Effects of Compliance on the Stability of Jets and Wakes

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Introduction

We carry out a spatio-temporal analysis[1] on a piecewise linear inviscid planar jet or wake with uniform density and infinitely thin shear layers, see Fig.1, when bound above and below by Kramer compliant (or flexible) walls [3]. We take the parallel flow approximation, and assuming small normal mode perturbations for velocity and pressure, we linearise the Euler equations about some base flow $U(z)\widehat{\mathbf{x}}$. From these linear equations, and with a suitable boundary condition, we derive a dispersion relation[2] (1), governing the absolute instability[3] characteristics of the flow. Scan the QR-code to read further on any points with a superscript.

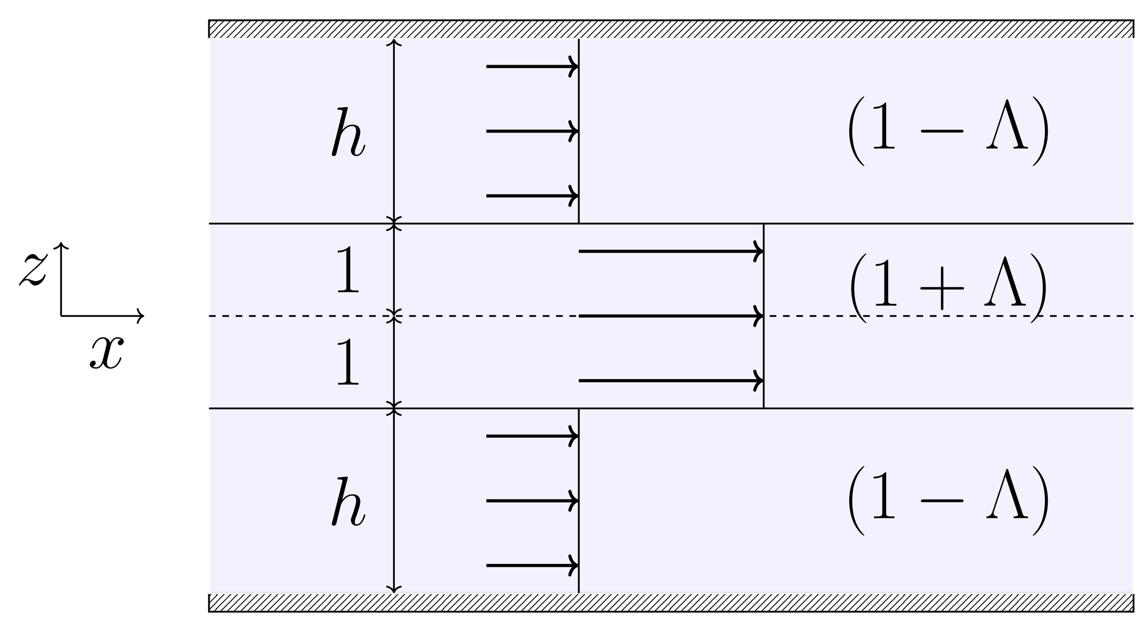
Flow setup and Dispersion relation

Our Kramer compliant wall consists of an elastic plate attached to a rigid back plate with identical springs. Between these spirngs there is a viscous damping fluid. These confine a piecewise linear flow[4] as shown in Fig.1, whose simplicity allows us to write down an explicit dispersion relation of the form

$$\mathbb{D}^{(v,s)}(\alpha,\omega) = \alpha Q X^{(v,s)} - (\alpha(1-\Lambda)-\omega)^2 Y^{(v,s)} = 0,^5 \quad \text{where} \quad Q = -m\omega^2 - id\omega + B\alpha^4 + T\alpha^2 + K. \tag{1}$$

Here, superscript v represents varicose (symmetric) modes, while s represents sinuous (anti-symmetric) modes.

Here, Λ and h represent the flow shear and confinement ratios respectively[6]. Effects of confinement on jets and wakes is explored further in [1, 2, 4]



Dimensionless wall parameters[7] m, d, B, T, K describe wall mass, damping, rigidity, tension and spring stiffness respectively. When these parameters are large, we tend to the rigid wall limit. In our AI analysis, we let $(B, K, m) = (2, 10, 0.1)$ while $d = T = 0$.

Fig. 1: Flow configuration, in dimensionless form, subject to confinement by compliant walls at $z = \pm(1+h)$.

Absolute Instability Analysis

Absolutely unstable is a term that is given to wavepackets, groups of waves, where the dominant behaviour shows growth both up and down stream of the initial perturbation, while also growing in time. These modes of instability exist in the rigid wall case, and are able to be modified by confinement by compliant walls. We find that compliant walls are able to stabilize or destabilize AI modes, i.e. increase how fast or slowly they grow in time, depending on the stability of the flow. They also introduce new modes of instability which lead to larger regions of (Λ^{-1}, h)-space where we see AI, see Fig. 2. This means we see instability for a wider range of shear values than we could in the rigid wall case. This hints at how compliant walls can control the stability of the flow.

Regions of AI

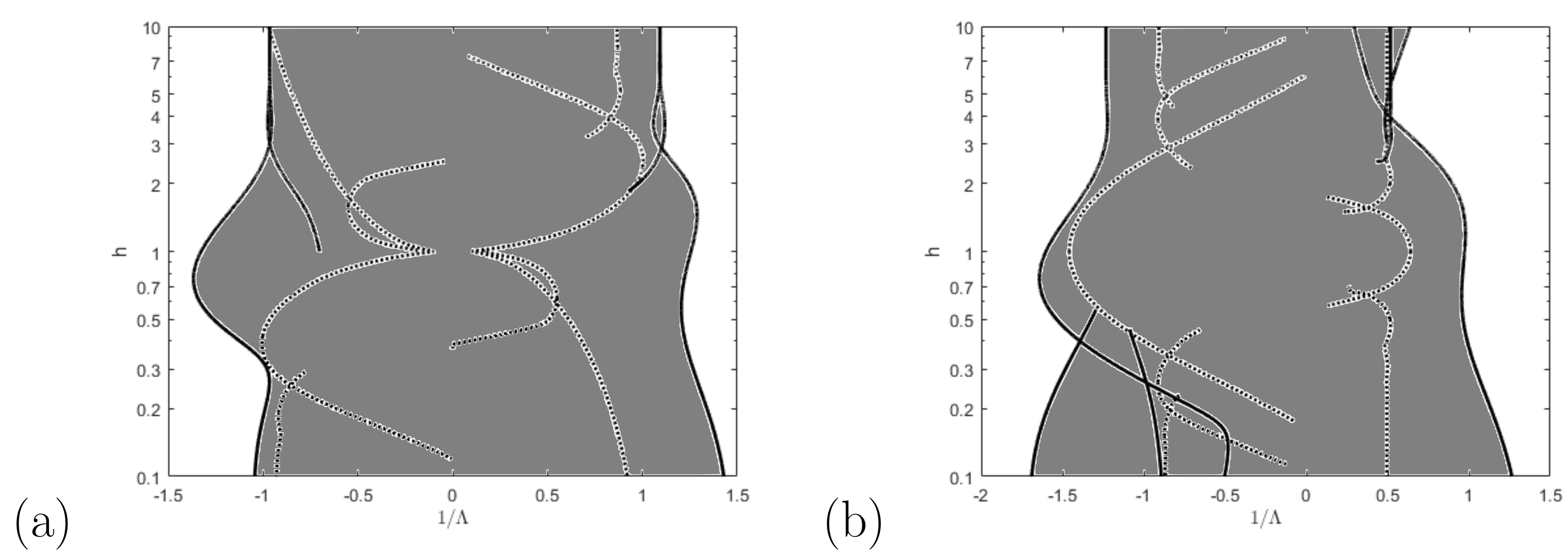


Fig. 2: Modified regions of AI (grey) in (Λ^{-1}, h)-space. Dotted and solid lines represent rigid wall and compliant wall regions respectively.

References

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