INVESTIGATION OF UNSTEADY FLOW ON THE BASE OF A BLUNT TRAILING EDGE AEROFOIL

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ABSTRACT

Detailed fluctuating pressure measurements along the span of a blunt trailing edge aerofoil with and without end plates were performed in a low turbulence subsonic wind tunnel at a Reynold's number based on chord of 1.6 x 10^5. The model aspect ratio of span to base height was 30 without end plates and 20 with end plates. The results reveal the highly three dimensional nature of the flow even with end plates, which help to explain the different vortex shedding modes along the span.

INTRODUCTION

Improving aerofoil performance in all modes of flight has attracted a great deal of interest in recent years. Several researchers, Bearman (1965 and 1967), Wood (1964), Tanner (1972) and Gai and Sharma (1981), have considered venturing away from the conventional sharp trailing edge design, which has disadvantages both at transonic and supersonic speeds. Blunt trailing edge aerofoils have been considered for use in areas ranging from turbine cascades to helicopter rotor blades. Although there have been several studies conducted on the nature of flow separation and wakes produced by blunt trailing edge geometries, (Petrusma and Gai (1989), Petrusma(1990), Tombazis and Bearman (1992) and Tombazis (1993)), they have primarily been concentrated on steady state aspects. As such, little is known about the unsteady flow characteristics or the noise generated from such geometries.

Unlike cylinder flow where major effort has been expended, (Hammache and Gharib (1982), Williamson (1989), and Williamson and Roshko (1990)), work on blunt trailing edge aerofoils is just beginning. While it is almost possible to completely eliminate three dimensional effects from the wakes of cylinders by using very large aspect ratios (AR>>100) as found by Lee and Budwig (1991), or through the modification of end constraints, this is not always possible for aerofoils where the aspect ratio is usually small (AR<40) as determined by Williamson (1989), Hammache and Gharib (1991) and Gerich and Eckelmann (1982).

End constraints have been shown to influence the nature of the vortex shedding over large spanwise distances as shown by Szepessy and Bearman (1992) and Szepessy (1994), and induce either parallel or oblique shedding. Work conducted by Szepessy and Bearman (1992) and Tombazis (1993) found that as Reynolds number increases, vortex shedding and turbulence in the shear layer begin to contribute to the three dimensional flow in the near wake. This unsteady vortex shedding must in turn affect the base pressure, and hence the base drag.

As part of a study of unsteady base flows, a detailed study of the fluctuating pressures on the base of a plain blunt trailing edge aerofoil was undertaken to determine the extent of three dimensional effects, the effect of end constraints, and provide some insight into how the process of vortex shedding is affected.

EXPERIMENTAL ARRANGEMENT AND TECHNIQUES

The experiments were conducted in a 460mm x 460mm open circuit wind tunnel, with a turbulence level of 0.25%. A modified NACA 0012 aerofoil with a parallel sided body and plain blunt trailing edge spanning the tunnel was used, as shown in figure 1. The model aspect ratio (span/base height) was 30. End plates as specified by Stansby (1974) were also used, creating an effective model aspect ratio of 20.

The Reynolds number based on chord for the experiments was 1.6 x 10^5. Previous studies by Petrusma and Gai (1989) and Petrusma (1990), had shown that at these flow conditions, the boundary layer just before separation was laminar. Measurements of the boundary layer at the trailing edge and just upstream of the trailing edge, conducted using a single axis hot wire probe, show that this was indeed the case. The Strouhal number was 0.26 corresponding to a shedding frequency of 330 Hz.

Fluctuating pressures were measured using ENDEVCO 8507C-2 miniature pressure transducers with a pressure range of 0 - 2 psi, and vented to the atmosphere. Each transducer was placed in a brass holder to facilitate its movement along the span. The transducers were calibrated in situ before use. Their output was fed into a PC30 A-D board and then analysed using a program written specifically for this task.

Three transducers were used and were positioned as shown in figure 2. Transducer #1 was located at the model centre and its position was fixed. Transducers #2 and #3 were positioned on either side of the centre and could be moved at half base height intervals spanwise. When transducers #2 and #3 were closest to the centre, this location was designated as position 18, while at position 1 they were furthest apart. Note that use of the end plates limited the maximum spanwise position available to position 4.

The fluctuating base pressures were recorded for each position at a sampling rate of 10 kHz. Transducer #2 and #3 were then progressively moved one position away from the centre towards position 4. This process was repeated for all positions both with and without end plates.

RESULTS AND DISCUSSION

The data presented here shows the fluctuating pressures normalised with respect to the r.m.s. pressure, plotted against time normalised with respect to the Strouhal period. Only two positions are shown for comparison purposes.

Figure 3 depicts the output from the three transducers at position 18, when all three are closest. The traces exhibit similar signatures and magnitude of fluctuation although transducers #2 and #3 show a slight asymmetry in the flow. The transducer signal for position 18 with end plates is given in figure 4. The signatures in all three traces are stronger and the fluctuations larger in magnitude compared to that without end plates and the flow symmetry is more pronounced. The end plates could therefore be seen to promote a stable and stronger two dimensional vortex shedding.

As the transducers were moved away from the centre, the pressure signals remained fairly constant for a short region before showing any changes in phase or magnitude in fluctuations. With no end plates, this region of nominally two dimensional flow extended for approximately six base heights, while with end plates this region was extended to approximately ten base height across the centre portion of the span.

Figure 5 depicts the transducer signals at position 4, when transducers #2 and #3 are nine base heights from the centre. The traces for transducers #2 and #3 show a considerable phase drift with a significant reduction in magnitude compared to the centreline reading of transducer #1. This would indicate that the vortex shedding is no longer two dimensional, and is seen to be attenuated. The transducer signals for position 4 with end plates is given in figure 6. The signal from transducer #1 is again strong, while it diminishes with spanwise distance for transducers #2 and #3. Here one would also expect maximum end wall effects which is clearly seen by the signal asymmetry and attenuation.

From these fluctuating pressure signals it could be concluded that as the spanwise distance is increased, flow symmetry and magnitude of fluctuations diminishes suggesting that away from the centre three dimensional effects would dominate the flow and that the flow would no longer exhibit two dimensional characteristics.

Cross correlation traces are also provided, with and without end plates for positions 18 and 4, in figures 7 to 10. The correlation between two points along the span were calculated as:

$$R_{ij} = \frac{\overline{(P_i' - P_{i\,rms})\,(P_j' - P_{j\,rms})}}{\sqrt{\overline{(P_i' - P_{i\,rms})^2}\;\overline{(P_j' - P_{j\,rms})^2}}} \quad (1)$$

Looking at the results for position 18 without end plates, figure 7, in view of the definition in equation (1), the correlations between different transducer outputs are similar although spanwise correlation periods are small as indicated by the zero crossings. This, when related to pressure signals for this same position is consistent with the large variations in phase and magnitude at small distance away from the centre region.

With end plates, the pressure traces have shown the flow to be more two dimensional in nature as the individual transducers show similiar responses in both phase and magnitude for a greater spanwise distance. This is supported by the spanwise cross correlation with longer periods as shown in figure 8. Therefore, it would appear that flow with stronger vortex shedding, as found with end plates, has enhanced spanwise correlation.

Turning to figure 9, we see that at position 4, without end plates, there is negligible correlation due to large out of phase spanwise fluctuations. The results also indicate significant asymmetry. This is seem from the pressure traces where spanwise variations in magnitude and phase are evident. With end plates, however, the situation improves, as seen in figure 10 with longer correlation periods. In comparison, the pressure traces at this position are attenuated due to the presence of the end plates.

The correlation data thus confirms the pressure signal data indicating the three dimensional nature of the flow and vortex shedding. They also reinforce the pressure data showing that end plate effects are quite significant.

CONCLUSIONS

Detailed pressure measurements across the entire span of a blunt trailing edge aerofoil with and without end plates are described. The results show that the flow is highly three dimensional although quasi-regular as evidenced by generally well ordered fluctuations in the midspan region. The results also show that while the spanwise equalisation of pressures is occurring, the regularity of vortex shedding is disrupted by three dimensional spanwise disturbances and the shedding attenuates.

The main difference between the results with and without end plates is that end plates seem to promote a stronger two dimensional flow across a larger portion of the span. Due to the low aspect ratios used in these series of experiments, the effect of yawing the end plates inwards was to considerably attenuate the flow and show that the vortex shedding can be influenced significantly by the boundary conditions. The details of these experiments will be described later.

The next step is to correlate these fluctuating pressure signals with the fluctuating velocity using hot wire anemometry.

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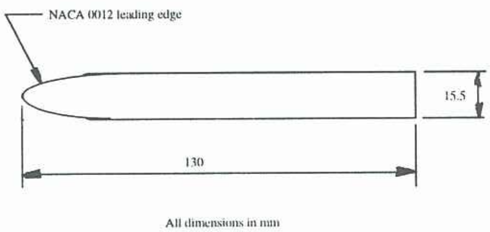

FIG 1 : BLUNT TRAILING EDGE MODEL

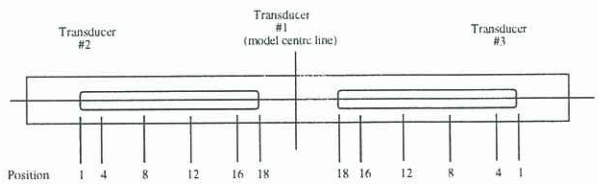

FIG 2 : REAR VIEW OF MODEL

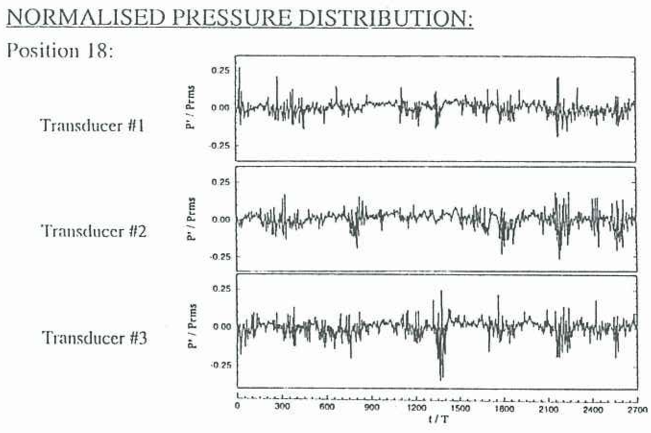

FIG 3 : NORMALISED PRESSURE DISTRIBUTION
- POSITION 18 -
- NO END PLATES -

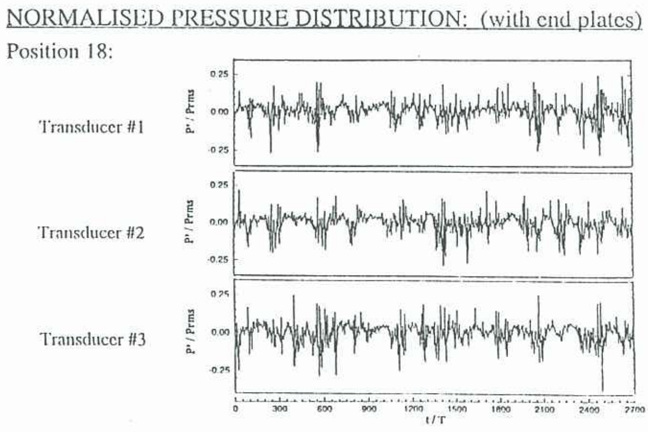

FIG 4 : NORMALISED PRESSURE DISTRIBUTION
- POSITION 18 -
- WITH END PLATES -

NORMALISED PRESSURE DISTRIBUTION:

Position 4:

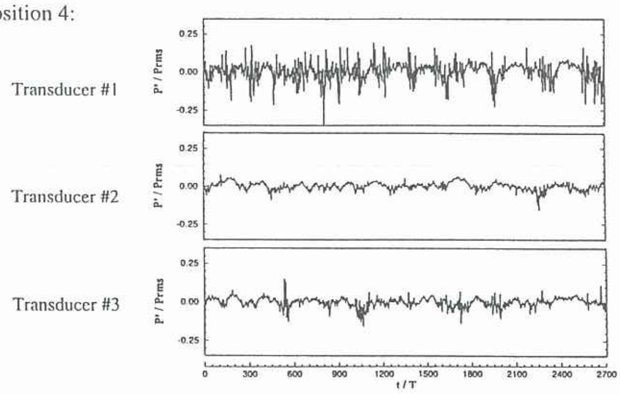

FIG 5 : NORMALISED PRESSURE DISTRIBUTION
- POSITION 4 -
- NO END PLATES -

NORMALISED PRESSURE DISTRIBUTION: (with end plates)

Position 4:

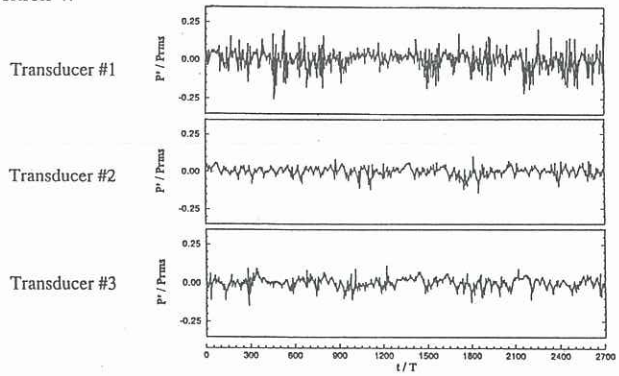

FIG 6 : NORMALISED PRESSURE DISTRIBUTION
- POSITION 4 -
- WITH END PLATES -

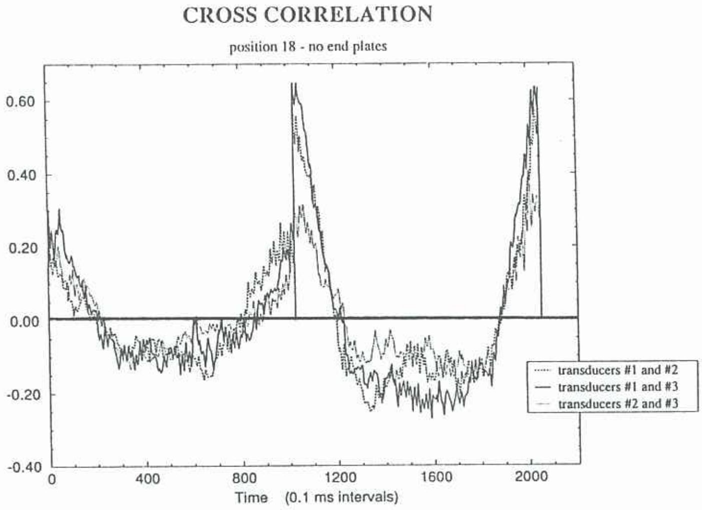

FIG 7 : CROSS CORRELATION
- POSITION 18 -
- NO END PLATES -

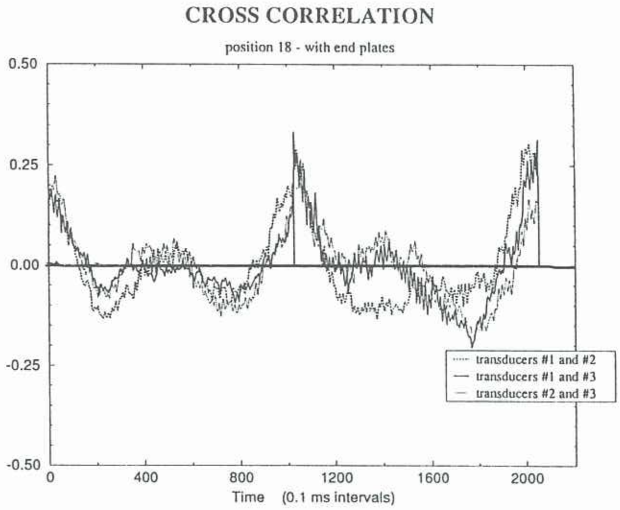

FIG 8 : CROSS CORRELATION
- POSITION 18 -
- WITH END PLATES -

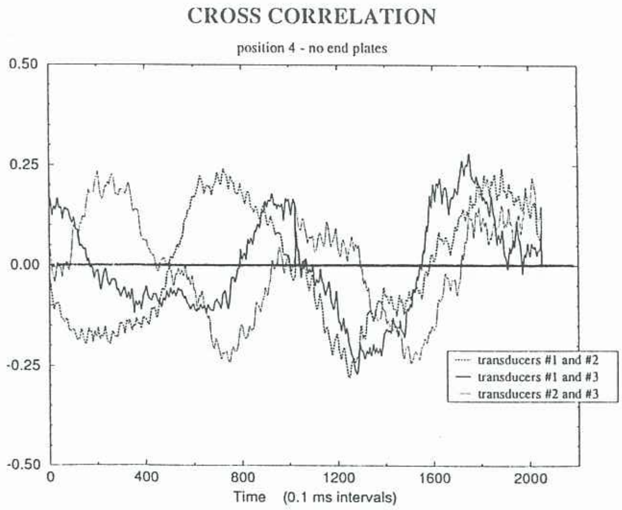

FIG 9 : CROSS CORRELATION
- POSITION 4 -
- NO END PLATES -

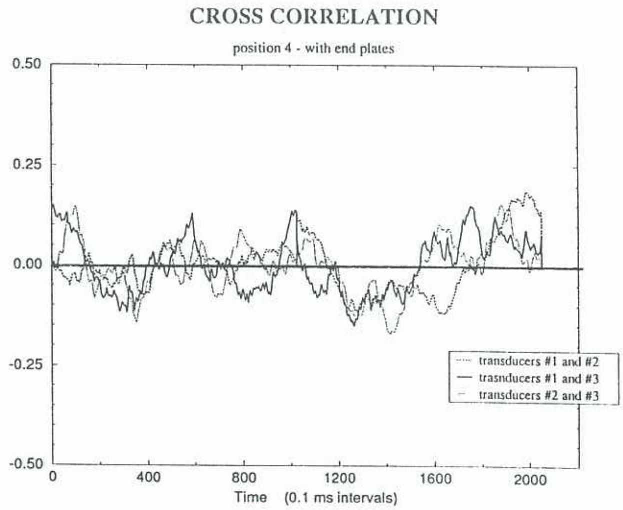

FIG 10 : CROSS CORRELATION
- POSITION 4 -
- WITH END PLATES -