Intermittent and Periodic Behavior in Ducted Inverse Diffusion Flames

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Gas turbine combustion, practically used in aviation, and power stations, has historically relied on non-premixed combustion due to its stable flames and relative robustness towards dynamic instabilities. However, associated with such flames are highly undesirable emission levels of NOx and soot, which become particularly relevant for higher hydrocarbon fuels. Inverse diffusion flames present a viable alternative to non-premixed combustion due to their 'hybrid' nature – they exhibit characteristics of both non-premixed and partially premixed flames, leading to their stability and also lower levels of NOx and soot emissions [1].

In the present work, an experimental investigation of the dynamic characteristics of a ducted inverse diffusion flame has been carried out. Time series obtained from the sound emitted by the flame was captured and analyzed using tools of nonlinear dynamics such as fast Fourier transforms, time delay phase plots, recurrence plots, and recurrence quantification measures. Variation of the duct length above the plane of the flame resulted in rich adn diverse dynamic characteristics, and three distinct regimes of operation were identified. Although similar investigations have been performed earlier for other experimental combustion systems [2, 3], none have investigated a ducted inverse diffusion flame.

Figure 1 presents the representative plots at the different flame positions inside the duct. Panels A1 – A4 correspond to a flame position of 24 cm. Three distinct frequencies are observed in the FFT plot (Fig. 1A1), the 100 Hz due to the natural frequency of the duct [4], the thermoacoustic instability generated 237 Hz [4], and a third peak of 422 Hz. The time delay phase plot (Fig. 1A2) is reminiscent of homoclinic orbits [5], though heavily contaminated by noise, and the black patches in the recurrence plot (Fig. 1A3) are due to the intermittent nature, which is observed in the time series as well. In fact, the recurrence patterns suggest the intermittency to be of Type-II [6], and the exponential tail of the distribution of the lengths of the vertical lines of the recurrence plot (Fig. 1A4) confirms the presence of a homoclinic orbit [7].

When the flame position was changed to 36 cm, a sharp tone was emitted by the flame due to positive coupling between the heat release and the duct acoustics. The FFT plot (Fig. 1B1), time delay phase plot (Fig. 1B2), and the recurrence plot (Fig. 1B3) indeed confirm the presence of a limit cycle.

On further changing the flame position to 50 cm, the periodic nature of the time series vanishes, and the system in fact demonstrates intermittent behavior, as evident from the recurrence plot (Fig. 1C3). Thus it can be concluded that the dynamics of a ducted inverse diffusion flame is a strong function of flame position within the duct, with the flame exhibiting transitions from intermittent to periodic behavior, and then again to intermittent behavior as the flame position is changed.

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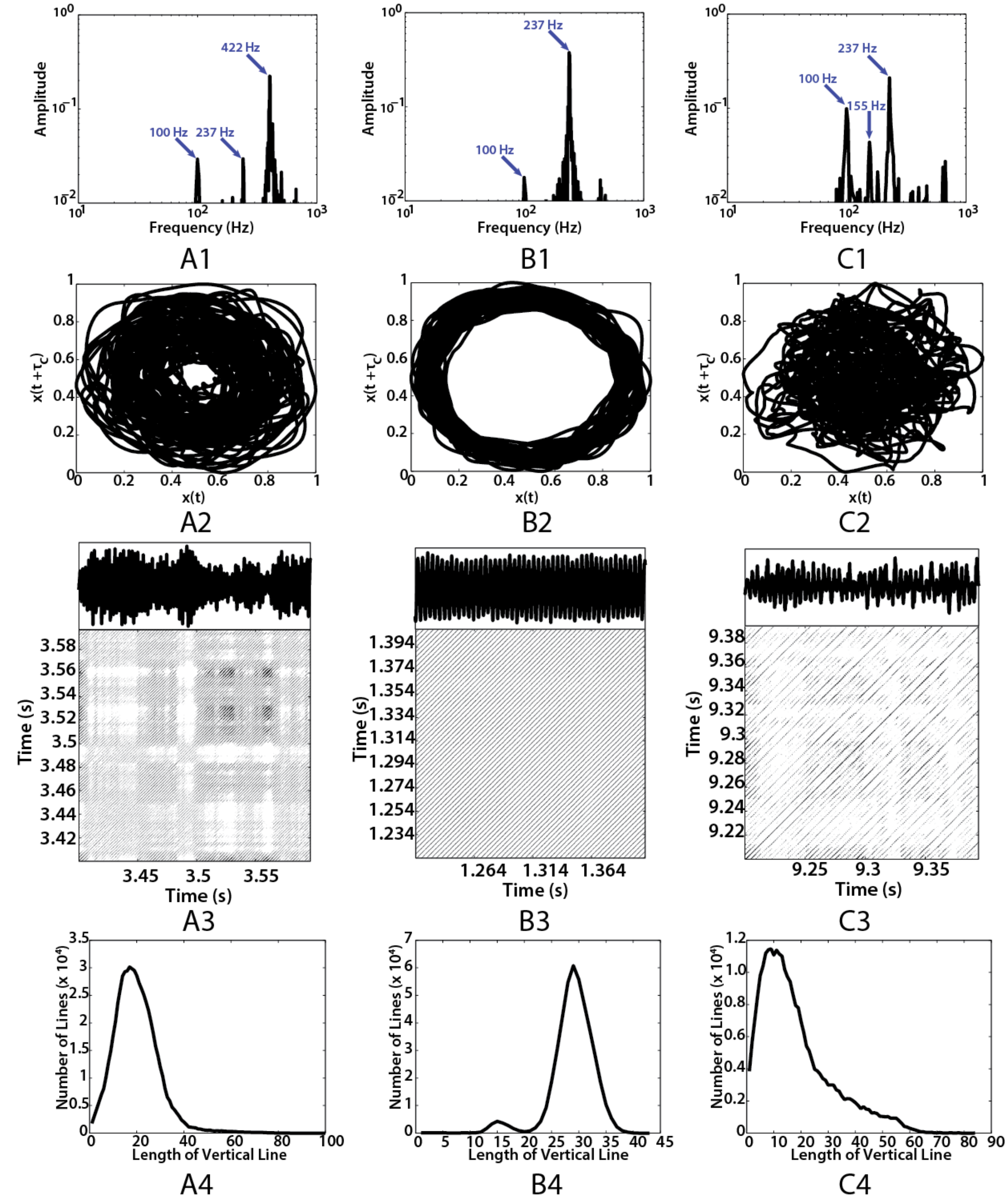

Figure 1: A1: power spectral density plot, A2: time delay phase plot, A3: recurrence plot, and A4: distribution of length of vertical lines in recurrence plot at acoustic length of 24 cm; B1: power spectral density plot, B2: time delay phase plot, B3: recurrence plot, and B4: distribution of length of vertical lines in recurrence plot at acoustic length of 36 cm; C1: power spectral density plot, C2: time delay phase plot, C3: recurrence plot, and C4: distribution of length of vertical lines in recurrence plot at acoustic length of 50 cm