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Studies on conical and cylindrical resonators

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Abstract

Spectral features of conical and cylindrical Hartmann resonators are compared in this work through a systematic parametric study. Experiments have been conducted by varying the following parameters: stand-off distance, nozzle pressure ratio and cone angle. Resonance frequencies of conical cavities are found to be higher than those of cylindrical cavities of the same length. Low ($\sim$kHz) and high frequency ($\sim$10 kHz) modes are observed in the spectra. Low frequency modes show an oscillatory trend with stand-off distance. The high frequency tones are found to be independent of cavity geometry and cavity length, and are similar to jet impingement tones.

Keywords: Hartmann whistle; Cylindrical and conical resonators

1. Introduction

Of late, resonant acoustics from air-jet devices such as Hartmann whistle have been found useful in flow and noise control applications, and have assumed importance. They are popularly used by Active Flow Control (AFC) research community as "powered resonance tube" (PRT) actuators [1,2] for applications like impingement noise suppression, separation control, etc. "Hartmann resonator" or "Hartmann whistle" consists of an underexpanded jet impinging on a cavity held inline with the axis of the jet. When the cavity inlet is kept at certain regions of the jet, strong flow oscillations occur. These flow disturbances cause high intensity acoustic radiation of discrete nature. Hartmann whistles exhibit strong directivity and are tunable for any desired frequency. The frequencies at which the whistle resonates depend on the geometry of the cavity, nozzle to cavity stand-off distance and inlet pressure ratio. Fig. 1 shows the typical flow structure near the mouth of a Hartmann whistle. The shock cell structures formed in the underexpanded jet are disrupted near the cavity, leading to the formation of a stand-off shock. The bulk of the subsonic flow downstream of this shock, impinges on the resonator, gets deflected at a high velocity [3]. The structure of the shock cells, position of the stand-off shock and Mach disk, gradient of stagnation pressure near the cavity inlet, instabilities in the shear layer, etc. play a significant role in the resonance phenomenon. Numerous studies have characterized the flow structure and its relationship with the resonance process. While studies on cylindrical resonators are common in the literature, studies on conical geometries are scarce. Therefore, such resonators are investigated in this paper and compared with traditional cylindrical resonators. Some of the earlier works on Hartmann resonators are discussed below.

1.1. Literature review

The studies concerning the Hartmann whistle have focused on various aspects like revealing the mode of operation, geometric modifications to enhance performance, theoretical modeling using analytical or wave diagram methods, or configurations for a specific application. In this section, representative works that have attempted to unravel the physics of the resonance phenomenon and the frequencies generated have been presented.

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Nomenclature

D_{noz}	jet diameter (mm)	R	nozzle pressure ratio
D_{res}	cavity diameter (mm)	S	stand-off distance between jet exit and cavity inlet (mm)
f_1	fundamental frequency (Hz)		
L	length of cavity (mm)	V	cavity volume (mm^3)
$OASPL$	overall sound pressure level (dB) re 20 μPa	α	semi-cone angle of cavity (degrees)
P_0	stagnation pressure (bar)		

Sarohia and Back [4] investigated the resonance phenomenon in a Hartmann whistle and found that depending on the parameters like stagnation-to-ambient pressure ratio (R), length of the tube (L), and the stand-off distance (S), the resonator resonates in one of the following modes: (i) Jet instability mode, (ii) Jet regurgitant mode, and (iii) Screech mode. They observed jet instability mode in subsonic jets ($R < 1.9$). This mode is characterized by toroidal vortices getting convected downstream and producing weak compression waves inside the cavity. The characteristic frequency of this mode is the vortex shedding frequency of the nozzle. As pressure ratio R is increased, the flow becomes supersonic and the jet instability mode ceases to operate. Jet regurgitant mode becomes the predominant mode for supersonic jets if the stand-off distance is more than the first shock position corresponding to free jet. The regurgitant mode comprises two phases; the inflow phase and the outflow phase. In the first phase, the jet flow enters the tube in an unrestricted manner. The incoming fluid compresses the indigenous fluid leading to a train of compression waves traveling inside the tube. The compression waves coalesce as they move downstream. The coalesced compression wave gets reflected and starts traveling upstream. This causes an expansion wave to move downstream, thereby causing the flow to get outside the cavity, signifying the outflow phase. As the outflow phase gains in strength, the interface separating the jet-flow and tube-flow moves upstream. When the momentum of the tube flow reduces below that of the jet, the interface rapidly moves downstream to the mouth of the cavity initiating the next inflow phase. Screech mode is observed beyond $R = 3.9$. It is a high frequency mode which occurs due to the presence of an oscillating normal shock (∼20 kHz) in front of the cavity. Stand-off distance and nozzle pressure ratio was found to be the governing parameters in determining the location, strength, and frequency of the oscillating shock. Sobeiraj and Szumowsky [5] observed that while the shape of the cavity edge considerably affects the acoustical phenomena and oscillatory modes (switching between screech and regurgitant), the shape of the nozzle edge is insignificant. The frequency corresponding to the screech mode is also seen to be higher than that for the regurgitant mode in the range $2 < R < 3.5$.

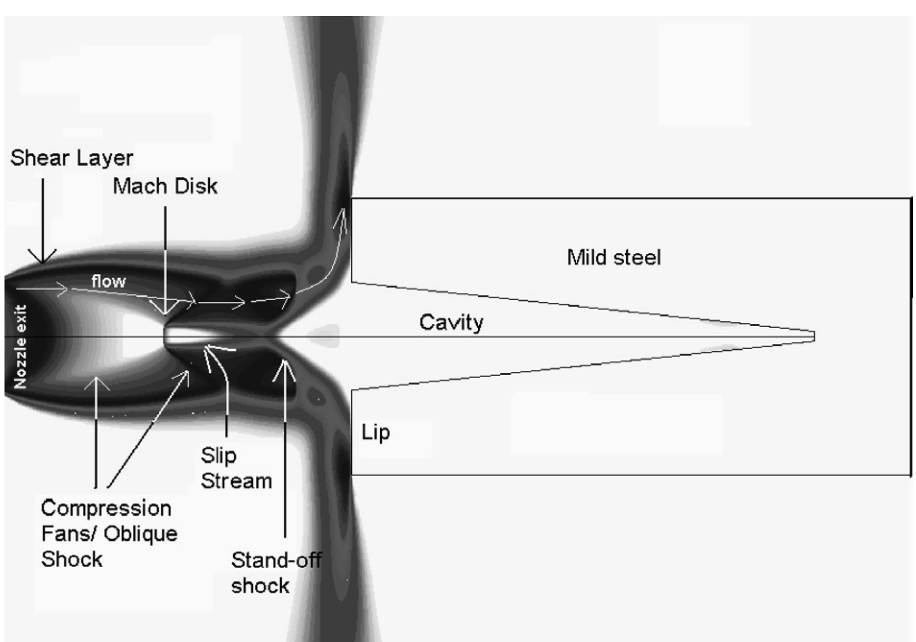

Fig. 1. Schematic of the flow around a conical Hartmann resonator.