Journal of Visualization, Vol. 4, No. 2 (2001) 179-184

Flame Patterns of Acoustic Wave and Flame Interaction in a Cylindrical Tube

Papadopoulos, T., Pritchard, M., Green, C. and Zhang, Y.

* Thermodynamics and Fluid Mechanics Division, Mechanical Engineering Department, UMIST, P.O.Box 88, Manchester, M60 1QD, UK.
e-mail:YZ100@umist.ac.uk
http://www.me.umist.ac.uk/staffpgs/yzd/index.html

Received 9 February 2001.
Revised 5 March 2001.

***Abstract*:** In this short paper, flame and acoustic wave interactions under laboratory conditions have been reported. The test rig consists of a cylindrical Perspex tube and a fuel tube (burner) positioned along the central axis of the tube. The acoustic characteristics of the rig are measured. The flame instability with and without acoustic excitation has been investigated. A high shutter speed colour camera has been applied to capture many interesting unstable flame patterns. It has been found that strong flame instability only occurs at particular frequencies. The position of the burner inside the cylindrical tube also has an effect on flame instability.

***Keywords*:** flame instability, flame and acoustic wave interaction, diffusion flame.

1. Introduction

Observations of unsteady flame phenomena date back to the early 19th century. It was not until the mid to late 19th century that systematic investigations into flame instabilities were carried out. The stimulus for such work was the prevention of explosions in coalmines. Research into flame properties and propagation was carried out thus laying the groundwork for further theories to be developed. After this period, interest in the subject declined until the invention of the jet and rocket engines. Large amplitude combustion induced oscillations are observed in most continuous flow systems such as rockets, boilers and afterburners of jet engines. These oscillations appear when the interactions of the sound and the thermo-acoustic source are phased to promote growth of the oscillation. Extensive researches have been carried out (Candel, 1992; Clanet et al., 1999; Clavin, 1985; Davis and Jumppanen, 1993; Davis and Li, 1995; Jones, 1945; Lawn, 1982; McManus et al, 1993; Parker, 1988). Thermo-acoustic instability remained a challenging problem facing the modern combustor designer. The situation becomes more pressing for the development of new generation of low pollutant emission combustors. Combustion instability, especially the thermo-acoustic instability, is a main obstacle in developing the new low emission burners and combustors. A simple test rig has been built to study the flame acoustic wave interactions and the flame patterns are recorded by high shutter speed video camera.

2. Experimental Apparatus

The experimental set-up is shown in Fig. 1. The main components of the rig were a simple burner, a Perspex cylindrical tube and a loudspeaker. The burner used in the experimental set-up was a single fuel pipe of 0.005 m internal diameter. At the end of the copper tube, there was a tap, which reduces the tube diameter to 0.0018 m.

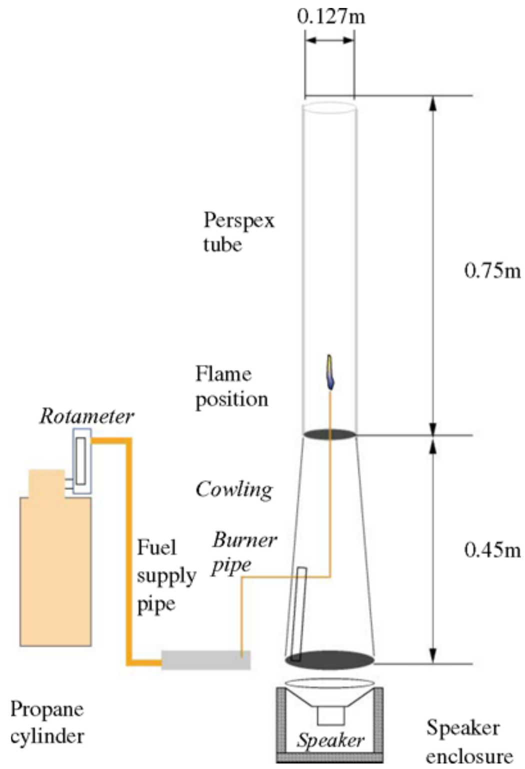

Fig. 1. The experimental set-up of the test rig.

The burner was connected to a propane gas cylinder. The burner nozzle exit could be moved up and down along the Perspex tube. The fuel was released from the copper tube and mixed with the surrounding air and a diffusion flame is created. A rotameter was used to measure and regulate the fuel flow. It was calibrated for propane with a dynamic range of 0.05E-3～0.75E-3 m^3/min. The flame was enclosed inside a Perspex-tube. The tube dimensions were 0.75 m in height and 0.127 m of inner diameter. It was supported by a steel holder. The Perspex tube is allowed vertical movement.

The loudspeaker (BUMPER model) has a maximum power of 350 Watt and its frequency ranges from 25 Hz to 4000 Hz. It was connected to a signal generator and was located below the tubing arrangement and the burner, providing the necessary acoustic excitation. The loudspeaker available for the experiment had a larger diameter than the Perspex tube. A thin sheet steel cone was used to connect the loudspeaker and the Perspex tube to ensure that as much of the sound as possible was transferred to the test section. An enclosure was also constructed for the loudspeaker. It is made of wood. The enclosure projects some of the sound energy from the back of the loudspeaker that would otherwise have been lost.

The range of the generated frequencies was between 15～10000 Hz. Both analogue and digital signal generators were applied to the study. The amplitude of the supply voltage for the analogue signal generator was varied between 0 and 40 volts.

The microphone used for the sound measurements was an electret type commercial microphone (ECM-1028 Electret Mike AOI). For the digitisation of the microphone's analogue signal, a PC soundcard was used. It was a Sound Blaster PCI 128 audio card from Creative Labs.

For the analysis of the acoustic signals, the SpectraLab v.4.32.14 (Sound Technology) spectrum analysis package was used. The data collection and processing procedure is shown in Fig. 2.

For the video recording of the flame, a colour video camera was used. This camera has four shutter speeds. In all the experiments the shutter speed was set at the highest level (1/4000 s) in order to reduce the flame movement to the minimum.

3. Results and Discussions

The measured harmonic frequencies of the experimental rig are listed in Table 1. Note that the second harmonic frequency is 264 Hz and it will be shown later that the flame oscillates the strongest if it is excited at this

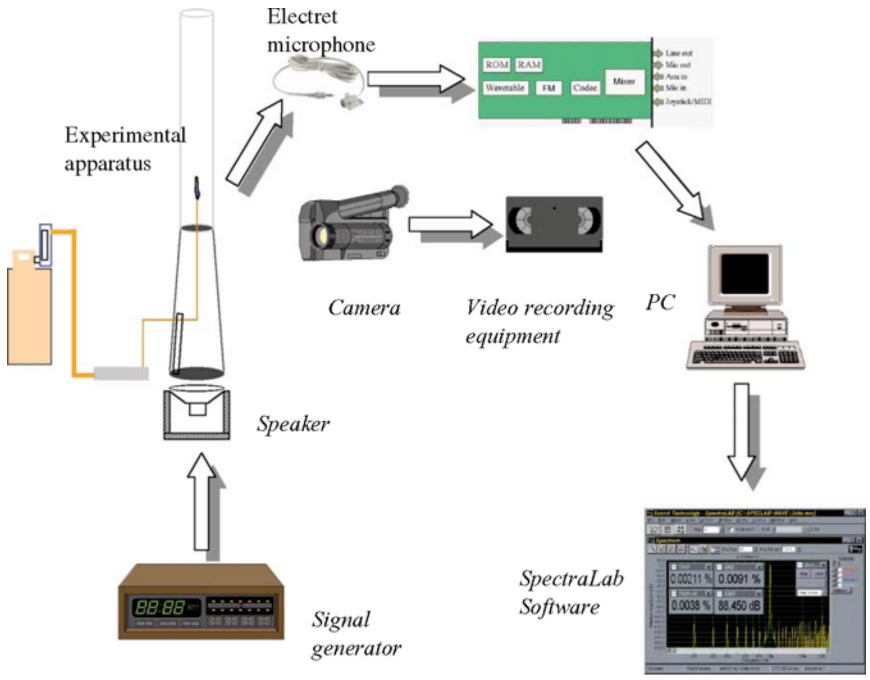

Fig. 2. The data collection and data analysis procedures.

Table 1. The measured harmonic frequencies of the testing chamber.

Harmonics	1st	2nd	3rd	4th	5th
Measured Values (Hz)	161	264	392	531	664

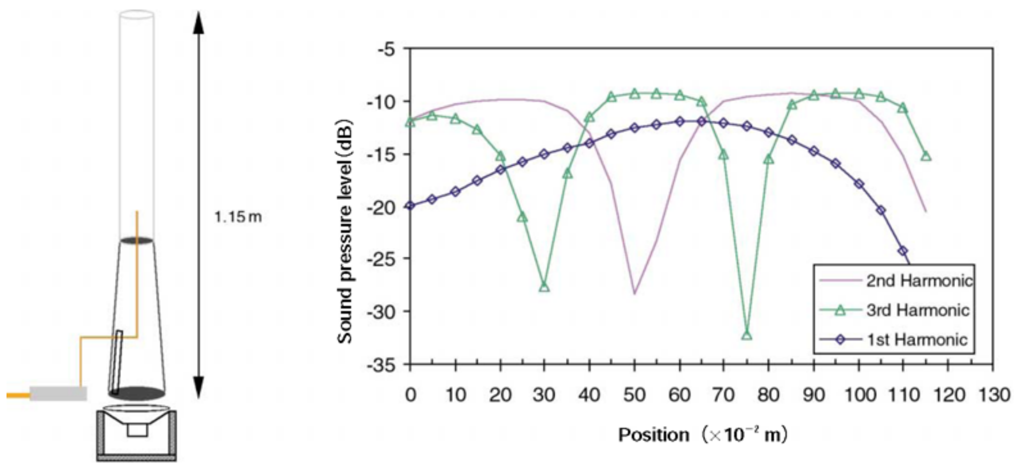

Fig. 3. The sound pressure level along the Perspex tube.

frequency.

Shown in Fig. 3 is the measurements of the sound pressure level versus the position along the axial direction of the Perspex tube (from the bottom to the top) under the excitation of the first, second and third harmonic frequencies.

Figure 4 is the images of a flame taken at different burner nozzle positions but without acoustic excitation. The fuel flow rate is 0.15E-3 m^3/min. It can be seen that the flame is unstable at certain positions. The Perspex tube has affected the image quality slightly by reflecting the flame and causing 'double' images (the brighter part is the real flame image and the darker part is the reflection). It can be seen that the flame is very unstable when the burner nozzle is 0.25 m above the bottom level of the Perspex tube, which is close to a pressure node of the second harmonic.

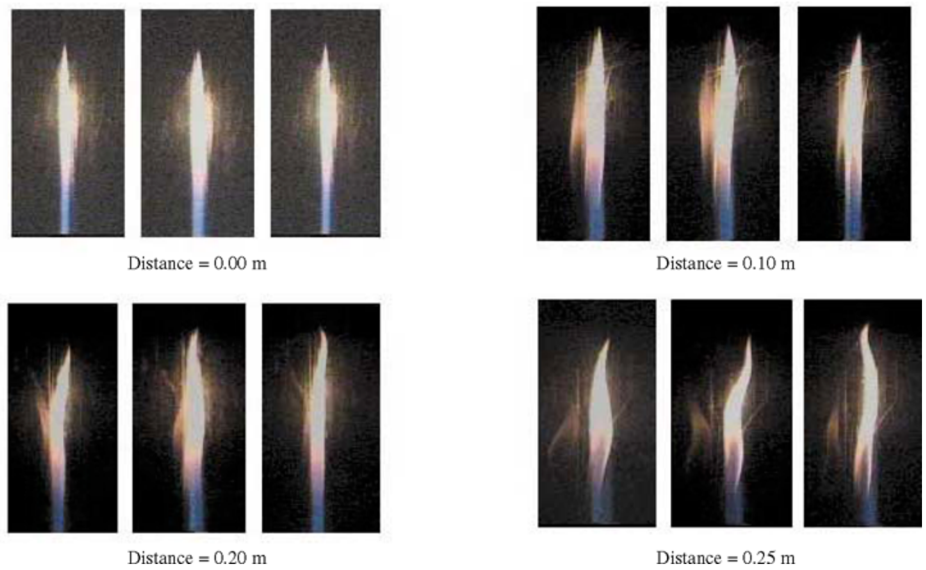

Fig. 4. Flame images with the burner positioned at different height from the bottom end of the Perspex tube.

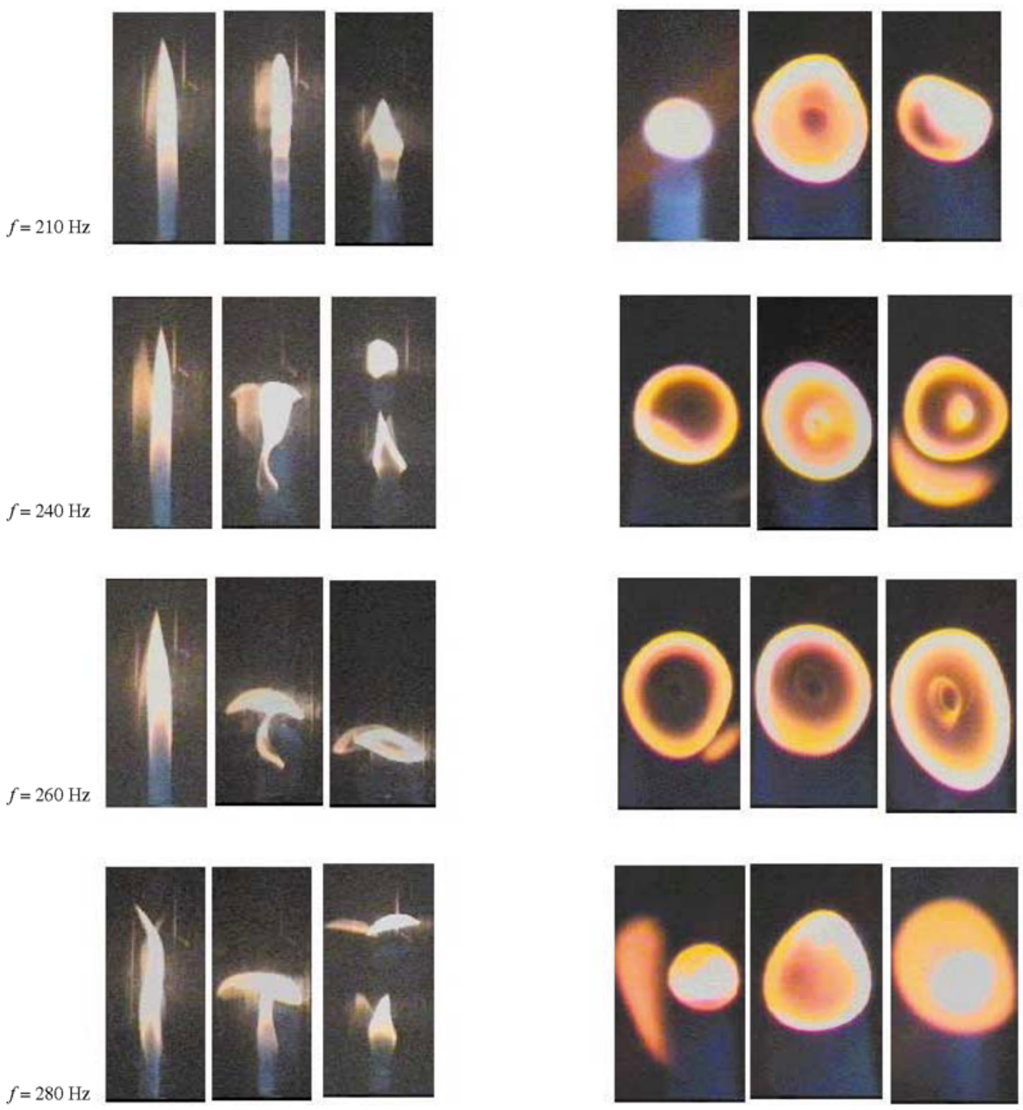

Fig. 5. (continued)

Fig. 5. Flame images at different excitation frequencies but at the same burner position. The first image of each row is the flame without excitation. The three images on the right-hand side are taken from the top of the Perspex tube.

Shown in Fig. 5 are the images of flames excited at different frequencies. The loudspeaker was operating at approximately less than one tenth of its maximum power range. In the figure, the first image of each row is the typical flame image without excitation. The three images on the left-hand side of each row were taken from the side of the tube. The three images on the right-hand side of each row were taken from the top of the Perspex tube. The fuel flow rate is the same as that of Fig. 4. The burner nozzle is 0.25 m above the bottom end of the Perspex tube. It is very clear that the flame oscillates the strongest when the excitation frequency was at the second harmonics of the Perspex tube. The 'doughnut' shape of the flame implies that a large-scale vortex has been induced by acoustic excitation.

Figure 6 is a plot of the sound level measured at the top of the Perspex tube, as a function of the loudspeaker frequency with and without a flame. There are two local peaks for both of the cases, which corresponds to the first and second harmonics of the rig. It can be seen that combustion has increased the sound level due to the strong flame oscillation. The existence of flame has also increased the peak frequencies slightly.

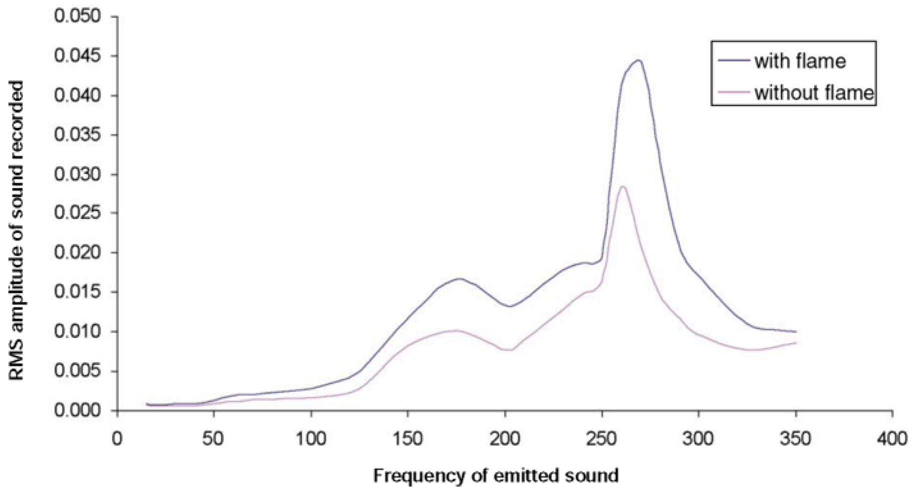

Fig. 6. The effect of combustion on noise generation.

4. Conclusion

The effect of acoustic wave on diffusion flame enclosed in a Perspex tube has been recorded by a high shutter speed colour video camera and analysed. The acoustic wave affects the flame by changing the pressure locally and therefore the fuel and air mixing, resulting in very complex and interesting flame patterns.

A flame inside a tube will flicker by itself. This effect is considerable when the burner nozzle is one third inside the Perspex tube.

With the present set-up it was found that a diffusion flame was most affected in the frequency rage of 200～300 Hz with the strongest oscillation occurring at the second harmonic of the test rig.

Acknowledgments

The research was partly funded by the Royal Society under grant number RSRG 20165.

References

Candel, M. S., Combustion Instabilities Coupled by Pressure Waves and their Active Control, Twenty-Fourth Symposium (International) on Combustion, (1992), 1277-1296.

Clanet, C., Searby, G. and Clavin, P., Primary Acoustic Instabilities of Flames, Journal of Fluids Mechanics, 385 (1999), 157-197.

Clavin, P., Prog. Energy Combustion Sci., 11 (1985), 1-59.

Davis, M. R. and Jumppanen, P. C., Optical Detection of the Response of a Diffusion Flame to Excitation, Journal of Combustion and Flame, 93 (1993), 349-374

Davis, M. R. and Li, H. L., Structures Induced by Periodic Acoustic Excitation of a Diffusion Flame, Combustion and Flame, 103 (1995), 151-160.

Jones, A. T., Singing Flames, J. Acoust. Soc. Am., 16 (1945), 254.

Lawn, C. J., Criteria for Acoustic Pressure Oscillations to be Driven by a Diffusion Flame, the Nineteenth Symposium (International) on Combustion, (1982), 237-244

McManus, K. R., Poinsot, T. and Candel, S. M., A Review of Active Control of Combustion Instabilities, Prog Energy Combust. Sci., 19 (1993), 1-29.

Parker, S. P., Acoustics Source Book, (1988), McGraw-Hill, New York.

Author Profile

Theofilos Papadopoulos: He graduated from the Mechanical Engineering Department of Patras University in 1999 in Greece. He then studied in the Mechanical Engineering Department of UMIST, UK for MSc degree. He is currently serving in Greek army.

Martin Pritchard: He is currently studying at Manchester University for a degree of Master of Engineering (MEng) in Aerospace Engineering, which is a joint course between Manchester University and UMIST.

Chris Green: He gained place at UMIST in 1996 to study Integrated Engineering and then Aerospace Engineering. He graduated in 2000 and joined Rolls-Royce PLC in Derby as Graduate Trainee. Since then he has been working on engine test rigs, carrying out researches on combustion instability damping for low emission combustor and working on concept designs for future engines.

Yang Zhang: He received his BEng degree in Cryogenic Engineering from Zhejiang University, China and his Ph.D. in Combustion from Cambridge University. He worked in No. 585 Research Institute, China, and studied English in Shanghai Foreign Language Institute before starting his Ph.D., which was in the area of Experimental Combustion and under the supervision of Prof. K N C Bray, FRS. After his Ph.D. he continued his research in Cambridge before taking up his current position as a lecturer at the University of Manchester Institute of Science and Technology. His research interests include the experimental and computational studies of reacting flows, experimental diagnostic techniques such as PIV, high-speed imaging, stereo imaging and computing, signal processing and flame pattern recognition.