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EXPERIMENTAL and ANALYTICAL ANALYSIS of FLOW PAST D-SHAPED CYLINDER

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Abstract- The study of flow past the bluff body is very important in aerodynamics. The D-Shaped cylinder is one of the bluff bodies which serve some vital operational function in aerodynamic. So it is necessary to study the flow past the D-Shaped cylinder. In this paper the flow past D-Shaped cylinder of dimensions B=90mm, H=80mm, and L=200mm is studied experimentally and analytically. The analytical results are validated with experimental results. The flow parameter drag co-efficient is calculated for different Reynolds number using Drag co-efficient relation and results of drag co-efficient are validated with experimental results. Based on the experimental and analytical results, the drag co-efficient of circular cylinder and D-Shaped cylinder are compared. The Strouhal number is calculated using Strouhal number co-relation for different Reynolds number and results of Strouhal number are validated with previous results from literature. The experimentation is carried in small open type wind tunnel. The Reynolds number regime currently studied corresponds to low Reynolds number. The present research involves the calculation of drag co-efficient for D-Shaped cylinder. This experiment is based on existing wind tunnel that is already developed. The focus of the present research is on finding the drag co-efficient both by experimentally and analytically.

Keywords—D-Shaped cylinder, Drag Co-efficient, Lift Co-efficient, Pressure Distribution, Strouhal Number, Flow Visualization.

I. INTRODUCTION

When an object moves through a fluid or object is at rest in flowing fluid, there is force acting on the body by the fluid. The force acts in the opposite direction of the relative velocity between the fluid and the body. This force is called as drag force or drag. The force depends on the shape and size of the body, as well as the density, viscosity, and velocity of the fluid. Aerodynamic forces exerted by airflow come from only 2 sources.

Pressure (P):- It acts on surface, normal to surface (Figure 1a)
Shear stress (τw):- It acts on surface, tangentially to surface (Figure 1 b)

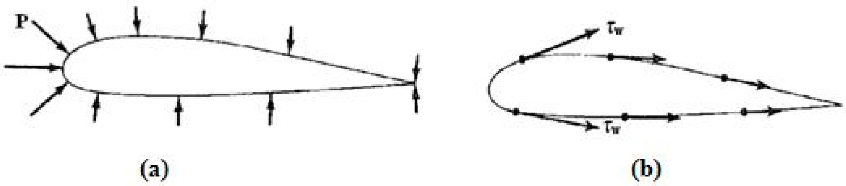

Fig. 1: (a) Pressure force exerted on surface, (b) Shear stress on surface.

The drag coefficient is a dimensionless quantity that is used to quantify the drag or resistance of an object in a fluid environment. The drag co-efficient depends on Reynolds Number which is dimensionless number. The drag coefficient (CD) is a non-dimensional parameter, but it takes into account every aerodynamic configuration aspect of the aircraft. This coefficient has two main parts: The first part is referred to as lift-related drag coefficient or induced drag co-efficient (CDi) and the second part is called zero-lift drag coefficient (CDo) [1].

Drag is generally divided into following types:

i. Skin friction drag: - It is the drag caused by moving a solid object through a fluid medium (in the case of aerodynamics, more specifically, a gaseous medium). Parasitic drag is made up of many components, the most prominent being form drag. Skin friction and interference drag are also major components of parasitic drag.
ii. Lift-induced drag: - It is a drag force that occurs whenever a moving object redirects the airflow coming at it.
iii. Wave drag: - It is a component of the drag on aircraft blade tips and projectiles moving at transonic and supersonic speeds, caused by the formation of shock waves around the body.

A wind tunnel is a research tool developed to study the effects of air moving over or around bluff bodies. Mostly it is used in automotive industry, laboratory research and construction. An advantage of using wind-tunnels is that experiments there can be performed under well controlled flow circumstances compared to experiments in the open environment. In wind tunnel, there is Two Component Digital Force Indicator which have two channel, $3^{1/2}$ digit DPM, capable of measuring lift force and drag force up to 20kg.

A. Objective of the research project:

1. The objective of this project is study of the flow over a D-Shaped cylinder by using wind tunnel in order to study the drag coefficient at different Reynolds number.
2. To make comparison between experimental and analytical results of drag coefficient.

B. Scope of the research project:

1. Calculation of drag coefficient of D-Shaped cylinder.
2. Preparation of D-Shaped Cylinder.

II. LITERATURE SURVEY

A. Circular Cylinder and Sphere cutting on the front surface

Aiba, S. And Watanabe [2] and [3] reported that the drag force decreased by 50% and 25% for a circular cylinder and a sphere, respectively, by cutting out at circumferential angle Θ_f=53° on the front surface of the bluff bodies. However, the pressure distribution, Strouhal number, and flow patterns are not clear. Based on the above work above the authors Tamotsu IGARASHI*** and Yoshihiko SHIBA*** [4] investigated the drag reduction of D-Shape and I-Shape cylinders Figure2. They found that the drag co-efficient of bluff bodies is small for a large Strouhal number S and small negative pressure co-efficient $-C_{pb}$ [4].

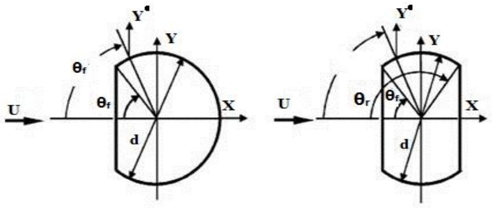

Fig. 2: Configuration of D-Shape and I-Shape test models and symbols [4].

B. Estimation of a D-Shaped Cylinder Wake Using Body-Mounted Sensors

Oksana Stalnov, et al, [11] investigated the effectiveness of a small array of body-mounted sensors, for estimation and eventually feedback flow control of a D-Shaped cylinder wake. The research was aimed at suppressing unsteady loads, a low dimensional Proper Orthogonal Decomposition procedure was applied, and linear stochastic estimator (LSE) was employed to map the surface mounted hot film pressure signals. The results show that the estimates of the first two modes of the wake flow field are accurate to within 35% RMS error, with respect to the measured POD time coefficients RMS. Figure 3 shows the Strouhal numbers correlation for circular cylinder and D-Shaped cylinder.

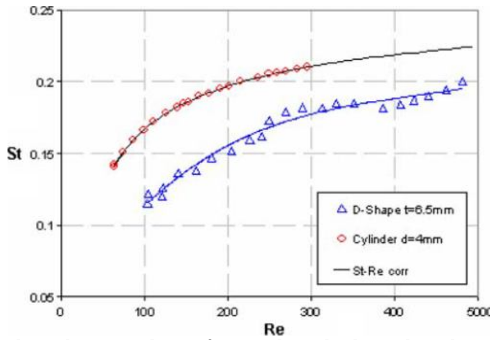

Fig. 3: Strouhal numbers correlation for circular cylinder and D-Shaped cylinder [11].

C. A Fundamental study of the flow past a circular cylinder using Abaqus/CFD

The frequency (f) of the vortices can be converted to a dimensionless number called the Strouhal number (St) using the Strouhal number relation. Figure 4 shows curves for various Strouhal numbers vs. those for various Reynolds numbers obtained from the analysis, as well as, those measured in the earlier.

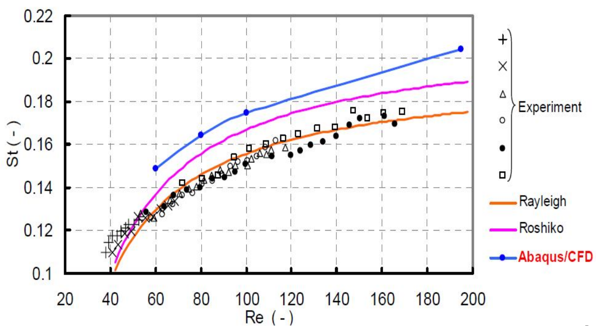

Fig. 4: Variation in the Strouhal number vs. various Reynolds numbers [22].

III. ANALYTICAL FORMULATION

A. Drag Co-efficient

In the drag co-efficient calculation, it is necessary to find out drag force F, which can be found from experiment conducted in wind tunnel. In wind tunnel there are two channels, capable of measuring drag force upto 20kg
The drag co-efficient is calculated from drag force using following formula:

$$C_d = \frac{2 \times F_d}{\rho \times A \times V^2} \quad (1)$$

Empirical formula used to calculate the drag co-efficient is:

$$\boxed{Cd = \frac{24}{\text{Re}} + \frac{2.6 \times (\text{Re}/5.0)}{1 + (\text{Re}/5.0)^{1.52}} + \frac{0.411 \times (\text{Re}/263000)^{-7.94}}{1 + (\text{Re}/263000)^{-8.00}} + \frac{\text{Re}^{0.80}}{461000}} \quad (2)$$

B. Strouhal Number

When considering a long cylinder, the frequency of vortex shedding is given by

$$St = \frac{f \times D}{V} \quad (3)$$

IV. EXPERIMENTAL METHOD

In this case the experimentation is carried out by using small open type wind tunnel.

A. Types of Tests

1 Force Test: -

The motion of air around the body produces the pressure and velocity variations, which produces the wind forces, and moments, that can be experimentally detected and measured in wind tunnel. The forces acting on the model are:-
Lift: - The force component acting upwards, perpendicular to the direction of the flight. The aerodynamic lift is produced primarily by the pressure forces acting on the vehicle surface.

$$F_l = (C_l \times A \times \rho \times V^2)/2 \quad (4)$$

Drag: - The net aerodynamic force acting in the same direction as the undisturbed free-stream velocity.

$$F_d = (C_d \times A \times \rho \times V^2)/2 \quad (5)$$

Where, F_d is Drag Force (N)
C_d is Co-efficient of Lift
ρ is Density of air (Kg/m^3)
F_l is Lift Force (N)
C_l is Co-efficient of Lift
A is Total surface area in contact with the fluid (m^2).

The strain gauge balance is capable of detecting the two components of aerodynamic force - lift and drag. These forces produce strain in various structures of aerodynamic models. Strain is the fundamental quantity sensed by strain gauge.

2 Pressure Test

In this test, insert tiny tubes into the model surface and connect them to a pressure measuring device. Here the pressure measuring device used is S-10 Pressure transmitter, it measures pressure in terms of water column. Fabrication of D-Shaped cylinder with S-10 in wind tunnel is shown in Figure 2.

Fig. 5: Fabrication of Model in wind tunnel with S-10 transmitter.

The pressure is calculated by using following empirical formula,

$$P = \rho \times g \times h \quad (6)$$

Where, P is Pressure in Pascal
ρ is density of air kg/m^3
h is height of water column in mm.

3 Flow Visualization

Allow the streamlines of air flow to look at the body's surface. It is the study of methods to display dynamic behaviour in liquids and gases. The laboratory flow visualization has become more and more exact, with careful control of the particulate size and distribution. There are several flow visualization techniques.

B. Non-Dimensional Numbers

1. Reynolds Number: -

The vortex shedding from a bluff body is a function of the Reynolds Number (Re). The flow characteristics of wind passing across bluff body are depend on magnitude of inertial to viscous within the flow (the parameter are called Reynolds Number). The Reynolds Number is defined as:

$$\mathrm{Re} = \frac{\rho \times V \times L}{\mu} \quad \text{OR} \quad \mathrm{Re} = \frac{V \times D}{\nu} \tag{7}$$

Where, V is the wind velocity,
D, L is the lateral dimension of the body,
υ is kinematics viscosity of air,
μ is dynamic viscosity of air.

Different *Re* will affect the formation of vortex shedding over bluff bodies.

2. Strouhal Number: -

In dimensional analysis, the Strouhal number (St) is a dimensionless number describing oscillating flow mechanisms. The parameter is named after Vincenc Strouhal, a Czech physicist who experimented with wires experiencing vortex shedding and singing in the win. When considering a long cylinder, the frequency of vortex shedding is given by

$$St = \frac{f \times D}{V} \tag{8}$$

Where, f is Vortex shedding frequency
St is Strouhal Number
V is Wind Velocity

V. D-SHAPED CYLINDER

A. Problem Definition: - Experimental and analytical analysis of flow past D-Shaped Cylinder for different Reynolds number is carried out.

B. Cylinder: - D-Shaped cylinder is half cut of circular cylinder and rectangular Cylinder as shown in figure 6. The small tiny tubes are inserted inside the cylinder to measure the pressure distribution on surface. The tubes are then connected to pressure transmitter or manometer which gives displacement in terms of mm of water column. Then pressure is calculated by using the equation 3.

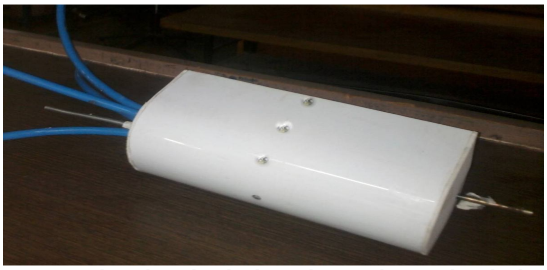

Fig. 6: Final D-Shaped Cylinder with tiny tubes inside cylinder.

VI. RESULTSand DISCUSSION

A. Validation of Drag Co-efficient.

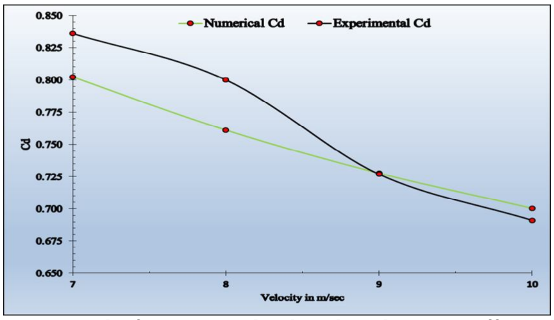

Fig. 7: Graph of Experimental and Analytical Drag Co-efficient.

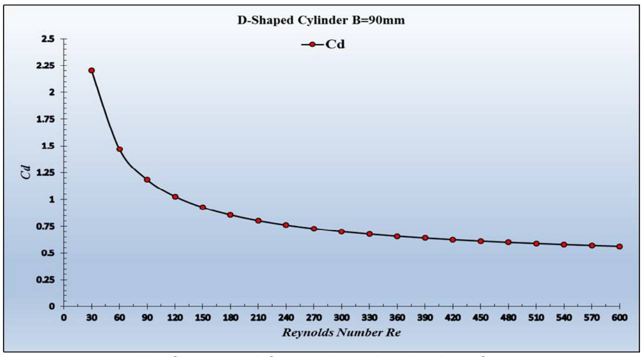

Fig. 8 Graph of Re vs Cd for D-Shaped Cylinder of B=90mm

From figure 7 of comparison between experimental and analytical values of drag co-efficient it is observed that experimental values are nearly same with analytical values. Based on this, calculation of drag co-efficient is made analytically for various Reynolds number
From figure 8, it is clear that drag co-efficient is reduced for D-Shaped Cylinder with increase in Reynolds number.

B. Validation of Strouhal Number.
The Strouhal number for D-Shaped cylinder is calculated by using Strouhal number co-relation (8). Figure 8 gives the co-relation of Strouhal number.

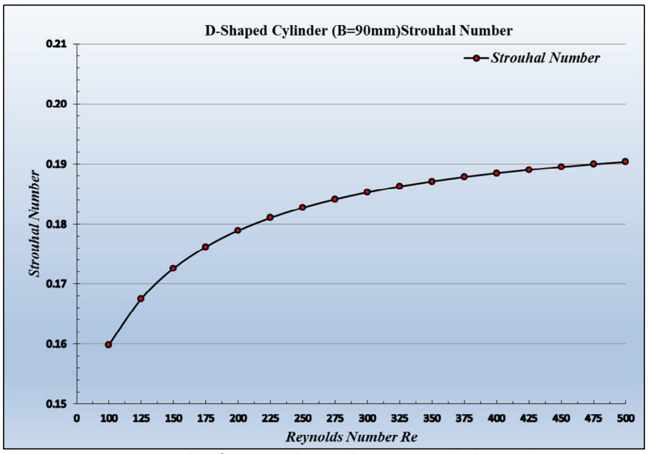

Fig. 9: Graph of Reynolds number vs Strouhal Number.

From figure 3, 4 and 9 it is clear that the Strouhal number changes with Reynolds number for D-Shaped Cylinder as obtained in previous results for D-Shaped cylinder and also for circular cylinder.

C. Flow patterns.

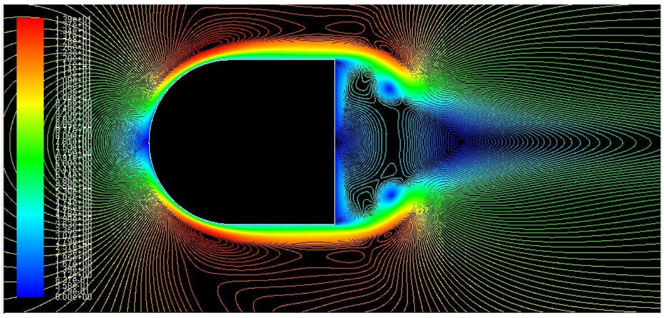

Fig. 10: Contours of velocity in FLUENT.

From figure 10 it is observed that the flow patterns are symmetric about the horizontal axis. Vortices are developed behind D-Shaped cylinder.

VII. CONCLUSIONS

The Reynolds number regime currently studied corresponds to low Reynolds number. The experimentation is carried in small open type wind tunnel. The present research involves the calculation of drag co-efficient for D-Shaped cylinder.
The results of drag co-efficient show consistent agreement between analytical and experimental results. By using relation of Drag co-efficient, it is observed that Drag co-efficient is a function of Reynolds number. Drag coefficient decreases with an increase in Reynolds number for D-Shaped Cylinder.

The results of Strouhal Number show consistent agreement between previous results from literature and analytical results. By using relation of Strouhal number, it is observed that the Strouhal number is a function of Reynolds number. From the flow patterns obtained it is clear that the vortices are symmetric about horizontal axis of cylinder at low Reynolds number.

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