AN EXPERIMENTAL STUDY ON THE UPSTREAM AND DOWNSTREAM INFLUENCES OF RECTANGULAR CAVITIES

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Abstract

Experiments have been conducted on the separated and reattached flows of tunnel wall cavities along with relatively thick approaching boundary layers in incompressible flows. For very shallow cavities, approaching boundary layer thickness affects the base pressure whereas for deep cavities, its effect is minimal. In shallow cavities, the maximum pressure occurs slightly below the shoulder of downstream wall. In deep cavities the vortical flow will have sharp curvature of streamlines at the rear shoulder showing a higher static pressure.

Nomenclature

U_α = free air stream velocity

L = Length

D = Height

$C_{pstatic}$ = Coefficient of static pressure

Introduction

Grooves, gaps, cutouts, recesses and surface depressions are sometimes inevitable on the aerodynamic surfaces such as cockpits, bomb bays; escape hatches etc. of the airborne vehicles. These discontinuities have a predominant effect on different parameters, as for example increase in skin friction, pressure drag, heat transfer and turbulence fluctuations in the velocities and pressures. The flow over cavities is also important in many non-aeronautical fields such as cavity flows in street canyons.

Extensive experimental and theoretical studies have been carried out in both supersonic and subsonic cavity flows by a host of researchers. Work on separation in compressible flows includes that of Nash [3] and Mcdonald [2]. Studies about incompressible flow were made by Tani et al. [5].They found out that the demarcating value of L/D ratio between shallow and deep groove as 1.4. They also presented some data of the turbulence characteristics of the flow within the cavities. Further different types of flow visualization techniques like shadow graph pictures, of two axisymmetric, annular cavities (L/D = 0.5 and L/D =1.0) were presented by Thomke [4] at M= 2.00 and 3.90 both for rectangular cavities and with rounded rear shoulder type of cavities.

Rossiter [10] carried out an extensive survey of fluctuating pressures of the cavity at subsonic and transonic speeds. He found that fluctuating pressures were of random nature for deeper cavities (L/D < 4) and showed periodicity for shallower cavities (L/D > 4).

Fox [1] made experimental study of the turbulent flows on the rectangular cavities (0.25 ≤ L/D ≤ 1.75), which were made in the surface of bodies placed in the middle of the wind tunnel stream at velocities ranging from 50 m/s to 180 m/s at relatively thin approaching boundary layers. He studied the mean velocities and surface pressures.

Chung [8, 9] performed experiments to study the effect of cavity geometry and Mach number on the acoustic characteristics of the compressible rectangular cavity flows. The study indicates that the corresponding length-to-depth ratio for the open- and transitional-type cavities increased with higher free stream Mach number.

Present investigation has been carried out to study the upstream and downstream influence of rectangular cavities on aerodynamic surfaces for incompressible flow.

Experimental Apparatus and Procedure

An open circuit, 30 cm × 30 cm suction type wind tunnel equipped with two contra rotating fans driven by

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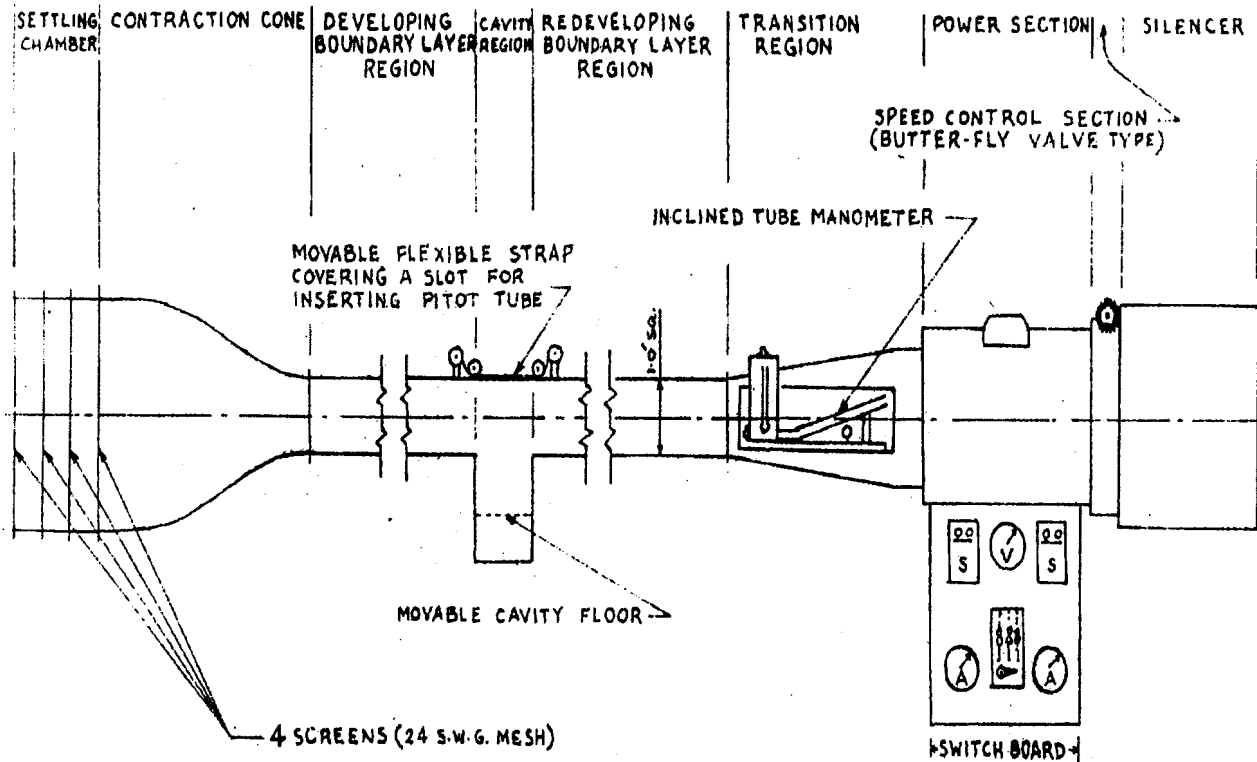
Fig. 1 Subsonic Wind Tunnel

two constant speed, three phase, induction motors of 3.6 H.P each, was used in the present study (Fig. 1). The maximum air speed obtained in the test section was 38.1 m/s with no model in the tunnel. The speed of air in the wind tunnel was controlled by means of a butterfly damper arrangement situated just downstream of the fans. For maintaining constant speed in the wind tunnel, which was likely to change due to fluctuation in the supply voltage, power factor etc., an inclined leg type of manometer was fitted near the fans, which registered the pressure drop across the fans. This pressure drop was kept constant which ensured constant speed in the experiment. Any variation in this was controlled by means of the butterfly valve.

To cut down the atmospheric turbulence and unsteadiness in the flow, four stainless steel screens of 24 S.W.G. mesh were provided and air flow was accelerated to test section by means of the contraction cone of contraction ratio 9.0.The test section length of wind tunnel was made long enough i.e., 5.5 m. As study of cavity flow field at relatively thick approaching boundary layers was main concern, therefore a two dimensional cavity having a cross section of 30 cm × 30 cm with variable depth from zero to 60 cm was positioned at a distance of 1.45 m from the start

of the test section so as to grow the boundary layer in that region. The rectangular cavity floor was raised or lowered down by means of an accurately machined lead screw having a pitch of 2.5 mm for setting any desired L/D ratio.

Total and static pressure measurements were made using two separate probes fabricated out of 1.25 mm outer diameter stainless steel hypodermic needles. The total head probe was formed with a blunt face. It was hand polished and tested with a high-powered microscope to ensure freedom from burrs, irregularities etc. The internal to external diameter ratio of this probe was 0.67.The static pressure probe had a solid nose, which was formed as streamlined shape of approximately ellipsoidal type. At a distance of about 8 diameters from the nose three equally spaced holes of 0.25 mm diameter were drilled radically into the probe. These opened in the common central portion of the tube. The stem of the probe was formed at a distance of 20 diameters from the top. This was done to nullify the positive head effect and negative stem effect error of the probe. The probes were mounted on the micrometer traversing mechanism having a least count of 1.25 mm. The micrometer screw was moved in one direction during one set of observations to avoid the small backlash error. To obtain the total head and static pressure

at any point in the rectangular cavities, the probes were inserted from the top wall of the tunnel through a slot, which was covered, with a sliding flexible strap of foam leather to avoid the atmospheric air rushing into the tunnel due to pressure differential. The pressures were measured by means of the Betz projection manometer having the least count of 0.10 mm of water.

Result and Discussion

The free air stream velocity U_∞ ahead of the cavity was 36 m/sec and the boundary layer thickness was 25 mm. The boundary layer was turbulent and followed the $1/7^{th}$ power law.

Upstream Influences of the Cavities

To ascertain the effect of cavity, both static and the total pressures at the wind tunnel floor at a point 12.5 mm ahead of the cavity were studied by the use of probes. The surface pressure coefficient vs. L/D ratio, have been shown in the Figs. 2 and 3 and, for the static and total pressure respectively. The static pressure coefficient (Fig. 2) showed a continuous decline from L/D=16 to L/D=3 and then increase upto L/D=1.5. Below this, oscillation in the surface pressure was observed in the L/D range 0.8 to 1.30. The total pressure coefficient curve also showed a similar type of trend as in the Fig. 3.

Downstream Influences of the Cavities

The cavity influences in the immediate vicinity of the downstream corner were studied (Fig. 4). The value of Cp increased with the increase of L/D ratio till L/D was equal to 4.80. After that the value of Cp dropped till L/D = 4 indicating three dimensional flow and some of the energy is observed in the third dimension, showing thereby a decrease in Cp in the x-direction. After L/D=4, the value of Cp increases till L/D=3 as the randomness decreases. At L/D=3, The value of Cp decreases because the recompression region becomes small and the mass from the separation wake mixes with shear layer thus retarding it and resulting in the lowering of Cp. At L/D=1.5, the value of Cp suddenly shot up by 0.42. This means that the main stream bridges the cut out. The flow in the cavity is the completely separation wake and recompression region is just near shoulder itself. The separation wake consists of the vortical flow which is independent of the main flow except for the periodic mass discharge near the front shoulder and capturing mass from the shear layer (near recompression region) near the rear shoulder which recir-

culates in the cavity. Coats et.al [6] has also found out same type of flow in his experimental research. Xavier et.al[7] has also experimented in the same line.

There is a sharp demarcation between the shallow and deep cavity i.e. (L/D = 1.5) as the Cp value in the downstream cavity influence suddenly shoots up by 0.42. This is in reasonable agreement with Tani et Al. Value of L/D i.e. (L/D)$_{exit}$ =1.428 which was determined on the basis that in shallow cavities, the maximum pressure occurs
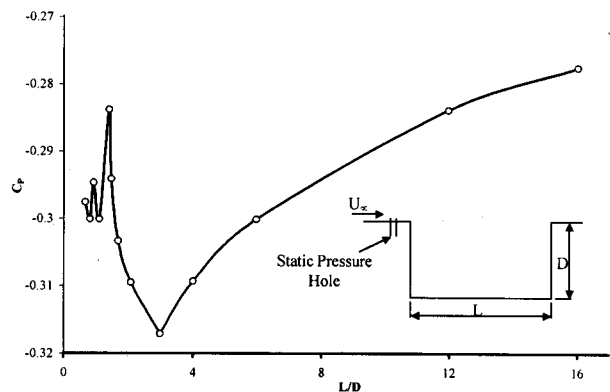
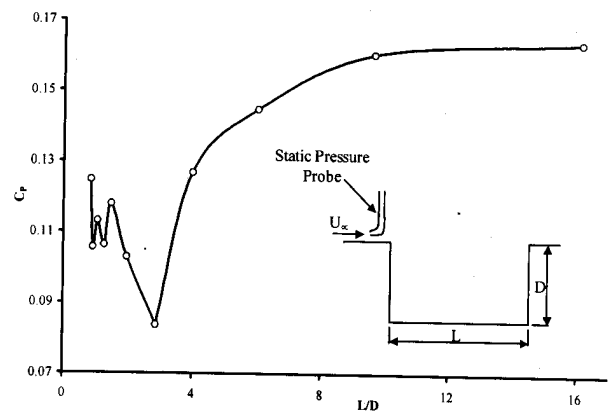

Fig. 2 Static Pressure Coefficient Upstream of the Cavity

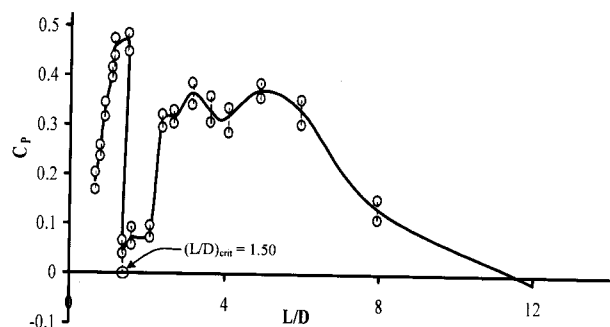Fig. 3 Total Pressure Coefficient Upstream of the Cavity

Fig 4 L/D vs Cp in the Down Stream of the Cavity

slightly below the shoulder of downstream wall. This criterion is reasonable as it implies that in deep cavities the vortical flow will have sharp curvature of streamlines at the rear shoulder thereby registering a higher static pressure slightly below the rear shoulder. However, the slight disparity in critical values of L/D may be due to the secondary effects like approaching boundary layer thickness, free stream turbulence. Xavier et.al [7] has also done same experimental investigation in same line.

Conclusions

1. Three dimensionality and randomness of the flow in the L/D range of 4 to 5 in two dimensional cavities exists.
2. Cavities have significant upstream influences. The static pressure, total pressure just upstream is affected.
3. The increase of approaching boundary layer thickness ahead of the cavity is seen. The maximum increase occurs at L/D = 1.5.
4. The upstream influences are limited to a small distance ahead of the cavities.

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