A Bionic Designed Car & Air Flow Simulation to Calculate Aerodynamic Effects by Using Airfoil Structured Spoiler

Prakash Shakti, Pratibha Singh

[1]*Assistant Professor, Automobile Engineering Department*
K. J. Institute of Engineering & Technology
Vadodara, INDIA (G.J.)

[2]*Assistant Professor, Mechanical Engineering Department*
K. J. Institute of Engineering & Technology
Vadodara, INDIA (G.J.)

Abstract: *This research work presents the biomimicry (bionic) designed and simulated airfoil which can be used in different areas like Automotive, Aeronautics, and Windpower. Basically airfoil based spoiler is the design that is going to be used in automotive. The idea is taken from the humpback whale tubercle and owl comb feather. By implementing these two things there are changes like flow pattern of wind, less turbulence, and a decrease in noise.*

Keywords — *Airfoil, Spoiler, Tubercle, Humpback, Comb, Turbulence, Wind noise.*

I. INTRODUCTION

Biomimicry is a design tool based on a matching the strategies used by living things. It is an idea for applying the natural principle on all disciplinary of engineering by designing and producing.

Bio = life of living thing
Mimicry = Emulating, Matching

The practice of adapting nature's best ideas to the invention of healthier, more sustainable technologies for people.

In this present work, a biomimicry airfoil spoiler will be used for the proper air flow pattern. A leading tubercles inspired from humpback whale, and trailing edge comb structure from owl feather will be used on spoiler.

1.1 Humpback Whale

The most amazing feature of the humpback is its acrobatic behaviour during feeding known as bubble netting, which involves creating a zone around the prey and then sudden lunging towards it, giving the whale an element of surprise. Due to the presence of the tubercles on the flippers, the whale has a minimum turning diameter of 14.8 m. [1] [2]

Humpbacks can also perform acrobatic manoeuvres and underwater somersaults. The flippers measure more than 9 m in length, are elliptical in shape and have a high aspect ratio. The wavy leading edge consists typically of 10 or 11 rounded tubercles.

Nature provided the humpback whales, tubercles on the fins to help the whale catch its prey. .[1] [2]

As discussed above the whale uses the bubble netting technique to segregate its prey and then it lunges towards it. During the lunge feeding the humpback whale travels at a speed of approximately 2.6 m/s towards the prey Hansen. The mean chord of the whale flipper is approximately 0.51 m. based on the sea water viscosity and density at 16 °C, the operational .[1] [2]

Reynolds number is estimated to be approximately 1.1*106. Thus, it can be said that tubercles offer performance benefits mainly noticeable in the transitional region. Shows the various passive and active devices, their effect on the flow and the benefits they provide. [1] [2]

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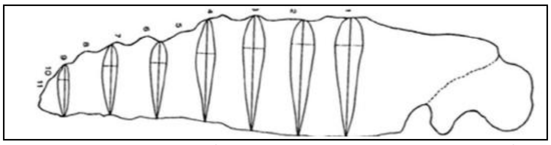

Fig. 1.1 Humpback whale flipper with Tubercle locations profile [2]

1.2 Barn Owl Feather

One species of nocturnal owls - the barn owl (Tyto alba) - is particularly adept at silent flight. Owls are capable of flying just inches from their prey without being detected. The quietness of their flight is owed to their specialized wing feathers. When air rushes over an ordinary wing, it typically creates a “gushing” noise as large areas of air turbulence build up. But the owl has a few ways to alter this turbulence and reduce its noise. . The owl has unique feather features – the leading edge (LE) comb, the down coat on flight feathers, and the trailing edge (TE) fringes – which are collectively referred to as the “hush kit”. First, the leading edge of the owl’s wing has feathers covered in small structures (hooks and bows) that break up the flowing air into smaller, micro-turbulences. Larger species of owls contributes to their ability to fly almost silently at frequencies above 1.6 kHz. . There has been considerable research on using
LE and TE features, modelled as serration, to reduce airfoil noise. [3][4][5]

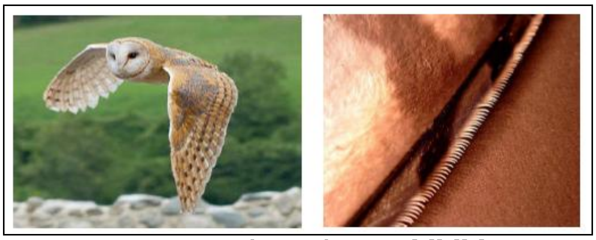

Fig 1.2 Barn Owl & Comb structre [3][4][5]

1.3 Bimimicry Aerodynamic Detail

Inspired from two living things sailent features we were implimenting ideas into biomimicry aerodynamic. The main purpose is to find a new structure of air flow pattern to reduce the wind noise, Drag, turbulence and wake. It is well known that airfoil self-noise is due to the interaction between an airfoil and the turbulence produced in its own boundary layer and near wake.
For 0 angle of attack, at low Reynolds number based on the chord length, largely laminar boundary layers develop, whose instabilities result in regular vortex shedding and associated noise from the trailing edge. Therefore, if the proposed biomimicry structures can control vortex shedding mode, it would be feasible to reduce the noise. We design an airfoil because we need a possible solution for maximum laminar flow and low drag

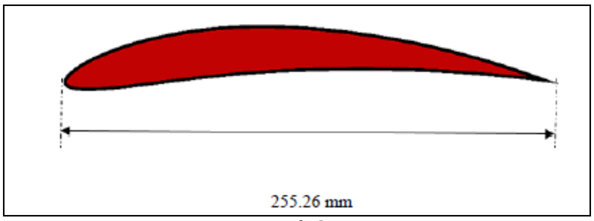

Fig 1.3 Airfoil Design

In this work we are using a sedan car and rear spoiler to calculate the different forces and moment after applying the biomimicry airfoil.

1.4 Bionic Spoiler Car

Inspired from nature and designed a sedan car with biomimicry techniqe to improve car aerodynamic performance so that we can get a proper air flow behind the car and reduce wind noise. As per future and present scenario this techniqe is also beneficial for electric & hybrid car aerodynamic performance.
The purpose of spoiler is to spoil the air and maintain the flow rate of wind. A spoiler is an vehicle aerodynamic device whose proposed design function is to 'spoil' opposed air flow through a body of a vehicle (car) in motion, typically termed as turbulence or drag.
For this research we changes the design pattern of spoiler and frontal look of car. The objective of spoilers used in passenger car is to decrease drag and increase fuel efficiency. In case of electric or hybrid car it is used to increase the battery performance. It also provide better road stabilities.
The flow of air converts turbulent and a low-pressure zone is generated, increasing drag and instability of car according to Bernoulli effect. Mostly drag occurs at the speed of 80-90 km/h.

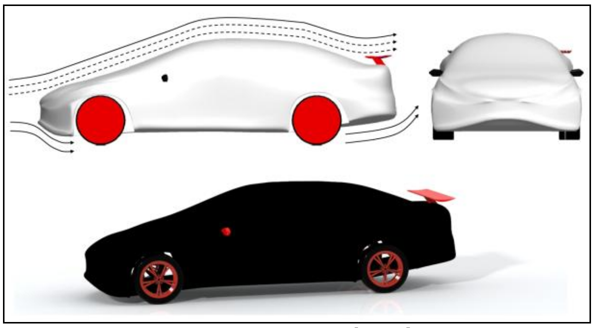

Fig 1.4 Bionic Car with spoiler

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II. DESIGN & CALCULATION

In present work we designed three different type of spoiler and attached in sedan car to validate the airflow pattern. The different airfoil (spoiler) are as given

a) Regular spoiler
b) Tubercle spoiler
c) Tubercle & comb (barn owl) spoiler

2.1 Spoiler Design

1. This airfoil series is controlled by 4 digits e.g. NACA 7410, which designate the camber, position of the maximum camber and thickness. If an airfoil number is

2. P is the position of the maximum camber divided by 10. In the example P=4 so the maximum camber is at 0.4 or 40% of the chord.

3. M is the maximum camber divided by 100. In the example M= so the camber is 0.07or 7% of the chord.

4. XX is the thickness divided by 100. In the example XX=10 so the thickness is 0.10 or 10% of the chord.

The equation for the camber line is split into sections either side of the point of maximum camber position (P). In order to calculate the position of the final airfoil envelope later the gradient of the camber line is also required. The equations are:[6][7]

	Front ($0 \le x < p$)	Back ($p \le x \le 1$)
Camber	$y_c = \frac{M}{P^2}(2Px - x^2)$	$y_c = \frac{M}{(1-P)^2}(1 - 2P + 2Px - x^2)$
Gradient	$\frac{dy_c}{dx} = \frac{2M}{P^2}(P - x)$	$\frac{dy_c}{dx} = \frac{2M}{(1-P)^2}(P - x)$

The thickness distribution is given by the equation:

$$y_t = \frac{T}{0.2}\left(a_0 x^{0.5} + a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4\right)$$

Where:

$a_0 = 0.2969$ $a_1 = -0.126$ $a_2 = -0.3516$ $a_3 = 0.2843$

$a_4 = -0.1015$ or -0.1036 for a closed trailing edge

- The constants a0 to a4 are for a 20% thick airfoil. The expression T/0.2 adjusts the constants to the required thickness.[6][7]
- At the trailing edge (x=1) there is a finite thickness of 0.0021 chord width for a 20% airfoil. If a closed trailing edge is required the value of a4 can be adjusted. [6][7]
- The value of yt is a half thickness and needs to be applied both sides of the camber line. [6][7]

Using the equations above, for a given value of x it is possible to calculate the camber line position Yc, the gradient of the camber line and the thickness. The position of the upper and lower surface can then be calculated perpendicular to the camber line. [6][7]

$$\theta = \operatorname{atan}\left(\frac{dy_c}{dx}\right)$$

Upper Surface $x_u = x_c - y_t \sin(\theta)$ $y_u = y_c + y_t \cos(\theta)$

Lower Surface $x_l = x_c + y_t \sin(\theta)$ $y_l = y_c - y_t \cos(\theta)$

The most obvious way to to plot the airfoil is to iterate through equally spaced values of x calclating the upper and lower surface coordinates. While this works, the points are more widely spaced around the leading edge where the curvature is greatest and flat sections can be seen on the plots. To group the points at the ends of the airfoil sections a cosine spacing is used with uniform increments of β. [6][7]

$$x = \frac{(1-\cos(\beta))}{2} \quad \text{where: } 0 \le \beta \le \pi$$

Table 2.1 Airfoil Generator Detail

Max Camber (%)	7	First digit. 0 to 9.5%
Max camber position (%)	40	Second digit. 0 to 90%
Thickness (%)	10	Third & fourth digit. 1 to 40%
Number of points	81	20 to 200
Cosine spacing	Yes	Cosine or linear spacing
Chord (mm)	255.26	Chord width in millimetres. (1 inch = 25.40mm)
X grid (mm)	10	X grid size in millimetres
Y grid (mm)	10	Y grid size in millimetres

Based on above we have designed a 3 different type spoilers.

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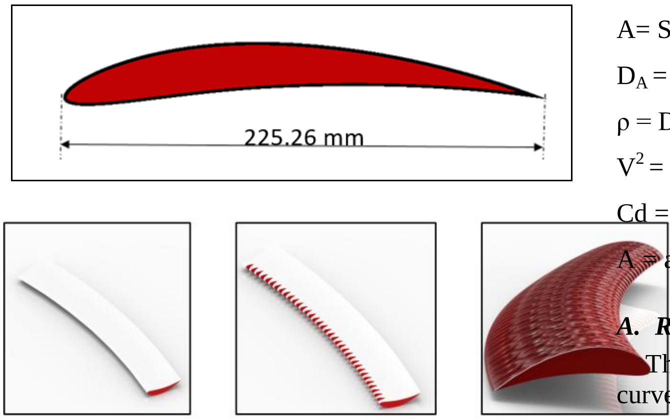


(a) (b) (c)

Fig 2.1 Airfoil Design & Bio mimicry Spoiler (a) Regular (b) Tubercle (c) Tubercle & comb

2.2 Mathematical Drag Calculation of Spoiler

A mathematical calculation done to see the drag force on tubercle & comb (barn) spoiler.

$\rho = 1.125 (P_r / 101.325) (288.16 / 273.16+T_r)$

$= 1.125 (101.1 / 101.325) (288.16 / 273.16+ 30)$

$\rho = 1.16180$ kg/m^3

Where,

ρ = Density of air kg/m^3
P_r = Atmospheric pressure, Kpa
T_r = Air temperature °C

$D_A = 1/2\ \rho\ V^2 \times Cd \times A$

$= 1/2\ 1.16180 \times 120^2 \times 0.33 \times 22.2$

$= 4.0795\text{x}10^{-6}$

A= length x height

= 15m x1.48 m

=22.2 m^2

Where,

A= Spoiler area,m^2

D_A = Aerodynamic drag

ρ = Density of air kg/m^3

V^2 = velocity of object km/hr

Cd = Co-efficient of drag

A = area of object m^2

A. Regular Spoiler

This Design Highlight the regular spoiler with curve angle 25˚

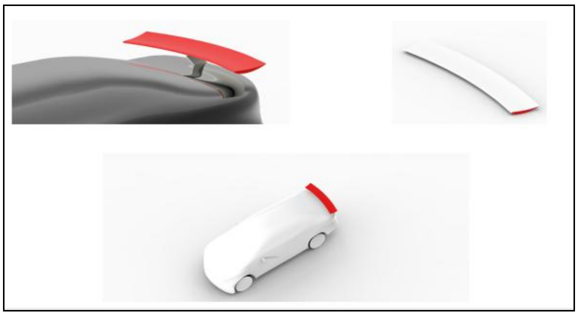


Fig 2.2 Regular spoiler attached with car

B. Tubercle Spoiler

This Design Highlight the tubercle spoiler

- Curve angle 25˚
- No. Tubercle Structure – 35 at 45 mm Space.

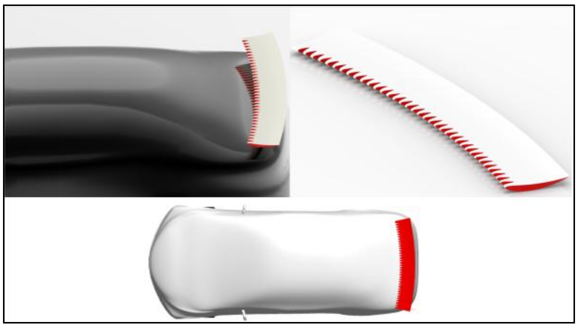


Fig 2.3 Tubercle Spoiler attached with car

C. Tubercle & comb (barn owl) spoiler

This Design Highlight the tubercle & comb (barn owl) spoiler

- Curve angle 25˚
- Comb Structure – 1 mm diameter
- No. of comb structure – 165 at 5 mm distance
- No. Tubercle Structure – 35 at 45 mm Space.

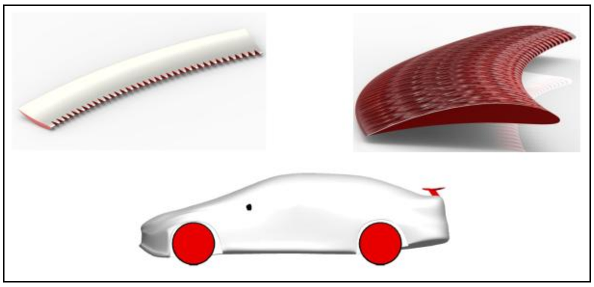


Fig 2.4 Tubercle & comb (barn owl) spoiler attached with car

III.DETAIL SIMULATION

A. ***Comparative Simulation***

1. Regular spoiler
2. Tubercle spoiler
3. Tubercle & comb (barn owl) spoiler

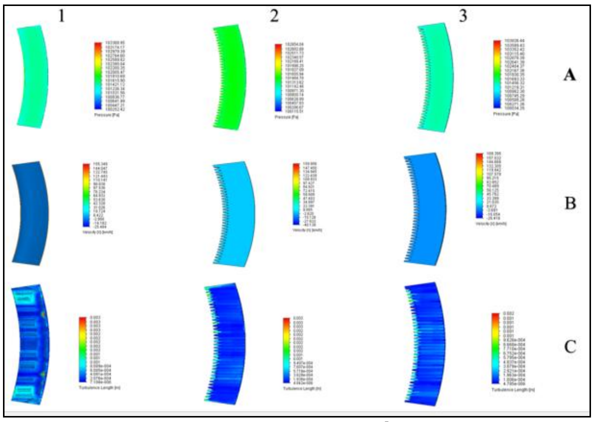


Fig 3.1 Comparative Simulation

Figure A is related to surface pressure. figure B is related to velocity effect on spoiler whereas figure C is for turbulence distribution.

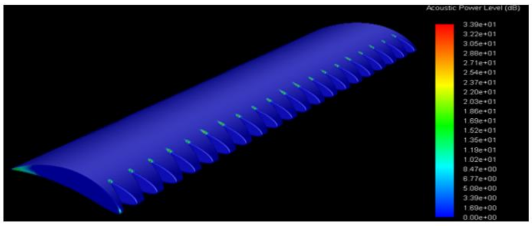
3.1 Noise Calculation

- Wind noise level of tubercles Spoiler - Maximum acoustic power level (dB)

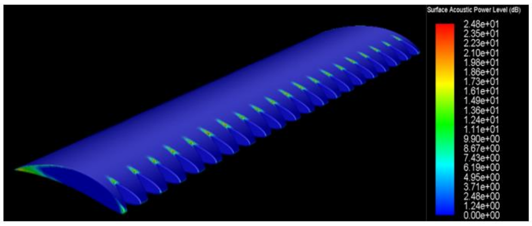
  = 3.39e+01

- Wind noise level of tubercles & comb combined spoiler – Maximum acoustic power level (dB)

  = 2.48e+01



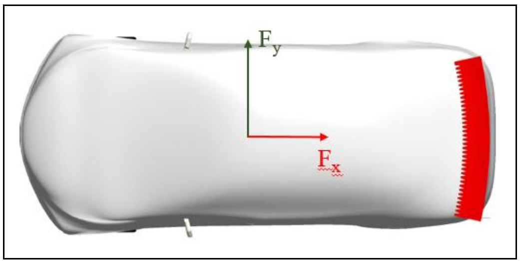
Acoustic power level of tubercles spoiler



Acoustic power level of tubercles & comb combined spoiler
Fig 3.2 Aerodynamic Noise Calculation

B. ***Simulation related to car & attached spoiler***

The aerodynamic simulation has done by using computer based simulation. The detail of forces is shown here which acts on vehicle body during flow simulation condition.



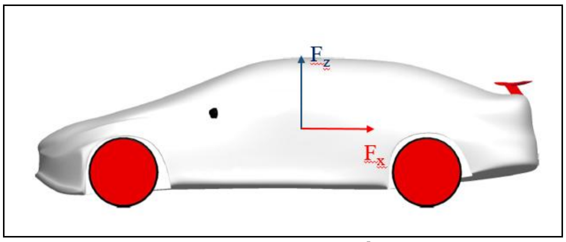


Fig 3.3 Forces acting on sedan car

- *Fx - Is force which generated along the direction of the wind which is called as the "drag" force*

- *Fy - Is force which is generated perpendicular and horizontal to the direction of the wind and it is called as the "lateral" force*

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- *Fz - Is force which is generated perpendicular and vertical to the direction of the wind so it it known as the "Lift" Force*

C. ***Data used for simulation:-***

Table 3.1 Input data

Velocity of wind	33.33 m/s or 119.988 km/hr
Temperature	28 °C
Density [kg/m³]	1.225
Sedan Car	Stationary Position
Turbulence Kinetic Energy	0.01 m2/s2
Wind tunnel size	19,590.52 mm x 1978.10 mm x 5000 mm (LxWxH)
Car Dimension	4420.01 mm (L) x 1696 mm (W) x 1498.2 mm (H)

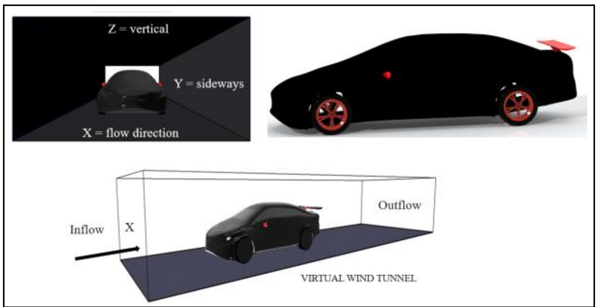

Fig 3.4 Virtual wind tunnel with boundary condition

3.2 Surface Pressure Drag

When the air attack at the frontal surface of car, the pressure builds up, so that produces a force. At the rear of the car, air is dragged along, dropping the pressure, creating a wake due to turbulence of air which is flowing above and below of the body behind the car. While calculating the pressure over the whole surface of car body, the total force acting on the car body can be obtain. To know the drag only we have to find out the component of the total force that is directed along the wind direction and this phenomena is known as pressure drag.

A high pressure acting on the front of car will push it back, producing aerodynamic drag. Frontal facing surfaces with facing upstream of the air have positive pressure, or backward facing surfaces with facing downstream of the air have negative pressure that produce aerodynamic drag. On other hand forward facing surfaces with negative pressure, or backward facing surfaces with positive pressure help in reducing aerodynamic drag.

3.3 Turbulence Effect

The pressure distribution around the car gives more hints on the details for the drag change with the introduction of upstream turbulence. The turbulence on a car body many effect in various way such as increase in wake region, drag coefficient also un proper stability.

So to improve this a bionic designed spoiler is used which changes the turbulence energy effect. The major changes is by using humpback whale & barn owl features on spoiler frontal and tail edges, which decrease the turbulence length as well as wind noise.
At last the overall 37% of car aerodynamic efficiency will increased by improving the turbulence area and this leads to increasing the fuel efficiency, car stability and wind noise.

3.4 Streamline Flow

Streamlines provide various understandings. First of all, by the use of streamline we can observe the changes like laminar flow zones (steady streamlines) to turbulent zones (swirling streamlines). The changeover from laminar to turbulent frequently occurs when the airflow is incapable to follow the surface of the car, because of the "negative angle". Due to this there is increased aerodynamic drag. Also there is observation of incompressible air, speed up and slowing of air which depends upon the velocity of wind.
In this the maximum velocity of wind goes up to 60.151 m/s but for calculation 33.642 m/s or 121.11 km/h is better as per the geometry of car design for decreasing drag.
Drag increases due to the upwind directly contact with the wind which comes below the car body.

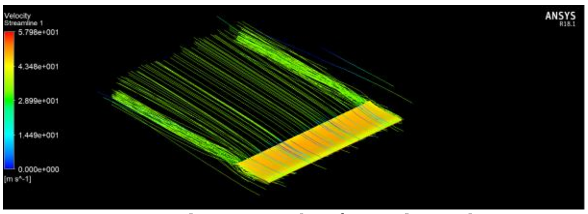

Fig 3.5 Velocity streamline for regular spoiler

Velocity stream line of air flow of normal spoiler 7.250e+001 [m*s^-1]

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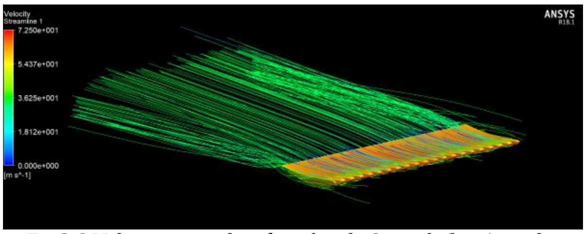

Fig 3.6 Velocity streamline for tubercle & comb (barn) spoiler

Velocity stream line of air flow of tubercles spoiler 5.798e+001 [m*s^-1]

3.5 Tubercle & Comb (barn) Spoiler Car

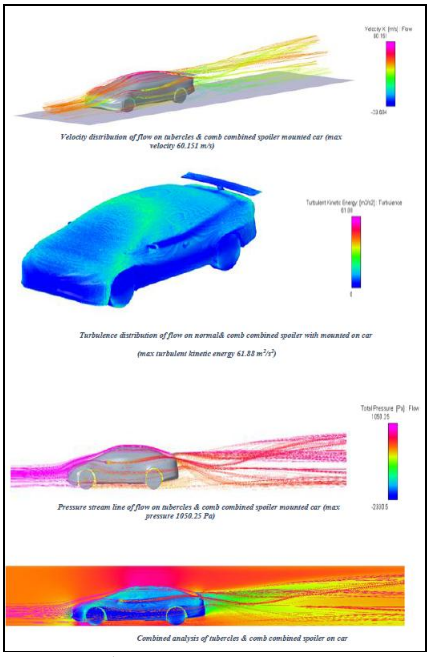

Fig 3.7 Calculation of Pressure, Velocity streamline and turbulence

Here is the calculation of velocity, turbulence and pressure on car. Pressure streamline of flow on tubercles & comb combined spoiler mounted car (max pressure 1050.25 Pa). Velocity distribution of flow on tubercles & comb combined spoiler mounted car (max velocity 60.151 m/s). Turbulence distribution of flow on normal& comb combined spoiler with mounted on car (max turbulent kinetic energy 61.88 m2/s2).

3.6 Drag & lift Force

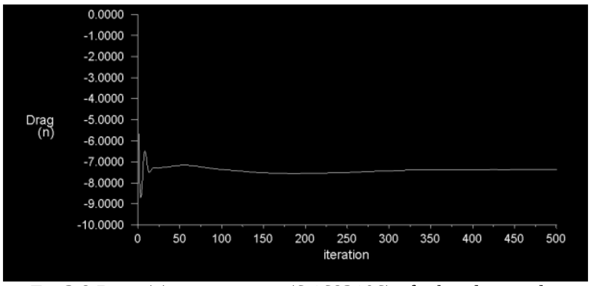

Fig 3.8 Drag (n) convergence (6.1683106) of tubercles spoiler

Drag (N) = Airfoil 6.3216438

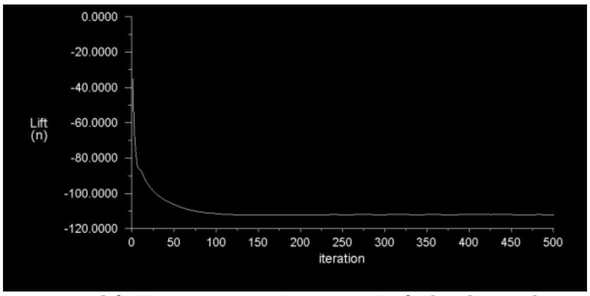

Fig 3.9 lift (n) convergence (-200.60999) of tubercles spoiler

Lift (N) = Airfoil 110.26414

The drag and lift force is separately calculated for spoiler.

For controlling the vehicle stability there must be control on lift forces because increase and decrease in lift may affect the weight of axle between front and rear.

The pitching moment will arises when the drag does not acts exactly at the centre of the car wheel base.

Lift force results in asymmetric flow of air above and below the vehicle.

The calculated lift force is almost good for controlled vehicle driving condition at 120 km/h

IV. CONCLUSION

In this present work the 3 different types of spoiler is designed by using bio mimicry technique to improve the car aerodynamic. After solving the aerodynamic simulation the conclusion is that "tubercle & comb" type spoiler is best for car spoiler. The result and design is compare to other type of spoiler option to improve performance and aero dynamic characteristic of car.

- Mach number is 0.02.
- Air noise of "tubercle & comb" of spoiler is 2.48 dB

- The maximum drag force is 6.321 N

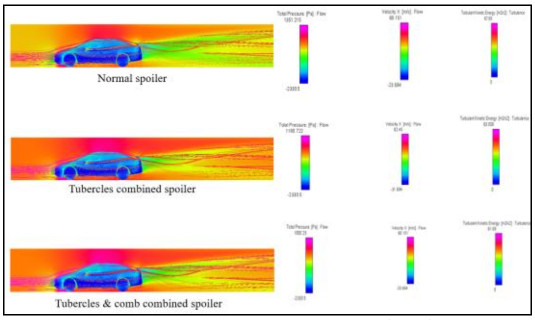

Fig 4.1 Compression Result of air flow

1. Tubercles at leading edge can substantially reduce airfoil unsteady forces. Airfoil lift and drag fluctuations are reduced respectively. In addition, wavy leading edge is split the air improved flow control of air it helps to flow air as near as possible to spoiler.
2. The wavy leading edge can also substantially split turbulence in micro turbulence then air is passes over the spoiler in laminar flow comb structure at end of spoiler is reduces vortex at exit also reduce wake.
The use of wavy leading edge and comb structure can mitigate noise radiation at all the azimuthal angles without significantly changing the noise directivity.

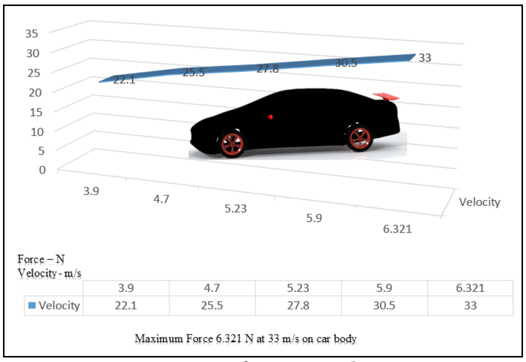

Fig 4.2 Drag forces Vs Velocity

Maximum Force 6.321 N at 33 m/s on car body

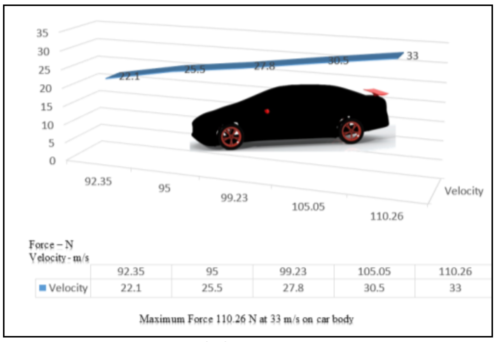

Fig 4.3 Lift forces Vs Velocity

Maximum Force 110.26 N at 33 m/s on car body. Fig 4.2 and fig 4.3 highlight the drag and lift force at different velocity of wind.

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