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SPONTANEOUS THERMOACOUSTIC OSCILLATION IN A CLOSED CYLINDRICAL TUBE WITH VARIOUS TEMPERATURE GRADIENT POSITIONS

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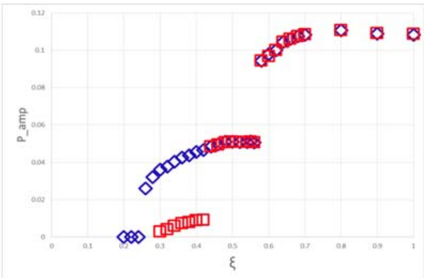
Spontaneous oscillations of a gas column are observed in a tube when a temperature gradient along the tube axis is imposed on the tube wall (Taconis oscillation). The authors have performed numerical simulations of the spontaneous thermoacoustic oscillations[1]. In the present study we fix the temperature of the hot part(300K) and the cold part(20K), but the ratio between lengths of hot and cold parts is changed. This paper presents how the acoustic oscillation and the flow structure depend on the length ratio and reveals the significant effect of vortices on the variation of the temperature of the fluid.

We consider the oscillations of a helium gas in a straight cylindrical tube with both ends closed. The wall temperature of both end parts is maintained at room temperature T_H = 300K and that of the central region is T_C = 20K. The tube length is L and the temperature gradient is located at l and $L-l$. The ratio of the length of the hot part to that of the cold part is $\xi = 2l/(L-2l)$. We did numerical simulations for various length ratios ξ. The radius r_0 is $2.7\times10^{-3}L$. Since the tube is very narrow, we assume that the flows are axisymmetric.

The basic equations are the axisymmetric compressible Navier-Stokes equations of a perfect gas. To solve the basic equations, we employ the block pentadiagonal matrix scheme[2]. The time development is by the second-order accurate three-point backward implicit scheme. The convective terms are evaluated by using fourth-order central differencing and viscous terms are evaluated by second-order central differencing. We use a rectangular grid system consisting of 300 points along the tube length and 36 points on the tube radius. The non-slip and isothermal boundary conditions and no pressure gradient in the normal direction of the wall are applied on the tube wall. Physical quantities presented in this paper are normalized by the tube length L=0.28m, the density ρ_0=0.167kg/m^3 and the acoustic velocity a_0=1004m/s.

The initial state is quiescent, $T = T_H$, and $p = p_0 = 1.2\times10^5$Pa. We gradually lower the temperature of the central part to T_C at $\xi = 0.3$. Then we continue time integration and obtain a steady oscillatory state. After obtaining a steady state at $\xi = 0.3$, we change ξ and continue the time integration until a steady state is obtained at each value of ξ. The length ratio ξ is increased from 0.3 to 1.0, then it is decreased from 1.0 to 0.3.

The variation of the pressure amplitude with the length ratio ξ is shown in Fig.1 The pressure amplitudes obtained when ξ is increased are plotted with squares, while those obtained when ξ is decreased with diamonds. The results show that we can divide the steady oscillation states into three groups. Figure 2 shows the spatial distribution of the pressure at several instants during an acoustic cycle for $\xi = 0.4$ or during a half period of a cycle for $\xi = 0.5$ and $\xi = 1.0$. These figures show typical temporal evolution of the pressure distribution of the steady oscillatory states which belong to each group. The first group includes the steady states with the pressure amplitudes smaller than 0.01. The oscillation corresponds to the second harmonic of the standing wave. In the second group the steady states have the values of the pressure amplitude between 0.03 and 0.052. The temporal evolution of the pressure distribution is approximately antisymmetric, and there is a discontinuity of the pressure. This discontinuity is a shock wave. The steady states with the pressure amplitudes greater than 0.1 belong to the third group. The oscillation corresponds to the first harmonic. When ξ is decreased below 0.42, the pressure amplitudes continuously decrease but do not decrease sharply to the values of the first group. For ξ between 0.3 and 0.42, the states obtained when ξ is increased belong to the first group, while the states of the second group are obtained when ξ is decreased. This fact indicates that the hysteresis exists in the present case. The thermoacoustic acoustic oscillations obtained in the present study are large amplitude oscillations, and the ratio of the pressure amplitude to the mean pressure is greater than 0.4 for the second and the third groups.



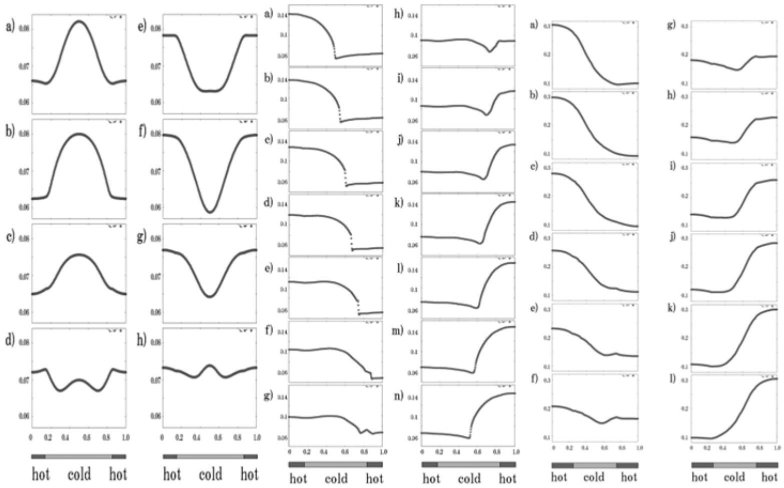


Fig.1. Variation of the pressure amplitude.

Fig.2. Temporal evolution of spatial distribution of the pressure.

Analysis of the vorticity and the temperature distributions reveals that the effect of vortices which move along the boundary layer and entrain the fluid is significant on the variation of the temperature. The difference of the boundary layer thickness between the hot part and the cold part is shown to play an important role in the thermoacoustic phenomena with large temperature ratios.

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