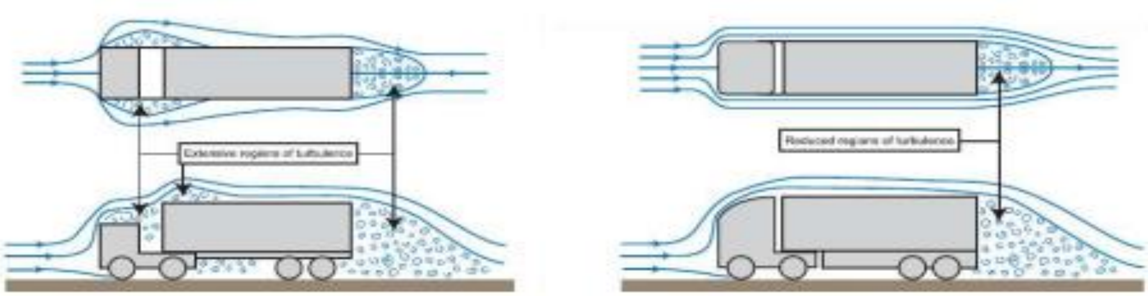
The area immediately behind a Class 8 tractor and in front of the attached trailer is defined as the tractor-trailer gap (The flow behavior in this gap region affects directly the pressures on the back-face of the cab and the front face of the trailer, both of which are large surfaces perpendicular to the truck motion and therefore strong contributors to the overall drag on the truck. When prevailing winds impinge on the tractor-trailer at even moderate oblique angles, the cross flow through the gap modifies the pressures on the cab and trailer faces resulting in an increase in overall truck drag [46]. This is a dominant region for which a wind-averaged-drag evaluation is required to ascertain the benefits of drag reduction devices. To minimize the effect of the gap flow on drag, completely sealing the gap would eliminate its drag contribution under crosswind conditions. However, due to operational requirements, a minimum gap distance is required to allow the tractor to articulate relative to the trailer to facilitate maneuverings at loading facilities and truck depots averaged-drag evaluation is required to ascertain the benefits of drag reduction devices.

2.9 Factors Contributing to Flow field Around Truck

The major factors that affect the flow field around the sino truck are the boundary layers,

2.9.1 Separation: During the flow over the surface of the truck, there is a point when the change in velocity comes to stall and the fluid starts flowing in reverse direction. This phenomenon is called 'Separation' of the fluid flow. This is usually occurred at the rear part of the truck. This separation is highly dependent on the pressure distribution, which is imposed by the outer layer of the flow. The turbulent boundary layer can withstand much higher pressure without separating as compared to laminar flow. This separation causes the flow to change its behavior behind the truck and thereby affect the flow field around the truck. This phenomenon is the major factor to be considered while studying the wake of the truck. Separation of flow field, friction drag and lastly the pressure drag.

Various aerodynamics devices have been developed mainly to guide the airflow around the tractor (figure), the most applied features are the front edge turning vane and the top cabin fairing placed on the tractor. These devices are aimed at reducing the separated flow regions on the front end of the truck, see figure. In the regions where the airflow separates from the tractor body the drag increases significantly, indicated by the regions of turbulence (regions which cause drag). The gap between the tractor and the trailer is furthermore a significant contribution to the total drag of the truck, which can be reduced by minimizing the gap (sometimes achieved by applying cab extension fenders) [51].



(a) Separated regions near tractor (b) Attached flow near tractor

Figure 6: Different flow topology due to tractor streamlining

As can be seen in figure 6 the turbulence regions are reduced by streamlining the tractor and minimizing the tractor-trailer gap. The drag created by the trailer however, is not significantly affected by this. The rear of the trailer is less aerodynamically optimized compared to most tractors, while nearly 60% of the total drag is caused by the trailer wheels and the base [52]. This focuses on the drag caused by the base of the trailer and assumes the flow coming from the tractor to be attached (as shown in 5(b)). Attached flow from the front end of the truck minimizes the effects of the fore body on the wake and therefore reduces the effect of the front of the model on the design of the drag reduction device. To facilitate this study in truck aerodynamics a model which is representative of a European tractor-trailer combination is used. A clean model with the maximum dimensions allowed in Europe for trucks is used in computations and in other research projects for wind tunnel tests. By using the same model as in other experiments and computations the results can be compared and a database with relevant data and drag reduction methods can be stored

2.9.2 Boundary Layer: The Aerodynamics boundary layer was first defined by the Aerodynamic engineer 'Ludwig Prandtl' in the conference at Germany. This allows aerodynamicists to simplify the equations of fluid flow by dividing the flow field into two areas: one inside the boundary layer and the one outside the boundary layer. In this boundary layer around the vehicle, the viscosity is dominant and it plays a major role in drag of the truck. The viscosity is neglected in the fluid regions outside this boundary layer since it does not have significant effect on the solution. In the design of the body shape, the boundary layer is given high attention to reduce drag. There are two reasons why designers consider the boundary layer as a major factor in aerodynamic drag. The first is that the boundary layer adds to the effective thickness of the body, through the displacement thickness, hence increasing the pressure drag. The second reason is that the shear forces at the surface of the truck causes skin friction drag.

2.9.3 Friction Drag: Each wall surface or material has a distinct friction which resists the flow of fluids. Due to molecular friction, a stress acts on every surface of the truck. 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.

2.9.4 Pressure Drag: The blunt bodies like large size truck show different drag characteristics. On the rear part of such vehicles, there is an extremely 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 truck as well as the separation of the flow field.

2.10 Shape changes affecting Drag

The Shape of the sino truck plays an important role in the drag reduction. Low drag is achieved by a shape which avoids sudden changes in the cross sectional area and has a degree of tapering towards the base of the vehicle. In practical design environment, drag reduction comes from attention to detail and it results from the accumulation of small incremental benefits in the development process. The shape changes that can affect the performance of the vehicle body the arrows show the required direction to morph the surface to create drag reduction, although this is very dependent on the initial shape. So the direction is susceptible to change as the original shape of the could be aerodynamically friendly or filled with blunt edges.

If steps are made to make small chamfers at the rear end of the roof and the side body, there will be a significant change in the drag. The footstep of the Sino truck is moved downward to decrease the ground clearance near the wheels and this makes major changes in the drag of the truck. Lowering the front bumper and bonnet, inclining the front windshield, rounding off the corners and sharp edges and lastly extending the front bumper are some of the ways contributing to reduce drag. The aerodynamicist usually works closely with the designers to use these ways with high level of compromises to make the vehicle more comfortable for the customers. It takes this point of compromises in view and makes available several external devices which was fulfilling the requirement of the designs as well as the aerodynamicist. forces acting on a Heavy truck.

To construct more effective trucks than competitors, Volvo needs analysis of how their trucks are performing compared to the main rivals. To be able to compare the fuel consumption on an accurate scale, different tests of the Volvo FH as well as its main competitors are carried out. The project will look into the test methods used to get hold of the fuel consumption and finding drawbacks in using the particular method. The results from the testing will be analyzed with the purpose of finding areas where Volvo needs to improve relatively to the competitors. The different driving resistances are the areas of interest, by dividing the complete drive resistance into the different losses caused by the rolling, aerodynamic and power train it is easier to recommend individual improvements suitable for the Volvo FH. The forces acting on a tractor with semi-trailer are summarized in Figure 2. The gravitational contribution Fig is not analyzed to any large extent in this study.

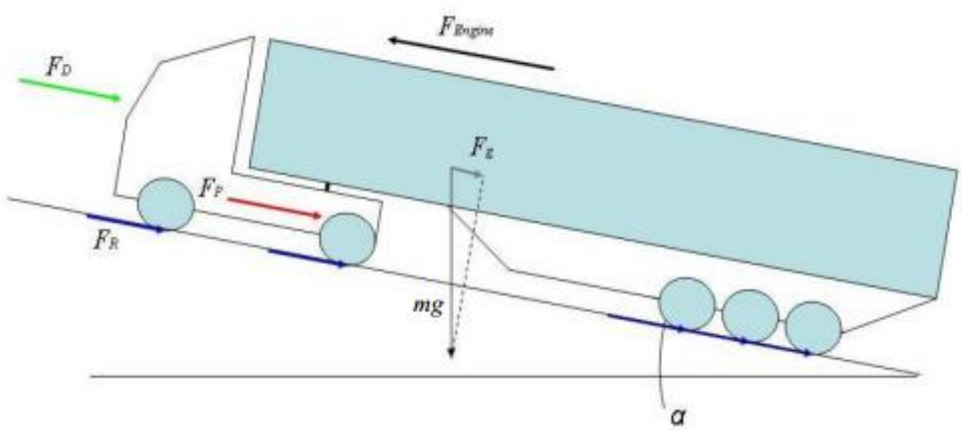


Figure 7: Complete set of forces acting on a truck

2.11 Models Applied in CFD Simulation for Truck

It is widely acknowledged that turbulence models are inexact representations of the physical phenomena being modeled, and no single turbulence model is the best for every flow simulation [25]. Consequently, it is necessary to provide a suite of models that reflect the current state-of-the-art. In this study, the focus is on the investigation of the *Cd* of the truck, as well as the effect of the drag reduction of the add-on devices. Hence, we do not need to compute all of the detailed relevant physical scales in the simulations. Therefore, the RANS model was chosen as the turbulence model. On one hand, it is accurate enough to satisfy the need in obtaining the C_d values; on the other hand, the center processing unit (CPU) time will be much less compared with other turbulence models.

RANS is one of the most widely used equations in CFD simulations. A trailer rear fairing provides at least a 1 percent fuel savings by decreasing suction at the trailer base while simulate. It is a set of panels that are curved or angled to reshape the back end of the trailer to make it more streamline. Box-style trailers that travel long distances at highway speeds should use a trailer rear fairing. In addition, simulate easily. To obtain the RANS equations, the Navier-Stokes equations for the instantaneous velocity and pressure fields are decomposed into a mean value and a fluctuating component. The averaging process may be thought of as time averaging for steady-state situations and ensemble averaging for repeatable transient situations. The main advantage of RANS is its relatively inexpensive computational cost; moreover, the numerical stability could be achieved with an appropriate models setting. Table 1 is a comparison of several widely used turbulence models, namely, the Direct Numerical Simulations (DNS) model, Large Eddy model, and RANS [26]. The mesh is generated with this method. This method divides the computational domain into small cubes, which are subdivided until they reach a desired resolution. Each subdivision dimidiates the size of the cube and provides a smooth variation in cell size [49].

Table 1: Comparison between several widely used turbulence mode for truck

Physics models	Advantages	Disadvantages
DNS	Compute all relevant physical scales	Very computationally expensive
Large Eddy	1. Simple sub grid models 2.Compute most of the relevant physical scales	1.Grid dependent 2.Relativelycomputationally expensive
RANS	1.Computationallyinexpensive 2. Numerically stable 3. Grid independent	1.Overdamp unsteady flow 2. Complex model required

2.11 Side wind performance

Sufficient crosswind stability has become an important criterion in the approval process of ground truck..Although a lot of efforts have been spent on investigating the crosswind stability of truck , the research of crosswind stability is a great challenge. In this study driving a truck on the road, the driver has to compensate continuously for small directional Deviations from the desired course due to disturbances such as crosswinds, road irregularities and unintended driver inputs. These types of deviations have a tiring effect on the driver and should therefore be minimized. When the magnitude of these disturbances increases, especially with crosswind, the directional deviation might become so large that the driver will have difficulties in compensating for it, and will thereby affect the traffic safety. This work is to Increase the understanding of the crosswind sensitivity of buses and to find solutions to the problem of improving the safety of truck with respect to crosswind performance. The results identify areas of high potential for improving the crosswind sensitivity of truck, such as the Centre of gravity location and the moment overshoot at gust entry. Furthermore, the study shows the importance of having a vehicle that facilitates prompt driver corrections for reducing.

The lateral deviation under excitation. Strong crosswind is considered as another factor that makes it difficult for drivers to control their truck while move. This study investigates the numerical evaluation using CFD.the value of yawing moment(Myawing), rolling moment(Mrolling) and pitching moment(Mpitching) values are smaller than each value of rotational resistance(Mrr), yawing resistance(Myr), Pitching resistance(Mr.) for the variable speed of model truck. the side wind and at the lower speed. the centrifugal (side) force created by the lateral acceleration were push a part of the truck's weight to the outside of the curve when the driver turns the steering wheel. The Static roll threshold (SRT) is the lateral acceleration required to transfer all the weight to one side of the vehicle order to assess the crosswind stability of truck in a more realistic way, more work has to be carried out. On the one hand, current developments in truck engineering have been showing a trend of faster, more energy efficient and more comfortable truck with a high capacity of heavy duet transportation [44].These trends require that the Truck has a much better handling stability. However, the demands for light-weight constructions and higher driving velocities are in conflict with crosswind stability.

Figure 8 :Side force acting on truck

Truck with high flat sides, such as furniture trucks and trucks transporting containers, are extremely susceptible to the effects of cross wind (wind blowing onto the side of the truck).In conditions of extreme crosswind, road controlling authorities may issue strong wind warnings for some stretches of road. When these are issued take note and, if the warning includes advice not to travel over a particular area of road don't. Truck was generate its own wind as it moves along the road. The faster you go, the greater the wind forces generated were created. The schematic of the gap flow shows that a portion of the flow leaving the trailing edge of the tractor will separate at the tractor trailing edge and turn into the gap region. This inward turning flow impinges on the trailer front face resulting in an increase in pressure on the trailer front face and subsequent increase in aerodynamic drag. The presence of crosswind flow will tend to increase the flow volume and velocity that enters the gap region and impinges onto the trailer front face. This increased gap flow was tending to increase the pressure on the trailer front face compared to the no crosswind condition. An additional result of the flow expanding into the gap region is the reduction in pressure acting on the tractor base and thus an increase in aerodynamic drag on the tractor. Another detrimental effect of the crosswind flow entering the gap is the flow separation that occurs on the leeward side of the trailer producing a significant side force on the Sino truck that may adversely affect the vehicle handling performance To reduce the aerodynamic drag associated with flow in the gap region, for either no crosswind or crosswind flow conditions, an aerodynamic design was conducted using existing published data. The design principle is based upon trapped vortex technology in which a region on a truck is constructed to capture or trap a vortex that is formed when the incident flow encounters an aerodynamically sharp edge. In the present design activity, a vortex-trap device was designed and located on the forward facing front face of the trailer the subject, patent pending, device is termed the Cross-flow Vortex Trap Device (CVTD). The leading edge of the adjacent surfaces comprising the CVTD were made aerodynamically sharp to ensure that the gap flow will separate at the leading edge of each adjacent surface and generate a vortex that is trapped between adjacent surfaces comprising the CVTD. Each trapped vortex imparts a low pressure on the forward facing surface of the trailer.

2.11.1 Trailer yaw

Any sino truck that is being towed by another truck were experience some degree of sway from side to side (yaw). The amount of yaw experienced by the towing sino truck is influenced by a number of factors, but speed and loading conditions are the most crucial factors. Yaw is generally explained as the way in which the trailer trails the towing sino truck. Once a trailer has started to yaw (sway from side to side) it can quickly develop into an uncontrollable situation and can easily result in the truck overturning. A safe method of reducing trailer yaw is to slow down but do not use the brake as this could easily develop into a jack knife situation. Trailer yaw should not be confused with rearward amplification. Trailer yaw is a swaying motion that can be encountered on straight roads and can develop without any steering input from the driver. Rearward amplification on the other hand is a result of a lane change or similar man oeuvre where the driver alters the path of the vehicle through the steering. For heavy truck such as tractor-trailer combinations, pressure drag is the dominant component due to the large surfaces perpendicular to the main flow direction and due to the large wake resulting from the bluntness of the back end of such truck. The pressure forces acting on the front and back face of the sino truck, as well as in the gap region between a tractor and trailer, are dominant. The large empty spaces in underbody regions of tractor-trailer combinations also contribute to the pressure drag. The cooling flows through a truck engine compartment are also dominated by pressure-drag effects. Although friction drag occurs along the external surfaces of heavy truck, particularly along the sides and top of truck and trailers, its contribution to overall drag is small [41] and is not a strong candidate for drag-reduction technologies.

Unlike flight sino truck that have streamlined bodies for which friction drag is the dominant contribution, road-truck aerodynamics is predominantly concerned with pressure drag and therefore the large body of knowledge concerning drag-reduction for flight vehicles is not strictly applicable to the road-truck and ground-transportation industries. All combination truck are different, but in general terms, at zero yaw, the drag on the tractor accounts for approximately 70% of the total drag and the trailer accounts for the remaining 30% of the drag. However, at yaw angles in excess of 5 deg the tractor drag component increases very little but the trailer drag increases substantially such that it can exceed that of the tractor [42]Aside from saving fuel, there are other potential benefits to reducing drag such as improved aerodynamic stability and reduced splash and spray. For heavy truck such as tractor-trailer combinations, pressure drag is the dominant component due to the large surfaces facing the main flow direction and due to the large wake resulting from the bluntness of the back end of such truck. Although friction drag occurs along the external surfaces of heavy truck, particularly along the sides and top of truck and trailers, its contribution to overall drag is small (10% or less) and is not a strong candidate for drag-reduction technologies. For heavy-duty sino truck, such as tractor-trailer combinations, the drag coefficient increases significantly with yaw angle. There are also a number of geometric factors that influence the aerodynamics of tractor-trailer trucks. The aerodynamic drag of tractor-trailer trucks due to changes in the flow field in the gap region between the tractor and trailer [43]. These trends require that the Truck has a much better handling stability. However, the demands for light-weight constructions and higher driving velocities are in conflict with crosswind stability.[45].In the absence of vortex shedding and assuming a steady wake proposed a base drag model[46].In real case situations a truck is always experiencing crosswind [47] introducing a side flow component on the model. The maximum side wind angle experienced by a typical truck is in the order of 10 degrees, and can have a large influence on the total drag and side force on the truck due to flow separation on the front end of the truck This is even more beneficial during cross-wind conditions since it prevents cross-flows. Different types of side skirts have demonstrated a drag reduction of drag counts[48].

The coast down is a difficult test to perform if accurate and repeatable results are to be obtained, parallel to that it is both time and cost consuming, especially if competitor vehicles are to be rented or bought for comparison. The basic principle is to measure for how long the truck is able to beach from a certain speed. A starting speed a bit above 85 km/h is sufficient for a truck because the maximum allowed speed is 80 km/h. When the starting truck has reached the starting speed and a sufficiently long straight, (800m is sufficient), the gearlever is put into neutral position. The truck is now coasting down the straight and the friction from moving components along with the approaching air decelerates the truck speed.

During the deceleration the time and speed are being measured. For good accuracy the speed is obtained from a 5thwheel mounted onto the truck. The 5thwheel is mounted tight to the truck but is allowed to follow the roads unevenness with help of a spring and damper. It’s important that the wheel has contact with the ground at all conditions and preferably not varying the contact load much, because it changes the effective rolling radius of the two wheel has to be calibrated prior to the measurement in order to find the calibration factor, which equals the amount of sensing pulses per meter road. To get the vehicle speed the amount of pulses per second is divided by the calibration factor. The coast down course has to be straight and flat to exclude side forces and the influence of gradients. Moreover the surface needs to be dry in order not to exaggerate the rolling resistance contribution. A day with absence of wind is also preferred so that a consistent measurement is conducted and variations in aerodynamic force are avoided. If the flow is hitting the truck from the sides the drag coefficient can increase with up to 70 % with 15º yaw angle. This is however based on a semitrailer without aerodynamic add-ons, and especially with side deflectors this increase in drag is significantly lower. The main reason why side winds affects drag is due to wind passing thru the trailer gap, but a secondary reason is the increased size of the wake Lastly it should be noted that even the frontal area increases with a slightly increases with a slightly angled head wind.

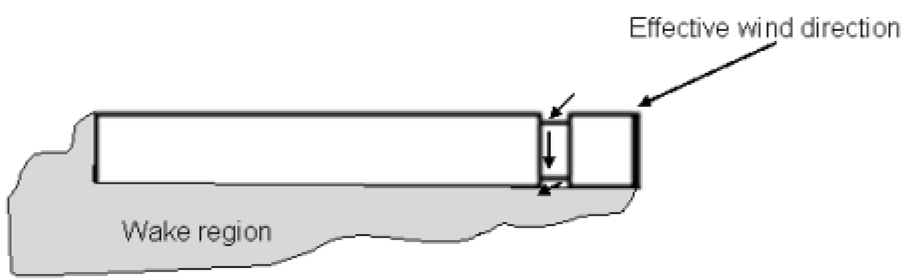


Figure 9: Side wind motion around tractor-trailer, plus wake region

Centrifugal force occurs when a moving object, such as a truck, changes direction. This is the same force that causes to slide across the seat and loose freight to slide across a deck when cornering at higher speeds. The weight of a truck means that when it is travelling in a straight line it will try to continue in that direction, even when the driver turns the wheel. Changing direction causes the truck's weight to move to the outside of the turn which, unless the driver controls its speed, can lead to the vehicle rolling over or sliding out.

3. MATERIALS AND METHODS

3.1 Methodology

This research was started with existing sino truck . The research was investigating what type of Drag reducing devices that can be used on trailers and how they work. CATIA -models of some of these devices together with own suggestions are generated. The Sino Truck model(321) and trailer devices are tested ,compared and evaluated by means of Computational Fluid Dynamics (CFD) in order to acquire an understanding of the flow field around the Truck and how combinations of the devices can improve drag even more. The procedure and case set up are further explained in this chapter. CATIA -models of the tractor and a simplified trailer are given and import into CFD. Small adjustments are done on the trailer to obtain correct dimensions. It scaled 3-D model of sino truck with its actual dimensions as shown below in table.2, by using the CATIA software. It knows the outer dimensions of the sino truck model321 then the model is modeled. It found out the external shape of the Sino truck model. After analysis the 2D format is a compatible one to view the result and Truck model is converted in to STL format, this file can reported to CFD software to analyze the external shape of the trailer-tractor for the analysis.

3.1.2 Model Geometry Specifications and Considerations

Table 2: Aerodynamic general Specifications Sino Truck(model 321)

No	Aerodynamic Specifications	
1	Minimum Tractor-trailer gap	1700mm
2	Minimum frontal corner	110mm
3	Curvature radius of side trailer	95mm
4	Curvature radius of side trailer	95mm

3.1.3 Sino Of truck Model321 Technical Specification

Table 3:Technical specification

Technical specification			
Maximum brake power($P_{b\text{-}max}$)	2941KW@6000rpm		Transmission efficiency= 0.95:1
Maximum brake Torque ($T_{b\text{-}max}$)	1821Nm@ 3600rpm		
specific fuel consumption(bsfc@$P_{b\text{-}max}$)	0.229gm/kwh@6000rpm	Wheel Front	2067/40R40
Vehicle Gross Weight (W_G)	36700N Or 36.7ton	Wheel Rear	205/40R40

3.1.4 Specifications of existing sino Truck

Table:4 specifications and detail dimension of sino truck model321

Specification	Detail
Length	16.72m
Width	2.80m
Height	3.88m

3.1.5 operating parameters of the Sino Truck (model 321)

This raw data(parameter) directly took from Masfine Industrial Engineering **.**the speed of the truck not randomly selected, the company most of time used depend on type of load. Above approximately80km/h the aerodynamic drag becomes dominating, which makes aerodynamics very important for long-distance transport where speeds up to 96km/h is common.

Table 5: operating parameters sino truck (model321)

	Range	
Truck speeds	64km/h 80km/h, 96km/h	
Inclined angle	0 degree	
Model No	Sino Truck (model321)	

3.2 The Selected Device for the improvement drag reduction Sino Truck

The selected device are the great role for the improvement of Sino truck (model321 drag redaction). while select the device it was not randomly; by understanding the place where the flow is very high and maximum drag created. in order to be improved chaotic behavior and Disturbed air These devices have great potential, During cross-wind condition, a larger amount of air enters these regions, which increase the possibility for the devices to improve the flow.

Table 6 : Selected cases

Gap treatment	Vortex stabilizer
	Gap fairing
Base treatment	Side plates
	Base plates
	Frame extension
under treatment	Side skirt

3.2.1 Reference(original model321)The Reference(Sino Truck 321) case represents an unmodified and tractor-trailer gap and All wheel pairs are in contact with ground and set to rotate.

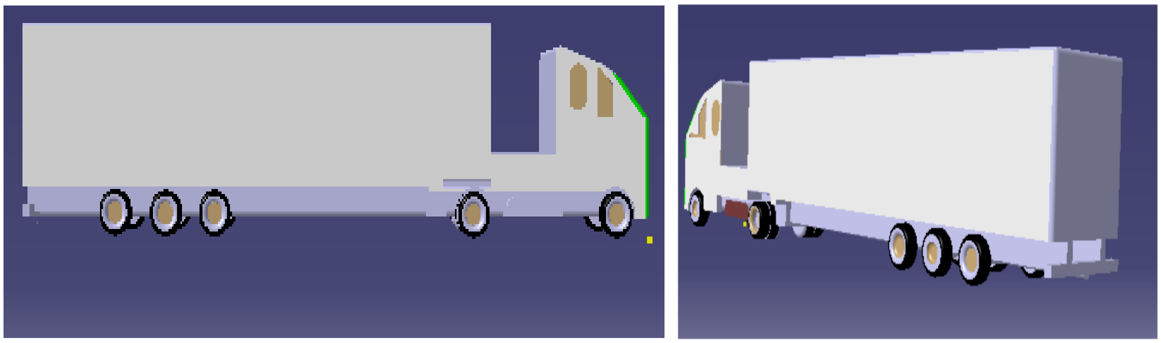


Figure 10:The baseline (model1 sino truck321)

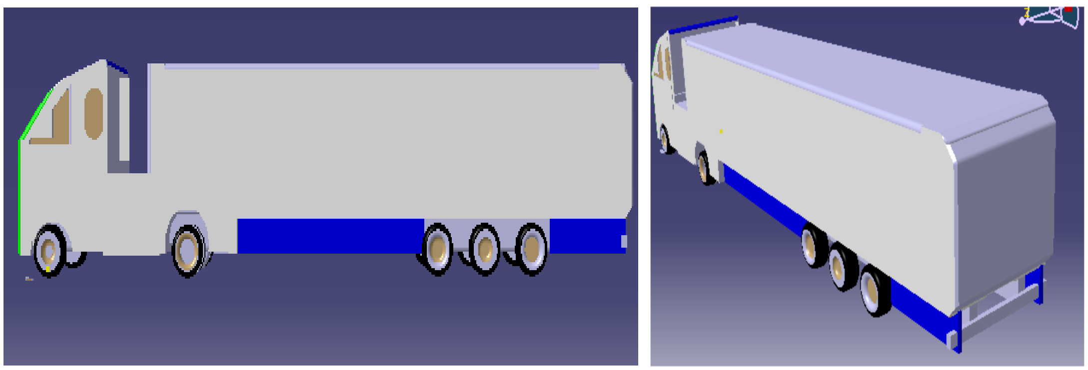


Figure 11:Model 2 sino truck321

3.2.2 Gap treatment

- **Vortex stabilizer** consists of two equal plates applied at the trailer front. The main objectives of the Vortex stabilizer are to reduce the disturbances from the cross-winds and to create stable vortices in the gap.

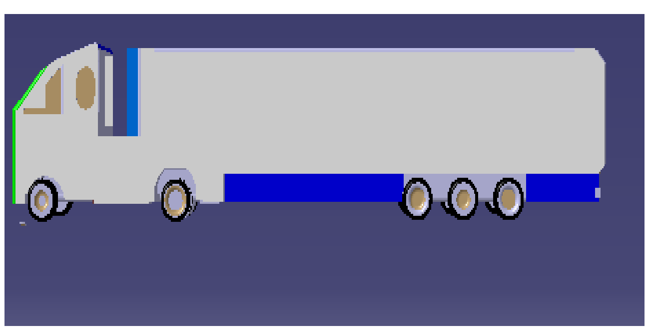
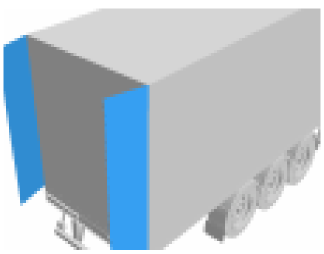
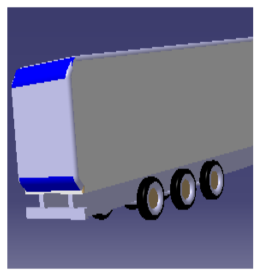


Figure 12: Vortex stabilize

- **Gap fairing** is used to improve the re-attachment of the flow on the trailer roof and to reduce the pressure peaks at the upper corners and at the edges of the trailer front. It is also designed to reduce the side clearance between the tractor and the trailer.

3.2.3 Base treatment Of Sino Truck (Model 321). Side plates are applied at the trailing edges on the sides of the trailer, where as Base plates are placed at the bottom and top of the trailer. The aim of adding these plates is to improve the drag by reducing the base wake. Optimal functionality of such plates is achieved with an inward some angle plate width that is1/5of the trailer width. This is applied to both Side plates and Base plates. Frame extensions a combination of Side plates and Base plates.

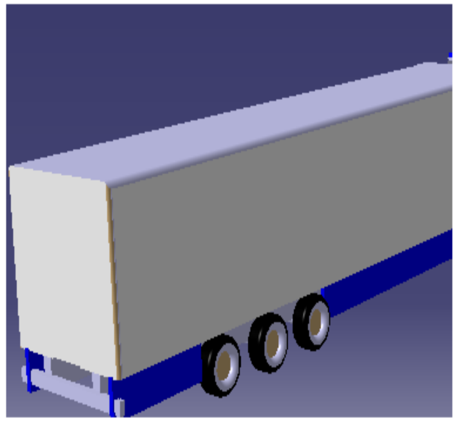




(a) Base plate (b) Frame extension

Figure 13: Base treatment

3.2.4 Undercarriage treatment The undercarriage devices are represented by Side skirts, sealed wheels. The advantage of Side skirts is the improvement of the flow along the sides of the trailer at ground level. Furthermore, a side-diffuser is implementing at the rear of the Side skirts for improvements of the flow at the rear. Side skirt is also modified with covered wheels and the case is called Seale wheels. Smooth under body represents a trailer where all the irregular geometries and beams are covered with a smooth surface.



(a) Side skirt

Fig 14: Undercarriage treatment

3.2.5 Aerodynamic Trailer: Teardrop is a modification of the trailer shape. Its roof is designed to improve the flow over the truck and to reduce the base wake., the shape of the teardrop is limited. The height of the trailer used in this project is 3.880 meters and 0.4 meters of added material is being used to shape the trailer.

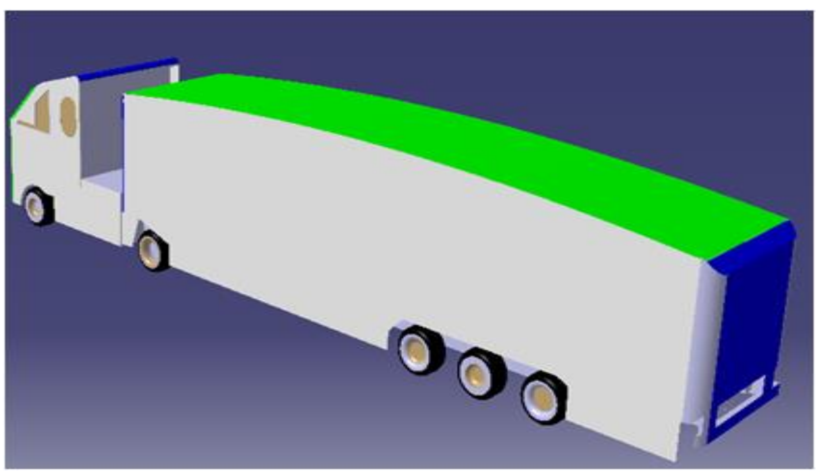


Figure 15: Teardrop

3.3 Baseline Model to the modified Model

A 3D comparison of the baseline and optimal model of Sino truck model is shown from different angles and In order to best serve the trucking community, and meet overall fuel consumption improvement goals. That said, there is still a strong benefit to trailer based devices such as side skirts and extention tails due to their demonstrated drag-reduction potentials. The advancement of aerodynamic drag reduction for sino truck is less mature and has been developed mainly through proprietary means by the manufacturers themselves.

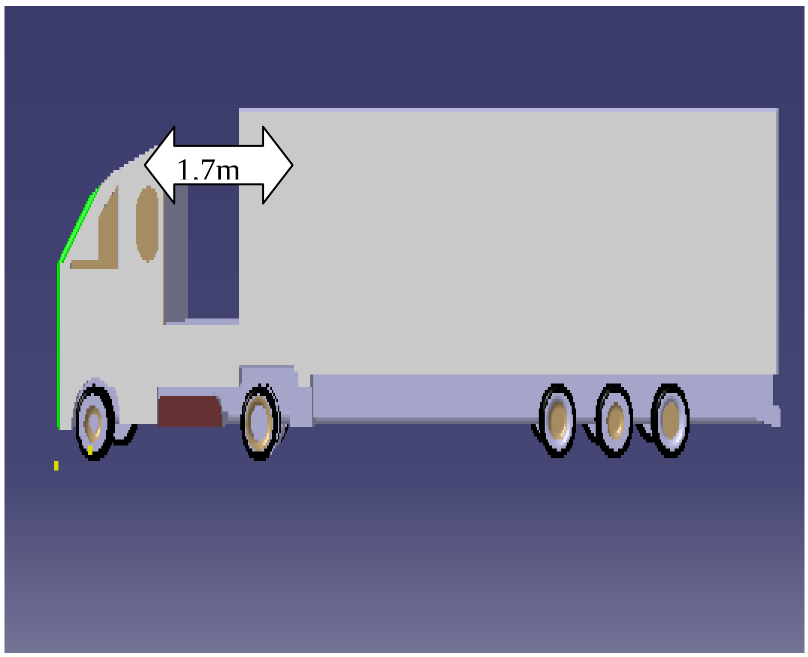
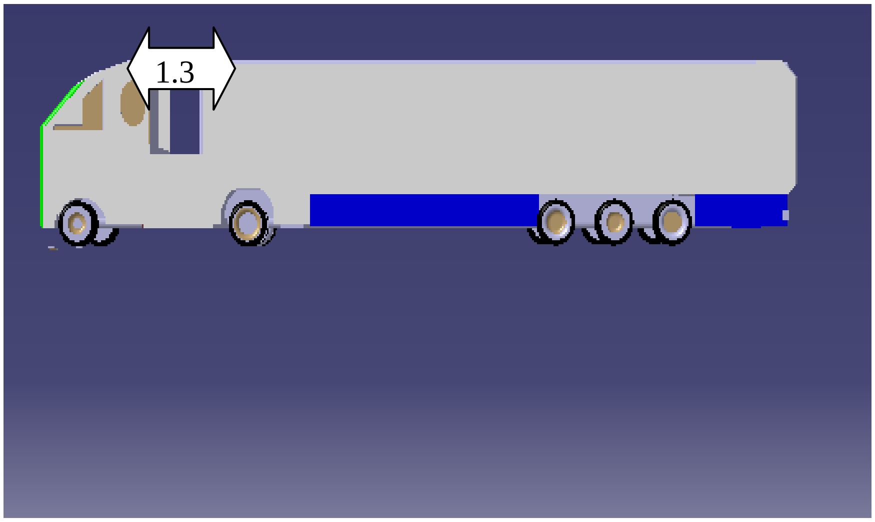
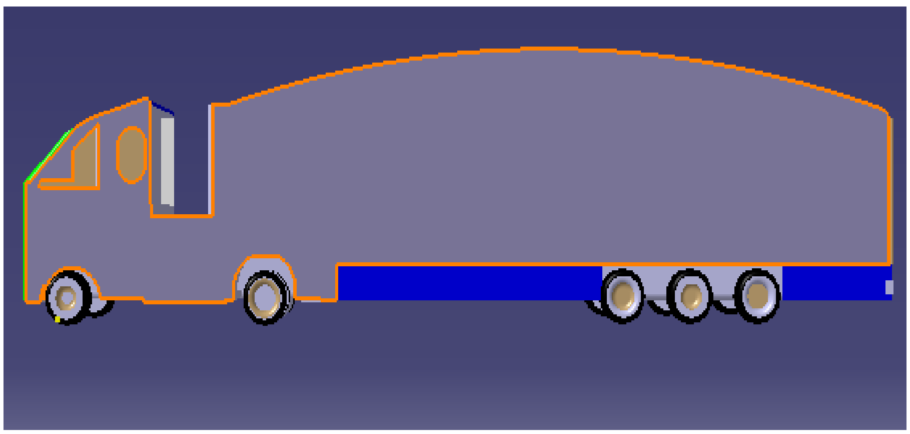


Figure 16:Baseline model 1 (Existing model of sino truck 321)



(b) Figure 17: Optimal (modification model 321)



(c) Optimal model3 (modification model321)

Comparison of between tractors.-Trailer gap the baseline and optimal configurations..

The rear area of the optimal model is visibly smaller.

3.3.1 Reducing Drag with Aerodynamic Device

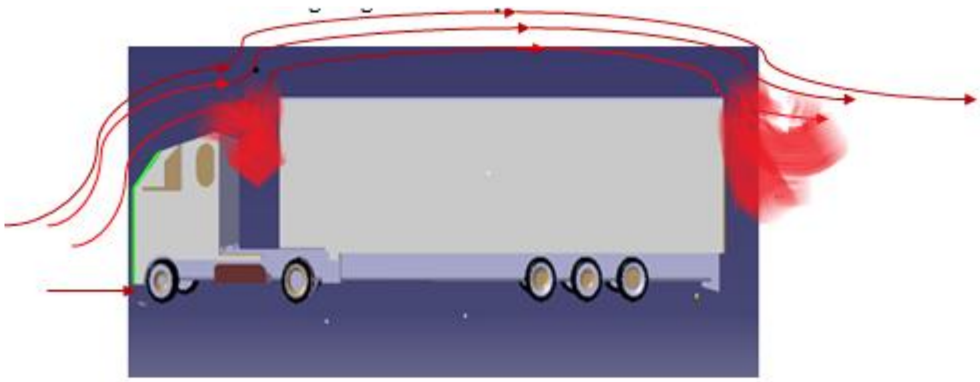


Figure 18:A Tractor-trailer without Aerodynamic devices installed produces a large amount of Drag (shown as shaded area)

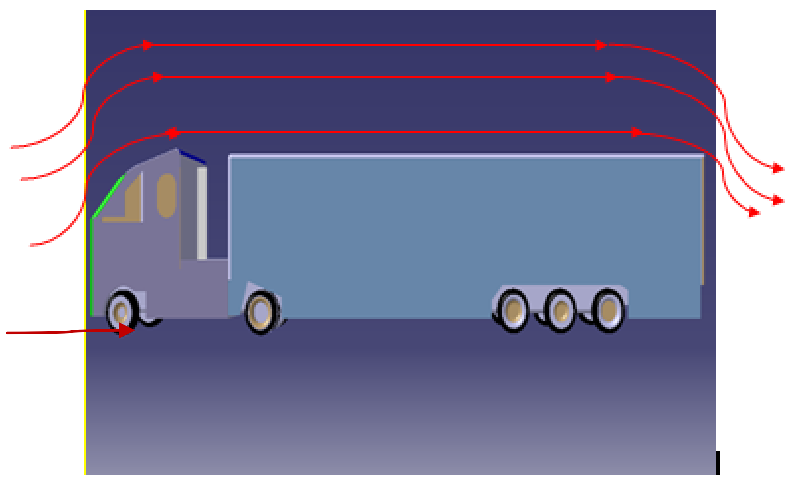
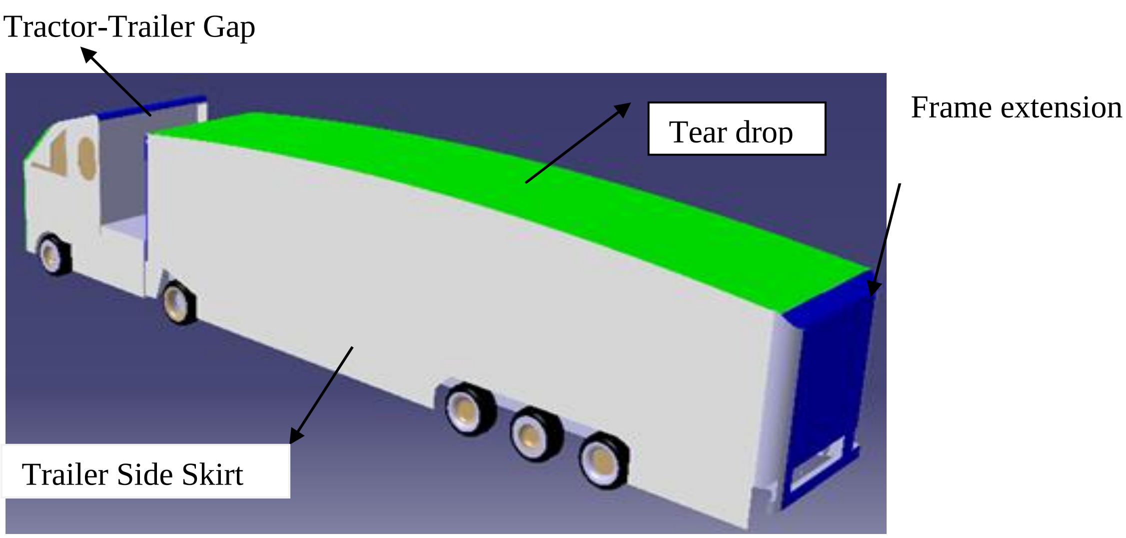


Figure 19: Tractor-trailer with Aerodynamic devices installed produces less Drag

Table 7: Different model modification

	Model existing 1	Model 2	Model 3
Overall length	16.72 m	16.72 m	16.72
Number of trailers	1	1	1
Gap #1 length	1.700 m	1.300 m	1.00m

Aerodynamic over all part selected case



3.4 Boundary and initial Conditions for CFD calculation

Boundary Conditions were applied on meshed models using CFD and were analyzed in moving road and rotating wheel conditions. In this simulation, straight wind condition was considered at Constant velocity inlet condition and zero gauge pressure at the outlet was applied. Operating condition was set to atmospheric pressure.

Table 8: Boundary condition settings

<table>
<tr><td rowspan="2">Velocity
Inlet</td><td>Magnitude (Measured normal to Boundary)</td><td>26.67m/s (constant</td></tr>
<tr><td>Turbulence Specification Method</td><td>Intensity and Viscosity Ratio</td></tr>
<tr><td>Pressure Outlet</td><td>Gauge Pressure magnitude</td><td>1atm</td></tr>
<tr><td></td><td rowspan="2">Fluid type</td><td rowspan="2">Air</td></tr>
<tr><td rowspan="2">Wall Zones No Property</td></tr>
<tr><td>Density</td><td>ρ = 1.189 (kg/m^3)</td></tr>
</table>

3.5 Sino Truck Aerodynamics: Numerical Evaluation Methods

In order to determine the usefulness of the methods used for the simulations in this thesis, and how well be able to simulate real aerodynamic flows. It may it be design all the geometries for the aerodynamics package before being imported and pre-processed to CFD. Since there exists previous CAD-data, modeling of -models needed for the Computational Fluid Dynamics (CFD) simulations were made from the data from optimizing the head shape of the sino truck, an efficient optimization approach is propose. Numerical evaluation methods involving Sino truck aerodynamics can be done using Computational Fluid Dynamics (CFD).

This thesis wasconducted by evaluating different drag reducing trailer devices by means of CFD Analytical methods in solving airflow behavior realistically can be done on simple generic type flow problems in either two-dimensional or three-dimensional form. As airflow behavior gets more complex when subjected to flow around complex geometrical domain or bluff bodies, (with the presence of turbulence and compressibility effect), solving airflow properties cannot be done analytically. This is because in order to obtain its complete turbulent and aerodynamic noise source properties, full unsteady Navies-Stokes (taking into account inertia, viscous and pressure forces) together with the continuity equation (mass conservation) need to be solved. Solving for RANS, continuity and turbulence model equations were done Computational Fluid Dynamics (CFD) simulations.

3.6 Aerodynamic Simulation Sino Truck Methods

Numerical simulations were perform on the truck 3D CATIA models using the CFD techniques The simulations are performed in STARCCM+ and each simulation was runs for many iterations. To make sure that the solution was stabilize. The convergence is checked from the residuals and the drag-plot. The drags from the two yaw cases are acquired by calculating the mean value of the last iterations. External aerodynamic simulations using computational fluid dynamics (CFD) are well-established tools in the product development process for the automotive and aerospace industries. CFD simulation technology helps engineers to understand the physical phenomena-taking place in their design and provides an environment to optimize the performance with respect to certain design criteria. In the automotive domain for example, the aerodynamic forces, e.g. lift, drag and cross force, have a strong impact on the Sino's fuel efficiency and handling behavior. CFD can be leveraged to analyze these forces and to determine an optimal design. In general, external aerodynamic flows exhibit a transient behavior, especially for road Sino truck. It is important to note that the drag reductions indicated above would drop significantly with a decrease in truck speed. The relationship between aerodynamic drag reduction, fuel economy, and Sino truck speed is depicted.

3.7 Description Of CFD Simulation Setup

CFD simulations became more and more popular Sino truck development process where get reduced. The general workflow to perform an aerodynamic CFD analysis of a Sino truck can be described in four steps the optimization tool are designed to be compatible with cargo computer aided engineering (CAE) process. In order to get the correct results in the desired time the correct physics models need to be chosen. Further validation of this study procedure is provided through numerical simulations to predict the overall drag and lift coefficient of the existing Sino truck and models with no guide vanes. The computational domain and its cells, the so-called volume mesh, can be generated and designed indifferent ways. The cells can be constructed in shapes of tetrahedral, hexahedra and polyhedral. The different cell types have different advantages and disadvantages that depend on the geometry and flowcharacteristics. For this project the hexahedral mesh with prism layers has been chosen since it is faster to generate and requires less memory, compared to the polyhedral mesh for example. which are subdivided until they reach a desired resolution. Each subdivision dimidiates the size of the cube and provides a smooth variation in cell size

Step: arranged domain of the experiment as flow

Size of the controlled region is domain is X= 80m, Y= 20m, Z= 12m.

Boundary conditions of the domain using inlet, outlet and ground plate.

Importing existing Sino truck model321

and the dimensions are L(X) = 16.72m, W(Y) = 3.88m, H (Z) = 2.80m

Make boundary palates like inlet, outlet, and ground plate.

Set initial condition wind velocity is V= 26.667/s

Set the position of sensor in the domain at X=

40 m, Y= 10m, Z= 1.4m as shown Calculate momentums of total force at Xpos=

24.9975, Ypos= 10 and Zpos = 1.4

Calculate drag coefficient from total forces at the

reference density of 1.189kg/m3, reference area in x, y

and z is 3.88X2.80 =10.864 m2.

The current domain material treated at air at 20°c,1atm For solution of velocity Turbulence

model is select KECHEN standard The simulation is one-phase

Optimization of grid using velocity and pressure at the position of probe average values at the speed of sino truck 96km/h.

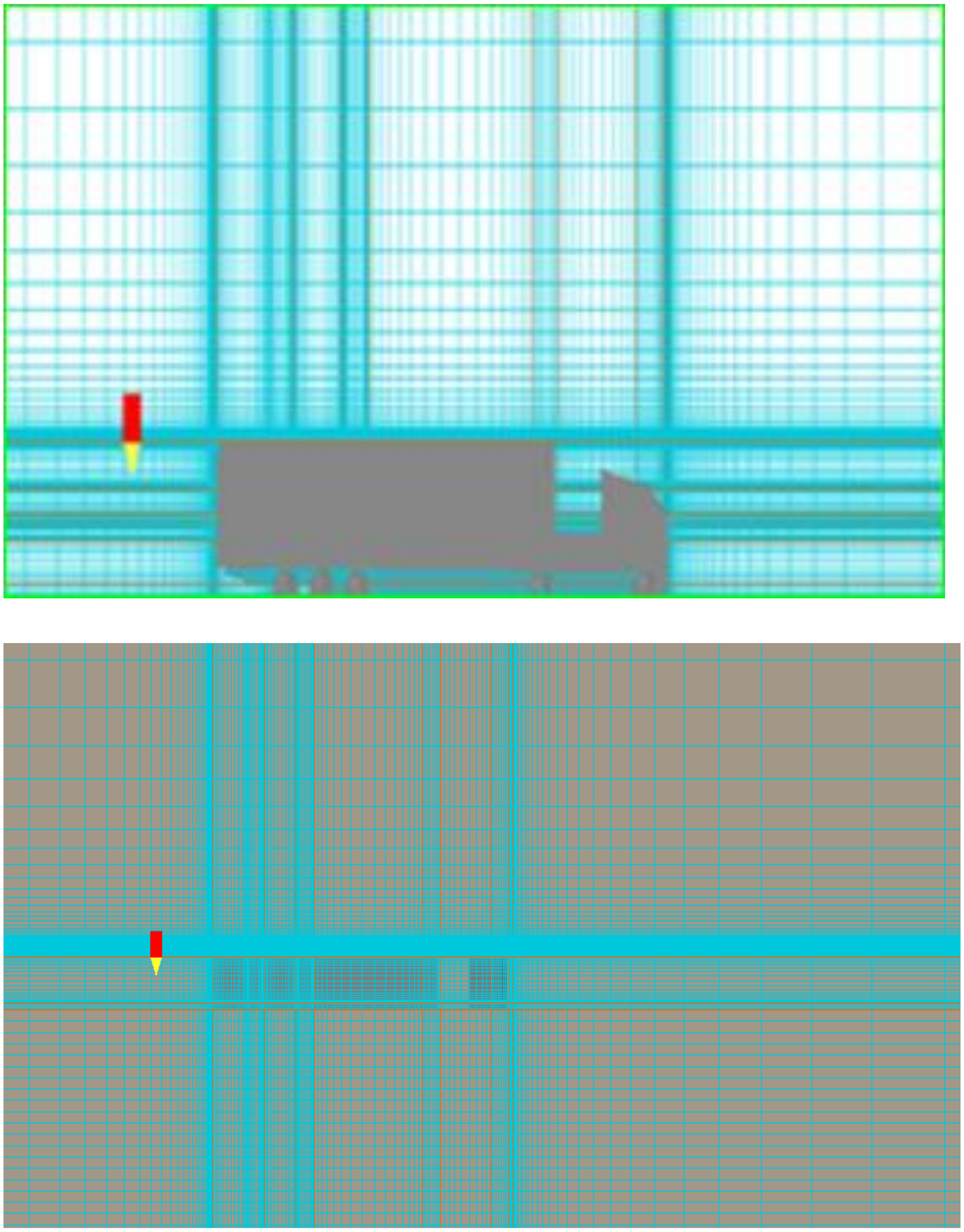


Figure 20: Optimum of Grid mesh

3.8 Sino truck model test in with different velocity.

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, Rear shape & Side panel shape. First one is the standard model of Sino truck which has a relatively flat front surface and sharp corners at front and rear side ad gap between trailer tractor reduced. Hence, it has more resistance to air which raises the drag force.

3.9 Total Drag Force (N) of sino truck Calculation

3.9.1 Drag

Drag is force acting on the surface of the truck by the flow in direction opposing the motion of the truck. The drag is the integral of local stream-wise component of normal (pressure) and tangential (skin friction) surface forces over all surface exposed to the stream. Direct evaluation of drag requires knowledge of the detailed stress distribution and integrating the pressure distribution over the complex surface of the sino truck, which is extremely difficult to obtain. But with the help of CFD detailed surface pressure distribution for a flow over an object can be easily obtained after the CFD set up is adequately validated. During the analysis of aerodynamics performance of two trucks, comparing the drag and lift forces do not yield much. One sino truck can generate less drag or lift other depending on test speed, density of air and projected frontal area of the Sino truck. Thus, the non dimensional coefficient is introduced to compare aerodynamic performances of a sino truck. The non-dimensional drag coefficient C_D is defined as:

$F_d = 1/2\rho AV^2C_d$……………………………………………………………………………(1)

$Cd=Fd/(1/2\rho AV^2$……………………………………………………………………………(2)

Where

C_D = Aerodynamic Drag Coefficient

A = Frontal Area of the sino truck($10.86m^2$)

ρ = Air Density(1.189kg/m^3)

V = Total Wind Velocity

F_D = Aerodynamic Drag Force of sino truck

3.9.2 Drag coefficient (Cd) calculation performance analysis of Sino truck model321

$\left((Cd\ model\ 1 - Cd\ model2)\frac{1}{Cd1}model\ 1x100\right)$...(3)

Total resistance force is:

Ft = Fd + Fr +Fg...(4)

Fr = (0.015+0.00016V)W

Where: Fr is rolling resistance

Fg : is gravitational resistance

Fd is drag resistance

V is cursing of truck is kM/h

W is curb weight of sino truck

Since Fg=0 because of at 0^o while =Wxsin0^o

This allows aerodynamicists to simplify the equations of fluid flow by dividing the flow field into two areas on the sino truck: one inside the boundary layer and the one outside the boundary layer. In this boundary layer around the sino truck, the viscosity is dominant and it plays a major role in drag of the sino truck. The viscosity is neglected in the fluid regions outside this boundary layer since it does not have significant effect on the solution. In the design of the body shape truck, the boundary layer is given high attention to reduce drag. There are two reasons why it considers the boundary layer as a major factor in aerodynamic drag for the truck. The first is that the boundary layer adds to the effective thickness of the body, through the displacement thickness, hence increasing the pressure drag. The second reason is that the shear forces at the surface of the sino truck causes skin friction drag. During realistic circumstances and driving conditions, the sino truck is subjected to crosswinds from several different directions. However, during CFD-simulations, only two yaw angles are used to save time. To simulate two yaw conditions; ground; bin let, outlet, sidewalls and roof. In 0° yaw the inlet is set to velocity inlet, whereas the side walls are defined as stationary wall with slip condition to simulate symmetry.

3. 9.3 Calculation of Power Requirements and fuel consumption.

Fuel consumption has been a core consideration since the beginning of the transportation era. The reasons related to our environment, and to economics. In the competitive truck industry, fuel consumption is an important sales argument. which means that fuel becomes a large part of the lifetime cost for truck.

$$\boldsymbol{P} = \frac{\boldsymbol{FtV}}{\boldsymbol{\eta t}} \quad \text{..........(5)}$$

Where, P = Power

Ft = Total Resistance

V = truck Speed in m/s

Ƞt = Transmission efficiency (0.95)

$$Psav = (FModel1 - FModel2) * V\ truck \quad \text{..........(6)}$$

3.9.4 Fuel Consumption The tests that are conducted by the manufacturers may not resemble the conditions of sino truck operation. it can conduct own monitoring to verify how much fuel are saving by using the aerodynamic equipment. To get an accurate result, it is important to compare the truck under similar conditions before and after the aerodynamic device is added to the truck.

Fuel saving which is reduced from the total resistance

$FS = power/QLHV * \rho * nt$...(7)

Where QLHV is lower heat value

nt=transmission efficiency(.95)

3.10 Forces and Moment on the Sino Truck for driving stability methodology

When the Sino truck is moving at a considerable speed, the air passing over it imposes various forces and moment on the truck The side force is cross wind acting on the truck and under the steady state wind conditions the equation for side force calculation is expressed as flow:

3.11 Calculation of rotational moment at each axis

3.11.1 X-axis moment (Rolling)

$$MX = FYx dz - Fx dy$$

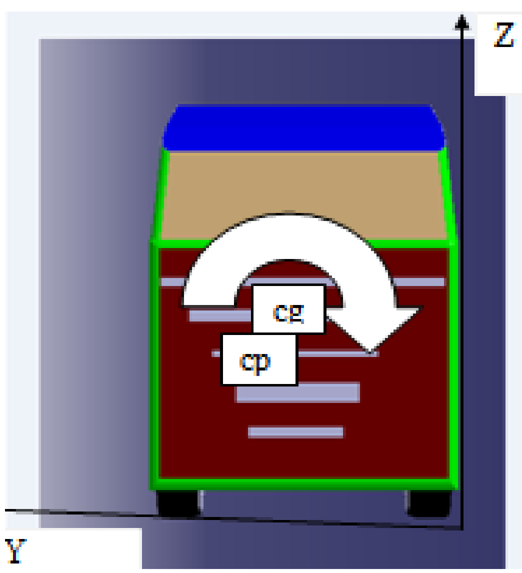


Figure 21:Frontal view of Sino Truck Model321

3.11. 2 Y-axis moment (Pitching)

$$MY = FYxdx - FXxdz$$

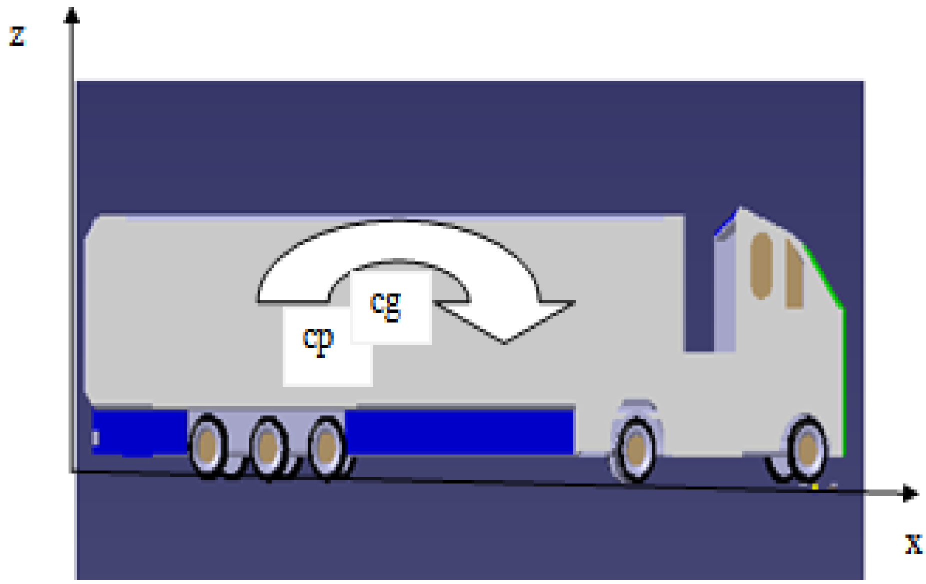


Figure 22:Side view Sino truck Model to show Pitching

3.11.3 Z-axis moment (Yawing)

$$Mz = FX \times dy - FY \times dx$$

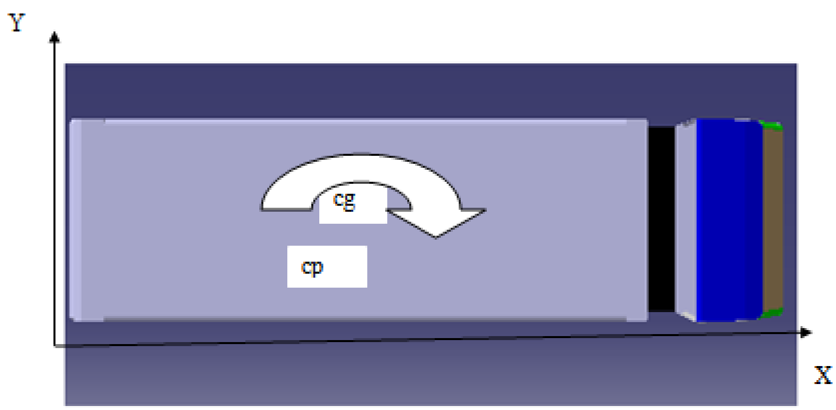


Figure 23: Top view of Sino Truck Model321

3.11.4 Yawing Resistance moment(My)

$M_{yr} = F_1 \times L_1 + F_2 \times L_1 + F_3 \times L_3 + F_4 \times L_3 + F_5 \times L_{4} + F_6 \times L_{4} + F_7 \times L_{5} + F_8 \times L_{5} + F_9 \times L_{2} + F_{10} \times L_2$

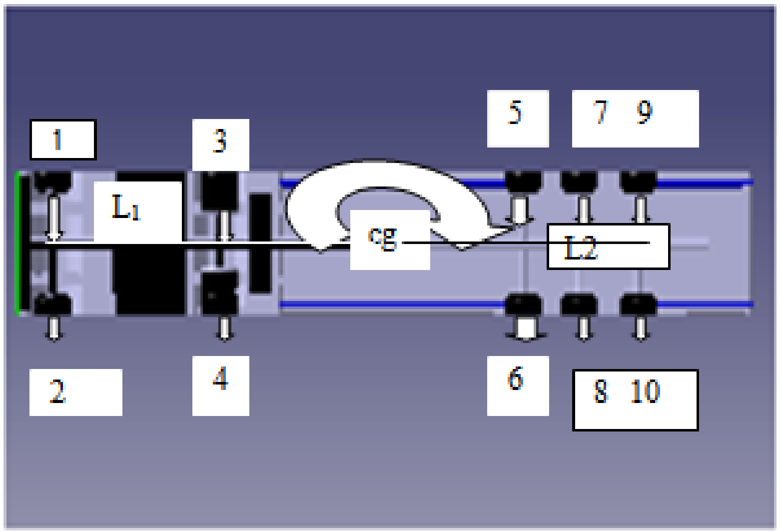


Figure 24:Bottom view of Sino Truck Model321

5. Rolling Resistance momentum (Mrr)

Mrr1 = Wxa and Mrr2 = Wxb

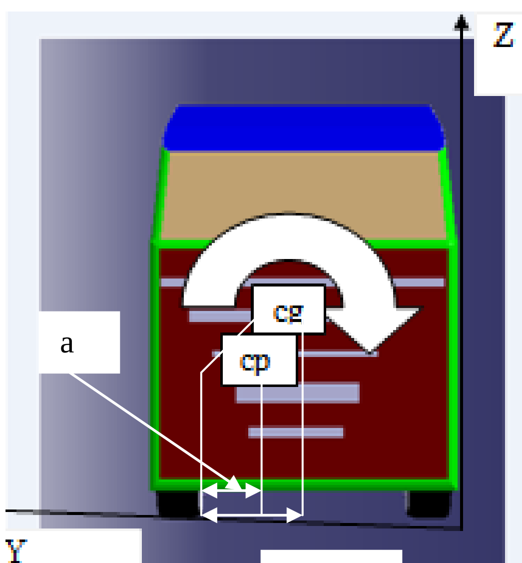


Figure25:Front view Sino truck Sodel321 Rolling resistance Moment

3.11.6 Pitching Resistance moment (Mpr)

Mpr = Wxa and MPr = Wxb

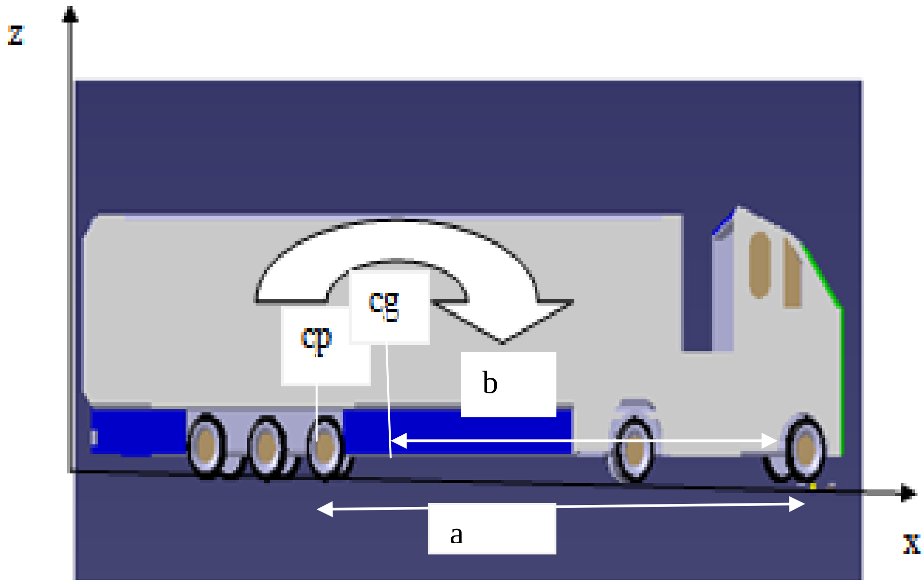


Figure23:side view sino truck Model 321pitching moment.

My, (Mr),(Mp**)** < (Mrr),(Myr), (Mpr) stable

My, (Mr),(Mp) >(Mrr),(Myr), (Mpr) un stable

With side wind speed64km/h is test model truck at different speeds The output of the driving CFD are compared with those obtained from the numerical simulation. Based on the comparison, it is expected that the driving CFD numerical simulation can well produce the equivalent moving conditions in the actual environment.

4. RESULTS AND DISCUSSION

4.1 Results and Analysis

In this section presents the results from the simulations and a detailed analysis of the reference (Existing Sino Truck Model321) case is done to identify problematic flow regions and to obtain an understanding of the flow charatesitst behavior. When working with CFD simulations it is important to remember that the results are calculated approximations of a real airflow and that assumptions has been made in order to solve the flow equations Then the result of the individual devices are showed and compared with the reference (original) case, followed by an evaluation of how the devices can be combined to improve the results. The results of these combinations are then presented and analyzed in the last part. In 0°, there is an almost symmetric wake created around the truck. Large wake structures are especially observed along the sides of the truck, origin from the separation at the front and amplified by rotating wheels and the disturbed flow underneath the truck. The flow losses along the trailer are then reduced until it reaches the rear part of the trailer are the air again separates and a large base wake is created.

Additionally, time-averages and simulates a steady state approximation of the time dependent flow. These are all approximations that affect and diminish the accuracy of the results, which needs to be kept in mind. However, even if the numbers presented in this report should to be considered with care, the same method is used for all cases which makes the cases comparable. The result gives a guideline of the tendencies in the flow behavior and are the major Drag can be gained over Sino truck (Model 321).

4.1.1 Optimamum grid test use velocity and pressure

Optimization is a process of getting the right solution or dimension required for the particular problem. Every problem can achieve highly effective results if Optimizations are performed on its design variable.

Table 9: Grid Test

No test	Grid test in x,y,z	Velocity in m/s	Pressure in bar
1	72x50x30	16.440	7.446
2	77x50x32	18.305	9.267
3	82x50x40	18.3084	7.162
4	122x50x47	14.087	8.654
5	152x50x52	14.654	10.54
6	162x50x73	14.543	4.621
7	2012x50x82	12.732	5.342

4.1.2 Comparing Air movement with and without a Cab roof deflector

Aerodynamic devices improve the streamlining of the tractor-trailer. The devices reduce the surface area that the air hits, so less drag is produced, and consequently, less fuel is used.

- When the cab does not have a deflector, air hits the front of the trailer and creates drag in the tractor-trailer gap

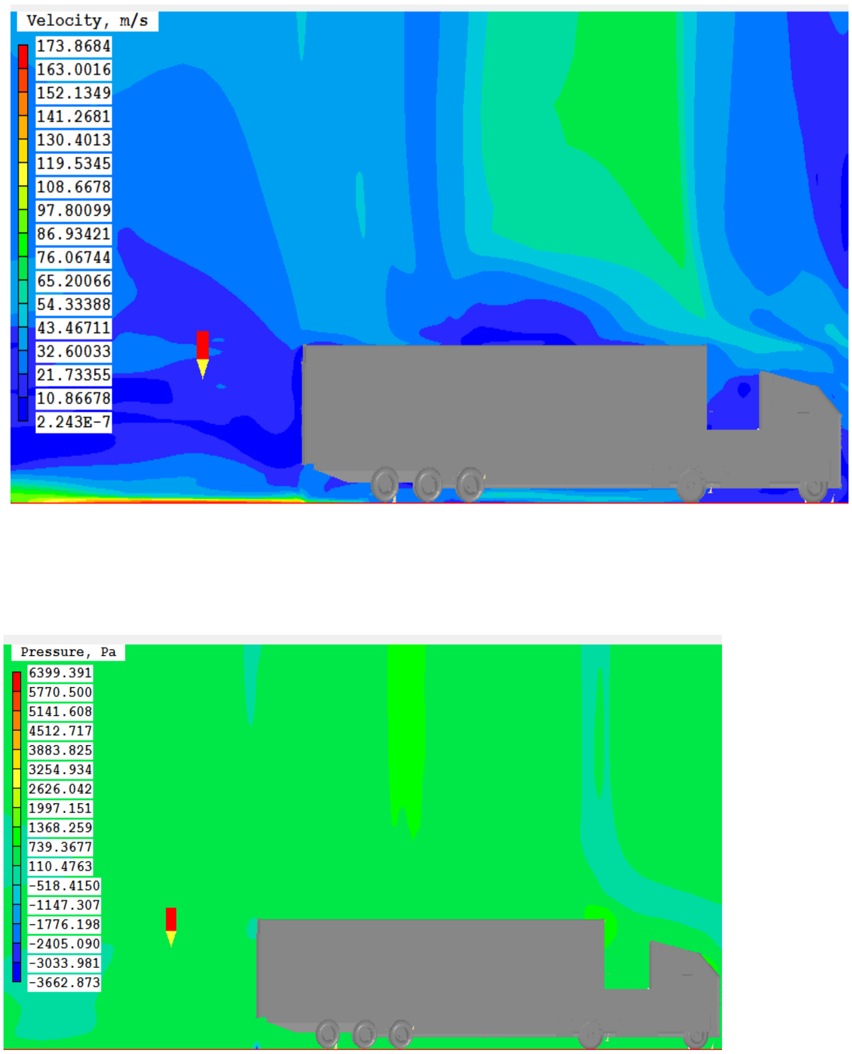


Figure 27:Model 1 velocity and pressure distribution (64kM/h)

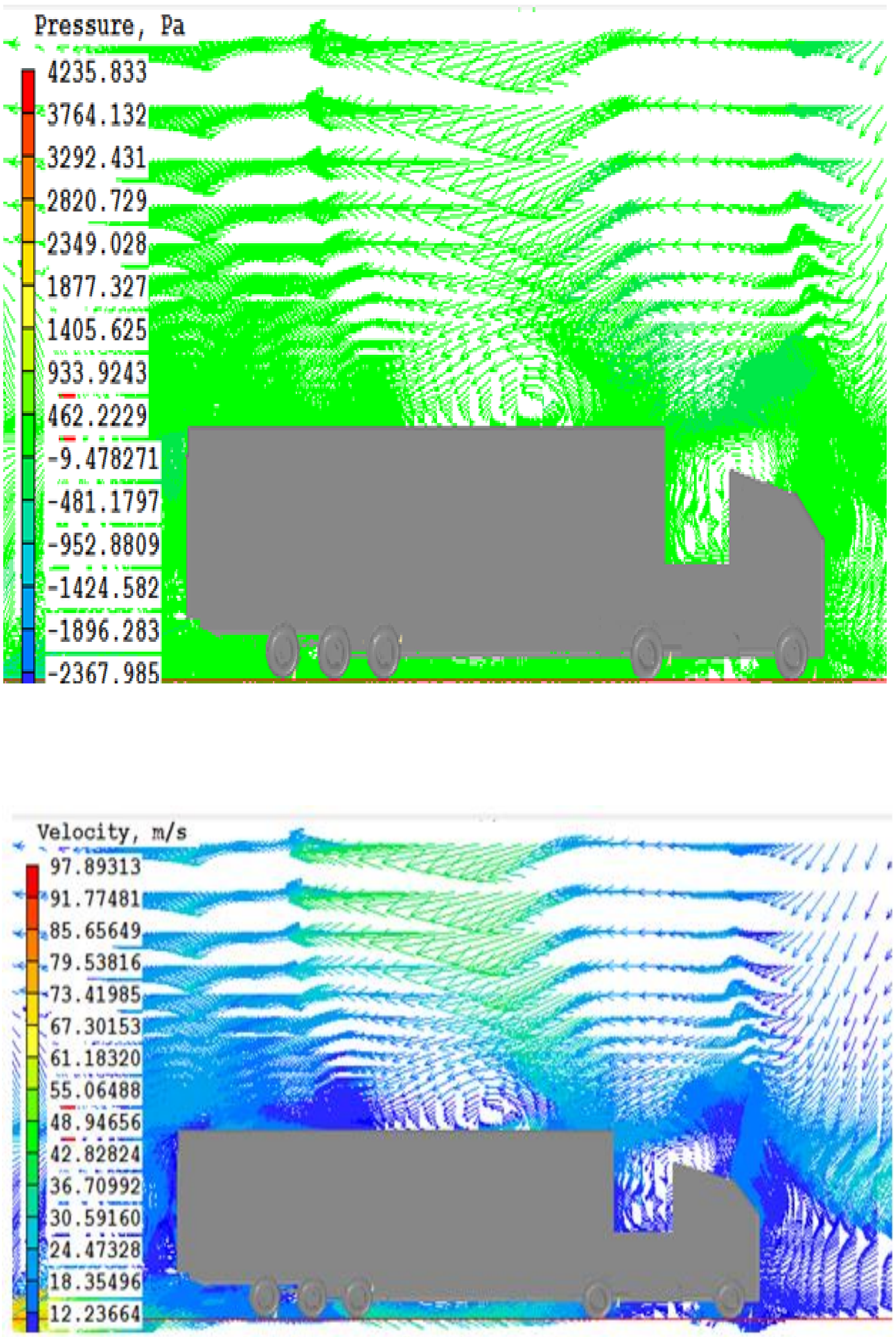
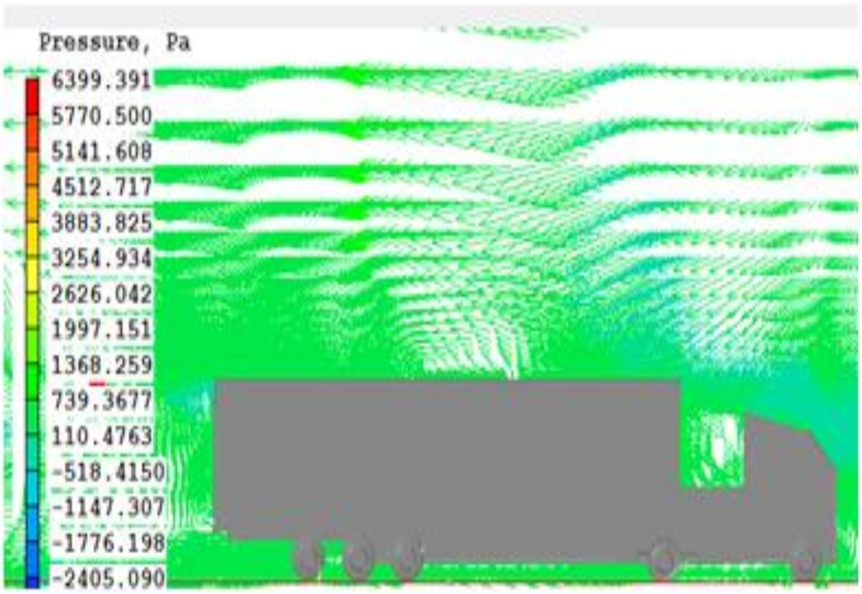


Figure 28:Model 1 Velocity and Pressure distribution (80kM/h)



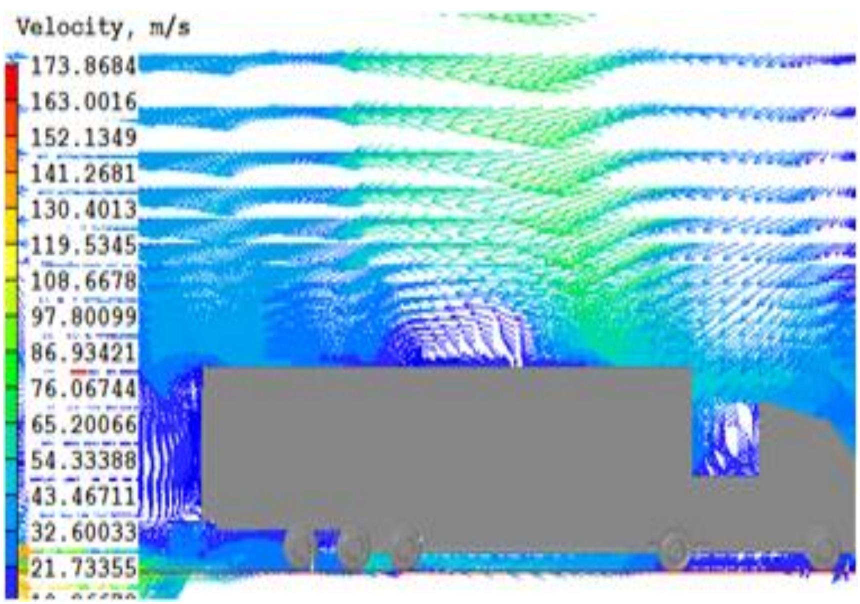
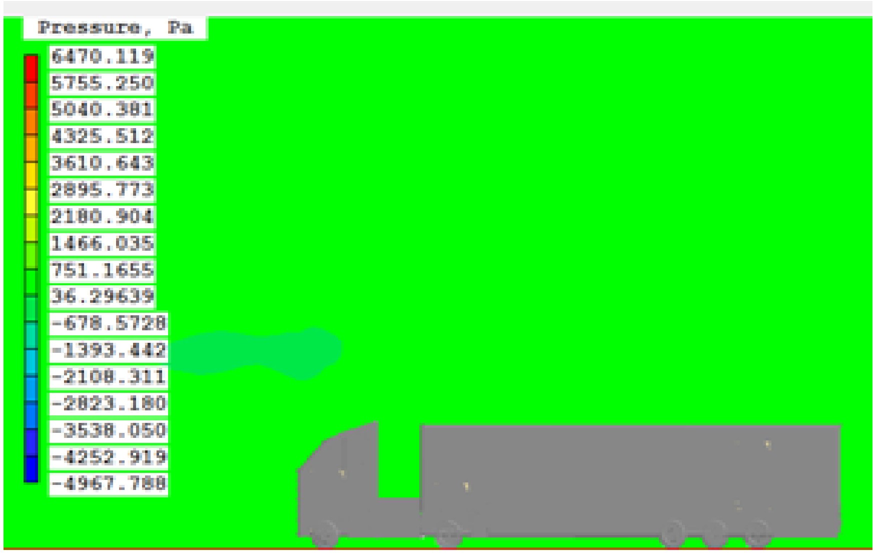


Figure 29:Model 1 Velocity and Pressure distribution (96kM/h)

- When a cab deflector is added, the air moves over the tractor-trailer gap, which reduces the area being hit.



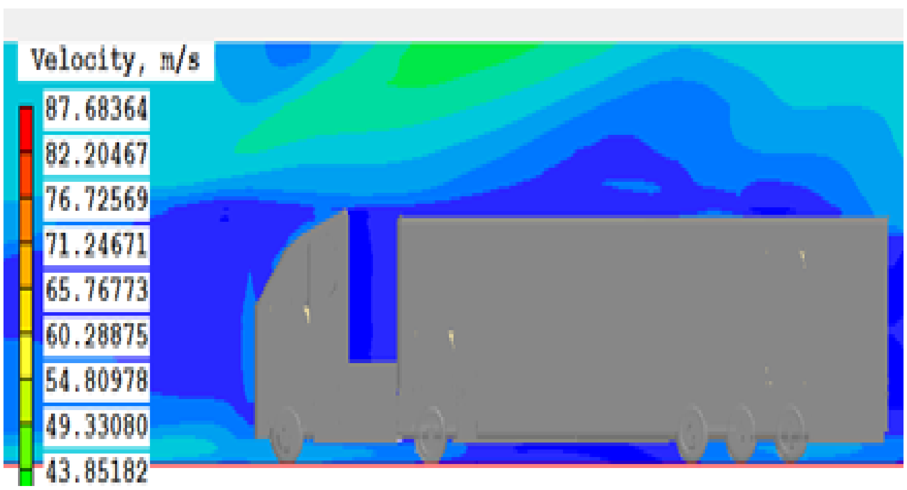


Figure 30: Velocity and Pressure distribution over Sino truckMode2(64km/h)

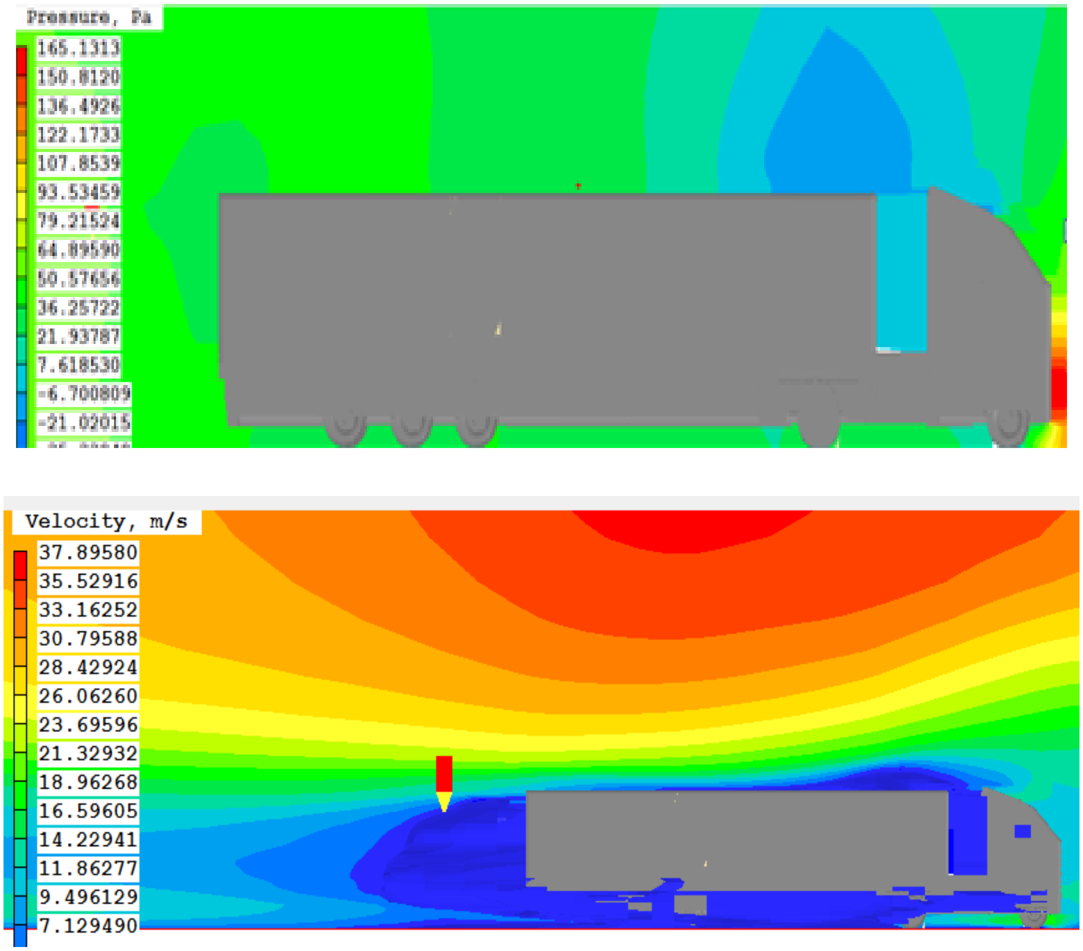


Figure 31: Velocity and Pressure distribution over Sino truck Mode2(80kM/h)

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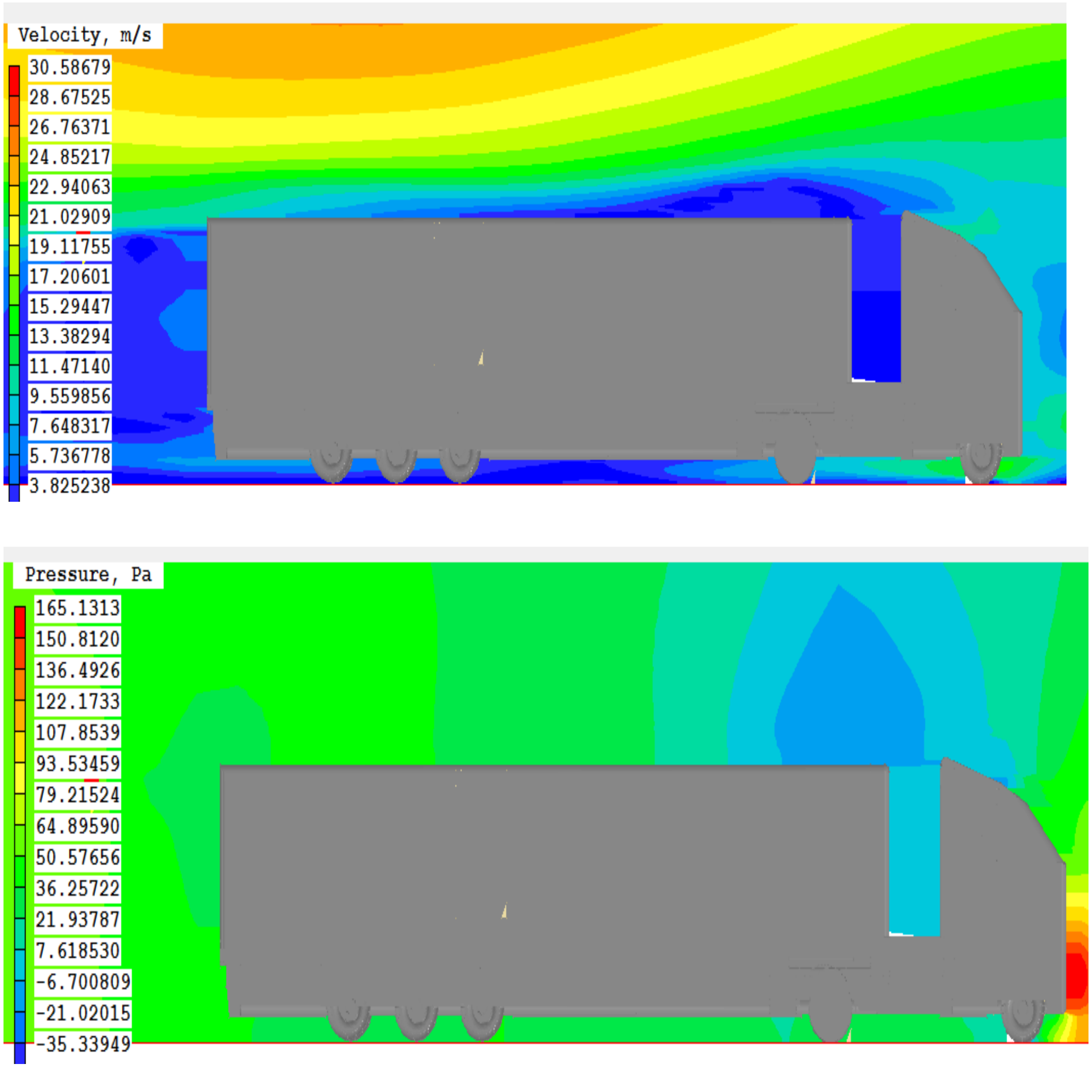


Figure 32: Velocity and Pressure distribution over Sino truck Mode3(64km/h)

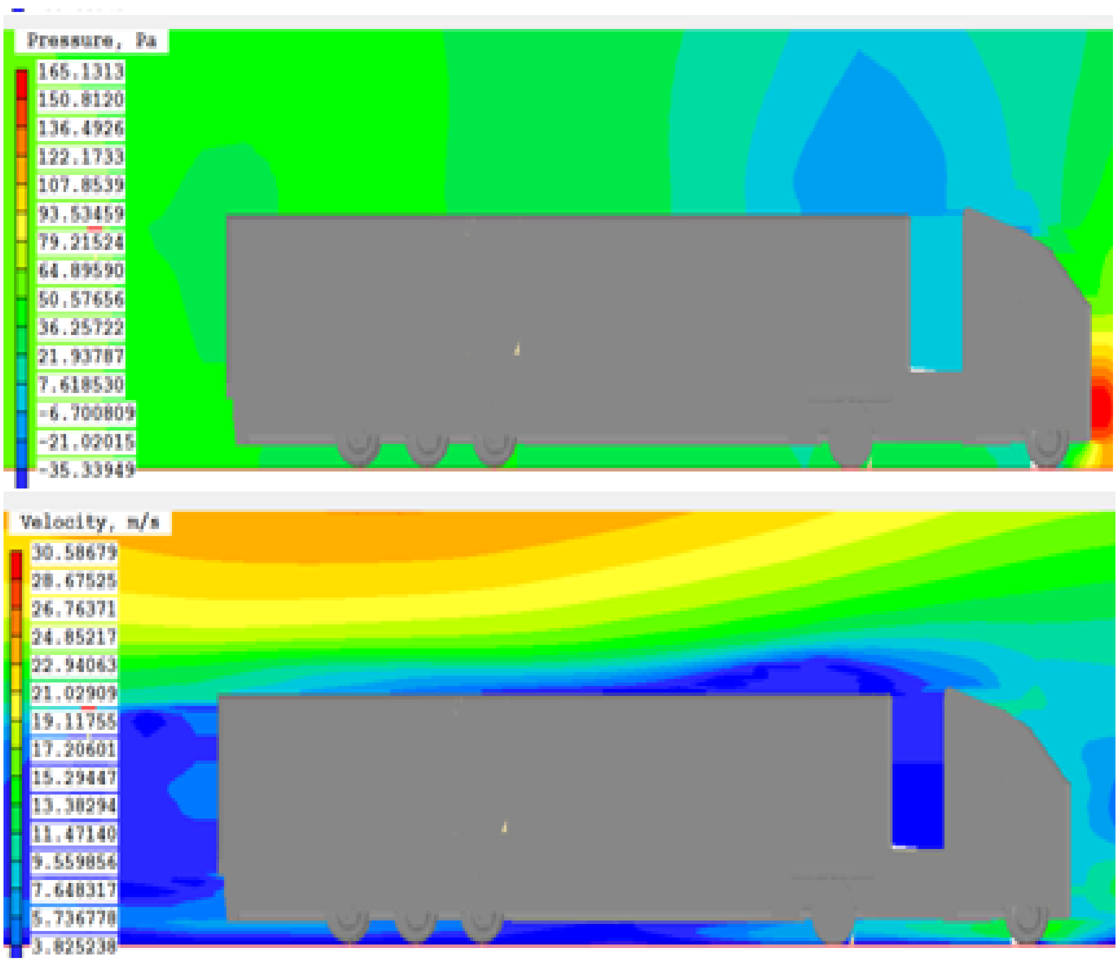


Figure 33: : velocity and pressure distribution over sino truck mode3(80km/h)

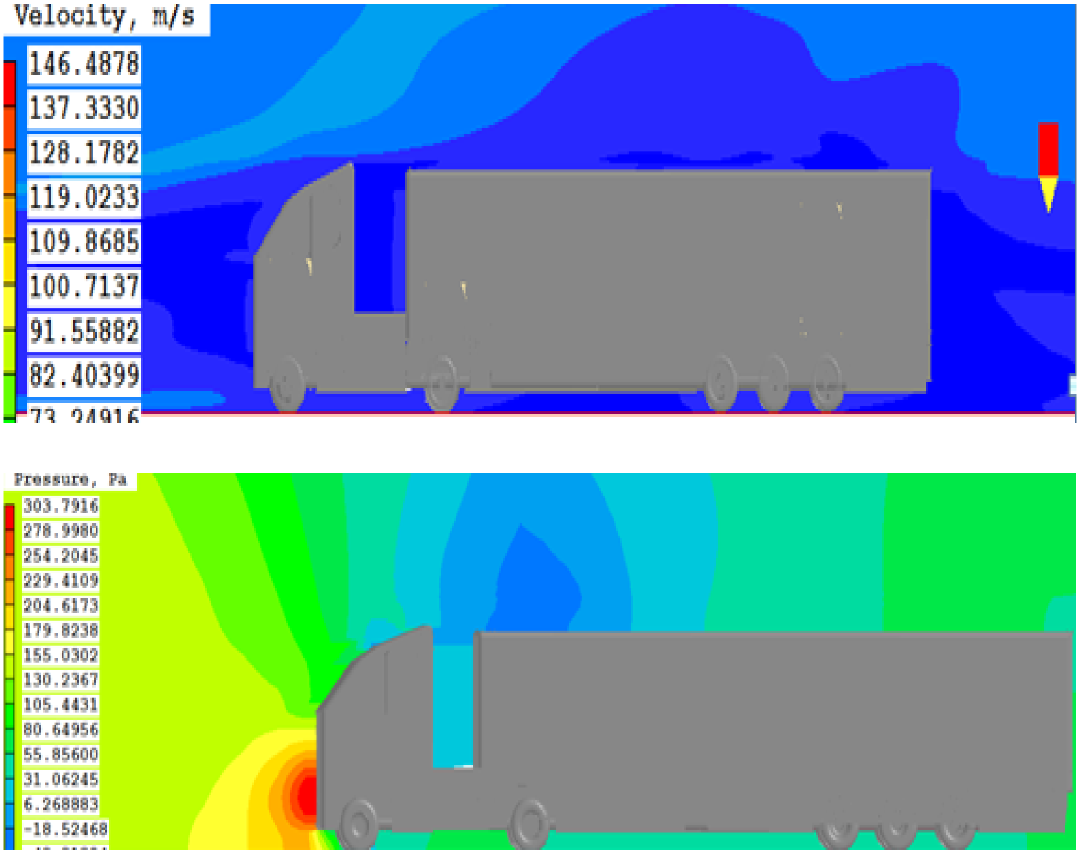


Figure 34: Velocity and Pressure distribution over Sino truck Mode3(96kM/h)

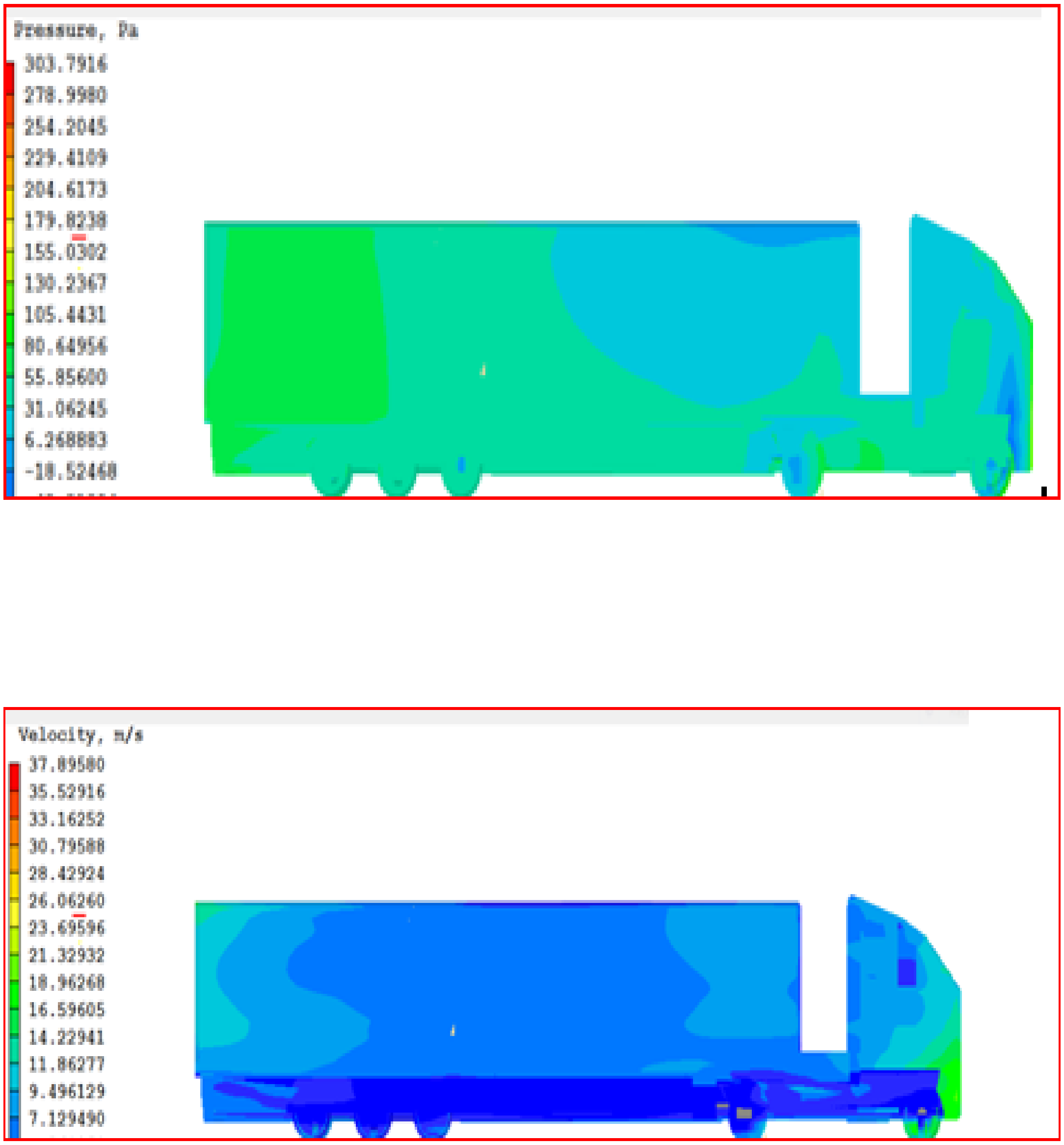


Figure 35: Total Pressure and Velocity contour for simulations at Y= 900mm

4.1.3 Air flow Underneath of the Trailer:

The airflow underneath the trailer indicates a very disturbed and chaotic behavior. The air that reaches the undercarriage of the trailer is already separated and turbulent due to flow disturbances from the tractor and its rotating wheels. Pictures from the 0° simulations reveals low velocities under the trailer and many large swirls at the fore part of the trailer undercarriage. In gradient , the flow disturbances under the trailer are increased. In contrast to 0°, a large amount of cross-winds with high velocity enters the undercarriage. The velocity of the flow is then significantly reduced as it hits the wheel bogies and the wheels. This creates a low-momentum flow underneath the trailer that separates at the rear.

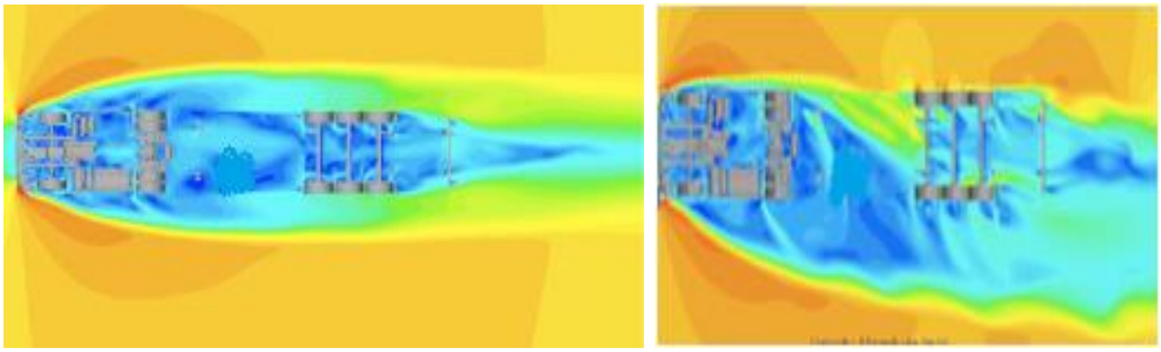
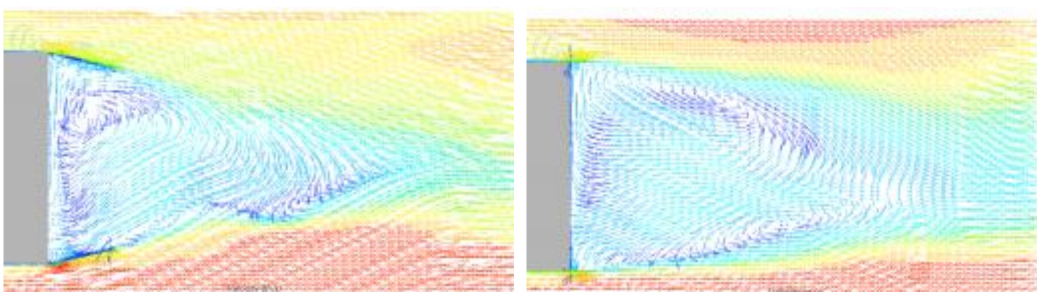


Figure 36: Velocity magnitude displayed 600mm above ground in 0° baseline and original

4.1.4 Side plates: The simulation show that a reduced low-pressure acting on the trailer back along with a significant reduction of the base wake. The angled Side plates guides the air towards the centre of the base wake.

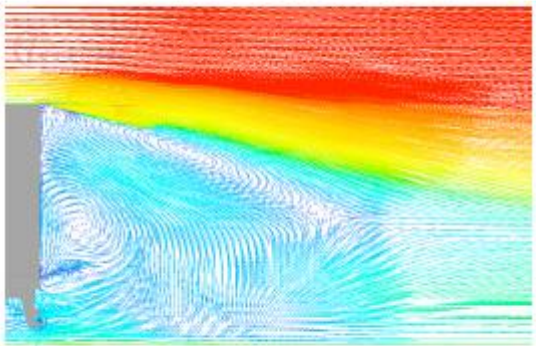


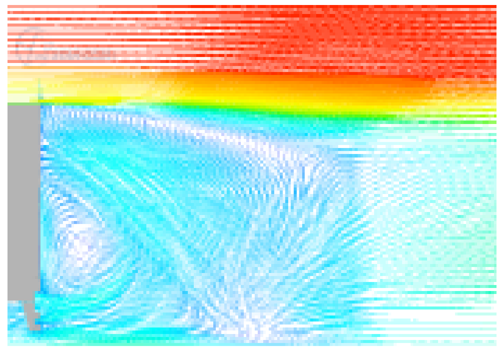
(a) Side plates modified   (b) Reference (original sino truck model 321)

Figure 37: Velocity vectors displayed in a z-plane of side plate

4.1.5 Base plates

The target of adding Base plates is to decrease(minimizing) the base wake by guiding the air from the roof and the undercarriage to the center of the base wake. The outcome of adding the Base plates is a higher pressure, although still a low-pressure, in the base wake that is decrease the pressure difference between the front and the rear. Pictures of the velocity vectors shows how the air stays attached over the edge of the trailer roof and along the upper base plate, The airflow maintains in the direction of the plates and the picture shows a significant vertical contraction of the base wake.





(a) Base plates (modified) (b) Reference (Baseline)

Figure 38: Velocity vectors of the base wake displayed in the symmetry plane

4.1.6 Rear of the trailer

Just behind the trailer, a large wake is generated as air separates from the surface at the trailing edge at the rear of the trailer. A low-pressure region is created behind the trailer when the separation occurs and air is sucked into the wake from all the sides. The low-momentum flow that exits from the undercarriage turns upward straight after the trailer and generates an up wash and a swirl behind the trailer. In the center of a swirl a substantial low pressure is obtained. At the upper part of the base wake, larger swirls are created due to the higher velocity of the air that travels over the roof. That visualizes the airflow behind the trailer.

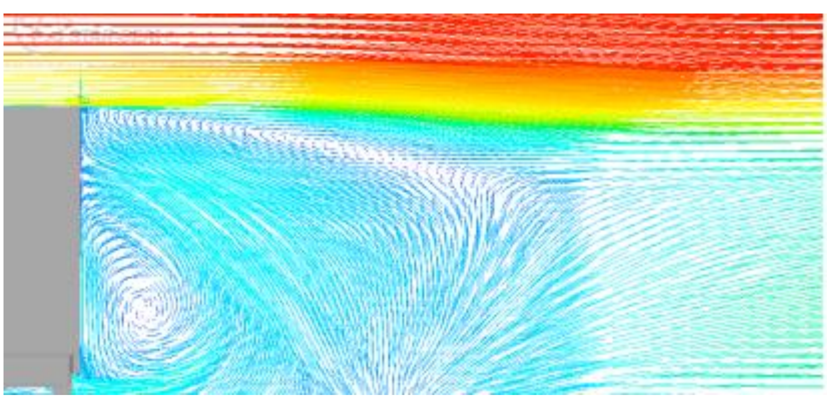
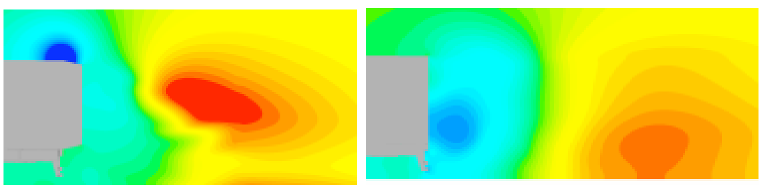


Figure 39:Velocity vectors displayed in symmetry plane rear trailer

4.1.7 Frame extension

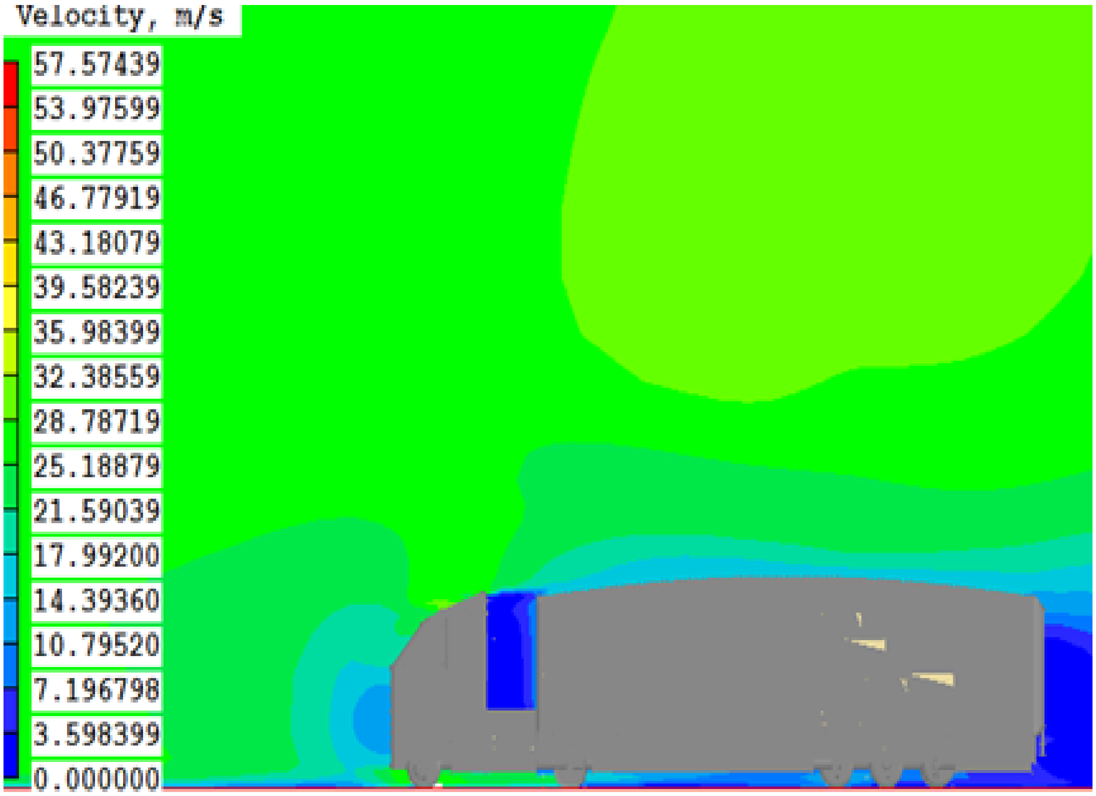
When combining Side plates and Base plates the device Frame extensions obtained. This device has very good results in both 0°and some gradient. The pressure distribution on the trailer back is almost uniform, except the low pressure acting on the plates due to acceleration. The mean pressure at the trailer back is definitely larger than the Reference case, which has a positive effect on drag. Compared to the Reference, no significant low-pressure swirl is created behind the trailer back. The same effects, regarding a strong downwash and a poor up wash, which are achieved with Base plates, also applies for Frame extension. The angle of the plates in Frame extension, especially the top plate and the two side plates, is very effective at guiding the air and reducing the base wake, in both yaw conditions.



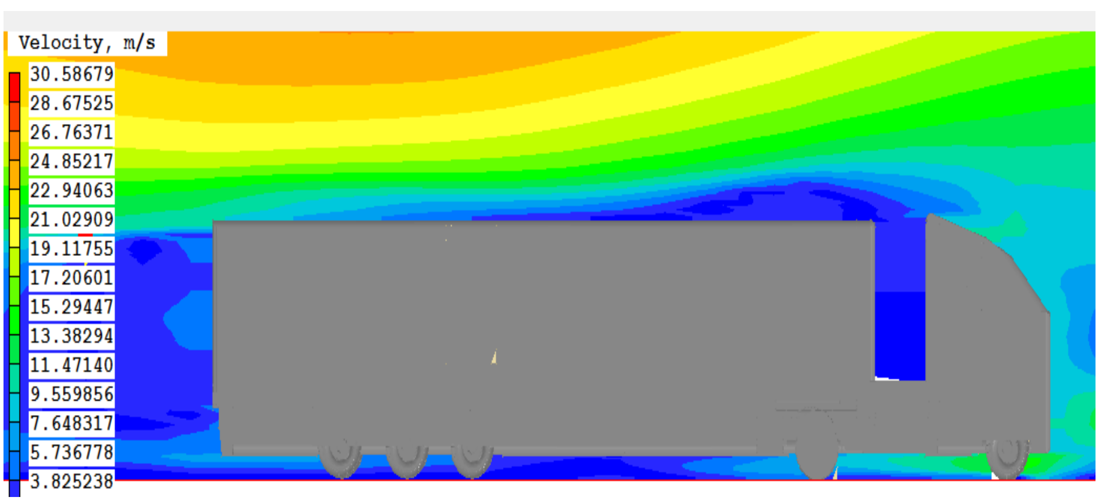
(a) Frame extension (b) Reference (Sino truck model 321)

Figure 40: Frame extension Pressure displayed in symmetry plane

Teardrop Due to the drop-shaped design of Tear drop in x-direction this configuration works best in 0°; the flow structure are mostly seen in the base wake are a fairly strong downwash and thereby a reduced base wake is obtained. The increased side area retards the improvements, and on the leeward side of the trailer a slightly larger wake is observed, when creating Teardrop, half-meter of extra material is added on the roof of the trailer, which means that, the frontal area of the truck is increased. However, to keep the result of Teardrop comparable to the Reference case, the same frontal area is used when calculating.Tear drop gives a significant improvement of the flow along the roof of the trailer, compared to the Reference. Together with the slope at the rear, this results in a substantial downwash. In addition, the air that exits from the undercarriage has a reduced velocity, thus a decreased up wash.



(a) Teardrop



(b) Sino Truck Model 321

Figure 41: Velocity magnitude displayed in symmetry plane

The figure above also shows that Teardrop represents a good flow attachment over the gap. As the flow follows closer to the surface, from the tractor and downstream the trailer, more air is also being transported into the gap, which increases the disturbances of the flow in this region. The effect of this is shown in pictures of the pressure coefficient at the trailer front, indicating that Teardrop experience an increased pressure at upper part of the trailer front, compared to the original (Reference).

4.2 Aerodynamics performance analysis of Sino truck model321

4.2.1 Drag coefficient at different speeds

Table 10: Drag coefficient at different speeds (C_d)

Drag coefficient at different speeds (C_d)			
Sino truck speed m/s	Model 1	model 2	model 3
64kM/h	0.4643	0.4123	0.3300
80kM/h	0.5492	0.512	0.4240
96kM/h	0.8943	0.8212	0.7480

From the table 10: It is observed that while the drag coefficient is increasing with increase speed all model. the percentage of C_D reduction in each model which is d/f from the each other duet shape and relative to the flow and fluid viscosity ,mass ,density and flow speed.

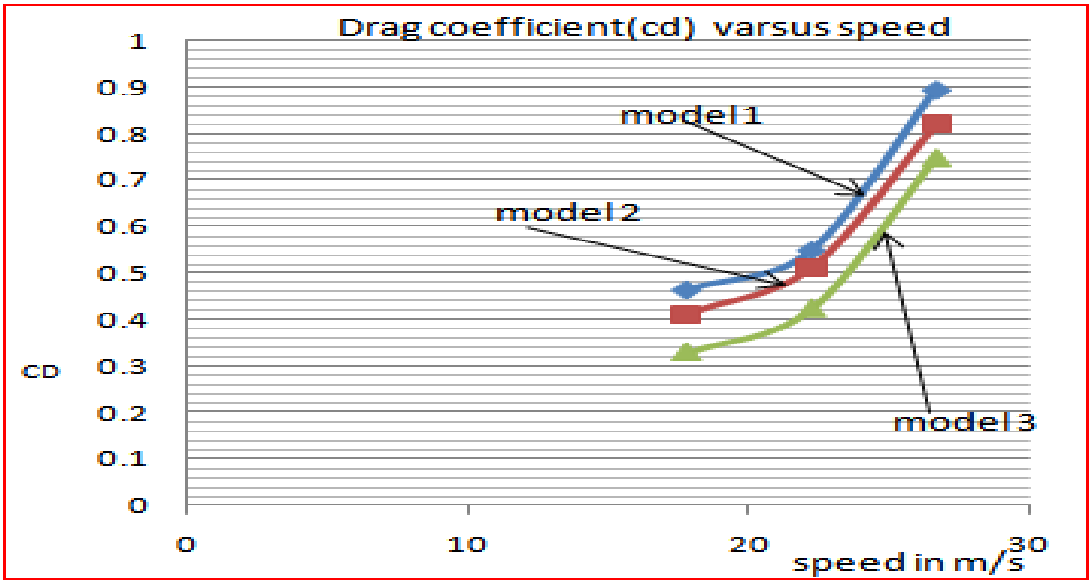


Figure 42 : Drag coefficient versus speed of models of Sino truck

4.2.2 Total Drag Force(N) at different speeds

Table 11: drag force versus speed

In km/h Speed	Model 1	model 2	model 3	Reduction of driving resistance
64km/h	947.9923	841.818	673.783	274.2093
80km/h	1750.65	1632.678	1351.566	281.112
96km/h	339815.57	3655.226	3330.218	336.48

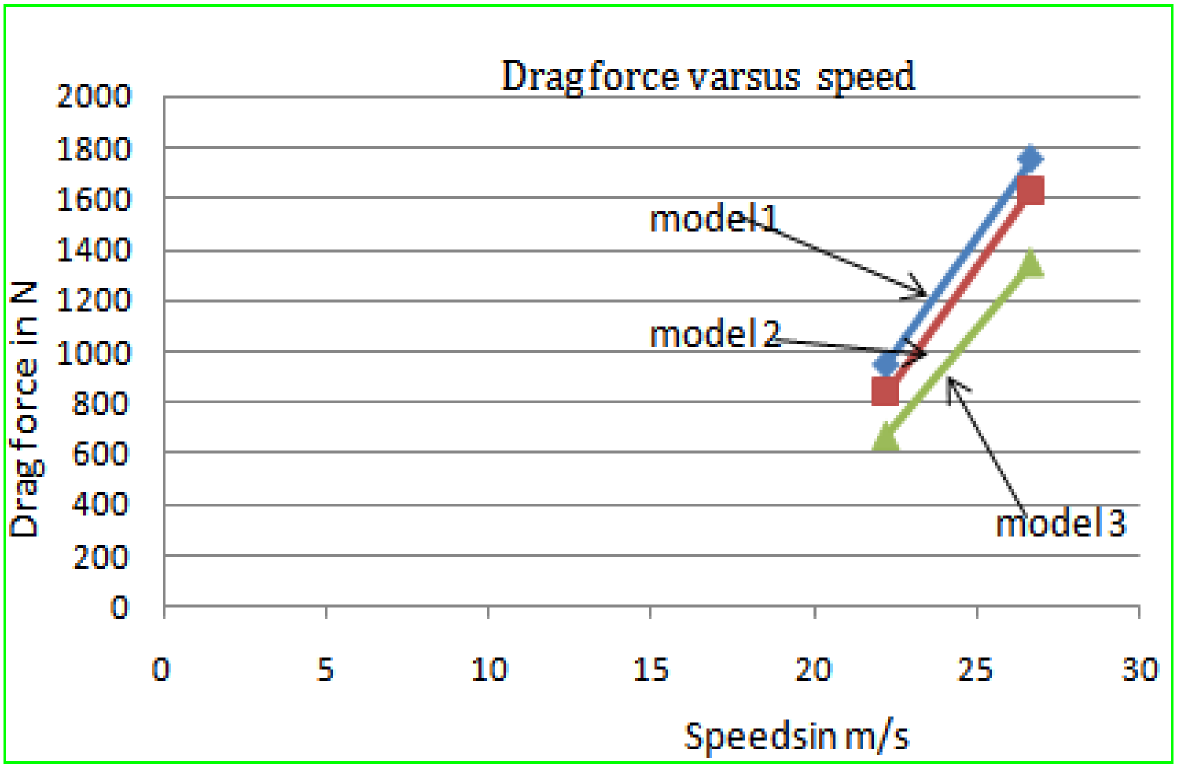


Figure 43: Drag Force versus Speed of Models

4.2.3 Total resistance force

Table 12: Total resistance

In km/h Speed	Model 1	model 2	model 3
64km/h	1618.331	1514.1215	1412.457
80km/h	2536.254	2192.654	1923.456
96km/h	3107.783	2611.355	2412.452

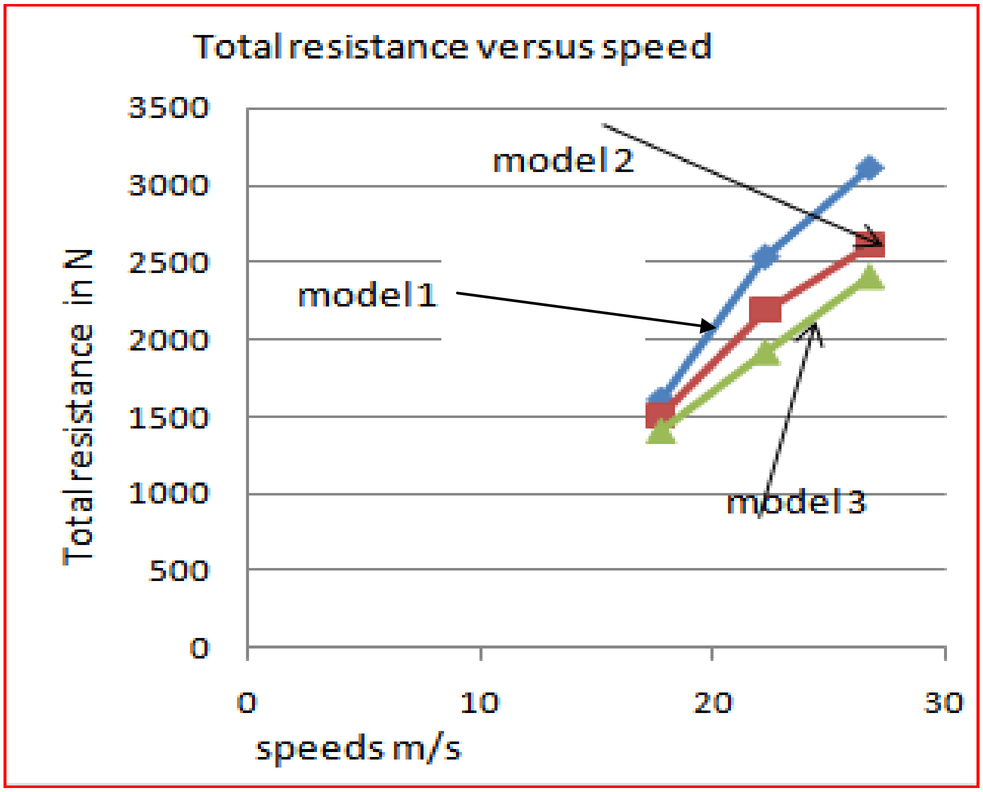


Figure 44:Total resistance

4.2.4 Power requirement.

Table 13: Power requirement kW

Power requirement kw				
In Speed kM/h	Power saving KW	Model 1	Model 2	Model 3
64kM/h	2.0587	1618.331	1514.1215	1412.457
80kM/h	6.127	2536.254	2192.654	1923.456
96kM/h	6.9533	3107.783	2611.355	2412.452

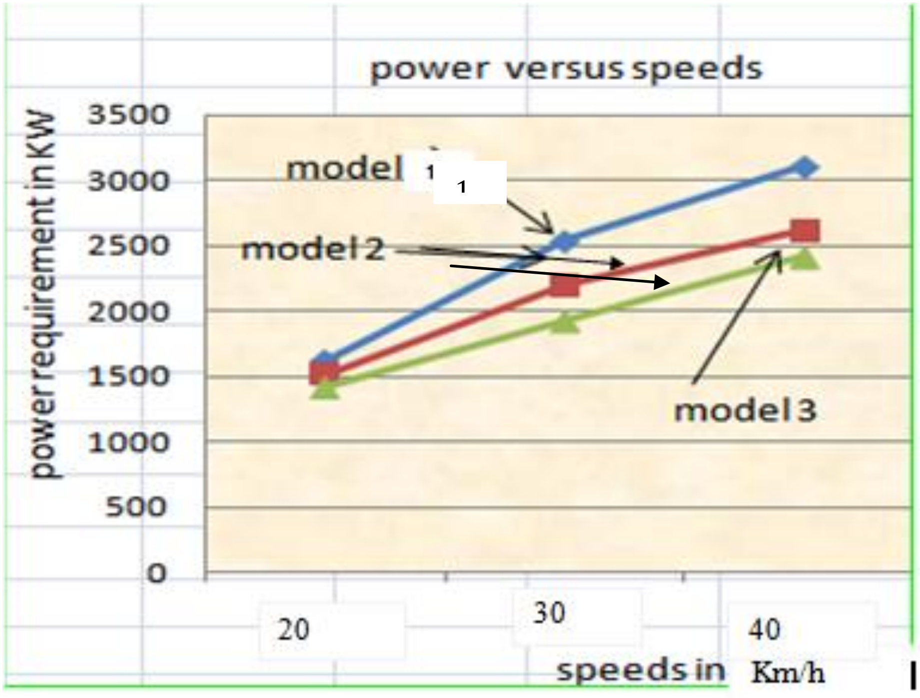


Figure 45: power requirement versus speed

The power requirement which applied by model one is greater than both model two and model three, the power required in model three more less than model Two. Mean that model one consume more fuel than two model similar model two consume more power than three.

4.2.5 Fuel Consumption

Table 14: Fuel reduction

Sino truckmodel321	Sino truck speed	Aerodynamic Drag Reduction to Increase Fuel Economy in percent	% fuel reduction
Model 1	64kM/h	-	-
	80kM/h	-	-
	96kM/h	-	-
Model 2	64kM/h	28.92	17.35
	80kM/h	22.79	13.67
	96kM/h	16.35	9.81
Model 3	64kM/h	11.23	7.04
	80kM/h	6.73	4.28
	96kM/h	8.17	5.26

Assume that average the truck driving for 8hr for one year the fuel consumption around 14lit/80km distance .taking 14lit/80km so the amount of fuel save in lit/80km can calculated as follow Amount of fuel save lit/80Km=fuel consumption ×percentages of fuel reduction /100

=14lit/80km×3/5(fuel reduction/100)

Table 15:Fuel saved in lit/80km

Sino truck model	Speed km/h	Drag coefficient	Aerodynamic Drag Reduction to (C_D)	%fuel reduction	Fuel save lit/80km
Model1	64kM/h	0.4643	-	-	
	80kM/h	0.5492	-	-	
	96kM/h	0.8943	-	-	
Model 2	64kM/h	0.4123	28.92	17.35	3.03
	80kM/h	0.512	22.79	13.67	0.23
	96kM/h	0.8212	16.35	9.81	0.171
Model 3	64kM/h	0.3300	11.23	7.04	0.123
	80kM/h	0.4240	6.73	4.28	0.75
	96kM/h	0.7480	8.17	5.26	0.9

4.3 Stability of Side wind

In order to assess the crosswind stability of truck in a more realistic way, more work has to be carried out. On the one hand, current developments in truck engineering have been showing a trend of faster, more energy efficient and more comfortable The pressure acting on the body surface is result in a force acting in the direction of travel (x), called drag, a force acting in the vertical direction (z), called lift, and a force acting in the lateral direction (y) called side force.

4.3.1 CFD calculation output Of the modified sino truck

Table 16: specifications of Sino truck model 321

Model dimension	Geometric
Weight(ton)	36.7kg
Length(m)	16.72
Width(m)	2.88
Height(m)	3.88
Cg height (m)	1.5
Cg location of longitudinal fro front (m)	11.55

In Ethiopia areas which are metrology station wind speed has been recorded four year ago 2004 At Gode station observed that wind velocity 12m/s[58].

Table 17: Boundary condition settings for stability from CFD

Velocity Inlet	Magnitude (Measured normal to Boundary)	26.67m/s (constant
	Turbulence Specification Method	Intensity and Viscosity Ratio
	Radius gyration	120
	Turbulence Viscosity Ratio	20
Pressure Outlet	Gauge Pressure magnitude	1atm
	Gauge Pressure direction	normal to boundary
	Turbulence Specification Method	Intensity and Viscosity
	Intensity and Viscosity Ratio	10%
	Backflow Turbulence Intensity	10
Wall Zones No Property	Fluid type	Air
	Density	ρ = 1.1859(kg/m^3)

4.3.2 Centrifugal Force and Momentum

$F_C=(mv^2/R)$ and this force forms a centring moment $Mc = (mv2xh/R)$=Fcxh

F_c at R=120m from table

$F_C=(36700X26.67^2/120)$=217.536KN and M_C=217.536X1.5m =304.55KNm

Table 18 :Centrifugal Force and *Mc*

Model 3	V(m/s)	Fc	M_c
		@ R=120	@R=120
	64kM/h	96.682N	145.023Nm
	80KM/h	150.99N	145,023Nm
	96KM/h	217.536N	304.55Nm

.

Momentum arising from truck body and yawing momentum assuming running on high way and μ=.97 and L_1=8.36, L_2=8.36, L_3=3.44,L4=L_3=3.44,L_5=4.75, while taking CCW

$$Myr = F_1XL_1 + F_2XL_1 + F_3XL_3 + F_4XL_3+F_5XL_{4+} F_6XL_{4+} F_7XL_{5+} F_8XL_{5+}F_9XL_{2+} F_{10}XL_2$$

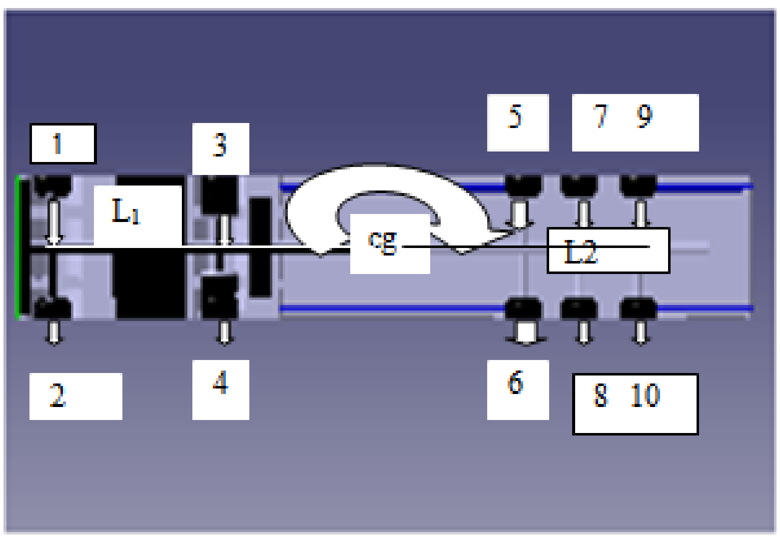


Figure 46:Body diagram of yawing momentum

Rolling resistance momentum(Mrr)

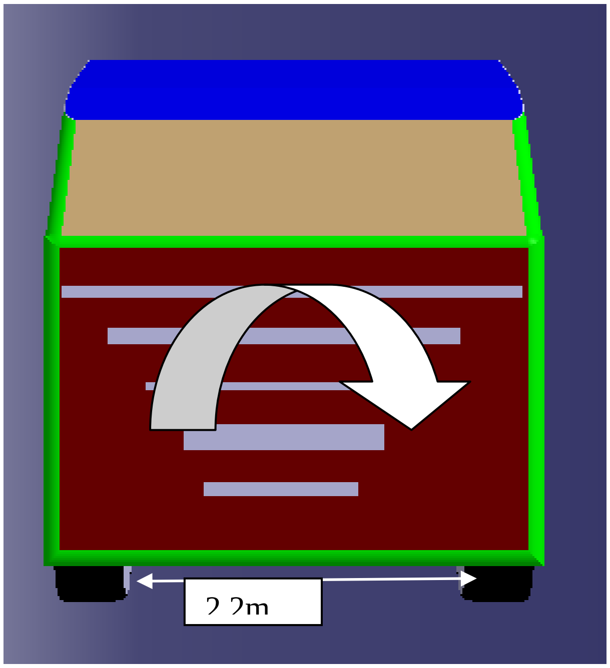


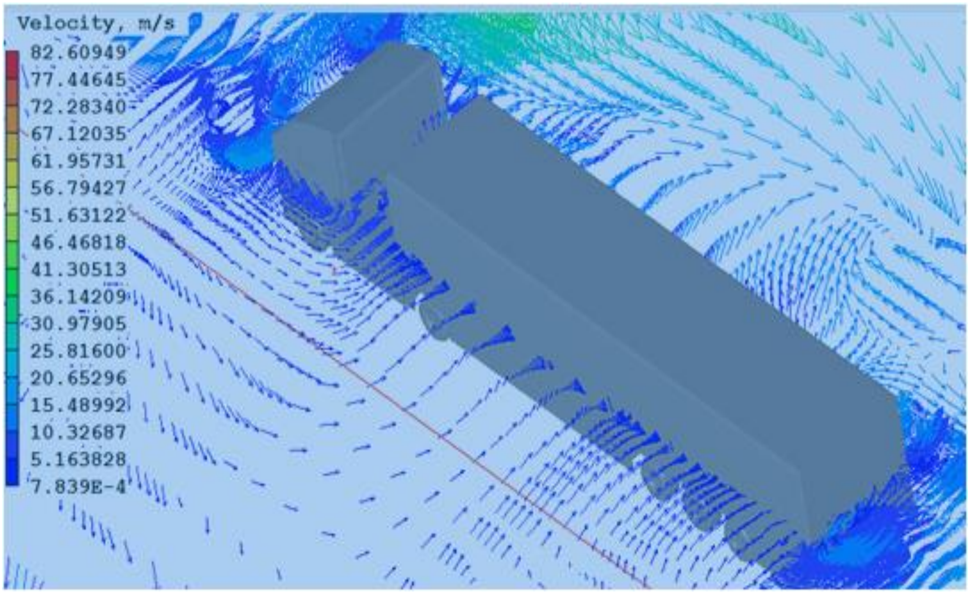
Figure 47: Rolling resistance momentum(Mrr)

Table19: Moments coordinates from CFD result

Speed And12m/s side wind	Mrolling	Mpitching	Myawing
64km/h	$1.0815*10^3$	$1.031*10^4$	$3.828*1^3$
80km/h	$8.21*10^3$	$7.65*10^3$	$8.65*10^3$
96km/h	$5.43*10^2$	$1.011*10^3$	$3.602*1^3$

Table 20: Moments about origin or rolling center

Truck Speed And 12m/s side wind	Moments about origin or rolling center		
	Mr	Mpr	Myr
64km/h	$3.227*10^4$	$6.193*10^5$	$3.397*10^5$
80km/h	$1.04*10^4$	$2.66*10$	$2.26*10^5$
96km/h	$1.10*10^2$	$2.033*10^5$	$5.305*10^5$



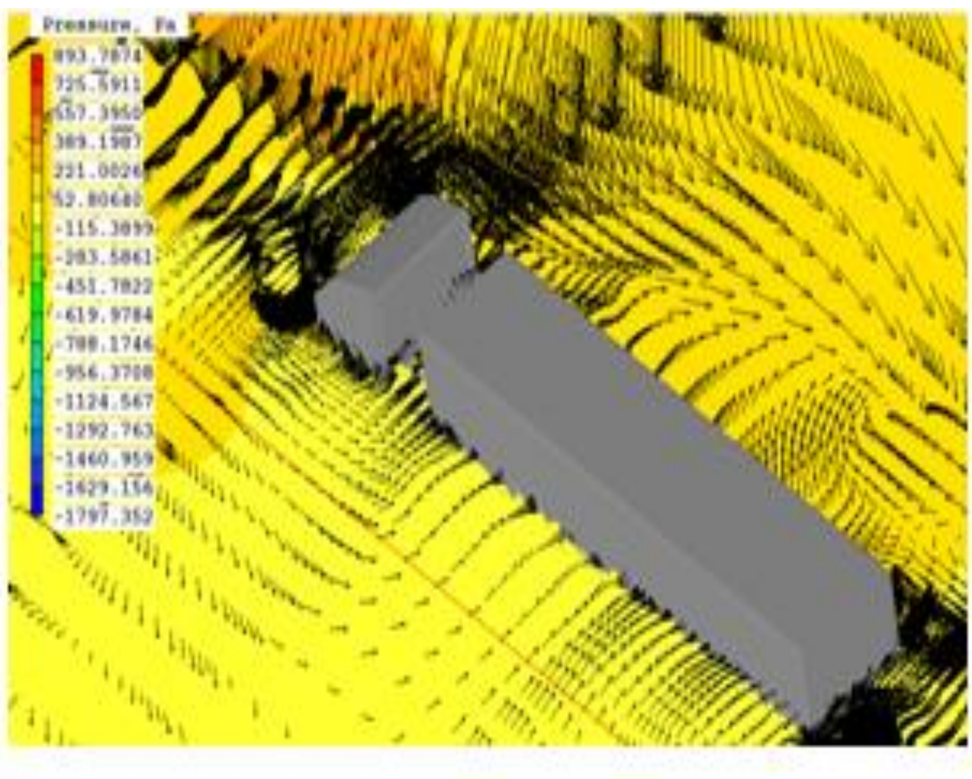


Figure 48:Pressure and velocity distribution respectively(64km/h)

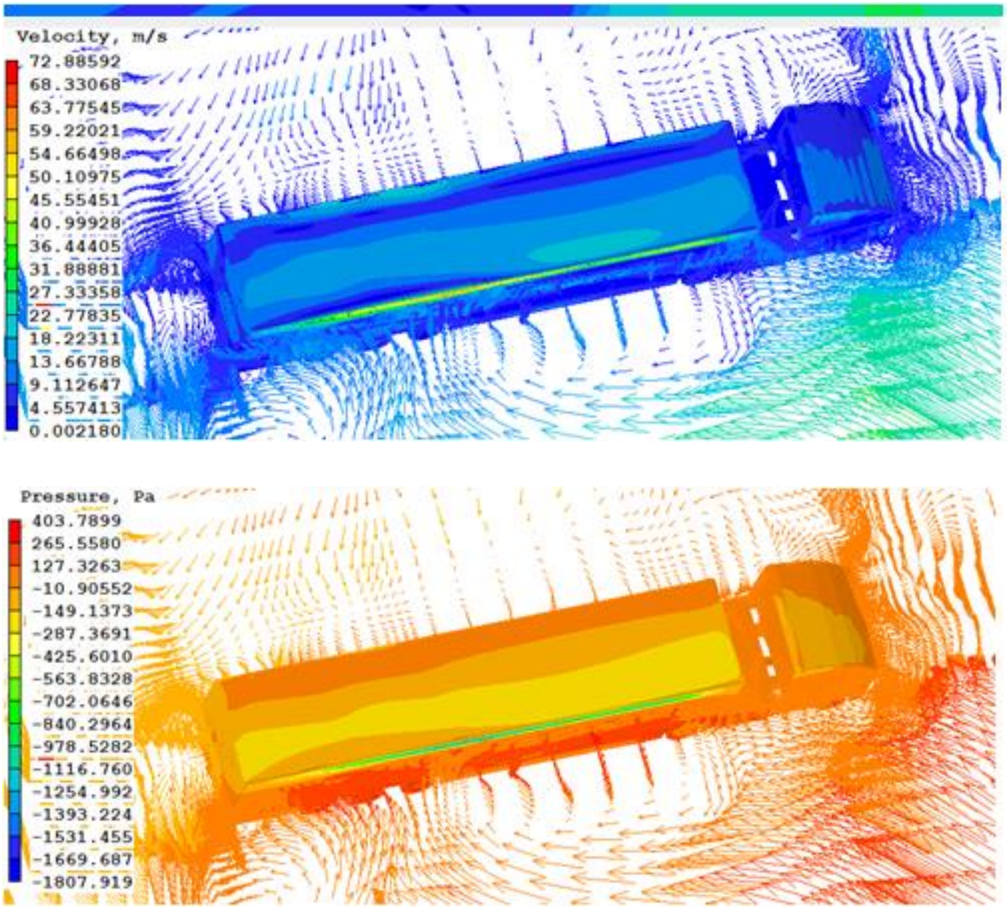
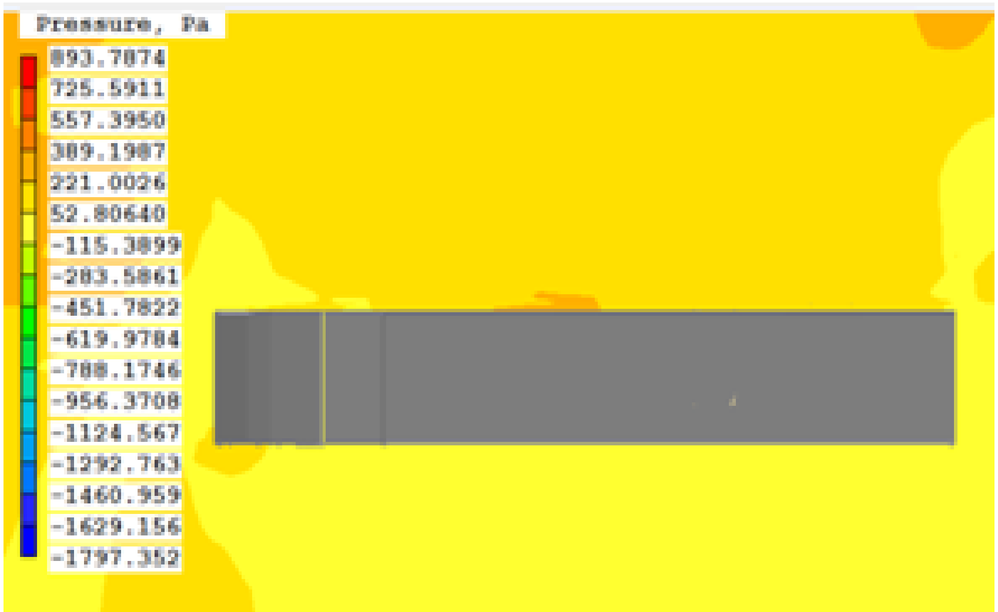


Figure 49: velocity and pressure distribution respectively(80km/h)



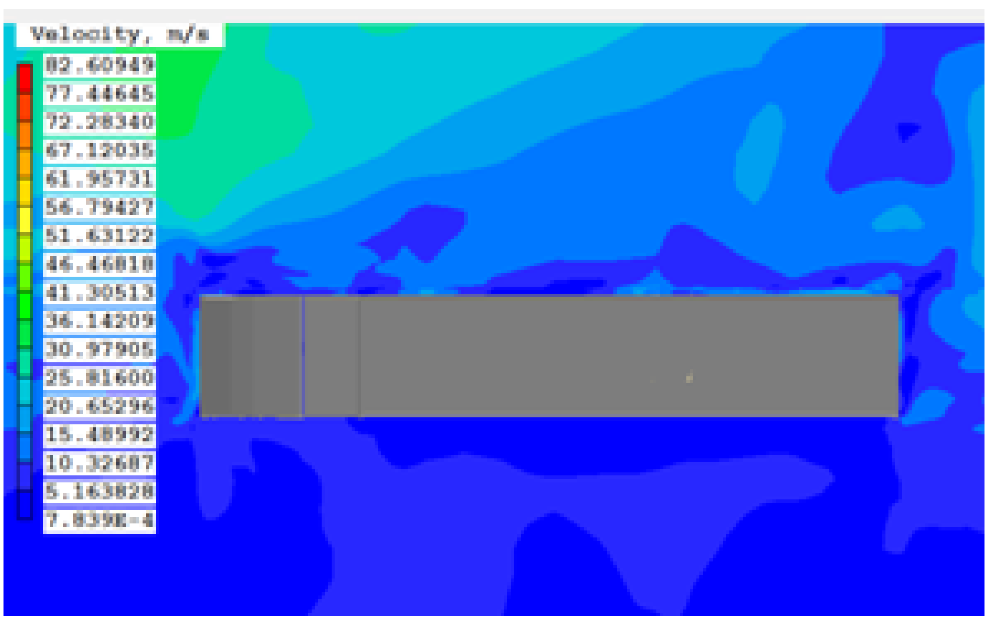


Figure 50 :Top view pressure and velocity distribution respectively

Figure 51 :Front view pressure and velocity distribution respectively

Stability of sino truck model 321Is evaluate the reduction of driving resistance. initial condition of this study is the modified sino truck model runs at a speeds from 64km/h to 80kM/h in a constant side wind 43.2kM/h. yawing moment(Myawing), rolling moment(Mrolling)and pitching moment(Mpitching) value less than the resistance momentum Mrr,Myr,Mpr. This model driving stability recommended under speeds 64kM/h-80kM/h with side wind for all speed 43.2 kM/h But when the model sino truck driving 96KM/h the value of rolling momentum resistance Less than Mrr. Sino truck driving is not recommended when driving speeds 96KM/h. duet side wind and high speed of truck.

5. CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Improving the aerodynamics Around a Sino truck Model321 in order to reduce the Fuel consumption and reduce Drag. it concludes that, Aerodynamic trailer Devices have a great potential of reducing drag. Compared to the tractor, the trailer is much more susceptible for aerodynamic drag improvements and thus the fuel consumption can be substantially reduced by using trailer devices. By combining the devices, even larger drag improvements can be achieved. In put velocity used for CFD simulation analysis are 64kM/h,80kM/h and 96kM/h with respect to the model1 at speeds 64kmph,80kM/h and 96kmph. The % Drag coefficient reduction for model two is 28.92, 22.79,16.35 and for model three are 11.23, 6.73 ,8.17 respectively and again the percentage of fuel consumption with respect to model one at speed of 64Km/h,80kM/h and 96kM/h , For model two are 17.35,13.65,9.81 and for model three are 7.04,4.28,5,26 respectively. The coefficient of drag (C_D) variation with respect to geometrical shape, this variation in the Drag distribution reflects the difference between a tractor-trailer. with advanced aerodynamic shaping, Tractor-trailer gap, Trailer underbody, Trailer side plate ,frame extention and side fairings Compared to the tractor, the trailer is much more susceptible for aerodynamic drag improvements and thus the fuel consumption can be substantially reduced by using trailer devices. This improvement in fuel economy correlates drag .The undercarriage, tractor-trailer and the base of the Sino Truck are the two regions which the greatest effects are achieved when adding aerodynamic devices to the trailer. It is not beneficial to aerodynamically change the geometry of the trailer since there are relative simple add-on devices that show the equivalent effect. to achieve further aerodynamic improvements, and thereby reduce the fuel consumption the whole truck during the aerodynamic development. CFD numerical evaluation are preformed to analysis the moving stability of a sino truck model 321which cross wind conducted with 43.2kM/h crosswind at the variable speed from 64km/h up to 96km/h. The results of the driving CFD is comparing with those obtained from the numerical simulation. This model driving stability recommended under speeds 64kM/h-80kM/h with side wind for all speed43.2kM/h But when the model sino truck driving 96kM/h the value of rolling momentum resistance Less than Mr, sino truck driving is not recommended when driving speeds 96kM/h. due to side wind and high speed of Sino truck.

5.2 RECOMMENDATION FOR FUTURE WORK

The Drag reductions achieved by the current system can be improved and the analysis methods should be validated. Although this thesis focused on the aerodynamic of individual drag reducing devices, there is more work needed to be worked upon. In order to continue the research in the investigated active flow system the following general recommendations can be made:

- Wind tunnel tests or full scale tests should be performed in order to validate the numerical results, the full scale effects and the yaw performance of the AFC system. (Naturally, the results of CFD simulations need to be verified with experimental data, such as wind-tunnel test, to ensure reliability of the results).
- External drag reducing device like Boat tail plate and Foot step were not simulate and optimized in this thesis additional Combination of these both devices could be simulated as future work.
- The continuing work should include other types of trailer's device like smooth under the body, base drop and manufacturing to see the efficiency of the trailer devices on different truck configurations.
- Drag reduction duet to the individual Aerodynamic trailer Devices could be simulated as future work.

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APPENDIX

A Mesh Settings by Part

Table 21: grid test (existing sino truck model 321 model testing in the domain.)

No test	Grid test in x,y,z	Velocity in m/s	Pressure in bar
1	72x50x30	16.440	7.446
2	77x50x32	18.305	9.267
3	82x50x40	18.3084	7.162
4	122x50x47	14.087	8.654
5	152x50x52	14.654	10.54
6	162x50x73	14.543	4.621
7	2012x50x82	12.732	5.342
8	2013x50x89	13.12	5.12

Table22 :Mesh settings for the tractor sino truck (model 321)

part	Minimum size(mm)	Target size(mm)	Thickness Near Wall (mm)
Frontal sino truck	11	13	0.05
Cab handles	2.5	6	0.05
Roof round-edges	2.5	6	0.05
Cab wiper	1.75	3.5	.005
Cab windshield	7	13	0.05
Cab -windows	7	13	0.05

Table 23: Mesh settings for the trailer of sino truck model 321

part	Minimum size(mm)	Target size(mm)	Thickness Near Wall (mm)
Trailer side edge	6	25	0.5
Trailer Top edge	6	28	0.5
Tunnel Roof	6	25	0.5
Tunnel Side Wall	6	25	0.5
Trailer Bottom Trailer mud wing	6	28	0.5

Table 24: Mesh settings for the devices

Device	Minimum size (mm)	Target size (mm)	Thickness Near Wall (mm)
Vortex stabilizer	6	24	.05
Gap fairing	6	24	0.05
Frame extension	6	24	0.05
Side skirts	6	24	0.05
Teardrop	47	58	0.25

B ,Drawing

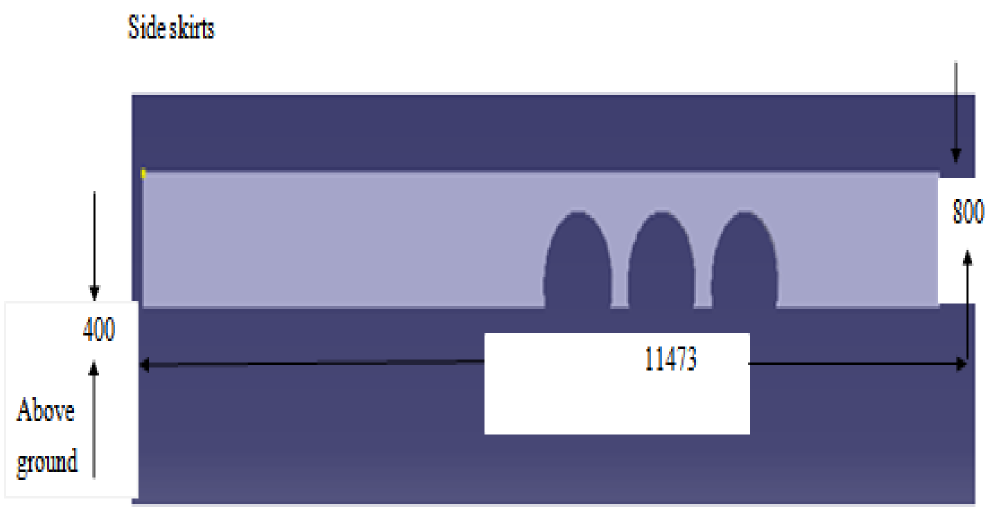


Figure 52: Side skirts

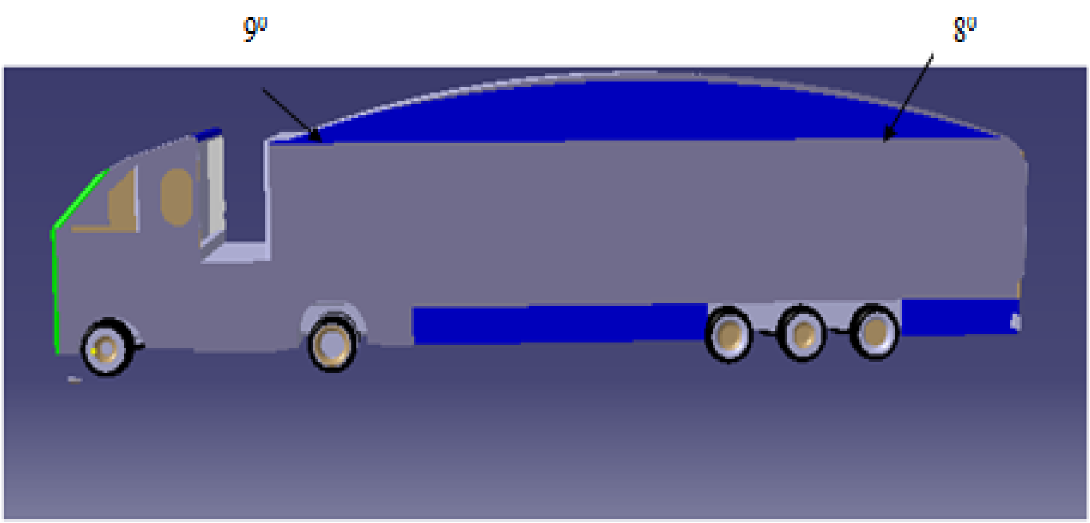


Figure 53: Teardrop – side view, measures in mm

Side plates

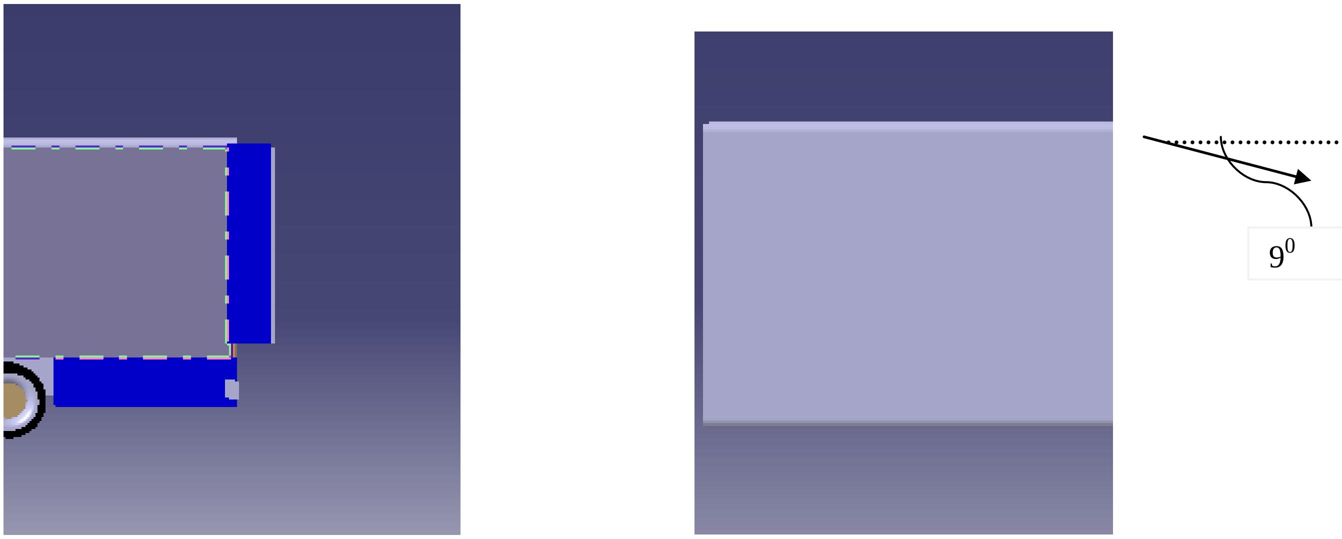


Figure 54: Side plates - side and top view, measures in mm

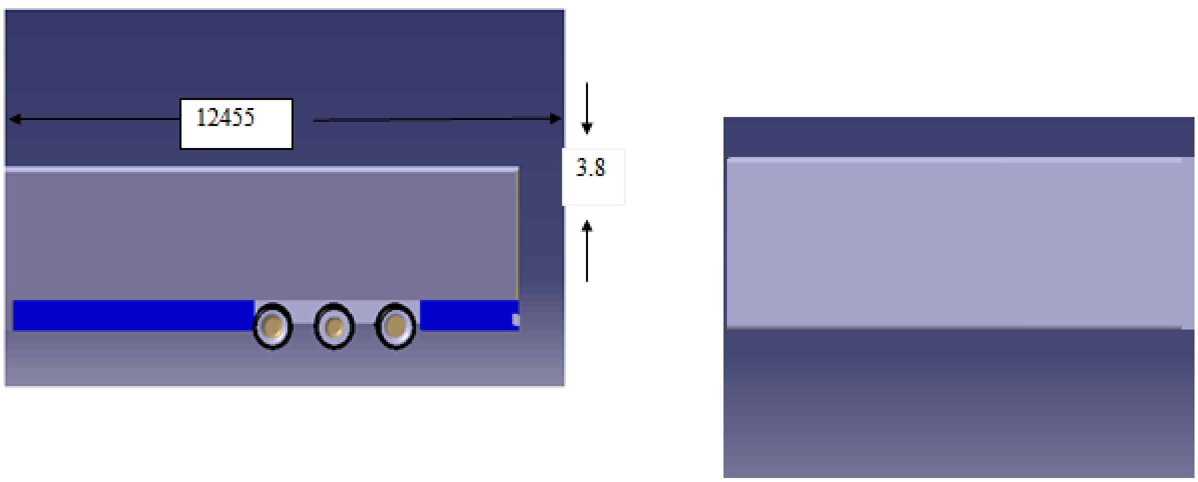
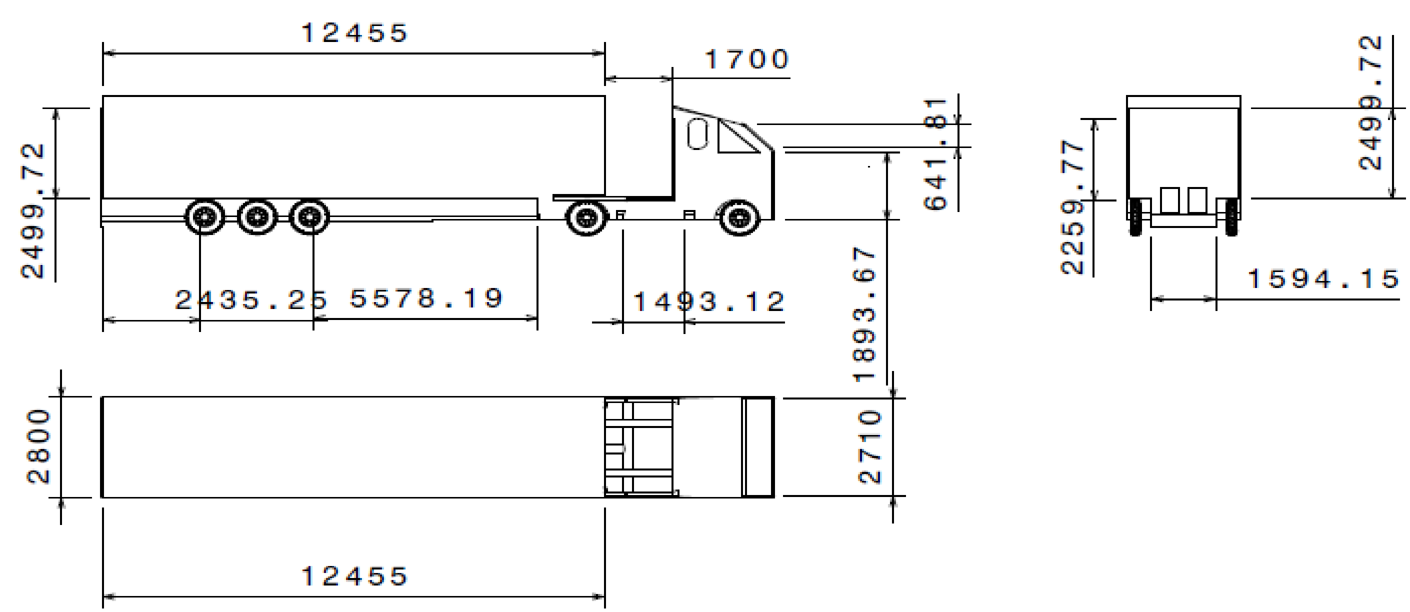


Figure55: Reference trailer - top and side view, measures in mm



Model By
Merga Deraro

sino Truck
Model Exit

A4

Adama Science and Technology University

Approved By Prof. Chul-Ho Kim

Dep't of Mechanical&Vehicle Eng

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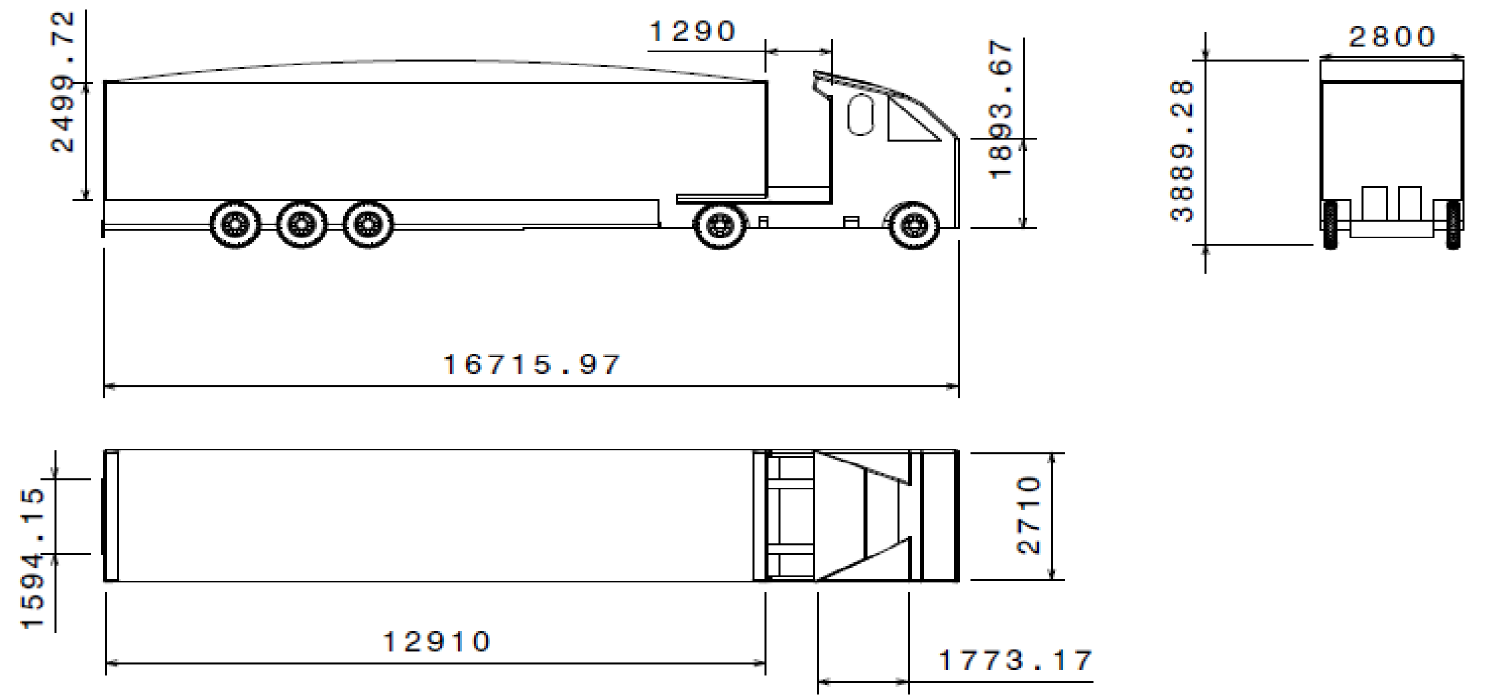

Model By
Merga Deraro

Sino Truck
model321

Adama Science and Technology University

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