

# VORTEX MANIPULATION BY CHANGING GEOMETRY AND ORIENTATION

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## ABSTRACT

*Effect of curvature and orientation on vortex formation is presented in this paper. Different types of chord are taken of radii 17.5, 25 of a circle keeping the chord length 35mm. Flow analysis is done at Reynolds no. 900 by changing the orientation of the arc. Increment of 5° is made to the flow direction in anti-clockwise fashion and the results are compared with a straight edge model. Introducing curvature in the model has shown effect on vortex size and formation. Arc-2 model shows significant effect at orientation 15°.*

***Keywords: Mass Entrainment, Stagnation Point, Streamline Flow, Vortex, Arcs***

## I. INTRODUCTION

Vortex dynamics play an important role in all the three transport processes. Therefore, vortex manipulation is the key for the efficiency of any device that involves mixing. For example, the fuel–air mixing in combustion chambers is a dictating process governing the combustion efficiency. A mixing process involving more than two streams or two species should have an appropriate combination of large and small vortices for efficient mixing. It is well known that large vortex structures are efficient suction creators, but they are highly unstable and easily get fragmented into small vortices. Therefore, they are short lived and cannot travel long distances in a flow field. In contrast, small vortices are stable and could travel long distances in a flow field, but because of their small size, they are poor suction creators. However, because of their long life they are efficient mixing promoters. Therefore, in a flow process such as a free jet, where the surrounding fluid needs to be inducted into the jet flow, and the inducted low momentum fluid mass needs to be transported towards the jet axis, an appropriate proportion of the mass entraining large vortices at the jet periphery, and the mass transporting small vortices inside the jet field for efficient mixing is required. However, even though it is understood that an appropriate proportion of large and small vortices are essential for efficient mixing, identifying such a proportion and generating the desired sizes of large and small structures still remains a black box. Even though vast literature is available for enhancing the mixing in a number of engineering devices, almost all the reported information is on the end result of mixing efficiency. For example, Griffin and Ramberg<sup>[1]</sup> studied vortex shedding from a vibrating cylinder in a uniform flow. They found that the vortex shedding takes place Re 190 onwards. Ayoub and Karamcheti<sup>[2]</sup> experimentally studied uniform flow past a finite cylinder at high subcritical and supercritical Reynolds number (Re), and reported cellular structure in the wake. Also, they found that the wake region could be subcritical even when the main flow is supercritical. Griffin<sup>[3]</sup> investigated bluff body vortex formation. In this study, he reviewed various definitions of length of the vortex formation region, which

have been proposed earlier. He visualized vortex shedding at Re 200 for a circular cylinder. Prasad and Williamson<sup>[4]</sup> studied the instability of shear layer separating from a bluff body. It was found that the span wise end conditions, which control the primary vortex shedding from the cylinder, affect the instability of the separated shear layer. There was wake formation even at Re 260. Okajima et al<sup>[5]</sup>. studied flow-induced oscillation of a circular cylinder in a water tunnel. They investigated the response amplitude of a two-dimensional circular cylinder with increasing flow velocity. Konstantinidis and Balabani<sup>[6]</sup> reported symmetric vortex shedding in the near wake region of a circular cylinder due to stream wise perturbation in the Re range 1200–1240. All these investigations are on the effect of the vortices shed by the cylinder on the flow field behind it. These investigations do not focus on the size of the vortex and its manipulation. But the vortex size and its management are essential for applications involving mass entrainment and mixing. For example, Lovaraju and Rathakrishnan<sup>[7]</sup> reported that introduction of vortices with control tabs into a jet flow can result in an enhanced mixing. This is because of the active interaction between the mass entraining vortices formed at the jet boundary and the stream wise vortices shed by the tab. Also, Thanigaiarasu et al. studied flat and arc tabs, and found that reducing the size of the vortices shed by changing the flat tab into a circular arc is more beneficial in view of mixing enhancement. Even though these studies present the effect of vortex size on the flow field intuitively, there is no direct information on the vortex size and management. Therefore, in this study an attempt is made to visualize and measure the size of vortices behind a flat plate and manipulate the vortex size with circular arc plates of three specific radii. In other words, an attempt is made to investigate the physics behind the generation and size manipulation of twin vortices behind flat and arc plates at some specified Reynolds numbers.

## II. EXPERIMENTAL SETUP

The channel is made of G.I sheet of 5mm thickness and the sheet was bent into the shape as shown in the figure. The width of the test section is of about 280mm and the depth of water will be maintained 8mm. Photographic view of the channel is shown in Fig.2.1. To get flow visualization dye is injected into the system. To inject the dye in channel injection system is established. The injection system comprises of mainly three parts such as burette, stand, and an injection valve consisting of a pipe connected to the burette as shown in the Fig. 2.2. A valve is provided at the end of the injection system for controlling amount of flow is to be injected into the channel. The main use of this injection system is to provide the flow along with the water without creating any disturbance in the flow.

### 2.1 Calculation of Reynolds number

The Reynolds number plays an important role in the fluid dynamics, because it is the only reference parameter for the representation of the drag on the bluff bodies. It also plays a main role in the representation of the flow feature in the visualization techniques. To find out the Reynolds number first the main parameter needed is velocity of flow which can be measured by the different techniques. Among the many other techniques, floating particle method is used to in the present study. In the floating particle method, time taken to the travel floating particle over a distance is estimated. The velocity can be calculated by dividing the distance with the time. After finding out the velocity the Reynolds number can be calculated with reference to the width of the model by using the following formula:

$$Re = \rho V D / \mu$$



**Figure 2.1: Open channel**



**Figure 2.2: Injection System**

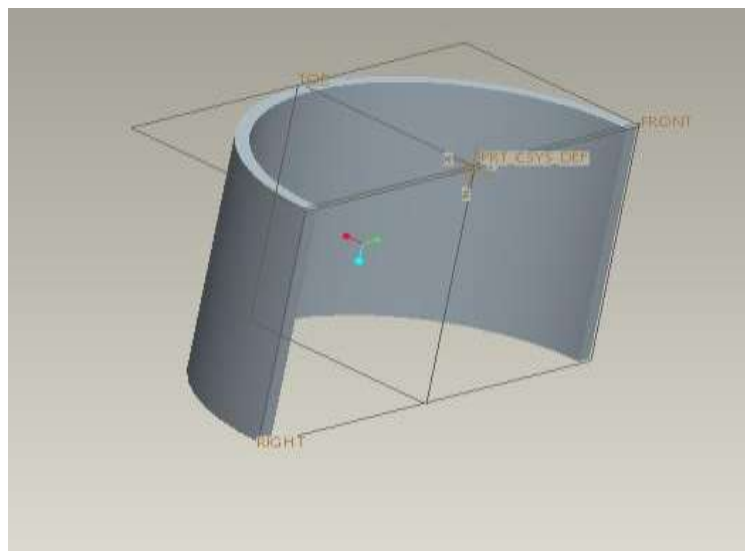
## 2.2 Experimental Model

Experiment is carried out with four different models, of which three models have an arc shape of different radii and same chord length, which are compared to a flat model of length equal to the chord length of arcs. The detailed dimensions of models are shown in below Table 2.2.1.

**Table 2.2.1: Details of Models**

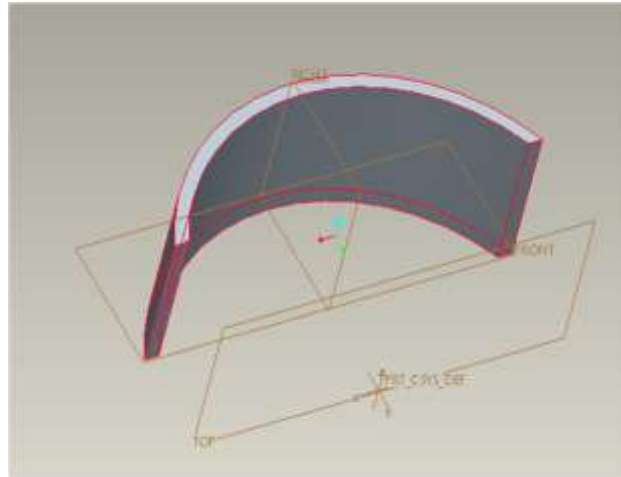
S.no	Model Name	Shape	Dimensions
1	Model-1	Arc	17.5R chord length 35
2	Model-2	Arc	25R chord length 35
3	Model-3	Flat	35*5

The Fig.2.2.1 shows the artistic view of Model-1 it contains radius of 17.5 and chord length equal to 35mm, i.e. it's a semi circular shape.



**Figure 2.2.1: Model-1 of diameter 35mm & chord length 35mm**

The Fig.2.2.2 shows the artistic view of Model-2 it contains radius of 25 and chord length equal to 35mm.

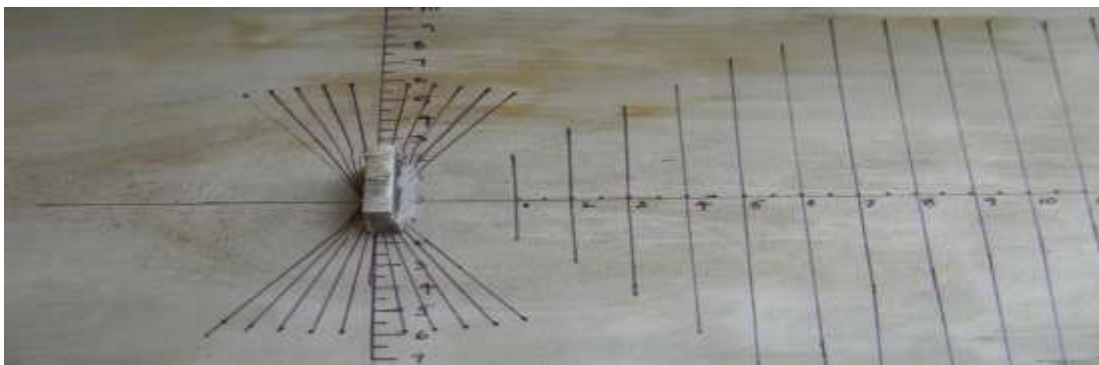


**Figure 2.2.2: Model-2 of diameter 50mm & chord length 35mm**

### 2.3 Experimental Procedure

In the first step, mark the scale and the angles on the test section portion of the channel, which will be used to measure the flow parameters. Fig.2.3 shows the marking on channel. Place the channel on fine and a straight place which has no inclination. Now, give the water supply to the channel at the water chamber, so that the fairly uniform flow will be entering into the test section due to the effect of wedge and screens. Test for the uniformity of the flow i.e., either the flow was going in the straight line from starting to the end of the channel, if not make some adjustments to get the uniform flow.

Velocity is to be set in the channel according to the requirement. The velocity of flow can be calculated by using the floating particle method. Now, inject the sufficient amount of dye at the second screen which will help to get the streamline flow. Take the video from the start to the end of flow pattern over the object for further investigation. From the video extract the frames and keep the necessary frames for the analysis.



**Figure 2.3: Marking on the Channel**

### III. RESULTS AND DISCUSSION

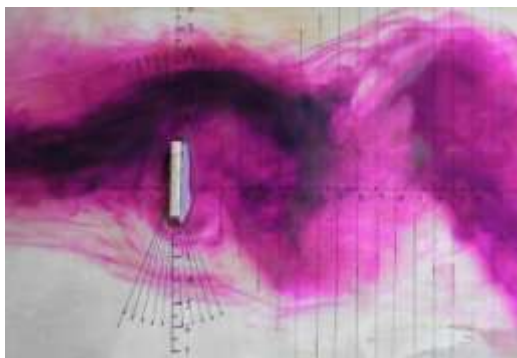
The experimental results consist of the video of the flow field over the flat and arc plates of the present scheme at different orientations from  $0^\circ$  to  $20^\circ$  at two Reynolds numbers and the vortex lengths, for different cases. When the model is at an angle with the incoming flow, the twin vortices assume different lengths. Before getting into the quantitative aspects of the vortex size, it is necessary to understand the flow physics behind the formation of these vortices. It was found that on reaching the forward stagnation point, the flow encounters a positive pressure zone popularly termed as pressure uphill, before reaching the edges of the model. These

curved streamlines, find a large space at the back of the model on reaching the edges and turn towards the model base. This process of turning towards the base results in the formation of two vortices of opposite nature. Because of these vortices formation, a low pressure region is created at the model base. When the flow velocity increases, the suction at the base increases as well. This low pressure at the base attracts the flow from the zone just downstream of the vortices, towards the base. Thus, a reverse flow towards the base is established.

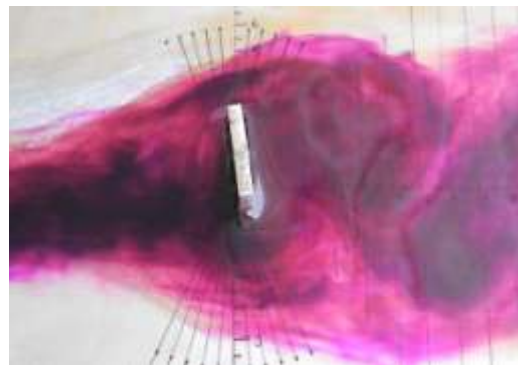
With increase in flow velocity, the suction at the base progressively increases reaching a stage at which the twin-vortex formation behind the model is due to the reverse flow rather than the roll-in of the incoming flow from the edges. Under this situation, the streamlines of the flow from the model face are pushed away by the vortices formed by the reverse flow. Thus, there is a definite location behind the model where the reverse flow begins and reaches the model base, establishing twin-vortex. However, there is no quantitative information about the location of the beginning of the reverse flow and its sensitivity to the object geometry and flow Reynolds number. To gain an understanding of this important aspect of reverse flow, the location, which has been identified as the end of the twin vortex, its sensitivity to the plate geometry, and its orientation has been analyzed in this study.

### 3.1 Flow over a Flat Plate

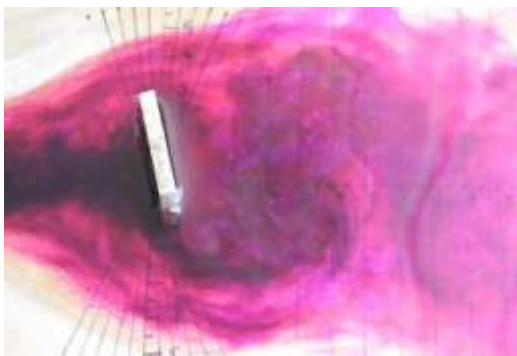
The following figures 3.1.1 ,3.1.2 ,3.1.3,3.1.4 & 3.1.5 shows the flow over a flat plate of orientation from  $0^\circ$  to  $20^\circ$ . Has changing orientation from  $0^\circ$  to  $20^\circ$  the left and right vortex increased up to  $5^\circ$  then after right vortex size increase and left vortex size decreased. The deviation of vortex size of left and right is same up to  $15^\circ$  no effect is then after.



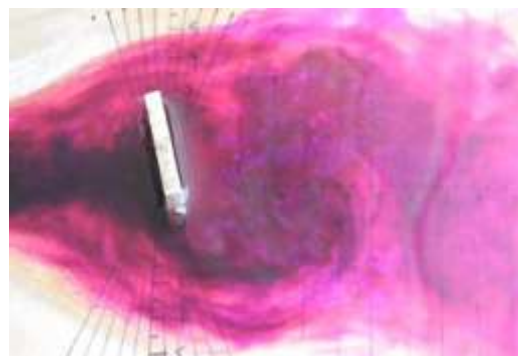
**Figure 3.1.1: Flat Plate at  $0^\circ$  Angle**



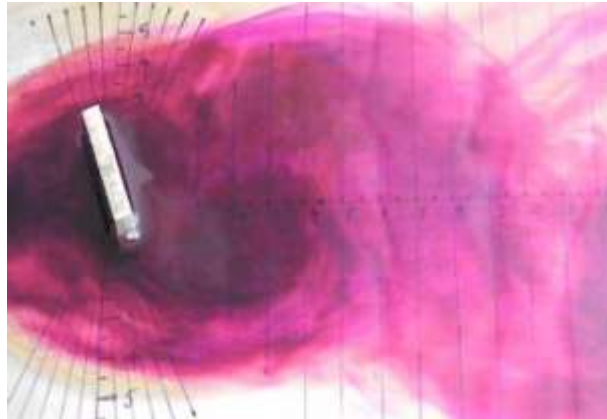
**Figure 3.1.2: Flat Plate at  $5^\circ$  Angle**



**Figure 3.1.3: Flat Plate at  $10^\circ$  Angle**



**Figure 3.1.4: Flat Plate at  $15^\circ$  Angle**



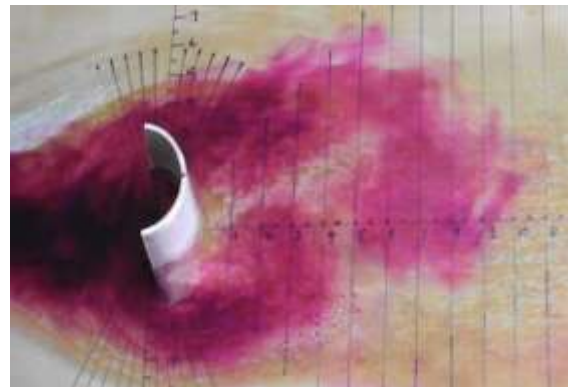
**Figure 3.1.5: Flat plate at 20° angle**

### 3.2 Flow Over a Model-1 Arc

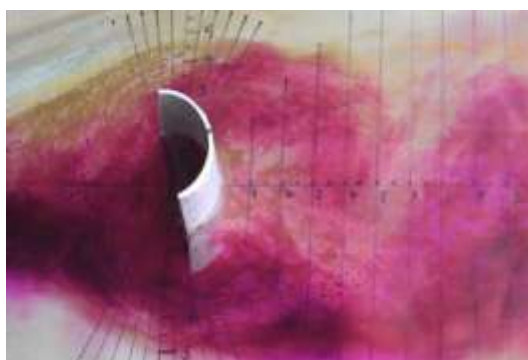
The following figures 3.2.1, 3.2.2, 3.2.3, & 3.2.4 show the flow over a model-1 arc of orientation from 0° to 20°. In this model left and right vortex increased up to 5°. Right vortex increased up to 5° and no significant effect then after .up to 15° later it is increased. Left vortex is decreased from 5° to 20°. In all the position right vortex size is more compared to left vortex.



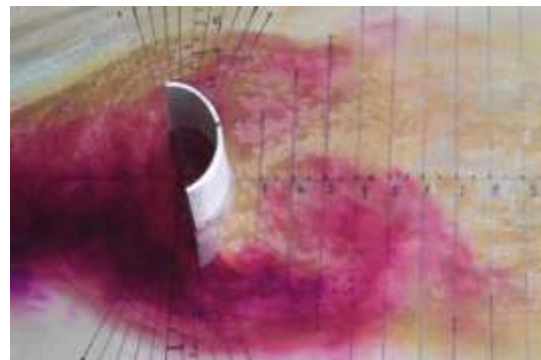
**Figure 3.2.1: Model-1 arc at 0° Angle**



**Figure 3.2.2: Model-1 arc at 10° Angle**



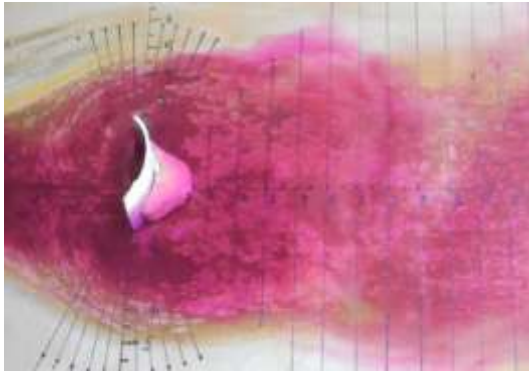
**Figure 3.2.3: Model-1 arc at 15° Angle**



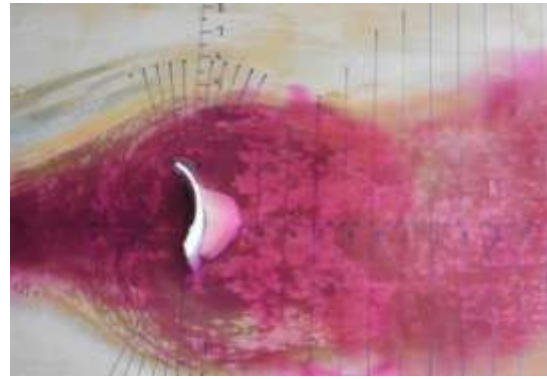
**Figure 3.2.4: Model-1 arc at 20° Angle**

### 3.3 Flow over a Model-2 arc

The following figures 3.3.1, 3.3.2, 3.3.3 & 3.3.4 show the flow over a model-2 arc of orientation from 0° to 20°. Arc 2 shows different effect compared to the other models. Vortex size increases up to 5°. Left and Right vortex size decreases every orientation. Left vortex size is less compared to right vortex size for model arc-2.



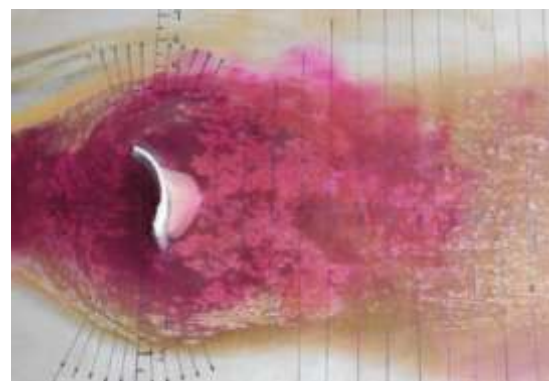
**Figure 3.3.1: Model-2 arc at 0° angle**



**Figure 3.3.2: Model-2 arc at 10° angle**



**Figure 3.3.3: Model-2 arc at 15° angle**



**Figure 3.3.4: Model-2 arc at 20° angle**

### 3.4 Vortex Size

To quantify the vortex size, the vortex length has been taken as the representative measure. The vortex size measured from the visualization pictures has been non dimensional zed with the chord of the flat plate and the arcs. Here the shortest distance between the tips of the plate is termed the chord.

The vortex length variation with plate orientation for Re 900 is shown. It is seen that up to a 100 orientation, the size of the vortex is almost closer to the chord length. Also, the difference between the left and right vortices is significant. However, beyond 100 the vortex behind the edge in the front (left vortex) is larger than that behind the edge in the rear (right vortex). The vortex size variation for arc-1 at Re 900 is shown. It is seen that the curvature introduced to the plate results in the elongation of the vortices at  $\Theta$  in the range 0°-15°. However, the difference between the length of left and right vortices continues to be not significant at all values of  $\Theta$ . Further, for  $\Theta$  beyond 15°, the size of the vortices appears to be significant to  $\Theta$ . The vortex size variation for arc-2 at Re 900 is shown. This is the case of an arc with reduced radius of curvature than the arc-1, i.e. the geometric deviation from the flat plate is larger than arc-1. For this case too, the vortex length is larger when compared with the vortex behind the flat plate for  $\Theta$  from 0° to 15°. However, the difference between the size of left and right vortices is lesser than that for arc-1 for  $\Theta$  ranging 0°-20°.

## IV. CONCLUSIONS

At Reynolds number 900 the flow over flat plate and arcs of radii 17.5 mm and 25mm is studied. It is found that there is a definite location behind the plate where the reverse flow begins and reaches the plate base, establishing vortex formation. The results suggest that it is possible to control the size of the vortex shed using

an object with geometrical modification, and changing its orientation. Flat plate model has show significant effect up to  $15^\circ$ . As introducing arc geometry vortex size is same at  $0^\circ$  orientations. As changing orientation arc-2 shows different vortex nature with arc-1 model. And left and right vortex size is show significant effects. Arc-2 model has show significant effect of left and right vortex formation at  $15^\circ$  orientation.

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