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SOUND EMISSION OF DUCTED PREMIXED FLAMES

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Sound emissions of laminar premixed flames stabilized on the outlet plane of a burner located at one end of a rectangular duct were experimentally investigated. Specifically, this research applied the approach of direct acoustic admittance measurement to investigate and elucidate the close relations between sound emission, non-reactive burner acoustic admittance, flame equivalence ratio and combustor length. The admittance data were obtained by directly measuring the amplitudes of velocity and pressure oscillations, and the phase relations between the oscillatory velocity and pressure. Results of this research reveal that flames would hardly induce sound emissions without the "right" acoustic property of the non-reactive burner system. Also, the reactive burner acoustic admittance is dominated by the non-reactive burner acoustic admittance. The flame is important in determining the strength of possible sound emissions. This study also shows that the fundamental frequency of the combustor system should be within the range of critical frequencies of the non-reactive burner system to sustain possible sound emissions. The critical frequencies, the frequencies for possible sound emissions and the "right" acoustic property of the burner system could be approximately predicted by knowing the distribution of the imaginary parts of non-reactive burner acoustic admittance.

1. INTRODUCTION

Sound emissions are observed in a variety of combustors. These generated acoustic oscillations in pulse combustors may offer such advantages as fuel saving, reduced pollutant formation and increased heat transfer rates. On the other hand, the existence of sound emissions in combustors could be detrimental to the performance of propulsion systems. Thus, studies related to sound emission in combustors have received much attention in the past. Raun *et al*. provided very good reviews of related work [1]. These researches include studies of combustion instabilities in dump combustors [2–4], studies of pulsating behavior in Helmholtz combustors [5–8], studies of acoustic instabilities of premixed flame fronts propagating in tubes [9–11], and studies of acoustic oscillations of flames stabilized on burners (or injectors) in combustor systems [12–14]. The present research is concerned with the experimental investigations of sound emissions of laminar

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premixed flames stabilized on the outlet plane of a burner located at one end of a rectangular duct by direct acoustic admittance measurements.

The research conducted by Tsuji and Takeno [12] investigated the characteristics of high frequency combustion oscillations in a research rocket combustor. Effects of the combustion chamber length, the propellant equivalence ratio and the chamber pressure on combustion oscillations were investigated. They found that the fundamental- and the higher harmonic-mode pressure oscillations occurred only for certain conditions of the chamber length, the propellant equivalence ratio and the chamber pressure. This study concluded that there existed a lowest, critical oscillation period (or the combustion-time lag) which is the essential parameter for the initiation of the combustion oscillations. The study of sound emissions in a laboratory combustion system by Schimmer and Vortmeyer [13] also obtained an instability range in the plane of equivalence ratio and oscillation period similar to that obtained by Tsuji and Takeno. They found that a change in the sign of the imaginary part of impedance occurred exactly at this lowest, critical oscillation period. By analogy to the electric line theory they define an inductive and a capative burner reactance. Sound emission was only observed at an inductive burner reactance. Janardan *et al*. [14] measured the reactive admittances using a modified impedance tube technique to investigate the driving of combustor oscillations by gaseous propellant injectors. They found that the injectors could sustain combustion instabilities over a wide range of frequencies and injector design parameters. In addition, the driving characteristics of the investigated injectors depend on the propellant equivalence ratio. The theoretical models developed by Hegde and Zinn [15] showed that the boundary acoustic admittance was an important quantity in the unsteady behavior of the flame. Also, Mugridge's [16] and McIntosh's [17] analytical studies showed that the admittance at the combustion zone inlet plane and the impedance of acoustic waves just downstream of the flame were important in determining flame stability.

The studies described above indicate that sound emissions in combustors are related to combustor length, flame equivalence ratio and burner (or injector) acoustic admittance. These relations are further investigated and elucidated in this research by using direct acoustic admittance measurement, as well as flame radiation measurement. This approach of direct admittance measurement has not been used, as far as the authors know, for such studies. In addition, this research further examines the lowest critical oscillation period obtained by Tsuji and Takeno [12] and Schimmer and Vortmeyer [13]. The admittance data were obtained by directly measuring the amplitudes of velocity and pressure oscillations, and the phase relations between the velocity and pressure oscillations. The combustion stability limit and the characteristics of sound emissions by laminar premixed flames stabilized on the outlet plane of a burner located at one end of a rectangular duct are first investigated in this paper. Effects of non-reactive burner (i.e., without flame) acoustic property, reactive burner (i.e., with flame) acoustic admittances, and flames on sound emissions are then discussed. Relations between the imaginary part of non-reactive burner acoustic admittance and sound emission, and effects of duct lengths on sound emissions are also investigated and discussed in this paper.

2. EXPERIMENTAL SET-UP AND ANALYSIS

The combustor system utilized in this research is shown in Figure 1. It consists of a 60-cm long, 4×8 cm^2 rectangular duct with a premixed flame burner of 30 cm in length located at one end of the duct. The length from the outlet plane of the burner to the open end of the duct is 0·57 m. A microphone mounted on the duct wall near the outlet plane of the burner is used to characterize the induced acoustic wave and to determine the dynamic pressure. The bottom section of the duct is water cooled to prevent heat damage to the microphone. An additional rectangular duct with two acoustic drivers was attached to the open end of the main duct when acoustic admittance measurements were performed. In this case, no sound emission was observed in the combustor, which makes the acoustic admittance measurements easier. Porous metal and ceramic matrices were installed inside the premixed flame burner to premix the air–methane mixture and to stabilize the flow. Ceramic matrices were also installed at the exit section of the burner. Air and 99·5% pure methane were injected from the bottom of the burner. Part of the air was diverted through an Al_2O_3 particle seeder, and was introduced into the burner to allow LDV measurements. Since the cold mixture velocities used in this research were below 25 cm/s, essentially laminar premixed flames were obtained that were stabilized close to the outlet plane of the burner. The combustor system was mounted on a linear, three-axes, translating system, which could be controlled by a computer.

Studies of sound emissions conducted in this research were investigated by using the direct acoustic admittance measurements as well as the flame radiation measurements. The acoustic admittance of a surface is defined by [18, 19]

$$Y = v'_{out\ of\ surface}/p' = \frac{|v'|}{|p'|}\cos\phi_{p'v'} + i\,\frac{|v'|}{|p'|}\sin\phi_{p'v'}$$

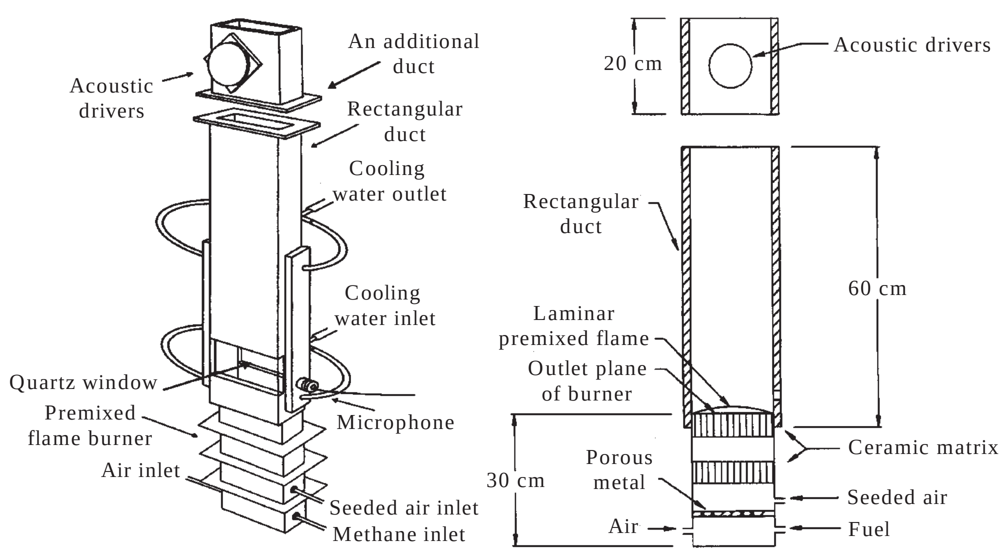

Figure 1. A schematic of the experimental set-up and the burner system (not to scale).

where v', p' are the complex velocity (normal to the surface) and pressure perturbations, respectively, $|v'|$, $|p'|$ and $\phi_{p'v'}$ are the amplitude of velocity oscillation, the amplitude of pressure oscillation and the phase relation between the velocity and pressure oscillations, respectively. The real part of acoustic admittance represents the wave amplification or attenuation upon incidence on a boundary. The imaginary part of acoustic admittance provides the information about the time delay between the instants at which an incident wave arrives at and a reflected wave departs from a boundary. When the real part of acoustic admittance is positive, acoustic energy is flowing from the boundary to the acoustic field [19], and it is said to be driving. In this case, sound emission might occur. On the contrary, when the real part of acoustic admittance is negative, it is said to be damping and sound emission will not occur. Thus, by knowing $|v'|$, $|p'|$ and $\phi_{p'v'}$ the acoustic admittance can be calculated and the self-excited sound emission can be investigated.

In this research, the oscillatory velocity and pressure data were obtained by using a LDV system and a microphone, respectively. The measurements were performed at a plane 10 mm above the outlet plane of the burner, where the investigated flames were mainly confined below this plane as confirmed by the flame radiation signal. Thus, effects of the flame and the burner system on the sound emission can be investigated and elucidated. These measurements were conducted for cold flow (i.e., without flame) and hot flows with different flame equivalence ratios over the frequency range of 200 to 850 Hz. The velocity amplitude, $|v'|$, and the phase information, $\phi_{p'v'}$, were obtained by using a conditional sampling technique [20, 21] which permits retrieval of the periodic velocity history by synchronizing the beginning of the sampling interval of the laser velocimeter data with respect to the periodic pressure oscillations. The pressure amplitude was obtained directly from the microphone signal. Typical measured slot (time) dependence of cold and hot flow velocities (normal to the outlet plane of the burner) at a point on the measurement plane exposed to 450 Hz acoustic waves is shown in Figure 2. Each curve shown in this figure was obtained using 5120 velocity data, and analyzed using the conditional sampling technique by placing the velocity data into 120 slots. This figure indicates that the presence of the acoustic wave results in the oscillatory flow velocity having the same frequency as the imposed acoustic oscillation. Similar results were obtained for other flame equivalence ratios and frequencies. The amplitudes of oscillatory velocities, $|v'|$, and phase differences between the velocity and pressure oscillations, $\phi_{p'v'}$, were obtained from these curves by using the method of least square approximation. This figure also shows that the presence of flame results in larger amplitude of velocity oscillation and the shift of $\phi_{p'v'}$. Since the acoustic admittances on the measurement plane may not be uniform, velocity measurements were conducted at 18 equally spaced locations on the plane for each run. The obtained data were averaged to obtain the real, Re (Y), and imaginary, Im (Y), parts of acoustic admittance. These admittances were not normalized with the characteristic admittances in order to evaluate the driving behavior of different flame character since the product of Re (Y) and $|p'|^2$ is proportional to the amount of acoustic energy flux [19].

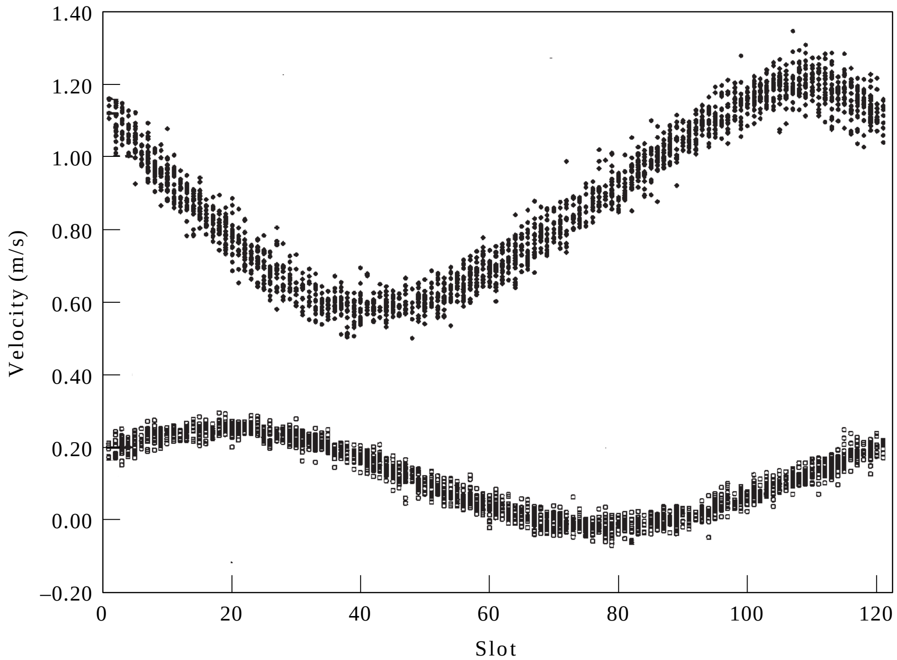

Figure 2. Distributions of slot (time) dependence of the normal component of the flow velocity without and with flames, measured at a point 10 mm above the outlet plane of the burner, exposed to a 450-Hz acoustic oscillation (each curve includes 5120 velocity data). ●, With flame of equivalence ratio 1·1; □, without flame.

Flame radiations are of interest because the radiation intensities from radicals such as C–C and C–H are proportional to the heat release rate [22] in the flame. Such flame radiation measurements were conducted in this research to determine the relationship between the heat release rate and pressure oscillations. As stated by Rayleigh's criterion [23], this relationship determines whether the flame adds or removes energy from the acoustic waves. Expressed mathematically [24], an oscillatory heat source adds energy to the acoustic wave when the inequality $\int_v |S_{p'q'}| \cos \theta_{p'q'} \, \mathrm{d}V > 0$ is satisfied, where $|S_{p'q'}|$ and $\theta_{p'q'}$ are the magnitude of the cross-spectrum and the phase difference between the acoustic pressure, p', and oscillatory heat release rate, q', respectively. The above integration is performed over the whole space, V, where driving or damping by the flame occurs. Since the flame radiation measurements were conducted over the whole flame region, the integral was approximated by $|S_{p'q'}| \cos \theta_{p'q'}$ which is called Rayleigh's integral (I_q) in this research. In a flame region where I_q is positive, driving of the acoustic wave occurs. Also, the larger the I_q is, the stronger the flame driving that occurs. The flame radiation measurements were performed by using a photomultiplier (PMT) system with a C–H optical filter placed between the flame and the PMT system, which permits passage of only the wavelength (431 ± 6 nm) of interest. The autospectra, the phase difference and cross-spectra between the flame radiation and pressure oscillations are determined using an FFT algorithm.

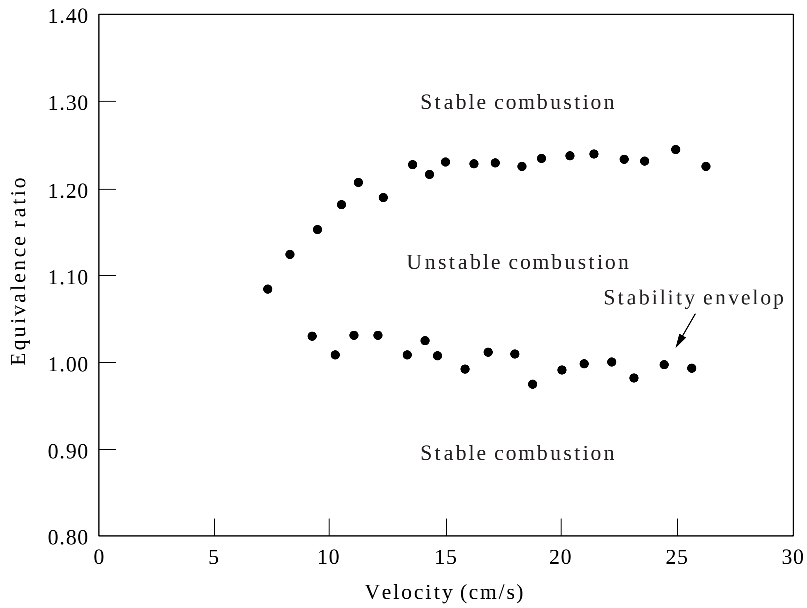

Figure 3. Combustion stability envelope of the investigated laminar premixed flames.

3. RESULTS AND DISCUSSION

Results of this study show that the investigated laminar premixed flames exhibited self-excited flame oscillations and induced sound emissions for certain mixture velocities and flame equivalence ratios, as shown in Figure 3. A typical autospectrum of the induced pressure oscillation is presented in Figure 4. The

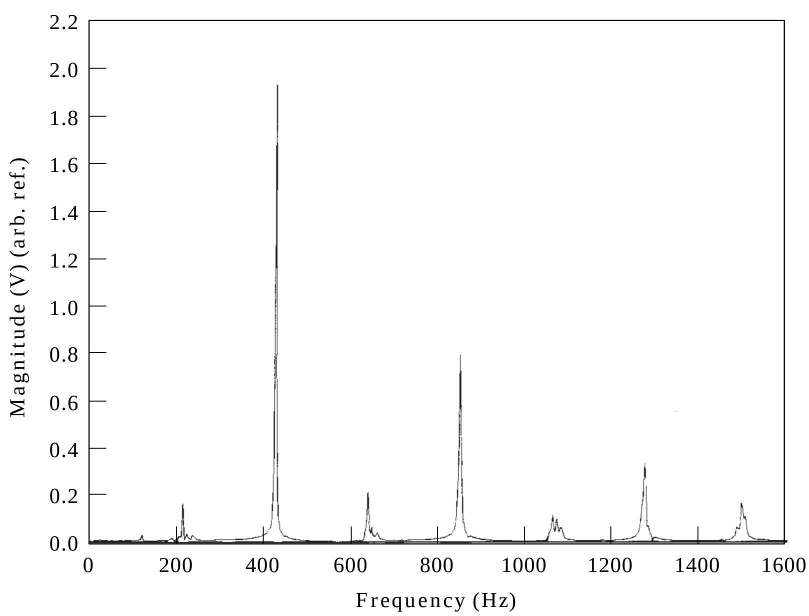

Figure 4. A typical autospectrum of the pressure oscillation. Cold mixture velocity $V = 13{\cdot}5$ cm/s; flame equivalence ratio $\phi = 1{\cdot}16$.

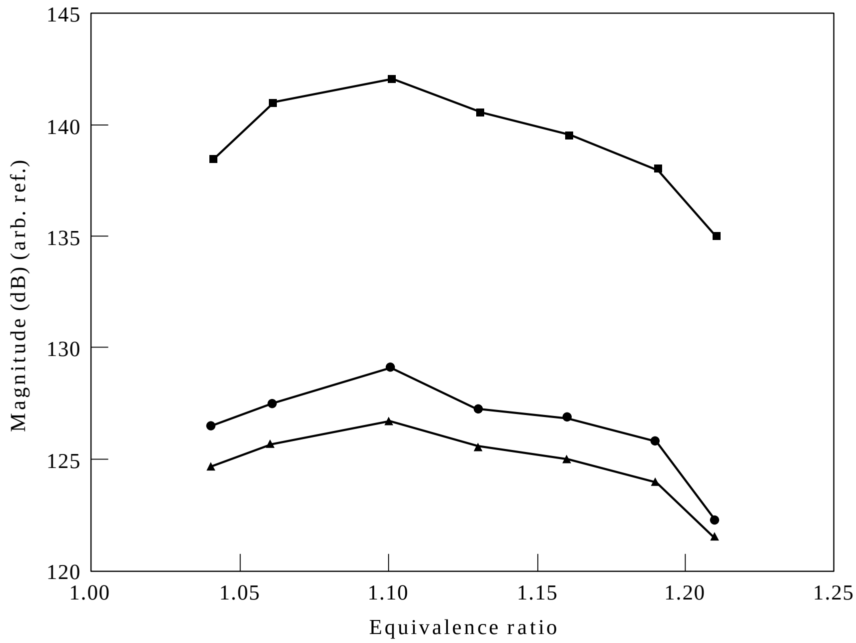

Figure 5. Equivalence ratio dependence of the magnitudes of flame radiation oscillations, pressure oscillations and the Rayleigh integral; $V = 13{\cdot}5$ cm/s. ●, Rayleigh integral; ▲, pressure oscillation; ■, radiation oscillation.

autospectrum of the flame radiation is similar to that of the pressure oscillation. This figure shows that the pressure oscillation peaks at the frequency of 420 Hz, which was estimated to be the fundamental frequency of the combustor system, as well as at its harmonics and sub-harmonics. The frequencies of induced sound emissions were found to weakly depend on the mixture velocity and the flame equivalence ratio conducted in this research. This result is due mainly to the low-speed combustion that causes the sound speed to vary a little inside the duct.

To further understand the characteristics of observed sound emissions, flame radiation and pressure measurements were conducted at different flame equivalence ratios. Figure 5 shows that the magnitude of the self-excited flame radiation oscillation is equivalence ratio dependent, reaching the maximum at the flame equivalence ratio of 1·1 and decreasing toward the lower and higher equivalence ratios. In addition, Rayleigh's integrals are all positive values over the test equivalence ratios, and exhibit a similar tendency to that of flame oscillations. This result indicates that the flame oscillation satisfies Rayleigh's criterion, and provides energy to the acoustic field resulting in the pressure oscillation inside the combustor. Since a larger Rayleigh's integral represents that the flame provides larger energy to the acoustic field, the magnitude of the pressure oscillation should be maximum at the equivalence ratio of 1·1, as indicated in Figure 5. It is known that the maximum laminar flame speed and the adiabatic flame temperature of the methane–air flame occur near the equivalence ratio of 1·1 [25]. This implies that the flame with an equivalence ratio of 1·1 has the maximum energy to cause the sound emission. In addition, this figure shows that only those flames possessing enough energy are able to sustain sound emissions. Similar results were obtained for other mixture velocities. The characteristics of observed sound emissions can be clearly elucidated by the measured admittance data as discussed below.

Figure 6 presents the frequency dependence of the real parts of acoustic admittances, Re (Y), of non-reactive (i.e., without flames) and reactive (i.e., with flames) burners. It was shown in this figure that the Re (Y) for a non-reactive burner are negative for all of the test frequencies, indicating that the non-reactive burner acts as an acoustic sink. This is expected since no acoustic sources, such as flames, are presented. The presence of flames is expected to modify the non-reactive burner admittance, where the modification depends on the flame equivalence ratio. The Re (Y) for reactive burners are positive for frequencies roughly between 360 and 730 Hz, and have the maximum positive value near 380 Hz for all of the four test flame equivalence ratios. This result indicates that flames at these frequencies overcome the damping of the non-reactive burner system and provide energy to the acoustic field. In this case, the flame might exhibit self-excited flame oscillations and induce sound emissions. It is noted in this figure that though the Re (Y) with the flame equivalence ratio of 0·9 are positive in the vicinity of 380 Hz, this flame did not exhibit a self-excited flame oscillation as indicated in Figure 3. A positive real part of acoustic admittance is only one of the necessary conditions to cause sound emissions. The flame should provide enough energy to sustain possible sound emission. Figure 6 also shows that the reactive burner acoustic admittances of different flame equivalence ratios exhibit similar tendencies but different values over the test frequencies. The reactive burner with the flame equivalence ratio of 1·1 exhibits the largest positive and

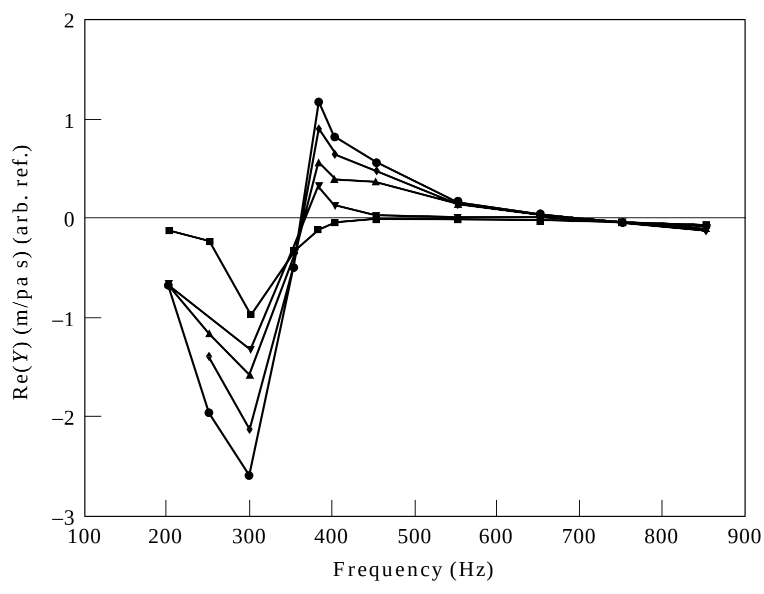

Figure 6. Frequency dependence of the real parts, Re (Y), of non-reactive burner admittance and reactive burner admittances for flames with different equivalence ratios; $V = 13{\cdot}5$ cm/s. ■, Non-reactive burner; ◆, reactive burner, $\phi = 1{\cdot}16$; ●, reactive burner, $\phi = 1{\cdot}10$; ▲, reactive burner, $\phi = 1{\cdot}04$; ▼, reactive burner, $\phi = 0{\cdot}9$.

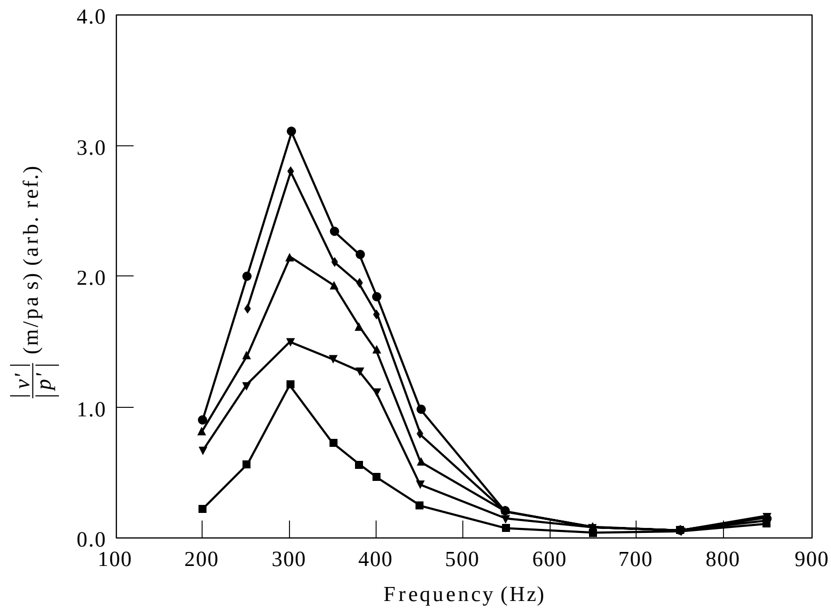

Figure 7. Frequency dependence of the ratios of oscillatory velocity and pressure amplitudes for the non-reactive burner and reactive burners with different equivalence ratios; $V = 13{\cdot}5$ cm/s. Key as for Figure 6.

negative values of Re (Y). Since the measured $|p'|$ for the flame equivalence ratio of 1·1 is also largest, this flame provides or absorbs the largest amount of acoustic energy from the acoustic field and exhibits the maximum driving and damping behavior. Similar results have been obtained and discussed in flame radiation studies. Results of these two measurements are in good agreement.

It has been shown in Figure 6 that the presence of flames modifies the acoustic property of the non-reactive burner system, where this modification can be described by the measured $|v'|/|p'|$ and $\phi_{p'v'}$. First, the temperature effect due to the presence of flames causes the acoustic wave inside the duct to redistribute, resulting in changes of the amplitudes of pressure and velocity oscillations at the measurement plane. In general, larger amplitudes of pressure oscillations are associated with larger amplitudes of velocity oscillations. Thus, distributions of the frequency dependence of $|v'|/|p'|$ for non-reactive and reactive burners are similar to each other, as shown in Figure 7. This result indicates that distributions of $|v'|/|p'|$ for reactive burners are mainly dominated by the acoustic property of the non-reactive burner system. The presence of flames only modifies the values of $|v'|/|p'|$ and results in larger values of $|v'|/|p'|$, which depend on flame equivalence ratios. The flame with the equivalence ratio of 1·1 exhibits the largest values of $|v'|/|p'|$ among the test flames. Second, the presence of flames results in changes of the phase differences between the pressure and velocity oscillations. Figure 8 shows that distributions of the frequency dependent $\phi_{p'v'}$ for non-reactive and reactive burners are similar to each other, indicating that the $\phi_{p'v'}$ for reactive burners are also dominated by the acoustic property of a non-reactive burner system. The presence of flames modifies the values of $\phi_{p'v'}$ and results in a decrease of $\phi_{p'v'}$. This phase decrease is dependent on the flame equivalence ratio, and the flame with an equivalence ratio of 1·1 results in the largest phase decrease. Since $|v'|/|p'|$ and $|p'|$ are also the largest for the flame with the equivalence ratio of 1·1, this flame exhibits the maximum flame driving/damping behavior. Flames with equivalence ratios of 1·16, 1·04 and 0·9 exhibit smaller flame driving/damping. The flame with the equivalence ratio of 0·9 did not result in enough phase decreasing and, thus, this flame could not induce sound emissions. Figure 8 also shows that the $\phi_{p'v'}$ for the non-reactive burner are close to 90° in the frequency range of 350 to 650 Hz, indicating that the real parts of reactive admittances in these frequencies have higher possibility to be positive. Thus, flames would possibly induce sound emissions at these frequencies. On the other hand, sound emission would hardly occur at the frequency of, for example, 200 Hz in the investigated combustor because the $\phi_{p'v'}$ for reactive burners hardly become less than 90°. The results discussed above reveal that the acoustic property of the non-reactive burner system plays an important role in sound emissions. The reactive burner admittances are mainly dominated by the non-reactive burner admittance. Flames are important in determining the strength of possible sound emissions. Flames would hardly induce sound emissions without the "right" acoustic property of the non-reactive burner system.

Figure 9 describes the frequency dependence of the imaginary parts of non-reactive burner admittance, Im (Y). They are positive for frequencies between 330 and 700 Hz, and the maximum positive value occurs at the frequency of 350 Hz. Comparing this figure with Figure 6 shows that distributions of Im (Y) of the non-reactive burner and Re (Y) of reactive burners are in good qualitative

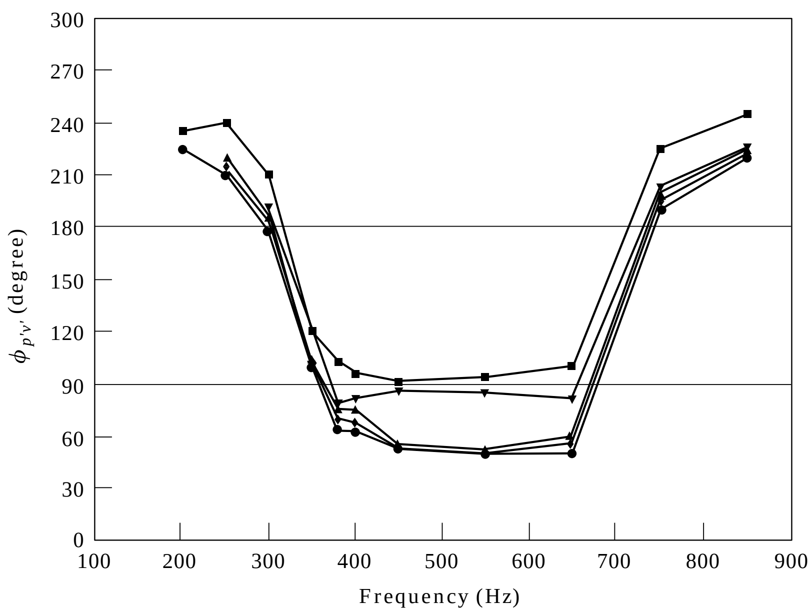

Figure 8. Frequency dependence of the phase differences between the velocity and pressure oscillations for non-reactive burner and reactive burners with different equivalence ratios. $V = 13{\cdot}5$ cm/s. Key as for Figure 6.

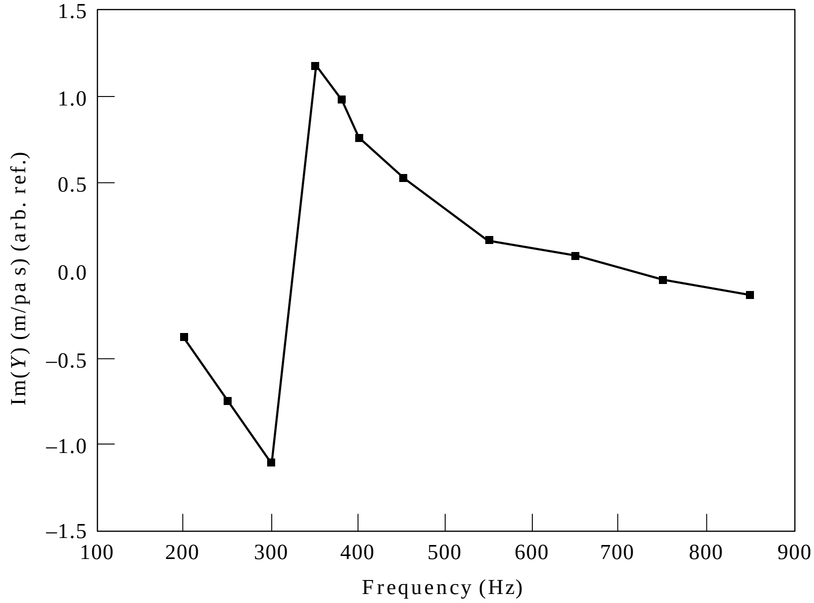

Figure 9. Frequency dependence of the imaginary parts of non-reactive burner admittance.

similarity. Similar results were obtained for different burner systems and could also be deduced from reference [14] for much higher mixture velocity as in the order of 5 m/s. This result is due mainly to similarity in the distributions of $|v'|/|p'|$ and $\phi_{p'v'}$ for a non-reactive burner to the respective distributions for reactive burners. A slight difference in the similarity is that the $\mathrm{Re}\,(Y)$ of reactive burners are positive for frequencies between 360 and 730 Hz, and the maximum positive value occurs at 380 Hz. This curve shift is reasonable since the real and imaginary parts of acoustic admittance differ by 90° and the presence of flames causes some decrease in $\phi_{p'v'}$. These results indicate that, in general, a positive $\mathrm{Im}\,(Y)$ of the non-reactive burner admittance is the necessary condition for flames exhibiting sound emissions. The frequencies with the sign change of real parts of admittances, which are 360 and 730 Hz in this study, are defined as the critical frequencies. These critical frequencies could, thus, be approximately predicted by knowing the distribution of imaginary parts of non-reactive burner admittance. Tsuji and Takeno [12] and Schimmer and Vortmeyer [13] concluded in their studies that acoustic oscillations only occurred with periods equal to, or larger than the critical period, which is the inverse of the frequency with the sign change of the imaginary parts of acoustic admittance. The critical frequencies defined in this research and in references [12, 13] are slightly different. However, this research shows that the critical frequency is not unique, and is determined by the acoustic property of a non-reactive burner system. It was also concluded from the results discussed above that the frequencies for possible sound emissions and the "right" acoustic property of the non-reactive burner system could be predicted by knowing the imaginary parts of non-reactive burner acoustic admittance.

The reason why the sound emission is favored for positive imaginary parts of non-reactive burner admittance can be further explained by the measured admittance data. It is noted above that the real parts of non-reactive burner admittance are always negative. In this case, the phase differences between the velocity and pressure oscillations are between 90° and 270°; that is, $270° > \phi_{p'v'} > 90°$. Thus, when the imaginary parts of non-reactive burner admittance are negative, $\phi_{p'v'}$ are within 180° and 270°; that is, $270° > \phi_{p'v'} > 180°$. The presence of flames, though resulting in the decrease of $\phi_{p'v'}$, would hardly cause positive values of $\cos \phi_{p'v'}$. In view of data shown in Figure 8, the presence of flames even causes more negative values of $\cos \phi_{p'v'}$ and, thus, the $\mathrm{Re}\,(Y)$ of reactive burners are negative and smaller than those of the non-reactive burner. The effect of the flame is to damp the acoustic wave, and the sound emission would not occur. On the other hand, when the imaginary parts of non-reactive burner admittance are positive, $\phi_{p'v'}$ are within 90° and 180°; that is, $180° > \phi_{p'v'} > 90°$. The presence of flames is possible to result in positive values of $\cos \phi_{p'v'}$, especially for $\phi_{p'v'}$ closer to 90°. In this case, the $\mathrm{Re}\,(Y)$ of reactive burners are positive, and the sound emission may occur.

Effects of combustor lengths on sound emissions were also investigated. Figure 10 presents magnitudes of the flame radiation oscillations and Rayleigh's integral for two different combustor lengths. The fundamental frequency of the combustor with 62 cm length is estimated to be 385 Hz. This figure shows that sound emissions are stronger for the combustor system with 62 cm length. It was shown above that the maximum positive values of $\mathrm{Re}\,(Y)$ of reactive burners occur at the frequency of 380 Hz. Thus, it is interesting from these results that if the fundamental frequency of the duct is closer to the frequency of a larger value of

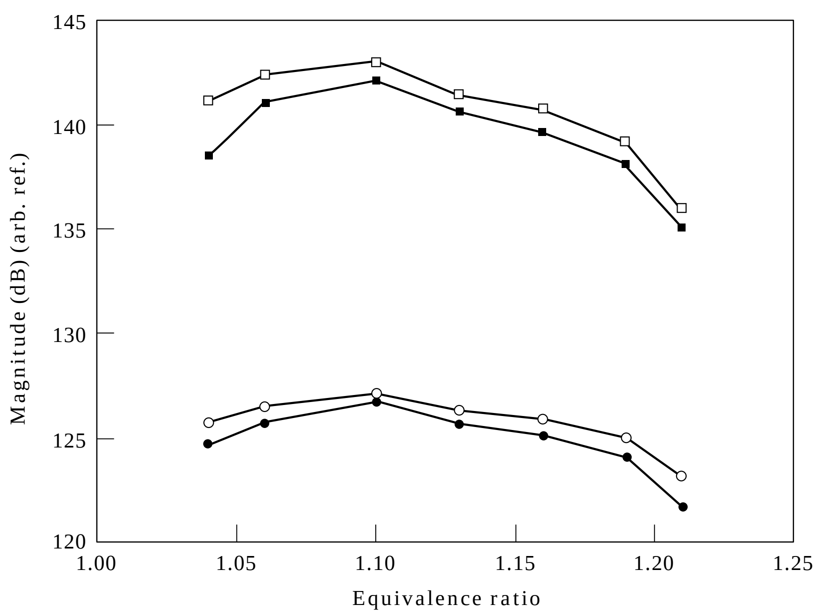

Figure 10. Equivalence ratio dependence of the magnitudes of the flame radiation oscillations and the Rayleigh integral for two different combustor lengths; $V = 13{\cdot}5$ cm/s. ●, Rayleigh integral, 57 cm combustor length; ○, Rayleigh integral, 62 cm combustor length; ■, radiation oscillation, 57 cm combustor length; □, radiation oscillation, 62 cm combustor length.

Re(Y), which could be approximately predicted by the imaginary parts of non-reactive burner admittance, the flame exhibits stronger oscillations. When the duct length was further increased to 77 cm, where the fundamental frequency of the combustor system is estimated to be 295 Hz, no sound emission was observed. The fundamental frequency of the combustor system should apparently be within the critical frequency range of the non-reactive burner system to possibly cause the sound emission. As discussed above, this critical frequency range is largely dependent on the acoustic property of a non-reactive burner system and could be predicted by the imaginary parts of non-reactive burner acoustic admittance.

4. CONCLUSIONS

This research shows that the investigated laminar premixed flames satisfy Rayleigh's criterion and provide energy to the acoustic field, resulting in self-excited flame oscillations and inducing sound emissions for certain mixture velocities and flame equivalence ratios. The acoustic property of a non-reactive burner system plays an important role in sound emissions. Sound emission is favored for positive imaginary parts of non-reactive burner admittance. Flames would not induce sound emissions without the right acoustic properties of a non-reactive burner system. This study also shows that reactive burner admittances are mainly dominated by non-reactive burner admittance. The presence of flames only modifies the values, not the trend, of $|v'|/|p'|$ and $\phi_{p'v'}$ of non-reactive burner admittance, and results in larger values of $|v'|/|p'|$ and a decrease in $\phi_{p'v'}$. Only the flames possessing enough energy are able to cause enough modification of $|v'|/|p'|$ and $\phi_{p'v'}$, and possibly result in sound emissions in combustors. The flame with the equivalence ratio of 1·1 makes the largest modification and, thus, causes the strongest sound emissions. This research further shows that distributions of the imaginary parts of non-reactive burner admittance and the real parts of reactive burner admittances are in good qualitative similarity. This result indicates that the frequencies for possible sound emissions and the critical frequencies could be predicted by knowing the distribution of the imaginary parts of non-reactive burner admittance. In addition, the critical frequency is not unique and dependent on the acoustic property of the non-reactive burner system. The fundamental frequency of the combustor system should be within the critical frequency range to possibly cause the sound emission. The results obtained in this research could be clearly elucidated by the measured admittance data.

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