# Experimental Analysis for Reduction of Drag using Various Techniques and Material

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**Abstract: - Research and Development in automobile industry has always been evident in our day to day life.A constant improvisation in various automobile parts since decades has not only made our vehicles faster but also safer. Modifications in engines, suspension, braking systems and design have made vehicles comfortable.Today, automakers are aiming to build cars that can self-park themselves, reduce the risk of accidents with the help of sensors and even automatically maintain the lane. All this just adds on to luxury. But in today's era where we face a situation of crisis where the resources have to be used wisely from environmental as well as economic point of view,most important is the crude oil. A time has come where every automobile organization aims at decreasing the fuel consumption rather than increasing the speed.It is appropriate to say that we have entered the phase of reverse development where we can manage to compromise with the speed but not with the mileage.Aerodynamics plays an important role in doing so. The most important aspect which should be considered while designing any efficient vehicle is its aerodynamic drag.Aerodynamic drag in a simpler term can be said as a resistance offered by the fluid (air in our case) on the solid body moving in direction of the fluid. Things are much better in cars as it is possible to achieve a near streamline type of body which provides easy flow of air with minimum resistance.But while considering heavy commercial vehicles such as trucks and trailers,aerodynamic drag is extreme.A major reason being our need to design them in such a way that they can carry heavy loads.Best available one is having a rectangular shape truck with large length trailers.But due to increase in surface area of impact for the air, the aerodynamic drag results in large power requirement from the engine to overcome it.A report suggests that at 100 kph, about 52% of the fuel is just used to overcome the aerodynamic drag.From commercial point of view,this result is quite devastating. Only the rear mirror consumes 937 Lit. of fuel through this aerodynamic drag.This emphasizes the need to improve either the complete design or to introduce various parts which can well help us to give these commercial vehicles an appropriate flow while moving into the fluid. The new research techniques in comparison to the traditional ones as well as the various add-on components and their effects in reducing drag, lies within the scope of this paper.**

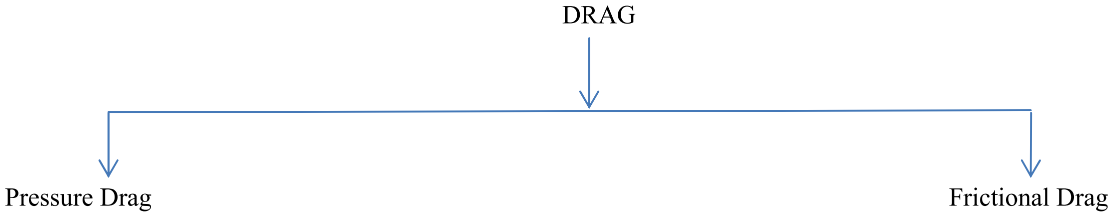
**Keywords: Aerodynamic Drag, Wind Tunnel, Computational Fluid Dynamics, Particle Image Velocimetry, Reynolds Averaged Navier-Stokes System, Skirting, Fairing, Oil Field Interferometry.**

## I. INTRODUCTION

Aerodynamics is the study dealing with the motion of air or fluid around the body moving relative to such field. While moving into the fluid streamline, drag force is induced on the body called as aerodynamic drag.

### *1.1 Drag in Heavy Commercial Trucks:*

For heavy tractor-trailer combinations, the most dominant drag is the pressure drag.The reason being large area of the front portion of the truck available for resistance for the in-coming air. Also large wakes originating from the blunt back end of the trailer. Another drag is the frictional drag which accounts for the resistance from side and top portion of the trailers. But contribution of frictional drag in the overall drag is minimum.




*1.2 Drag importance*

The drag is considered as a major factor while designing of any vehicle. Considering an F1 car, the drag plays the most important role in making the car run fast. Both the types of drag are looked upon while designing the car. Earlier, to achieve increase in the speed in such competition, engine output was to attempted to be increased.. But being in the league where the 3rd decimal point of the same time decides the championship, it was important to reduce the engine power usage for overcoming drag. The only way to do it is to improve the design, to make it more streamlined and to provide easy passage of the flow. For e.g. the recently developed DRS (Drag Reduction System) system developed by the Mercedes team proved a vital modification in winning them the title.

But things are different when considering the impact of drag on truck-trailer combinations. With this, also there is a huge scope for improvement in this field. The newly developed add-on components can be used to give the incoming air, a perfect streamlined flow and hence reducing the drag.

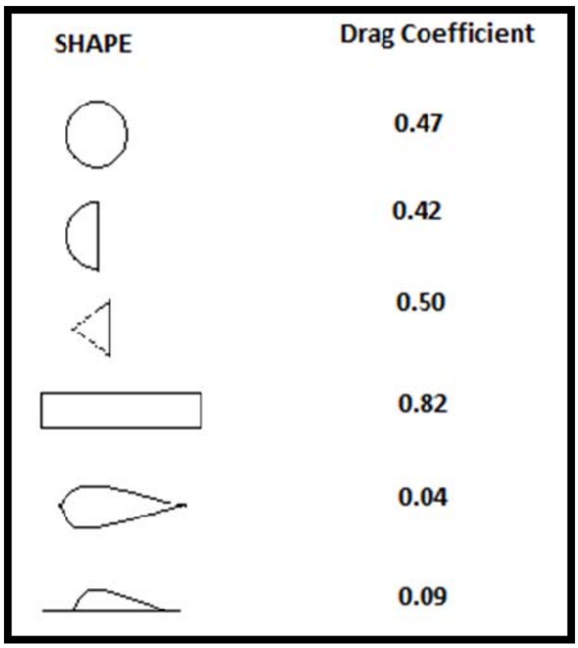



Figure 1.2.Shows least aerodynamic drag co-efficient in case of streamlined and semi-streamlined body.

*1.3 Drag Calculation:*

$$F_d = 0.5 \text{ x } p \text{ x } u^2 \text{ x } C_d \text{ x } A$$

Where, $F_d$corresponds to Drag Force
P as mass density of the in-coming fluid
u as relative flow velocity of fluid
A is the reference area in plane perpendicular to the direction of motion

$C_d$ is the co-efficient of drag.
Therefore, decreased co-efficient of drag will ultimately lead to reduction in Aerodynamic Drag Force.

## II. PROPOSED ALGORITHM

The incapability of heavy truck-trailers combinations or LCV to attain an aerodynamic stable configuration of even a near streamlined body, leads for a great amount of drag causing increased fuel consumption.This problem was realized way before in 1950’s - 1960’s but reducing fuel consumption wasnever considered to be the priority until the world face the fuel crisis in 1970.One can imagine what impact this drag causes,how much power it takes to overcome it when,according to a report, at 100 kph these trucks and trailers consume about 52% of fuel just to overcome the drag effect.When we take this concept to a larger scale, on anaverage heavy trucks and trailers cover around 2,00,000 km annually and the duration for which these vehicle travel at top speed is very less.If every vehicle faces such high drag,it greatly affects the fuel intake globally leading to more emission.Another way of looking at it is, even a slightest of changes brought about in the design consideration can reduce the amount of fuel consumption on a large scale.Various new technologies have come to play their part in doing so ranging from reducing the gap between the truck and trailer,to using skirts either partially or fully and using fairing etc.All such modifications when merged together greatly reduce the amount of fuel consumption. Even today, the trucks which are manufactured aren’t of aerodynamic stability and the truckers/buyers are forced to buy it due to lack of options.Bringing about the overall change in the structure and design won’t be possible that quickly as it needs a revolution. However improving the presently available model by including the add-on components can be another viable option.The add-on components are to be designed such that they reduce the aerodynamic drag so that it facilitates easy passage of the vehicles.For this, firstly the regions which show scope for improvement have to be identified. These regions are detected by undergoing various testing on the trucks.

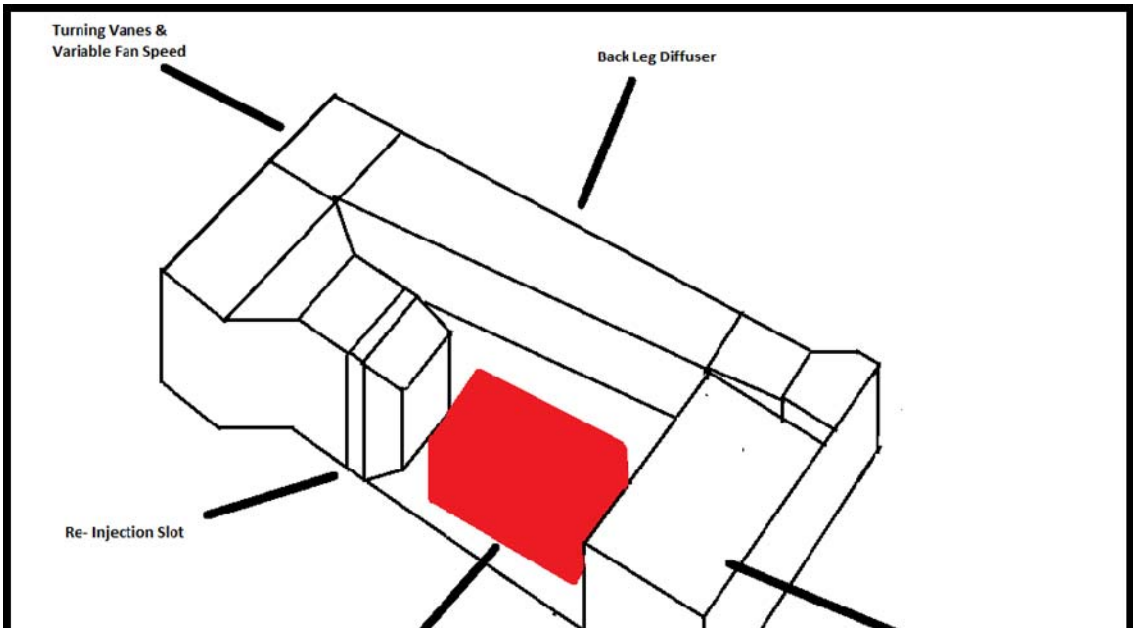



Figure 2.1. shows a Wind Tunnel set-up.

## III. EXPERIMENTDESCRIPTION

Table 3.1 Shows the experimental Description

| EXPERIMENT | DESCRIPTION |
|---|---|
| **Wind Tunnel** | **Enclosed Structure in which high speed wind is targeted on vehicles.** |
| **Computational Fluid Dynamics** | **Replica of actual model is investigated on ANSYS.** |
| **Average of Observations** | **No. of modified truck-trailers are run on similar conditions and further investigated after long duration of testing.** |
| **PIV** | **Installed in Wind Tunnel and images with help of Laser Nd:YAG are studied.** |
| **OFI** | **Skin frictional drag measurement method.** |
| **RANS** | **Computational mesh diagrams in different yaw angle.** |
| **LES** | **Computational mesh diagrams in different yaw angle.** |
| **PSP** | **Time average pressure acting on body is determined.** |

Wind Tunnel testing was the most traditional technique used for the study of air flow and calculating drag redu0ction.An caricature of the original model with known dimension scale is subjected to wind of definite speed and turbulence. The flow of wind is studied and drag reducing components are framed as per the observations. The entire picture of the process happening in Wind Tunnel, when depicted in ANSYS, it is coined as CFD technique. By CFD technology, low cost testing of sample vehicles are done. Mesh diagram clearly denote which area has large drag and needs to be rectified. Other mentioned techniques are modifications brought in Wind Tunnel and combining it with latest development.

Once the areas for developments were identified, corresponding changes required at those points were developed. Observations show that the truck part of the truck-trailer combination contribute to about 40-50% whereas the trailers contribute to 60-50%. Hence both the parts need equal improvement to enhance the fuel saving.

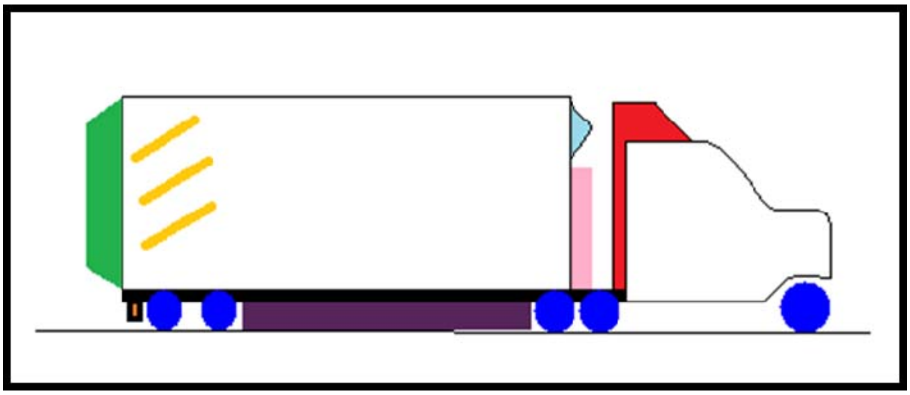


Figure3.1 Shows the truck-trailer combination with various add-on components

Table 3.1:The components used and tested in various technologies are:

| Sr. No. | Part | Add-on Components |
|---|---|---|
| **1** | **Truck** | **Fairings** |
| **2** | | **12’’ Radius front side post** |
| **3** | | **Deluxe Front** |
| **4** | | **Bumper** |
| **5** | | **Freight Wing NXT Leading Edge Fairing** |
| **6** | | **Laydon composite trailer nose fairing** |
| **7** | | **Roof deflector** |

| | | |
|---|---|---|
| **8** | **Truck-Trailer Gap** | **Labyrithine gap seal** |
| **9** | | **Cross-flow Vortex Trap Device** |
| **10** | | **Small cab extender** |
| **11** | **Trailer** | **Laydon composite trailer side skirt (Partial)** |
| **12** | | **Freight Wing leading edge fairing** |
| **13** | | **Transtex Composite folding rear trailer deflector** |
| **14** | | **VSD** |
| **15** | | **UFD** |
| **16** | | **Boat tail** |
| **17** | | **Aerovolution inflatable rear trailer fairing** |

The results in each technology were noted for baseline as well as the truck-trailer with add-on components. The results are important in determining how useful these components when fitted individually are or in combination.

## IV. REVIEW ON EXPERIMENTS CONDUCTED BY SOME RESEARCHERS

*4.1] Jason Leuschen et al[1]:* The National Research Centre of Canada have investigated the drag reduction in Class 8 tractor-trailer combination by introducing various aerodynamic components either individually or in combination. The major problem concerning to such large tractor-trailer is that due to the ineffectiveness of such vehicles to achieve a streamlined body, a large area is available for the aerodynamic drag to take place b the moving fluid .If said that at 100 kph, the amount of fuel consumption required to overcome the drag is 52%. Such high increment in power output means thata large emission of Greenhouse gases(GHS), hence theseresearch's is considered important from both economic as well as environmental perspective. The test was conducted inside a Wind Tunnel at NRC, Ottawa, Canada. A stationary commercial vehicle was introduced in a air flow field at different yaw angles. The speed of the wind was per determined and the flow was observed keenly. The effect of all the inbuilt part of the truck on the aerodynamic drag was calculated. Later the add-on components were installed and the reduction brought about by them was determined. The drag coefficient and ultimately the annual fuel saving were calculated.

*4.1.1 Material specifications*

- Volvo VN 660 1:10 scale model with 28 ft. trailer having 1.14 m cab and trailer gap along with sidecorners of front rounded with 5-inch radius.
- Wind Tunnel 9.1 m x 9.1 m x 22.9 m with maximum speed of 200 kph.
- Turntable of diameter 6.1 m having 360 degrees rotation.
- Wind providing system: DC motor with 8-bladed fan.
- Drag Reducing Hardware:
  - i) Labyrithine tractor-trailer gap seal
  - ii) Trailer vortex generator
  - iii) ManacCardolle bogey fairings
  - iv) Aerovolution inflatable rear trailing fairing
  - v) Transtex Composite floding rear trailer deflector
  - vi) Laydon composite trailer side skirt and nose fairing
  - vii) Freight Wing NXT Leading Edge Fairing
  - viii) Freight Wing Belly Fairing

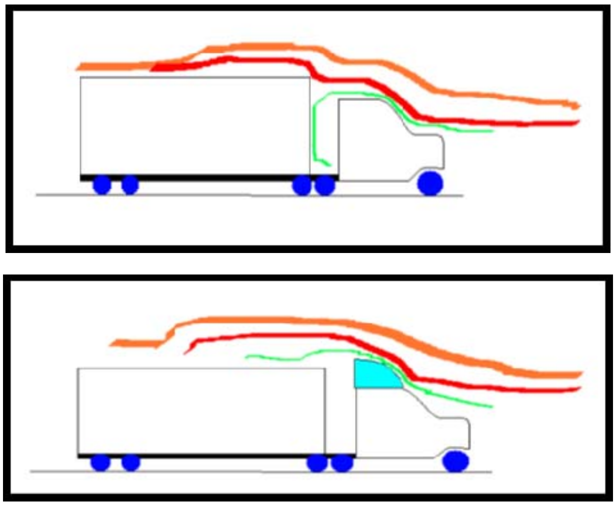
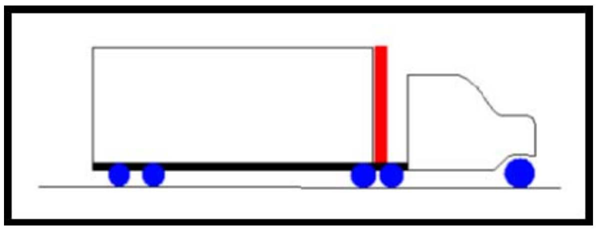
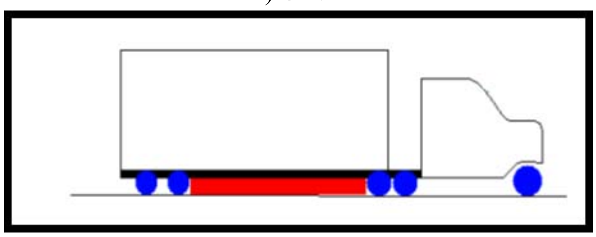


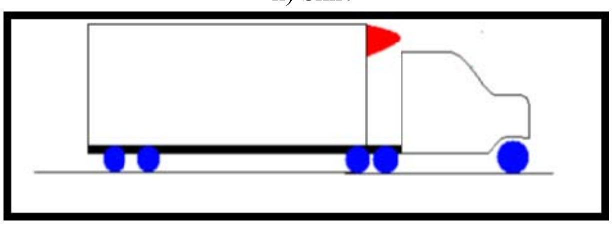
Fig. shows a Baseline truck with no add-on components and one with fairing. The difference in the air flow is observed as the one with fairing causes easy flow with drag effect.



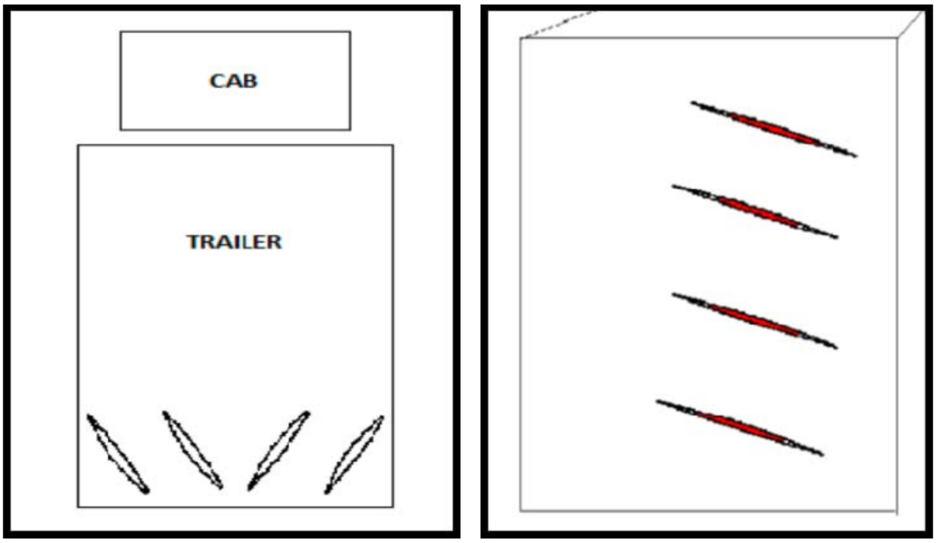
i) CFVD



ii) Skirt



iii) Manac Prototype leading edge fairing




iv) Vortex Generator (Top and Side View)

*4.1.2 Experimental procedure*

As per the fig., the 1:10 scale model of Volvo VN 660 was placed inside the atmospheric wind tunnel of rotating platform. The tractor-trailer is stationary and the wind from the 8-bladed wind turbine was projected on the test piece at a rate of 28.6 m/s. The measurements were taken at different yaw angles of the Volvo VN 660 with the wind off. Cubic splines were fitted to measure the wind-off side and drag force which were eventually subtracted from the wind-on side and drag forces. This was conducted for every yaw angle. Measurements were made for yaw angles of -3.33, 0.00, 3.33, 6.66, 9.99 degrees and the coefficient of drag was determined.
Apart from it, the effect of various present components and parts of the truck on aerodynamic drag was measured and subsequent amount of fuel saved were noted.
A large variety of newly developed hardware were also employed on the truck and their respective effect and usefulness were coined.

*4.1.3 Conclusion*

As per the result obtained in the Wind Tunnel, the components which are already a part of the tractor-trailer combination show a noteworthy drag and fuel changes. The bug deflectors and mirrors increase the fuel consumption. Roof deflectors and side extenders are observed to reduce the drag coefficient as well as the fuel consumption which are very much beneficial economically. Also the gap (between the cab and front face of trailer) and its effect on drag coefficient was verified showing it should be minimum.

Table 4.1.3(a): Following results were obtained:

| COMPONENTS | Annual Fuel Saving | Diff. in Cd |
|---|---|---|
| **Bud deflectors** | **-903** | **-0.0150** |
| **Fender mirrors** | **-588** | **-0.0098** |
| **Side mirrors** | **-938** | **-0.0156** |
| **Bumper** | **120** | **0.0020** |
| **Roof deflectors** | **4,318** | **0.0717** |
| **Side extender** | **2,499** | **0.0415** |
| **Skirt** | **1,596** | **0.0265** |
| **Fifth wheel forward** | **982** | **0.0163** |
| **Hub cap** | **120** | **0.0020** |

| | | |
|---|---|---|
| **Engine cooling inlet blocked** | **6** | **0.0001** |
| **Sun visor** | **54** | **0.0009** |
| **Prototype roof deflector filter** | **825** | **0.0137** |
| **Wrap-around splash guard** | **292** | **0.0049** |

Table 4.1.3(b): The various drag reducing hardware and its impact on drag reduction can be observed below:

| **HARDWARE** | **Annual Fuel Saving** | **Diff. in Cd** |
|---|---|---|
| **Labyrithine tractor-trailer gap seal** | **108** | **0.0018** |
| **ManacCardolle bogey fairings** | **2017** | **0.0335** |
| **Freight Wing NXT Leading Edge Fairing (w/o roof fairing)** | **2222** | **0.0369** |
| **Freight Wing NXT Leading Edge Fairing (w roof fairing)** | **-144** | **-0.0019** |
| **Laydon Composite trailer skirt** | **2264** | **0.0376** |
| **Laydon Composite trailer nose fairing** | **813** | **0.0135** |
| **Transtex Composite folding rear trailer deflector** | **3047** | **0.0506** |
| **Aerovolution inflatable rear trailer edge** | **2638** | **0.0438** |

Except the leading edge with roof fairing, all the other add-on components used have produced the desirable effect. The annual fuel saving shows that if these hardware are used, whether individually or in combination will be very much beneficial in reducing the drag coefficient.

*4.2] Richard M. Wood et al[2]:* The researchers have investigated three devices undergoing extensive operational testing of about nine months and covering around 85,000 miles. The intent being, to minimize factors having impact on fuel economy such as operational routes, type and geometry, environmental condition and load carried. The test program evaluated Crossflow Vortex Trap Device (CVTD), Undercarriage Flow Device (UFD), Vortex Strake Device (VSD). These add-on devices were meant to reduce the aerodynamic drag at three major portions of the truck-trailer combination, namely-

- Gap between the cab and leading edge of the trailer
- Trailer base
- Undercarriage

Under ideal condition, 40%-50% of the overall drag attributes t tractor and 60%-50% to the trailer. The tractors have comparatively an advanced aerodynamic structure whereas the trailers with minimum aerodynamic stability provide huge scope for development using UFD and VSD.

| **Sr. No.** | **SPEED** | **DRAG REDUCTION** |
|---|---|---|
| **1** | **20** | **6%** |
| **2** | **40** | **3%** |
| **3** | **60** | **2%** |

The above mentioned drag reduction is needed if one desires to increase the fuel economy by 1%.
Each of the three devices were evaluated distinctly and compared with the Baseline trailers (one's in which no drag reducing devices were installed). Each baseline trailers were send to the same route and each of the trailers with add-on hardware were send on the same routes other than baseline trailers. The tires and thread depth were entirely same. The fuel was filled from fleet owner fuel supply system with the same fuel fill procedure for each of the trailers. Cummins engine INSITE professional CELECT Plus data acquisition and analysis software was utilized for the collection of data.

Table 4.2: Data sheet between the period of July 2002 – March 2003 is mentioned below:

| **Sr. No.** | | | |
|---|---|---|---|
| **1** | **Available Trips** | | **115** |
| **2** | **Available Miles** | | **182494** |

| | | | |
|---|---|---|---|
| | | **Baseline Trailer Miles** | **97165** |
| | | **Baseline Trailer Trips** | **86** |
| | | **Baseline Trailer Avg. Speed** | **47.8** |
| | | **Experimental Trailer Miles** | **85329** |
| | | **Experimental Trailer Trips** | **69** |
| | | **Experimental Trailer Avg. Speed** | **47.4** |

The average speed was approximately 47.4 mph.

*4.2.1 Material specifications*

- Cross-flow Vortex Trap Device: 12-inches wide extending vertically on the trailers front face.
- Vortex Strake Device: 36-inch long, 2-inch wide, with 30 degrees leading edge inclination.
- Undercarriage Flow Device: Forward 45-inch, Inboard 39-inch and 40-inch from vehicle base towardsground.

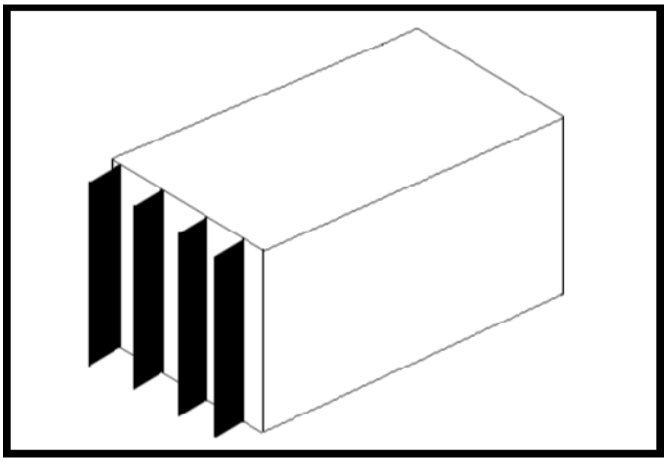


Figure 4.2.1(a): CFVD on leading edge of trailer

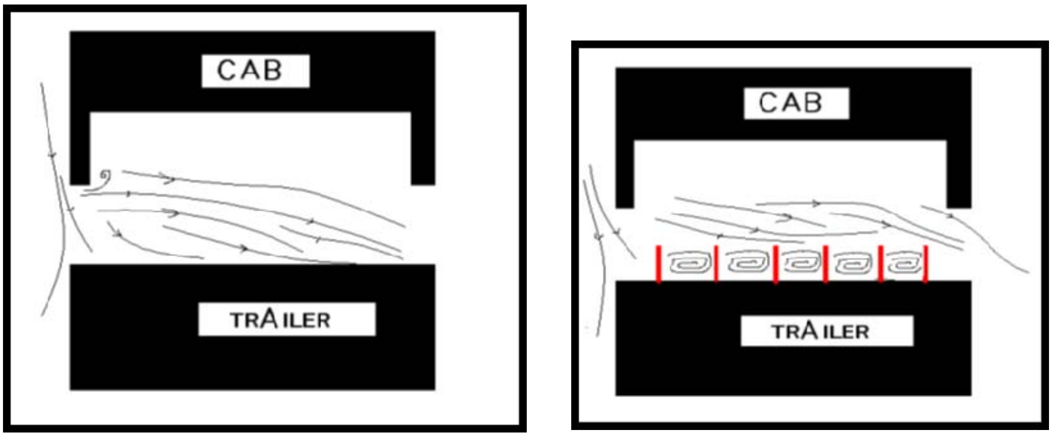



Figure 4.2.1(b): shows respectively the cross-flow vortex with and without CFVD

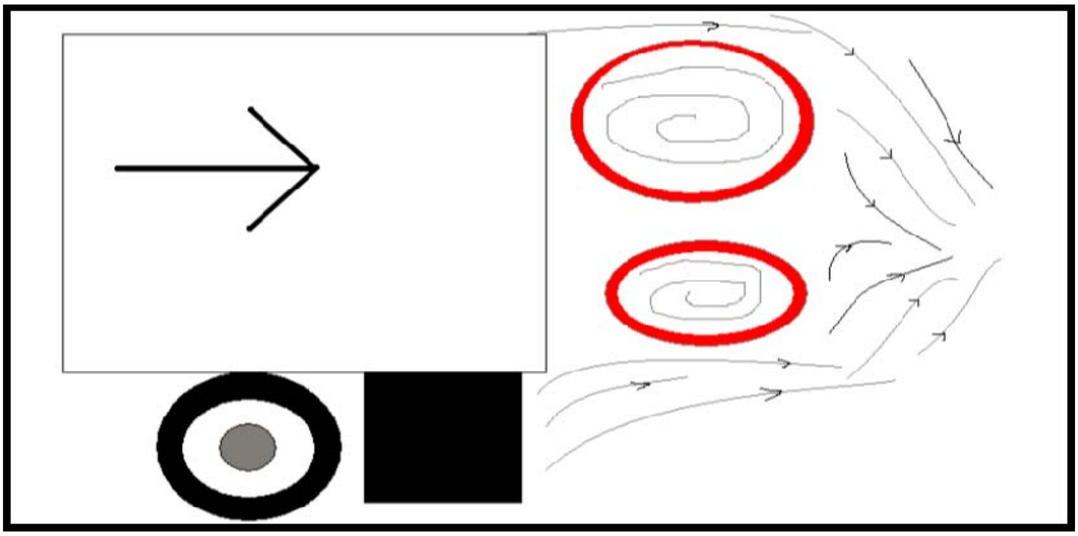


Figure 4.2.1 (c): The black box at the base represent the UFD energizing the undercarriage air to flow through it.

*CVTD= Cross-flow Vortex Trap Device, VSD=Vortex strake device, UFD=Undercarriage flow device

*4.2.2 Conclusion*

Baseline trailers have high drag coefficient due to the least aerodynamic structure and hence high fuel consumption. The three components that were extensively tested for 85,000 miles show positive outcomes in reduction of drag and subsequent fuel saving. CVTD in the tractor-trailer gap traps the cross-field air and increases its velocity, which ultimately leads to reduction of pressure and ultimately drags. VSD provides limited number of large size vortex when installed at the top and side of the trailer, energizing the outgoing flow and reducing the drag. UFD collects the undercarriage flow, accelerates it through the bluff base wake and ultimately reduces drag. All this efforts adds up to reducing fuel consumption.

Table 4.2.2: Refer the following result:

| Sr. No. | COMPONENTS | Percentage of Fuel Saved |
|---|---|---|
| **1** | **CVTD** | **3.5 – 8.3** |
| **2** | **VSD** | **2.2 – 4.9** |
| **3** | **UFD** | **0.8 – 3.3** |
| **4** | **OVERALL** | **6.5 – 16.5** |

*4.3] C. Pevitt et al [3]:* The economic loss due to extensive fuel utilization just for overcoming the aerodynamic drag as well as the environmental effect owing to Greenhouse emissions have made the research and development (R&D) an important factor specially for commercial trucks. The researchers have investigated the aerodynamic drag reduction in case of MACK 600R Class 8 truck. The results were obtained by implanting three components namely front fairing, side skirts, gap filling. The research was conducted in RMIT Royal Melbourne Institute of Technology. The RMIT Wind Tunnel was used. The test specimen was located on a rotating turn table by means ofof JR3 Multi axis load cell sting. Testcan be carried out for all roll, pitch and yaw. At a wind speed ranging between 40 – 120 kph, test were conducted atyaw angles between 0 – 15 degrees taking 5 degree interval. Different add on components were implanted on the truck and respective drag coefficient were calculated. Each recording was conducted for 10 sec. and in order to keep the electrical interference to minimum, frequency was set to 20 Hz.
The Stimulation procedure includes Computational Fluid Dynamics (CFD) stimulation. Here for the same drag calculation ANSYS CFX Software is utilized. In this a replica model of the one used in Wind Tunnel Testing is used. As the model is a duplicate of the test sample, validity is limited but the accuracy of the result is capable of validating the Wind Tunnel results. In CFD the sting is not taken and its drag is assumed to be neglected. Mesh convergence and turbulence were formed. Mesh convergence diagram gave a better understanding of the drag, as the magnitude of drag is highly dependent on the mesh around it. Turbulence model was also verified. Entire procedure was carried out for all 3 add-on components.

*4.3.1 Material specification*

- Wind Tunnel: Area of 6 meters
- JR3 Multi axis load cell sting
- MACK 600R Class 8 Tractor-Trailer combination with trailer dimension 3m x 2m x 9m.
- Front Fairing component
- Partial Side Skirt
- Full length Side Skirt
- Gap Filling Components

*4.3.2 Conclusion*

The comparative study of the results obtained relating to drag reduction obtained in CFD and Wind Tunnel was found to be quite similar and close .They can be termed as an alternative testing technology for one another. With simple modifications such as fairings, skirts and gap reduction the drag can be reduced to about 20% -30%. At 0 degree yaw angle and applying fairings, the drag was reduced to 20%. At 5 degree yaw and adding full skirt, a total reduction of 35% can be achieved. When considered individually, maximum reduction was brought about by full skirt whereas least by fairings.

Table 4.3.2: Reduction by Add-on Components

| Sr. No. | ADD-ONS | Cd by EFD | Cd by CFD |
|---|---|---|---|
| 1 | Gap Fills | 26% | 24% |
| **2** | **Partial Skirts** | **25%** | **24%** |
| **3** | **Full Skirts** | **27%** | **30%** |
| **4** | **Fairings** | **18%** | **20%** |

*CFD= Computational Fluid Dynamics, $C_d$=Co-efficient of Drag

*4.4] Kevin R. Cooper et al[4]:* Till 1960's, the fuel price were cheap and the truckers didn't wanted the fancy add-on components on their rigs. As the world faced the 1970 energy crisis, trucker's community and manufacturers accepted these gadgets as it saved fuel and earned profit. The researchers have tested these components in the University of Maryland's Wind Tunnel. A 1:6 model size of the actual test specimen was taken into consideration. Experiments were conducted at different yaw angles of 0 and 10 degree. The speed of the wing was kept constant at 65 mph. Later on, coefficient of drag Cd of the add-on components at 65 mph was obtained. This was subtracted with the Cd obtained for baseline vehicle with no add-on components.

Along with this, comparison was made with another test carried out at National Research Centre NRC's Wind Tunnel wherein actual size test specimen was subjected to wind testing with the same add-on components.

*4.4.1 Material specification*

- Wind Tunnel: Maryland University 19 ft. diameter with motor capacity of 2000 HP and maximum speed of 230 mph. 7.75 ft. height and 11.04 ft. wide.
- Wind Tunnel: NRC Canada, 9.1 m x 9.1 m x 22.9 m with maximum speed of 200 kph.
- Turntable of diameter 6.1 m having 360 degrees rotation.
- Wind providing system: DC motor with 8-bladed fan.
- COE Tractor with Model 'A' van Trailer.
- Boat Tail
- Full Skirt
- Fully Skirted Boat tail
- Roof fairing
- Faired Gap

- Height Trailer Skirt
- Deluxe Front
- Square front post
- 12” radius front side post

*4.4.2 Conclusion*

Table 4.4.2(a): Add-on Components Effect- Wind Tunnel 1

| Sr. No. | Components | Cd(0 degree) | Cd(10 degree) | Diff Cd 65 mph | Diff. Cd 65 mph |
|---|---|---|---|---|---|
| 1 | **Square Front Post** | **1.017** | **1.503** | **1.169** | **-** |
| 2 | **Boat Tail** | **0.460** | **0.520** | **0.503** | **0.121** |
| 3 | **Full Skirt** | **0.317** | **0.329** | **0.351** | **0.152** |
| 4 | **Fully Skirted with boat tail** | **0.184** | **0.160** | **0.189** | **0.169** |
| 5 | **Roof Fairings** | **0.641** | **1.007** | **0.842** | **0.102** |
| 6 | **Faired Gap** | **0.558** | **0.824** | **0.689** | **0.153** |
| 7 | **Deluxe Front** | **0.828** | **1.118** | **0.994** | **0.062** |
| 8 | **Height Trailer Skirt** | **0.803** | **1.052** | **0.994** | **0.050** |
| 9 | **12’’ Radius front side post** | **0.900** | **1.167** | **1.056** | **0.113** |

All the add-on components used were effective in reducing the drag coefficient when compared with the baseline vehicle. Fully skirted trailer in combination with boat tail provided the maximum reduction.

The results obtained in the NRC Wind Tunnel Testing with and without the inclusion of the add-on components also show the similar trends in drag coefficient reduction.

Table 4.4.2(b): Add-on Components Effect- Wind Tunnel 2

| Sr. No. | Components | Cd(0 degree) | Cd(10 degree) | Diff Cd 65 mph | Diff. Cd 65 mph |
|---|---|---|---|---|---|
| 1 | **10’’ Front Post** | **0.765** | **0.979** | **0.871** | **-** |
| 2 | **Gap Filler** | **0.440** | **0.513** | **0.485** | **0.055** |
| 3 | **Rear trailer skirt + bevel** | **0.482** | **0.583** | **0.540** | **0.031** |
| 4 | **Gap seal** | **0.509** | **0.615** | **0.571** | **0.029** |
| 5 | **Extension panels** | **0.511** | **0.660** | **0.600** | **0.044** |
| 6 | **Front trailer skirts** | **0.550** | **0.710** | **0.644** | **0.080** |
| 7 | **Roof fairing + Skirt + Extender** | **0.569** | **0.833** | **0.724** | **0.147** |

The results were virtually identical.

*4.5] Rose McCallen et al[5]:* Experiments on models of integrated trucks and trailers were carried out at NASA Ames Research Centre and University of Southern California. Computational Stimulation technologies were conducted at Sandia National Laboratory, Caltech and LLNL. Heavy truck-trailer configuration weigh about 85,000 pounds, have wind-averaged coefficient of drag Cd 0.6. At 70 mph, 655 of the total fuel expenditure accounted for drag overcoming. Changing the different truck components can bring about reduction in the drag co-efficient from 0.6 to 0.3 saving 4 billion gallons of diesel.
The testing was initially carried out inside a Wind Tunnel with model of 1/14 of actual sample with the wind speed of 22 m/s.Another is the Computational Fluid Dynamic technique in which the drag around various components oftractor-trailer combination is determined using ANSYS. The tractor-trailer gap also plays a large role in overall drag. To determine such complicated flow Digital Particle image Velocimetry (DPIV) was used in which pulsed, dual head Nd:YAG laser with its output formed in sheet of light is determined. Oil film Interferometry (OFI) scans the skin friction while Pressure Sensitive Plants (PSP) calculates the time average pressure acting on the body.
The results obtained by RANS Reynold’s Averaged Navier-Stokes by SNL using GTS geometry were compared withtraditional techniques of drag measurement. Drag traces for yaw angle of 0 and 10 degrees were observed.

Another technique was Large Eddy Stimulation (LES), which was used todetermine the outcome of applying Boat Tail plateson the flow field at the trailing edge of the trailer.

#### *4.5.1 Material specification*

• Wind Tunnel: 7 ft. x 10 ft., 22 m/s.
• Class 8 Tractor- trailer combination: 1:14 scale model with 3D PIV system with Nd-YAG laser.
• PIV: Particle Image Velocimetry
• OFI: Oil Field Interferometry
• RANS: Reynolds Averaged Navier-Stokes System
• LES: Large Eddy Stimulation

#### *4.5.2 Conclusion*

Advanced computational techniques like 3D PIV, LES approach, RANS modelling, etc. can be used for validating the experimental results. These mentioned techniques can well be used for measurement of drag reduction in vehicles and can very well replace the conventional techniques for accurate results.
Also the boat tail used as an add-on component has proved beneficial in overcoming drag reduction.
G/L is ratio of gap to the root of frontal area.

Table 4.5.2: The truck and leading edge of trailer gap also has to do with the drag reduction.

| **Sr. No.** | **G/L Ratio** | **Drag Effect** |
|---|---|---|
| **1** | **0** | **Minimum Drag** |
| **2** | **0 - 0.5** | **Gradual Increase** |
| **3** | **0.5 –0.6** | **Sudden increase** |

*PIV: Particle Image Velocimetry, OFI: Oil Field Interferometry, RANS: Reynolds Averaged Navier-Stokes System, LES: Large Eddy Stimulation, CFD: Computational Fluid Dynamics

## V. CONCLUSION

Aerodynamic Drag of heavy commercial trucks can be experimentally verified with the variety of technologies. Apart from the conventional technique of Wind Tunnel, stimulated computation from CFD also provided results close to the Wind Tunnel. Even the techniques which are not very popular in use have also shown their capacity to be used on a large scale for accurate measurement in drag calculation.

Add-on components designed with the perspective of bringing about the reduction in drag also showed positive results. These components when considered performing separately or in combination are found to be quiteprofitable in reducing thefuel consumption to a very large and profitable scale.

With the collective use of research and developments in this field, efforts should be increased for attaining the dual benefit ofenvironmental and economical betterment.

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