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Observation of Unsteady Shock Behavior around a Biconvex Circular Arc Airfoil with Circular Cavities on It in a Channel

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Abstract

Shock wave-Boundary Layer Interactions (SWBLI) are observed in practical high-speed internal flows. In the present study, a numerical computation has been performed to observe the shock characteristics over a 14% biconvex circular arc airfoil in a two dimensional channel. The cavity has been incorporated in such a manner that the mean position (along the chord length) of the cavity is placed where static pressure fluctuation of airfoil surface (for base airfoil) is maximum. The length and depth of the cavities are kept 10% and 0.8% of the chord length respectively to avoid structural failure. The shock wave behavior has been studied for a particular pressure ratio of 0.71. Reynolds averaged Navier-Stokes equation with k-ω shear stress transport (SST) two equation turbulence model has been applied for computational analysis. This study tries to make a comparison between the two cases (a) airfoil with no cavity (base airfoil) and (b) airfoil with cavity.

Keywords: Shock, Oscillation, Cavity, Transonic

1. Introduction

Transonic internal flow around an airfoil is associated with self-excited unsteady shock wave oscillation. This unsteady phenomenon generates buffet, high speed impulsive noise, non-synchronous vibration, high cycle fatigue failure and so on. The flow field for transonic flow over an airfoil shows different characteristics depending on various parameters like pressure ratio (ratio of back pressure to inlet total pressure), airfoil geometry, fluid properties and etc.

Nagamatsu, H. T.[1] showed by placing a thin cavity with a porous top surface at the airfoil chord wise position where a shock wave would normally occur reduces the drag. The higher pressure behind the shock wave circulates flow through the cavity to the lower pressure ahead of the shock wave. The Mach number distributions over the model, the wake impact pressure surveys used to determine profile drag and schlieren photographs for 2.8 percent porosity and solid airfoil cases are presented and compared. Results indicate that the profile drag coefficient can be reduced by as much as 40 percent through the use of this passive drag control system. Bahi et al.[2] ,Rizwanur et al[3] investigated shock behavior over supercritical airfoil RAE 2822 with or without shock control cavity. It was observed that the presence of cavity changes the shock behavior from oscillating to steady and the shock strength weakens. Richard Barnwell[4], Dennis Bushnell[4], Henry T. Nagamatsu[1] investigated shock behavior with a porous top surface. The porosity of the porous surface was chosen to be from 1% to 3% of the total airfoil surface and was a variable. The presence of the porous surface and cavity decreased airfoil drag at transonic speeds. The porous top surface extended from a location about 50 to 60% of the chord length from a leading edge of the airfoil to a location about 80 to 90% of the chord length from the leading edge. A cavity was defined under the porous surface in the airfoil which has a depth of from 0.05 to 0.2% of the chord length.

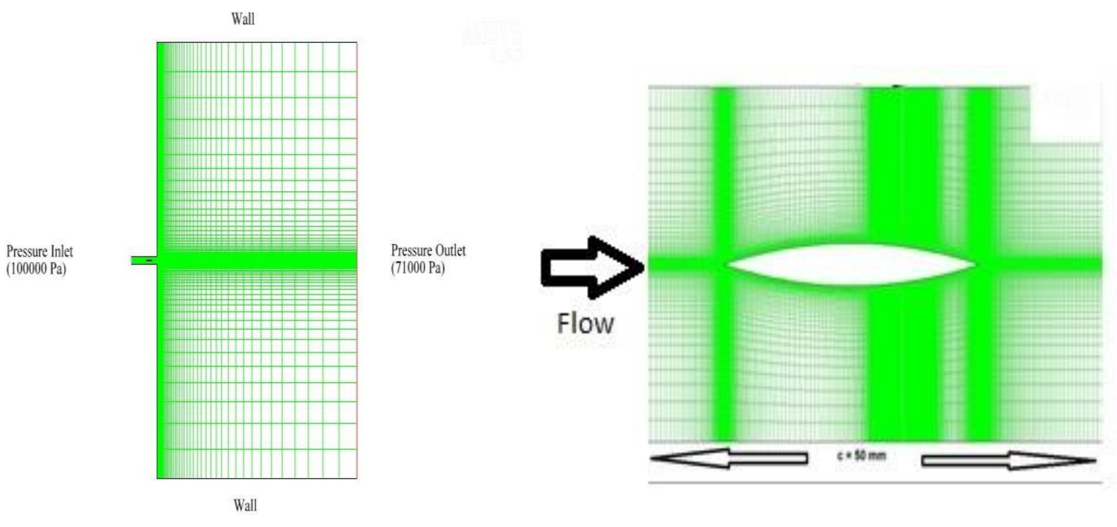
Hamid et al.[5] numerically studied the transonic internal flow over a 12% thick symmetric circular arc. Based on the geometry of reference[5], Hamid et al[6] also modified the geometry at *PR*=.69 & it was observed that the use of cavity totally change the entire flow characteristics and shock properties, which can be used as effective passive control technique to overcome detrimental effect of unsteady shock oscillation.

The present study numerically investigates the flow characteristics over a 12% biconvex circular arc airfoil in a two dimensional channel using cavity for pressure ratio of 0.71 & the study also makes comparison between base airfoil and airfoil with cavity. Cavity of different depths are being investigated and transonic flow behavior for 0.8%*c* cavity is used in this study. The present investigation find totally different types of shock characteristics including pressure fluctuation, coefficient of pressure due to modification of the geometry with this depth of cavity.

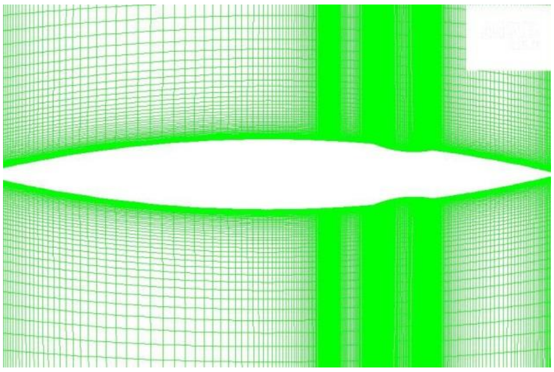
Nomenclature			
c	Chord length(mm)	*x*	Stream wise coordinate(mm)
M	Mach number	*y*	Normal coordinate(mm)
P	Pressure (Pa)	C_p	co efficient of pressure
PR	Pressure Ratio	**Subscripts**	
q	Dynamic pressure (Pa)	*0*	total condition
t	Time (millisecond)		

2. Computational Method

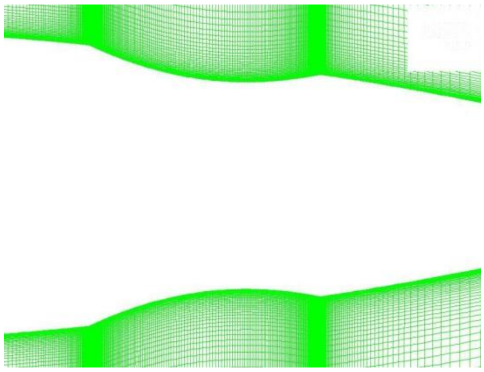
In our current study the flow is considered as compressible, turbulent & unsteady. The governing equations of continuity, momentum and energy are solved by Density-based solver. Finite volume method is used to approximate the equations for numerical solution. Reynolds Averaged Navier-Stokes (RANS) equations along with two additional transport equations of k-ω SST model is used as the flow is assumed to be turbulent. Gauge total pressure is kept at 100000 pascal at inlet, type is pressure inlet and operating pressure 0 pascal. While at the outlet the gauge pressure is kept constant at 71000 pascal; type is pressure outlet and operating pressure 0 pascal. The flow is considered as air with its viscosity varying with Sutherland's law.



(a) (b)



(c)



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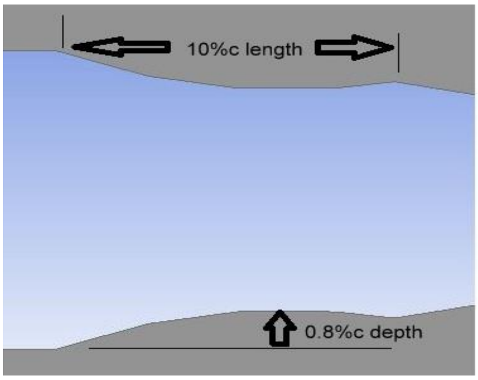
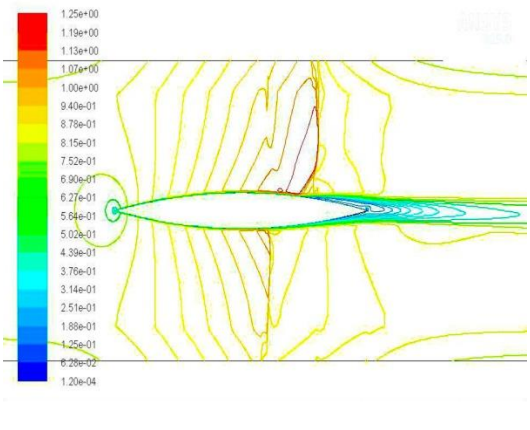
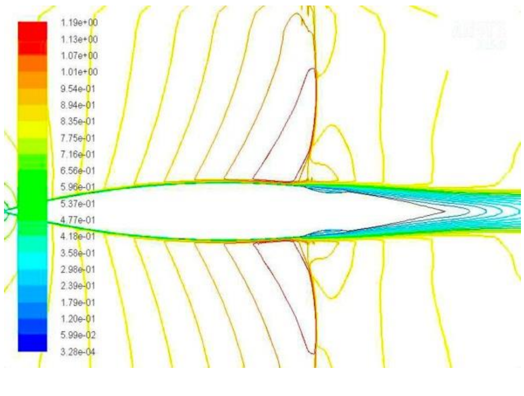


(e)

Fig. 1. (a) Computational domain with boundary conditions, (b) Close view of base airfoil with grids, (c) Close view of airfoil with cavity of length 10%c and depth 0.8%c, (d) Zoomed view of the cavity, (e) height and width of the cavity



(a)

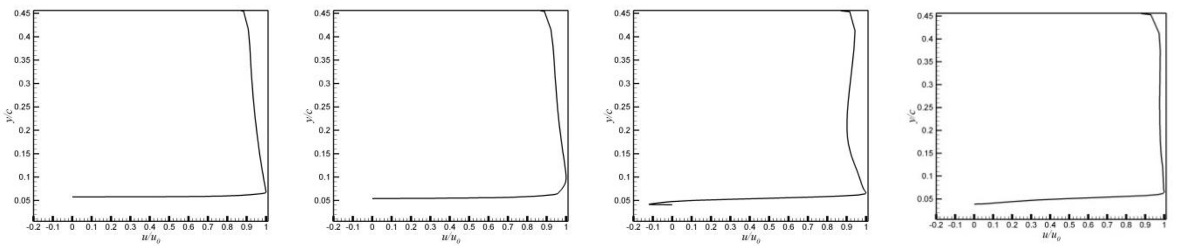


(b)

Fig. 2. Mach contour for (a) base airfoil, (b) airfoil with cavity of 0.8%c depth

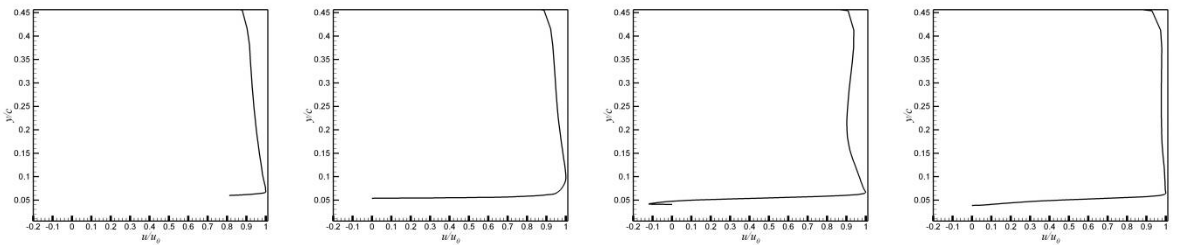
The airfoil used is biconvex arc in nature with a chord length, c of 50 mm & maximum thickness of 0.12c; leading and trailing edge are kept sharp. Angle of attack is kept zero degree throughout the operation. Surface modification is done by introducing cavity on both upper and lower surface of the airfoil of length 10%c and depth of 0.8%c. The mean position of cavity is fixated at x/c=0.73 of the airfoil, where the static pressure fluctuation is maximum for base airfoil. The origin of the co-ordinate system is located at leading edge of airfoil. Structured mesh is used to discretize the geometry with 93000 grids in case of without bump & 111000 grids in case of with bump model. The minimum normal grid spacing is 5μm.

3. Result and Discussion



(a) x/c=0.66 (b) x/c=0.72 (c) x/c=0.72 (d) x/c=0.80

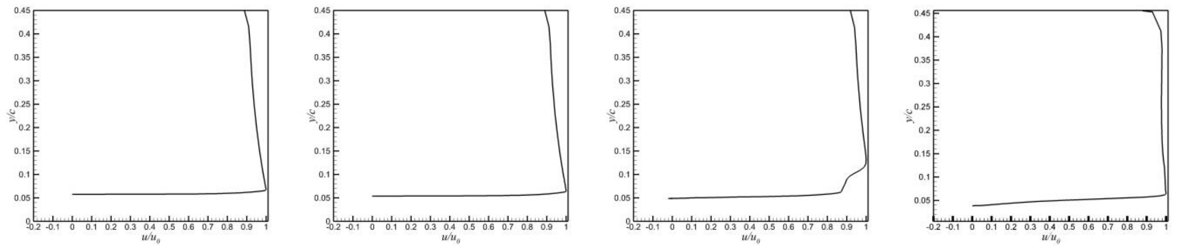
Fig. 3. Variation of non-dimensional x-velocity (u/u_0) at different locations of upper wall of base airfoil.



(a) x/c=0.60 (b) x/c=0.66 (c) x/c=0.72 (d) x/c=0.80

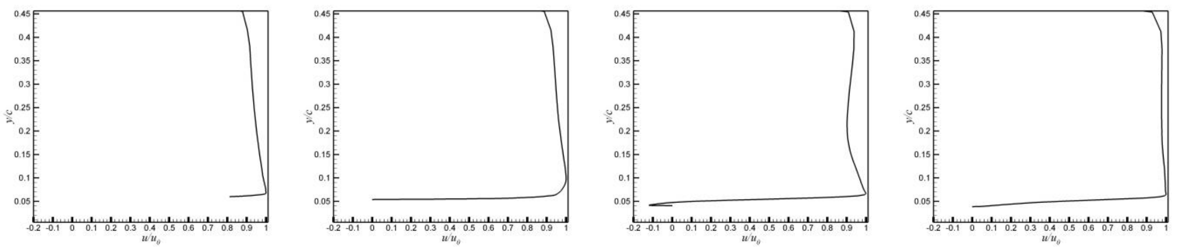
Fig. 4. Variation of non-dimensional x-velocity (u/u_0) at different locations of lower wall of base airfoil.

Here from fig-3 and fig-4, it is observed that a boundary layer separation is formed at x/c=0.72 for both the upper and lower wall because of the adverse pressure gradient at the airfoil surface.



(a) x/c=0.60 (b) x/c=0.66 (c) x/c=0.72 (d) x/c=0.80

Fig. 5. Variation of non-dimensional x-velocity (u/u_0) at different locations of upper wall of airfoil with cavity.



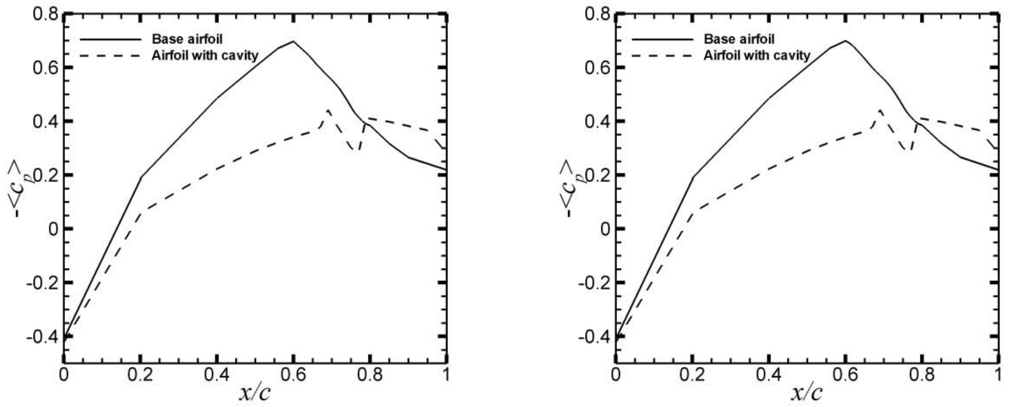
(a) x/c=0.60 (b) x/c=0.66 (c) x/c=0.72 (d) x/c=0.8

Fig. 6. Variation of non-dimensional x-velocity (u/u_0) at different locations of lower wall of airfoil with cavity.

But from the fig-5 and fig-6, it is observed that a boundary layer separation at the upper and lower wall of airfoil with cavities goes more downstream of the flow at x/c=0.8 which is one of the objectives to keep the flow more attached with the surface.

The reason for formation of boundary layer here is viscosity and inertia; viscosity takes care of reduction of speed at the body surface, and inertia is the reason for transition of velocity between layers until it gets to the free stream.

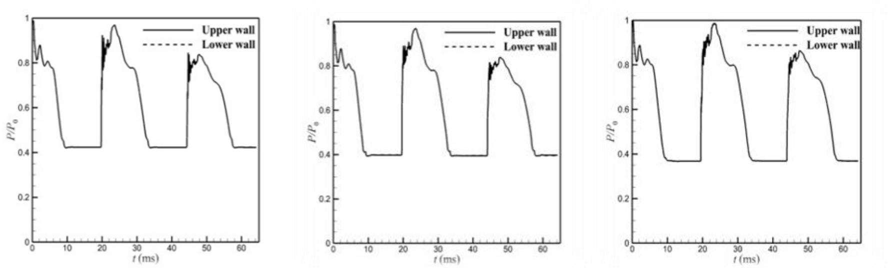
Fluid particles flowing along the top of the wing surface experience a change in pressure, moving from the ambient pressure in front of the wing, to a lower pressure over the surface of the wing, then back up to the ambient pressure behind the wing. The region where fluid must flow from low to high pressure (adverse pressure gradient) is responsible for flow separation.



(a) (b)

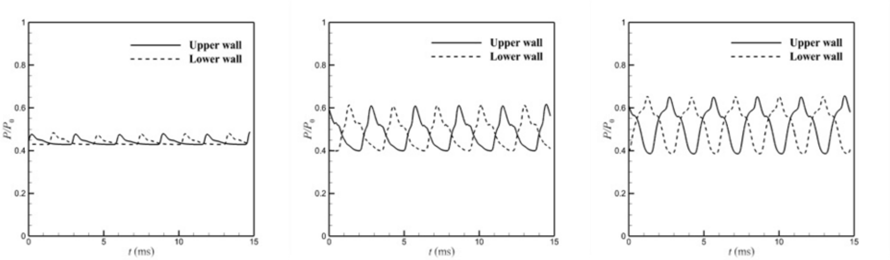
Fig. 7. -C_p distribution over the two airfoils: (a) upper wall and (b) lower wall

From fig-7, the negative co-efficient at different locations indicate that with the cavity the adverse pressure gradient decreases for the wall of the airfoil.



(a) x/c=0.6 (b) x/c=0.66 (c) x/c=0.72

Fig. 8. Pressure fluctuations with time for different locations of airfoil with cavity



(a) x/c=0.60 (b) x/c=0.66 (c) x/c=0.72

Fig. 9. Pressure fluctuations with time for different locations of base airfoil

From fig-8 and fig-9, the non-dimensional pressure with respect to time for both the cases, base airfoil and the airfoil with cavity is observed respectively. Here it is seen clearly that the pressure fluctuates less when cavities exist on the airfoil.

4. Conclusion

A numerical computation is carried out to observe the unsteady shock behavior around a biconvex circular arc airfoil with circular cavities on it in a channel. From this study the following conclusions can be made:
(i) The airfoil with cavities reduces the pressure fluctuation, keeps the flow more attached with the airfoil and consequently decreases the effects of various adverse conditions like stall.
(ii) In the present study, the computation is done for a specific PR of 0.71, it can be extended for other pressure ratios to find where the adverse effects are minimized.
(iii) The study can be extended for different geometries or different locations of the cavities to find the more auspicious condition.

5. Acknowledgement

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6. Reference

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