Dynamical transitions in a hydrogen-enriched turbulent combustor due to acoustic mode interaction

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Abstract. Different dynamical systems exhibit transitions due to nonlinear interaction among various acoustic modes. In this study, we analyse the nonlinear interaction between the acoustic modes, resulting in different dynamical states observed due to the addition of hydrogen in a turbulent combustor. Successive increments in H_2 fraction increase the value of the dominating frequency of the acoustic pressure (p') fluctuations due to an increase in flame temperature. Correspondingly, we observe the emergence of periodicity due to the nonlinear interaction between different acoustic modes of the combustor. The combustor exhibits various states like period-1 LCO, period-2 LCO, chaotic oscillations, and intermittency. We report 1:1 frequency locking, in which both p' and heat release rate oscillations ($\dot{q}'$) repeat their behaviour in every cycle during P1-LCO. We also show 2:1 frequency locking during P2-LCO, where two cycles of the p' oscillations lock with one cycle of the $\dot{q}'$ oscillations.

Introduction

In order to meet emission and operational requirements, integrating hydrogen with natural gas in the fuel used in gas turbine engines is the promising solution [1]. Therefore, the combustion community is quite interested in the dynamics of hydrogen-enriched combustion in modern combustors. In the present study, we investigate the dynamical transition occurring due to the hydrogen enrichment in a swirl-stabilized turbulent combustor [2]. We find that the interaction of unstable combustor modes is caused due to the addition of hydrogen in the fuel. As a result, the system exhibits various dynamical states, such as chaotic oscillations, intermittency, period-1 limit cycle oscillations (LCO), and period-2 LCO. We analyze the coupling between the acoustic pressure and heat release rate fluctuations throughout various dynamical states, as well as the dynamics of the flame and the flow during these states.

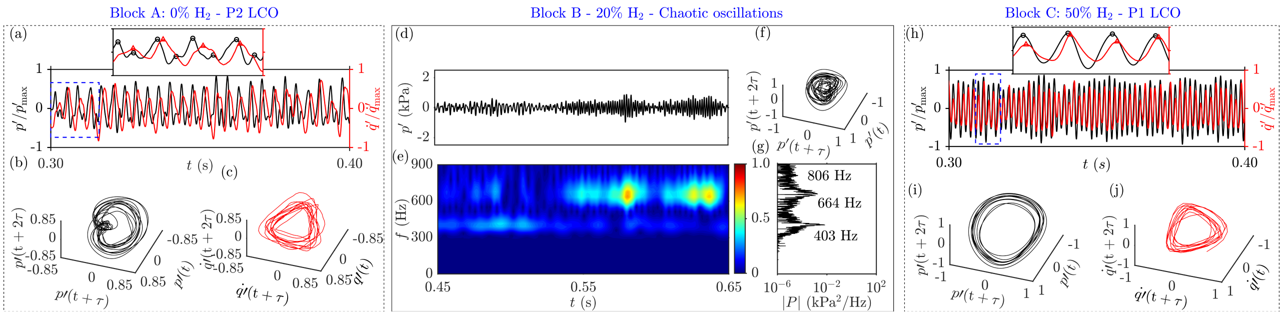

Figure 1: Block A - (a) time series of acoustic pressure (p') (black) and heat release rate ($\dot{q}'$) (red); (b,c) Phase portraits of p' and $\dot{q}'$ for 0% hydrogen; Block B - (d) time series of p', (e) corresponding scalogram, (f) phase portrait, and (g) power spectrum for 20% hydrogen; Block C - (h) time series of p' and $\dot{q}'$; (i,j) Phase portraits of p' and $\dot{q}'$ for 50% hydrogen.

Results and discussion

We notice a change in the frequency of the acoustic pressure oscillations with the addition of hydrogen due to a rise in the flame temperature. In the absence of hydrogen, we observe two oscillations of the acoustic pressure fluctuations over a time period, i.e. period-2 LCO. We also show the existence of 2:1 frequency locking between the acoustic pressure and heat release rate oscillations. With the addition of hydrogen, we notice the transition of period-2 LCO to period-1 LCO via chaotic oscillations characterized by interactions between various acoustic modes. Additionally, 1:1 frequency locking is observed during the state of period-1 LCO with 50% hydrogen in the fuel mixture. We also notice that the dynamical state of the combustor has a considerable impact on the flow and flame dynamics. The flame intensity alternates periodically between the inner and outer shear layers when the combustor exhibits P1-LCO. However, the flame stabilizes primarily in the IRZ during P2 LCO, and the flame shape is observed to be extremely narrow at the base. Moreover, during the state of P2-LCO, we observe that the region of maximum heat release rate shifts farther away from the combustor inlet. The occurrence of P1 and P2 limit cycle oscillations would subject the combustor walls to variable amplitude loads, which might necessitate extra structural reinforcements.

References

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