Acoustic Impact of Fire Suppression Nozzles

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Abstract

The acoustic impact of fire suppression nozzles is investigated via a fundamental study of single orifice jet flow. Different orifice diameters and pressure ratios were experimentally and computationally investigated. A circular-arc array of microphones was used to quantify the directionality of the radiated noise field with narrow band spectral analysis. Shadowgraph images and mean-flow computational fluid dynamics (CFD) simulations were performed to understand the associated shock structure of the jet fields. Results show that noise mechanisms are dominated by broadband jet mixing in the downstream direction and shock screech tones and broadband shock noise in the upstream direction, particularly at intermediate pressure ratios. The directionality is shown to be significant and a method to account for this in suppression nozzle noise assessment is presented.

Keywords: Nozzle acoustics, clean agent

Introduction

Clean agent based fire suppression systems (either inert gases or chemical agents) are deployed in a diverse range of building environments including computer data centers. When the system is activated and the fire suppression agent is discharged from the nozzle, the noise levels in the area can reach very high levels for brief periods of time. This high noise level has been associated with performance reduction in hard drives at the data centers, sometimes leading to permanent damage of the hard drives. At least one recently reported incident of data center downtime [1] has been attributed to noise from the discharge of the fire suppression agent. Testing on various hard drive brands performed by IBM [2,3] and Siemens [4] has shown that Sound Pressure Levels (SPL or Lz) greater than 110 dB tend to reduce hard drive read-write performance by at least 50 %. To our knowledge, a detailed understanding of the noise generation mechanisms from fire

suppression nozzles has not yet been presented. The objective of this study is to gain a preliminary understanding of noise generation mechanisms through a detailed characterization of a compressible jet flow at conditions relevant to fire suppression nozzles.
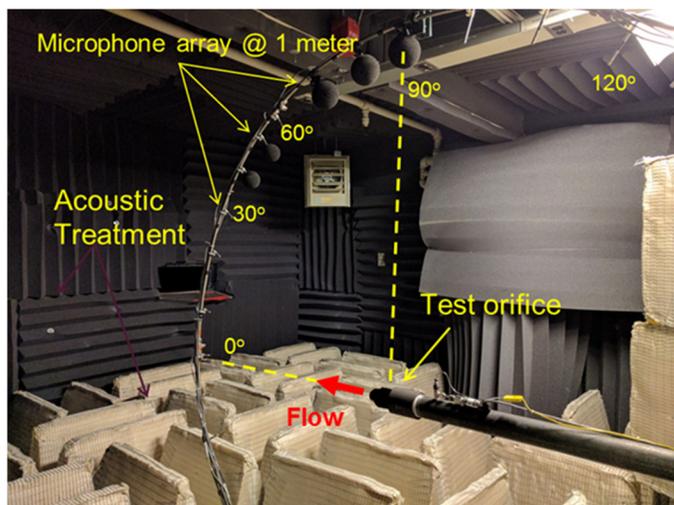

Figure 1.   Orifice jet noise experimental arrangement.

Aeroacoustics Characterization

An aeroacoustics jet flow experiment was set up at the United Technologies Research Center to characterize the acoustic emission from a single orifice jet flow during a fire suppression discharge. Figure 1 shows the experimental arrangement for the orifice noise testing. An orifice typical of a fire-suppression nozzle body was installed at the end of a horizontal 50 mm pipe that was supplied by a regulated and metered 26 bar air system (air was used as reasonable surrogate gas for an inert gas like nitrogen). The gas temperature and pressure were measured just upstream of the orifice.

Pressure ratios (PR=P_{INLET}/P_{ATM}) were varied from 2-10, which spans a typical discharge range for a fire suppression nozzle. The radiated noise was measured with an array of 19 microphones at one meter radius from -20 to 160 degrees as shown in Fig. 1. The microphones were simultaneously recorded with a high-speed data system and later processed with MATLAB signal processing scripts. Measurements were obtained under steady conditions, unlike a typical suppression nozzle discharge, since the nozzle discharge event can be thought of as a sequence of quasi-steady conditions. This approach allows long sample records to be obtained and useful statistical averaging to be performed. Three orifice sizes were studied: 5, 8, and 13 mm diameter.

Processing and Interpreting Noise Measurements

Figure 2 shows an example of radiated noise results for an 8 mm orifice for a range of pressure ratios from PR=3-10 in terms of OSPL (overall sound pressure level) versus radiation angle. The solid lines correspond to an OSPL that is integrated over a 0-50 kHz range. An interesting observation is that the highest pressure ratio (and highest mass flow rate) does not correspond to the highest noise level (see PR of 5) in this data set. The physics of this non-intuitive result is explained later. Also note that for a given PR, there is a significant variation in noise level versus microphone angle (or "directionality"), on the order of 10 dB.

Range of jet noise radiation angles experienced
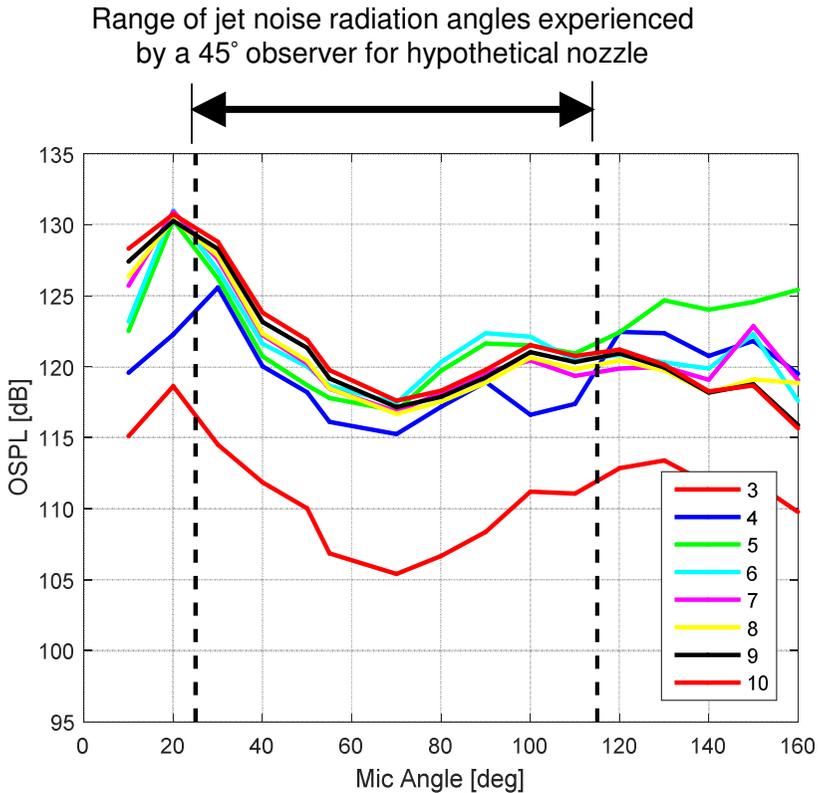by a 45˚ observer for hypothetical nozzle

Figure 2.   Acoustic radiation from 8 mm orifice at one meter versus observer angle for a range of orifice pressure ratios.

For a hypothetical 360° dispersion nozzle with 12 orifices oriented downward at 20°, an observer at the "45 deg." location will see a range of radiation angles relative to each orifice jet axis as indicated by the vertical dashed lines in Fig. 2. To understand the expected noise level at this observer point, the sound power from each jet, accounting for the relative observer angle to the jet axis, needs to be summed.

An example using the data in Fig. 2 is shown in Fig. 3 for the above described hypothetical nozzle versus pressure ratio for the entire frequency band as well as two bandlimited ranges that have been suggested to affect hard drive performance. As shown in the figure, band limiting the sound spectrum has a significant impact on the expected SPL level (10-20 dB for the example range).
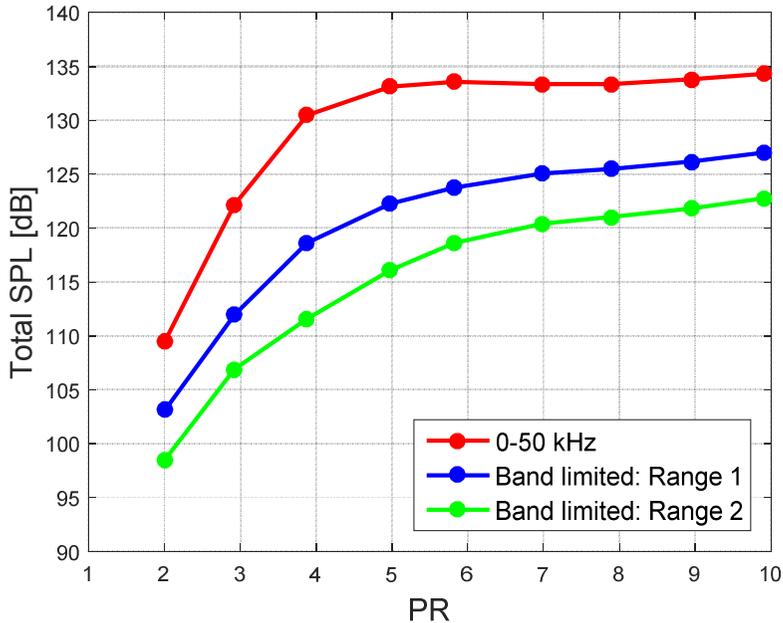

Figure 3.   Estimated SPL at 45° / 1 meter for a 12 orifice nozzle with 8 mm diameter orifices.

Noise Generation Mechanisms

The primary acoustic source during a discharge is the jet (or multiple jets) of the agent emanating from the nozzle, which is typically choked and under-expanded over much of the duration. Shadowgraph images were obtained for the three orifice sizes. The flow patterns were found to be geometrically similar (i.e., when scaled on orifice diameter) and depended on pressure ratio only. Fig. 4 shows the shadowgraph images and corresponding CFD results for the 13 mm orifice which show good agreement in shock structure spacing. Downstream of the orifice exit, for PR<6, a periodic system of expansion and oblique shock waves form. At PR=6 and above, a normal shock disk forms downstream of the orifice (not captured by CFD), followed by a quasi-periodic and turbulent shock cell structure.

The noise due to under-expanded jets has been extensively studied by the aeroacoustics community in the context of engine jet noise (e.g., see [5]). In Fig. 5 the primary mechanisms of noise generation from the orifice jet flow are illustrated: a) broadband jet mixing noise and b) shock associated noise (screech tones and broadband shock noise). Broadband jet mixing noise is due to turbulence generated by the jet shear layer which radiates predominantly in the forward direction (low angles in Fig. 5) and in the absence of screech tones, is the dominant noise source of jet flows.
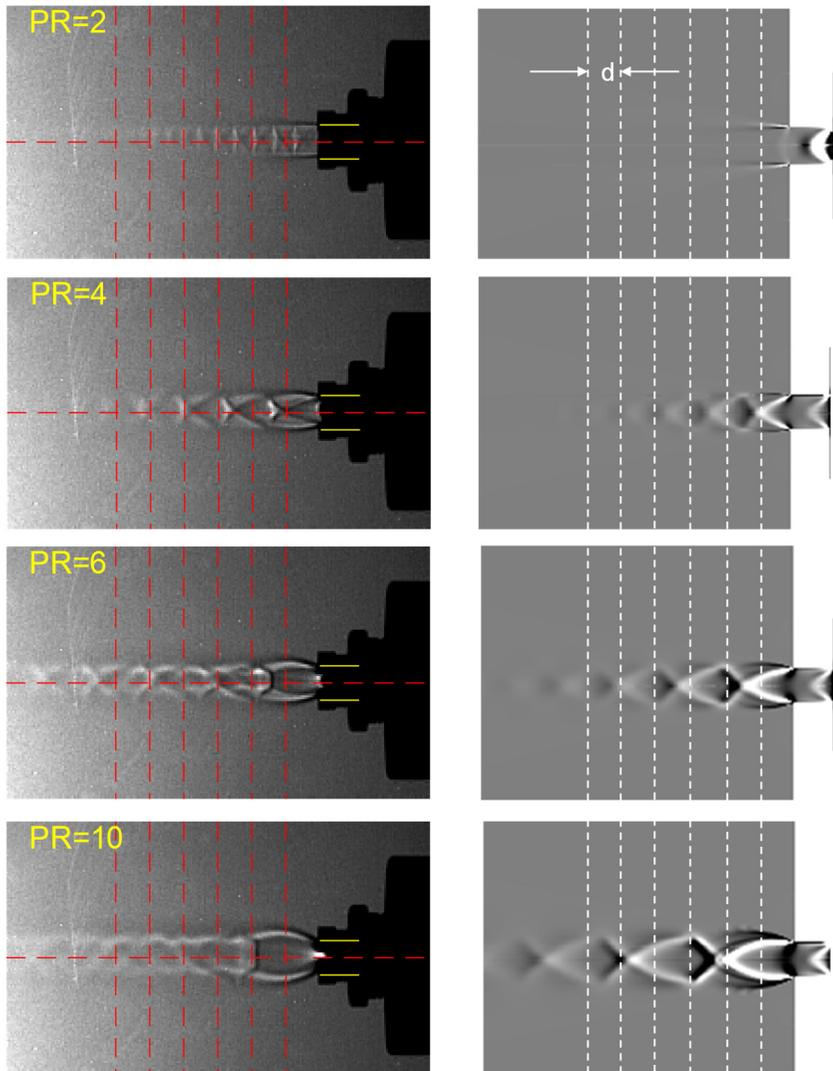

Figure 4.   Shadowgraph images (left) and CFD model results (right) for 13 mm orifice over a range of pressure ratios.

Shock screech tones are associated with a strong feedback loop between turbulent structures shedding from the lip of the orifice and interacting with the shock cell structure in the jet. The shock screech tone most likely exists for the periodic shock cell structures observed in the PR=2 and 4 shadowgraph images (versus the shock disk structure for PR=6 and 10). It is the presence of strong screech tones that causes the non-monontic OSPL trend with PR in Fig. 2. However it should be noted that the existence of the screech tone depends on other factors specific to the geometry. Broadband shock noise is generated by weak interactions between shear layer turbulent structures and the shock cell structure. These noise mechanisms are relatively complex and are described in detail in Ref. [5].
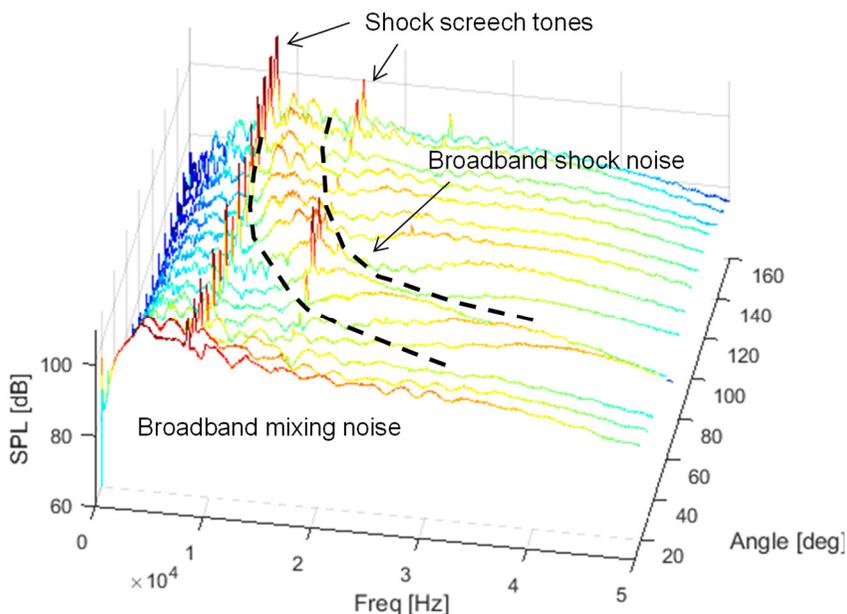

Figure 5.   Waterfall plot of radiated noise spectra from a 13 mm orifice at PR=5 as a function of observer angle.

Application to Data Centers

The impact of the suppression nozzle acoustics on hard drive performance in a data center is a result of three primary features:

1. The acoustic characteristics of the nozzle in terms of the sound power level (PWL or Lw) and radiation directivity. The sound power level of a source is the average acoustic energy flow through a unit sphere surrounding the surface. To fully characterize the source one should also consider the directivity of the source since this need not be omni-directional and can vary depending on the direction of

measurement. These metrics are unique to the acoustic source and useful because they are independent of the environment.

2. The acoustic path from the source (nozzle) to the receiver (hard drive) can be affected by the walls in the room and the racks in which the hard drives are installed. These multiple paths (wall reflections and direct path) will significantly modify the final noise at different frequencies and is very strongly dependent on the specific environment.

3. The noise arriving at the hard drive (measured in terms of Sound Pressure Level or SPL or Lz) is a result of the combination of nozzle acoustics characteristics and the acoustic path. The read-write performance of the hard drive has been shown to be affected significantly when the SPL levels increases beyond about 110 dB, although this number is very dependent on the specific drive being tested.

Summary

The jet noise associated with flow emanating from an array of body orifices is the dominant noise mechanism of fire suppression nozzles. The flow patterns and radiation characteristics for a typical orifice were studied in isolation (versus an array in a fire-suppression nozzle) to better understand the noise mechanism, frequency content and directionality. Results show that the noise mechanisms are dominated by broadband jet mixing in the downstream direction and shock screech tones and broadband shock noise in the upstream direction, particularly at intermediate pressure ratios. The radiated noise directionality was shown to be significant and a method to account for this directionality was presented. The results also show that band limiting the spectrum can significantly underestimate the overall sound pressure level.

Acknowledgements

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