Contents lists available at ScienceDirect

Aerospace Science and Technology

www.elsevier.com/locate/aescte

Experimental study of supersonic flow over cavity with aft wall offset and cavity floor injection

Tanuj Gautam, G. Lovejeet, Aravind Vaidyanathan *

Department of Aerospace Engineering, Indian Institute of Space Science and Technology, Trivandrum 695547, India

A R T I C L E I N F O

Article history:
Received 21 November 2016
Received in revised form 5 July 2017
Accepted 18 July 2017
Available online xxxx

A B S T R A C T

Experimental studies were conducted at Mach 1.71 supersonic flow over open cavity to find the best configuration of combined passive (aft wall offset) and active methods (cavity floor injection) to optimize the noise suppression. Cavity of length to depth ratio 3 with 0%, 5% and 10% aft wall offset were analyzed with the combined effect of 2 bar, 4 bar and 6 bar injection pressures, injected from locations 25%, 50% and 75% from front wall. Experimental methodology includes instantaneous schlieren visualization and unsteady pressure measurements. In all the schlieren images, the presence of shear layer and various cavity flow features are clearly visible. Suppression in tonal amplitude for increase in offset and injection pressure is observed for various injection locations. Injection location at 75% cavity length from front wall was found to provide the maximum suppression. Spectrogram plots clearly indicate the redistribution of energy among tones and broadband noises. Increase in the number of tones is observed for higher injection pressure and aft wall offset combination. Nature of acoustic wave is confirmed from correlation and coherence plot. Over All Sound Pressure Level (OASPL) and normalized mean pressure plot are used to perform comparative study for various configurations.

1. Introduction

The suppression of pressure oscillations inside open cavities has been of great interest since the suspended cutouts existed on aircrafts. Airplanes, cars and trains exhibits open cavities on their surfaces, generating aerodynamic noise, increased drag, and are one of the main sources of dangerous pressure fluctuations. The structure of cavity flow-field depends on several parameters such as Mach number, nature of approaching boundary layer, and L/D ratio of the cavity. Krishnamurthy [1] and Roshko [2] in the mid-1950's, were the first to rigorously study the supersonic flow past cavities and to identify the oscillatory behavior of the cavity flow field for a wide range of supersonic Mach numbers. In general, cavities are divided into open and closed cavities as defined by Charwat et al. [3]. Cavities in which the boundary layer separates at the leading edge and again reattaches near the aft wall corner, without interacting with cavity floor are referred to as open cavities. Cavities where the separated shear layer interacts with the cavity floor and further separates ahead of the aft wall are termed as closed cavities. At supersonic speeds involving turbulent shear layer, the distinction between open and closed cavities was observed to occur at $L/D = 11$.

Open cavity flows result in the formation of longitudinal pressure and flow oscillations. These oscillations are attributed to the shear layer interactions with the cavity. Rossiter [4] explained that the presence of the fluctuating surface pressures inside the cavity are driven by the shear layer oscillations and the feedback loop is formed due to its interaction with the aft wall. The discrete frequencies of this feedback loop are referred to as Rossiter tones. As the flow passes over cavity, the incoming boundary separates from the leading edge of the cavity and forms the shear layer. Rossiter [4] developed a semi-empirical relationship for estimating these frequencies for transonic flows. The equation was modified by Heller and Bliss [5], assuming the cavity temperature to be the same as the freestream stagnation temperature. The resulting modified Rossiter's formula for supersonic flow is presented here.

$$St = \frac{fL}{U_\infty} = \frac{n - a}{\frac{M_\infty}{\sqrt{1+\frac{r(\gamma-1)}{2}M_\infty^2}} + \frac{1}{k}} \quad (1)$$

The constant K and α were assigned values of 0.57 and 0.25, respectively by Ünalmis et al. [6]. It is to be noted that the modified Rossiter formula only estimates the frequencies of the cavity oscillations. Still it remains next to impossible to determine the mode that exists for longer duration of time and the corresponding am-

* Corresponding author.
E-mail addresses: tanuj61012@gmail.com (T. Gautam), lovejeetgujrati@gmail.com (G. Lovejeet), aravind7@iist.ac.in (A. Vaidyanathan).

http://dx.doi.org/10.1016/j.ast.2017.07.024
1270-9638/

Nomenclature

Symbols

a	Speed of sound (m/sec)
α	Time delay for acoustic wave generation
D	Depth of cavity (mm)
f	Frequency (Hz)
γ	Ratio of specific heats
K	Ratio of vortex convection speed to free stream speed (U_c/U_∞)
L	Length of the cavity (mm)
M	Mach number
n	Mode number
P	Pressure (bar)
PSD	Power spectral density
r	Recovery factor for temperature inside the cavity
SPL	Sound pressure level (dB)
OASPL	Overall all sound pressure level (dB)
T	Temperature (Kelvin)
U	Velocity (m/sec)
OF-x	Aft wall offset of 0%, 5% or 10%
Inj-x	Injection pressure (× bar) 2 bar, 4 bar or 6 bar
X/L-z	Non-dimensional distance from leading edge of cavity of 25%, 50% or 75%
ρ	Density (kg/m^3)
MPCC	Maximum positive cross-correlation
VR	Vertical right
HT	Horizontal top

Subscripts

∞	Free stream condition
o	Stagnation conditions
avg	Average
rms	Root mean square value
c	Vortex convection

Table 1
Active flow control methods.

Type	Suppression methods	Effect and problem	Study
Active	Steady mas injection through porous plates	Disturbance in shear layer instability	Vakili and Gauthier [9]
Active	Leading edge microjets	Disrupts the feedback loop	Zhuang et al. [10]
Active	Leading edge jet-pulsed blowing	Noise suppression depends on frequency and amplitude of jet	Lamp and Chokani [11]
Active	Piezoelectric flap actuator	Reduction of flow-induced oscillations	Stanek et al. [12]
Active	Blowing through pulsed perforated plate	Optimum control location: Below the leading edge	Smith [13]
Active	Steady jet and pulsed blowing with short and long duration pulse	Steady injection more effective than pulsed injection in noise suppression	Bueno et al. [14]
Active	Upstream mass injection	Attenuation of peak dynamic pressure	Meganathan and Vakili [15]

Table 2
Passive flow control methods.

Type	Suppression method	Effect and problem	Study
Passive	Aft wall offset 0%, 5% and 10%	Noise reduction and feedback loop disturbance	Malhotra and Vaidyanathan [7]
Passive	Aft-wall offset with different ramp angle	High amplitude tones for higher ramp angle	Vikramaditya et al. [8]
Passive	Ramped trailing edge for varying angle	Increase in Rossiter modes amplitude and shear layer upliftment	Baysal et al. [16]
Passive	Sloped bottom and flow path modifier at bottom of cavity	Negatively sloped bottom suppresses oscillations of cavities	Kuo and Huang [17]
Passive	Slotted, vented, slant, beak and valley aft walls	Pressure oscillation reduction at high Mach number	Perng and Dolling [18]

plitude in a cavity. As a consequence, almost all the techniques used for suppression of cavity oscillations are partially effective. Thus, methods involving passive and active techniques are introduced to reduce the cavity oscillations at certain designed cavity configuration. The main objective is to suppress the amplitude of oscillations by altering the flow features of the cavity by passive method such as aft wall offset [7] and aft wall ramp angles [8], and also by employing active methods. Active flow control devices can deliver better performance for a wide range of operating conditions but are complicated as compared to passive devices [9]. Typical active and passive control methods are summarized in Table 1 and Table 2 respectively.

Malhotra and Vaidyanathan [7] employed a passive method of aft wall offset to control the cavity oscillations. The unsteady pressure measurements [7] indicated the reduction in tonal amplitude for all the cavity cases, and also the redistribution of acoustic energy among different modes. In their study [7] it was proposed that a combination of passive and active suppression mechanism would be better than either one of them.

In this context, the present study focuses on oscillation suppression by combined effect of aft wall passive technique and cavity floor mass-injection strategy for L/D = 3 cavity. There are many studies that utilize secondary upstream injection [19,20,22] as it leads to the thickening of the shear layer, thereby resulting in altering the instability characteristics. But it should be noted that, the upstream injection could lead to the formation of bow shock upstream of the supersonic flow and could lead to flow separation and pressure losses. In this context, an alternative method of injection through the cavity floor is proposed to modify the flow field inside the cavity, thereby altering the shear layer instabilities to regulate the oscillations.

The entire study is presented as follows: first, the results from the baseline cavity with various aft wall offset configuration for the no injection case are analyzed using Sound Pressure Level (SPL),

Please cite this article in press as: T. Gautam et al., Experimental study of supersonic flow over cavity with aft wall offset and cavity floor injection, Aerosp. Sci. Technol. (2017), http://dx.doi.org/10.1016/j.ast.2017.07.024