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Analysis of Flow Oscillations in an Open Cavity by a Passive Control Method

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Abstract : ***Numerical simulations are performed to evaluate a submissive controller method, utilised to suppress the pressure oscillation made in an open cavity flow. The open cavity considered in this work has the aspect ratio of 2 (Length of the cavity/Depth of the cavity=2). As the passive control technique, a non-smooth surface is installed, upstream of the cavity. The parameters like flow instability, noise around cavity are investigated using large eddy simulation, coupled with acoustics model, for smooth and non-smooth cases. The experimental and computational data available in literature are utilized for validation of results for the smooth case. By flow visualizations, it is established that locating a non-smooth surface at the upstream effectively suppresses hollow stream oscillations. By comparing the current ground structures in cases of smooth and non-smooth surfaces, the mechanism of oscillation control by non-smooth surface is analysed.***

Keywords: passive control, pressure oscillation, open cavity flow, numerical simulation, non-smooth surface, large eddy simulation

1.INTRODUCTION

A bench mark problem in the field of aero-acoustics has been the pressure oscillation in an open cavity flow. This problem has pulled considerable attention for the previous few periods. By the virtue of high theoretical and real-world impact, this problem has obtained, several investigations have been conducted in this area. Still, the studies adequately examining the simple natural system initiating oscillations controller covering a diverse series of stream surroundings, are few in number. At present-day the maximum difficulty for researches of unsolidified dynamic forces and aero-acoustics to find a suitable technique to exactly demonstrate the source of noise and disruptions causing oscillation. For examiners in area of stream controller, suppression of various modes of oscillation seems to be the challenge having most significance. The issues discussed above along with many other issues, make the analysis of oscillations in the flow over cavity, a typical problem in the area of flow control.

2. Literature Survey

The 3-D flow past a rectangular cavity was investigated by Kyoungsik Chang et al. [1] using Long Eddy Simulation. The flow was incompressible in this case and the cavity was considered to be two dimensional. This was the first computational work successful in resolving all the three-dimensional structures arising as a result of cavity oscillations in shear layer mode. Two different types of boundary layer flows, one developing laminar and the other fully turbulent, were analysed for the same cavity Reynolds number ($Re_D = 3360$). The complex phenomena associated with resonant cavities were absent. In both the cases, it was found that the resolved stress at the upstream of the separated shear layer was dominated by that in the downstream part. The methods to suppress the cavity oscillations are broadly classified as active and passive control methods. Active flow control methods are known to suppress noise and are adjustable according to different flow conditions [2,3], and inactive controller methods like, spoilers, physique insertion and change of cavity possess the ease in implementing and are least expensive. Furthermost of these models were proved efficient in decreasing the forceful compression levels. Wang et al.(4) carried out practical and arithmetical analysis to study the sound produced in the case of a subsonic flow. They proposed an alternate solution as a vented spoiler. This proved to be superior in noise reduction as it modified the flow structure of the shear layer. In another numerical study carried out by Chokani and Kim [5] for a supersonic flow, it was observed that the submissive numeric controller was able to significantly suppress the scale of the small incidence fluctuations. Sarno and Franke [6] tested fences (invariable and fluctuating) and flow injections (balanced and vivacious) at the prominent control. They found the static fences to be more efficient. In an experimental study conducted by Stallins et al. [7], at subsonic and transonic velocities, it was reported that the porous floor and that along with slot vents were the most significant effect in the distribution of the shallow cavity pressures. Zhang et al. [8] conducted investigation on cavity flow oscillations at supersonic speed to determine the consequences of leading-edge compression rams, increased façades and physique insertion. Ukeiley et al. [9] observed a leading-edge barrier having a cylinder-shaped shaft adjourned parallel to it, in the impending borderline layer. It was claimed that this technique was quite successful in façade compression control. Alam et al. [10] attempted modification of hole geometry for a square cavity by attaching two plane shields to the forward-facing wall of hole in parallel and upright planes. This method was claimed to be quite effective in suppressing the pressure oscillations. Another numerical investigation performed in case of supersonic cavity flow to evaluate the method of stable physique insertion in the upstream, reported that the solid

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interface between the upstream border level and the insertion movement could force the shear layer to lift up [11].

This upward displacement of the shear layer might have resulted in weakening of the important twisters formed on the irregular edge.

Even though the aforementioned submissive controller techniques were reported to be capable of attenuating cavity produced compressed fluctuations, most of these controller mechanisms have not been found to perform appropriately in a widespread of flow conditions and also could not overwhelm simultaneously several acoustic models. To overcome these shortcomings, submissive approaches such as deflector [4] and sub-cavity [12], are gaining attention. However, introducing a deflector results in increase of drag. Also, the factors of rate and assembly dependability needs to be measured. On the other hand, the presence of sub-cavity in the stream-wise direction causes accretion of foreign particles and dirt, which develops the requirement of periodic cleaning or servicing. On the pretext of these factors, devising an economical and technically appropriate method to obtain a instability boundary layer and increase its viscosity while eluding the increase of slog, becomes crucial. For the past few decades, the method of introducing non-smooth surfaces has been successful in drawing attention of the researchers. The non-smooth surface results in reduction of pressure drag and friction drag [13,14]. At the level of rough surface, the turbulent edge can be obtained, which will result in increase in forward momentum. The edge thus refrains the inappropriate pressure slope moderately extended before it departs from the surface [15]. Therefore, in the present work, rough surface is acquaint with turbulent edge and rise the viscosity of the upstream edge.

3. GOVERNING EQUATIONS AND BOUNDARY CONDITIONS

Three dimensional unsteady filtered Navier-stokes equations for Newtonian incompressible flow in Cartesian co-ordinate system are

Continuity:

$$\frac{\partial \bar{u}_j}{\partial x_j} = 0 .$$

Momentum:

$$\frac{\partial \bar{u}_i}{\partial t} + \frac{\partial}{\partial x_j}\left(\bar{u}_j \bar{u}_i\right) = -\frac{\partial \bar{P}}{\partial x_i} + \frac{1}{\mathrm{Re}}\nabla^2 \bar{u}_i - \frac{\partial \tau_{ij}}{\partial x_j} + \bar{F}_i .$$

Where ui represents the velocity field , Re is the Reynolds number, Fi is the body force

The boundary conditions may be as follows

At Inlet the wall normal and the spanwise velocity components have been set to zero. Mathematically, $u_{in}=U_\infty$,$v_{in}=0$,$w_{in}=0$ where the subscript "in" indicates the inlet plane.

At Outlet a non reflective boundary condition (convective) is imposed which can be written as,

$$\frac{\partial u_i}{\partial t} + U_c \frac{\partial u_i}{\partial x_c} = 0$$

Here subscript c denotes the direction normal to the outflow boundary. the convecting Uc is considered as constant across the outflow boundary .

At Upper boundary free-slip condition is applied . so the boundary condition at this surface is ,

$$v = 0, \frac{\partial u}{\partial y} = 0 , \frac{\partial w}{\partial y} = 0$$

At Lower boundary no slip condition is applied. So the boundary condition at this surface is u=0,v=0,w=o.

Disturbance strip Turbulences are applied to generate the conversion process following Alam et al. [10]

This is done through process of disturbance strip applied on the flat plate region at the inlet of the domain.

We apply turbulences to the barrier standard velocity ,that are sinusoidal in time and in the span wise direction next to the formula

$$v = a_f \exp[-b_f (x - c_f)^2] \sin(\omega t) \sin(\beta y)$$

Where af,bf and cf are coefficients adjusting the stream wise deviation of the coercing ω is the frequency and β is a span wise wave number.

3. COMPUTATIONAL DOMAIN

3.1 Geometrical model of a rough surface cavity

An object is a four-sided cubicle with a huge volume and lesser opening at the top. The depth and length(L) of the cavity is D (=50mm), 2D respectively. And overall box dimensions are: 1) span wise width 3D, 2) depth 3D 3) length 11D.

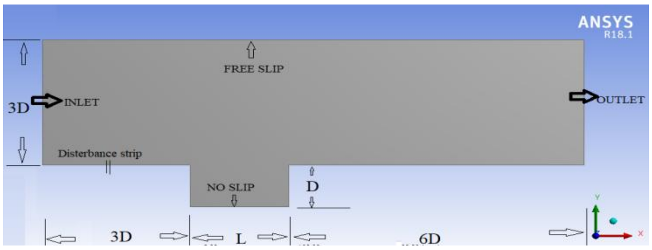

Fig 3.1. Computational domain with applied boundary conditions

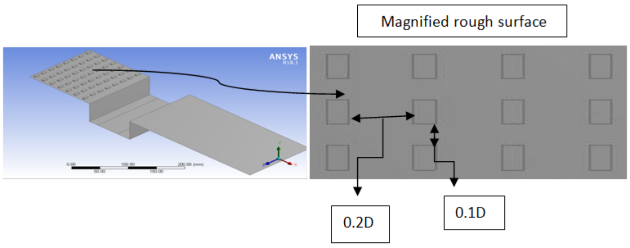

Fig 3.2 Detailed view of the upstream plate

As shown in fig the upstream leading surface modified by the creating of non-smooth surface (rough surface), this roughness may prompt a turbulent edge and rises the thickness of the upstream borderline[15]

Meshing: in the meshing the grid is very fine near the surface of the cavity and is slowly stretched out away from it.

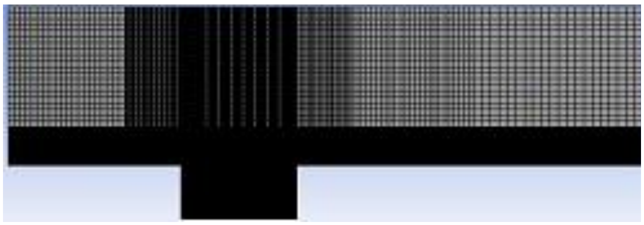

Fig 3.3. Shows the grid distribution

3.2 Validations of computational domain

3.2.1 Mean flow characteristics: Fig 3.4 shows The comparison of a longitudinal mean velocity profile with the computational data of Chang et al.(2006) at five stations from x/D=0.02 to x/D=1.7. a very good agreement is observed at all stations between the computational data and the laminar case predictions by the present LES.

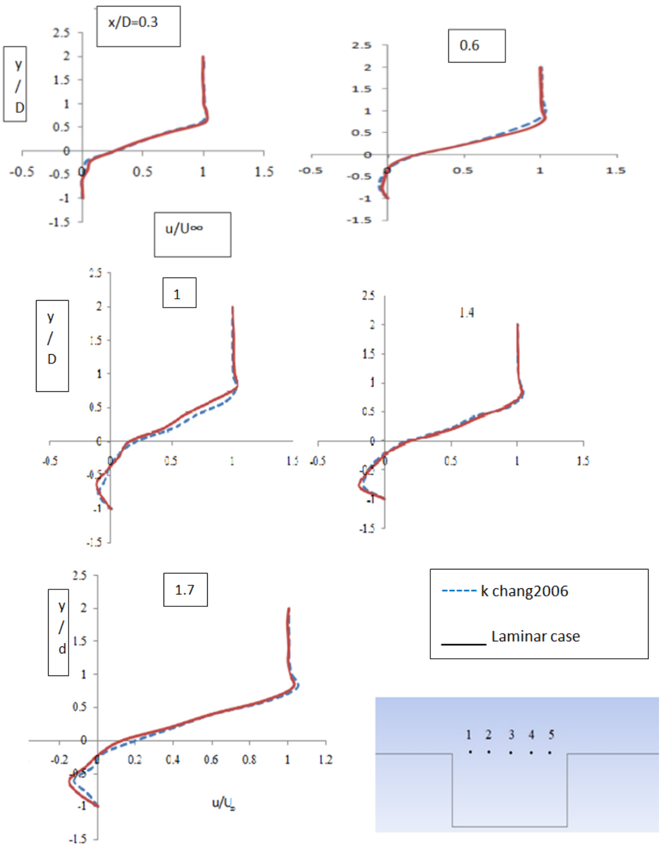

Fig 3.4: Comparision of mean stream velocity profiles at different stations

Fig 3.5 shows about the normal stress u'u',v'v' at different the stream wise locations .The stresses are non-dimensionalized by the inlet free stream velocity. The stresses correspond to the apparent stress induced by the laminar instabilities and the convection of coherent structures present in the separated shear layer and cavity regions. The averaging process generates relatively high value of stresses only in the downstream half of the shear layer and then inside the cavity near the bottom and downstream of the cavity The results of the instant LES are in good overallagreement with that of Chang et al. (2006).

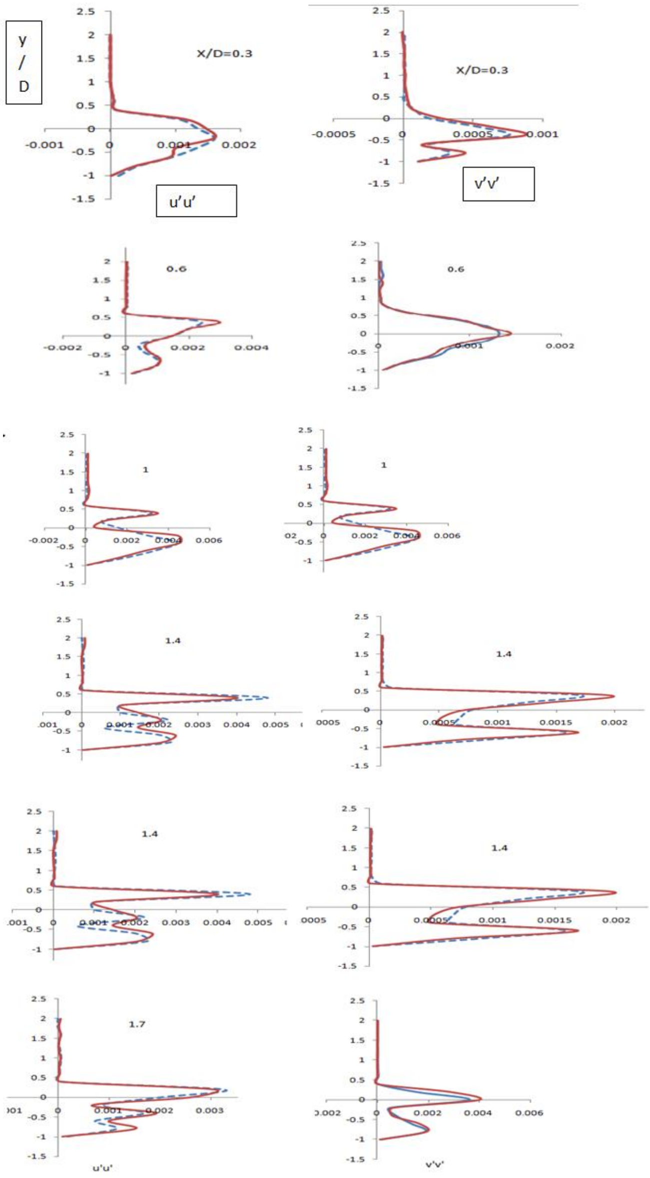

Fig 3.5 comparision of Reynolds stress at different stations

3.2.2. Velocity spectra: The time history of the vertical velocities are extracted at all 5stations.And observe that the up to station 2 there is no substantial peak in velocity spectra. Downstream of the separation (starts from the station 3), peaks are observed indicating shear stress oscillating at the fundamental frequency corresponding to a strouhal number StD=fD/U=0.49 The amplitude of these oscillations is growing in the stream wise direction. Concomitantly, very low-energetic frequency modulations are clearly observed in the same time series. We suspect that these very low energetic frequency oscillations and the main oscillatory frequency is due to shear layer interactions with the recirculating motions inside the cavity (Chang et al. 2006).Fig 3.6 shows pressure spectra at stations 5 the strouhal number StD=(0.36,0.70).

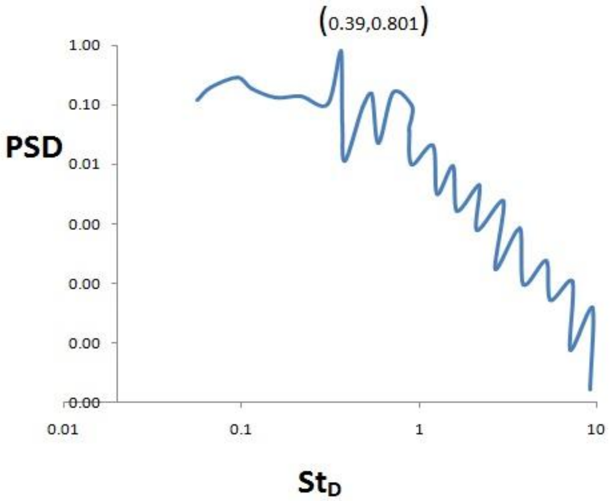

Fig 3.6 shows pressure spectra at station 5

4. RESULTS AND DISCUSSION

4.1 Meanflow characteristics: Figure 4.1 shows the comaprision of longitudinal velocity profiles between rough and smooth(regular) surface cavities. From the statistics were taken 4,5 stations as shown after flow had achived the state of dynamic stability. we don't observer much differences the remaining velocity profiles.

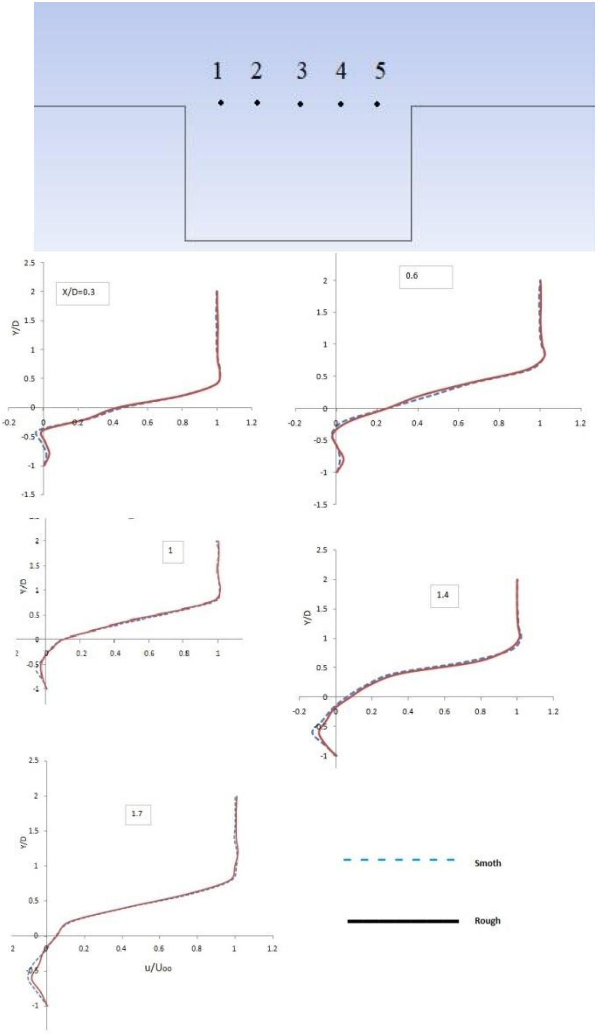

Fig 4.1 Comparison of mean scream velocity profiles at different stations

Figs 4.2, 4.3 shows Reynolds normal stress of u'u',v'v' respectevely at 5 stations. And we observed that the shear layer energy reductions starts from the station 3, so that we achive good cavity stabilty.

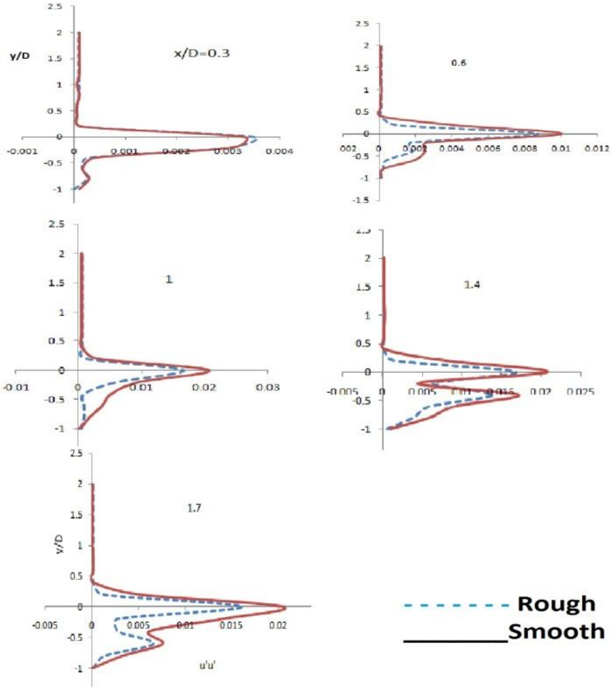

Fig 4.2 profiles of u'u' at different stations

Velocity spectra: From the velocity history we observed at station 5th the strouhal number reduced from 0.39 to .30 so that the cavity oscillations are reduced effectively by the modifications. And Fig 4.4 shows pressure spectra at station 5th

5. CONCLUSIONS

In the existing work, we demonstrated that the rough surface is operative in restraining the oscillation in an open cavity. For the better understanding of the mechanism and physics of this method, computational analysis was done using ANSYS Fluent. The flow visualization resulted in understanding of flow grounds and uncertainties produced by detaching of broken turbulences at the principal edge. It is clear from the simulation results, that the overview of rough surface could promote turbulent edge and increases the thickness of borderline. To summarize, it can be said that the characteristics of the rough (non-smooth) surface, effectively suppress the flow oscillation.

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