

Vortex Shedding from a Segmented Blunt Trailing Edge Aerofoil in Subsonic Flow

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INTRODUCTION

The key to the drag of a bluff body is in the dynamics of the vortices which form in the near wake region (Roshko 1955; Nash 1963 and 1965; Wood 1964; and Bearman 1965 and 1967a). Therefore, any device employed to increase the base pressure must affect the formation of these vortices. Thus a systematic study of the near wake region with particular attention to the formation or otherwise of these vortices assumes significance.

There is sufficient data regarding base pressure recovery and vortex formation and shedding (example, Wood 1964; Bearman 1965 and 1967a) of blunt base aerofoils incorporating base bleed and splitter plates. However, as yet, there is no detailed data regarding vortex formation and shedding from a segmented blunt trailing edge aerofoil.

It was first established by Tanner (1972) and Pollock (1969) that segmented blunt trailing edge aerofoils yield considerable base drag reduction, of the order of 50% or more. They attributed this to the fact that the discontinuous trailing edge inhibits two-dimensional periodic vortex shedding. Gai and Sharma (1981) did further detailed measurements which confirmed these findings.

The above investigations were all restricted to making base pressure measurements and in the case of Pollock (1969) some Schlieren flow visualisation to monitor vortex shedding.

Gai and Sharma (1983) made a wake exploration study of a segmented blunt trailing edge aerofoil using hot wire measurements. They found that castellations on a blunt trailing edge result in weakened vortices. They also observed a much faster rate of vortex decay with a segmented base and this was maximum for the 'M' configuration base.

In the present paper attention is focussed on vortex shedding, their strength and the effect of segmented base on the Strouhal number variation. There was a belief that vortex shedding was almost always completely inhibited by a discontinuous/curved separation line (see Berger and Wille 1972); however, the present experiments show that vortex shedding does persist in the presence of a castellated trailing edge and that the shedding frequency and strength are very much dependent on the geometry of these castellations.

EXPERIMENTAL ARRANGEMENT AND TEST CONDITIONS

Three base configurations, plain base as a basic configuration, rectangular castellations as an example of the simplest segmented base and the 'M' base, which appears to give the highest base pressure recovery (Tanner 1972; Gai and Sharma 1981) were chosen. The two dimensional models with an elliptic forebody and parallel sides had a chord of 80 mm with a thickness to chord ratio of 10 per cent (Fig. 1).

The experiments were conducted in a low turbulence blower-driven wind tunnel having a test section length of 2740 mm and cross section 229 mm x 305 mm. The models

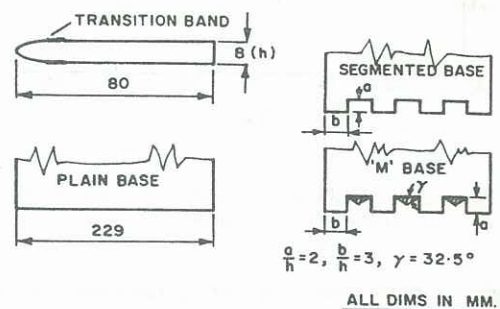


Fig. 1: Model Details.

were all mounted vertically across the test section and were fitted with end plates. The flow conditions were: free stream velocity of 25 ms^{-1} and the Reynolds number based on free stream conditions and model chord of 1.18×10^5 . The free stream turbulence level in the test section was of the order of 0.3 per cent.

The boundary layer at the trailing edge was rendered turbulent by a transition strip placed at 15 per cent chord from the leading edge.

Some experiments were conducted at a Reynolds number of 8×10^4 to study the effect of Reynolds number.

For probing the flow, a Disa $5 \mu\text{m}$ miniature hot wire in association with a Disa constant temperature anemometer system was used. To measure the vortex shedding frequency, the hot wire output was connected to a Bruel & Kjaer Heterodyne Analyser Type 2010, fitted with a constant band width filter, and the signal from the analyser was then recorded on a Bruel & Kjaer level recorder type 2307 to obtain the frequency spectrum.

RESULTS AND DISCUSSION

Vortex Formation and Strength.

Bearman (1967a) has argued that increase in base pressure is a direct consequence of the downstream displacement of the vortex formation and also that it is independent of the agency employed to interfere with that vortex formation.

The vortex formation distance x_v corresponding to the peak position of $\left(\frac{u_{rms}}{U_\infty}\right)$ (see Bearman 1965) from the

base is shown plotted against the base pressure in Fig. 2 in the manner suggested by Bearman (1967a). Results of Bearman are also indicated.

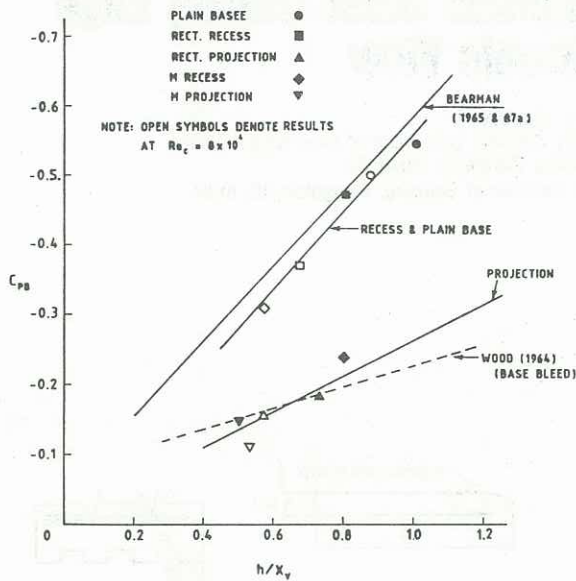


Fig. 2: Base Pressure Variation with Vortex Formation Distance

Figure 2 shows some interesting features. Firstly we note that the recess results (for both Reynolds numbers) barring one 'M' recess data point fall approximately in a straight line and close to the mean of Bearman's data of both splitter plate and base bleed. Secondly, the data points pertaining to projections show some scatter but may be roughly seen to lie along a line of different slope. The considerable scatter in the projection data is possibly due to three-dimensional effects at the free ends. The results of Wood (1964) as given in Bearman (1967a) are also indicated on the figure.

Considering the amplitude of $(\frac{u_{rms}}{U_{\infty}})$ peak behind a plain base as reference, it is possible to have an estimate of vortex strength attenuation from the respective $(\frac{u_{rms}}{U_{\infty}})$ peaks of projections and recesses. Fig. 3

shows a plot of vortex strength attenuation against the vortex formation distance. It is interesting to note that castellations seem to be more effective than other base drag reducing devices. Some Reynolds number effect is also evident.

Measurement of Shedding Frequency

To measure the vortex shedding frequency, the hot wire probe was kept just at the wake edge and about 3 base heights downstream and the frequency spectrum recorded on a Bruel & Kjaer level recorder using a constant band width filter. The peak value in this spectrum corresponds to the frequency of vortex shedding. The hot wire signal was also displayed on an oscilloscope. The frequency spectrum and the CRO traces are shown in figures 4(a) through 4(e) and 5(a) through 5(e).

Tests by previous workers on a 2-D blunt trailing edge aerofoil have showed that the Strouhal number based on free stream velocity and vortex shedding frequency is around 0.24. For the present model, using this value of Strouhal number gives a vortex shedding frequency of about 750 Hz. The frequency spectrum, Fig. 4(a) shows that for a plain blunt base, the peak occurs at around 746 Hz and is sharp and prominent. The sharp single peak indicates that the shedding is very regular and periodic which is further confirmed by the C.R.O. display in Fig. 5(a) showing a clear sinusoidal wave.

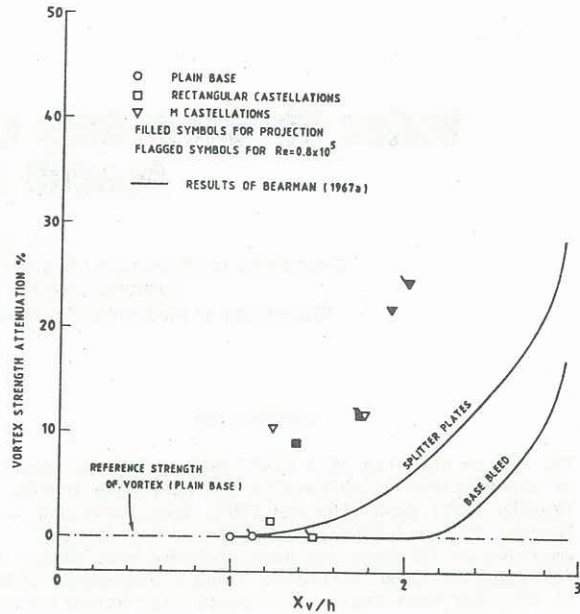


Fig.3: Vortex Strength Attenuation Vs. Vortex Formation Distance.

Figs. 4(b) and (c) for the simple rectangular castellated base show firstly, that with the recess, the periodic shedding persists, the peak having shifted to ~800 Hz. Secondly, it is seen from Fig. 5(b) that shedding is still regular.

The spectra behind the projection show some notable features. There appear more than one peak, clubbed together in the frequency range 600 Hz to 800 Hz, reduced in sharpness and amplitude. This would indicate that the shedding frequency is not single valued but consists of a band of frequencies. The corresponding wave form, Fig. 5(c) verifies that shedding is not very regular. Further, the reduced amplitude of peaks suggests that the vortices are weakened.

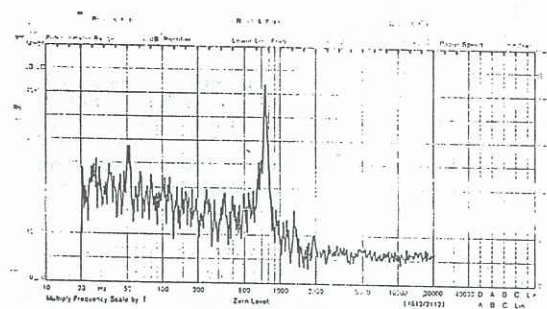
In the case of 'M' castellated base, the recess and projection both seem to influence the regular vortex shedding as is evident from Figs. 4(d) and (e) which show multi peaks with reduced amplitudes at different frequencies. This would imply that there is no single predominant frequency but several frequencies randomly appearing. The waveform is also distorted as shown by Figs. 5(d) and (e) indicating that regular shedding has almost ceased. The frequency range in which these peaks lie is approximately 800 Hz to 900 Hz for the recess and 650 Hz to 800 Hz for the projection. Another feature of these frequency spectra is that in the higher frequency range (>1 kHz) several small amplitude peaks are seen to occur and their nature suggests that they may be due to the highly three-dimensional nature of the flow in the base with this configuration.

Taken together, the results from Figs. 4 and 5 show that changes in shedding frequency and vortex strength are clearly due to changes brought about at the trailing edge.

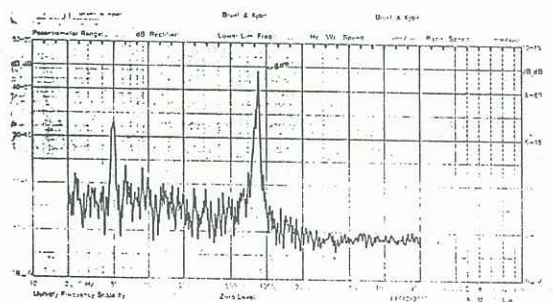
Strouhal Number

It has been pointed out by Maull & Young (1973) that if there is a change in spanwise base pressure coefficient, the Strouhal number also undergoes a change and if the base pressure coefficient variation occurs in cells (such as the projection and recess in the present case) then the shedding also breaks down into number of spanwise cells in each of which the frequency is constant. Thus, the projection and the recess each have different Strouhal numbers corresponding to their respective values of the base pressure coefficient.

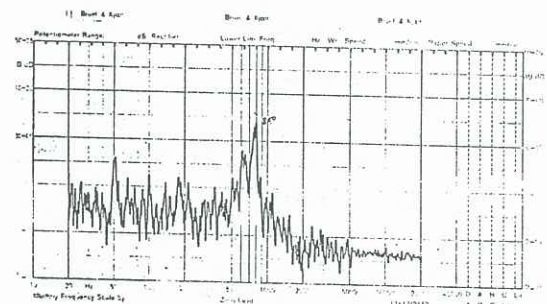
Fig.4: Frequency Spectra of Vortex Shedding.



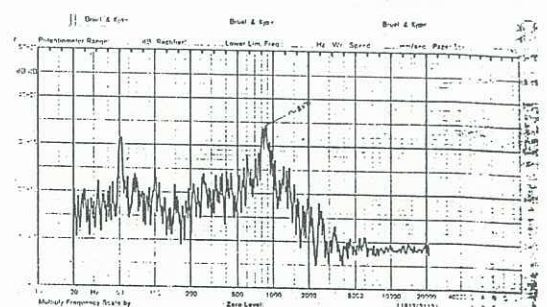
(a) Plain Base



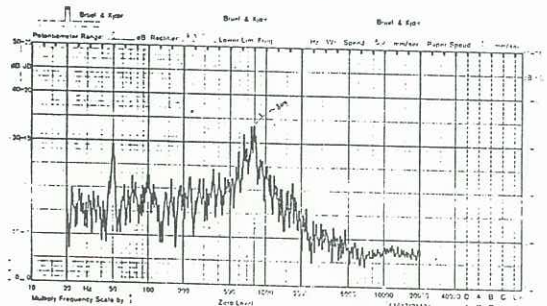
(b) Rectangular Recess



(c) Rectangular Projection

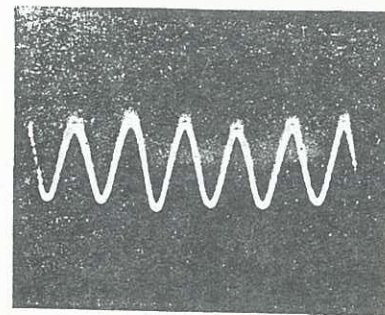


(d) 'M' - Recess

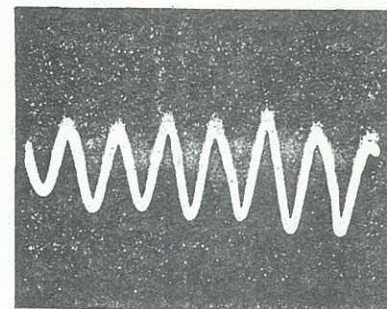


(e) 'M' - Projection.

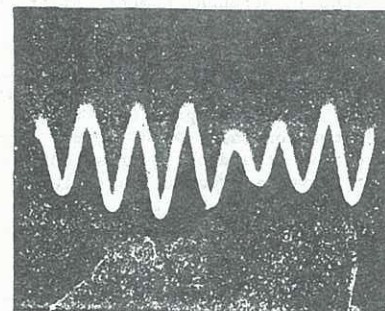
Fig.5: C.R.O. Traces of Vortex Shedding.



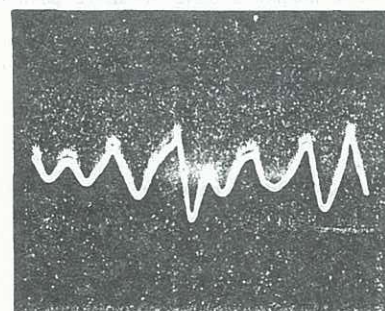
(a) Plain Base



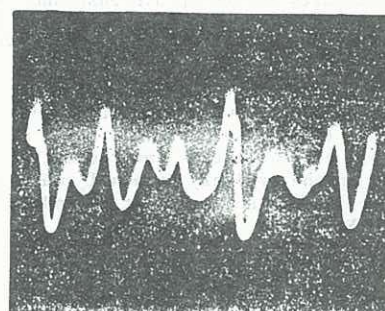
(b) Rectangular Recess



(c) Rectangular Projection



(d) 'M' - Recess



(e) 'M' - Projection.

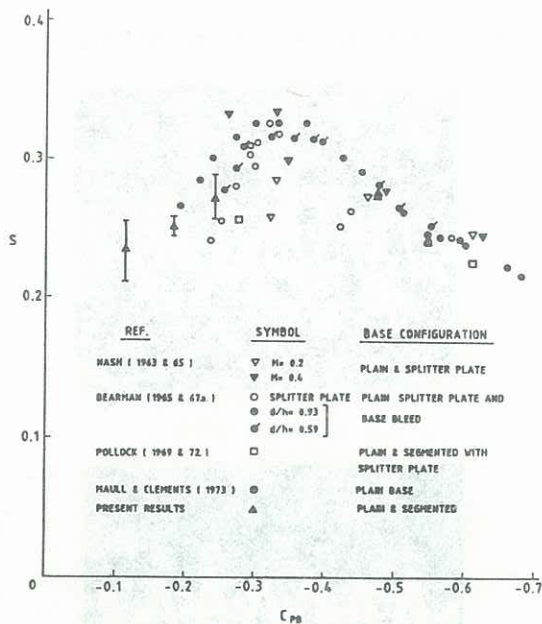


Fig. 6: Strouhal Number Variation with Base Pressure Coefficient.

Figure 6 shows the Strouhal number variation with the base pressure coefficient. Also shown are the results of other investigators for comparison. The plot shows a definite trend in Strouhal number variation with the base pressure although there is some scatter in the data. This variation is irrespective of the type of wake interference method used. Initially, there is an increase in Strouhal number with the base pressure recovery which, on attaining a peak, reverses and then seems to fall monotonically with further increase in base pressure. The trend of the results seems to indicate that there is a unique variation of Strouhal number with base pressure and that it is independent of the method used to interfere with the wake.

In his paper, Bearman (1967b), after a careful examination of all the available experimental data, defines a new Strouhal number S_B based on the Kronauer stability criterion. When this new Strouhal number is plotted against Roshko's base pressure parameter $K (= \sqrt{1 - C_{pB}})$, it was found that it was constant for a wide variety of bluff body geometries including splitter plates and base bleed. S_B is related to the ordinary Strouhal number by

$$S_B = S \left(\frac{b}{h} \right) \frac{1}{K}$$

where 'b' is the spacing between shear layers and 'h' is the base height. For a parallel sided body such as in the present instance $b \approx h$.

The variation of S_B with K along with various experimental data reproduced from Bearman (1967b) is shown in Fig. 7. We note that S_B for various wake interference devices has a universal value of around 0.181 and the present results for the plain base and rectangular recess are in agreement with this result. The figure also shows that for $K \leq 1.15$ (or $C_{pB} > -0.3$) there is a trend away from the line $S_B = 0.181$; also our results of rectangular projection and 'M' segmented base fall in accordance with this trend and lie in between Wood's (1964) and Bearman's (1965 and 1967a) data. In this context, it is interesting to note that the reversal in the ordinary Strouhal number versus base pressure trend also occurs at around $C_{pB} \approx -0.3$ as seen from Fig. 6.

CONCLUSIONS

The experiments have shown that both the shedding frequency and strength of vortices are influenced by

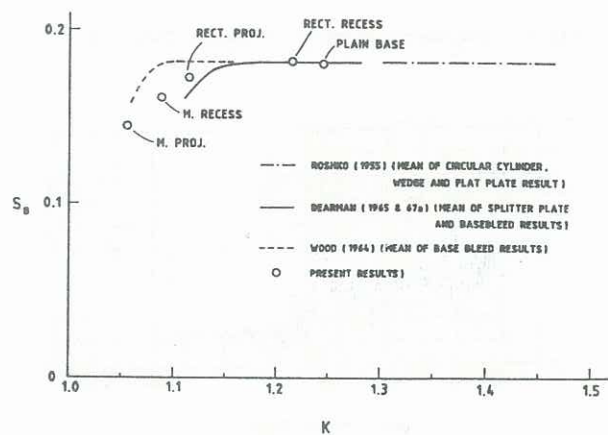


Fig.7: Bearman's Universal Strouhal Number S_B Vs K .

the segmented trailing edge and they are strong functions of the geometry. This is reflected in the variation of the Strouhal number. These experiments, along with previous similar investigations, show that there is a characteristic variation of the Strouhal number with base pressure coefficient which seems to be independent of the agency employed to interfere with the vortex formation behind a two-dimensional bluff body.

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