Vortex-Induced Vibrations: From bio-inspired sensors to design of marine structures

Heather Beem, Dixia Fan, Hendrik Hans, Fangfang Xie, Remi Bourguet, Michael Triantafyllou

Department of Mechanical Engineering, Center for Ocean Engineering

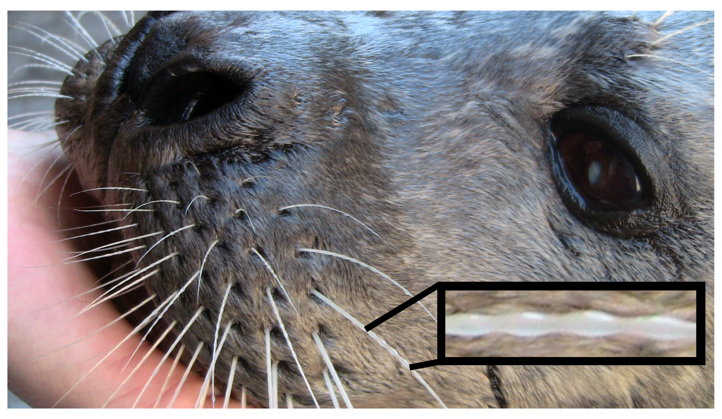
censam · Sea Grant · SMART Singapore-MIT Alliance for Research and Technology

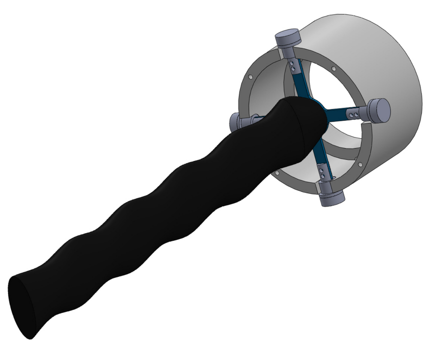
As water flows across a bluff body (i.e. cylindrical object), the object tends to vibrate. This is a result of the flow being unable to stay attached to the body surface and therefore peeling off into swirling vortices. The shedding occurs on alternate sides of the object. Each vortex exerts a force back onto the object, causing the object to move in an oscillatory manner.

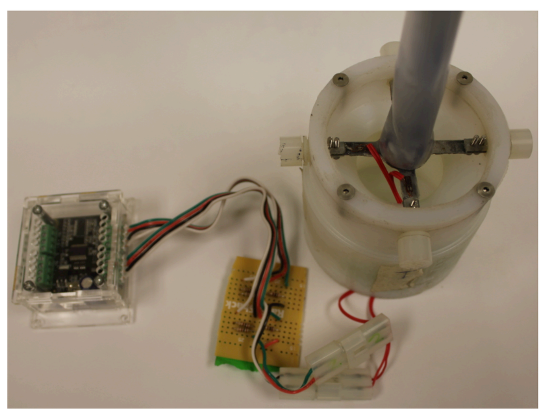
We study this fundamental fluid mechanics phenomenon of VIV with two goals: 1- To better design and predict performance of large offshore structures and 2 - To design new vibration-based sensors mimicking the whiskers of harbor seals, used to detect specific flow features.

Seal Whiskers as Sensors

Harbor seals can use their whiskers to detect the wake of a fish up to 30 seconds after it has passed [1]. This is enabled by the unique vibration properties of their whiskers.







A new sensor has been designed to mimic the harbor seal whisker's ability to detect vortex wakes. A flexure-based system allows the model whisker to freely vibrate in response to the flow conditions.

Towing tank experiments with the sensor trailing a circular cylinder elucidate the mechanisms of detection that seals may employ. The whisker's undulatory, elliptical shape reduces VIV in open water. Thus, the device provides a clear indication of the wake because it 1- vibrates with high signal-to-noise ratio and 2- synchronizes with the wake's frequency.

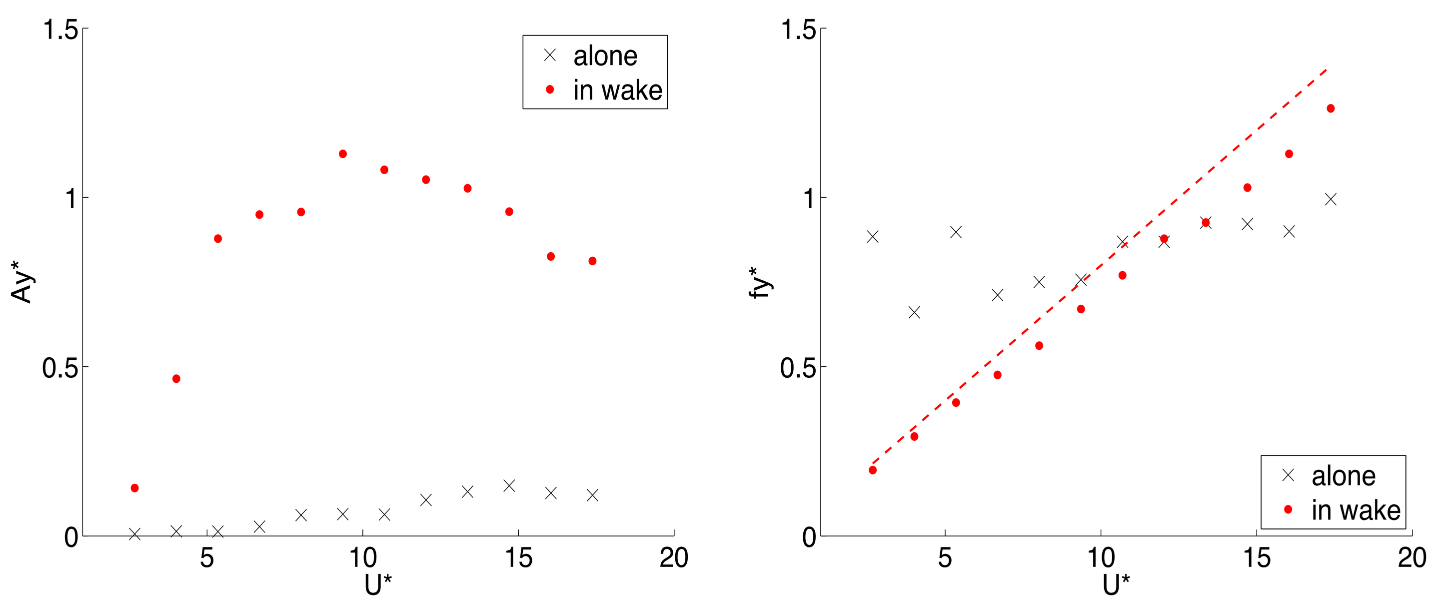


Fig. 1 Non-dimensional amplitude (Ay*) and frequency (fy*) versus the reduced velocity ($U^* = U/(f_n d)$) highlight the sensor's response to a vortex wake.

This technology can enable AUVs to *passively* "feel" the flow. With minimal power, *targeted sensing* can be used to hone in on objects of interest.

Hydrodynamics of a Blowout Preventer

Motivated by safe design of ultra-deep offshore wells, an investigation of the hydrodynamic performance of a riser-BOP (Blowout Preventer) system has been conducted.

This initial study investigated the potential VIV characteristics of a new BOP design. Forced vibration experiments of a scaled model in a towing tank were used to build a database of hydrodynamic coefficients. These will then be incorporated into a detailed model of the global riser dynamics. CFD was used to reveal the underlying mechanisms.

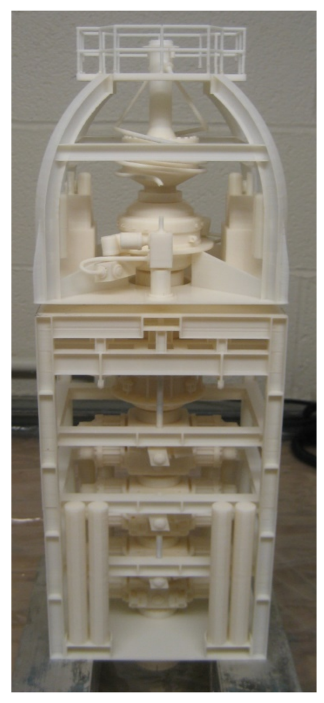


Fig.1 3D-printed, scaled model of the BOP

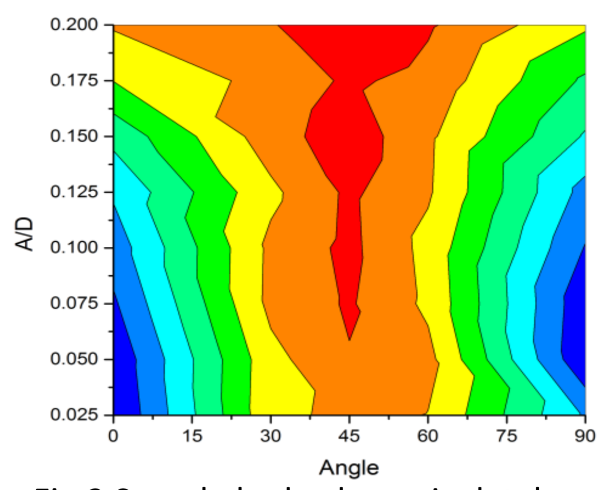


Fig.2 Sample hydrodynamic database (C_d) for BOP

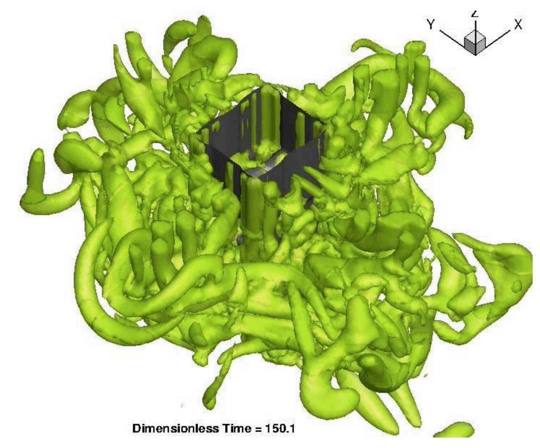


Fig.3 CFD on the BOP oscillating in still water highlights a large vortex ring

Global Riser-BOP-Casing Model

A global model of the riser-BOP-casing system has been developed. It is implemented into code, which includes the riser section encountering wave excitation at a point along its length, a BOP section with distinct mass and bending properties and with externally imposed hydrodynamic coefficients, and a soil/casing region modeled with equivalent springs and dashpots.

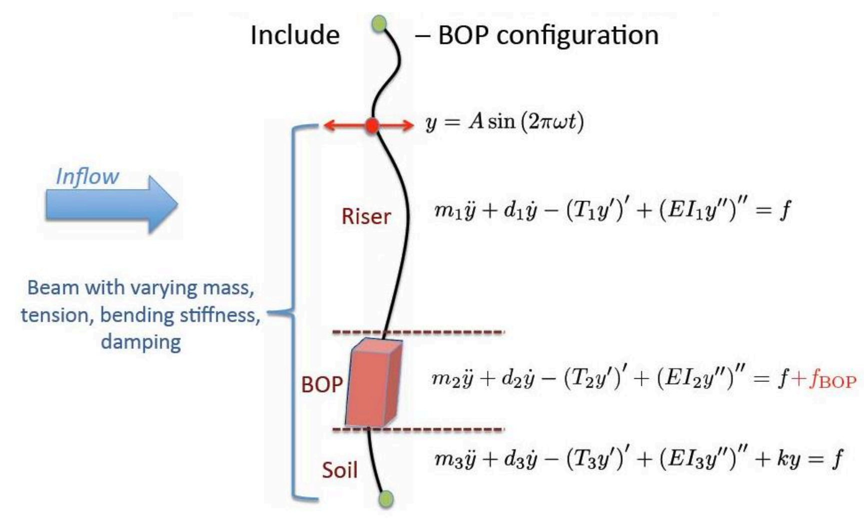
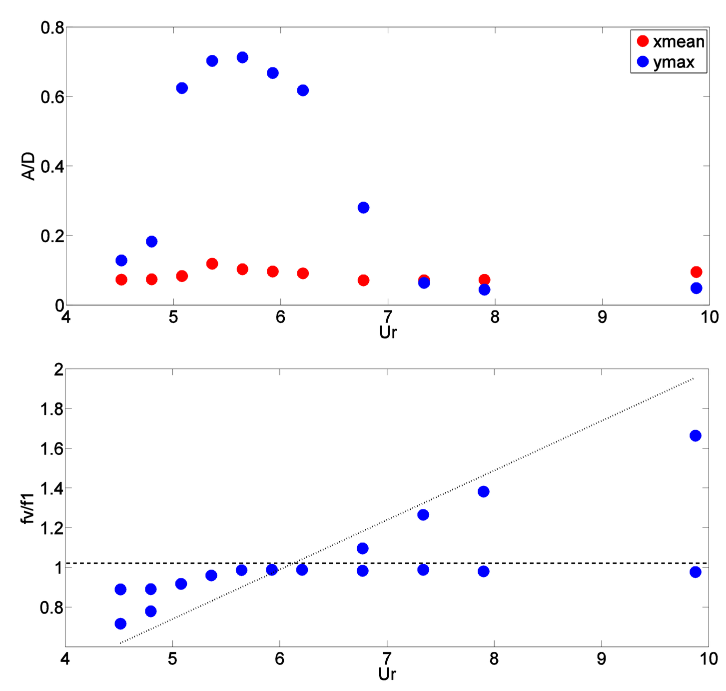


Fig.4 Riser with BOP undergoing wave-induced excitation

Flexible Cylinders - Direct Numerical Simulation

A numerical simulation tool has been developed to study VIV on flexible cylinders. This tool uses Direct Numerical Simulation (DNS) with Smoothed Profile Method Formulation (SPM) [2]. It employs a fixed computational mesh without conformation to the geometry of the particles. The method represents the particles by certain smoothed profiles to construct a body force term added into the Navier–Stokes equations.

Use of this tool provides the advantage of modeling multiple complex shapes. This holds great promise for studying such systems as dual flexible risers or the aforementioned flexible riser+BOP model.



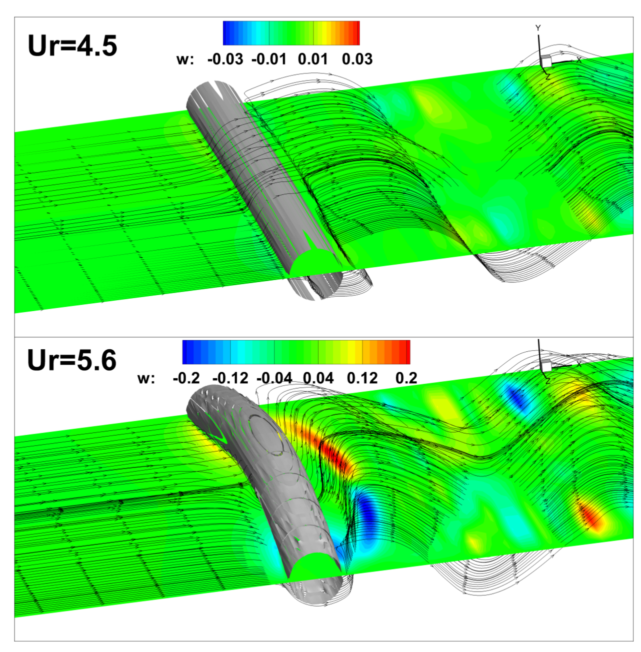


Fig. 1 VIV of flexible cylinder by DNS-SPM code. (a) Amplitude of vibrations as a function of the reduced velocity(Ur). (b) Vibration frequency of flexible cylinder with Ur. (c) Sketch of w-velocity contour of flow around flexible cylinder.

References:

[1] Schulte-Pelkum, N., et al. "Tracking of biogenic hydrodynamic trails in harbour seals (Phoca vitulina)." *Journal of Experimental Biology* 210.5 (2007): 781-787.

[2] Luo X., Maxey M., Karniadakis G.: "Smoothed profile method for particulate flows: error analysis and simulations." *J. Comput. Phys.* 228, 1750–1769 (2008)

Acknowledgments:

This research programme/project is funded by the National Research Foundation (NRF), Prime Minister's Office, Singapore under its Campus for Research Excellence and Technological Enterprise (CREATE) programme. Support was also provided by ONR grant N00014-13-1-0059, monitored by Thomas Swean, Jr. The authors also acknowledge the Wiliam I. Koch Chair funding.

Thanks to Kathy Streeter and the New England Aquarium Staff for allowing us take close-up pictures of their seals. Drs. Dahl and Weymouth provided advice and support, and Matthew Hildner assisted in the design and testing of the whisker sensor.