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EXPERIMENTAL INVESTIGATION OF DRAG FORCE REDUCTION MECHANISM FOR FLOW AROUND A CIRCULAR CYLINDER

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Abstract

Drag is generated by the interaction and contact of a solid body with a fluid. Drag implies a great role on fluid mechanics and aerodynamics while it is conducted for any kind of moving object of different shape. A significant number of experiments were executed for reduction of drag force because drag causes high power consumption and also structural failure of the object. Reduction of drag force of circular cylinder by attaching circular rings is described in this experiment. For accomplishing this experiment models are tested in 36x36x100 cm subsonic wind tunnel. Drag measurements are carried out by using an external balance. Drag force over circular cylinders of different diameter without any rings are tested first. Then circular rings attached circular cylinders are tested. It is observed that there is reduction of drag even though the projected area increased because rings causes more attached flow than the plain cylinder. The optimum value of drag reduction is found when ring is 1.3d and aspect ratio of cylinder is approximately 12. The experimental results show drag reduced by this optimum configuration is 25%.

Keywords *Drug reduction, Circular ring and Cylinder.*

1. Introduction

Drag is a mechanical force. It is generated by the interaction and contact of a solid body with a fluid (liquid or gas). It is not generated by a force field, in the sense of a gravitational field or an electromagnetic field, where one object can affect another object without being in physical contact. For drag to be generated, the solid body must be in contact with the fluid. If there is no fluid, there is no drag. Drag is generated by the difference in velocity between the solid object and the fluid. There must be motion between the object and the fluid. If there is no motion, there is no drag. It makes no difference whether the object moves through a static fluid or whether the fluid moves past a static solid object [1]. There is an additional drag component caused by the generation of lift. Aerodynamicists have named this component the induced drag.The presence of the fluid viscosity slows down the fluid particles very close to the solid surface and forms a thin slow-moving fluid layer called a boundary layer. The flow velocity is zero at the surface to satisfy the no-slip boundary condition. Inside the boundary layer, flow momentum is quite low since it experiences a strong viscous flow resistance.
Therefore, the boundary layer flow is sensitive to the external pressure gradient (as the form of a pressure force acting upon fluid particles). If the pressure decreases in the direction of the flow, the pressure gradient is said to be favorable. In this case, the pressure force can assist the fluid movement and there is no flow retardation. However, if the pressure is increasing in the direction of the flow, an adverse pressure gradient condition as so it is called exist. In addition to the presence of a strong viscous force, the fluid particles now have to move against the increasing pressure force. Therefore, the fluid particles could be stopped or reversed, causing the neighboring particles to move away from the surface. This phenomenon is called the boundary layer separation [2]. The drag on a circular cylinder placed in slow stream of viscous liquid midway between two parallel planes were first obtained in numerical

form for a special case by Bairstow, Cave and Lang as early as 1921 on the basis of Stokes' equations of motion. In 1923, Harrison obtained an analytical expression for the drag experienced by the cylinder using a kind of image method. But, no agreement can be found between these two results. Several experiment were done different times to reduce Drag force for increasing efficiency in the field of aerodynamics and decreasing the friction [2]. The origin of the boundary-layer theory can be traced to an investigation conducted by Prandtl (1904) concerning the motion of a fluid with very small viscosity. The situation in the field of fluid mechanics before the introduction of Prandtl's concept is examined, taking into account the difficulties presented by the nonlinear terms in the Navier-Stokes equations. Attention is given to details regarding Prandtl's investigation, the prototype of the boundary-layer concept, developments related to the slow acceptance of the new concept, steady two-dimensional laminar boundary layers, unsteady two-dimensional laminar boundary layers, three-dimensional laminar boundary layers, instability and transition to turbulence, boundary-free turbulent shear flows, wall-bounded turbulent shear flows, boundary layers in compressible fluids, higher approximations, and flow with separation [4]. The purpose of this research is to reduce the drag force of a plain circular cylinder by attaching the rings on the surface of the cylinder.

2. Experimental Set-up and Procedure

Wind tunnel tests are carried out by using a closed type test section of low scale large noise wind tunnel apparatus in Fluid Mechanics Laboratory, Department of Mechanical Engineering, Khulna University of Engineering & Technology. The size of the test section is 36 cm high, 36 cm wide and 100 cm long. Seven models are constructed using diameters of cylinders (d) are 21.6 mm, 26.6 mm, 33.3 mm, 39.15 mm & 48.7 mm respectively. And the ring diameters (D) are 26.767 mm, 28 mm, 29 mm, 32.72 mm, 38.367 mm, 44.63 mm & 53.55 mm respectively. Three models are constructed with the same diameter of cylinder and it is 21.6 mm. A sample model schematic is shown in Fig. 1. The models of Cylinder are mounted on the test section with the help of a pivot rod. Drag measurement is carried out using balance. By using drill machine holes are created in every specimen exactly at the center because a holder is made to hold the specimen at the trace section on the balance arm of subsonic wind tunnel. As the holes are created exactly at the center, so the models are symmetrical and no lift force is found. Numbers of rings are three for each specimen. Photograph of the wind-tunnel test section with specimen is shown in Fig. 2.

For this experiment Reynolds number varies on the basis of free stream velocity of air and calculated using the following formula-

$$\text{Reynolds number}, \ \boldsymbol{Re_d} = \frac{\rho u l}{\mu} \qquad (1)$$

Where,

$\boldsymbol{\rho_\infty}$ = Free stream density in kg/m^3 (1.225 kg/m^3)

U =Free stream velocity

$\boldsymbol{l}$ =Model length

$\boldsymbol{\mu}$ =Dynamic Viscosity (0.0000178 $kg/m.s$)

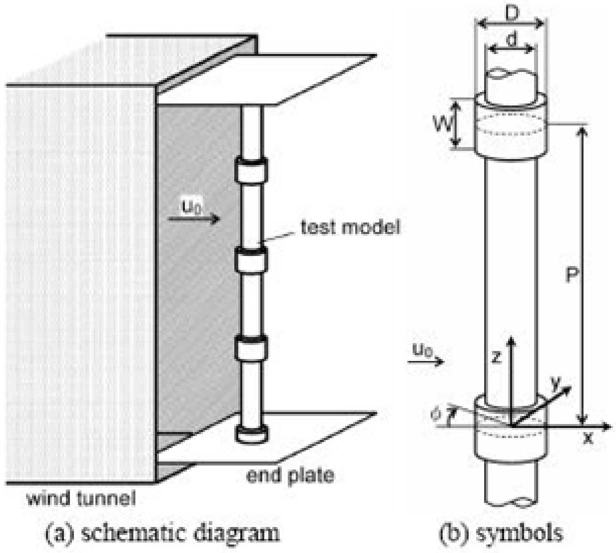

Fig.1. Cylinder with ring

The drag coefficient C_d is defined as:

$$C_d = \frac{F_d}{\frac{1}{2}\rho v^2 A}, \qquad (2)$$

Where,

F_d = drag force, which is by definition the force component in the direction of the flow velocity
ρ = mass density of the fluid
v = speed of the object relative to the fluid, and
A= projected area = $0.5[\pi dL + n\pi\,(D-d)\,W]$ m^2

Fig. 2. Photograph of wind tunnel test section

3. Results and Discussion

The experimental results of drag coefficients (*Cd*) for different ring to cylinder diameter ratio (D/d) at various Re_d is shown in Fig. 3 to 10.It has been observed that the drag coefficient of the cylinder decreases as the Reynolds number increases. For specimen-1(D/d=1.34) Fig. 3 shows that the drag is reduce when the ring is fitted on the cylinder. And maximum reduction obtained at Re_d = 4460 which is about 17%. Fig. 4 and 5 indicates reduction of coefficient of drag with respect to Reynolds number. And maximum reduction of C_d obtained at Re_d = 4460 for both. For the specimen-2 (D/d=1.3) maximum reduction is 25% and for specimen-3(D/d=1.24) maximum reduction is 15%. Fig. 6 and 7indicates reduction of drag coefficient for specimen-4 (D/d=1.23) and 5(D/d=1.15) with respect to Reynolds number. And maximum reduction of C_d obtained at Re_d = 2746 and 6875. For the specimen-4 maximum reduction is 14.3% and for specimen-5 maximum reduction is 11.4%. Fig. 8 and 9 indicates reduction of coefficient of drag with respect to Reynolds number for specimen-6 (D/d=1.14) and 7 (D/d=1.1) respectively. And maximum reduction of C_d obtained at Re_d = 5388 and 5027. For the specimen-6 maximum reductions is 15% and for specimen-7 maximum reduction is 7.1%. Fig. 10 indicates the percentage reduction of C_d for every specimen due to rings attached along the cylinder. It is observed for velocity 3 m/s almost all specimen possesses best result. For the ring configuration *D/d* =1.3 percentage reduction is found maximum. So it is suggested for reduction of drag of cylinder by attaching cylindrical rings optimum ring configuration is *D/d* =1.3. The addition of rings reduced drag coefficient because it helps in formation Karman vortex at the tip which has the properties of suction while air flows through the rings and cylinder. More the percentage increases of the ring diameter stronger the vortex, as a result more negative pressure. In return flow being more attached than the flow through plain circular cylinder. As a result drag decreases due to the addition of rings along the span of cylinder.

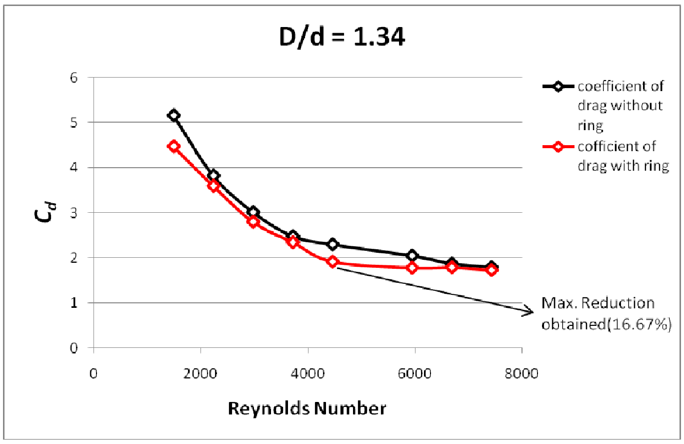

Fig. 3. C_d Vs Re_d of specimen-1 (D/d=1.34)

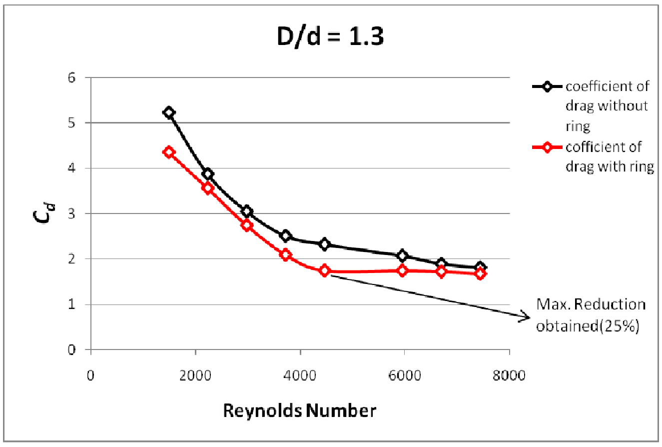

Fig. 4. C_d Vs Re_d of specimen-2 (D/d=1.3)

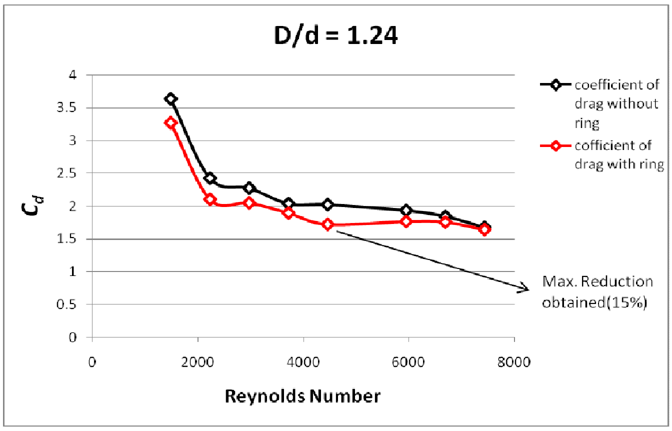

Fig. 5. C_d Vs Re_d of specimen-3 (D/d=1.24)

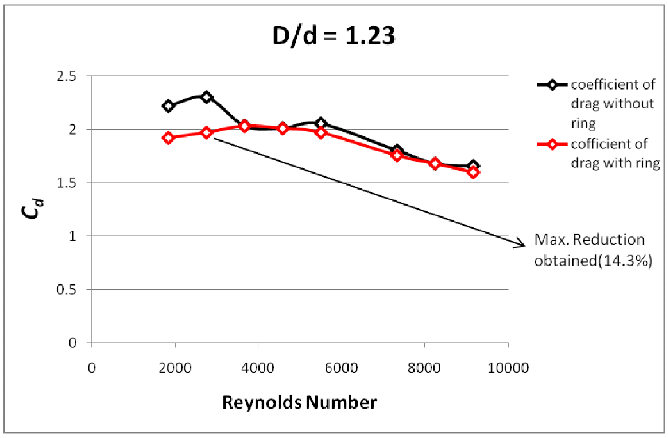

Fig. 6. C_d Vs Re_d of specimen-4 (D/d=1.23)

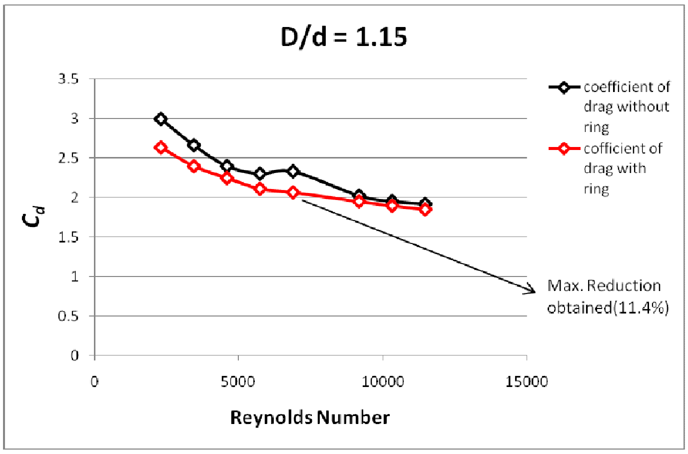

Fig.7. C_d Vs Re_d of specimen-5 (D/d=1.15)

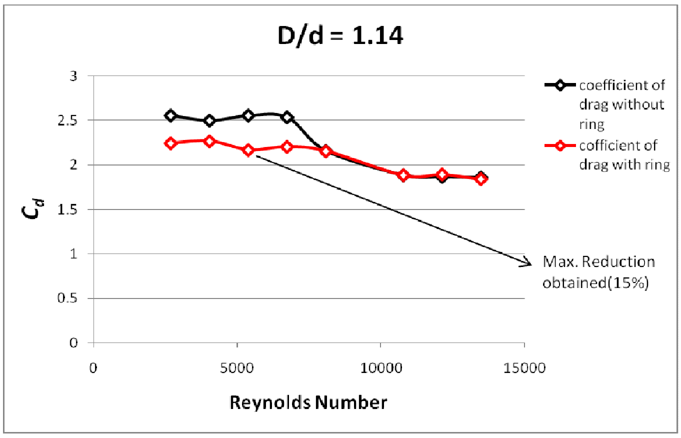

Fig. 8. C_d Vs Re_d of specimen-6 (D/d=1.14)

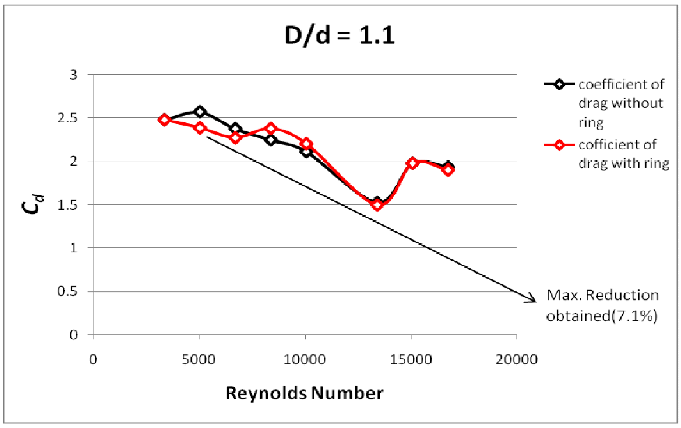

Fig. 9. C_d Vs Re_d of specimen-7 (D/d=1.1)

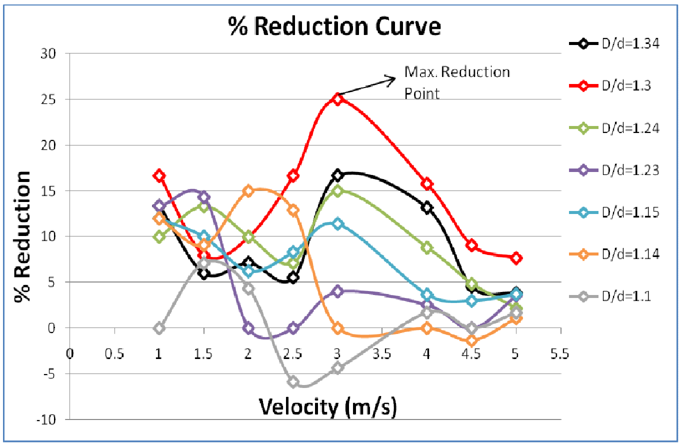

Fig. 10. Percentage of reduction of C_d for using rings along cylinder

4. Conclusions

Accomplishing the objectives of this research, series of experiment were done and it can be concluded that the drag is somewhat related to the materials interacting (as regular solid on solid friction is), a great portion related to shape, and slightly related to by temperature. Surface area of the substances directly correlates to the amount of drag experienced. The optimum ring configuration for drag reduction was found to be D/d =1.3, W/d =1.18 at Re_d =4460, where D is the ring diameter and W is the spanwise width of the ring. This configuration reduced the drag force by 25%. This paper is all about for reducing drag and the reason behind it or the characteristics of the vortex formed are not investigated. Flow characteristics and boundary layer phenomenon or how the flow attached due to attachment of ring can be studied further.

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