INDIAN INSTITUTE OF TECHNOLOGY KANPUR

AE471A: BTECH PROJECT

PROJECT REPORT

Project title:

Control of vortex shedding behind a cylinder using a control cylinder.

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Abstract:

This project explores the control of vortex shedding behind a circular cylinder using a secondary control cylinder in a two-dimensional flow environment. The experiment was conducted using a soap film tunnel, which provides a nearly inviscid, laminar, and visually transparent medium suitable for studying flow structures. A primary cylinder was placed in the flow path, and a smaller control cylinder was strategically positioned in its wake to observe the effect on vortex shedding.

The objective was to investigate how the presence and placement of the control cylinder influences the wake behavior, particularly the suppression or modification of the Von Kármán vortex street typically formed behind bluff bodies. By varying the position of the control cylinder along the centerline and offset positions, significant changes in the vortex pattern were observed.

a) First we will look how vortex shedding occurs without the control cylinder.
b) Secondly we observe how the secondary (control cylinder) will affect the vortex shedding of the primary one when we move the cylinder in X axis assuming that the soap film is aligned in Y axis.

The results indicate that the control cylinder can effectively alter the vortex shedding behaviour, leading to partial or complete suppression of vortices under specific configurations. This experiment demonstrates a passive flow control strategy with potential applications in reducing vibrations, drag, and noise in engineering systems. The soap film visualization technique proved to be an effective method for capturing and analysing two-dimensional flow features in real time.

Objective:

The objective of this experiment is to investigate how the vortex shedding behind a primary circular cylinder can be controlled by introducing a smaller secondary (control) cylinder. By systematically moving the control cylinder along the X-axis, the study aims to observe changes in the wake pattern and understand how its position influences the suppression or alteration of the Von Kármán vortex street in a two-dimensional soap film flow.

Introduction:

When a fluid flows past a bluff body like a circular cylinder, it leads to the formation of alternating vortices in the wake region, known as a **Von Kármán vortex street**. This unsteady flow phenomenon can cause undesirable effects such as structural vibrations, noise, and increased drag in various engineering applications.

To mitigate these effects, **passive flow control techniques** can be employed. One such method involves placing a **control cylinder** in the wake of the primary cylinder to modify the vortex shedding pattern. This experiment aims to investigate the impact of a secondary control cylinder on the vortex formation behind a primary cylinder using a **soap film tunnel**, which provides a simple and effective way to visualize two-dimensional flow behavior.

The objective is to identify configurations where the control cylinder effectively alters or suppresses vortex shedding, contributing to a better understanding of passive wake control strategies.

Theory:

When a fluid flows past a bluff body such as a circular cylinder, the boundary layer separates from the surface, forming alternating vortices on either side of the wake. This phenomenon, known as **vortex shedding**, creates a repeating pattern called the **Von Kármán vortex street**. The shedding of vortices generates oscillating forces on the body, which can lead to vibrations, noise, and structural fatigue in engineering systems like bridges, chimneys, and aircraft components.

The nature of vortex shedding depends on the **Reynolds number (Re)**, a dimensionless quantity defined as:

$$R_e = \frac{\rho U D}{\mu}$$

Where

- ρ is fluid density
- U is flow velocity
- D is cylinder diameter
- μ is dynamic viscosity

In the range $47 < Re < 10^5$, vortex shedding is periodic and well-developed behind a circular cylinder.

To control this unsteady wake behavior, **passive flow control methods** such as introducing a secondary (control) cylinder have been studied. The presence of a control cylinder in the wake can interfere with vortex formation, altering the shedding frequency or suppressing it entirely. The effect largely depends on its **position, size, and spacing** relative to the primary cylinder.

In this experiment, a **soap film tunnel** is used to study two-dimensional flow. The thin soap film behaves like an inviscid fluid with negligible surface tension, making it an excellent medium for visualizing flow separation and vortex formation. This setup allows direct observation of how the control cylinder influences the vortex street behind the primary cylinder.

Experimental Setup:

The experiment was conducted using the **horizontal soap film tunnel** available in the Fluid Mechanics Lab of the department. This setup allows the generation of a two-dimensional, laminar flow between two horizontally stretched nylon strings, across which a thin soap film flows under gravity.

To adjust the **film tension**, the strings can be tightened or loosened as required, ensuring a uniform and stable film thickness. The **flow rate** of the soap solution through the tunnel was precisely regulated using a **flow meter**, allowing consistent flow conditions throughout the experiment.

A **2% soap solution** was prepared by mixing 200 ml of commercial liquid soap into 10 litters of tap water. This mixture produced a stable film ideal for flow visualization.

To **illuminate the soap film**, a **high-intensity sodium vapor lamp** was used, which enhanced the visibility of flow structures such as vortex shedding and wake disturbances. The sodium lamp provided sharp contrast and clarity under low ambient light conditions.

For **visual recording**, a **high-resolution DSLR camera** was mounted. This setup allowed us to capture clear images and videos of the flow patterns for further analysis.

Soap solution at height for continuous flow.

White board above lamp to visualise the flow more efficiently.

At the end container to collect the soap solution.

Figure1. Soap film tunnel

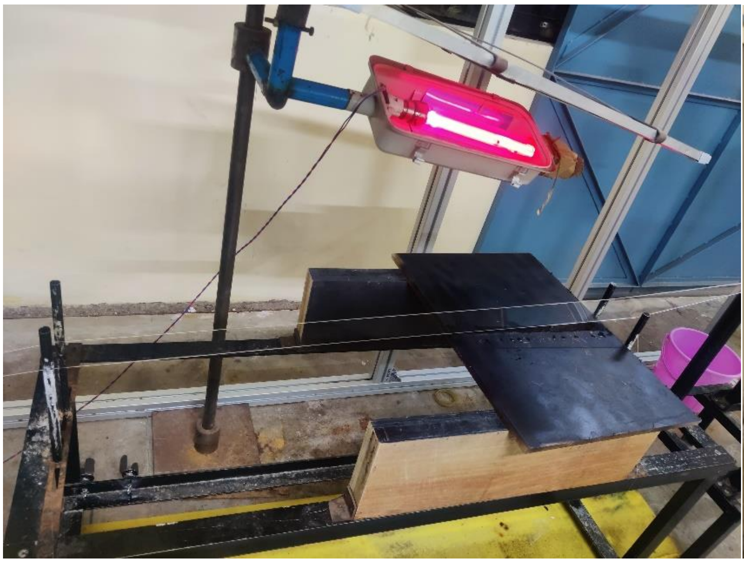


Figure 2. Threads are stretched and soap bubble formed

Figure 3. Soap solution in the container with flow meter.

This setup provided an excellent platform to observe and analyze the influence of a control cylinder on the vortex shedding behind the primary cylinder in real-time.

Methodology:

A primary circular cylinder with a diameter of 10 mm was fixed in the flow path. A secondary control cylinder with a diameter of 5 mm was introduced downstream of the primary cylinder to study its influence on vortex shedding.

The control cylinder was positioned along the X-axis (horizontal direction), while the soap film flow was aligned vertically along the Y-axis. By systematically varying the lateral position of the control cylinder, both on and off the centerline, the resulting changes in the wake structure were observed and recorded. Flow patterns were visualized in real time through the interference fringes in the soap film, allowing clear identification of vortex formation and suppression.

Observation and Results

1. Without Control Cylinder

When only the primary 10 mm cylinder was placed in the soap film tunnel, a clear and periodic Von Kármán vortex street was observed in its wake. The vortices alternated from side to side, forming a symmetrical pattern characteristic of laminar shedding in the observed Reynolds number range. The shedding was strong, continuous, and well-defined, confirming the natural unsteady wake behavior behind a bluff body.

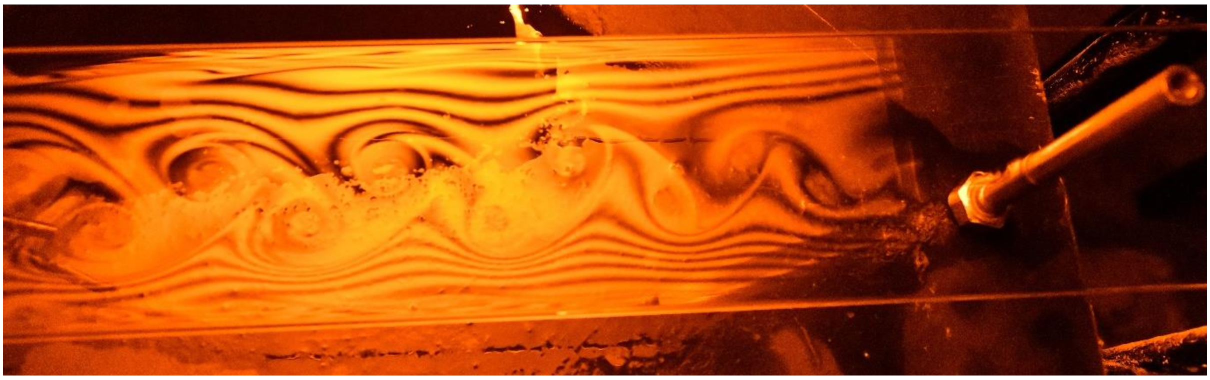


Figure4. Vortex formation in low speed flow of 15 mL^3 /min

Figure5. Vortex formation in high speed flow of 26 mL^3/min

2. With Control Cylinder (5 mm) on Centerline

Placing the 5 mm control cylinder directly on the centerline behind the primary cylinder led to significant disruption in vortex formation. In several cases, the vortex street was either suppressed or became irregular. The presence of the control cylinder appeared to disturb the symmetry of the wake, reducing the strength and periodicity of shedding. In certain positions, the vortex street was completely eliminated.

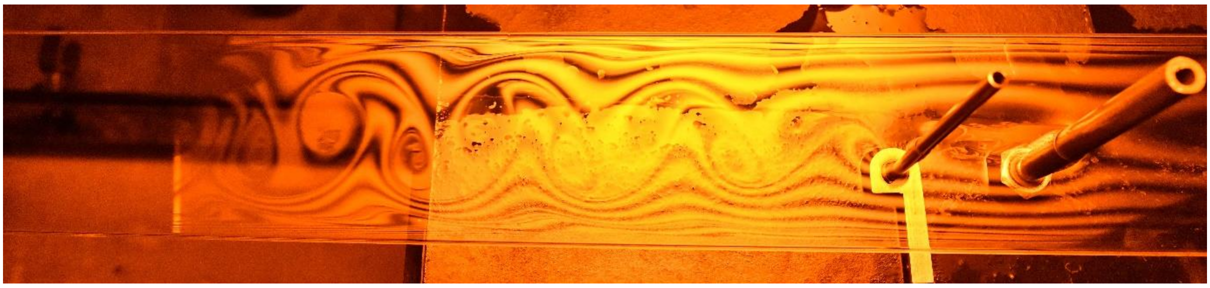


Figure 6. Vortex shedding**With Control Cylinder (5 mm) on Centerline**

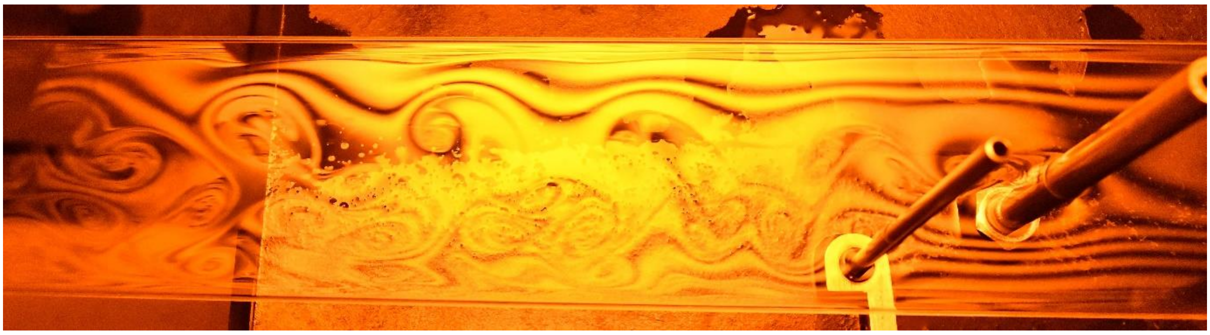
3. Control Cylinder Offset from Centerline

As the control cylinder was moved along the X-axis to positions off the centerline:

- **Slight Offsets:** The wake exhibited asymmetrical shedding, with one side showing stronger vortices and the other side becoming less active.

- **Larger Offsets:** The wake began to recover its periodic shedding behavior, though still with noticeable distortion compared to the baseline (no control cylinder) case.

- **Optimal Position:** Certain intermediate positions yielded the most effective suppression, where the vortex strength decreased and the wake appeared more stabilized.



Overall, the experiment showed that the position of the control cylinder has a significant impact on the wake behavior. The results demonstrated successful passive control of vortex shedding by modifying the geometry of the wake with a secondary bluff body.

Real-World Applications and Future Relevance

The findings from this experiment have meaningful implications for various engineering and industrial fields where control of fluid flow around bluff bodies is critical. The ability to passively suppress or manipulate vortex shedding can contribute to improved performance, safety, and efficiency in the following areas:

1. **Structural Engineering**
   Tall structures like bridges, towers, chimneys, and high-rise buildings are susceptible to wind-induced vibrations caused by vortex shedding. Strategically placed passive control elements—similar to the control cylinder used in this study—can reduce oscillations and prolong structural life without requiring active control systems.
2. **Aerospace and Automotive Design**
   In aircraft, rockets, and automobiles, managing unsteady wake flow can reduce aerodynamic drag and minimize noise. Incorporating small passive elements downstream of structural parts could lead to quieter and more fuel-efficient designs.
3. **Marine Engineering**
   Offshore structures such as risers, pipelines, and underwater cables experience vortex-induced vibrations from ocean currents. Passive wake control strategies

inspired by this study could minimize fatigue and mechanical stress in such components.

4. **Wind and Water Turbines**
   The stability and efficiency of rotating blades can be affected by unsteady wake effects. Insights from vortex control could inform blade design and placement to reduce turbulence and enhance performance.

5. **Bio-Inspired Design**
   This work may also influence biomimetic applications. Many animals—like fish or birds—naturally control wake structures for efficient movement. Passive flow control using secondary structures can inspire more efficient robotic or autonomous underwater vehicle (AUV) designs.

In summary, the passive control method demonstrated in this study shows great potential for real-world application across sectors. Its simplicity, energy efficiency, and effectiveness make it a promising technique for improving flow-related performance and reducing structural risks in future designs.

Discussion & Conclusion

This study demonstrates that introducing a control cylinder in the wake of a primary cylinder can significantly influence vortex shedding behavior. The soap film tunnel provided an effective medium for observing two-dimensional flow patterns in real time.

The presence of the 5 mm control cylinder altered the wake characteristics behind the 10 mm primary cylinder. Centerline placement was most effective in suppressing the vortex street, whereas off-center positions led to asymmetric or partial vortex suppression. These observations confirm that even small geometric changes in the wake can lead to significant changes in vortex dynamics.

The ability to suppress or distort vortex shedding through passive means offers a valuable technique for reducing unsteady forces in engineering systems, such as bridges, towers, and pipelines. The simplicity and clarity of the soap film setup make it an excellent educational and research tool for visualizing flow phenomena.

References

1. Williamson, C.H.K., "Vortex dynamics in the cylinder wake," *Annual Review of Fluid Mechanics*, Vol. 28, 1996, pp. 477–539.

2. Taneda, S., “Visual observations of the flow past a circular cylinder performing various oscillations,” *Journal of the Physical Society of Japan*, Vol. 11, No. 3, 1956, pp. 302–307.

3. Couder, Y., Chomaz, J. M., & Rabaud, M., "On the hydrodynamics of soap films," *Physica D: Nonlinear Phenomena*, Vol. 37, 1989, pp. 384–405.

4. Zdravkovich, M.M., "Flow around Circular Cylinders: Volume 1: Fundamentals," Oxford Science Publications, 1997.