Passive Control of Flow over Cavity

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ABSTRACT

The flow past the weapon bays when its doors are open can lead to unfavorable pressure conditions inside and around the bay. The cavity environment can be prone to unsteady pressure oscillations which can sometimes have amplitudes high enough to damage the aircraft components. For controlling the flow Passive control methods involve simple geometric modifications and helps to reduce the sound pressure level. We have analyzed the effect of change in various parameters like length, depth and Mach number of the cavity flow. Also a passive control technique is introduced in the form of triangular chevrons. Numerical simulation data were obtained using time averaged Unsteady Reynolds-Averaged Navier–Stokes (URANS) CFD predictions. The URANS approach used here employed the ANSYS Fluent code and adopted the realizable k−ε turbulence model. From this simulation we obtained suppression in the noise levels up to maximum value of 5db.

Keywords: Cavity Flow; Passive Control Technique; Unsteady Reynolds Averaged Navier-Stokes (URANS) method; k-ε turbulence model.

1. INTRODUCTION

The concept of cavity flow has been an area of active research and renewed significance in the past few years. The cavity flow oscillations have attained practical significance and have consequently been the subject of numerous studies. The major study of this cavity flow is to suppress the noise that arises from the aircrafts as it can lead to detection on the radar of enemies. This has led our interest to grow in this concept and we choose to do our project on this topic. The suppression of this acoustic waves is carried out in this present work. We have analyzed the effect of varying length, depth, Mach number on a clean cavity. We used the passive control as it is quite simple than active control where actuators are required. Here in passive control no such actuator are needs and it helps to suppress the noise level just by changing the geometry. We have introduced a passive control technique in the form of triangular chevrons at the upstream edge of the cavity to reduce the noise levels.

By using this suppression technique sound reduction of 5 *db* is observed.

2. LITERATURE REVIEW AND OBJECTIVE

Rowley, Colonius and Basu [1] performed the numerical simulation which investigated the resonant instabilities in two dimensional flow past an open cavity. As the Mach number increases form 0.2 up to 0.8 the flow changes its mode from steady to shear layer to wake mode.

S. Izawa et al. [2] used static plate and small block kept on the floor for a mach number less than 0.18. It showed large noise suppression effect when plate is near the upstream edge ot the downstream edge.

Stanek et al. [3] investigated cylindrical rod in crossflow and fences for various mach number in transonic and supersonic range. He concluded that the optimal location is rod centre at the boundary layer and acoustic suppression is due to high frequency rod shedding.

Thangamani, Knowles and Saddington [4] implied 13 different passive techniques for mach number M = 0.71 and LxWxD = 320x160x64 in mm and concluded that front wall slant shows best satisfactory performance in tonal amplitude suppression, noise control and favorable pressure gradient side the cavity with a reduces drag.

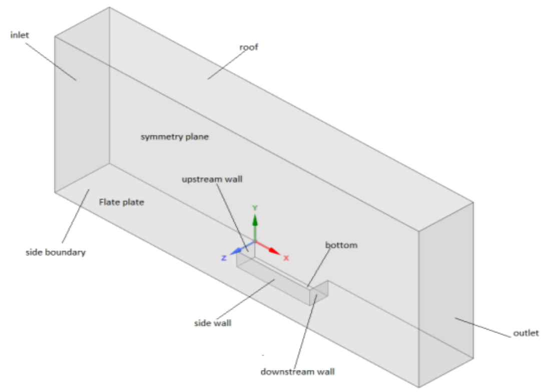
Omari et al. [5] performed the simulation of lid driven cavity flow at moderate Reynolds number with aspect ratio of 1 and 1.5 and concluded that the pressure drop coefficient is a strong function of positon, Reynolds number and aspect ratio.

The main objectives for this study are to analyze the effect of change in the length, depth and Mach number for the cavity flow and also to design and develop a passive control technique to suppress the noise levels.

3. MATERIALS AND METHODS

We have performed CFD analysis using ANSYS Fluent software. In this experiment we have studied clean cavity for the effect of varying length, depth and Mach numbers. A passive control technique is then designed to suppress the noise levels. The geometry for passive control technique is in the form of triangular chevrons mounted vertically at the upstream edge of the cavity. For the analysis Unsteady Reynolds Navier-Stokes (URANS) method was followed with Realizable k-ε turbulence. The time-step for the turbulence was kept as 0.0001 s and was run for about 500 time steps.

Only the half section of the geometry was used for the numerical calculation due to symmetry as it helps reducing the computation power. The cavity has a length(L) of 160mm, depth(D) of 32mm and a width(W) of 40mm(for half geometry), the inlet and outlet boundaries are at 320mm, the roof is kept at the height of 2L. The side boundary is kept at distance of 2W from the side wall, see figure 1(a) .The flow Mach number(M) was set as 0.85 . For the Mesh 1.9 million cells were created for the half section. The mesh is shown in figure 1(b).



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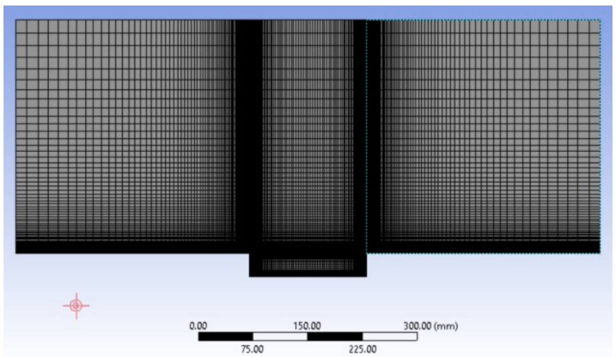

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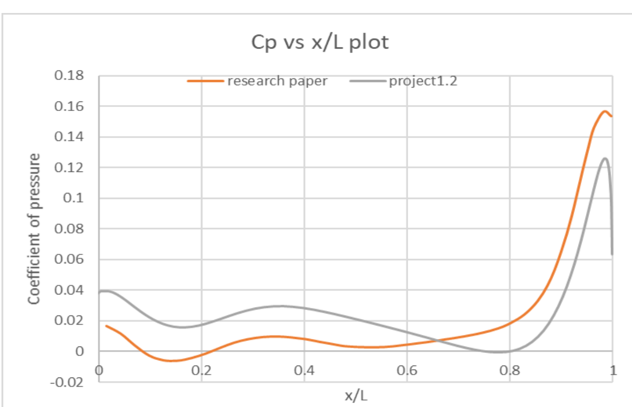
Figure 1: (a) Half geometry of clean cavity and (b) Mesh for clean cavity

3.1 Validation of results

For the validation of numerical analysis we have used the reference from the study Experimental and computational investigation of an open transonic flow [6]. The validation result for the comparison of mean coefficient of pressure values over the length of the cavity is shown in fig 2. Also the SPL vs frequency distribution shows the range of 160-140 *db* and the peak also occur at the same frequencies.

As we can see in the above plots, our numerical results are close to the results from the research paper. Now we did the analysis by changing the length, depth and Mach number for the cavity flow of the clean cavity



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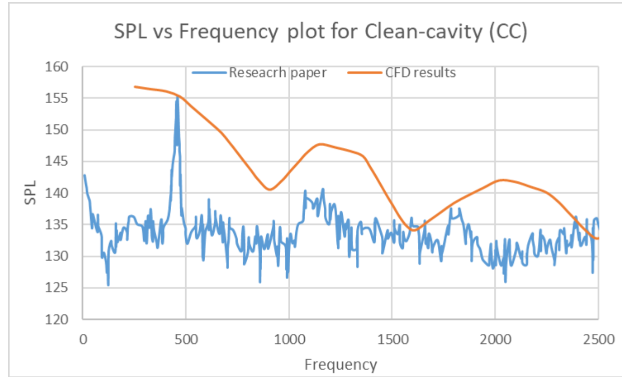

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Figure 2: (a) Distribution of Coefficient of pressure over the length of cavity and (b) Pressure spectra plot for validation results

3.2 Analysis of varying parameters

Here each one of the parameters from length, depth and Mach number is changed while keeping the other two constant. For this analysis, the following models as shown in table 1 were used.

Table 1: Models with varying parameters.

Model	*L(mm)*	*D(mm)*	*M*	*L/D*
L2	64	32	0.85	2
L4	128	32	0.85	4
L6	192	32	0.85	6
L8	256	32	0.85	8
D2	160	80	0.85	2
D4	160	40	0.85	4
D6	160	26.67	0.85	6
D8	160	20	0.85	8
M5	160	32	0.5	5
M6	160	32	0.6	5
M7	160	32	0.7	5
M8	160	32	0.8	5

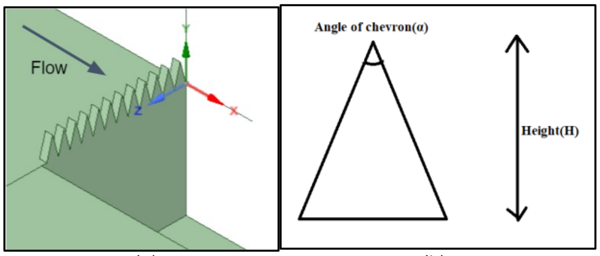
The results for all the above model for the varying length, depth, Mach number will be discussed in the section 4.

3.3 Passive Control of Flow over Cavity

To control the flow over the cavity passive technique was adopted where we change the geometry of the cavity to suppress the noise levels. We used vertical chevrons at the upstream edge of the cavity in this passive control. The length and depth was kept *160mm* and *32mm* respectively

3.3.1 Changing chevron angles:

For the analysis we changed the angles of the chevron while keeping the height the same. The models with various chevron angle are given in the Table 2.



(a) (b)

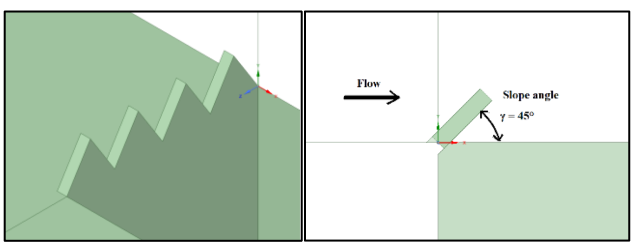
Figure 3: (a) Representation of chevron used for the passive control over the cavity model (TTS630) and (b) representation of angle and height used for the chevron geometry

Table 2: Models used for the passive control analysis of vertical chevrons

Model	*Height(H)*	*Angle(α)*	*M*	*L/D*
TTS630	6mm	30°	0.85	5
TTS645	6mm	45°	0.85	5
TTS660	6mm	60°	0.85	5
TTS690	6mm	90°	0.85	5

3.3.2 Effect of slope of chevron on the cavity flow:

Here the height and the base for the chevron was kept 8mm and 10 mm respectively and then it was simulated for the variation in the slope for angle 90° and 45°. Fig 4 shows the vertical alignment of chevron and also the chevrons mounted and the 45° slope. Table 3 gives the detail about the geometric parameters used for the model for the variation of slope.



(a) (b)

Figure 4: (a) Geometry of TTS810 model and (b) geometry of the TTS810-45 model

Table 3: Models with variation in slope

Model	*Height(H)*	*Base(B)*	*Slope(γ)*	*M*	*L/D*
TTS810	8mm	10mm	90°	0.85	5
TTS810-45	8mm	10mm	45°	0.85	5

4. RESULTS AND DISCUSSION

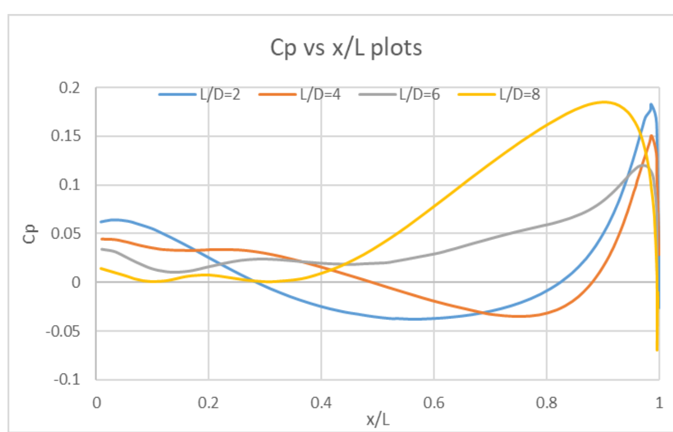
The results are obtained for the clean were used for the validation part. And then further analysis was done by changing the length, depth and Mach numbers. We plot the time average pressure data over the length of cavity. The CFD result of pressure contour shows uniform pressure for nearly 80% of the cavity length. And we see a sharp increment near the downstream wall. The time average pressure data at the offset planes was also obtained and showed slight reduction in the coefficient of pressure values suggesting higher velocity at the side walls.

Similarly, results we obtained for the varying length and depth models and they were quite identical for the same aspect ratios. Fig 5 shows the variation of pressure coefficient over the length of the cavity at the symmetry plane. We can observe as the aspect ratio increases the pressure distribution shifts from the downstream wall up to the midway. Also the Sound pressure levels decreases as the aspect ratio increases. This is because open type of cavity flow changes to transitions type. Also the velocity streamline of the higher *L/D* ratio shows elongated vortices inside the cavity. Table 4 shows the results of the maximum pressure, maximum velocity and the peak SPL values for the varying length and depth models

Table 4: Results for the maximum pressure, velocity and peaks of the Sound Pressure levels

Model	*Max Pressure (Pa)*	*Max velocity (m/s)*	*Peak SPL value (in db)*
L2	15300	307	149
L4	17300	303	142
L6	17700	309	141
L8	17800	317	140.5
D2	16000	306	144
D4	17800	305	141
D6	17800	310	140.5
D8	18700	318	139
M5	6020	177	145
M6	8590	212	148
M7	11875	248	151.5
M8	15440	284	152
CC	21800	305	156

The results of variation of the Mach number for cavity flow is discussed here. For higher mach number the flow velocity increases, this results in increased pressure values at the downstream wall. For *M=0.85*, highest pressure values were observed. This means there is more noise as the mach value increases and it can be seen in the fig 6(b).



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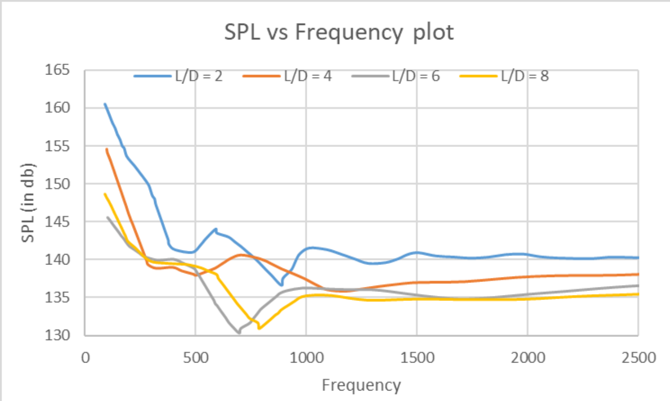

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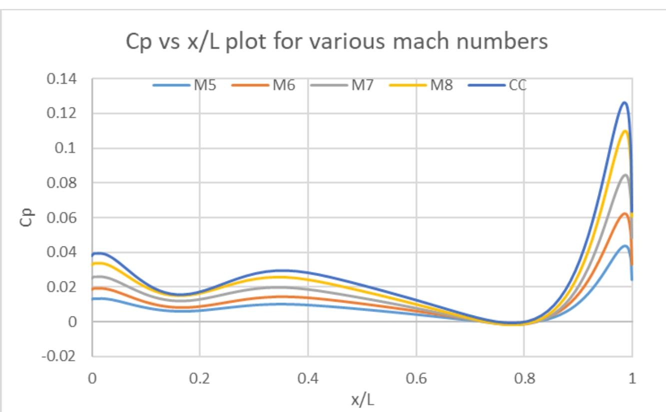
Figure 5: (a) comparison of mean pressure profiles for the various aspect ratios while varying the length and depth and (b) Comparison of unsteady pressure spectra for the centreline at x/L = 0.9 for various aspect ratios.

To suppress the noise level the Passive control technique was adopted and the results are discussed here. The results for the variation in the chevron angle that showed (in fig 7) there is a huge negative pressure region within the cavity and it increases near the downstream wall. There is no drastic change in the mean pressure profile over the length of the cavity. For the pressure spectra, the peak attains higher values of SPL for chevron angle of 30° and lower value for the rest of the angles as compared to the clean cavity but it can be seen that they all occur at a higher frequency (see fig 8).



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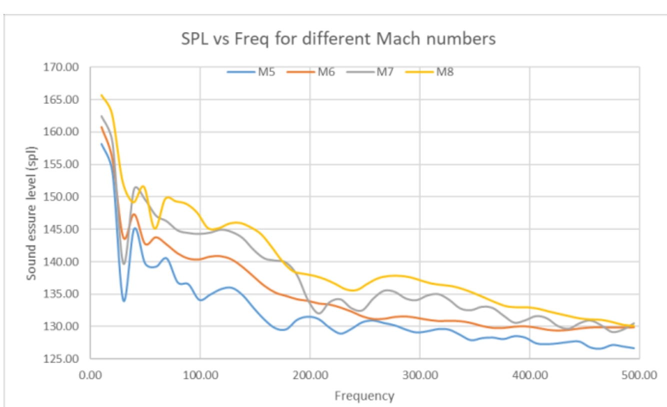

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Figure 6: (a) Mean pressure profiles for various mach numbers and (b) Unsteady Pressure spectra for various mach values.

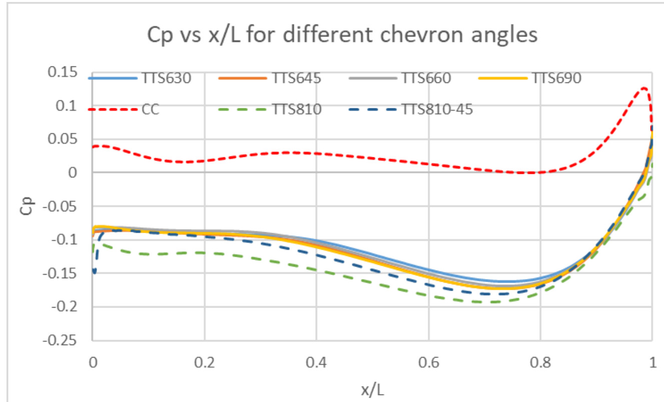

Figure 7: Mean pressure profiles at the symmetry plane for the analysis of models with varying chevron angles and slope.

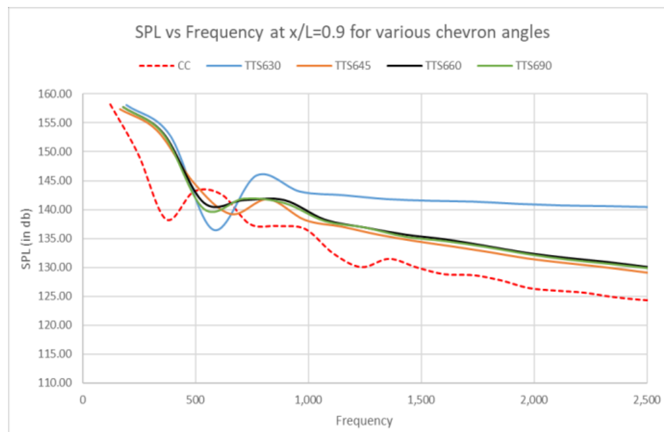

Figure 8: Comparison of pressure spectra for various chevron angles.

Table 5: Peak in the pressure spectra at for various models

Model	*SPL(in db)*	*Frequency of the peak (Hz)*
TTS630	146	769
TTS645	142	820
TTS660	142	714
TTS690	142	714
TTS810	139	792
TTS810-45	141.5	784
CC	144	494

For the analysis of the varying slope of the chevrons the mean pressure profile showed similar trend as for the earlier vertical chevrons. The pressure spectra were obtained at length *x/L = 0.9* and are showed in fig 9. It is observed that we have a good amount of noise reduction and the peaks for this geometry are lower than any other cases also they occur at higher frequency as compared to the clean cavity. Here we get the highest reduction of 5 *db* for the model TTS810 where the slope angle is 90° and we get reduction of 2 *db* for the model TTS810-45 where the angle of slope is 45°.

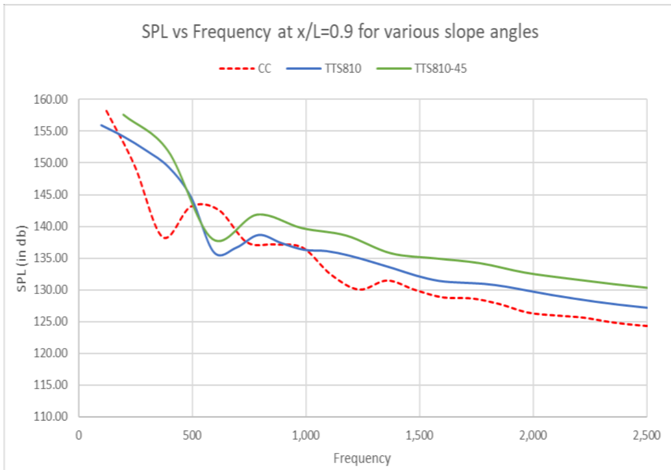

Figure 9: Comparison of pressure spectra for different slope angles.

5. CONCLUSIONS

The growth in mean pressure coefficient starts at 80% of the length of the cavity when the cavity is open, and as the aspect ratio increases the growth starts at 50% of the total length. With increase in the *L/D* ratio the pressure in the cavity at the downstream wall increases. Also the maximum velocity increases above the cavity. From the velocity streamline we observe that the open type cavity is changing to a transitional type cavity and we see bottleneck form of vortices within the circulation zone inside the cavity. The cavity with lower Sound Pressure Level is desired so higher aspect ratio is preferable. When the Mach number increases, the flow velocity increases resulting in higher pressures and higher sound pressure levels.

The passive control technique helps to suppress the noise levels and the dominating peaks occurs at higher frequency than that in the clean cavity. Highest reduction of 2 *db* with frequency 714 *Hz* is observed in the model with chevron angle 60°. For TTS810 we got maximum reduction of 5 *db* in the sound pressure level. For TTS810-45 we got reduction of 2.5 *db* in the sound pressure level for *x/L=0.9.*

More work can be done for the analysis of the effect of change in the width of the clean cavity. Also the height of the chevrons can be varied and analysed accordingly. The chevron strip can also be shifted away from the upstream edge to see the effect on the flow controls.

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NOMENCLATURE

L	Length of the cavity	[m]
H	Height of the cavity	[m]
W	Width of the cavity	[m]
M	Mach number	--
α	Chevron angle	°
γ	Slope angle	°

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