SELF-EXCITED SELF-SELECTED COMBUSTION OSCILLATIONS IN A RIJKE-ZHAO TUBE

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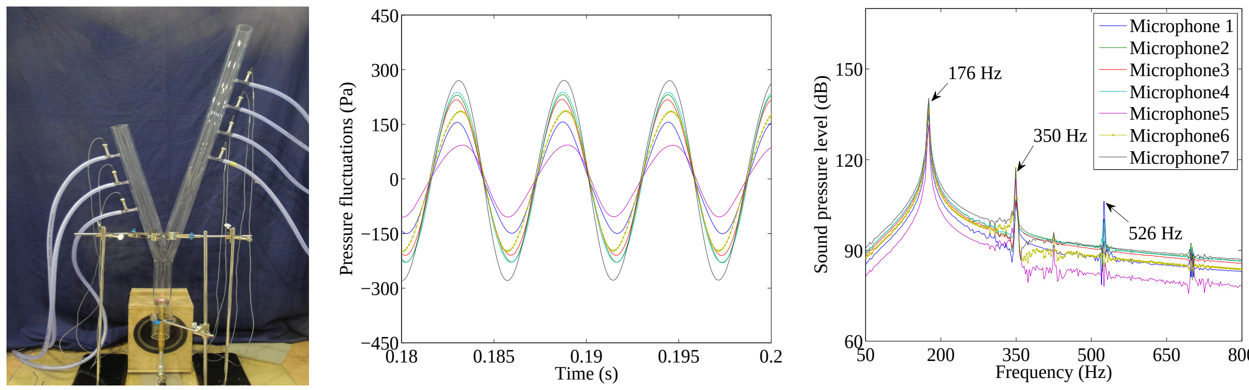
Summary Combustion instabilities occurred in a Rijke-Zhao tube are considered in this work. It is a mother tube, which splits into two bifurcating daughter tubes with different lengths. As a laminar premixed flame is placed inside the mother tube, it provides a mechanism to produce combustion instabilities, which are characterized by large self-excited oscillations. Experimental results show that the fundamental mode corresponding to the longer upper branch is the easiest one to be triggered and grow into a limit cycle. The resulting temperature fields in the upper bifurcating branches are dramatically different; one is close to the ambient temperature, while the other is 'hot'. To mitigate combustion instabilities in Rijke-Zhao tube, an observer-based controller is experimentally implemented, and it results in a sound-pressure-level reduction of more than 45 dB at 7 microphones. In addition, the controller is demonstrated to prevent the onset of new combustion instabilities, when fuel flow rate is varied.

DESCRIPTION OF EXPERIMENTS AND RESULTS

In this work, a Rijke-Zhao tube with a unique structure and geometry is experimentally tested. It has a mother tube (bottom stem), which splits into two or more daughter tubes (i.e. upper branches) with different length, see Fig. 1(a). As a laminar premixed flame is placed inside the mother tube, it provides a mechanism to produce self-excited combustion oscillations [1]. However, since the Rijke-Zhao tube can be assumed to consist of two conventional Rijke tubes [2], the differing upper lengths are expected to give rise to two potential fundamental modes at different frequencies. Are these two potential modes excited simultaneously or only one mode is naturally selected to be triggered? Does such self-selected combustion oscillations affect the flow field (temperature and flow velocity) in the upper branches? is observer-based controller applicable to stabilize Rijke-Zhao tube? The present study addresses these questions. Both experimental and numerical investigations are conducted.



(a) (b) (c)

Figure 1. A Rijke-Zhao tube (a) Experimental setup with a loudspeaker attached, (b) Measured pressure fluctuations and (c) their pressure spectra of a Rijke-Zhao tube.

The experimental investigations involves designing and testing a Rijke-Zhao tube, see Fig. 1(a). T-shaped junctions protruding from both bifurcating upper branches are designed for placing microphones to measure pressure fluctuations and thermocouples to measure temperatures. The flow velocity along the upper branches of the Rijke-Zhao tube is also measured by using hot wire anemometer (HWA). To measure pressure fluctuations along the Rijke-Zhao tube, 2 arrays of B&K microphones (Type 4794) are implemented: one array with 4 microphones applied to the longer upper branch, the other array with 3 microphones attached to the other branch. The measurements are shown in Fig. 1(b) and 1(c). It can be seen that there are combustion excited oscillations in both upper branches, and the maximum pressure oscillation can reach about 137 dB. The dominant mode in Rijke-Zhao tube is at around 176 Hz and it has several harmonics (see Fig.1(c)). This frequency corresponds to the fundamental mode with a wavelength of twice of the total length of the mother tube and the upper longer branch. This is confirmed by observing the pressure spectra of the excited combustion oscillation, when the upper shorter branch was blocked, as shown in Fig. 2(a) and 2(b).

To measure the temperature field inside the Rijke-Zhao tube, an infrared camera was used. It captures the quartz tube surface temperature spectrum. However, it represents the 'hot' status of the air flow inside each branch. The camera was set to operating range of 0° to 500° Celsius. Fig. 3(a) shows the temperature measurement. It can be seen that the surface temperature of the short branch is around 26° Celsius, indicating that the air flow temperature inside the branch

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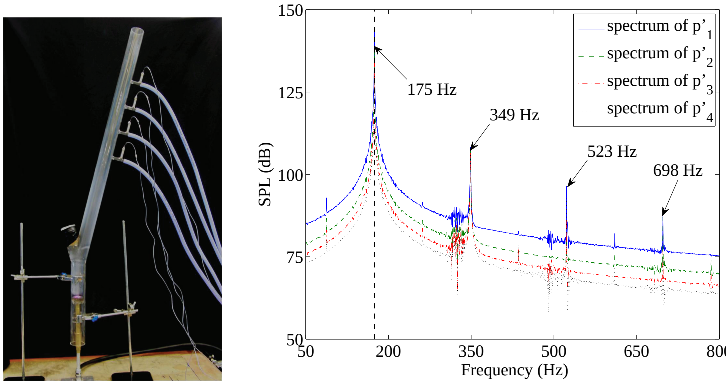
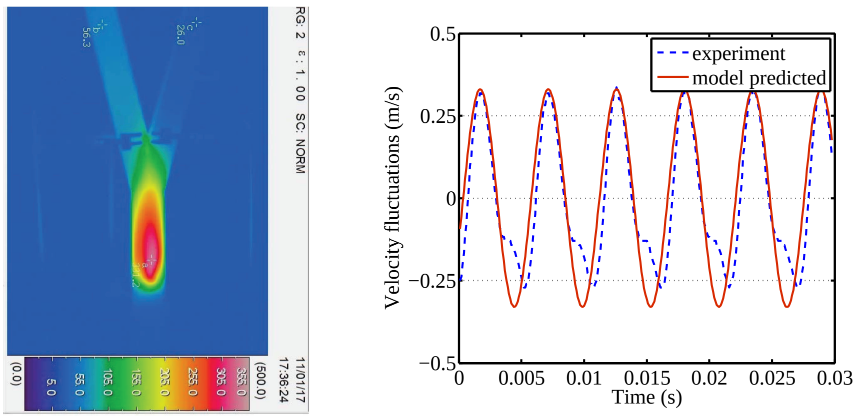


(a) (b)

Figure 2. Pressure spectra of a Rijke-Zhao tube with the shorter upper branch removed (a) experimental setup (b) corresponding pressure spectra.



(a) (b)

Figure 3. (a) Temperature measurement by using an infrared camera, (b) Velocity oscillation measurements at 5 cm to the exit of the upper short branch by using a hot wire anemometer.

was very close to room temperature as measured by using two arrays of thermocouples, which are placed side by side to the microphones. And it is much lower than the temperature in the other branch. In addition, the 'oscillating' nature of the flows is confirmed via direct flow measurement by using hot wire anemometer (HWA), as shown in Fig. 3(b).

DISCUSSION AND CONCLUSIONS

In summary, a Rijke-Zhao tube is experimentally designed and tested. It has a mother tube (bottom stem), which splits into two or more bifurcating daughter tubes with different lengths. It is found from our experiment that the fundamental mode corresponding to the longer branch is the easiest one to be triggered and grown into limit cycle. The resulting temperature distribution in the bifurcating upper branches are dramatically different due to the self-selected and self-excited combustion instabilities. To gain insight on the mode selection, triggering and the resulting flow field, a thermo-acoustic model which captures the dynamic response of a premixed laminar flame to flow disturbances is developed [3]. Numerical simulations reveal that the flow disturbances at higher frequencies (lower wavelength) pass through the flame smoothly. However, at lower frequencies (longer wavelength), the flow perturbations lead to a strong flame response. This shed lights on our experimental findings on mode selection and triggering. Finally, to mitigate combustion instability in Rijke-Zhao tube, an observer-based controller [4] is experimentally implemented and it results in a reduction of 45 dB at 7 microphones. It is also able to prevent the onset of new limit cycle due to the further variation of fuel flow rate.

References

[1] Lieuwen T.C., Yang V.: Combustion instabilities in gas turbine engines. AIAA Progress in Aeronautics and Astronautics, vol. 210 2005.
[2] Raun R.L., Becksead M.W., Finlinson J.C., Brooks K.P.: A review of Rijke tubes, Rijke burners and related devices. *Prog. Energ Combust.* **19(4)**:313–364, 1993.
[3] Zhao D.: Nonlinear self-excited combustion oscillations of a premixed laminar flame. *Appl. Mech. Mater.* **110-116**,1150–1154, 2012.
[4] Zhao D.: Tuned Passive control of combuston instabilities. *PhD Thesis*, University of Cambridge, Eng. Dept., UK, 2009.