Dynamics of curved cantilevered pipes conveying fluid

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Abstract. The dynamics of curved cantilevered pipes conveying fluid was studied experimentally. Besides displaying a rich dynamical behaviour, interest in the subject arises mainly because in real-world applications, such as soft robots and solution mining, fluid-conveying pipes usually suffer geometric imperfections, often resulting in a curved pipe shape. A table-top-size apparatus consisting of a pressure vessel and a hanging straight or curved cantilevered pipe was utilized. Four different scenarios were investigated: (i) a straight pipe discharging water and submerged in air (pressure vessel filled with air), (ii) a curved pipe discharging water and submerged in air, (iii) a straight pipe aspirating water and submerged in water (pressure vessel filled with water), and (iv) a curved pipe aspirating water and submerged in water. It was found that curved cantilevered pipes conveying fluid exhibit interesting and extraordinary nonlinear fluid-structure interaction dynamics.

Introduction

The moderately simple fluid-elastic system of a pipe conveying fluid displays a rich dynamical behaviour and has become a *paradigm* in dynamics [1]. Even though the gyroscopic conservative system of a pipe with both ends supported cannot flutter [2] — despite the prediction of coupled-mode flutter by linear theory — cantilevered pipes become unstable via either a sub- or supercritical Hopf bifurcation into periodic motion [3]. Exploring the underlying Fluid-Structure Interaction (FSI) mechanisms of the dynamics of pipes conveying fluid, some studies in this topic are fundamental, rather than "application oriented" [4]. The interested reader is refereed to [1,4] for a comprehensive review of the extensive studies on the subject. Compared to straight pipes, studies on initially curved pipes are limited — even though pipes commonly used in real-word applications usually suffer geometrical imperfections, including curvature. Additionally, works concerning curved pipes are mostly focused on pipes with supported extremities. The seminal work of Misra et al. [5,6], which compares the results of extensible or inextensible centreline theories, and that of Zhou et al. [7] investigates the dynamics of curved cantilevered pipes discharging fluid only theoretically. To the best of authors' knowledge, there is no experimental study investigating the dynamics of cantilevered *curved* pipes discharging or aspirating fluid. Motivated by this lacuna, the purpose of this study is to explore experimentally the dynamics of initially curved fluid-discharging/aspirating cantilevered pipes, using the facility shown in Fig. 1.

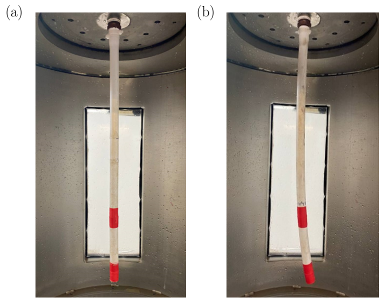

Figure 1: Photograph of (a) straight, and (b) curved cantilevered pipe used in the experiments.

Results and discussion

The flow velocity was increased to instability, and the motion of the pipe was tracked with a non-contacting high-speed camera system. The obtained time-series data from the recorded videos was processed to yield bifurcation diagrams, phase portraits, PDFs, PSDs, Lyapunov exponents, and position-triggered Poincaré maps. It was found that both discharging and aspirating curved pipes undergo a large flow-induced static deformation prior to the onset of an oscillatory instability about the static equilibrium position. Compared to straight pipes, the onset of flutter instability of their curved counterparts occurred at almost the same flow velocity. However, it may depend on the initial curved shape of the pipe, and this needs further investigation.

References

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