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MEASUREMENTS IN THE WAKE OF SEGMENTED BLUNT TRAILING EDGE AEROFOIL IN SUBSONIC FLOW

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SUMMARY The study describes measurements in the wake of a segmented blunt trailing edge aerofoil. The results showed that castellations are instrumental in weaking the process of primary vortex shedding with a consequent increase in base pressure and reduction in base drag. A segmented "M" base was found to be a very effective configuration for reducing the drag.

1. INTRODUCTION

In order to reduce the base drag of a blunt trailing edge aerofoil at subsonic speeds, the periodic vortex shedding must be suppressed. In the past, this has been achieved through the addition of splitter plates, introduction of base bleed, suction and base cavities. A much simpler method, that of modifying the geometric shape of the trailing edge has been proposed by Tanner (1972) and Pollock (1972). Some further experiments on this method of base drag reduction have also been reported by Gai & Sharma (1981).

From a basic fluid mechanics point of view, the relationship between drag and wake of a blunt body is of great interest and any geometry which offers an interesting situation to study such a relationship is of value. In the present study, flow exploration in wakes behind blunt segmented trailing edge geometries is described. This helps towards a better understanding of the base drag reduction mechanisms and the physics of base flows.

2. EXPERIMENTAL DETAILS

The experiments were conducted in a low turbulence blower-driven wind tunnel having a long test section and cross section of 229mm x 305 mm. The turbulence level in the test section was of the order of 0.3 per cent. A two-dimensional aerofoil with an elliptic fore body and parallel sides with three different trailing edge geometries was chosen for the tests. The trailing edge was 8 mm thick with thickness to chord ratio of 10 per cent. The three geometries were those of plain base, a simple segmented base and a segmented base with triangular fillets inside the recesses (see Fig. 1). The model was mounted vertically across the test section and was fitted with end plates. The flow conditions were: free stream velocity of $21 \mathrm{ms}^{-1}$ and the Reynolds number based on free stream conditions and model chord of 1.18×10^5. The boundary layer at trailing edge was rendered turbulent by a transition strip placed at 15 per cent chord from the leading edge.

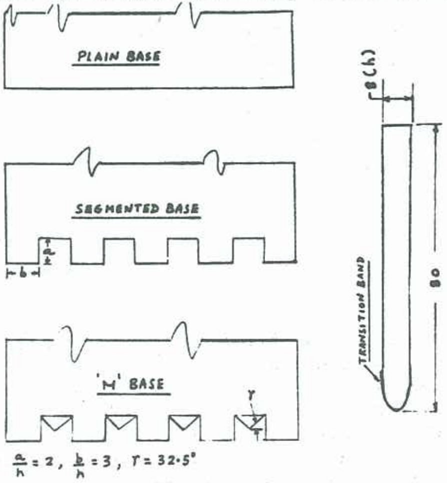


Figure 1: Model details

For probing the wake flow, a Disa 5μm miniature hot wire in association with a Disa constant temperature amemometer system was used. A thin blunt-tipped static probe of 1mm dia. was also used to measure pressures in the wake.

Figure 2 shows the orientation of the hot wire for making measurements in the wake and within the confines of projections and recesses.

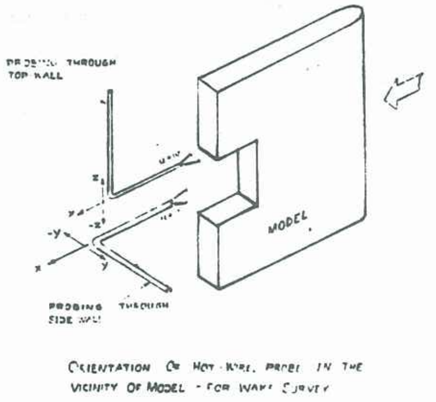


Figure 2: Orientation of hot wire probe in the vicinity of model.

3. RESULTS AND DISCUSSION

It has been recognised that the region of flow close behind a bluff body plays an important role in the determination of vortex shedding and its frequency. Hot wire traverses were therefore made alternatively behind a projection and a recess along the wake axis. Figure 3 shows the mean velocity profiles across the wake at different streamwise stations for the three configurations. From the profiles we note that the wake trails from the projection and the recess start independently and there seems to be little mixing up to about ten base heights. Evidence of complete mixing appears only for profiles at $x/h = 50$. The velocity overshoots at the edge of the shear layer in the near wake are due to the entrainment process down the wake.

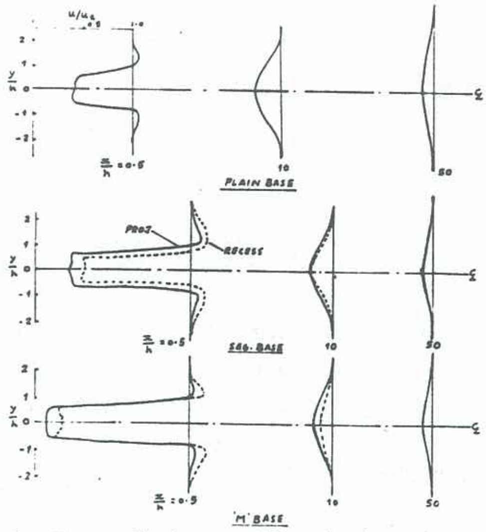


Figure 3: Mean velocity profiles in the wake.

We also note that the wake width is somewhat less for a castellated base.

Figure 4 shows the static pressure distribution along the axis in the near wake. The pressures are non-dimensionalised with respect to the free stream pressure and velocity. The results show that a significant spanwise variation exists in the near wake and even after a distance of ten base heights the pressures

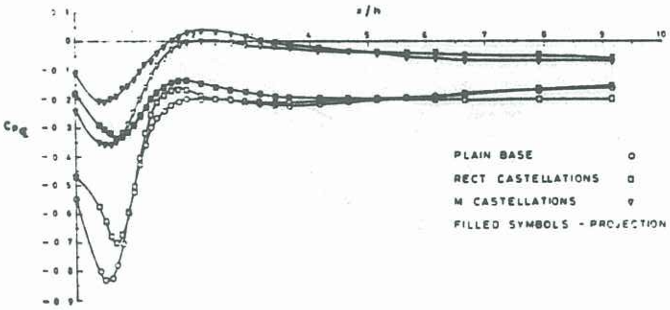
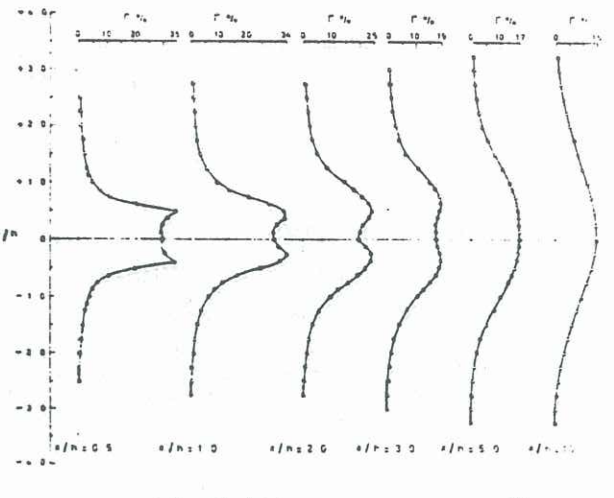


Figure 4: Pressure variation along the wake axis.

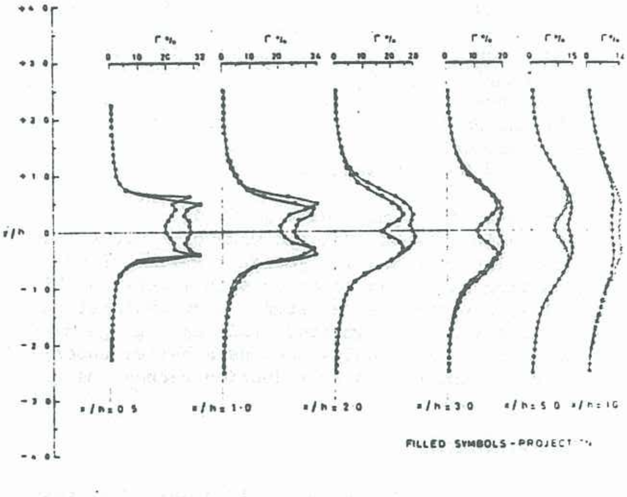
have not completely equalised. We also note the significant rise in pressures behind the projections for a castellated base, most notably for the "M" configuration. Also, there is a slight shift downstream of the pressure minimum for castellated bases. It should be pointed out, however, that in view of the difficulties in estimating true static pressure in our unsteady wake, the above results should be considered only as indicative of the trends.

Figure 5 shows the plots of longitudinal turbulence intensity profiles at various streamwise distances in the near wake. Once again, the profiles behind the projection and recess are distinct from each other and appear to merge approximately ten base heights downstream for the simple segmented and the "M" base. An interesting feature of these profiles is the rapid reduction in turbulence level behind a castellated base. For example, at $x/h = 10$, it is reduced by about 50 per cent for the "M" base in comparison to the plain base. We also note that very near to the base ($x/h \leq 2$) turbulence levels at the shear layer edge of the "M" base are nearly twice as large as those in the central core. This effect is minimum for the plain base. This is thought to be due to large mean rates of strain produced in the shear layer due to castellations. Again, the reduction in wake width is evident for a castellated base. Further, a rapid decay of distortion in the inner turbulent core occurs within about five base heights. This shows that large scale fluctuations are rapidly broken down into small scale turbulence thus promoting the mixing process.

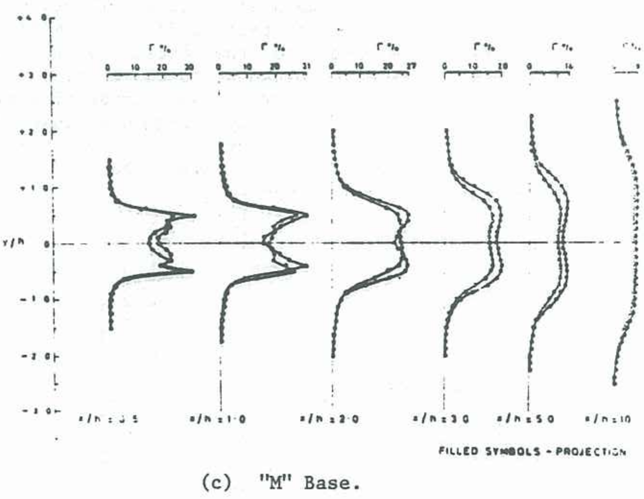
Figure 5: Longitudinal turbulence intensity profiles in the wake.



(a) Plain base



(b) Simple segmented base



(c) "M" Base.

The position of vortex formation using a hot wire is shown in Figure 6. The scale of fluctuations represents the unsteadiness in the wake. The maximum amplitude and its location corresponds to the position and strength of the primary vortex (see, for example, Bearman, 1967). As seen from the figure, the vortex formation is pushed further downstream for the segmented base this being maximum in the case of "M" base. We notice again that vortex streets from the projection and the recess start independently in the formation region consistent with the mean velocity and turbulence data. Other notable features are that the peak turbulence levels for the segmented base are much smaller and turbulence decay much faster, reducing by nearly threefold at $x/h = 10$ for the "M" base. This suggests that castellations not only reduce the strength of the vortex street but also large scale fluctuations in the near wake into small scale wake turbulence leading to better mixing. Bearman (1967) has shown that increase in base pressure is a direct consequence of the downstream displacement of the vortex formation distance and also that it is independent of the agency employed to interfere with vortex formation. The present study and the base pressure data obtained earlier (Gai & Sharma, 1981) are consistent with such a view.

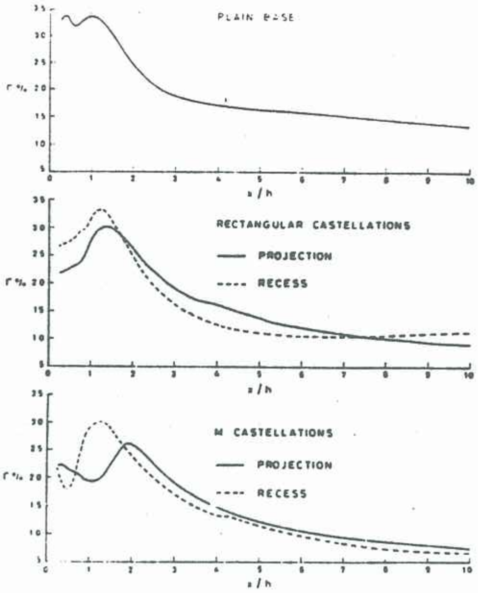


Figure 6: Vortex formation distance

In Figure 7 is shown a plot of base pressure against the inverse of the vortex formation distance x_v in the manner proposed by Bearman (1967). The results of Bearman are also shown. While the data of Bearman shows a linear variation in base pressure with the inverse of the vortex formation distance, the present results indicate a non-linear dependence. This is presumably due to the fact that with a segmented base, the line of separation from which vortices are shed is discontinuous.

To measure the vortex shedding frequency, the hot wire probe was kept just at the wake edge and the frequency spectrum recorded on a Bruel and Kjaer level recorder using a constant bandwidth filter. The peak value corresponds to the frequency of vortex shedding. For the plain base, this peak was quite sharp and the CRO pattern was sinusoidal indicating regular periodicity with the corresponding Strouhal number being 0.24.

However, the frequency spectra and CRO display of the wake behind a segmented base showed irregular vortex shedding and distortions in the periodicity. The peak in velocity fluctuations corresponding to the predominant frequency indicating vortex shedding progressively became smaller and was particularly so for the "M" base. This suggests that a decrease in the strength of the vortex occurs and is consistent with the data of Figure 6. The calculated Strouhal numbers showed a small increase at first, depending on the base pressure and then decreased with further increase in base pressure. Bearman (1967) observed a similar effect which was found to be independent of the method adopted to suppress vortex shedding.

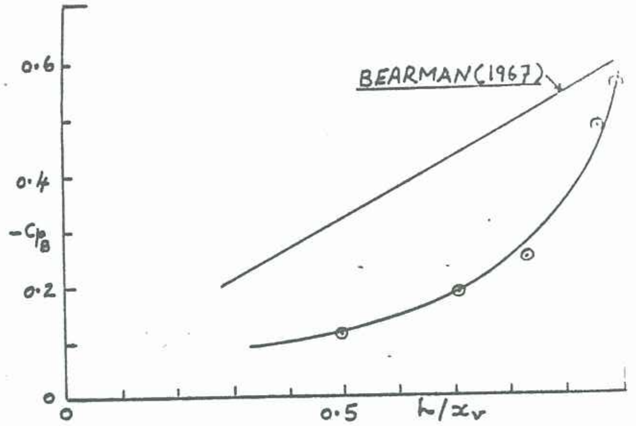


Figure 7: Base pressure coefficient Vs inverse of vortex formation distance.

Hot wire explorations were also made within the recess and in front of the projections to observe the spanwise flow. These showed that in the case of a simple segmented base the velocities were higher (and pressures lower) in the recess while they were lower at the projections. There seemed to be a sharp discontinuity in velocity at the junction of a projection and a recess. The pressures measured within the confines of the recess and at the projection were consistent with the above results. The results with the "M" base indicated that velocities in the recess and at projection were of the same order and the discontinuity across the junction was less sharp. This would suggest that the "M" base configuration provides a better spanwise communication to the flow.

4. CONCLUSIONS

The experiments have shown that castellations influence both periodicity and strength of vortex shedding. The weakened vortices are formed further away from the base thereby increasing the base pressure and there is loss of order in the street. Further, the vortex decay is much faster with segmented bases and this was maximum for the "M" base.

An interesting feature is the apparent slow mixing for a considerable distance in the near wake. It was at least ten base heights before the vortices were completely broken up and mixing could be considered to have begun. Complete mixing took as far as fifty base heights.

5. REFERENCES

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