DRAG REDUCTION OVER A CIRCULAR CYLINDER

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ABSTRACT

The flow past a circular cylinder has been extensively studied in the past so as to understand the complex flow field acting around the cylinder. The presence of boundary layer separation makes the flow highly unsteady leads to a phenomena of vortex induced vibration which can be highly damaging for cylinder.

The major contribution drag on cylinder is due to the pressure drag, it is also observed that the interaction of vortices leads to a higher pressure drag. Therefore the present work aims to restrict the interaction of vortices. The restriction has been bought using a splitter plate fixed at angle Θ=180°. Due to the presence of splitter plate, the two vortices in the upper and lower half of the cylinder become blind and do not interact each other. Mainly the present case have been studied with the Effect of length between splitter plate and cylinder.

The measurement of surface pressure distribution carried out in the subsonic wind tunnel at a Reynolds's number 35000 and some specified cases of splitter plate with circular cylinder. Results of the present computation were validated present experiments. The pressure distribution along the surface the cylinder, effect splitter plate, strouhal number and time variation of lift and drag were investigated.

Keywords: Circular cylinder, Pressure drag, Splitter plate, Cfd analysis and Experiment.


1. INTRODUCTION

Flow past a circular cylinder is a classic problem in fluid mechanics. Most of the man made things structures are bluff bodies. The studies about circular cylinder generally come under “bluff body aerodynamics” which mainly related to the study of separated flows. Some of the
examples of cylindrical shapes are bridges, heat exchangers tube bundles, power transmissions, roof-top chimneys, aircraft struts, marine structures and etc.

A circular cylinder usually experiences boundary layer separation and very strong flow oscillations in the wake region behind the body. In certain Reynolds number range, a periodic flow motion will develop in the wake as a result of boundary layer vortices being shed alternatively from either side of the cylinder. This regular pattern of vortices in the wake is called as “vortex sheet or von Karman Vortex Street”. It creates an oscillating flow at a discrete frequency that is correlated to the Reynolds number of the flow. The periodic nature of the vortex shedding phenomenon can sometimes lead to unwanted structural vibrations, especially when the shedding frequency matches one of the resonant frequencies of the structure these vibrations are called as “vortex induced vibrations”. As a result due to the periodic nature of vortex shedding the cylinder experiences lateral forces.

1.1. Flow separation:
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 as 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. If the pressure decreases in the direction of the flow, the pressure gradient is said to be favorable. However, if the pressure is increasing in the direction of the flow is said to be adverse pressure gradient. 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.

1.2 Flow over a circular cylinder:
For very small values of $Re$ no separation occurs. The separation first appears when $Re$ becomes 5. For the range of the Reynolds number $5 < Re < 40$, a fixed pair of vortices forms in the wake of the cylinder. The length of this vortex formation increases with $Re$. When the Reynolds number is further increased, the wake becomes unstable, which would eventually give birth to the phenomenon called vortex shedding in which vortices are shed alternately at either side of the cylinder at a certain frequency. Consequently the wake has an appearance of the vortex street. For the range of the Reynolds number $40 < Re < 200$ the vortex street is laminar. The shedding is essentially two-dimensional, i.e., it does not vary in the span wise direction.

With a further increase in $Re$, however, transition to turbulence occurs in the wake region. The region of transition to turbulence moves towards the cylinder, as $Re$ is increased in the range $200 < Re < 300$. Bloor reports that at $Re = 400$, the vortices, once formed, are turbulent. Observed in the range $40 < Re < 200$ becomes distinctly three-dimensional in this range the vortices are shed in cells in the span wise direction. It may be noted that this feature of vortex shedding prevails for all the other Reynolds number regimes $Re > 300$

For $Re > 300$, the wake is completely turbulent. The boundary layer over the cylinder surface remains laminar, however, for increasing $Re$ over a very wide range of $Re$, namely $300 < Re <3*10^5$. This regime is known as the subcritical flow regime

With a further increase in $Re$, transition to turbulence occurs in the boundary layer itself. The transition first takes place at the point where the boundary layer separates, and then the region of transition to turbulence moves upstream over the cylinder surface towards the stagnation point as $Re$ is increased
In the narrow $R_e$ band $3 \times 10^5 < R_e < 3.5 \times 10^5$ the boundary layer becomes turbulent at the separation point, but this occurs only at one side of the cylinder. So the boundary layer separation is turbulent at one side of the cylinder. So the boundary layer separation is turbulent at one side of the cylinder and laminar at the other side. This flow regime is called the critical flow regime. The flow regime the flow asymmetry cause a non – zero mean lift on the cylinder.

The next Reynolds number regime is the so-called supercritical flow regime where $3.5 \times 10^5 < R_e < 1.5 \times 10^6$. In the regime the boundary layer separation is turbulent on the both sides of the cylinder. However transition to turbulence in the boundary layer has not been completed yet the region of transition to turbulence is located somewhere between the stagnation point and the separation point.

The boundary layer on one side becomes fully turbulent when $R_e$ reaches the value of about $1.5 \times 10^6$. So in this flow regime the boundary layer is completely turbulent on one side of the cylinder and partly laminar and partly turbulent on the other side. This type of flow regime called the upper-transition flow regime prevails over the range of $1.5 \times 10^6 < R_e < 4.5 \times 10^6$.

1.3 Drag reduction on circular cylinder:
The flow over circular cylinder had been subjected to intensive research for a long time. A circular cylinder produces large drag due to pressure difference between upstream and downstream direction of the flow. The difference in pressure is caused by the periodic separation of flow over surface of the cylinder. Periodic separation induces fluctuations in the flow and makes the cylinder vibrate. To reduce the amount of drag or the drag coefficient of a cylinder various active and passive flow control methods have been employed and tested successfully. One of the passive control used for drag reduction is splitter plate.

1.4 Splitter plate:
The issue of controlling the effects of fluid flow on bluff bodies (specifically the drag force, and vortex shedding) led Roshko (1954, 1955) to study the effects of placing an impediment in the wake of a two-dimensional or infinite bluff body, specifically a “splitter Plate”. Since then, the application and study of the splitter plate as a flow control device for two-dimensional bluff bodies has been widespread.

The splitter plate is an example of a passive flow control technique. These techniques may be used to suppress or weaken vortex shedding, typically by attaching additional devices in the flow field (like Roshko’s splitter plate), or by trying to modify the shape of the bluff body altogether. Other examples of passive control techniques include control cylinders and small rods.

A thin splitter plate placed near to the rear of a bluff body cylinder can directly alter the cylinder wake. For the detached plate case, it is possible for the free shear layers to roll up and interact with each other inside the gap and consequently introduce new modes of flow structure, which can result in abrupt jumps in pressure drag and vortex shedding frequency. However, when the splitter plate is attached normal to the rear surface of the bluff body splitter plate the interaction between the two free shear layers is delayed until the end of the plate.

2. METHODOLOGY

2.1 Computation methodology:
Computational Fluid Dynamics (CFD) is playing an ever increasing role in missile aerodynamic design. The design of modern tactical supersonic missiles is heavily dependent
upon the prediction of the vortical structures which appear along the leeward side of missiles bodies and inside the inlet. Accurate prediction of the flow field, and more precisely the loss of total pressure in the core of the vortices, is all the more needed that they generally strongly interact with wings or control surfaces located downstream. CFD has become an important tool in missile aerodynamic research.

- Gambit is the program used to generate the grid or mesh for the CFD solver.
- Fluent is the CFD solver which can handle both structured grids, i.e. rectangular grids with clearly defined node indices, and unstructured grids. Unstructured grids are generally of triangular nature, but can also be rectangular. In 3-D problems, unstructured grids can consist of tetrahedral (pyramid shape), rectangular boxes, prisms, etc.

2.2 Computational plan of work:
The computations were done on a single cylinder with various viscous models like laminar, spalart-allmaras turbulence model, k epsilon turbulence model and k-omega turbulent models. In order to reduce the drag coefficient we implemented a passive control technique i.e. splitter plate is used. The splitter plate effects are studied at different positions and lengths on the plate. Effect of space between cylinder and splitter plate. One more case is the effect of thickness of plate.

2.3 Experiment methodology:
Experiments are required to validate the results from computation. In experiments pressure measurement on a single cylinder and cylinder with splitter plate at Reynolds number 35000 were done.

L= Splitter plate length, D= Diameter of the cylinder, Z=spacing between cylinder and plate

<table>
<thead>
<tr>
<th>Table 1 Plan of work</th>
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<table>
<thead>
<tr>
<th>Computations conducted</th>
<th>Experiments conducted</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Single cylinder</td>
<td>1) Single cylinder</td>
</tr>
<tr>
<td>2) Effect of space between cylinder and splitter plate Z/D=0.5, 1, 1.5 and 2 at L/D=0.5, 1 and 2.</td>
<td>2) Effect of splitter plate length of Z/D=0.5, 1 and 2, L/D=1.</td>
</tr>
</tbody>
</table>

Figure 1 Grid generation of circular cylinder
2.4. Experimental models:

![Fabricated model of circular cylinder.](image1)

**Figure 2** Fabricated model of circular cylinder.

![Fabricated model of circular cylinder with splitter plate.](image2)

**Figure 3** Fabricated model of circular cylinder with splitter plate

3. RESULTS:

3.1 Computation results:

Initially computations were performed over a circular cylinder of diameter 30mm at Reynolds’s number equal to 35000 by using software’s ‘GAMBIT’ and ‘FLUENT’. Then the results are compared with the experiments performed on circular cylinder body of same diameter 30mm and at same Reynolds’s number 35000. In order to observe the effects of wake on the drag a splitter plate was used so that the separated vortex will not be able to interact with each other. The splitter plate can also be used as a passive control technique. All the experiments and computations were carried out at subsonic speed velocity of 17 m/s.
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**Figure 4** Contour plots of instantaneous vorticity on single cylinder at Reynolds’s number=35,000

**Figure 5** Time averaged distribution of Cp of present computation with igarashi\(^1\) at Reynolds no 35000.

<table>
<thead>
<tr>
<th>St no</th>
<th>Pressure coefficient (drag)</th>
<th>Viscous coefficient</th>
<th>Mean drag coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present results-computation Igarashi(^1)</td>
<td>0.218 0.212</td>
<td>0.99 0.014</td>
<td>1.01 1.12</td>
</tr>
</tbody>
</table>

**Table 2** Comparison of results of present computation with Igarashi\(^1\) literature.

The table gives the computation result of coefficient of drag \(C_D\) value is 1.01 and the Igarashi\(^1\) literature value is 1.12 there is a good agreement between the results.

### 3.2 Cylinder with splitter plate:

The major contribution of drag on cylinder is due to the pressure drag, it is also observed that the interaction of vortices leads to a higher pressure drag. Therefore the present work aims to restrict the interaction of vortices and observe their effect on the body. The restriction has been bought using a splitter plate fixed at angle \(\phi=180^\circ\). Due to the presence of splitter plate, the two vortices in the upper and lower half of the cylinder become blind and do not get interact each other.

Following cases are have been aimed in the present section

- Effect of length of splitter plate attached with the cylinder at \(\Phi=180^\circ\)
3.3 Effect of gap between the cylinder and splitter plate:
Splitter plate is placed at some distance Z/D=0.5, 1 and 2 the length of the plate is kept constant L/D=1. Table .4.3 gives the information about drag coefficient and strouhal number. The net drag coefficient at different spacing’s Z/D=0.5, 1 and 2 are 0.84, 0.80 and 0.75. the drag coefficient for a single cylinder is 1.01 and with the splitter plate at Z/D=0.5 is 0.84 from this we can observe that there is a decrease 17 % drag coefficient. When the plate placed at Z/D=2 net drag coefficient is 0.75, the drag reduction is 25%. From fig.4.22 we can conclude that the drag coefficient is decreasing with the increasing of spacing between the cylinder and plate from Z/D=0.5 to Z/D=2.

Following cases have been solved numerically:
 i) At spacing Z/D=0.5 and 2 with splitter plate length L/D=1

![Streamline pattern](image)

**Figure 6** streamline pattern over circular cylinder with splitter plate at Z/D=0.5, 1 and 2, L/D=1
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Figure 7 Cp distribution of cylinder with splitter plate Z/D=0.5, L/D=1 with single cylinder

Figure 8 Cp distribution of cylinder with splitter plate Z/D=1, L/D=1 with single cylinder

Figure 9 Cp distribution of cylinder with splitter plate Z/D=2, L/D=1 with single cylinder

<table>
<thead>
<tr>
<th>SPLITTER PLATE LENGTH FROM CYLINDER</th>
<th>FREQUENCY</th>
<th>ST NO</th>
<th>NET-DRAG COEFFICIENT</th>
<th>% change in drag coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z/D=0.5</td>
<td>86.2</td>
<td>0.1517</td>
<td>0.8495</td>
<td>17%</td>
</tr>
<tr>
<td>Z/D=1</td>
<td>67.3</td>
<td>0.1184</td>
<td>0.8041</td>
<td>21%</td>
</tr>
<tr>
<td>Z/D=2</td>
<td>54</td>
<td>0.0950</td>
<td>0.7569</td>
<td>26%</td>
</tr>
</tbody>
</table>

Table 3 Computation results of cylinder with splitter plate L/D=1, Z/D=0.5, 1 and 2
4. EXPERIMENT RESULTS:
The experiments are conducted on a circular cylinder of diameter 30mm at Reynolds’s number is 35,000 on subsonic wind tunnel. There are total 24 ports on the cylinder which are at equal angle of 15°. All the ports are connected to the pressure sensor box. The pressure sensor box is connected to the data acquisition card of computer. The values at each and every port are given by lab view software.

4.1 Comparison of computation results with experiment:
Experiment on single cylinder has given the drag coefficient value of 1.015 which is close to the drag coefficient of the computation results. From the fig we can observe the trend of Cp distribution of experiment and computation results.

4.2 FOR A SINGLE CYLINDER

<table>
<thead>
<tr>
<th></th>
<th>NET DRAG COEFFICIENT</th>
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</thead>
<tbody>
<tr>
<td>COMPUTATION</td>
<td>1.011</td>
</tr>
<tr>
<td>EXPERIMENTS</td>
<td>1.015</td>
</tr>
</tbody>
</table>

Table 4 Comparison between computation and experiment result of single cylinder at Reynolds’s number 35000.

![Figure 10](image-url) Cp distribution comparison of computation results with experiments for single cylinder Reynolds’s number 35000.

4.3 Cylinder with splitter plate at some space:
For the effect of spacing case the experiments are carried out for 3 cases Z/D=0.5, 1 and 2, L/D=1 out of all the computations. For the experiments with splitter plate at Z/D=0.5, 1 and 2, L/D=1 the net drag coefficient values are 0.84, 0.80 and 0.72.

<table>
<thead>
<tr>
<th>SPACE BETWEEN THE CYLINDER AND BODY</th>
<th>SPLITTER PLATE LENGTH</th>
<th>COMPUTATION (NET DRAG COEFFICIENT)</th>
<th>EXPERIMENT (NET DRAG COEFFICIENT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z/D=0.5</td>
<td>L=1D</td>
<td>0.8495</td>
<td>0.8423</td>
</tr>
<tr>
<td>Z/D=1</td>
<td>L=1D</td>
<td>0.8041</td>
<td>0.8006</td>
</tr>
<tr>
<td>Z/D=2</td>
<td>L=1D</td>
<td>0.7569</td>
<td>0.7242</td>
</tr>
</tbody>
</table>

Table 5 Comparison of computation and experiment results for cylinder with splitter plate at diff length of spacing between the cylinder and plate.
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**Figure 10** Cp distribution comparison of experimental result of single cylinder with experiment results of diff cases of spacing between cylinder and plate.

**Figure 11** Comparison of experimental results with computation results of single cylinder with plate Z/D= 0.5, 1 and 2, L/D=1

The computation results and the experimental results are following the same trend the values close. From computation and experimental results we can observe that with the increasing of spacing the net drag coefficient is decreasing because the separated vortices of the cylinder meets at a critical gap. When the plate is closed to the critical gap there is major reduction pressure drag. So that the total drag has been reduced when the plate is at critical gap. From Fig we can observe decreasing of Cp distribution with space increasing from cylinder to the body. Fig gives the trend of decreasing the drag coefficient with the increase of space from cylinder to the body by both computational and experimental results.

**Figure 12** Comparison experiment and computed pressure distribution for cylinder with splitter plate at Z/D=0.5, L/D=1

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5. CONCLUSION

Numerical simulation was carried out for flow over a circular cylinder at Reynolds number 35000 and the splitter plate with the single cylinder. The experiments were conducted on single cylinder and specified models of splitter plate with cylinder. The effect of splitter plate of cylinder on drag, frequency and strouhal number has been observed.

A number of important conclusions were made in this investigation.

1) Computation made on single cylinder revealed the pressure of vortex induced vibration as revealed in previous studies.

2) The introduction of splitter plate at $\Phi=180^\circ$ altered the wake and hence, the drag forces and frequency of vortex shedding changed.

3) Increase in gap between cylinder and leading edge of splitter plate, also helped in reduction of drag force, however the interaction of flow in the gap may lead to additional flow complexities.

4) Agreement between the computed and measured results were reasonably good.
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