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Determination of drag coefficient for TOYOTA car model (Using Strain Gauge Method)

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Abstract: *The flow field around an automobile is very complex, characterized by a high degree of three dimensionality, flow separation, reattachment and vortex formation. Flow visualization as well as flow simulation are helpful tools during the aerodynamic design of vehicles. The research-undertaken deals with an experimental estimation of* C_D *(drag coefficient) for TOYOTA car,(scale 1/20) using the strain gauge method (FLA-6-11 type, 120Ω, 2.12 gauge factor, half-bridge connection), which was proved to be practical and reasonably accurate. Experiments were run within a subsonic aspiration wind tunnel, covering an air speed up to 33 m/s (i.e., Reynolds number* 5.7×10^5*). Results for drag coefficient were obtained in the range of 1.10 to 0.53. It was noted that the magnitude of* C_D *decreased from 1.10 at 21.18 m/s to 0.53 at 33.00 m/s (i.e., decrease of drag coefficient by about 50%). Comparison of our results with those given by other authors is satisfactory.*
Key words: *Strain gauge, Drag coefficient, Wind tunnel, Aerodynamics of automobile, Static loading, Dynamic loading, Half bridge connection.*

I. Introduction

Recently the incentive to reduce the aerodynamic drag of road vehicles has increased again. Different methods to estimate drag coefficient of cars have been utilized in the past [1,2]. In the present paper, we use strain gauges with bending moment diagram in order to estimate drag coefficient, the matter that proved to be practical, accurate, and easy.

It is known that loads acting transversely to the plane of a large dimension cause a member to bend. A bar member subjected to this loading is called a beam. In order to resist these loads, a beam must be supported at one or positions along its length. If a beam has one end built-in, it is called a cantilever [3]. We used this idea in order to fix a model of a vehicle at a free end of a cantilever, and estimate the drag coefficient from bending moment diagram of the beam.

II. The Experimental Equipment and Instrumentation

A subsonic wind tunnel, aspiration type, with a maximum speed of 33 m/s, was used. Its cross section and active length are respectively: 230x230 mm^2 and 500mm [4]. Four strain gauges, FLA-6-11, 120 Ω, 2.12 ±1% gauge factor, wire gauge type were used, with adhesive P-2, and coefficient of thermal expansion=$11.8 \times 10^{-6}/^oC$. The temperature coefficient of gauge factor is $+0.1\pm0.05\%/10^oC$ [5]. The sting made of hot rolled, medium carbon steel (0.45%C), damped effect, E= $203.4 \times 10^9 \, N/m^2$, and $I_z=1.4426 \times 10^{-10} \, m^4$.

A model reproducing a TOYOTA , made from PVC, scale 1/20, and blockage ratio of 16% was tested. The extensometer bridge which was used, was provided with internal impedance of 120Ω to 500Ω, the range of ±20000 points, maximum resolution:1μΩ/Ω, and Amplificatory linearity is 0.002%. The gauge factor regulator is 1 to 5 for 4 digits, and the excitation stability is 0.01%. The branching type is a half-bridge and full-bridge with analogical exit of 0-2V for 0-20000 μΩ/Ω. The minimum charge is 2000Ω, and passer band of analogical exit is 0 to 10 KHz[6].

III. The Experimental Procedure

Dimensions of the sting were chosen so as to reproduce minimum strain that we can read it via strain gauges. The model was fixed at the reference point of the sting as shown schematically in (fig.1a).

From the bending moment diagram, (fig.1b), we can write $M_o=F_Y.X_C + F_X.Y_C$. The value of $(F_Y.X_C)$ approaches to zero[3]. We need two equations in order to find the two unknowns F_X and M_O, and these two equations could be obtained via the sting in its vertical position. Experimental procedure for TOYOTA model is shown in fig. (2).

1-3-1 Drag force and fluid velocity calculation

The model and four strain gauges were fixed-as shown before in (fig.1a)-at reference point (O), (B), and (A) respectively. L_a is the distance of strain gauge (A) from the reference point (O). L_b is the distance of strain gauge (B) from the reference point (O). From the bending moment diagram, (fig.1b), we have:

$M_A = M_O + F_X.L_a$ (1)
$M_B = M_O + F_X.L_b$ (2)

M_A, M_B have direct relationship with readings of strain gauges ε_A, ε_B respectively as shown in subsequent equations:

$\varepsilon_A = \sigma_A/E = M_A.h/ 2 I_z .E \Longrightarrow M_A = 2I_zE\varepsilon_A/h$ (3)
$\varepsilon_B = \sigma_B/E = M_B.h/ 2 I_z.E \Longrightarrow M_B = 2I_zE\varepsilon_B/h$ (4)

Where I_z represents the second moment of area for the sting around Z-axis as shown schematically in (fig.3). By solving equations (1) and (2), we can find the unknowns F_X and M_O. Drag coefficient could be estimated by the relationship:

$C_D = F_X/ 0.5\rho V_\infty^2 A$ (5)

And fluid velocity (air-speed) could be estimated by:

$$V_\infty = \sqrt{2g(\rho_w / \rho_a)\Delta h} \quad (6)$$

1-3-2 Deviation analysis for measurements

From equation (6):

$V = \text{constant x } \sqrt{H}$
$\ln V = \ln \text{constant} + \ln H^{1/2}$ (7)

By differentiating the equation logarithmically

$dV/V = 0.5 \text{ x } dH/H$

Where dH represents the absolute error ratio in total pressure head that could be estimated:

$$dH = \sqrt{(H - H_m)^2 + (\delta H)^2}$$

Where H represents the total head.
Deviation analysis for drag force measurements could be estimated from:

$$dF_X/ F_X = \pm\sqrt{(d\varepsilon_A / \varepsilon_A)^2 + (d\varepsilon_B / \varepsilon_B)^2} \quad (8)$$

Deviation analysis for drag coefficient could be estimated from:

$$dC_D/C_D = \pm\sqrt{(dF_X / F_X)^2 + (2dV / V)^2} \quad (9)$$

IV. Results and discussion

Figure(4) shows the results of the wind tunnel calibration . Good stability in velocity distribution within the working section, was obtained.

Experiments were run at an air speed from 21.17 m/s to 33.00 m/s (i.e., Reynolds number from 3.67 10^5 to 5.72 10^5), results for drag coefficient were obtained in the range of 1.10 to 0.53 as shown in figure (5). It was noted that the value of CD decreased from 1.10 at 21.17 m/s to 0.53 at 33.00 m/s (i.e., decrease of drag coefficient by about 50% within the range of an air speed of 12 m/s).

Figure (6) shows that dV/V ratio varies from ± 3.57% to ± 1.47 % (i.e., decreases by 59%), while dF_X/F_X varies from ± 3.66 % to ± 1.42 % (i.e., decreases by 61 %), and dC_D/C_D ratio varies from ± 8.02 % to ± 3.26 % (i.e., decreases by 59 %), at the working range of an air speed.

For the undertaken model, the separation tends to occur when air flows from a low pressure to a high one, which is known as an adverse pressure gradient. Conversely, a flow from a high pressure to a low one, is known as a favorable pressure gradient, which is not only inhibits the separation but also slows down the rate of boundary layer growth and delays the transition. A flow separation is particularly and likely to occur when the air tries to go around a very sharp bend, Figure (7&8).

Figure (9) shows the flow visualization around TOYOTA model with re-circulating bubble or spiral vortices at the rear. Figure (10) shows the scheme for the trailing vortices at the rear part of the vehicle.

V. Conclusion

The re-circulating bubble or spiral vortices determine the drag and stability. From the flow visualization that consolidated with the strain gauge method results, it can be seen that as the size of vortices are small, the drag coefficients are low.

Notations

F_X: Total drag force (N).
F_Y: Lift force (N).
M_A: moment at A (N.m).
M_B: moment at B (N.m).

M_O: Pitching moment (N.m).
ε_A: Strain at strain gauge A (μ strain).
ε_B: Strain at strain gauge B (μ strain).
E: Young modulus of elasticity (N/m^2).
(X_C,Y_C):Centroid co-ordinates of the sting.
I_z: Second moment of area (m^4).
σ_A: Stress at A (N/m^2).
σ_B: Stress at B (N/m^2).
b: Width of beam (m).
h: Thickness of beam (m).
ρ_a: Air density (kg/m^3).
ρ_w: Water density (kg/m^3).
V_∞: Undisturbed air flow (m/s).
g: Gravitational acceleration (m/s^2).
Δh: Head difference (m H_2O).
C_D: Drag coefficient.
A: The model frontal area (m^2).
L_a: The distance of strain gauge A from the reference point (O).
L_b: The distance of strain gauge B from the reference point (O).
Subscript (O): Reference point (model fixing position on the sting at the back of the model).

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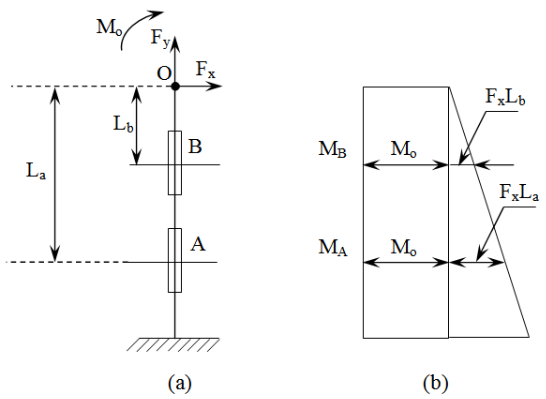

Figure (1): (a) The vertical position of the sting (schematically)
(b) The bending moment diagram for the sting

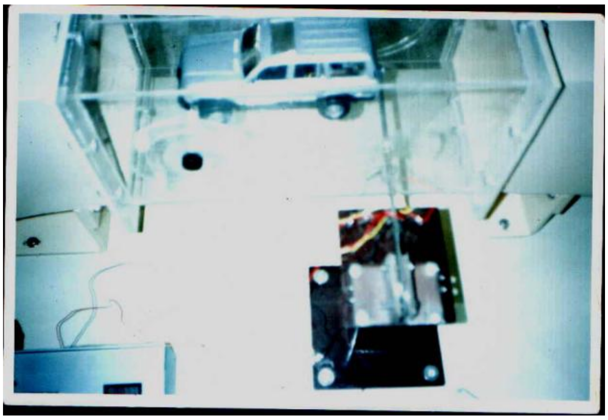

Figure (2): Experimental procedure for TOYOTA model

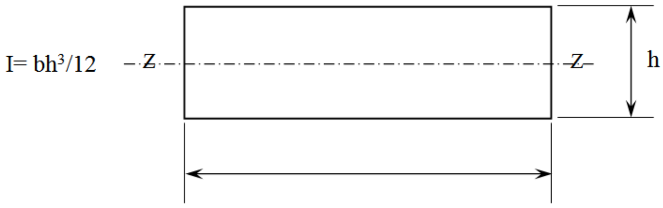

Figure (3): The second moment of area for the sting

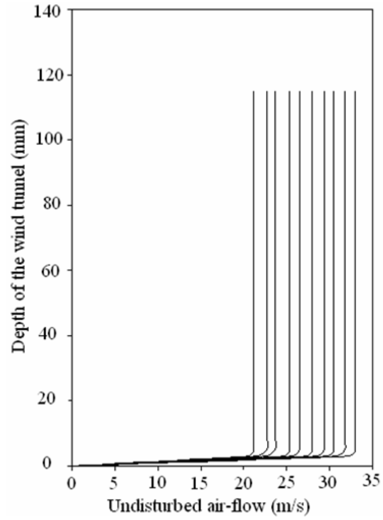

Figure (4): Velocity distribution within the test section.
From calibration of the wind tunnel

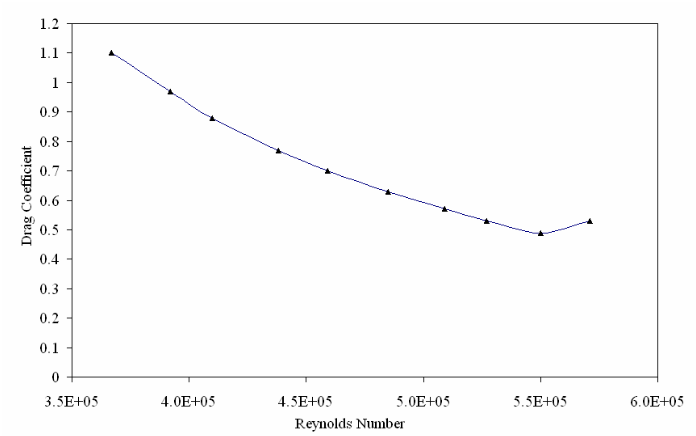

Figure (5): Drag coefficient versus air speed for TOYOTA model

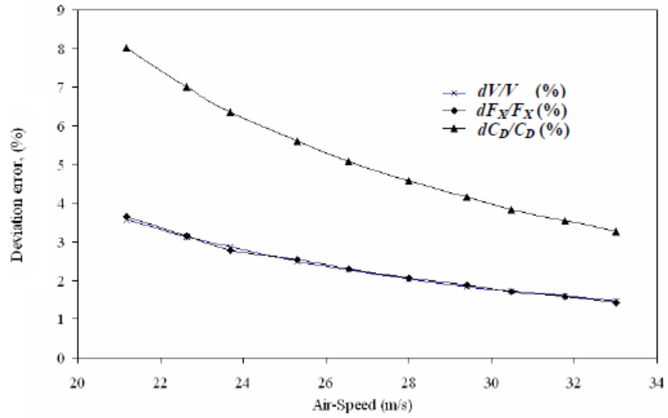

Figure (6): Variation of errors deviation with an air-speed for TOYOTA mode

Figure (7): Flow visualization around TOYOTA model

Figure (8): Attached flow at the right and left sides for TOYOTA model

Figure (9): Re-circulating bubble or spiral vortices at the rear part of TOYOTA model

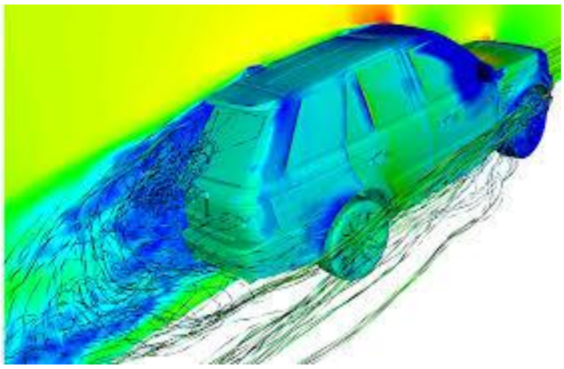

Figure (10): Scheme for the trailing vortices at the rear part of the vehicle[7]