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Effect of Passive Flow Controlling Dimples on Drag Reduction and Improved Fuel Efficiency

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Abstract

With rising fuel prices and decreasing fuel reserves, vehicles are being made more fuel efficient. Vehicle aerodynamics plays a crucial role in determining fuel consumption. This paper investigates the influence of passive flow control technique of imparting a dimpled body design in aerodynamic drag reduction by delaying flow separation and reducing the amount of wake region created behind the vehicle. For this, Ahmed bodies with 25° and 35° of slant angles have been used. Experiments were performed to compare the drag variations at various velocities when dimples of a fixed aspect ratio were imparted to the top surface of the Ahmed body behind the rear legs. For the 25° Ahmed body, the highest drag reduction of about 40% was obtained for the lowest flow velocity of 3m/s. Previous literature shows a sudden increase in drag force when the slant angle is increased beyond 30° .Hence tests were conducted on the Ahmed body with 35° slant angle with and without dimples. It revealed that the dimples had no effect in reducing its drag at low flow speeds. In fact, it was found that the dimpled body suffered an increased drag at higher velocities. Based on the studies conducted and by also taking the ease of fabrication into consideration, dimples were imparted on the super-mileage vehicle developed by us for 'Shell Eco Marathon Asia 2015'. The dimpled design imparted an increase in fuel efficiency of about 7%. This paper thus serves to prove the aerodynamic as well as fuel efficiency advantage that the dimpled design imparts to a vehicle.

Introduction

It is a well known fact that the dimples on a golf-ball reduces its drag [1] by keeping the flow attached to the ball for a longer period of time and thus delaying flow separation. But it has never been implemented on a vehicle to test how the possible reduction in drag could be converted to an increase in fuel efficiency of the vehicle. This paper investigates it by conducting wind tunnel tests by dimpling the surface of the generalised vehicle geometry, called as Ahmed Body [2], and then by testing the mileage of a dimpled Super-Mileage vehicle.

Wind Tunnel Setup

Wind tunnel tests were conducted using the Low Turbulence Wind Tunnel, shown in figure 1, at the Fluid Dynamics Laboratory of College of Engineering, Trivandrum.

Test Section	500mm×500mm×2000mm
Maximum Speed	30m/s
Turbulence Intensity	0.07%–0.6%

Table 1. Specifications of the Low Turbulence Wind Tunnel.

Figure 1. The Low Turbulence Wind Tunnel.

Wind tunnel tests were conducted on the dimpled and non-dimpled Ahmed Bodies with 25° and 35° slant angles, as in Table 2. The 35° Ahmed Body was also selected for the experiment because previous literature [3] showed a drastic increase in the drag coefficient when the slant angle was increased beyond 30°.

Ahmed Body	156.6mm×58.3mm×50.7mm
Slant Angles	25° and 35°
Dimple Size	5.5mm Diameter, 3mm Depth
Number of Dimples	64

Table 2. Specifications of the model

Two Ahmed body models, one with 25° slant angle and the other with 35° slant angle, having a scaling factor of 0.15 were designed using Solidworks and 3D printed in the FabLab facility at Technopark, Trivandrum..

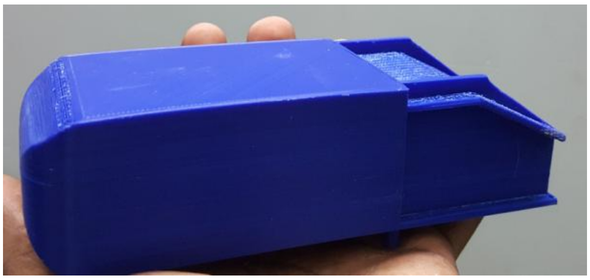

Figure 2. The 3D Printed Ahmed Body with reduced area of cross section at the rear. The image shows how the model looked before surface finishing works were done and clay was applied.

The models were designed in such a way that they had a reduced area of cross-section at the rear portion, as in figure 2, which could be filled with clay. The clay layer, as in figure 3, ensured the easy implementation of the required dimples and also allowed the use of one 3D printed model to test the cases with and without the dimples; thereby saving cost. This clay layer will also facilitate future studies where different aspect ratios of dimples will be tested. But proper care has to be taken to ensure the uniformity and the dimensional accuracy of the imparted dimples. Here, dimples were produced on the clay layer by applying pressure using accurately shaped metal bits.

Figure 3. The image shows the 3D Printed Ahmed Body after surface finishing works were done, clay was applied and dimples were imparted.

The drag force was measured using a one-component force balance, as shown in figure 4. The estimated maximum error in the measured drag force was recorded at low flow velocities and was within ±0.02N. The device was exclusively made in-house for this experiment. It was tailor-made so that it can not only accommodate the different test models, but can also be easily fitted on to the available wind tunnel. It had a digital display which displayed the drag force readings in grams, which were later converted to coefficient of drag values using equation (1).

$$C_D = \frac{2F_D}{\rho u^2 A} \qquad (1)$$

Where,

C_D =Drag Coefficient

F_D =Drag Force

ρ =Mass density of air

u =Flow speed of the object relative to the fluid

A =Reference Area

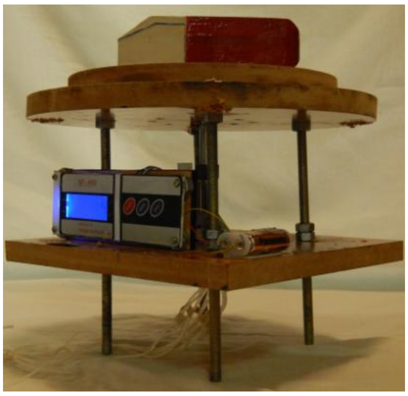

Figure 4. Ahmed Body mounted onto the force balance.

Wind Tunnel Test Results

The speed of rotation of the wind tunnel fan was varied from 168rpm–600rpm, which produced flow velocities ranging from 3m/s–12.87m/s and the drag force was measured.

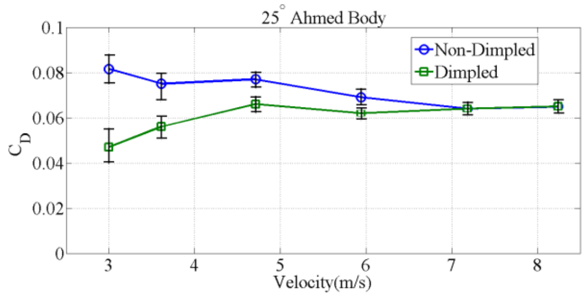

Figure 5. Variation of C_D with Velocity for 25° Ahmed Body

For the 25° Ahmed Body, as shown in figure 5, it was observed that the drag reduction caused by imparting the dimples were more prominent at lower velocities. As the flow velocity was increased, the dimples did not have any significantly measurable effect on the drag. At low velocities, due to the low momentum of the free stream air, the flow near the wall-region seemed to stick closer to the body and followed the curves of the dimples. This kept the flow attached to the body for a comparatively longer distance downstream and thereby decreased the pressure drag by reducing the amount of wake region created behind the vehicle.

But as the velocity was increased, the resulting higher momentum caused the free-stream air to be unable to trace the curves of the dimples, thereby avoiding the presence of the dimples and causing no noticeable change in drag.

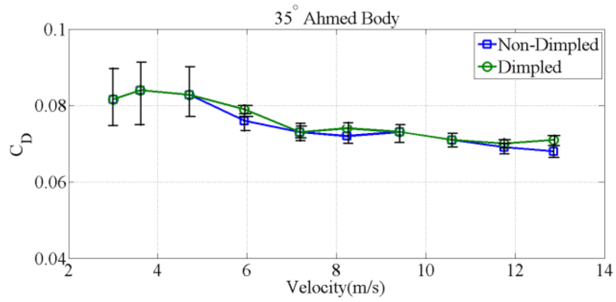

Figure 6. Variation of C_D with Velocity for 35° Ahmed Body

For the 35° Ahmed Body, as shown in figure 6, at low flow velocities, there were no detectable changes in the drag experienced by both the designs. But as the velocity of flow was increased, the dimples caused the drag to increase rather than to decrease, which was contrary to what was observed in the case of the Ahmed Body with 25° slant angle. This might be due to the fact that the non-dimpled 35° Ahmed Body has a wake region which is much larger than that of the non-dimpled 25° Ahmed Body. This is caused due to advancement in the point of start of separation due to an adverse pressure gradient which in-turn is caused by the much steeper change in surface profile. And this already large wake region, causes the flow over the dimpled body to start to separate at the location of the dimples, which is at a much upstream location. This might be due to the negative effect of the increased turbulent interactions of the higher velocity free-stream flow with the already large wake region, which in-turn disturbs the flow over the dimples and contributes to the enlargement of the wake and thereby increasing the pressure drag.

Dimpled Super-Mileage Vehicle

The findings of the wind tunnel tests and some initial CFD simulations provided encouraging results to impart the dimpled design onto the super-mileage vehicle of 'Team Go Viridis' for 'Shell Eco Marathon Asia 2015'. Due to the drag reduction offered by the dimples to the 25° Ahmed Body and also due to the increase in drag perceived in the case of the 35° Ahmed body, proper care was taken while designing the vehicle to ensure that dimples of the same aspect-ratio were imparted and that the changes in the area of cross-section were smooth and did not go beyond 30°. This was done in addition to making the vehicle streamlined, as seen in figure 7.

Figure 7. The dimpled super-mileage vehicle by ‘Team Go Viridis’ at ‘Shell Eco Marathon Asia 2015’

The design imparted perceivable changes in the drag-force experienced by the vehicle and it was measured by comparing the mileage of the dimpled vehicle to that of its non-dimpled design. In order to conduct tests on the non-dimpled vehicle, special care was taken to un-dimple the dimpled vehicle by covering it with wide, thin layer of polyethylene film over the dimpled region, thereby making it smooth and also ensuring that the weight of the vehicle in both conditions remained the same.

The body of the vehicle was made using Fibre Reinforced Plastic (FRP). While fabricating the FRP body, the dimples were imparted to the body by creating the exactly shaped dimples on a Plaster of Paris mould by using a specially built drill bit.

Sl.No.	Dimpled Vehicle	Non-Dimpled Vehicle
1	2025m	1879m
2	2035m	1876m
3	2033m	1877m

Table 3. Distance travelled by the vehicle using 5ml of gasoline

The vehicle was test driven under the conditions specified for the ‘Shell Eco Marathon Asia 2015’ competition, which included travelling at an average speed of 25km/h and coasting for certain periods of time on a level surfaced track. It was observed that the mileage of the vehicle powered using a 35cc, single cylinder gasoline engine was improved by around 7% by imparting the dimples. The distance travelled by the test vehicle using 5ml of gasoline fuel under dimpled and non-dimpled conditions is shown in table 3.

Conclusions

It has been experimentally proven that just as the dimples on a golf ball helps in reducing its drag, it helps to reduce the drag on a vehicle when it is imparted to it in the proper way.

From wind tunnel experiments conducted on Ahmed bodies with 25° and 35° slant angles, it was found that the dimples served to decrease drag at low velocities for the model with 25°slant angle, but increased drag at high velocities for the model with 35° slant angle. For the 25° dimpled Ahmed Body, at low velocities, the air flowed along the curves of the dimples and ensured a much longer distance of attached flow downstream and resulted in a much smaller wake region, thereby causing a reduction in pressure drag. While for the 35° Ahmed Body, which already has a larger wake region, the dimpling triggered the earlier separation of flow at higher flow velocities, which in-turn added up to a much larger wake and higher pressure drag.

The results of the experimental study provided impetus to impart a dimpled design to the super-mileage vehicle of ‘Team Go Viridis’ which resulted in about 7% advancement in mileage.

Future studies can include studying dimples of different aspect ratios, imparting dimples on the sides of the body to note the possible effects on the up-wash from the left and right sides at the slanting region to the upper surface of the body, varying spacing of the dimples, varying the position of the dimples with respect to the edges, providing dimples of shapes other than circles, etc.

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