Synchronized wave motion between a flowing fluid and a phononic subsurface

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Abstract. We present a new concept in passive flow control based on interfacing a *phononic subsurface* to a flowing fluid. The phononic structure is designed to provide an out-of-phase response near resonance, and in doing so attenuation target instabilities in the flow by continuous destructive interference. Flow stabilization delays transition to turbulence and reduces skin-friction drag, which in turn improve fuel efficiency for air, sea, and land vehicles and other similar applications.

Introduction

Flow control is a classical engineering problem that spans multiple disciplines. The aim is to devise passive or active means of intervention with the dynamical structure of a flowing fluid in a manner that causes desirable changes in the overall flow behav-ior [1]. For streamlined bodies cruising through a flow, such as air or water, there is a key interest in the control of flow disturbances which often appear in the form unsta-ble, perturbative waves. These are fluctuations in the flow velocity field that if left to grow are likely to trigger laminar-to-turbulent transition, which in turn causes signifi-cant increases in skin-friction drag for wall-bounded flows. A rise in drag reduces the fuel efficiency in aircrafts and ships. It is therefore desired to device intervention methods to impede the growth of these instabilities. Alternatively, in some scenarios, the objective may be to speed up the growth of the instabilities and transition to pre-vent or delay flow separation.

Results and Discussion

This research shows that phonon motion underneath a surface interacting with a flow may be tuned to cause the flow to stabilize, or destabilize, as desired [2]. The underlying control mechanism utilizes core concepts from crystal physics, primarily, the principle of destructive or constructive interferences and the notion of symmetry breaking. This is realized by installing a "phononic subsurface" (PSub), which is an architectured structure placed in the subsurface region and configured to extend all the way such that its edge is exposed to the flow, forming an elastic fluid-structure interface. The PSub may take the form of a phononic crystal or a subwavelength elastic metamaterial, with finite extent, and is typically oriented perpendicular to the fluid-structure interface. It is engineered to exhibit specific frequency-dependent amplitude and phase response characteristics at the edge exposed to the flow. These quantities represent the two core properties on which the PSub design theory is based on. Figure 1 shows results for an example model. This approach represents an unprecedented capability to passively synchronize wave propagation across the interface of a structure and a flowing fluid, and achieve favorable, and predictable, functional alterations to the flow properties. We will present the theory and provide demonstrations using coupled fluid-structure simulations in a channel flow with examples given comprising single or multiple PSubs.

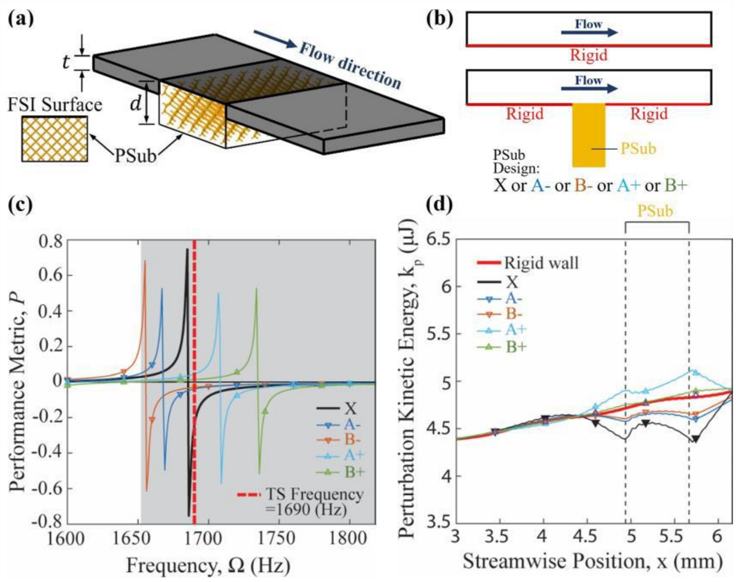

Figure 1: Stabilization or destabilization of a flow instability by PSub design. (a) Employment of PSub in a flat plate. (b) Different PSub configurations, (c) PSub performance metric for configurations in (b). (d) Wave instability kinetic energy versus position.

References

[1] Gad-el-Hak, M.: Flow Control: Passive, Active and Reactive Flow Management. Cambridge University Press, Cambridge (2000).

[2] Hussein, M.I., Biringen, S., Bilal, O.R., and Kucala, A.: Flow stabilization by subsurface phonons. Proceedings of the Royal Society A 471, 20140928 (2015).