

Numerical and experimental investigation of thermoacoustic instability in a T-shaped system

S. H. Li and Dan Zhao

Aerospace Engineering Division, Nanyang Technological University, Singapore
639798

Abstract:

In this work, a T-shaped standing-wave thermoacoustic system is numerically and experimentally studied to gain insights on the nonlinear coupling between unsteady heat release and acoustic disturbances and the conversion process of heat to sound. Three parameters are considered: (1) heat source location, (2) heat flux and (3) the inlet flow velocity. Their effects on triggering limit cycle oscillations are first investigated in 2D numerical model by varying one parameter, while all the other parameters remain constant. Four concentric constant-temperature rings are used as heat sources. And mean flow appears due to the natural convection. The main nonlinearity is identified in the heat fluxes. To characterize the transient (growing) behavior of the pressure fluctuation, the thermoacoustic mode growth rate is defined and calculated. It is found that the growth rate decreases first and then ‘saturates’. Similar behavior is observed in examining the slope of Rayleigh index, which is widely used as an onset/triggering indicator to characterize the phasing between unsteady heat release and sound. The transient behavior of heat flux cannot be simply described by a growth rate due to its nonlinearity. As the heat source location, heat flux or inlet flow velocity is varied, the head-driven acoustic signature is also found to change in terms of frequency and sound pressure level (SPL). In addition, the overall efficiency of converting the input heat power into acoustic power is defined and calculated. To validate our numerical findings, a cylindrical T-shaped duct made of quartz-glass with a metal gauze attaching on top of a Bunsen burner is designed and tested, as shown in Fig. 1.

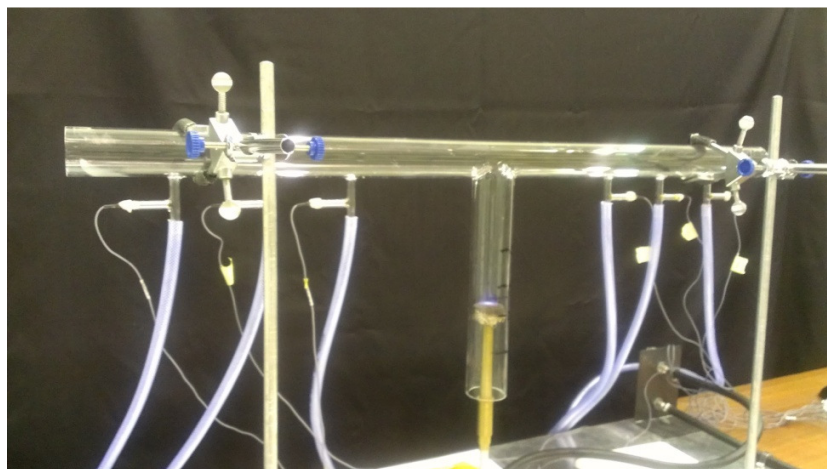


Fig. 1 experimental setup of a T-shaped standing wave thermoacoustic system with a premixed laminar flame confined.

To monitor the temperature and acoustic fields in the bifurcating branches, an infrared thermal imaging camera and two arrays of microphones are used. As a premixed laminar flame is placed in the bottom branch of the tube, self-sustained thermoacoustic oscillations might be generated, depending on the 3 identified critical parameters. It is shown that Supercritical Hopf bifurcation is associated with the thermoacoustic system, as shown in Fig. 2. Comparison is then made between the experimental measurement and numerical predictions. Good quantitative agreement is obtained in terms of the mode shape, mode frequency, sound pressure level (SPL) and the behavior of supercritical bifurcation.

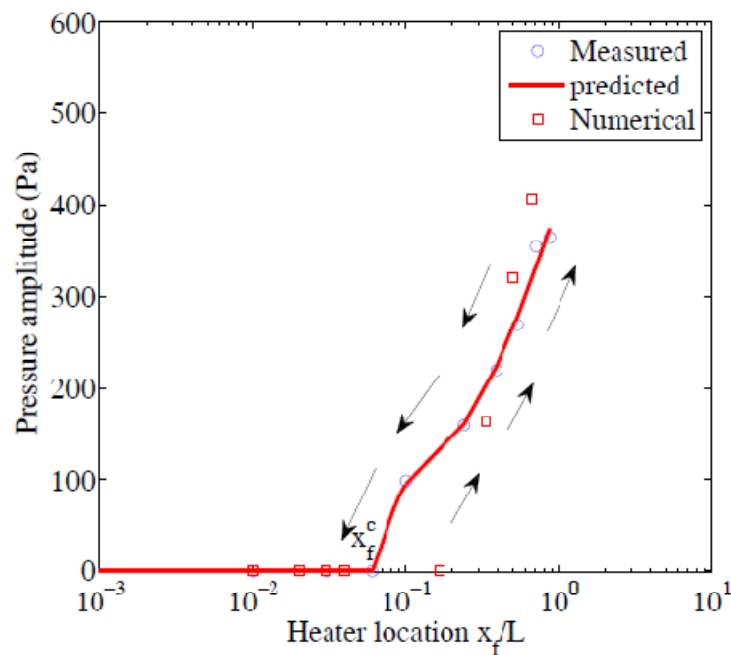


Fig 2. Hopf bifurcation diagram of measured and numerical predicted thermoacoustic oscillations, as the fuel flow rate is set to 300 ml/min.

Keywords: acoustical energy, standing wave, thermoacoustic oscillations, T-shaped, energy conversion, combustion instability.