Delayed acoustic self-feedback control of limit cycle oscillations in a turbulent combustor

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Abstract. We use delayed acoustic self-feedback to suppress limit cycle oscillations (LCO) in a turbulent combustor during thermoacoustic instability (TAI). The acoustic field of the combustor is coupled to itself through a single coupling tube attached at the antinode position of the acoustic standing wave. As the length of the coupling tube is increased, the amplitude and dominant frequency of the acoustic pressure fluctuations (p') gradually decrease toward the state of maximum suppression of the LCO. Correspondingly, the p' signal changes from LCO to low amplitude aperiodic oscillations via intermittency. The temporal synchrony between the global heat release rate (HRR) and p' fluctuations changes from synchronized periodicity to desynchronized aperiodicity through intermittent synchronization. At optimum parameters, this method suppresses the large amplitude LCO by disrupting the feedback loop between acoustic, hydrodynamic, and HRR fluctuations present in the combustor during TAI.

Introduction

Time-delayed feedback has been used to stabilize unstable periodic orbits in various dynamical systems such as lasers and neural networks [1]. Recent research has demonstrated that delayed acoustic self-feedback using a connecting tube suppresses limit cycle oscillations in several laminar systems, such as acoustic pipelines [2] and Rijke tubes [3]. A Hopf bifurcation causes a laminar system, such as a Rijke tube, to lose stability and become unstable [4]. In contrast, turbulent thermoacoustic systems are complex systems in which large amplitude limit cycle oscillations arise due to closed-loop interaction between hydrodynamic, acoustic, and heat release rate fluctuations. Such large amplitude self-sustained limit cycle oscillations in combustion systems can lead to performance loss and structural damage to components of gas turbines and rocket engines. In this study, we show that delayed acoustic self-feedback disrupts this complex interactions between the flame, the flow, and the acoustic field of the turbulent combustor, thus mitigating the limit cycle oscillations.

Results and Discussions

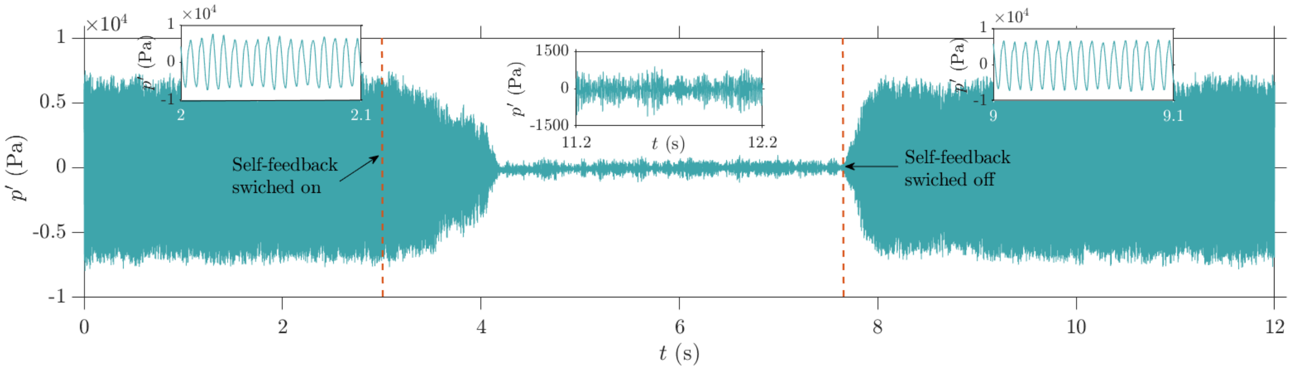

Figure 1: Acoustic pressure time series p' indicating the influence of delayed acoustic self-feedback on the amplitude of limit cycle oscillations. The magnified sections illustrate the dynamics of p' during different stages of delayed acoustic self-feedback.

As we approach the state of maximum suppression, the dynamics of acoustic pressure fluctuations changes from limit cycle oscillations to low-amplitude aperiodic oscillations via intermittency. In addition, the coupled behaviour between acoustic pressure and heat release rate oscillations changes from phase synchronisation to desynchronization via intermittent synchronisation. Furthermore, the coherent zones of acoustic power production observed in the spatial field of the combustor during the state of thermoacoustic instabilities entirely disintegrate during the state of maximum suppression. The magnitude of acoustic pressure fluctuations during the suppression state is comparable to that observed during the stable operation state of the combustor

References

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