Control of free and installed jets and their sound

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Introduction

We develop closed-loop control strategies for application to turbulent jets in free and installed configurations. The goal is to attenuate a given observable (jet dynamics, radiated sound,…) using a small number of sensors and actuators. Control laws may be constructed either from the linearised Navier-Stokes equations [5], where linearisation is performed about the time average of the turbulent flow, or using measured transfer functions between sensors, actuators and observers [1,2,3,4].

In this paper we present an overview of some recent results, obtained in three separate studies. In the first (Study 1) [1], a simplified model of jet-flap interaction (JFI) noise is used to assess a closed-loop control strategy involving flap-edge-mounted actuators that attenuate JFI noise by means of a localised actuation dipole that cancels the dipole source that arises when a jet, modelled using a Ginzburg-Landau equation, grazes a trailing edge whose acoustic scattering is modelled using a tailored Green's function (cf. Figure 1). In the second (Study 2) [2], we present an experimental implementation of closed-loop control of jet dynamics: synthetic jets, informed by upstream hydrodynamic pressure measurements, are used to attenuate axisymmetric coherent structures in a turbulent jet (cf. Figure 2). In the third study (Study 3), we undertake an experimental implementation of Study 1. Piezoelectric actuators are used to generate an edge-mounted dipole that attenuate the natural JFI dipole via the cancellation mechanism of Study 1.

Methodology and key results

In each of the studies, with sensors, actuators and observers denoted, respectively, *y(t)*, *u(t)* and *z(t)*, implementation of control is straightforward, taking the form of the convolution integral,

$$u(t) = \int_{-\infty}^{\infty} k(\tau) y(t-\tau) d\tau$$

where *k(t)* is the control kernel, computed to achieve either inverse, feed-forward wave-cancellation control (IFFC WC), as outlined in [3], or causal optimal control using the Wiener-Hopf approach, as outlined in [1,2,5].

Sample results from Studies 1, 2 and 3 are shown, respectively, in Figures 1, 2 and 3. The control law is found to successfully attenuate the target objectives: JFI noise in Studies 1 & 3 and axisymmetric, turbulent-jet dynamics in Study 2. The studies confirm, furthermore that: (1) the Wiener-Hopf approach is consistently superior to IFFC wave cancellation; and, (2) when sensors are moved close to and downstream of the actuators, the WH approach maintains control authority, whereas the performance of the IFFC approach is degraded.

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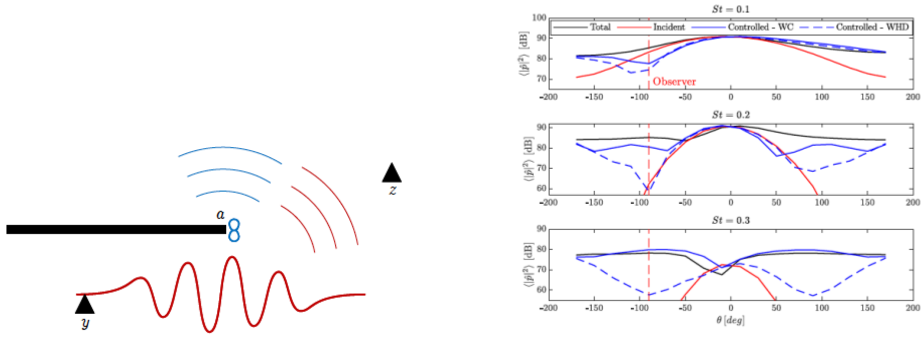

Fig. 1. **Left**: Setup of JFI Study 1 (Ginzburg-Landau equation coupled with half-plane Green's function). **Right**: SPL of JFI noise; Dashed black: uncontrolled; Solid blue: control by IFFC wave cancellation; Dashed blue: Optimal control using Wiener-Hopf approach.

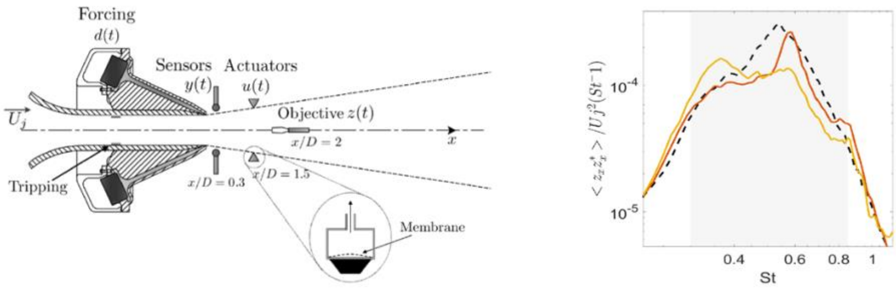

Fig. 2. **Left**: Setup of Study 2 (experimental control of turbulent jet). **Right**: PSD of velocity fluctuations measured by hotwire on jet axis. Dashed black: natural jet; Solid red: control by IFFC wave cancellation; Solid yellow: Optimal control using Wiener-Hopf approach

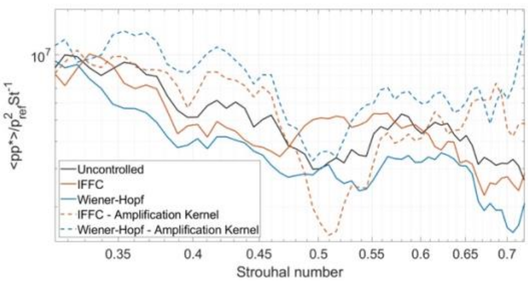

Fig. 3. Study 3 (experimental control of JFI). PSD of controlled and uncontrolled sound field.

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