MODEL DESIGN AND CALIBRATION FOR CLOSED-LOOP CONTROL OF SWIRLING JET INSTABILITIES

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Abstract

In this work the first steps towards a closed-loop control of a swirling jet undergoing vortex breakdown is presented. Thereby, the focus is laid on flow structure identification and model calibration. The vortex breakdown is a phenomenon which occurs in swirling jets, when the ratio of the jets axial to azimuthal momentum exceeds a certain threshold. In this case the jet forms a recirculation region in the centre that is accompained by a strong oscillatory mode. Preliminary findings consistently indicate that this kind of flow is globally unstable to a spiral mode with azimuthal wave number m=1 (see [3]).

The control of this global mode is of great fundamental interest in order to understand the stability mechanism involved in complex turbulent flows. Furthermore, it is of great technical importance, as the vortex breakdown is used in gas turbines for combustion stabilization, where its oscillatory behaviour is undesired.
To control the flow, an experimental facility is used that allows the actuation of azimuthal modes in the jets outer shear-layer by using a loudspeaker array, which is mounted circumferentially around the nozzle lip. The flow is actuated with constant frequencies; thereby the different azimuthal modes are achieved by a phase shift between the single speakers. It is shown that the actuation with a double helical mode with azimuthal wave number m=2 gives good results in damping the natural m=1 mode. In this case the actual control mechanism is not to directly act on the natural mode, but to introduce a different mode which prevents the natural mode from growing.

For closed-loop control of such system, the interaction between the natural and actuated mode must be represented by a simple, but still physically reliable model. As input for the model calibration the flow transients were measured with a high-speed particle image velocimetry (PIV) system, while the actuation was switched on and off several times. Thereby the focus was laid on transients between the actuated and natural flow state. To extract the coherent structures (actuated and natural mode) from the PIV measurement the dataset was reduced to the most dominant features employing proper orthogonal decomposition (POD). The reduction shows that the flow features of interest are represented well by the five most energetic POD modes. The oscillations of the natural and actuated flow are each represented by two modes, while the mean-field changes between the two states is represented by a shift mode (see [2]).

The dynamic model that describes these basic flow interactions arises from the Galerkin projection of the Navier-Stokes equation on the extracted POD basis (see [1] and [2]). The actual projection is not carried out, as the PIV measurement delivers not all necessary physical quantities to accomplish this. Instead the temporal amplitudes of the POD modes are fitted to a generic reduced order model which is applicable to a wide class of flows that are similar to the one investigated here. This so called generalized mean-field model (see [1] for details) covers the identified flow dynamics very well and gives also a hint for the underlying flow mechanism which dampens the natural mode. Thus, the actuation alters the mean flow such that the priorly unstable natural mode is stabilized. A currently conducted stability analysis, based on the measured mean flows, seem to proof this assumption.

Reference

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