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# Control of thermoacoustic instability with a drum-like silencer

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ABSTRACT

Theoretical investigation is carried out by a novel method of controlling thermoacoustic instability with a drum-like silencer. It is shown that by decreasing the frequency of thermoacoustic system, the instability can be suppressed with the help of drum-like silencer. The purely reactive silencer, which is composed of a flexible membrane and a backing cavity, is usually known as a noise control device that works effectively in low frequency bandwidth without any aerodynamic loss. In present research, the silencer is exploited in a Rijke tube, as a means of decreasing the natural frequency of the system, and consequently changing the resonance period of the system. The "transfer element method" (TEM) is used to consider the interactions between the acoustic waves and the flexible membranes of the silencer. The effects of all possible properties of the silencer on the growth rate and resonance frequency of the thermoacoustic system are explored. According to the calculation results, it is found that for some properties of the silencer, the resonance frequencies are greatly decreased and then the phase difference between the unsteady heat release and the pressure fluctuation is increased. Consequently, the instability is suppressed with some dissipation that can not be able to control its onset in the original system. Therefore, when the damping is low, but not zero, it is effective to control thermoacoustic instability with this technique.



## 1. Introduction

Thermoacoustic instability which is specifically termed as combustion instability when the instability is due to unsteady combustion, often appears in many practical systems such as rocket motors, gas turbines, and premixed prevaporised (LPP) combustors of aeroengines for civil use [1,2]. In these systems, unsteady heat release oscillations couple with acoustic oscillations that will grow if the unsteady heat release is sufficiently in phase with the pressure, as a result, instability occurs [3,4]. Especially, for the aeroengines that serve for the civil aviation aeroplanes, due to the drive for low $NO_x$ emission requirements, these engines often operate in premixed lean modes and are more susceptible to external perturbations [5]. Combustion instability has many undesired features. It displays large-amplitude pressure oscillations which will not only induce troublesome mechanical vibrations but also enhance the heat transfer rates at the combustor walls, which in some extreme situations, makes the components melt and then causes catastrophic result [7]. Therefore, it is an imperative need to investigate the mechanisms behind thermoacoustic instability and to find effective methods to control it.

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**Nomenclature**

| | |
|---|---|
| $c_0$ | sound speed |
| $c_p$ | specific heat capacity at constant pressure |
| $c_v$ | specific heat capacity at constant volume |
| $D_c$ | depth of the backing cavity |
| $G$ | Green's function |
| $G^+$ | Green's function for the enclosed annular cavity |
| $G^-$ | Green's function for the circular tube |
| $j$ | section number |
| $J_m$ | Bessel function of the first kind of order m |
| $J'_m$ | first derivative of $J_m$ |
| $k_0$ | wavenumber |
| $k_{mn}$ | eigenvalue of hard wall duct eigenfunction |
| $L$ | length of the tube |
| $L_p$ | heat release position |
| $L_s$, $l$ | length of the silencer |
| $L_w$ | position of the silencer |
| $L_x$ | length of the outlet section |
| $M$ | Mach number |
| $m$ | circumferential mode number |
| $m_0$ | specific circumferential mode number zero |
| $m_x$ | mass per unit area of the membrane |
| $n$, $\mu$ | radial mode number |
| $\bar{p}$, $\bar{\rho}$, $\bar{u}$ | time-mean components of pressure, density, and velocity |
| $p'$, $\rho'$, $u'$ | fluctuation components of pressure, density, and velocity |
| $p_i$ | undisturbed incident acoustic pressure component |
| $p_s$ | acoustic pressure disturbance component induced by the silencer |
| $p_s^+$ | acoustic pressure disturbance in the backing cavity |
| $p_s^-$ | acoustic pressure disturbance in the tube with drum-like silencer |
| $p_w^-$ | acoustic pressure in the tube for the hard wall condition |
| $P_{mn}$ | unknown amplitude of acoustic pressure wave |
| $q'_j$ | unsteady heat release rate per unit area |
| $\tilde{q}_j$ | complex amplitude of unsteady heat release per unit area |
| $Q'_j$ | unsteady heat release rate for the whole cross section |
| $Q_o^j$ | orthogonal transformation value for unsteady heat release rate per unit area |
| $R$ | radius of the tube |
| $R_0$ | ideal gas constant |
| $\mathbf{r}(r, \varphi, x)$ | vector coordinate |
| $\mathbf{r}'(r', \varphi', x')$ | vector coordinate that denotes mass singularities |
| $R_c$ | acoustic reflection coefficient |
| $s(\tau)$ | duct wall surface |
| $S_{emn}$ | unknown amplitude of entropy wave |
| $t$ | time coordinate |
| $T$ | a period of time |
| $T_x$ | tension per unit length of the membrane |
| $U$ | mean flow velocity |
| $V_n$ | normal velocity of the membrane |
| $V'_n$ | acoustic velocity of the mass singularity |
| $x^{+j}$ | axial reference position for downstream propagation waves |
| $x^{-j}$ | axial reference position for upstream propagation waves |
| $Z$ | wall impedance |
| $\beta$ | heat conduction coefficient |
| $\gamma_{mn}^{\pm}$ | axial wavenumber |
| $\Gamma$ | orthogonal value of hard tube eigenfunction |
| $\Gamma'$ | orthogonal value of enclosed annular cavity eigenfunction |
| $\xi$ | amplitude of the particle displacement |
| $\rho_0$ | constant mean density |
| $\rho_{emn}$ | density disturbance induced by entropy wave |
| $\tau$ | time associated with emission of sound wave; delay time |
| $\phi$ | eigenfunction of the enclosed annular cavity |
| $\psi$ | eigenfunction of the tube |
| $\omega$ | angular frequency |

One early study on the interaction between sound waves and unsteady heat release was due to Lord Rayleigh [3]. Rayleigh criterion has been frequently quoted in the research history of thermoacoustic instabilities. It elucidates the mechanism of the coupling between acoustic waves and unsteady heat release in view of energy conservation, that is to say, self-sustained acoustic oscillations are excited as long as the acoustic energy gain is larger than that dissipated at the boundaries [1]. Lieuwen [6] presented a review about the interaction between acoustic waves and a premixed combustion process.

The early work on combustion instability was focused on the mechanisms of unstable combustion of liquid and solid propellant rocket motors [8–10]. However, it can also occurs in many other practical devices and leads to calamities. Thus, this issue causes a lot interest, and a large number of researchers has contributed to promoting the understanding of its physics and control strategies [11–13]. Lieuwen et al. [14] found that, for the lean premixed gas turbine combustors, the regions of the instability depend upon the ratio of the delay time to the period time, which affects the phase difference between the pressure oscillation and the unsteady heat release. A simple geometry is systematically investigated by Dowling [15] to determine the importance of various flow parameters on the frequency of thermoacoustic oscillations. Li et al. [16] discussed the effect of axial distribution of heat source on the lowest oscillation frequencies. Actually, for a Rijke tube which is about to be investigated in the present paper, the phase difference between the unsteady heat release and acoustic pressure is the key parameter. To eliminate the instability, we can alter the phase difference between the unsteady heat release and pressure oscillations by changing the frequency of the system instead of adding some dissipation devices.