***Paper ID: KL-07***

# Implication of Vehicle Aerodynamics on Fuel Savings and the Environment

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## Abstract

*Road vehicles use a large amount of power to overcome aerodynamic resistance (drag) at normal highway speed. The reduction of aerodynamic drag allows not only increasing profit margin of vehicle operation but also reduces energy consumption and greenhouse gas emissions. In order to minimise aerodynamic drag and thereby fuel consumption, streamlining the body shape and minimising flow separations are paramount. Various methods and application of energy saving devices for cars and commercial vehicles are explored and the need for aerodynamic streamlining of commercial vehicles especially truck shapes in developing countries is stressed.*

Keywords: Aerodynamics, drag, fuel savings, vehicle, greenhouse gas.

## 1. Introduction

According to European Regulations, the $CO_2$ emission from a new vehicle in 2012 cannot be exceeded by 120 grams per km and in 2020 this figure should be limited to 95 grams per km [1]. Additionally, stiff market-competition and rising fuel price force vehicle manufacturers to develop fuel efficient vehicles to be competitive, and economically viable. One way to develop fuel efficient vehicles is the reduction of aerodynamic drag as it accounts for around 80% of the total drag at vehicle cruising speeds over 80 km/h [2]. The reduced drag will not only lower the fuel consumption but also the $CO_2$ emissions. The major drag reductions have been achieved by optimising vehicle exterior body shapes over four decades. At low speeds the main source of drag is the rolling resistance. Typically, the aerodynamic drag of a medium-sized car accounts for 75-80 percent of the total resistance to motion at 100 km/h, the rest being mainly rolling resistance [2]. Therefore, reducing aerodynamic drag contributes significantly to the fuel economy of a road vehicle. The primary objectives of this paper are to give a broad overview of possible reduction of aerodynamic drag for modern passengers cars, medium and large trucks widely used and to give some insights into the research work that are being undertaken at RMIT University in Australia.

## 2. Aerodynamic drag of passenger cars and trucks

The aerodynamic shape of passenger cars is greatly dictated by the functional needs of the consumers. The shape of the car should be such that consumers can drive or ride comfortably, can see out of the car and also that the vehicle complies with safety regulations. Drag reduction, more efficient engine technology and weight reduction, became the primary design goals for vehicle engineers and designers around the world in the 1960's to 1980's. Average drag coefficients for typical cars dropped substantially from around 0.5 in the 1960's to typically 0.3 in the late 1980's and mid 1990's [2, 29]. Lowering the drag coefficient for passenger cars below 0.30 will require attention of the underside and internal (cooling) flows. For example, the underneath of many cars is aerodynamically very rough (axles, wheels, muffler, fuel tank, shock absorbers, brake, etc). Streamlining the under-body will not only reduce the drag but also decreases lift. However, this streamlining will create problems for thermal management (exhaust, brake and differential cooling performance). Other adds-on such as side rear view mirrors, roof racks, and antenna do not increase drag significantly but they are the potential sources of aerodynamic noise. In passenger car design, the shape is entirely the domain of the major manufacturers. However, for commercial vehicles where load shapes are determined by the operators, changes can be affected by the operators, including the fitment of shape-changing devices generally known as drag-reducing or add-on aerodynamic devices.

### *2.1 Drag reduction of passenger cars*

The aerodynamic efficiency indicator (drag coefficient) started to fall from around 0.50 for a typical passenger car in 1960s to 0.28 in 2012 (see Fig. 1. The future drag reduction areas that will come from sources other than upper body shape are the smooth under-body, wheel and wheel wells and convoy driving. However, it is not easy to achieve the drag optimisation in these areas as they are interrelated with vehicle cooling performance. The major drag reductions have been achieved so far by optimising vehicle exterior body shapes over four decades. Further reduction can affect the vehicle styling – an important factor for customer perception (aesthetics) and marketing. The only areas left for further reduction of drag without affecting the styling are the vehicle under body, wheels and wheel wells and cooling drag. However, these areas are very sensitive to vehicle cooling needs. The overall drag generated by various body parts of a typical passenger car is shown in Fig. 3. The figure shows that a significant portion (55% of the total drag) of aerodynamic drag is produced by the lower section of the vehicle body. Only 45% of the aerodynamic drag is produced by the upper portion of the body. The wheels and wheel wells, and under body drag are generated by the lower portion of a car. The breakdown of drag of a typical family size passenger car clearly indicates the potential areas that can be targeted for possible aerodynamic drag reduction.

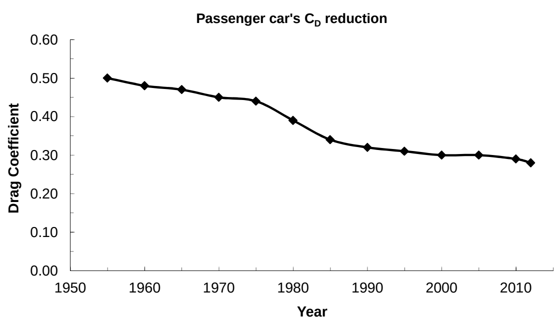



Fig. 1. Passenger car drag reduction chronology [29]

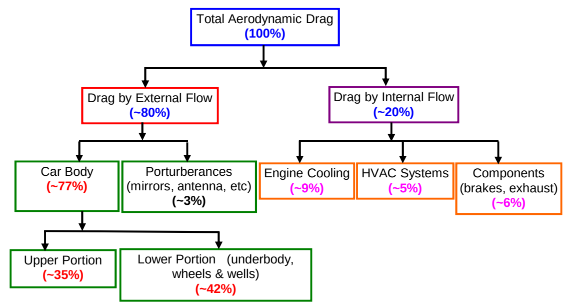



Fig. 2. Breakdown of passenger car aerodynamic drag [29]

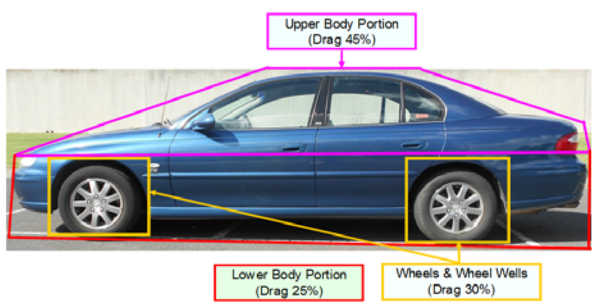



Fig. 3. Aerodynamic drag from external flow over the body [29]

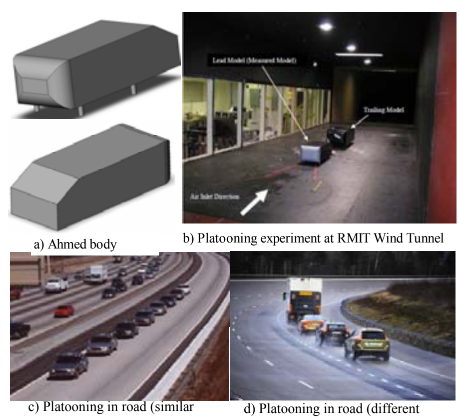



Fig. 4. Vehicles platooning [11, 29]

Freight movement by road vehicles especially by trucks has been gaining momentum world-wide, especially in the developing countries, due to faster road infrastructure development than rail network. Commercial road vehicles (trucks, buses, vans etc) are competing well with traditional rival rail systems thanks to increasingly better road infrastructures, engine and aerodynamic efficiencies and improved payload capacity. However, escalating fuel prices, the need for profitable operation and the greenhouse gas reduction strategy have forced commercial vehicle manufacturers and operators to explore all possible areas for reducing operating costs. The minimum fuel consumption leads to lowering the operating cost which can be achieved by reducing aerodynamic drag. Most high bodied commercial trucks and delivery vans are box type rectangular shape due to load carrying requirement. The box shape generates significantly higher aerodynamic drag compared to streamlined passenger cars. The frontal shape of an un-streamlined truck/van generates most of the drag due to the flow separations and an associated large wake. For un-streamlined trucks or vans, it is estimated that almost 67% of the total drag is exerted on these forward faces, with the remainder 33% coming from the back and the sides due to the complex flow pattern (eg, a combination of separation, reattachment and vortices) [27-28]. For a typical truck at a steady head wind velocity of 80 km/h, nearly 50% of the consumed fuel is used to overcome aerodynamic drag. It may be noted that with an increase of the velocity, the drag force will rise with the square of the velocity as shown in eq. (1).

$$F_D = C_D \tfrac{1}{2} \rho A V^2 \qquad (1)$$

Where, $C_D$, $\rho$, $V$, $A$ are the drag coefficient, air density, velocity and projected frontal area of the truck respectively. The frontal areas of a high-bodied truck, bus, light van, and car are in the ratio of approximately 9: 7: 2.

In order to correctly related the drag coefficient ($C_D$) with the fuel consumption reduction of a particular vehicle, detailed information about vehicle speed cycle, annual mileage (distance travelled), and baseline engine fuel consumption is required. This is generally being done for a specific vehicle (e.g. [26]). Therefore, discussions in this paper are limited to the reduction of drag coefficient. The reduction of fuel consumption stemming from the decreased $C_D$ value can be determined for specific vehicles if the vehicle's operating environment is known. Vehicle-specific influences on drag coefficient of truck are a) tractor design (classic/aero-style, day-cab/sleeper), b) trailer configuration (dry box, flatbed, tanker), c) gap region between tractor and trailer; and d) appendages (mirrors, deflectors, external air filters, lights, skirts). The environmental influences on truck $C_D$ are a) air properties (barometric pressure, temperature, humidity), b) terrestrial winds (Speed; turbulence intensity, gustiness, wind direction).

### *2.1.1 Aerodynamic drag associated with cooling flows*

The cooling drag associated with the radiator of internal combustion (IC) cars is around 10% of the total aerodynamic drag [2, 5, 29]. The airflow passing through the front end grille and radiator is responsible for the generation of cooling drag. Generally the velocity of the airflow going through the radiator is a function of the vehicle speed and the heat transferred by a radiator is a function of the airflow rate across the radiator [6]. However, the air flow is not uniformly distributed over the entire radiator due to the wake of the bumper bar, etc. which can deteriorate the radiator heat transfer effectiveness due to non-uniform flow on both the air and coolant sides. It is extremely hard to study the complex air flow through the radiator either experimentally and computationally. The RMIT Vehicle Aerodynamics Research Group has developed a special methodology (Specific Heat Dissipation) that can be used to assess the radiator cooling performance as well as cooling drag measurement. Therefore, an experimental program was designed that investigated methods of reducing the airflow through the radiator and engine compartment by shielding the front-end of a passenger vehicle and also measures cooling effectiveness. The velocity distributions as well as the non-uniformity of the cooling airflow across the radiator were measured. In order to investigate the correlation between drag and cooling performance of front grille configurations, an Australian made Ford Falcon AU was selected. This vehicle is a large range family vehicle with a four-speed automatic transmission fitted as standard equipment. The air conditioning and engine cooling components consisted of an air conditioning condenser fitted in front of the radiator, a mechanically driven centrifugal water pump, dual electric fans with shroud combination and an air dam. The air dam aids in engine cooling by creating a favourable pressure gradient for the cooling airflow. The front-end cooling air intakes consist of a decorative grille and a lower intake area. To study the variable front-end geometry, four front-end shielding methods were employed. In each of the methods the front-end cooling air intakes were shielded by an area of ¼, ½, ¾ and totally shut as shown in Fig. 5. The shielding methods employed were vertical, horizontal, side-to-side and side-to-centre. More details about the experimental set up can be found in [7].

The cooling performance and drag were measured using the RMIT University Industrial Wind Tunnel. It is a closed return circuit wind tunnel with a rectangular test section (3 m width, 2 m height and 9 m length). The maximum air speed of the tunnel is approximately 150 km/h. More details about the tunnel can be found in [8]. The solid blockage ratio for the test vehicle is approximately 30%. Despite the high blockage ratio, the tunnel can be used for evaluating cooling performance of a passenger vehicle with confidence using RMIT developed methodology [9-10]. The methodology comprised of 24 pairs of hypodermic tubes inserted into the radiator and condenser assembly, a pressure measuring unit, a computer and the associated software. The system is relatively cheap, reliable, and suitable for measuring complex airflow both in wind tunnel and on-road testing. A detailed description about the system can be found in [10].

In the vertical shielding method evenly-distributed vertical strips were used. The underlying principle for this type of shielding is that many vehicles already have vertical strips as part of their decorative grille and lower cooling intakes. To implement this type of shielding one could envisage plates sliding behind each other that would change the area of the cooling air intakes. However, other vehicles exhibit the opposite by having decorative grilles and lower cooling air intake openings that are covered by horizontally placed strips. The analogous method of shielding that is envisaged is that of having horizontal plates sliding behind each other. The other configuration investigated was closing the intake opening from one side to the other. This configuration was chosen as it can be applied to small vehicles that have very small radiators and even smaller A/C condensers placed in front of these radiators.

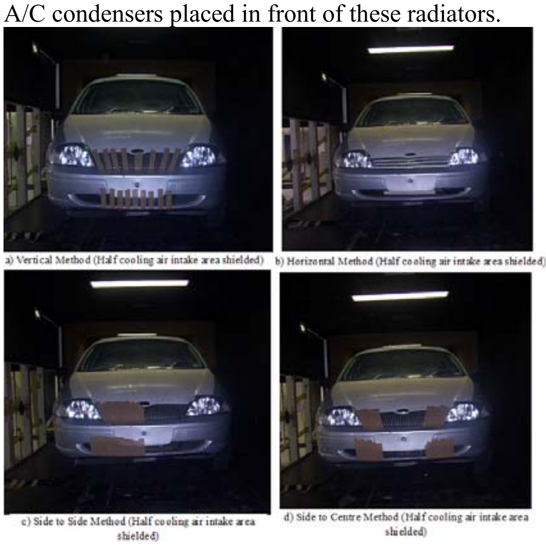



Fig. 5. Test vehicle at RMIT Industrial Wind Tunnel [7, 29]

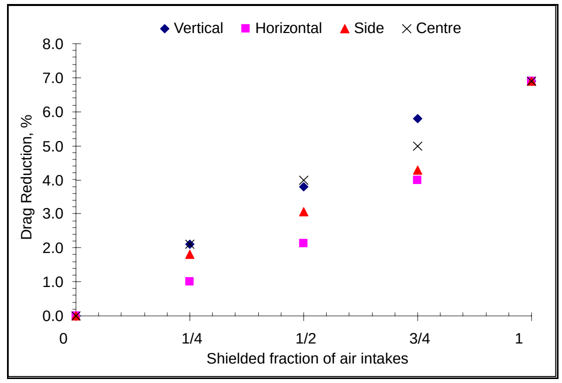



Fig. 6. Drag reduction with shielding at 100 km/h [7, 29]

Instead of this normal arrangement, it was envisaged that the condenser could be placed besides the radiator. Then, in periods of extended non-operation of the condenser (e.g. winter), one could entirely block off the condenser side to the cooling airflow. The last option considered is to symmetrically shield both the grille and lower cooling air intake from both sides to the centre. This last method was used to investigate the interaction between external and internal flows. A/C condensers placed in front of these radiators. Figs 5 and 6 show the effects of shielding on the reduction in drag and heat rejection. The drag reduction was measured on a six-component force and moment balance in the full size open jet wind tunnel at Monash University, Australia. Further details of the test methodology and the influence of shielding on other coefficients (e.g. lift) can be found in [7]. It can be seen that a maximum of 7% drag reduction was achieved by completely shielding the radiator and that the horizontal method gave the least drag reduction when partially shielded. However, the method of shielding made negligible difference to the heat dissipated.

#### *2.1.2 Drag from vehicle under-body*

In spite of obvious progress made by production car aerodynamics over the decades, the area of under-body airflow of passenger vehicles still demands detailed investigation and analysis. There are few known published works related to the area of under-body and wheel well airflow. Regarding the under-body of a passenger car, designers look at cooling of under-body components (exhaust, differential, brakes and engine), ground clearance and ramp angle, and simplicity of maintenance. Researchers are trying to find a compromise between these important parameters thus it requires in-depth understanding of all aerodynamic and heat transfer parameters and features of complicated three dimensional under-body airflow. Most vehicle manufacturers are putting emphasis on under-body streamlining and developing special vents or channels for directing air to cool the exhaust, differential and brakes. A significant reduction of drag was achieved without compromising the cooling performance.

#### *2.1.3 Drag reduction from platoons (convoys)*

Today's increasing traffic density and Intelligent Transport Systems (ITS) make the formation of platooning (convoys) of vehicles much easier than a decade ago. Under such compact driving conditions (see Fig. 4) considerable favourable interference can occur between vehicles, with potentially drag reductions for both leading and trailing vehicles. The reduced dynamic pressure in the wake of the first vehicle influences the drag coefficient of the vehicle behind (trailing vehicle). Consequently, notable improvement in aerodynamic drag can be achieved even when the distance between the vehicles may be relatively great [14-16]. The reduction of drag by platooning was first exploited in motor racing [2]. The effects of platooning for commercial vehicles have well studied by Hucho [2]. The study showed when a convoy of commercial vehicles is driven at speeds of 80 km/h with an inter-vehicle spacing of 40 m, a drag reduction of 20% can be achieved for the second vehicle and around 30% for the third and every additional vehicle in the platoon for commercial vehicles. However, this

drag reduction will be very shape specific. Since 2004, a series of studies, both experimentally and computationally, was undertaken on platooning effects at RMIT University [16-19].
In order to study the influence of the basic vehicle shape on potential drag reduction the Ahmed body was selected. This is the most researched generic vehicle shape and it features a variety of rear slant angles which can replicate the essence of flows associated with a wide range of vehicle geometries. In particular with a rear slant angle (measured from the horizontal) of 25 degree, the flow is attached down the rear of the model and due to the high levels of lift and associated induced drag the total drag coefficient is high. When the angle is increased to greater than 30 degree the flow does not attach down the rear of the model and the lift and associated induced drag falls. Figure 7 shows the variation of drag with rear slant angle for an isolated Ahmed body. To investigate how the rear slant angle influences two vehicles of similar size in convoy, a series of experiments were undertaken where 25 degree and 35 degree slant models were placed at various inter-vehicle spacing. The drag reduction varies strongly as a function of vehicle spacing with negligible reduction for spacing greater than 2L (see Fig. 7). Further details of this effect and mapping of the wake flow can be found in [19].

In order to study the influence of different size vehicles a similar experiment was conducted but with Ahmed body of 30 degree rear slant angle and of different scale. The leading vehicle was 75% scale of the trailing and the experimental set up can be seen in Fig. 4b. Figure 7 shows the variation of drag coefficient of the leading Ahmed model with vehicle spacing. The reductions in drag coefficients for very close coupling vehicles varied widely and this is dependent on rear slant angle. Surprisingly for some geometries a small drag increase is noted for the trailing vehicle.  More details can be found in [17]. Fundamental considerations indicate very significant reductions are possible for extremely closely coupled vehicles, as demonstrated by the very low drag coefficients (per unit volume) for streamlined train shapes. Since the increasing use of intelligent transport systems permit very close coupling it is recommended that further attention be paid to this aspect.

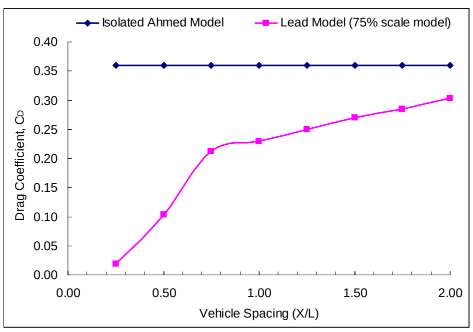



Fig. 7. Effects of platooning on drag coefficient for two different scale Ahmed models [29]

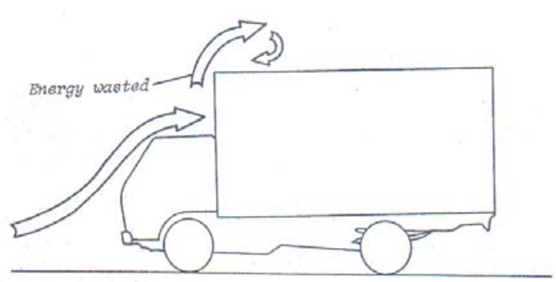



Fig. 8. Flow pattern around a bread delivery van [26-28]

### *2.1.4 Drag reduction from wheels and wheel wells*

Passenger car's wheels and wheel wells generate a significant amount of aerodynamic drag (~25%). Part of the drag originates from the wheels and wheel wells directly, but also due to notable interactions with surrounding flow fields. The high level drag contribution by wheels and wheel wells is primarily due to extremely un-streamlined wheels, the oblique approach of wind (under yaw), and rotation of wheels within wheel wells [2]. Our aerodynamic understanding is limited for both stationary and rotating wheels even without the presence of wheel wells. At present no consistent physical model for the flow around a wheel within a wheel well is available apart from limited data [18, 20-23]. Only the phenomenological data are available which indicate that the smaller the volume of a wheel housing relative to the wheel's volume, the smaller the drag and lift of a wheel; the effect on drag, however, is comparatively small. Considering the huge effort spent on optimising vehicle upper body and under-body, despite being the large drag contributor by wheels and wheel wells, it is time now to look into more closely the aerodynamics of wheels.

The aerodynamic study on wheels and wheel wells at RMIT indicated that the clearance gap around the front wheel and well, except on top reduces aerodynamic drag and lift. The aerodynamic performance of the total vehicle can be improved further using skirt around the front wheel well. The larger diameter front wheel reduces drag but increases lift. A smaller gap on top of the rear wheel or the wheel being shifted into the rear wheel-well caving is the most effective way to reduce aerodynamic drag. The larger rear wheel diameter similar to front wheel reduces the drag. The larger gap around the rear wheel and wheel well increases drag therefore it is not recommended to use. The effects of cooling were not considered in these studies. However, a combined study on aerodynamics and brakes cooling is needed to optimise the aerodynamic parameters and cooling performance. Further details can be found in [18].

***2.2 Drag reduction of trucks***

A decisive factor is the aerodynamic quality of the vehicle shape is the drag coefficient ($C_D$). Due to varied shapes and sizes, commercial vehicles have a wider range of drag coefficients than cars. Buses have drag coefficients about 1.5 times those of cars, and tractor-semi-trailers units, and trucks and trailers units about double. Only light vans, which are more aerodynamically efficient, have the drag coefficients close to passenger cars [2]. Drag coefficients of various commercial vehicles are shown in Fig. 9. Heavy commercial vehicles are considered aerodynamically inefficient compared to other ground vehicles due to their un-streamlined body shapes. As mentioned earlier, a large commercial vehicle travelling at 100 km/h consumes about approximately 52% of the total fuel to provide power to overcome the aerodynamic drag [1-2]. In contrast, a passenger car under the same driving conditions, consumes approximately 4 times less to overcome drag. Generally, a heavy commercial vehicle's annual mileage can vary between 100,000 km and 160,000 km. Therefore, any reduction of aerodynamic drag will result in huge fuel savings and reduction of greenhouse gas emission. Although a significant effort was made by researchers over the decade to develop various fuel saving devices for commercial vehicles [2], there is still scope to further reduce the aerodynamic drag.

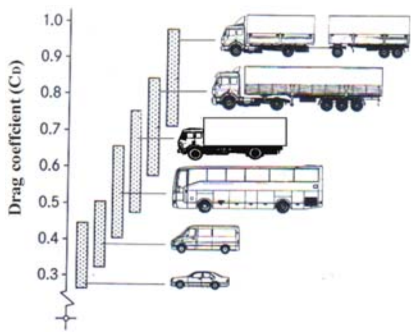



Fig. 9. Drag coefficients of different commercial vehicles [2]

The fuel consumption in litre (L) as a function of the total drag ($F_D$) for a petrol engine powered truck is given as [38]:

$$\frac{L}{100} = 0.01264 \times F_D \tag{2}$$

While for a diesel engine powered truck:

$$\frac{L}{100} = 0.008051 \times F_D \tag{3}$$

As discussed earlier, the external shape of a commercial vehicle (truck, bus, van etc) is determined mainly by the cargo space (trailer box).

Therefore, the main option for drag reduction is to improve the aerodynamic shape of the front end of the vehicle (cab or cabin) using various devices in front of the trailer to minimise the aerodynamic drag.

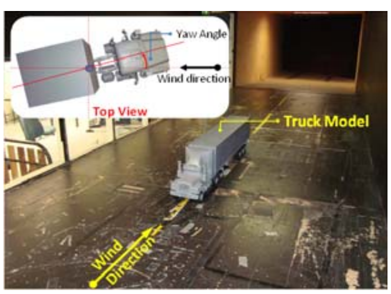
Commercial vehicle manufacturers are looking for every opportunity to minimise the fuel consumption by improving aerodynamic efficiency (i.e., lowering the drag force). Fuel savings through aerodynamic refinements of the tractor (cab) and the trailer, the development of electronically controlled engines, training drivers to drive for fuel economy, and developing more efficient transmissions offer opportunities to increase the efficiency of trucks and cars significantly. This will not only reduce operating costs (increase greater profitability) but also reduce dependency on fossil fuel and save environment from exhaust pollution. Researchers in various countries including Australia have been working hard to refine the commercial vehicle body-shape (cab and trailer) in order to reduce the aerodynamic drag.

Visualised airflow over a truck model without any drag-reducing devices shows the complex nature of airflow over the cabin and the body (Fig. 8). Usually, airflow passes over the cabin and hits the trailer if the trailer height is greater than cab height. Depending on the trailer height, gap (measured from the cabin rear end to the body front) and magnitude of crosswinds, the airflow may negotiate the sharp-edged corner of trailer or forms a reverse flow below the stagnation line in the gap or on the trailer and cabin-top. The separated flow generates significant aerodynamic drag. In order to avoid this unwanted flow separation, various devices can be used on commercial vehicles.

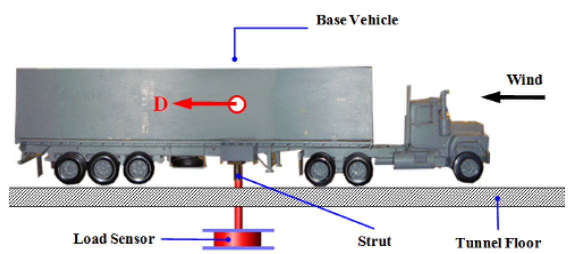
Many trucks are equipped with various fuel saving devices or add-ons using aerodynamic shapes in front as well as different parts of the truck to minimize drag. Without out changing the projected frontal area of the truck, it is possible to modify the shapes of the truck including the container box in a more streamlined way. These external attachments can minimize aerodynamic drag based on their external shapes, sizes and placements. The aerodynamic effects on current designs of aerodynamic fairings (front and side) and their combinations were not well studied and documented. As the number of trucks have been increased significantly worldwide due to increased logistic transportation, it is utmost important to study the effectiveness of fuel saving devices on existing trucks in order to minimize aerodynamic drag. Although a series of research on truck aerodynamics has been undertaken in 1970s, 1980s and early 1990s (see Copper [25], Saunders et al. [26], Watkins et al. [27-29]), there is significant scope to improve aerodynamic efficiency further. Most of these studies focussed on fore-body of the cab and cabins and the use of various fuel saving devices. Recently we have undertaken several aerodynamic studies to look for possibilities for further reduction of aerodynamic drag using aerodynamic fairings with various combinations in order to increase its effectiveness. The RMIT Wind Tunnel was used to measure the aerodynamic drag on the experimental model. The maximum speed of the tunnel is approximately 145 km/h. Details of this tunnel can be found in [8]. In order to keep the airflow around the test vehicle as practical as possible, a 10% scale model of a semi-trailer truck was used. The experimental truck model was connected through a mounting strut (see Fig. 10) with the JR3 multi-axis load cell, also commonly known as a 6 degree of freedom force-torque sensor made by JR3, Inc., Woodland, USA. The sensor was used to measure all three forces (drag, lift and side forces) and three moments (yaw, pitch and roll) at a time. Each set of data was recorded for 10 seconds time average with a frequency of 20 Hz ensuring electrical interference is minimized. Multiple data sets were collected at each speed tested and the results were averaged for minimizing the further possible errors in the raw experimental data.

All three forces (drag, lift and side force) and their corresponding moments were measured. Tests were conducted at a range of wind speeds (40 km/h to 120 km/h with an increment of 10 km/h) under four yaw angles (0º, 5º, 10º and 15º) to simulate the crosswind effects. Yaw angle ($\psi$) can be defined as the angle between the vehicle centerline and the mean direction of airflow experienced by the vehicle as indicated in Fig. 10a. Various fuel saving devices (front and side faring) were designed and manufactured for attaching on the base truck model. These add-ons were 10% scale of their full-size to match the scale model. Figure 11 shows different add-ons used in this study

The $C_D$ as a function of speed for various configurations of fairing at 0º yaw angle is presented in Fig. 12. The figure shows that the baseline model has almost constant $C_D$ value about 0.8. Similar results were found by Watkins et al. [27-29]. Generally, $C_D$ values for a semi-trailer truck are ranges from 0.5 to 0.9 depending on the aerodynamic design of the truck. The baseline model has the highest $C_D$ value whereas the model with any fairing attached has lower $C_D$ values. Experimental data also indicate a decrease of $C_D$ values with the increase of speed for the baseline model with any fairing attachment. The baseline model with the front and side fairing, and gap filled (i.e., configuration–a) as shown in Fig. 12 has the minimum $C_D$ value among all other configurations tested.

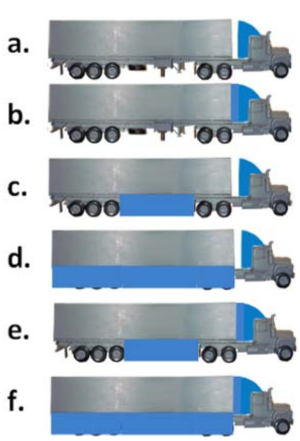


a) A semitrailer truck in RMIT Wind Tunnel



b) Experimental set up (baseline)

Fig. 10. Test vehicle in RMIT Industrial Wind Tunnel [31]



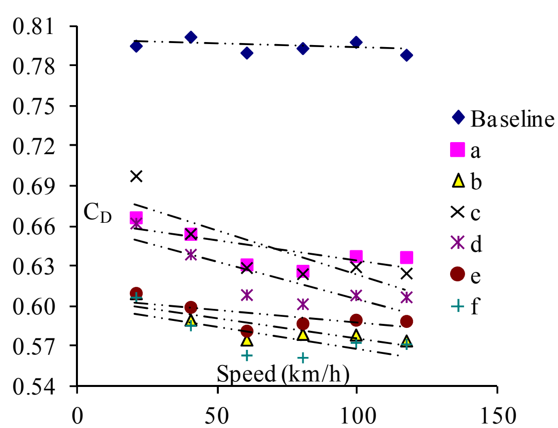



Fig. 11. Different combinations of fairing on the baseline semi-trailer truck model [31]

Fig. 12. Drag coefficient as a function of speed for different test configurations at ψ = 0º base line [31]

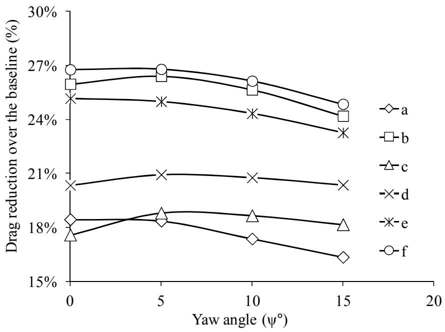



Fig. 13. Drag increase over base vehicle in percentage as a function of yaw angle [31]

**Table 1**. Percentage reduction of drag on yaw angle variation from 0º to 15º over the baseline [31]

| Configuration | Average drag reduction |
|---|---|
| a | 17.6% |
| b | 25.5% |
| c | 18.3% |
| d | 20.6% |
| e | 24.4% |
| f | 26.1% |

As mentioned earlier that the base vehicle model has also been tested alone with all attachments with different combinations at other yaw angles (ψ = 5º, 10º and 15º) to study the cross wind effect. The percentage of aerodynamic drag decrease over the base vehicle is shown in Fig. 13 for four yaw angles (ψ = 0º, 5º, 10º and 15º). The yaw angles have different effects on different combinations on the baseline model. For example, aerodynamic drag decreases with the increase of yaw angles for configuration a, e and f. However, the drag increases with the increase of yaw angle up to 5º and thereafter drag decrease with further increase of yaw angle for configurations b, c and d. Table 1 represents the percentage reduction of average drag over the baseline on yaw angle variation from 0º to 15º. The results show that the about 17.6% drag decreased with the "configuration a" and about 26.1% drag reduction with "configuration f".

### *2.3 Fuel savings for General Trucks in Bangladesh*

Road transport is a very fast growing sector in many developing countries. The average annual growth rate of motor vehicles in Bangladesh alone is 10%. Recent studies showed that an average growth of freight and passenger traffics in Bangladesh is approximately 7.7 and 8.3 percent respectively since 199. Over 73% of passenger-km and 66% of freight (ton-km) are now moved by commercial road vehicles.

According a report published by the Bangladesh Road Transport Authority (BRTA), the number of registered motor vehicles rose to 1,899,193 in May 2013 compared to 300,000 in 1995 (over 6.33 times). Currently the number of registered trucks is 96,348 (see Table 2). However, the number would be significantly higher if the unregistered trucks included. The majority trucks in Bangladesh are powered with imported engines and chassis mainly from India (over 90%) and UK (less than 10%). Typical trucks operated in Bangladesh are shown in Fig. 14. Rapid expansion, improved road infrastructures and globalisation will increase the volume of freights significantly in the near future. Commercial vehicles such as trucks will play a dominant role in future transportation in Bangladesh. It is worthwhile mentioning that the total length of paved road network in Bangladesh has been increasing rapidly. There was only 600 km of paved road in 1947, 4000 km in 1971 and over 21,481 km (National Highways – 3,544 km, Regional Highways – 4,278 km & Local or country Road – 13,659 km) in 2013 [32].

At present, the average speed on national highways in Bangladesh is approximately 40 to 50 km/h due to traffic congestion, roadside obstructions, pedestrians and non-motorised transports and lack of traffic rules. However, this cruising speed will be increased significantly with the implementation of traffic rules, construction of double or more lane freeways, segregation of various modes of vehicles, pedestrians, and the expansion of road width. As discussed earlier, with the increase of speeds, the aerodynamic drag will increase and fuel saving will be a required criterion for profitable operations of truck fleet in Bangladesh. Currently locally made cab and body are not at all aerodynamically efficient as shown in Fig. 14. Most body (cab) makers in Bangladesh have no expertise in aerodynamics of vehicles. Streamlining fore-body and various aerodynamic devices will reduce the aerodynamic drag which will intern reduce fuel consumption and greenhouse gas emission. It will also reduce the dependency fuel import and save import bills. The cab shape can be designed in more aerodynamically efficient ways using indigenous and modern technologies if the cab makers are appropriately trained and skilled. It is no doubt that current vehicle body shape (cab and trailer) consumes more fuel per km than it supposed to be. The total fuel consumption by truck fleet in Bangladesh is not known yet as no study was undertaken on this important issue. Truck fleets in Bangladesh are old and smaller in type. In order to obtain a comprehensive fuel saving characteristics of a particular aerodynamic device, truck specific wind tunnel, on-road tests and computational fluid dynamics (CFD) modeling are required.

**Table 2.** Various motorized registered vehicles in Bangladesh till May 2013, adapted from [33]

| Types of Vehicles | Prior 2010 | 2010 | 2011 | 2012 | Till May 2013 | Total Till May 2013 |
|---|---|---|---|---|---|---|
| Ambulance | 2506 | 287 | 219 | 181 | 83 | 3276 |
| Auto Rickshaw | 108436 | 18327 | 20423 | 23545 | 6909 | 177640 |
| Auto tempo | 13977 | 289 | 175 | 626 | 126 | 15193 |
| Bus | 26016 | 1762 | 1761 | 1439 | 474 | 31452 |
| Cargo Van | 2911 | 611 | 489 | 282 | 188 | 4481 |
| Covered van | 3760 | 1898 | 2354 | 1421 | 797 | 10230 |
| Delivery Van | 15564 | 1499 | 1004 | 774 | 325 | 19166 |
| Human Hauler | 5846 | 674 | 1152 | 715 | 197 | 8584 |
| Jeep | 30162 | 2124 | 2134 | 1569 | 507 | 36496 |
| Microbus | 59404 | 6975 | 4051 | 3044 | 998 | 74472 |
| Minibus | 24749 | 895 | 276 | 249 | 77 | 26246 |
| **Motorcycle** | **650147** | **109110** | **114616** | **101588** | **34664** | **1010125** |
| Pick Up (Utility Vehicle) | 23273 | 8967 | 10460 | 7625 | 2686 | 53011 |
| **Passenger Car** | **196870** | **22960** | **12950** | **9224** | **3393** | **245397** |
| Special Purpose Vehicle | 5900 | 471 | 396 | 226 | 91 | 7084 |
| Tanker | 2379 | 327 | 317 | 195 | 113 | 3331 |
| Taxicab | 44361 | 19 | 75 | 172 | 42 | 44669 |
| Tractor | 16855 | 3745 | 5200 | 3494 | 945 | 30239 |
| **Truck** | **73336** | **9535** | **7327** | **4335** | **1815** | **96348** |
| Other | 934 | 383 | 7 | 1 | 428 | 1753 |
| **Total** | **1307386** | **190858** | **185386** | **160705** | **54858** | **1899193** |

Fig. 14. Typical truck fleets in Bangladesh

## 3. Concluding Remarks

The reduction of aerodynamic drag is vital to achieve higher vehicle fuel economy and lower greenhouse gas emission. Platooning offers a reduction in aerodynamic drag on all vehicles (cars, trucks and buses) in the platoon, even the lead vehicle. In order to achieve the full benefit of platooning, smart technology and specially developed roads are required to form or leave the platoon, keep optimal spacing and interact between the platoon vehicles and non-platoon vehicles.

An average 5 to 25% fuel consumption reduction can be achieved using various aerodynamic devices and forebody streamlining. The aerodynamic fairings have notable impact on aerodynamic drag. The front fairing alone can reduce around 17% of drag. Further drag reduction up to 26% is possible using various combinations of aerodynamic fairings in different parts of the truck body. The baseline model with the front fairing and side covering including filling the gap between the truck and container box exhibits maximum drag reduction among all configurations tested.

Fuel savings are more relevant for developing countries like Bangladesh than oil rich Middle East. However, the reduction of fuel consumption reduces greenhouse gas production. Many developing countries' truck fleets are old and smaller in type. There are opportunities for incremental decreases on passenger cars and trucks drag. A comprehensive study is needed on goods trucks used in Bangladesh to determine fuel saving characteristics of a particular aerodynamic device.

## Acknowledgement

The authors express their sincere thanks to former research associates and members of Vehicle Aerodynamics Research Group: Harun Chowdhury, Giaccino Vino, Hussain Jama, Riccardo Pagliarella, Eton Ng, Satya Prasad Mavuri, Gokul Krishna Rajamani for obtaining data used in this paper.

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