Fluidic control of cavity configurations at transonic and supersonic speeds

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Summary. An experimental study has been conducted to investigate open and closed cavity configurations with and without fluidic control at transonic and supersonic speeds. The cavity models were of $\frac{L}{D} = 2$, 6, 11 and 18. The investigation was carried out at Mach numbers of 0.8, 1.4 and 1.7. The passive flow control technique employed wedges of 15^o, 30^o, 45^o and 60^o were placed at the leading and trailing edge of each cavity. Pressure measurements, and oil flow, were employed to examine the characteristics of the induced flowfield. Experimental results revealed the basic flow features and defined the cavity flow field types.

1 Introduction

Roshko [1], Krishnamurty [2] Rossiter [3], and Sarohia [4] are some of the early investigators that studied the resulting flow field inside cavities. The main variable affecting cavity flow is the length-to-depth ratio. The first classification occurs in deep-cavity flow (open cavity), where the aspect ratio is less than 10; there is a large recirculation zone with one stationary, vortical structure and the shear layer bridges the cavity. In the second classification, where the aspect ratio is greater than 13, the cavity is considered shallow, (closed cavity) and creation and rollup of vortices at the leading edge of the cavity takes place. The last classification occurs in cavities with aspect ratio that lies between the open and closed,(transitional cavities). Johannesen [5] in 1954 using Schlieren photography and pressure measurements, typified the open cavity flow by a series of weak compression waves above the shear layer. The intensity of the compression waves increased up to the critical aspect ratio. A breakthrough study was published by Rossiter [3] in 1964. He suggested that the momentary flow separation at the leading edge results in periodic shedding of localised vortices, producing acoustic tones.

A major issue that occurred after the aerodynamics and the acoustics inside the cavities were understood, was to control the cavity flows in order to eliminate or alleviate all the undesired phenomena. There are some interesting recent reviews by Colonius [6], who provided a summary of numerical simulations on active flow control of acoustic resonance and Cattafesta et. al. [7], who reviewed the experimental work on the same field.

2 Experimental Set-up

The experiments took place in the Plint TE25/A Supersonic Wind Tunnel, at Mach numbers of 0.8, 1.4 and 1.7. The$\frac{L}{D}$ ratios chosen to cover open transitional and closed cavity flows are 2, 6, 11, and 18. The length of each is set to 90 mm. There are 33 static pressure tappings; the pressure tappings inside the cavity are placed in three lines parallel to each other and to the direction of the flow. Four different wedges were manufactured for each cavity model. The wedges were designed at four different angles of 15^o, 30^o, 45^o and 60^o and placed at the edges of the cavity.

Average pressures inside and outside of the cavities were obtained via the aid of pressure transducers. Oil flow technique was employed to visualise the surface flow inside and outside the cavities.

3 Results and Discussion

The most effective wedge for cavity $\frac{L}{D}$=2 was that of 30^o. At a freestream Mach number of 0.8 and the 30^o wedge placed at the cavity leading edge, the pressure was increased over the cavity floor. The pressure coefficient distribution has a concave up shape, meaning that the flow recirculates with less momentum compared to the no control case. The pressure at the trailing edge dropped, meaning that the wedge interacts in an efficient way with the shear layer impingement and the natural feedback loop for resonance is disturbed.When the 30^o wedge was placed at the cavity trailing edge, similar effects were obtained. The pressure coefficient was similarly distributed over the cavity floor, but the magnitude was decreased in that case, Fig. 1.

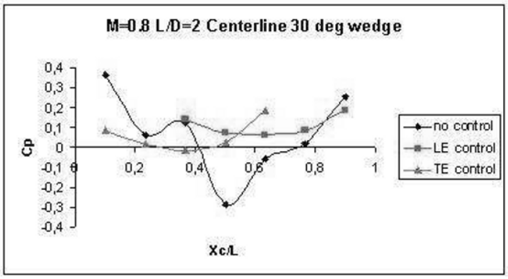

Fig. 1. Pressure Distribution on Cavity Floor For $\frac{L}{D}$=2, M=0.8 no control case and with 30^o wedge placed at leading and trailing edge

As the Mach number was increased to Mach no. of 1.4, the magnitude of the pressure coefficient is smaller for both the leading and the trailing edge wedge, compared to the no control case because less free stream flow becomes entrained into the cavity. Again there are indications that the feedback loop is disturbed since the pressure recorded at the traling edge is reduced.

The oil flow results show that the flow bridges the cavity, impinges on the trailing edge and entrains inside. It separates just ahead of the wedge and a large recirculation region is formed on top and bottom corner, Fig. 2.

At Mach number 1.7, the wedge located at the trailing edge causes the pressure along the cavity floor to increase dramatically. This indicates that it probably worsens the cavity oscillations instead of suppressing them. This is not the case for the leading edge wedge, that reduced the magnitude of pressure and caused an almost uniform pressure distribution.

The most pronounced effect for cavity $\frac{L}{D}$=6 was again that of 30^o. The pressure distribution became more uniform when the wedge was placed at the cavity leading edge and there is no indication of flow recirculation inside the cavity. A pressure drop was observed at the cavity trailing edge, meaning that acoustic suppression may be

Fig. 2. Oil Flow Picture on Cavity Floor For $\frac{L}{D}$=2, M=1.4 no control case and with 30^o wedge placed at leading and trailing edge

possible.The 30^o wedge placed at the trailing edge of the cavity changed the flowfield from open to transitional.The pressure distribution shows a large longitudinal pressure gradient, causing the problem of store nose-up pitcing moment. Fig.3

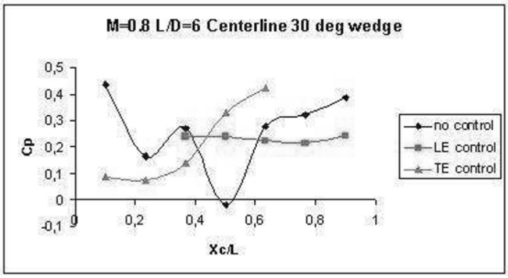

Fig. 3. Pressure Distribution on Cavity Floor For $\frac{L}{D}$=6, M=0.8 no control case and with 30^o wedge placed at leading and trailing edge

As the Mach number increased the effect of the 30^o wedge placed at the leading edge became minimal. As the Mach number increased to 1.4, a typical open cavity pressure distribution was observed, but the magnitude of pressure dropped meaning that less flow has entrained the cavity. At Mach no. 1.7 the flowfiled changes to transitional again, without indications of large longitudinal pressure gradient.

The oil flow results show a similar behaviour as the one described for $\frac{L}{D}$=2. The only difference is that only one vortical structure is formed at the top corner, Fig. 4. Similar results were obtained for the three different Mach numbers.

For $\frac{L}{D}$=11 and 18, a transtional cavity flow field occurs. Since acoustic fields exist in transitional-open cavities and store-nose up pitching moments exist in transitional closed cavities, controlling the flow aims in suppressing the acoustic modes in transitional open cavities as well as decreasing the longitudinal pressure gradients in transitional closed cavities so that the problem of store nose-up pitching moment is not severe. At M=0.8 the cavity flow field is transitional closed. When the Mach number increased from 0.8 to 1.4 and finally to 1.7 the flow field changed from transtional closed to transtional open.

At M=0.8 the cavity is transitional closed type. Figure 5, show an increase of pressure along the cavity floor, for both the leading and trailing edge case. When the wedge was placed at the leading edge, the recirculatory region just after the leading edge moved a bit further closer to the trailing edge and the increase of pressure at that region suggests

Fig. 4. Oil Flow Picture on Cavity Floor For $\frac{L}{D}$=6, M=0.8 no control case and with 30^o wedge placed at leading and trailing edge

that momentum was reduced. This is the most effective flow control case, since the longitudinal pressure gradient in the cavity is slightly decreased compared to the no control or the trailing edge control case. When the wedge was placed at the trailing edge the only effect that had on the flow field was that the pressure was increased along the cavity floor, meaning that more flow entrains the cavity. Similar effects were observed for greater Mach numbers.

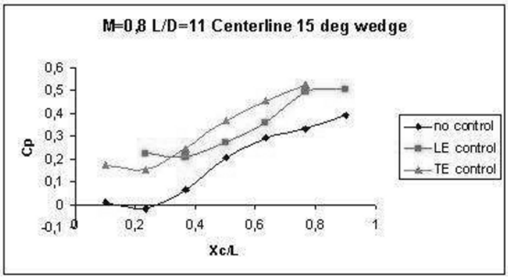

Fig. 5. Pressure Distribution on Cavity Floor For $\frac{L}{D}$=11, M=0.8 no control case and with 15^o wedge placed at leading and trailing edge

The oil flow results show no indication of shear layer impingement on the cavity floor and the flow field obtained is similar to the transitional open cavities flow field without flow control. The shear layer bridges the cavity, impinges on the trailing edge wall and entrains.The flow separates again just ahead of the wedge and there is a vortical structure shown on the top corner. Fig. 6

For $\frac{L}{D}$=18, the 15^o wedge case placed at the leading edge of the cavity caused the flow inside the cavity to behave as in transitional closed cavities. The pressures measured close to the leading edge of the cavity were increased compared to the no control case and the overall distribution show that a lower adverse pressure gradient was observed.There is a low pressure region at $\frac{Xc}{L}$=0.4, where separation occurs.The pressures measured at the trailing edge of the cavity were unaffected compared to the no control case. When the wedge was placed at the trailing edge, the pressure distribution shows a dramatic increase of pressure close to the cavity leading edge and then a constant drop until $\frac{Xc}{L}$=0.6, which is also the point of separation. Fig.7.

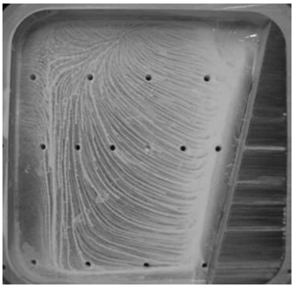

Fig. 6. Oil Flow Picture on Cavity Floor For $\frac{L}{D}$=11, M=0.8 no control case and with 15^o wedge placed at leading and trailing edge

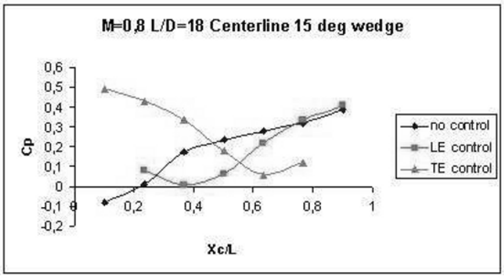

Fig. 7. Pressure Distribution on Cavity Floor For $\frac{L}{D}$=18, M=0.8 no control case and with 15^o wedge placed at leading and trailing edge

When the Mach number increased to 1.4, the leading edge wedge does not affect the flow field, and at 1.7 the pressure drops dramatically indicating that less flow entrains the cavity. The wedge placed at the trailing edge causes the same effects for greater Mach numbers as those described for the 0.8 M case.

The oil flow reults for the $\frac{L}{D}$=18 cavity show that the shear layer impinges in the middle of the cavity floor and also the impingement line is parallel to the wedge. Again the same vortical structure is obtained as those described in previous cases. Fig. 8

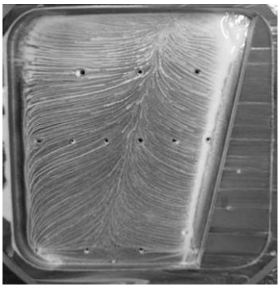

Fig. 8. Oil Flow Picture on Cavity Floor For $\frac{L}{D}$=18, M=0.8 no control case and with 15^o wedge placed at leading and trailing edge

4 Conclusions

Experimental results reveal the basic flow features of cavities with passive flow control at transonic and supersonic speeds. The wedges for the open control case cavities placed at the cavity leading edge, appear to reduce the pressures measured at the cavitis trailing edge, and to interact in an efficient way with the shear layer so the natural feedback loop for resonance is disturbed. For the transitional case cavities the wedges placed at the leading edge decreased the longitudinal pressure gradients so that the problem of store nose-up pitching moment is not severe.

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