# Chimera-like states observed during the transition to thermoacoustic instability in turbulent combustor

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Natural and engineering systems that can be modeled as networks of oscillators coupled with each other in space and time, can be studied under the purview of synchronization. For a long time, researchers have studied the spatiotemporal dynamics and patterns exhibited by such networks of oscillators [1, 2]. We adopt the techniques developed for studying pattern formation in a network of coupled oscillators so as to investigate the spatiotemporal dynamics of the reactive flow field.

Thermoacoustic systems with a turbulent reactive flow, prevalent in fields of power and propulsion, are highly susceptible to oscillatory instabilities. Recent studies showed that such systems transition from combustion noise to thermoacoustic instability through a dynamical state known as intermittency [3, 4, 5]. However, as these analyses were in the temporal domain, this transition remains still unexplored spatiotemporally. We, here, present the spatiotemporal dynamics during the transition from combustion noise to limit cycle oscillations in a turbulent bluff-body stabilized combustor.

We conduct experiments on a backward facing step combustor, where a bluff-body is used as a flame holding device. Firstly, from the experiments performed, we obtain the 2D heat release rate field within the combustor by imaging the chemiluminescence ($CH^*$) of the reacting flow field. Simultaneously, the unsteady pressure data is also acquired. Subsequently, for each location (i.e. the discretized locations represented by each pixel of the chemiluminescence image) in the reactive flow field, we calculate the instantaneous phase difference between the heat release rate and the acoustic pressure obtaining an instantaneous phase field. This phase field represents the phase distribution of the reactive flow field at a particular instant of time.

We observe that the aperiodic oscillations during combustion noise are phase asynchronous, while the large amplitude periodic oscillations seen during thermoacoustic instability are phase synchronous. We find something interesting during intermittency: patches of synchronized periodic oscillations and desynchronized aperiodic oscillations coexist in the reaction zone. In other words, the emergence of order from disorder happens through a dynamical state wherein regions of order and disorder coexist, resembling a chimera state. Generally, mutually coupled chaotic oscillators synchronize but retain their dynamical nature; the same is true for coupled periodic oscillators. In contrast, during intermittency, we find that patches of desynchronized aperiodic oscillations turn into patches of synchronized periodic oscillations and vice versa. Therefore, the dynamics of local heat release rate oscillations change from aperiodic to periodic as they synchronize intermittently. The spatiotemporal state that we observe in our system during intermittency is similar to a chimera state [6, 7]. However, since the spatially extended oscillators that represent our system may not be identical, we may not strictly consider the spatiotemporal dynamics during intermittency in our system as a chimera state.

Characterization of global synchrony is needed to confirm the synchronization transition quantitatively at the onset of thermoacoustic instability. Kuramoto [2] developed an order parameter to quantify the synchronization transition. The temporal variations in global synchrony, estimated through the Kuramoto order parameter, echoes the breathing nature of a chimera state.

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