International Baccalaureate:
Extended Essay

Physics

Title: Vortex Shedding Frequency

RQ: How does increasing the number of faces of a bluff body (ranging from 2 to 12) affect the vortex shedding frequency in laminar flow, measured in Hz?

Word count: …

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Nomenclature

f_v Vortex shedding frequency (Hz)

L Characteristic length (m)

Re Reynolds number ($dimensionless$)

St Strouhal number ($dimensionless$)

V Flow velocity (m s^{-1})

Introduction

Despite its widespread significance, the study of fluid dynamics is largely overlooked by the IB Physics syllabus. Defined by the American Heritage Dictionary as “the branch of applied science that is concerned with the movement of liquids and gases”, fluid dynamics is one of the two subfields of fluid mechanics, “the study of fluids and how forces affect them”1.

From the air we breathe to the water we consume; fluids are present in almost every aspect of our lives. Although observing fluids in action is a daily occurrence for all, countless remain unaware of the highly complex and intricate theories governing these seemingly simple and elementary phenomena. Ultimately, a profound youthful interest in cars and planes - everything with an engine really - coupled with a fascination for the motion of fluids led to the topic of this essay: vortex shedding. Specifically, this essay will concern itself with the question: **How does increasing the number of faces of a bluff body (ranging from 2 to 12) affect the vortex shedding frequency in laminar flow, measured in Hz, in a 2D plane?**

Over the past century, vortex shedding has garnered a multifold of attention, with hundreds of papers published2, allowing one to consider it as one of the most extensively studied phenomena in fluid mechanics of this time3. This partially elucidated phenomenon is quintessential in a broad range of scientific and engineering contexts. 3Bridges may suffer from vortex shedding excitation, a severe challenge which undermines their structural integrity. 5This was exemplified by the collapse of the Tacoma Narrows Bridge on the 7th of November 1940, where vortex shedding acted as the instigating factor. Aside from maintaining bridges, vortex shedding will continue to hold significance, especially when considering the rapid progress in the field of aerospace.

As previously mentioned, the IB Physics Syllabus doesn’t directly concern itself with vortex shedding or, in general, the majority of fluid dynamics. 8Nevertheless, links can be made to section C: Wave Behavior. Section C.1, Simple Harmonic Motion, concerns itself with, as the name suggests, simple harmonic motion, 9“the simplified theoretical model representing oscillations”. Basic concepts such as frequency and time period are discussed, ideas required in order to analyze the frequency of the vortex shedding caused by a bluff body. Furthermore, the topic of this essay also links to section C.4, Standing Waves and Resonance. Concepts of natural frequency, vibrations and resonance are key when discussing the problems caused by vortex shedding, like the one detailed above, and the significance of the frequency of vortex shedding.

Background

Fundamentals of Fluid Dynamics

Firstly, the definition of vorticity, a vortex and a bluff body must be understood. Vorticity is the 6"curl of velocity", in other words the 7"rate of local fluid rotation". A vortex is the 7"rotating motion of a fluid around a common centerline", characterized by the "vorticity in the fluid". Bluff body is defined as an object that, 8"as a result of its shape, has separated flow over a substantial part of its surface".

Next, one must distinguish between a Newtonian and a non-Newtonian fluid. A Newtonian fluid is a fluid in which 3"viscosity is constant and not dependent on the shear rate", whereas a non-Newtonian is a fluid in which its viscosity is dependent on the shear and therefore is not constant.

Moreover, one must also consider the type of flow. There are two key factors of flow when investigating vortex shedding: laminar vs. turbulent flow and compressible vs. incompressible flow. Laminar flow is characterized as a 2"flow condition in which fluid particles follow smooth and steady streamlines with little movement of particles between adjacent layers". On the other hand, turbulent flow is known to have "chaotic variations in the magnitude and direction of fluid particle velocity and amplitude of pressure". A compressible flow is a flow in which the 3"density of a fluid does not remain constant", conversely, an incompressible flow is a flow in which the "density of fluid remains constant". To adhere to the scope of this essay, vortex shedding in a Newtonian fluid which exhibits laminar and incompressible flow will be analyzed.

Lastly, two dimensionless numbers must be considered: the Reynolds' and Strouhal number. The Reynolds' number expresses the 4"ratio between inertial and viscous forces". Given by the equation (equation), it allows one to classify if a flow is laminar or turbulent, with low Reynolds' numbers signifying laminar flow and high Reynolds' numbers indicating turbulent flow. The Strouhal number denotes the 5"ratio of inertial forces due to the local acceleration of the flow to the inertial forces due to the convective acceleration". 5Given by the equation (equation), high Strouhal numbers represent a flow in which oscillations dominate, whereas low Strouhal numbers characterize a flow in which oscillations are carried away by the high-velocity fluid.

Works Cited

"List of Figures in LaTeX", chatgpt.com/c/67adcdd2-c90c-800c-8b14-b2ff05229044. Accessed 13 Feb. 2025.