Technical Notes

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Effect of Porosity Strength on Passive Shock-Wave/Boundary-Layer Control

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Nomenclature

c = model chord length
C_D = profile drag coefficient
C_p = pressure coefficient
M_{S0} = shock Mach number at zero porosity
ps = porosity, open area/model area
$p_{0,\infty}$ = stagnation pressure, freestream stagnation pressure
x = distance along chord
X_{S0} = shock position at zero porosity
y = distance from the model surface normal to chord

Introduction

A SIMPLE and economical concept for drag reduction at transonic speeds appears to be passive shock-wave/boundary-layer control.[1,2] The concept consists of having a porous surface with a plenum chamber underneath the shock location. The high pressure downstream of the shock wave forces some of the boundary-layer flow into the plenum and out ahead of the shock wave. The boundary layer ahead of the shock wave is thickened and compression waves are formed in the supersonic region, thereby reducing entropy changes and flow separation and, therefore, drag. The porous surface could be made of normal holes,[1,2] inclined holes,[3] or slots.[4] The effect of strength of porosity of normal holes on drag reduction has been discussed in Refs. 1 and 2. The effect of strength of porosity of inclined holes on drag reduction is discusssed herein.

Experiments

Experiments were performed in a small blowdown transonic tunnel 101 mm square with an atmospheric intake. The test section had closed sidewalls and roof, and a slotted floor of 9.6% porosity. The model was a circular-arc half airfoil (Fig. 1) of 101 mm span set on the tunnel roof with its leading edge 560 mm from the beginning of the constant-area test section. The momentum thickness Reynolds number R_θ at the foot of the shock was 10^4.

Although mounting the model on the tunnel roof in a small tunnel produced a relative boundary-layer thicknesss much larger than that in free flight, the resulting momentum thickness Reynolds number at the foot of the shock of $R_\theta = 10^4$ was comparable to that which can be obtained on a model mounted in the freestream of larger tunnels.

Four models were tested. Three of them had porous regions with a plenum extending from 75 to 88% of the model chord. The porous surface was made of 1-mm-diam holes normal to the surface (NH), inclined at 60 deg to the normal and forward facing (FFH), and inclined at 60 deg to the normal and backward facing (BFH). The ratio of hole diameter to the displacement thickness at the foot of the shock was approximately unity. The plenum had an average depth of 4 mm resulting in a ratio of plenum depth to the boundary-layer thickness at the shock foot of 4. The fourth model was a solid model. All of the models had pressure orifices on the centerline.

Measurements were made of pressure distribution on the model surface and total pressures in the wake 0.1 chord downstream of the trailing edge for two nominal shock Mach numbers $M_{S0} = 1.3$ and 1.37 and for porosities (based on the open area to total model area) of 0 (solid model), 1.07, 1.6, and 2.97%. The two shock Mach numbers of $M_{S0} = 1.3$ and 1.37 correspond to shock position $X_{S0/C}$ of 0.8 and 0.85, respectively.

Results and Discussion

Typical effects of the strength of porosity on the pressure distribution on the model can be observed from Fig. 2, where plots of C_p vs x/c are shown for the FFH model, $M_{S0} = 1.37$ and $ps = 0$, 1.6, and 2.9%. The shock position for this case, $X_{S0} = 0.85$, is nearer the end of the porous region.

For the model with zero porosity, a large divergence of C_p at the trailing edge indicates a significant shock-induced separation, which was confirmed by china-clay flow visualization. The pressure distribution in the region of shock/boundary-layer interaction is changed considerably by porosity. The general effect of increase in porosity is to reduce the pressure gradient in this region.

The porous region, through the plenum, also appears to set up a communication between the two sides of the shock wave, reducing the shock strength and spreading the region of interaction. A single, strong shock wave is split into several weaker waves as observed by the shadowgraphs.[1-3]

The effect of porosity on the stagnation pressures in the wake 0.1 chord downstream of the airfoil can be seen in Fig. 3, which shows the variation of the nondimensionalized stagnation pressure with vertical distance for the FFH model, $M_{S0} = 1.37$, and for three porosities of 0, 1.6, and 2.9%. The general effect of porosity appears to be an increase in the viscous losses near the surface but a reduction of losses across the shock system possibly due to the reasons discussed earlier. Similar results were obtained with the BFH and NH models for both values of M_{S0}.

The measurements by Nagamatsu et al.[2] with a porous surface made of normal holes show that by carefully controlling the porous region relative to the shock wave, the viscous losses can also be reduced.

The drag coefficients C_D, obtained by the integration of the stagnation pressure profiles and nondimensionalized with respect to the corresponding zero porosity values plotted against porosity, for the three cases, are shown in Figs. 4a and 4b. Figure 4a refers to $M_{S0} = 1.30$ and Fig. 4b refers to $M_{S0} = 1.37$. It appears from this figure that the FFH model produces the best results for drag reduction. The optimum porosity for maximum drag reduction is within 1-2% for both values of M_{S0}. Comparison of Figs. 4a and 4b indicate that, for a given configuration of porous surface and poros-

Received Dec. 19, 1985; revision received July 18, 1986.

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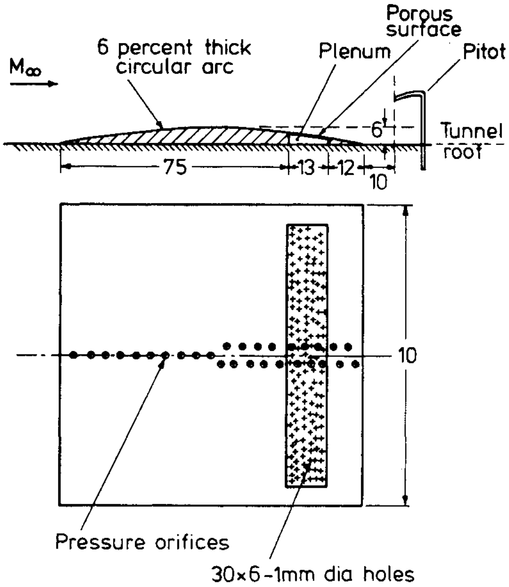

Fig. 1 Circular-arc model.

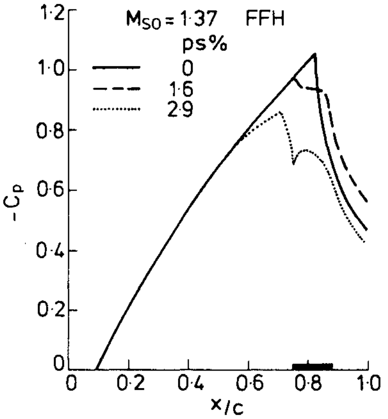

Fig. 2 Pressure distributions.

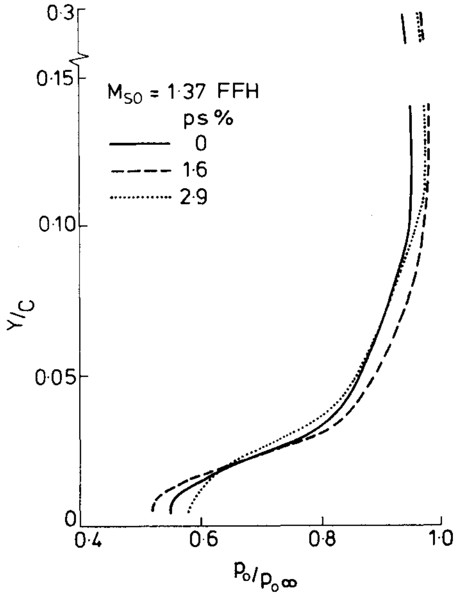

Fig. 3 Wake profiles.

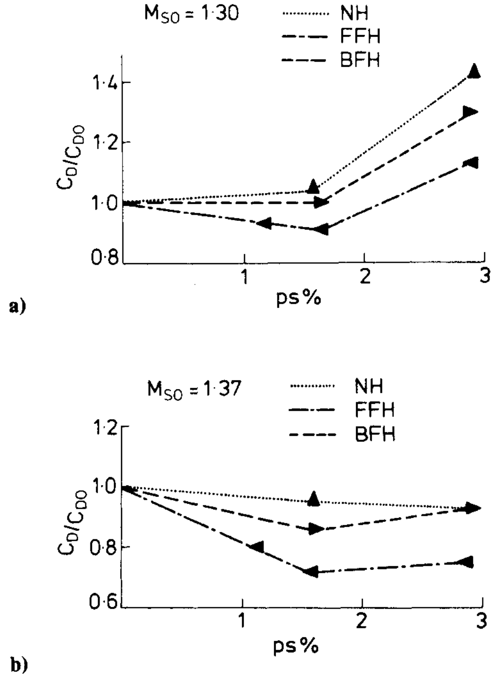

Fig. 4 Effect of porosity on drag. a) $M_{S0} = 1.3$, $X_{S0} = 0.8$; b) $M_{S0} = 1.37$, $X_{S0} = 0.85$.

ity, a larger reduction in drag is achieved with the shock wave nearer the end of the porous region.

Conclusions

It may be concluded from these results of passive shock-wave/boundary-layer control that the forward-facing-holes configuration with a porosity of 1–2% produces maximum drag reduction. The relative position between the porous region and shock position for passive shock-wave/boundary-layer control for the maximum drag reduction needs further experimentation.

Acknowledgments

The author wishes to acknowledge the financial support given by the Science and Engineering Research Council, U.K., for these investigations. The author also wishes to thank Mr. D. G. Mabey, of RAE, Bedford, and Mr. D. J. Butter, of the British Aerospace Group, Manchester, for their valuable suggestions.

References

[1]Bahi, L., "Passive Shockwave/Boundary Layer Control for Transonic Super Critical Aerofoil Drag Reduction," Ph.D. Thesis, Rensselear Polytechnic Institute, Troy, NY, 1982.

[2]Nagamatsu, H. T., Dyer, R., and Ficarra, R. V., "Supercritical Aerofoil Drag Reduction by Passive Shockwave/Boundary Layer Control in the Mach Number Range 0.75–0.9," AIAA Paper 85-0207, Jan. 1985.

[3]Raghunathan, S. and Mabey, D. G., "Passive Shockwave Boundary Layer Control Experiments on a Circular Arc Model," AIAA Paper 86-0285, Jan. 1986.

[4]Theide, P., Krogman, P., and Stanewsky, E., "Active and Passive Shockwave/Boundary Layer Control of Supercritical Aerofoil," AGARD-FDP Symposium, Brussels, Belgium, May 1984.