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Transient evolution of the global mode in turbulent swirling jets: experiments and modal stability analysis

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Abstract

Swirling jets undergoing vortex breakdown are dominated by a strong coherent structure that is characterized by a precessing vortex core and the large-scale roll-up of the shear layers. These fully synchronized flow dynamics play an important role for the stabilization of swirl flames commonly applied in gas-turbine combustion. It is now well accepted that these flow dynamics are the manifestation of a saturated global instability triggered by a hydrodynamic feedback loop. Yet, the origin of this instability is still discussed controversially. Nonlinear wavefront theory predict the global mode to be selected in the lee of the breakdown bubble, while linear local and global stability analysis predict the region upstream of the breakdown bubble to be more influential. In this work, we intend to clarify this controversy. We consider a turbulent swirling jet undergoing a control parameter transient. The flow undergoes a transition from a globally stable non-vortex breakdown state to a state with a strong recirculation bubble and the associated global mode. High-speed Particle Image Velocimetry measurements are the basis for a local linear stability analysis of the temporarily evolving base flow. This analysis reveals that the onset of the global mode is strongly linked to the formation of the internal stagnation point. Several transition scenarios are discussed and the ability of a frequency selection criterion to predict the wavemaker location, frequency and growth rate of the global mode are evaluated. We find excellent agreement between the linear global mode frequency and the experimental results throughout the entire transient. The corresponding growth rate qualitatively conforms to experimental observations. We find no indication for a global mode that is selected in the lee of the breakdown bubble. The present study confirms that the flow upstream of the vortex breakdown bubble is most influential for the onset of the global mode. Given that the flow under investigation is