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Study and Comparison of Aerodynamic Forces on an Aircraft and Suspension Bridge

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Abstract: - Aerodynamic forces are time varying forces experienced by objects undergoing air flow. The effect of these forces depends upon the shape and size of the objects. The aerodynamic force acting on a bluff body like bridge deck is different from that acting on a stream line body like an aircraft.This paper focus on the study and comparison of aerodynamic forces acting on an air craft and a bridge deck.

Keywords: - *Aerodynamic coefficients, Aerodynamic forces, Bluff body, Self-excited forces, Streamlined body.*

I. INTRODUCTION

Researches are booming in the area of aero-dynamics of civil structures, which are not usually designed to influence or accommodate the airflow over them, but rather with other objectives in view. The aero-dynamics of such structures is characterized by separated flow and turbulent wakes exhibiting widely varying degrees of flow organizations. A body immersed in a fluid flow is subjected to surface pressures induced by the flow. If the oncoming flow is turbulent, this will be one of the sources of time dependent surface pressure. If the body moves or deforms appreciably under the induced surface pressure, these deflections, changing as they do the boundary conditions of the flow, will affect the fluid forces, which in turn will influence the deflections. Aero-elasticity is the discipline concerned with the study of the phenomenon wherein aero-dynamic forces and structural motions interact significantly.

If the body in the fluid flow deflects under some forces and the initial deflection gives rise to successive deflections of oscillatory and/or divergent character, aero-elastic instability is said to be produced. All aero-elastic instabilities involve aero-dynamic forces that act on the body as a consequence of its motion. Such forces are termed self-excited.

A body is said to be aerodynamically bluff when it causes the wind flow around it to separate from its surface leaving a significant trailing wake. In contrast, wind flow around a streamlined body remains tangential and attached to its entire surface, leaving a narrow trailing wake. Most civil engineering structures, including the bridge sections of the long span bridges qualify as bluff bodies, while the shapes of an airfoil belong to the category of a streamlined body. The fundamental aspects of aero-elastic phenomena that need to be taken into account in the design of certain structural members, towers, stacks, tall buildings, suspension bridges, cable roofs piping system and power lines are not completely understood.

Without aerodynamics airplanes cannot fly. Thus while considering performance of an aircraft it is no surprise that aerodynamics is a vital aspect. The philosophy of good aerodynamics is primarily derived from low drag.

Aerodynamics is dynamics related with flow of air. It is classified into two external aerodynamics and internal aerodynamics. External aerodynamics deals with flow of air over a body. Internal aerodynamics deals with flow of air with in ducts.

II. AERODYNAMIC FORCES ON SUSPENSION BRIDGE

Bridge deck is a bluff body. A bluff body is defined as a body for which the major contribution to the drag force is due to pressure forces arising from separation of the boundary layer flow adjacent to the surface over the rearward facing part of the body. For example, a body of circular or rectangular cross section is a bluff body and so is a flat plate or aero-foil inclined at a high angle to the oncoming flow.
Aero-dynamic forces on a bridge deck is sum of

- Mean Static Component
- Self-excited force component

The Mean Static Components consists of Lift force, Drag force and pitching moment. Self-excited forces due to structural motions are time varying and they are in vertical, horizontal and torsional directions. Since they occur due to unsteady aerodynamic effect they may be expressed in terms of convolution integrals of impulsive response functions [4].

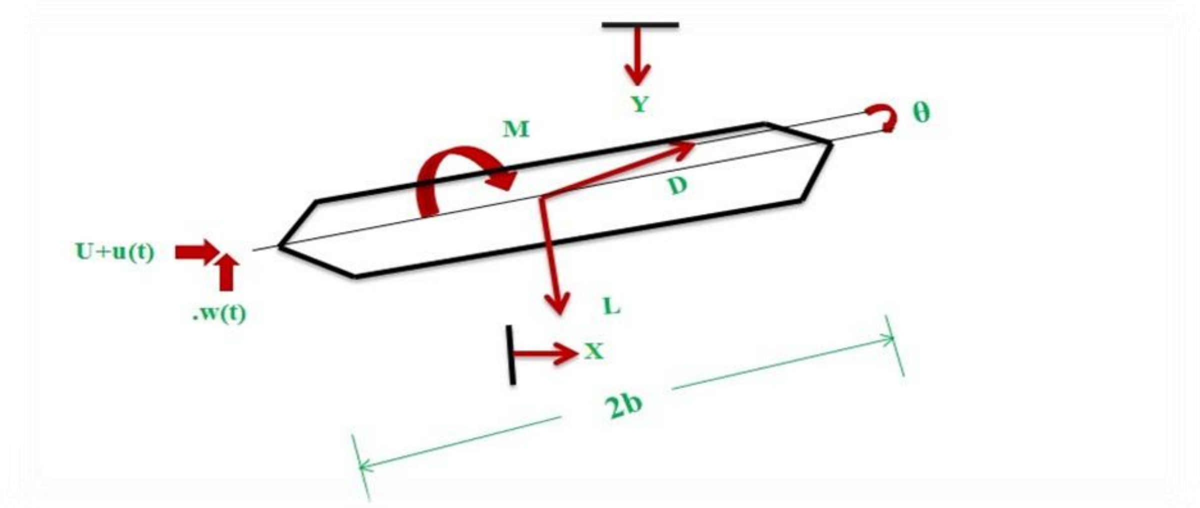

Figure 1: Aerodynamic forces on bridge deck

Let ,
U be the mean wind velocity
W = 2b IS the width of bridge deck
L_s is static lift
D_s is static drag
M_s is static moment
C_D is mean drag coefficient
C_L is mean lift coefficient
C_M is mean pitching moment coefficient
α_s is mean static angle of attack of wind in bridge section
ρ is density of air
Now static components can be expressed as,

$$L_s = \frac{1}{2}\rho\, U^2 W C_L \alpha_s$$

$$D_s = \frac{1}{2}\rho\, U^2 W C_D \alpha_s$$

$$M_s = \frac{1}{2}\rho\, U^2 W C_M \alpha_s$$

Self-excited forces, which are time varying components can be expressed in terms of convolution integrals of impulsive response function.
Considering,
X as horizontal displacement
Y as vertical displacement
θ as torsional displacement
I_x as aerodynamic impulsive response function
where x is

$$\begin{array}{llll} & L_x & D_x & M_x \\ & L_y & D_y & M_y \\ L_{se}(t) & L_\theta & D_\theta & M_\theta \end{array}$$

$$=\rho\, U^2 \int_{-\infty}^{t} [I_{LY}(t-\tau)Y(\tau) + I_{LX}(t-\tau)X(\tau) + I_{L\theta}(t-\tau)\theta(\tau)]\, d\tau \quad \text{.......EQ(1) [1]}$$

$$D_{se}(t) = \frac{1}{2}\rho\, U^2 \int_{-\infty}^{t} [I_{DY}(t-\tau)Y(\tau) + I_{DX}(t-\tau)X(\tau) + I_{D\theta}(t-\tau)\theta(\tau)]\, d\tau \quad \text{.......EQ(2) [1]}$$

$M_{se}(t) = \frac{1}{2}\rho U^2 \int_{-\infty}^{t} [I_{MY}(t-\tau)Y(\tau) + I_{MX}(t-\tau)X(\tau) + I_{M\theta}(t-\tau)\theta(\tau)]\, d\tau$ …….EQ(3) [1]

Aerodynamic forces in terms of respective coefficients are:

$L = C_L \frac{1}{2}\rho u^2 W\alpha_s$ …….EQ(4)

$D = C_D \frac{1}{2}\rho u^2 W\alpha_s$ …….EQ(5)

$M = C_M \frac{1}{2}\rho u^2 W^2\alpha_s$ …….EQ(6)

III. AERODYNAMIC FORCES ON AIRCRAFT

Aircraft is a streamline body in shape of an airfoil. A streamline body is defined as a body for which the major contribution to the drag force in the free-stream direction results directly from the viscous or skin friction action of the fluid on the body. For example a thin flat plate lying parallel and edge on to the oncoming flow is a streamline body since the flow remains attached to the surface and skin friction accounts for up to 90 per cent of the total drag [2][3].

Aerodynamic forces and moments on body are due to two basic sources:

Pressure distribution over the body surface

Shear stress distribution over the body surface

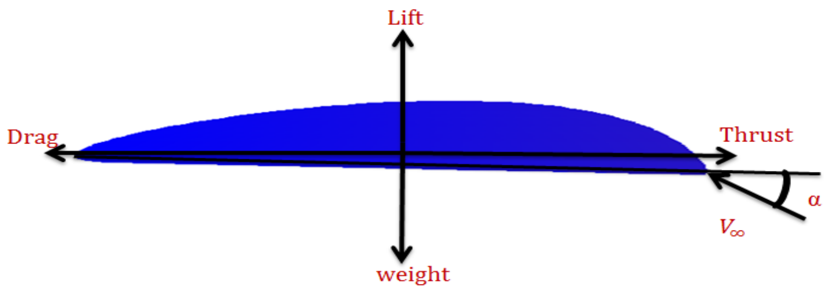

Figure 2: Forces on Aircraft

Pressure acts normal to the surface and shear stress acts tangential to the surface. Shear stress is due to “tugging action” on surface, which is caused by friction between the body and the air. The net effect of the pressure and shear stress distributions integrated over the complete body surface is a resultant aerodynamic force R and moment M on the body.

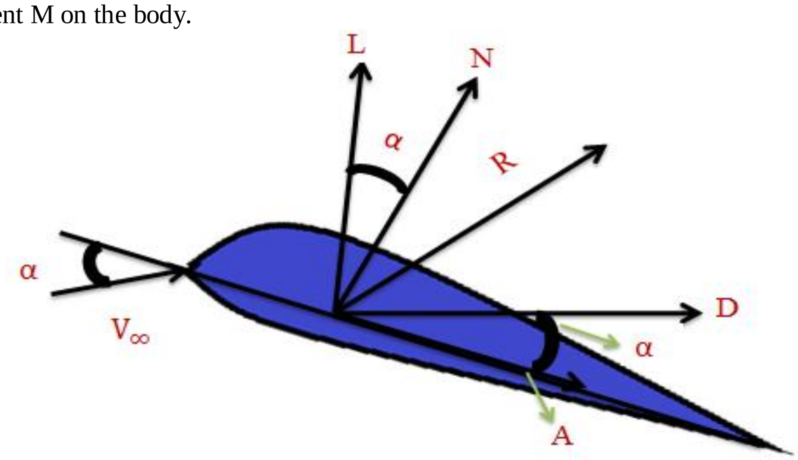

Figure 3: Aerodynamic forces on an Aircraft

Here we have,

V_∞ is relative wind velocity

A is axial force

N is normal force

R is resultant aerodynamic force

α is angle of attack of wind on aircraft

D is drag
L is lift
Geometrical relation from figure 3 implies
$L = N \cos \alpha - A \sin\alpha$
$D = N \sin\alpha - A \cos\alpha$
Wing lift, drag and pitching moment depend upon:

- Wing cross-section shape,
- Wing planform shape,and
- Dynamic pressure.

Lift, drag and pitching moment are defined in terms of

- wing surface plan form area S,
- dynamic pressure q
- wing mean aerodynamic chord c and
- aerodynamic coefficients

Dynamic pressure q,

$$q = \frac{1}{2}\rho v^2 \text{.......EQ(7)}$$

$$L = C_L \frac{1}{2}\rho v^2 S \text{.......EQ(8)}$$

$$D = C_D \frac{1}{2}\rho v^2 S \text{.......EQ(9)}$$

$$M = C_M \frac{1}{2}\rho v^2 SC \text{.......EQ(10)}$$

IV. COMPARISON OF AERODYNAMIC FORCES

Comparing equations 4, 5,6 and 8, 9, 10 it is clear that the behavior of bridge deck and aircraft under aerodynamic forces have similarities. Lift, Drag and moment produced in both cases are directly proportional to the density of air, their respective aerodynamic coefficients and mean wind velocity. In case of bridge deck these forces and moments produced also depends upon width of deck and the angle of attack of wind on deck. On the other hand in case of aircraft the aerodynamic forces and moments in addition to the above mentioned factors, depends upon wing surface plan form area and wing mean aerodynamic chord. Due to the boundary layer separation in stream lined body the airfoil shaped aircraft will experience minimum drag and hence the effect of aerodynamic forces and moments experienced by the aircraft will be much lesser while compared to that of bluff body (bridge deck).

V. CONCLUSION

The aerodynamic forces acting on an aircraft and a bridge deck were analyzed and compared. It was found that the effect of force acting on aircraft is much less compared to that of a bridge deck due to the streamline body shape of aircraft. Thus it can be stated that if we implement a streamlined configuration to bridge deck, the effect of aerodynamic forces and moments can be minimized.

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