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Experiments on Vortex Rings: Interaction with Circular Surfaces

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Abstract: **Vortex rings can be easily produced in the laboratory by pushing a definite column of fluid into a tank containing stationary fluid at a certain velocity. The velocity of a single vortex ring is reducing up on its propagation and diameter is increasing due to the conservation of momentum. The Reynolds number has no influence in the ring diameter and it is depending on stroke ratio only but Reynolds number effecting inversely to the core diameter of the vortex ring. Interaction of vortex rings with cylinders shows cut and reconnection of vortex rings for small diameter cylinders. The interaction produces a pair of secondary vortices having opposite vorticity and reduces the diameter of the primary ring. The interaction with higher diameter cylinders causes the ring to become turbulent and no such observations as other are visible.**

***Index Terms*— Circular surfaces, Reynolds number, Ring diameter, Stroke ratio, Velocity, Vortex rings**

I. INTRODUCTION

It is very easy to identify a vortex ring if we observe a smoke ring that is ejected by a smoker, Explosion of an atomic bomb or volcanic eruption. A vortex ring is visible as a smoke-filled torus shaped thing which is propagating with a velocity. It is really interesting to observe a vortex ring because of its aesthetics. It is observed that this visual fascination is enjoyed other than humans. For example, dolphins can generate vortex rings for entertaining purposes and they are enjoying by playing with it. The understanding of scientific aspect and technological applications of vortex rings are even more interesting.

Batchelor [1] contributed to the study of the vortex ring. In his book, he explains different experimental techniques for generating vortex rings. More theoretical and experimental works on vortex formation, structure, stability etc. are studied by Saffman [2]; Norbury [3]; Maxworthy [4]; widnall and Sullivan [5]; Didden [6] etc.

The study on the interaction of vortex rings is started in the late 20th century. The advancements in technology lead to the study of vortex rings into the next level on the later 1990's. It helps in resolving many controversial findings of the past, the works of Lim [10]; Dabiri, [11]; Gharib et.al [12] are the major works. Due to the improvements in the study of vortex rings, the practical application of the vortex rings is also improved to many fields. A major application of the vortex rings is in starting the jet flow. Vortex rings are considered as the basic building blocks of the starting jet flows mixing, noise generation, and Heat transfer. Another application is in projecting smoke and other effluents to higher altitudes in the atmosphere, this can avoid the construction of chimneys and oil well firefighting [13]. The locomotion of aquatic creatures like jellyfish, salp etc. and insect flight leads the vortex ring to be studied for its potential aspect in propulsion.

This paper is mainly divided into two. Study of vortex rings generating from circular nozzles and the interaction of vortex rings with circular cylindrical surfaces. In Circular Vortex rings, the study of the vortex rings generating from circular nozzles and effect of major parameters in vortex ring evolution and propagation are carried out and then the study of vortex rings interacting with circular cylinders of different diameters are also done.

II. EXPERIMENTAL SETUP

The experiments on vortex rings are carried out at the Jet flow and acoustics lab at NIT Calicut and the vortex ring generator consists of a tank where the fluid is filled, a nozzle which is connected to the tank from the piston-cylinder mechanism. The piston cylinder is actuated by compressed air produced and stored in the separate tank as shown in fig 1.

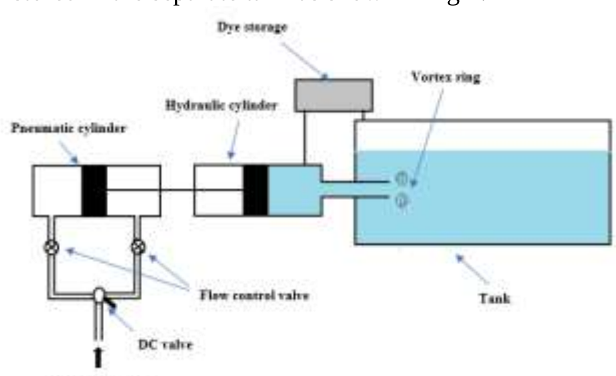

Figure 1: Schematic representation of vortex ring generator

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The tank in which vortex rings are generated is made up of 4mm thick acrylic sheets at a dimension measuring 1m X 0.3 m X 0.4m, in which water is filled at a height of 30 cm. The piston cylinder is the major part of the vortex ring generator in which the ring formation is occurring due to the action of piston-cylinder. A piston of 45mm diameter is actuating pneumatically inside a cylinder using compressed air stored in a tank and a nozzle of 19mm diameter is connected to the tank exit of the cylinder where the fluid is ejected. The piston cylinder is actuated by using compressed air, the air that is compressed using a 12V, 7.2 Amps DC portable compressor and it is stored in a cylinder. The air from the cylinder to the piston-cylinder is controlled by a solenoid valve connected in between them, which can get instantaneous control of the air.
A circular nozzle of 19 mm diameter which is made of the mild steel rod is used in this experiment. For the interaction of vortex rings with circular cylinders, cylindrical surfaces having different diameters are used. Cylinders made up of copper having diameter 0.2mm,0.6mm,1.5mm and 2.5mm are used in our experiment for the study. The dye used for the visualization of vortex rings are methylene blue alkaline and a suitable quantity of the dye is thoroughly mixed with water for getting the required dye concentration.

III. VORTEX RING CHARACTERISTICS

Vortex rings are generated using the circular nozzle of diameter 19mm at different stroke ratios (L_N/D_N) ranging from 1 to 5, where L_N is the length of fluid column ejected through the nozzle and D_N is the nozzle diameter. The formation and propagation of vortex rings at each stroke ratios are visualized using dye and images are captured and analyzed. During the first stage of the vortex ring formation, a definite quantity of fluid slug is ejected from the nozzle at a certain velocity and which rolls up immediately to form a vortex ring. The vortex ring formed is then propagated forward and more fluid from the surroundings are entrained to the vortex ring, thereby the volume of the ring goes increasing.

A.Vortex rings of different stroke ratios

When comparing all the vortex rings generated using the nozzle at different stroke ratios ranging from 1 to 5, the major observation is that vortex ring generated at stroke ratio 4 onwards a trailing edge is found behind the leading vortex rings as shown in fig 2. It is known that the fluid coming out from the nozzle is entering into the vortex ring and the ring is propagated. Until L_N/D_N 4 the fluid ejected will occupy in the vortex ring during propagation. In other words, the vorticity produced out from the nozzle with L_N/D_N 4 will accumulate inside the vortex ring itself. Beyond the stroke ratio of 4, the vortex rings generated cannot occupy the vorticity of the rest of the fluid and this will form as the trailing jet behind the ring.

Figure 2: Vortex rings generated at different stroke ratios, a)1, b)3, c)4 and d)5

The maximum circulation that a vortex ring can achieve is at L_N/D_N ratio 4, beyond that the circulation will be the same for the ring generated. The vortex rings having trailing jets will break down easily and it is converted to a turbulent vortex ring.

B.Propagation of a single vortex ring

A vortex ring generated at a stroke ratio of 1 is captured along its propagation up to $5D_N$ distance away from the nozzle exit. It is found that the vortex ring diameter is increasing upon its propagation. The relationship between vortex ring diameter and propagation distance is shown in fig 3. Due to the entrainment of fluid, the volume of the vortex ring is increased gradually and for conserving the momentum according to the momentum conservation, the propagation velocity should decrease.

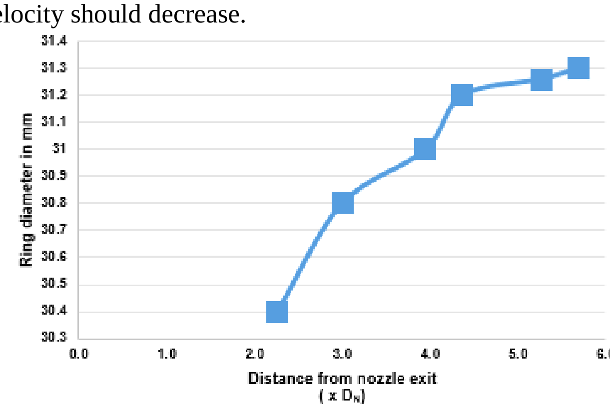

Figure 3: Dimensionless ring diameter along propagation

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It is shown in fig 4, that the propagation velocity of vortex ring is decreasing upon its propagation after formation, at the initial stage of the vortex ring formation, an increase in velocity is found but when the volume of the ring starts increasing, the velocity shedding of vortex ring is started.

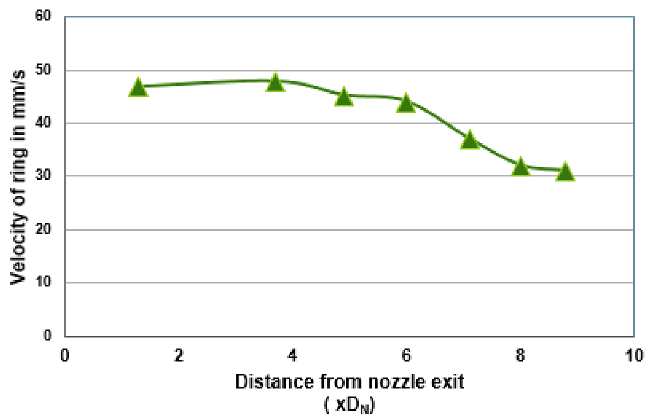

Figure 4: Propagation Velocity of vortex ring

Vortex rings at varying Reynolds Number and stroke ratios

In order to find the vortex ring characteristics along with Reynolds number, a number of vortex rings are generated at different stroke ratios at three different Reynolds numbers. The Reynolds number chosen for the experiment are Re 1200, 1700 and 2500. All vortex rings at $5D_N$ distance from nozzle exit are captured and analyzed.

The relationship between dimensionless ring diameter (D/D_N) and stroke ratio (L_N/D_N) is studied first, it is observed that the dimensionless ring diameter is increasing with increase in stroke ratio but there is no considerable change in dimensionless ring diameter is noticed by varying Reynolds number as shown in fig 5.

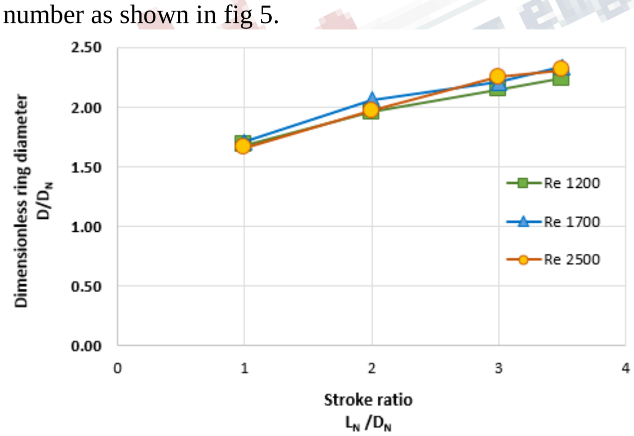

Figure 5: Ring diameter Vs stroke ratio at different Reynolds numbers

It is then concluded that the ring diameter is a function of stroke ratio only and it is not depending upon Reynolds number, by curve fitting, we obtained the relation between dimensionless ring diameter and stroke ratio as,

$$\frac{D}{D_N} = 1.7\left(\frac{L_N}{D_N}\right)^{0.22} \quad (1)$$

The relationship between the dimensionless core diameter (c/D_N) with stroke ratio (L_N/D_N) at different Reynolds number is also studied. The vortex ring core size is increasing with increasing stroke ratio, such that the amount of fluid that forms the ring is increasing with increasing stroke ratios. The major observation in this is that the core diameter is dropping drastically with increase in Reynolds number as shown in fig 6. It is concluded that the vortex ring core diameter is a function of stroke ratio and Reynold number.

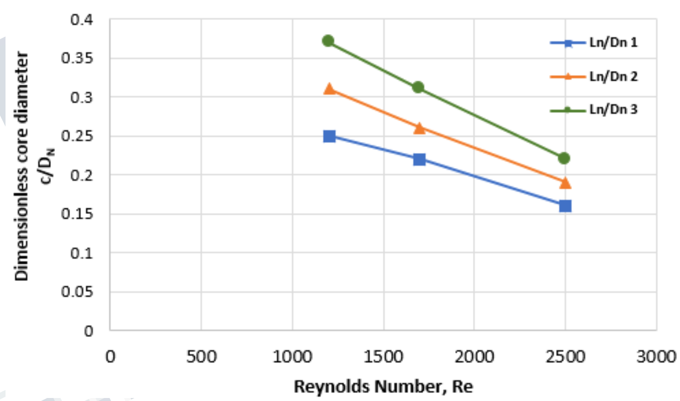

Figure 6: Core diameter Vs Reynolds number

IV. INTERACTION OF VORTEX RING WITH CYLINDRICAL SURFACES

The vortex ring interaction with cylindrical surfaces are studied by vortex rings produced from the nozzle is allowed to interact the circular cylinders placed across the vortex ring at $5D_N$ distance away from the nozzle exit. The circular cylinders of different diameters such as 0.2mm, 0.6mm, 1.5mm and 2.5 are used for the interaction. The Reynolds number and stroke ratio are kept constant as 1400 and 1 so that we are changing the circular cylinder diameter only.

A.Interaction with 0.2mm cylinder

The different stages of vortex interaction with the 0.2mm diameter cylinder are shown in fig 7 (a) – (d) The vortex ring is passing through the cylinder and it is noticed that the ring is cut by the cylinder in fig 7 (b). It is then reconnected

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immediately after it passes the cylinder. The vortex core near the cylinder slows down and rest of the core will propagate with the same velocity, this will create a pressure difference between the core near the cylinder and rest part of the core. This will result in the core near the cylinder to stretch and furtherly it will divide the ring into two. The divided ring will move axially and then reconnects immediately after passing the cylinder.

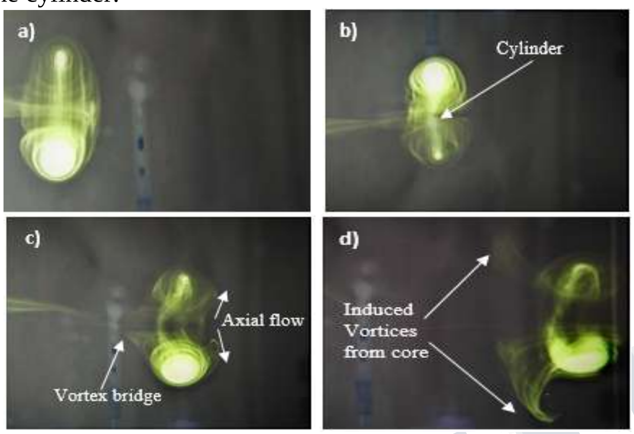

Figure 7: Interaction of vortex ring with cylinder of diameter 0.2mm

During the stretching of vortex core near the cylinder, the core having opposite vorticity will come into contact each other and this will result in vorticity cancellation at a point, these canceled vorticities will be trapped near the cylinder and form a bridge-like structure as shown in fig 7 (c). This bridge will diffuse to the surrounding medium after a period of propagation. When the vortex ring is reconnected on the other side of the cylinder, it is observed that the vortex core will not be the same as before. A distorted vortex ring is found after the reconnection. A more interesting observation is that the generation of a secondary vortex ring. A pair of vortex rings having opposite vorticity is found rotating in the periphery of a vortex ring, this will eventually move away axially from the major vortex ring. A considerable amount of vorticity is shed in this manner; it is clearly shown in fig (d) that the intensity of the dye is reduced. This vortex shedding will cause a reduction in the propagation distance of the ring.

B. Interaction with 0.6mm cylinder

When the interaction is done with 0.6mm, the phenomenon of cutting and reconnection is same as that of the first case. The axial flow of the divided vortex ring is more intense here also a more distorted vortex core is found after the reconnection of the vortex ring. The increase in cylinder diameter causes the vortex ring is to separate effectively.

Interaction with 1.5mm cylinder

During the interaction with 1.5mm cylinder, the vortex ring is divided into two as it passes through the cylinder as discussed in the earlier cases shown in fig 8. A major difference in this is that the vortex core deformation. It is observed from fig 8 (b) that the core of the vortex ring is deformed into seed like shape as it passes through the cylinder. In the earlier experiments, even though the ring is divided into two the core keeps its initial shape but here a considerable deformation is found. In the first two experiments, we don't know that from where the secondary vortex rings are generated, here in fig 12 (b) it is clearly shown that the secondary rings are generated from the two sides of the circular cylinder as the vortex ring passes through it.

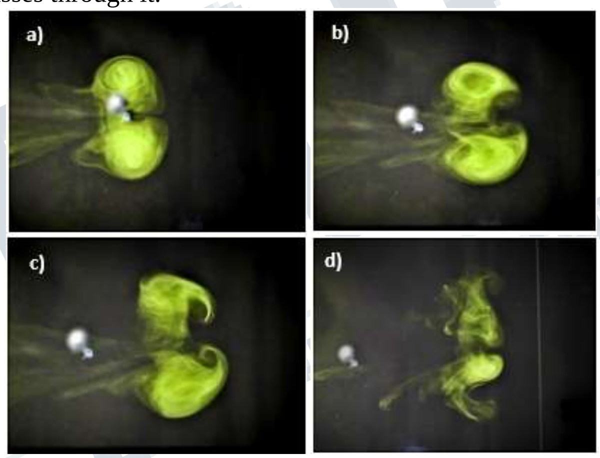

Figure 8: Interaction of vortex ring with cylinder of diameter 1.5 mm

The generation of secondary vortices is mainly due to the shear between the vortex ring and the circular cylinder. The generated vortices, which has opposite vorticity is propagated away from the major vortex ring axially as discussed earlier. The reconnection of the vortex ring is present in this case also but the diameter of the vortex ring is reduced drastically. From this, we can conclude that a major portion of the vorticity in the vortex ring is diffused to surroundings due to the interaction with a cylinder of 1.5mm diameter.

C. Interaction of vortex rings with 2.5mm cylinder

Interaction of the vortex ring generated from a 19mm nozzle at a stroke ratio of 1 and a Reynolds number 1400 is done with a circular cylindrical surface of diameter 2.5mm shown in fig 9. The effect of increasing cylinder diameter is clearly understood from the images that there is no reconnection is visible after the passes through the cylinder. The cylinder divides the vortex ring into two as it propagates and these separated rings are moved axially, they are trying to reconnect

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but the vortex core didn't reconnect again. The vortex core became turbulent and it is suddenly diffused into the surrounding medium. The effective separation of the ring by 2.5mm diameter cylinder causes the vortex core deformation similar to the case of 1.5mm cylinder shown in fig 9 (a) - (d).

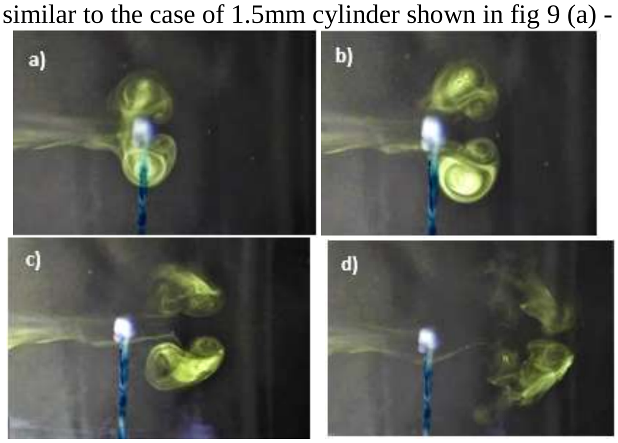

Figure 9: Interaction of vortex ring with cylinder of diameter 2.5 mm

REFERENCE

[1] Batchelor, G. K. 1967 An Introduction to Fluid Dynamics. Cambridge University Press.
[2] Saffman, P. G., (1970) "The Velocity of Viscous Vortex Rings", Studies in Applied Mathematics. **49**(4): 371-380.
[3] Norbury, J., (1973) "A family of steady vortex rings", Journal of Fluid Mechanics. **57**: **3**: 417-431.
[4] Maxworthy, T., (1972) "The structure and stability of vortex rings", Journal of Fluid Mechanics. **51**: 15-32.
[5] Widnall, S. E. & Sullivan, J. P., (1973) "On the stability of vortex rings", Proceedings of the Royal Society of London A. **332**: 335-353.
[6] Didden, N., (1979) "On the Formation of Vortex Rings: Rolling up and Production of Circulation", Journal of Applied Mathematics and Physics (ZAMP). **30**: 101-116.
[10] Lim, T. T., (1997(a)) "A note on the leapfrogging between two coaxial vortex rings at low Reynolds numbers", The Physics of Fluids. **9** (1): 239-241.
[11] Dabiri, J. O., (2005) "Unsteady Fluid Mechanics of Starting-Flow Vortex Generators with Time-Dependent Boundary Conditions", PhD thesis, California Institute of Technology.
[12] Gharib, M., Rambod, E. & Shariff, K., (1998) "A universal time scale for vortex ring formation", Journal of Fluid Mechanics. **360**: 121-140.
[13] Akhmetov, D. G., Lugovtsov, B. A. & Tarasov, V. F., (1980) "Extinguishing gas and oil well fires by means of vortex rings", Combustion, Explosion & Shock Waves. **16**: 490-494

