DAYANANDA SAGAR COLLEGE OF ENGINEERING

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Accredited by National Assessment & Accreditation Council (NAAC) with 'A' Grade

Department of Mechanical Engineering

Batch Number 48

Mini Project Final Presentation

Title: Modeling and Simulation of von Kármán Vortex Street of Bluff Bodies for Piezoelectric Energy Harvester

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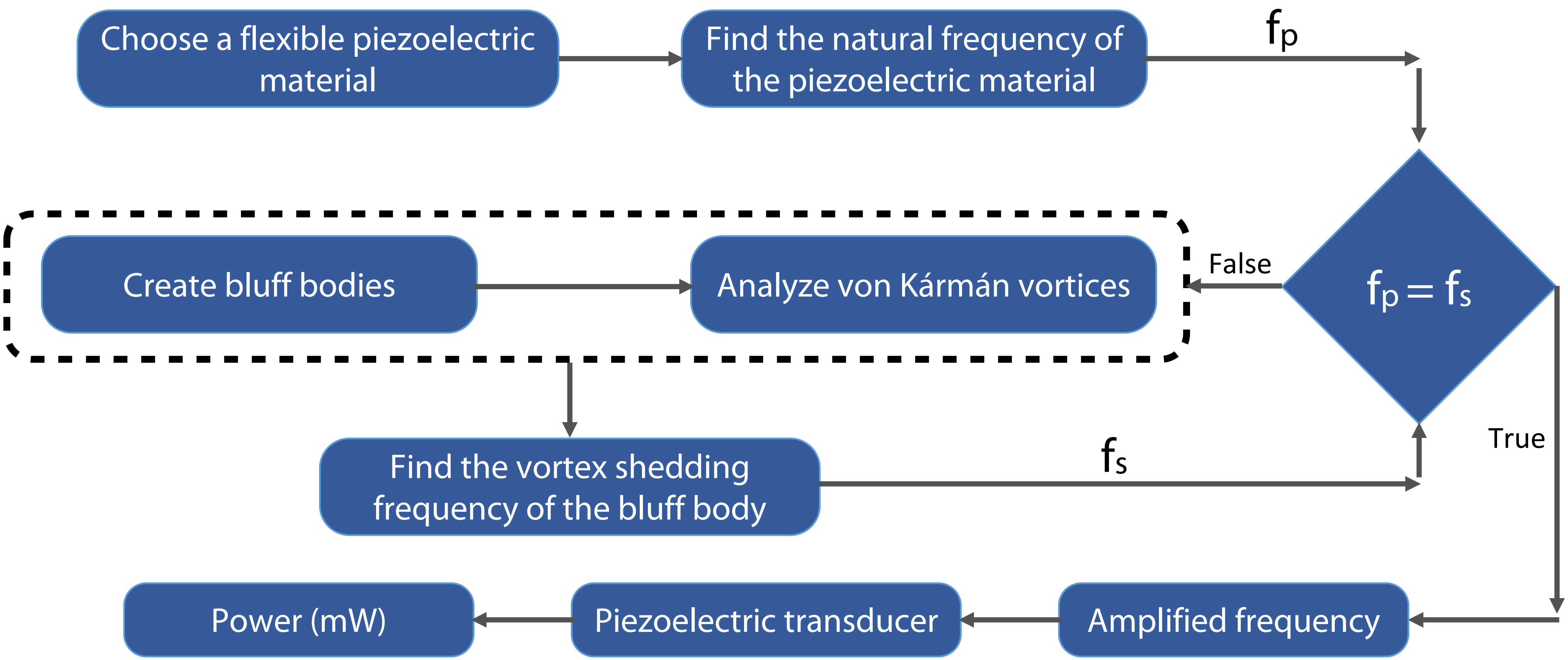
Abstract

This study presents the creation of a von Kármán vortex for a vibrating piezoelectric energy harvester device using a cylinder. The effects of two parameters, which are the diameter and the position of the cylinder, were investigated on the Kármán vortex profile and the amplitude of the vibrating flexible piezoelectric material, respectively. A simulation was conducted to determine the effect of the creation of the Kármán vortex by the bluff body i.e, a cylinder. A piezoelectric energy harvester is attached and vibrated from the vortices generated within the turbulent boundary layers. One of the applications is, this vibration provides a measured output voltage and can be used in wireless sensors.

Objectives of the Project

- To understand the effects of von Kármán vortices
- To simulate the boundary layer separation and vortices generated by bluff bodies
- To model and optimize the bluff body design so as to obtain the desired von Kármán vortex street
- To harvest electrical energy from VIV (*Vortex Induced Vibrations*) with the help of piezoelectric transducer
- To generate sufficient electrical energy to run power sensors

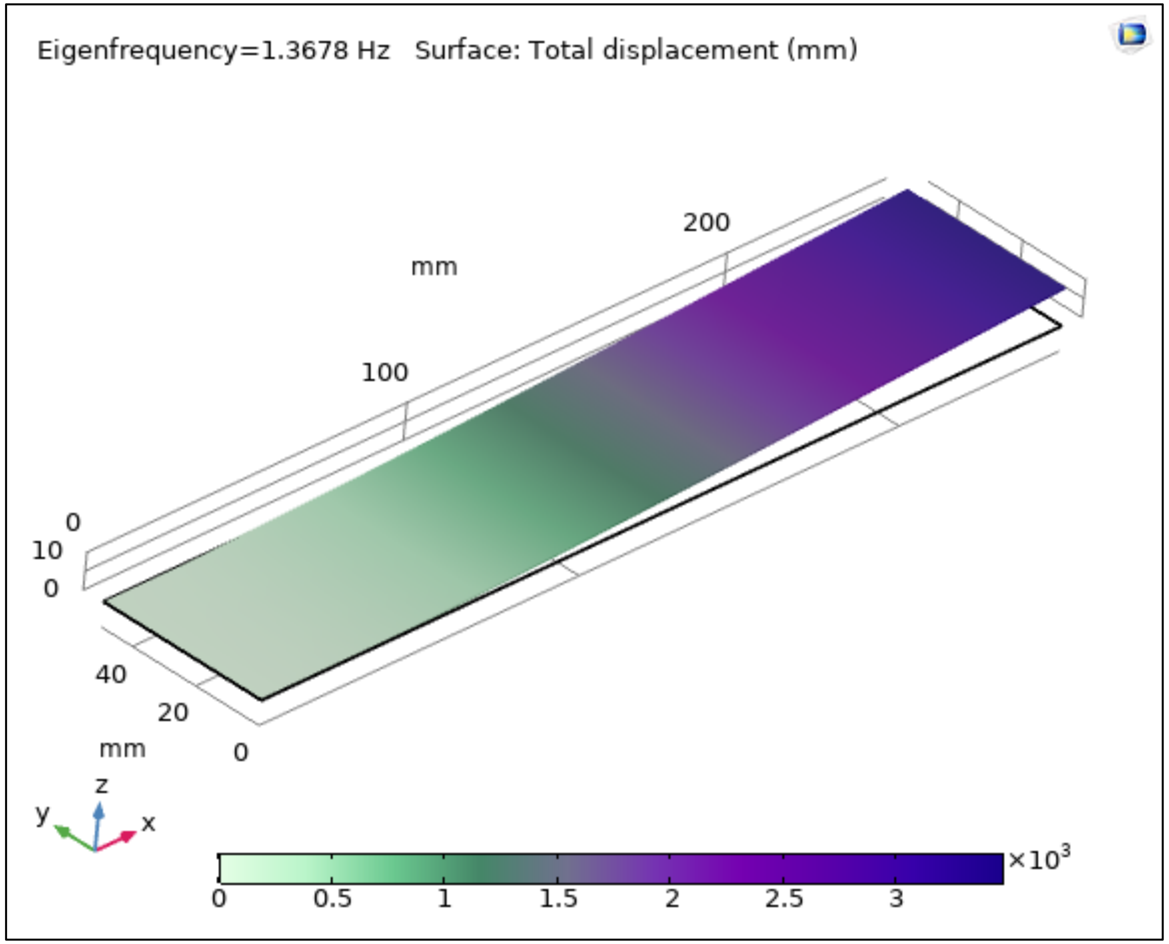
Method and Methodology



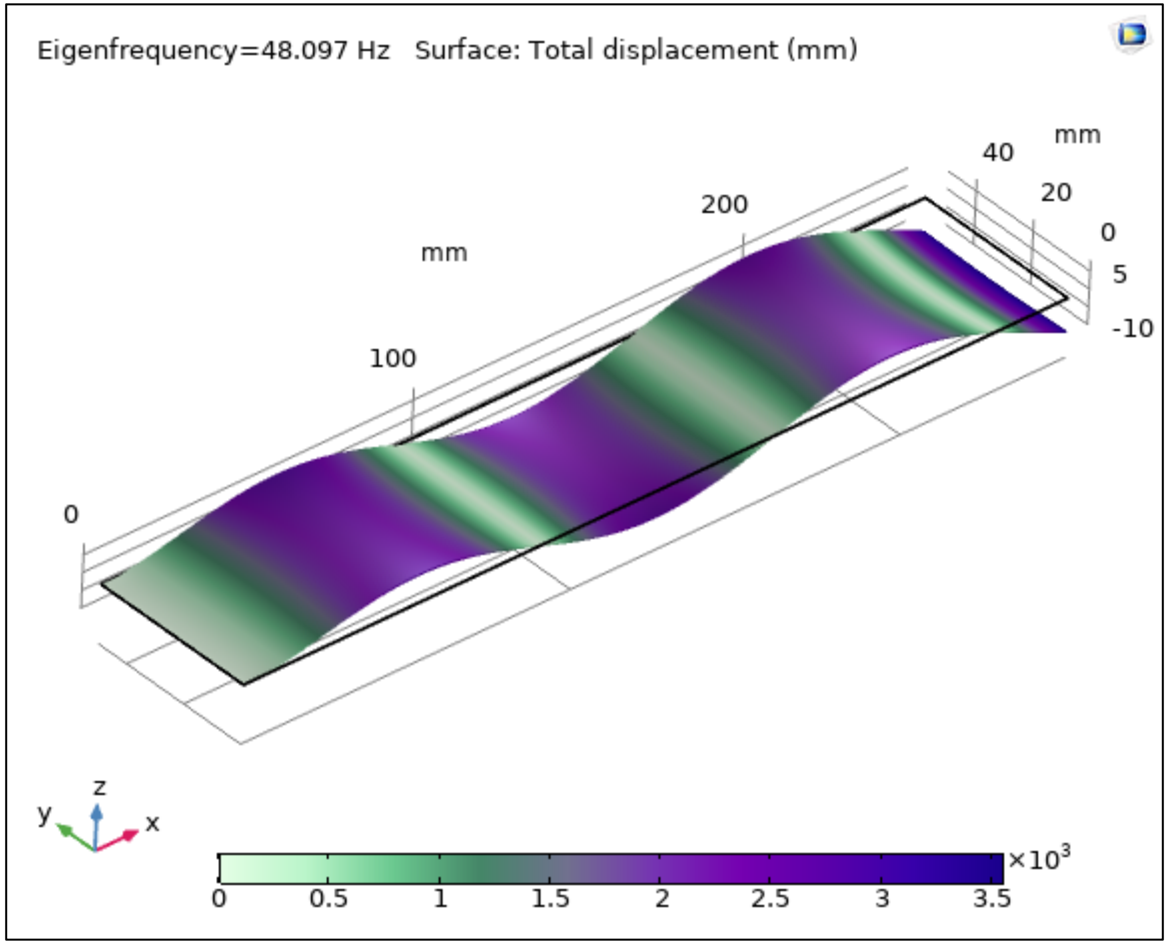
Design, Analysis and Simulation

- For the design of the bluff body, an iterative process was carried out to determine the most suitable dimensional specifications.
- Initially a laminar flow analysis was conducted on different bluff bodies on COMSOL Multiphysics, the following parameters were taken into consideration;
    1. Shape and size of bluff body
    2. Reynolds Number
    3. Strouhal Number
    4. Scruton Number
    5. Mean inflow velocity

Solid Mechanics Study:



PVDF at Mode 1

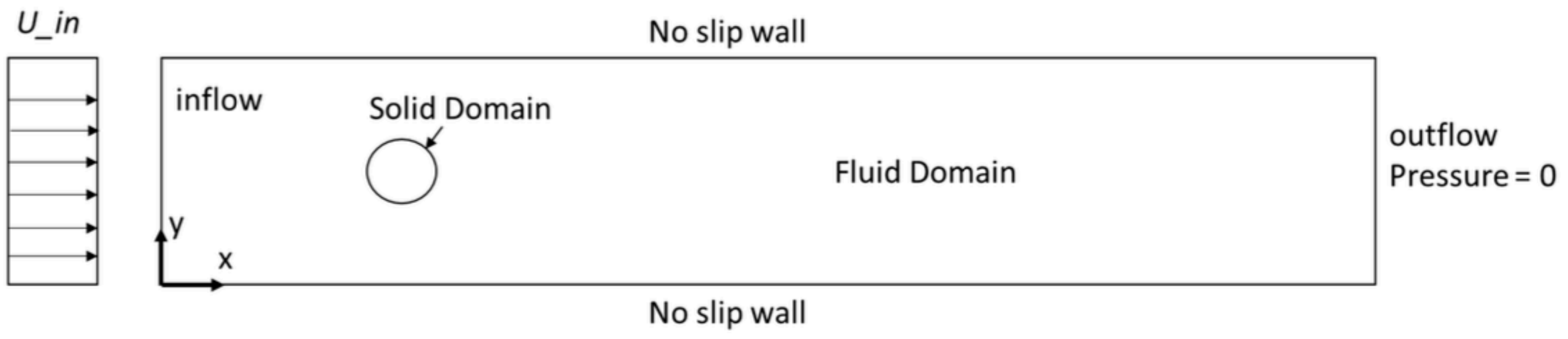


PVDF at Mode 6

Solid Mechanics Study contd.

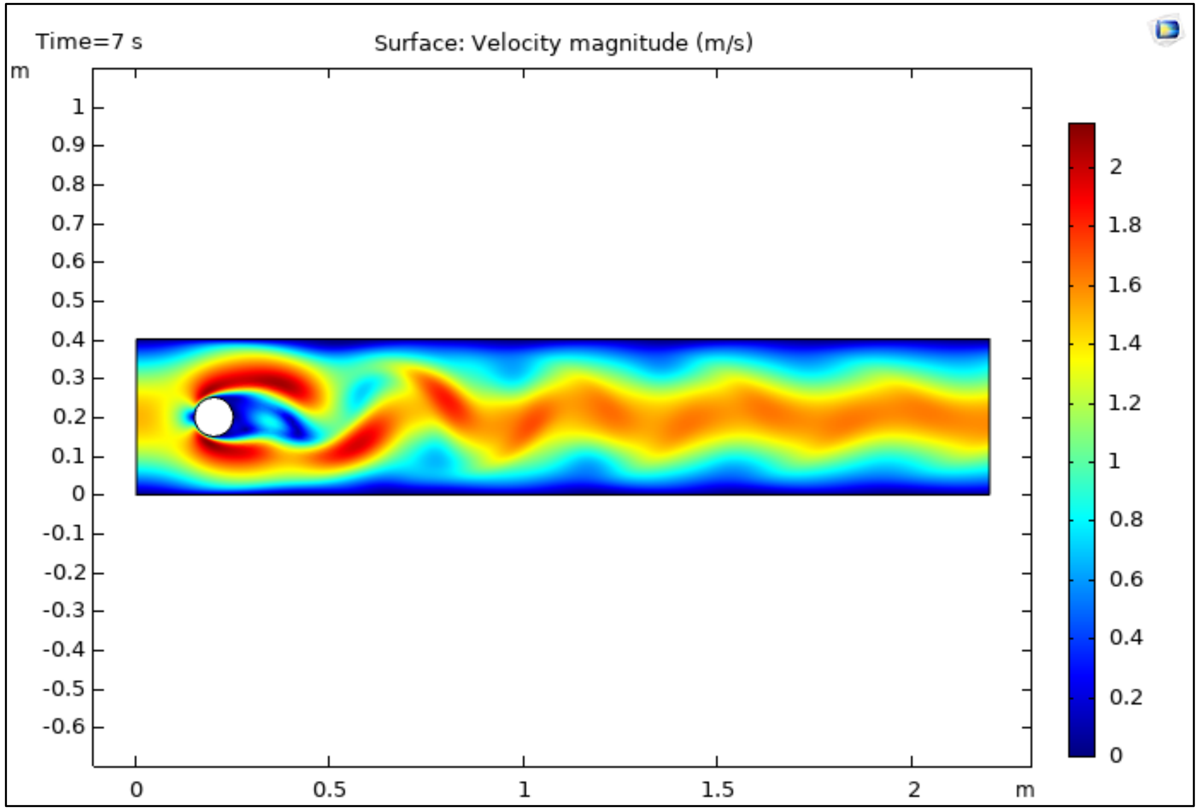
Material	PVDF		PZT-5A	
Mode	Eigenfrequency (Hz)	Angular frequency (rad/s)	Eigenfrequency (Hz)	Angular frequency (rad/s)
1	1.36	8.59	3.76	23.66
2	8.71	54.71	23.96	150.59
3	13.68	85.97	37.66	236.68
4	24.44	153.58	67.29	422.84
5	41.89	263.22	115.33	724.68
6	48.09	302.21	132.41	831.98

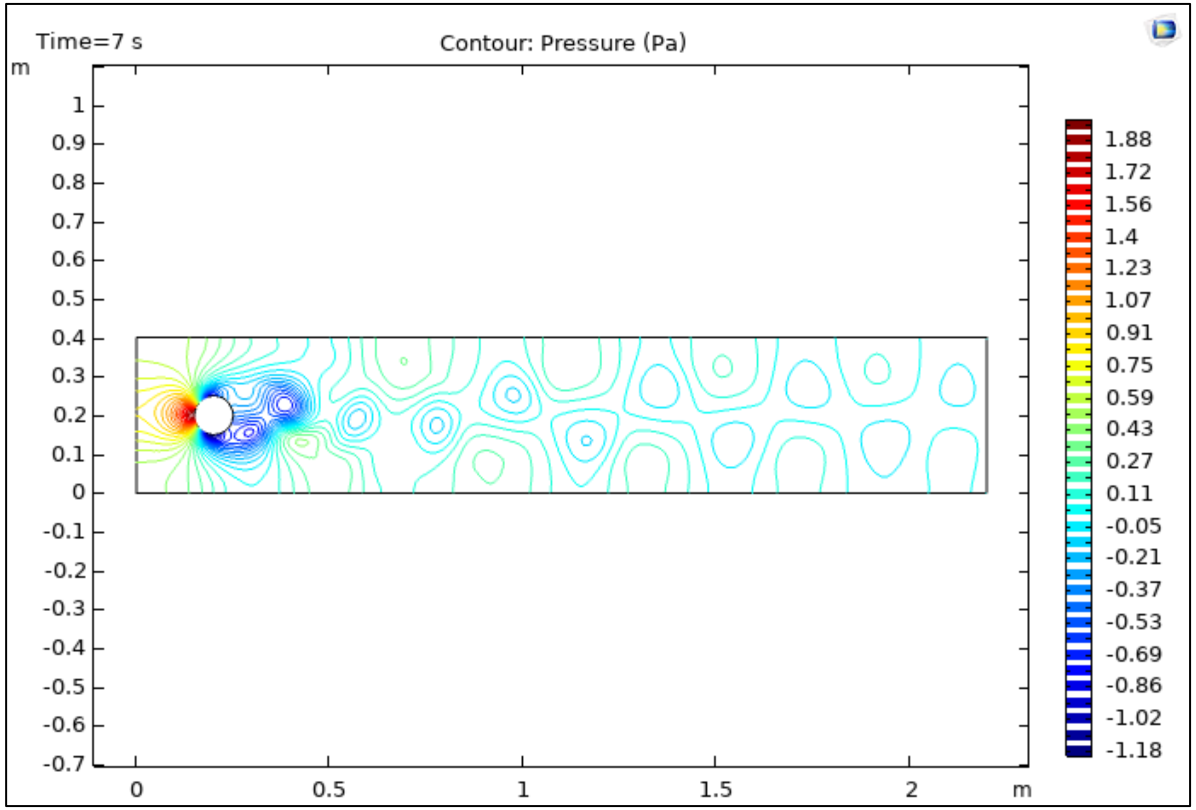
Initial Conditions and Parameters



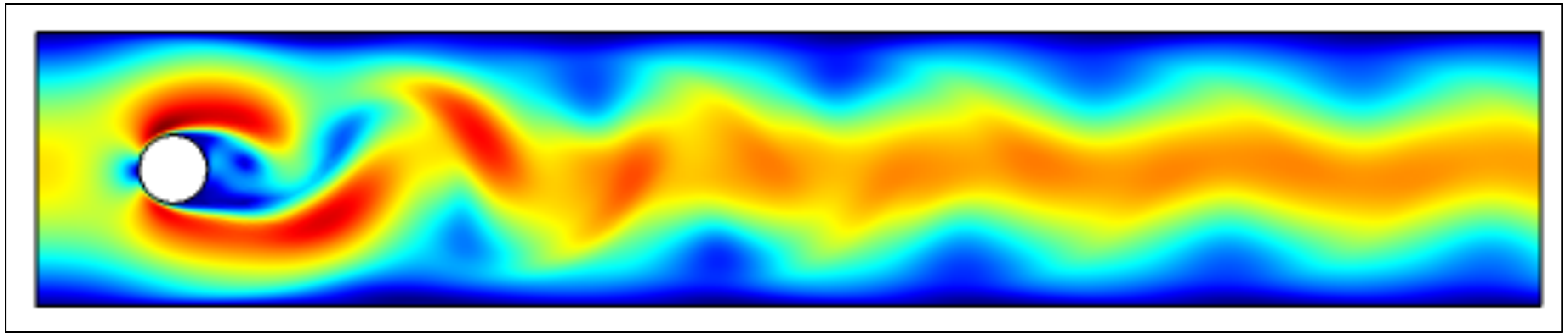
The mean inflow velocity and the diameter of the bluff body was monitored to limit the Reynolds number from exceeding the range of 100 to 300. The following range of Reynolds number is considered as this is the transition range to turbulence in vortex generated by the bluff body and also this is unsteady flow.

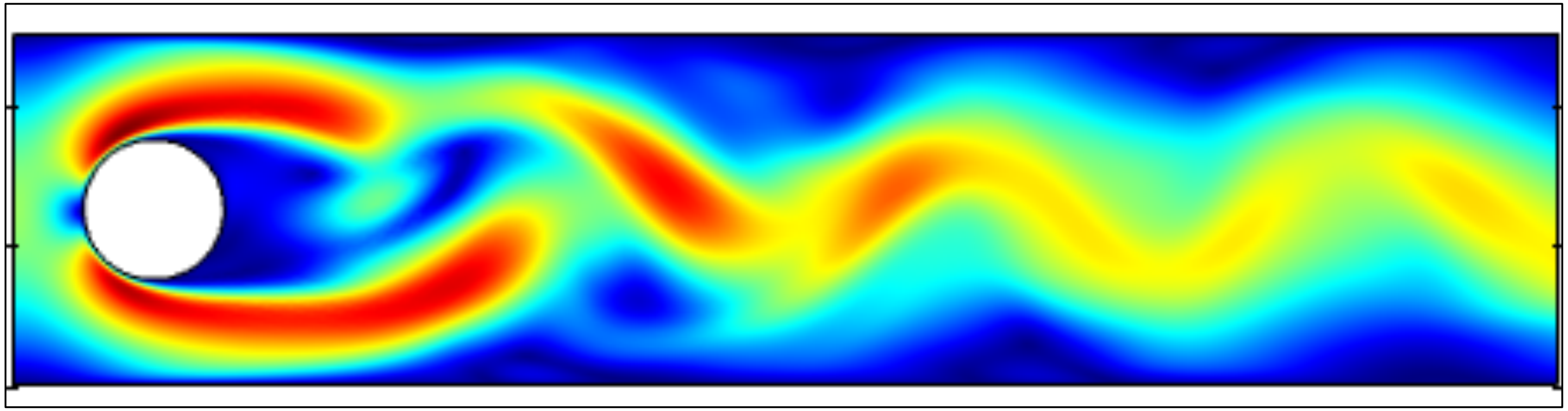
Laminar Flow Simulations



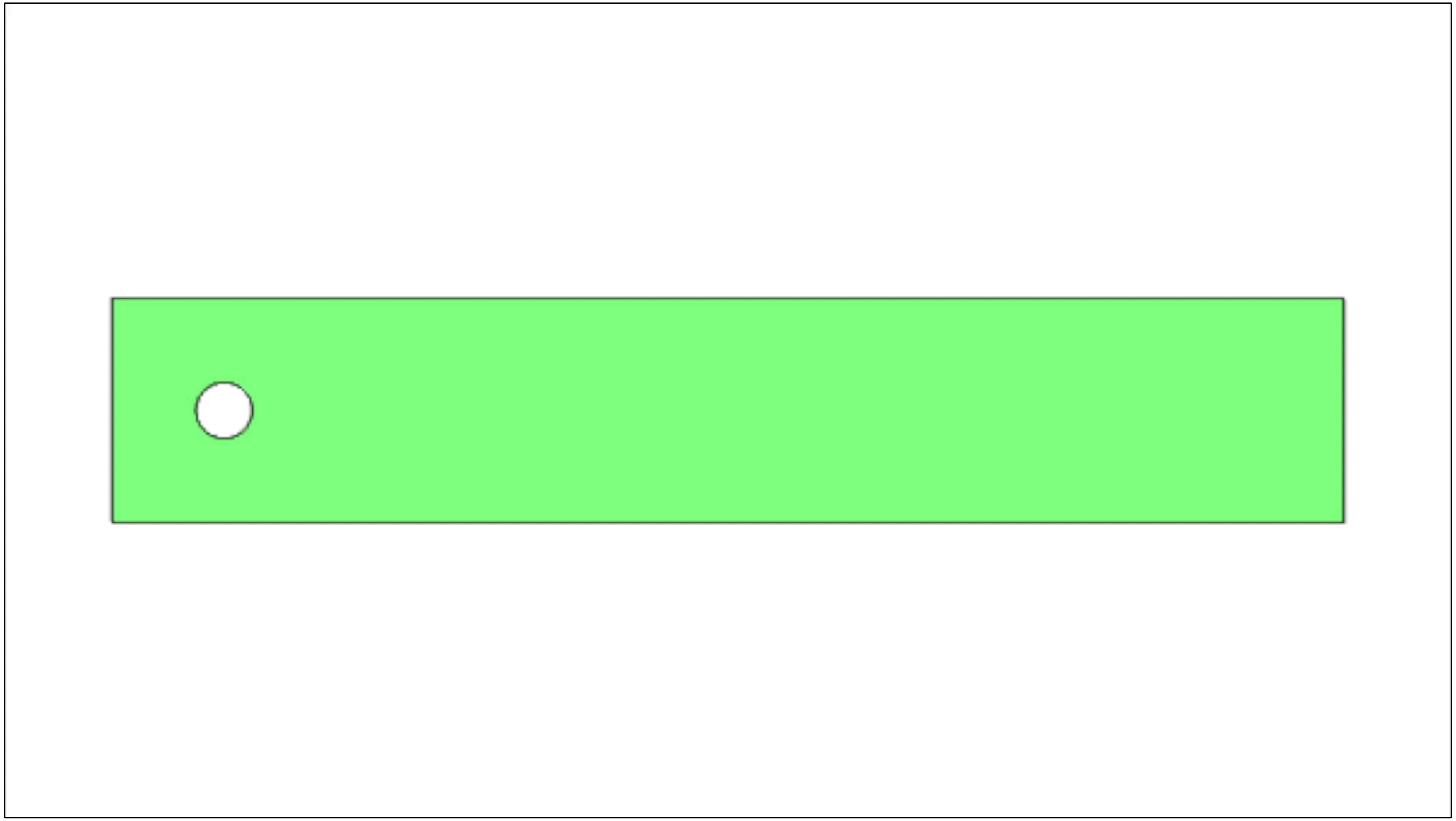


Laminar Flow Simulations contd.

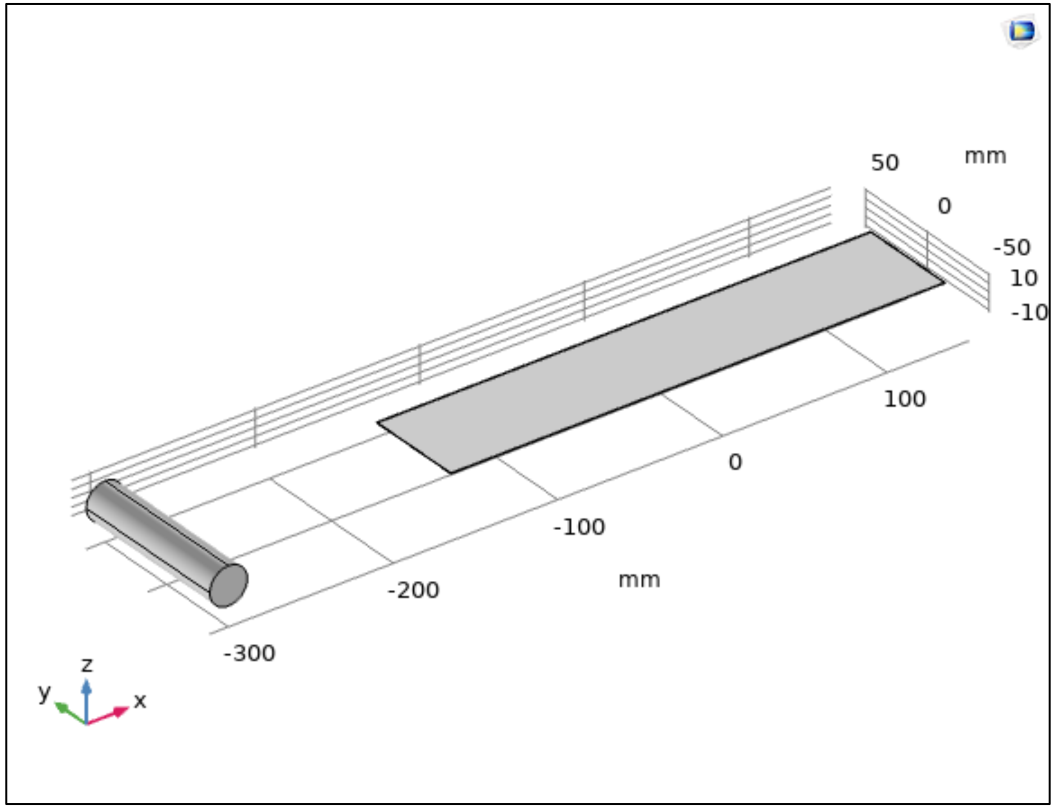


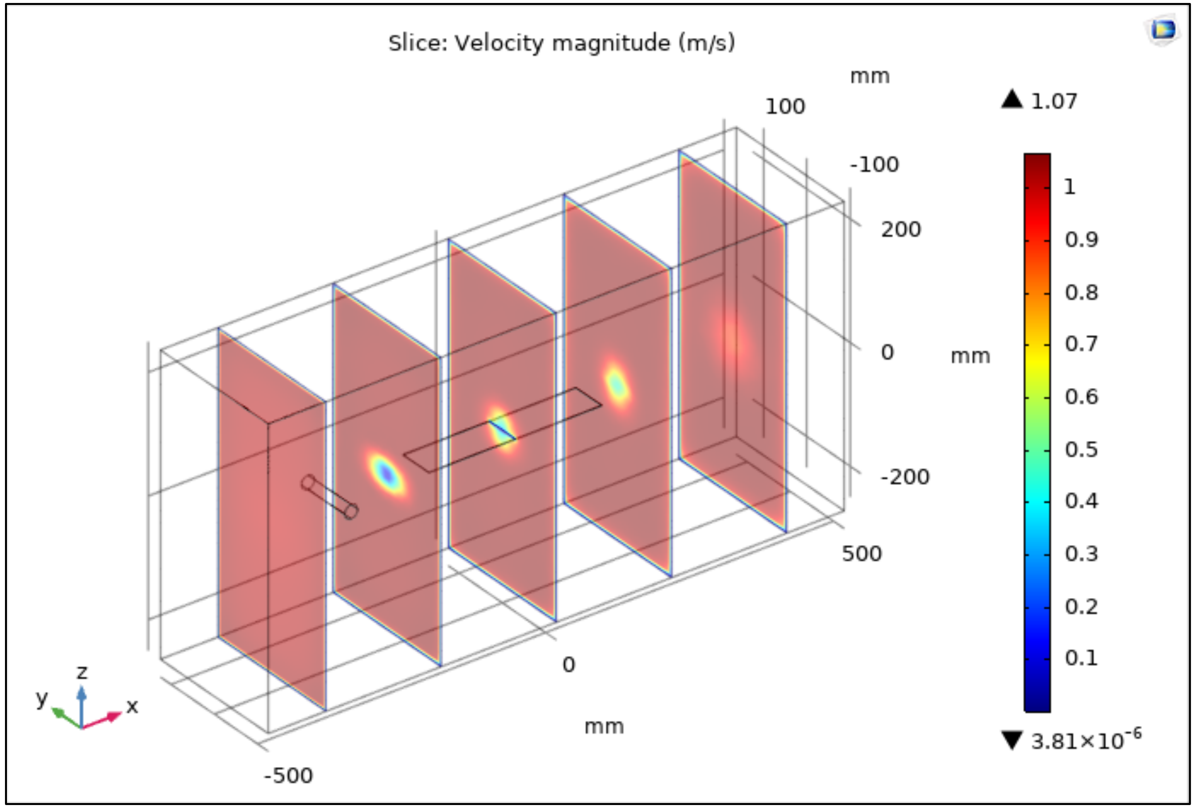


Simulation of Vortex Shedding



Fluid-Solid Interactions





Fluid-Solid Interactions contd.

Mode	Eigen frequency (Hz)	Angular frequency (rad/s)
1	8.74	54.94
2	54.79	344.28
3	69.49	436.67
4	154.78	972.56
5	215.74	1355.56
6	306.69	1927.01

Results and Discussion

Flow visualization is an important tool to better understand fluid dynamics. The power harnessed from this setup can be significantly improved if the alternating frequencies generated from Kármán vortices match the resonant frequency of PVDF.

Solid Mechanics Study

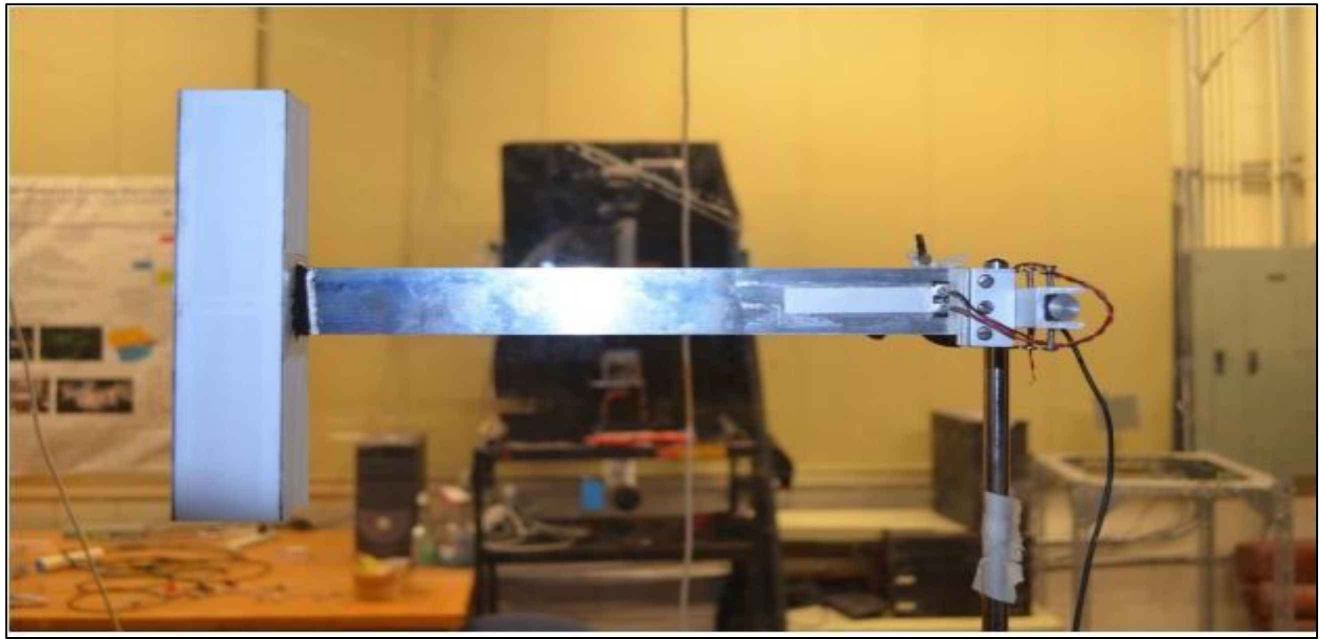
Material	PVDF
Mode	Eigenfrequency (Hz)
1	1.36
2	8.71

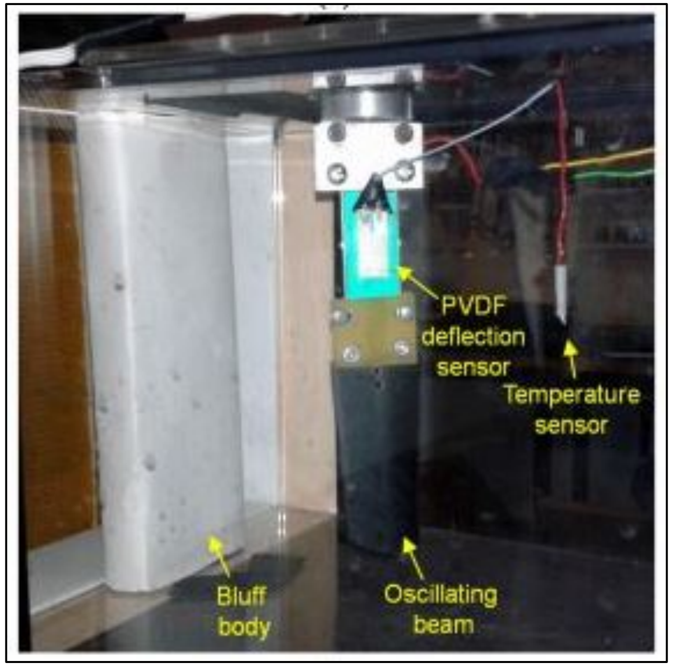
Fluid-Solid Interactions

Mode	Eigen frequency (Hz)
1	8.74

Results and Discussion contd.

The below two images are actual setups of the bluff body and a piezoelectric material in the wake region of the bluff body. A strip of PVDF is attached to the oscillating beam to which a deflection sensor is also attached to measure the frequency.





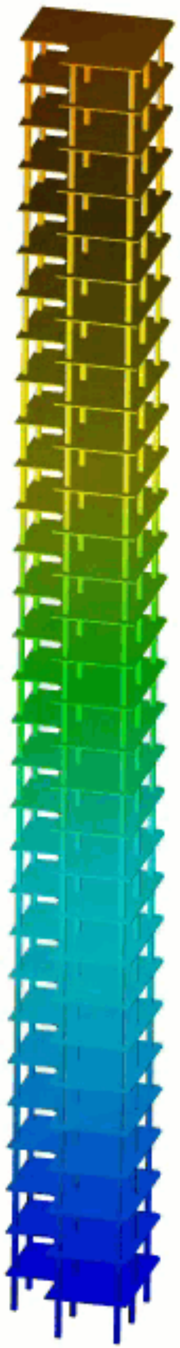
Real Life Applications

CFD vs. Frequency Response Results

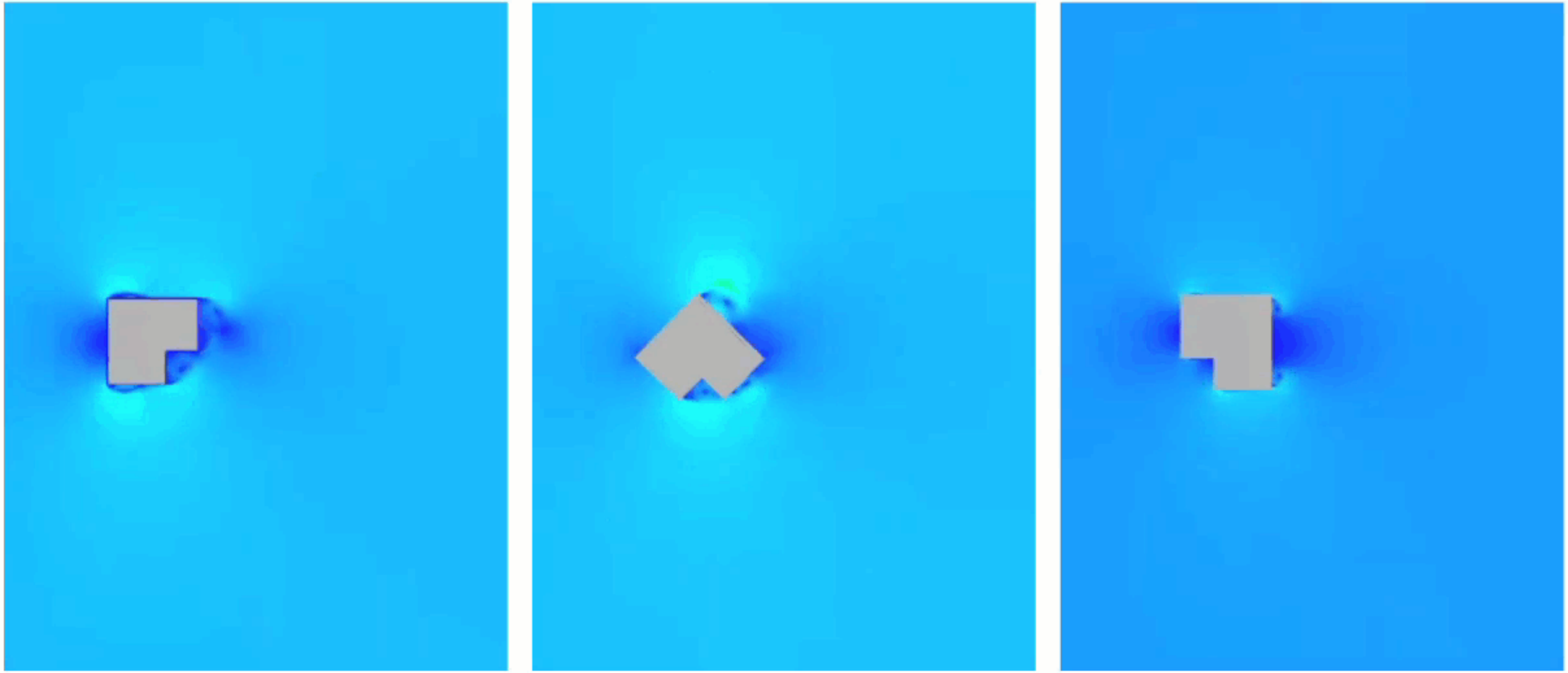
Modal Frequencies (FEA)	
Mode	Frequency
1	0.209739
2	0.218836
3	0.299477
4	0.65987
5	0.679429
6	0.906195
7	1.19709
8	1.22184
9	1.53931
10	1.73041
11	1.76
12	2.2
13	2.3
14	2.35
15	2.9

CFD Analysis	
Flow Direction	Force Frequency
x	1.9
x	2.1
x	2.9
45	0.6
45	2
90	2.2
90	2.6
90	2.6

Modal frequencies compared to vortex shedding analysis



Real Life Applications



Conclusions

- The results of the analyses conducted in this report inclusive of the modelling and simulation of von Kármán Vortex Street, suggests that for the piezoelectric material PVDF, the dimensions, location and structural setup was arrived at after a series of provisional analyses.

- As the research has demonstrated that the shedding frequency generated by the bluff body through von Kármán vortices is nearly equal to the eigenfrequency of the piezoelectric flag.

- This brings the transducer efficiency to its experimentally maximum value. This paper inherently provides an alternative methodology to improve the efficiency of energy harvesters by moulding the system in accordance with the energy harvester, as opposed to the conventional need for changing the chemical and physical composition of the harvester.

Research Paper

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Simulation of Kármán Vortex Street of Bluff Bodies for Piezoelectric Energy Harvesters

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Abstract: This study investigates the creation of Kármán vortices generated from bluff bodies. Computational analyses were carried out to understand the effects of various parameters on the frequency of the vortices. From the concept of resonance and exploiting the deviation in Strouhal's law, we propose to achieve efficient power output from piezoelectricity. After an in-depth survey, flexible piezoelectric materials were considered to be most feasible in the given case for harvesting energy. This paper presents a novel approach to substantiate and consolidate the results of resonance between the shedding frequency from the bluff body and the natural frequency of the piezoelectric material through a one-way coupled fluid-solid interaction analysis. Given the prevalence and protean nature of piezoelectric materials, it is deemed to be the future for energy harvesting and as a source of power for a variety of electronic sensors.

***Keywords**: Kármán Vortex Street, Piezoelectricity, Energy Harvesters, Fluid-Solid Interaction, Vortex-Induced Vibrations.*