Nonlinear dynamics of imperfectly supported pipes conveying fluid

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Abstract. We present numerical results from ongoing research on the nonlinear dynamics and stability of flexible pipes conveying fluid, imperfectly supported at the upstream end (i.e., inlet) and free at the other (i.e., exit). The three-dimensional (3-D) nonlinear equations of motion are developed using the extended Hamilton's principle, and the support imperfection is modelled as cubic stiffness terms. The support imperfection appears to alter the dynamics of the pipe in several ways, including critical flow velocities, amplitude of oscillations, and 2-D/3-D motion.

Introduction

Pipes conveying fluid are ubiquitous in engineering systems. Examples are brine strings used in solution mining and underground hydrocarbon storage, and seawater intake risers used in natural gas liquefaction. Flexible pipes conveying fluid with one end free exhibit quite complex and sometimes unexpected or counter-intuitive dynamical behaviour. Among those are 'destabilization by damping' and chaotic motion of cantilevered pipe with an end-mass [1]. Despite a large volume of studies on the dynamics of pipes conveying fluid, with few exceptions, all deal with perfectly supported systems, such as, cantilevered, pinned–pinned, and clamped–clamped pipes. Our research is motivated by the fact that in real-world systems, loose or imperfect supports may exist or occur (due to, e.g., manufacturing defects, installation errors, or wear), which might alter the dynamics and stability of the system. Kheiri et al. [2] developed a 2-D linear model to examine the effects of imperfect upstream (or inlet) support on the stability of pipes conveying fluid. The imperfectly-supported pipe was found to be generally less stable compared to the cantilevered (or perfectly-supported) pipe conveying fluid. Kheiri [3] developed a 2-D model to investigate the nonlinear dynamics of imperfectly-supported pipes conveying fluid. Large-amplitude oscillations and chaotic motion were observed. The present work is the extension of the authors' previous studies, with a special focus on 3-D dynamics and support imperfection asymmetry.

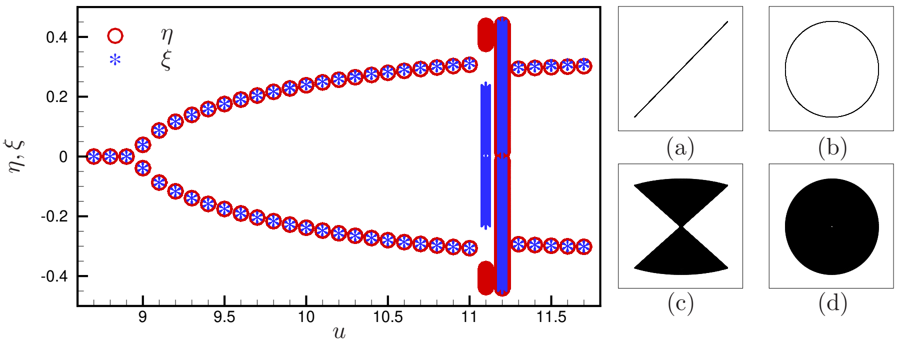

Figure 1: Bifurcation diagram showing the variation of the peak dimensionless displacement of a horizontal pipe conveying fluid as a function of the dimensionless internal flow velocity, u (mass ratio: $\beta = 0.45$, support imperfection: $\kappa = 30\eta' + 300\eta'^3$). The subplots show the trajectory of the free end of the pipe at (a) $u = 10.5$, (b) $u = 11.6$, (c) $u = 11.1$, and (d) $u = 11.2$.

Results and discussion

Figure 1 shows a typical bifurcation diagram for an imperfectly supported pipe conveying fluid. The pipe lies in the horizontal plane and the fluid-to-fluid+pipe mass ratio is $\beta = 0.45$. The variation of the peak dimensionless displacements in the y- and z-directions (represented by η and ζ, respectively) are shown as a function of the dimensionless flow velocity u. As seen, the system undergoes a Hopf bifurcation at $u \simeq 8.9$, leading to limit cycle oscillations. At $u \simeq 11.1$, quasi-periodic motion appears, which becomes periodic again at slightly higher flow velocities. At lower values of u motion is planar while it becomes 3-D at higher values of u, as evidenced by the subplots shown in the figure. Our numerical results show that a pipe with imperfect support may become unstable at a lower or higher flow velocity (depending on system parameters) compared to the perfectly supported pipe. Quasi-periodicity is often observed while periodic motion is the most prevalent form of motion. With symmetric support imperfection, both planar (at lower u) and 3-D (at higher u) motions are observed while with asymmetric imperfection planar motion is dominantly observed.

References

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[3] Kheiri M. (2020) Nonlinear Dynamics of Imperfectly-supported Pipes Conveying Fluid. *J. Fluids and Structures* **93**:102850.