NOTE ON THE USE OF CORRELATION TECHNIQUES TO DETERMINE THE FORMS OF VIBRATION OF A CONTINUOUS STRUCTURE EXCITED BY RANDOM PRESSURES

by

B. L. Clarkson
University of Southampton
England

I. INTRODUCTION

In the present state of knowledge, it is not possible to calculate theoretically the modes of vibration and the stresses induced when a typical aircraft structure is subjected to random acoustic pressures of the type associated with jet noise. The more rigorous analyses of the form put forward by Powell cannot be applied directly because the modes of vibration of a practical structure cannot yet be estimated a priori. On the other hand, the simplified approaches made on the basic assumption that each panel is vibrating completely independently of its neighbors are unable to account for the overall vibrations which undoubtedly occur in many cases. It is clearly necessary, therefore, to investigate in detail the form of vibration which takes place in actual aircraft structures and hence obtain a better understanding of what theoretical assumptions and approximations may be justified. The best way of doing this is to use correlation techniques to compare the vibration taking place in different parts of the structure at each resonant frequency.

II. CORRELATION TECHNIQUE

To determine the form of vibration taking place in a lightly damped aircraft structure it is necessary to isolate each resonant frequency and measure its associated mode shape. The frequency spectrum of the strain as measured by a strain gauge at the center of a tailplane skin panel, for example, will show several marked peaks corresponding to the resonances of the panel and surrounding structure. The strain in the center of an adjacent panel would generally show a very similar spectrum; but these frequency spectra are insufficient to determine the mode of vibration. If, however, the signals from the two gauges are passed through a pair of matched filters of appropriate center frequency, it is possible to correlate the two strains at each resonant frequency. The correlation measurements will indicate whether the two panels are in phase, out of phase, or on the average, bear little relationship with one another.

If there is any marked phase relationship, then any form of vibration analysis must take into account the motion of both panels; but if, on the other hand, there is no relationship, then it is reasonable to use the single panel analysis. In a similar way, by correlating the strain at several points on a single panel, it is possible to determine the mode shape.

Figure 1 shows the correlator and time delay unit of the Aeronautical Engineering Department of the University of Southampton which was used to obtain the strain correlation measurements discussed later in the paper. The correlator and time delay unit have been described in detail by McLachlan (1) and Tanner (2), and mention here is made of only the main operational limits, which are:

Band width:	0 to 20 k.c.s.
Integration time:	Variable in 10 sec. increments from 10 secs. to 10 mins.
Time delay:	Rotating drum, off contact heads, F.M.
Delay in discrete increments:	1 micro second to 140 millisecs.accuracy ± 1 micro sec.

III. EXPERIMENTAL RESULTS

In order to discover the type of results which might be obtained in a detailed test on an aircraft structure, a limited test was made using only a few strain gauges positioned in the centers of adjacent panels of a tailplane. The all moving tailplane is shown diagramatically in Figure 2 and its position relative to the jet exit nozzle is approximately eight nozzle diameters downstream and two diameters out from the jet center line.

The skin of the tailplane is integrally machined to give a panel thickness of 0.05 in. leaving chordwise and spanwise stiffeners 0.15 in. thick, the chordwise stiffeners being then attached to pressed ribs. The panel size is approximately 3 in. x 6 in., the larger dimension representing the rib spacing. Five strain gauges were positioned in the center of adjacent panels as shown in Figure 2.

The frequency spectrum of the strain measured by the center gauge is shown in Figure 3. The other gauges measured similar spectra and from these it can be seen that there are four major structural resonances being excited by the jet noise.

In comparing the two panels, their strain signals are passed through a pair of matched filters 1/3 octave wide, in order that only that portion of the signal in the region of a resonance will be studied. The resultant signals are now compared and their correlation coefficient measured. If the correlation coefficient is say 0.9 this means that for 90% of the time the two panels are exactly in phase. If, on the other hand, the correlation coefficient is -0.5 then the panels are exactly out of phase for 50% of the time and completely independent of one another for the remainder of the time. In cases where there may be travelling wave effects, the maximum correlation will occur when one of the signals is advanced or retarded in time with respect to the other. Thus, correlation measurements should be made with a time delay in one channel.

The results of such correlation measurements on these five panels are shown in Figures 4 and 5. In Figure 4 the panels in the chordwise direction are compared and Figure 5 shows the corresponding results in the spanwise direction. In each figure the left hand diagram shows a comparison of the center strains of adjacent panels and the right hand diagram shows a comparison the the center strains of the two outer panels. The curves are drawn for the different resonant frequencies as indicated in the frequency response spectrum (Figure 3).

IV. DISCUSSION OF RESULTS

Turning first to the correlations made in the 250 c.p.s. frequency band, it is seen that all the panels are exactly in phase for about 90% of the time. The stresses induced at this frequency are thus definitely of an overall nature although, as shown in Figure 3, this is not a major structural resonance. In three of the major modes investigated, there is a much higher correlation chordwise than spanwise. The fourth mode could not be investigated with the equipment described as there was no third octave filter of appropriate center frequency. However, in this case the correlation can be obtained from the cross power spectrum in a manner similar to that described in the preceding paper on noise pressures. In fact, this method may well be a better way of covering the whole frequency range and will be used in subsequent analyses.

The actual values of correlation coefficient in Figure 4 show clearly the mode shape in the chordwise direction. At 800 c.p.s., for example, panels 2 and 4 (adjacent) are exactly out of phase for 90% of the time, whilst the two outer panels (4 and 5) are exactly in phase for 65% of the time. In the spanwise direction, the correlation values are small for these main structural modes, indicating that panels in this direction behave almost independently of one another.

These results have not attempted to indicate in detail the type of vibration taking place but rather to illustrate the use of this method in studying random vibrations. However, it can be seen from these initial results that any form of analysis on this structure would have to consider the whole line of panels in the chordwise direction between the ribs but could justifiably regard the panels as being independent of one another in the spanwise direction for the main structural modes.

V. CONCLUSION

As a result of this preliminary investigation, it can be concluded that the correlation of strains in different parts of a structure in frequency bands corresponding to the resonant frequencies forms a powerful method of studying the response of a structure to random loads. It is vital that this type of measurement be made on typical parts of aircraft structures in order to determine what form of vibration is taking place. Knowing this, more reasonable theoretical assumptions and approximations can be made in any form of analysis. In cases where an existing aircraft structure is experiencing high stress levels, the information on the form of vibration will enable damping materials to be used in the most efficient manner.

REFERENCES

1. McLachlan, K. R., "The Development of an All-Purpose Correlator," Univ. of Southampton Report to be published.
2. Tanner, P. L., "Variable Time Delay for Jet Noise Research," Univ. of Southampton M.Sc. Thesis, July 1959.

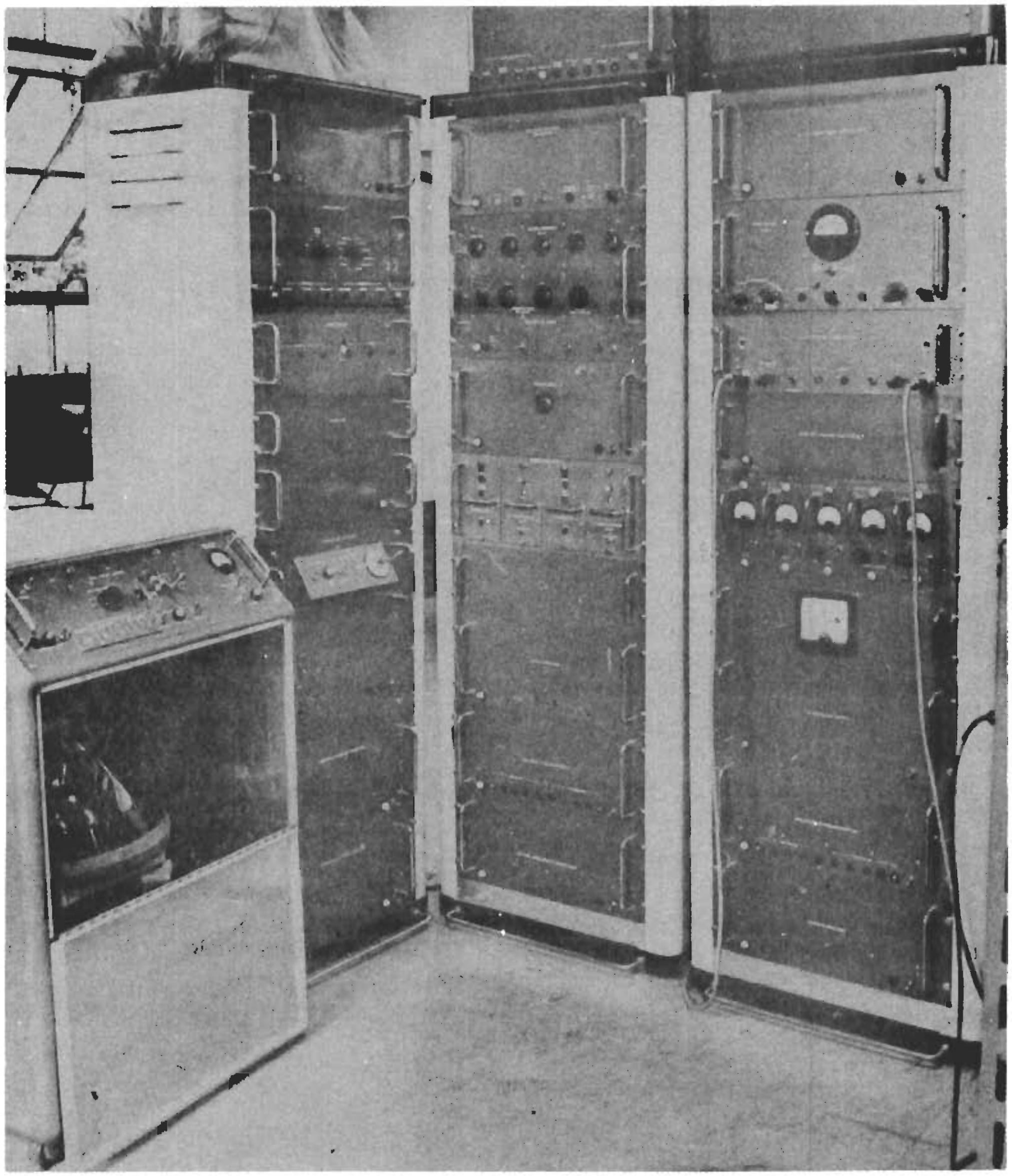

Figure 1 - SOUTHAMPTON CORRELATOR

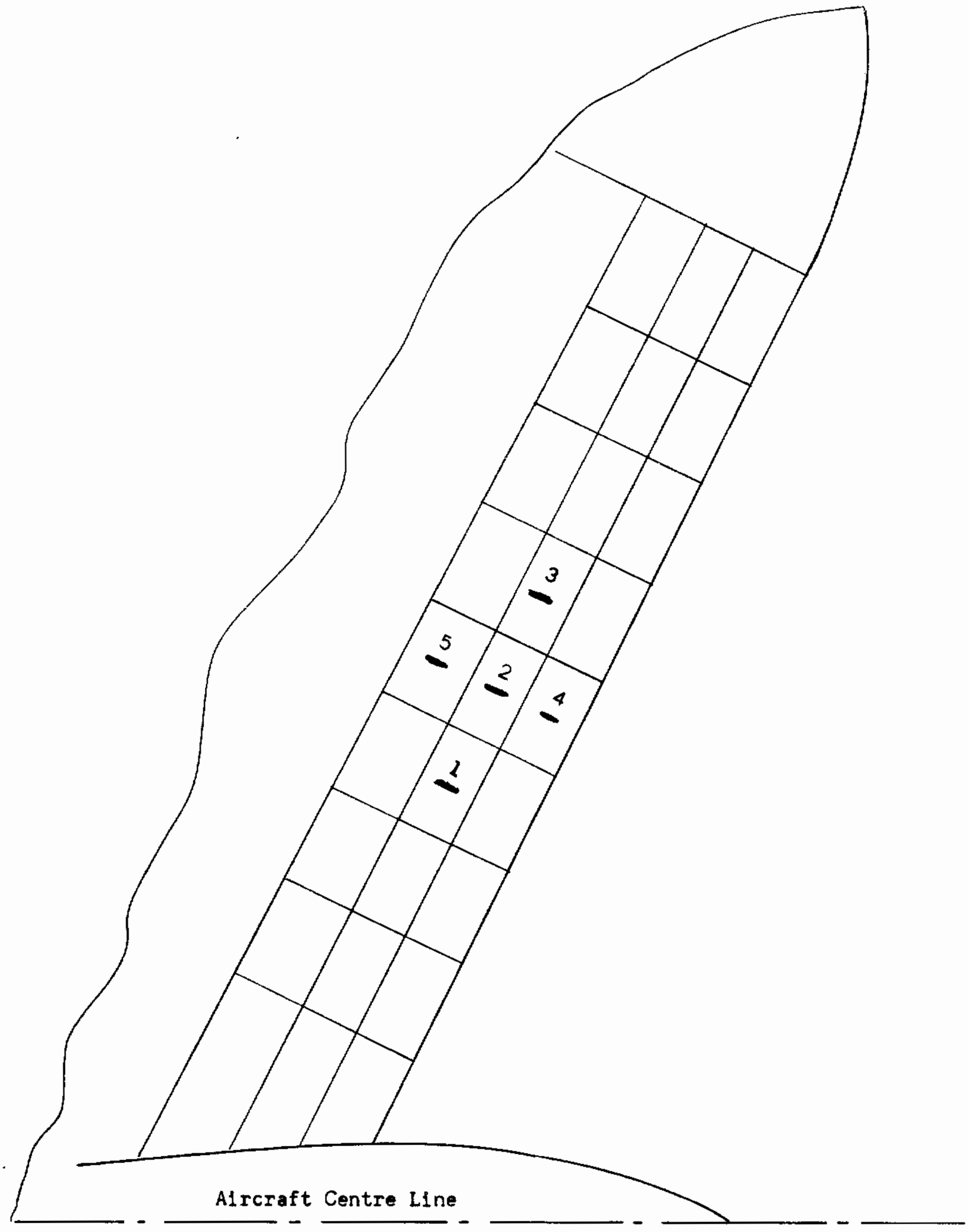

Figure 2 - Position of Strain Gauges on Tailplane Bottom Surface

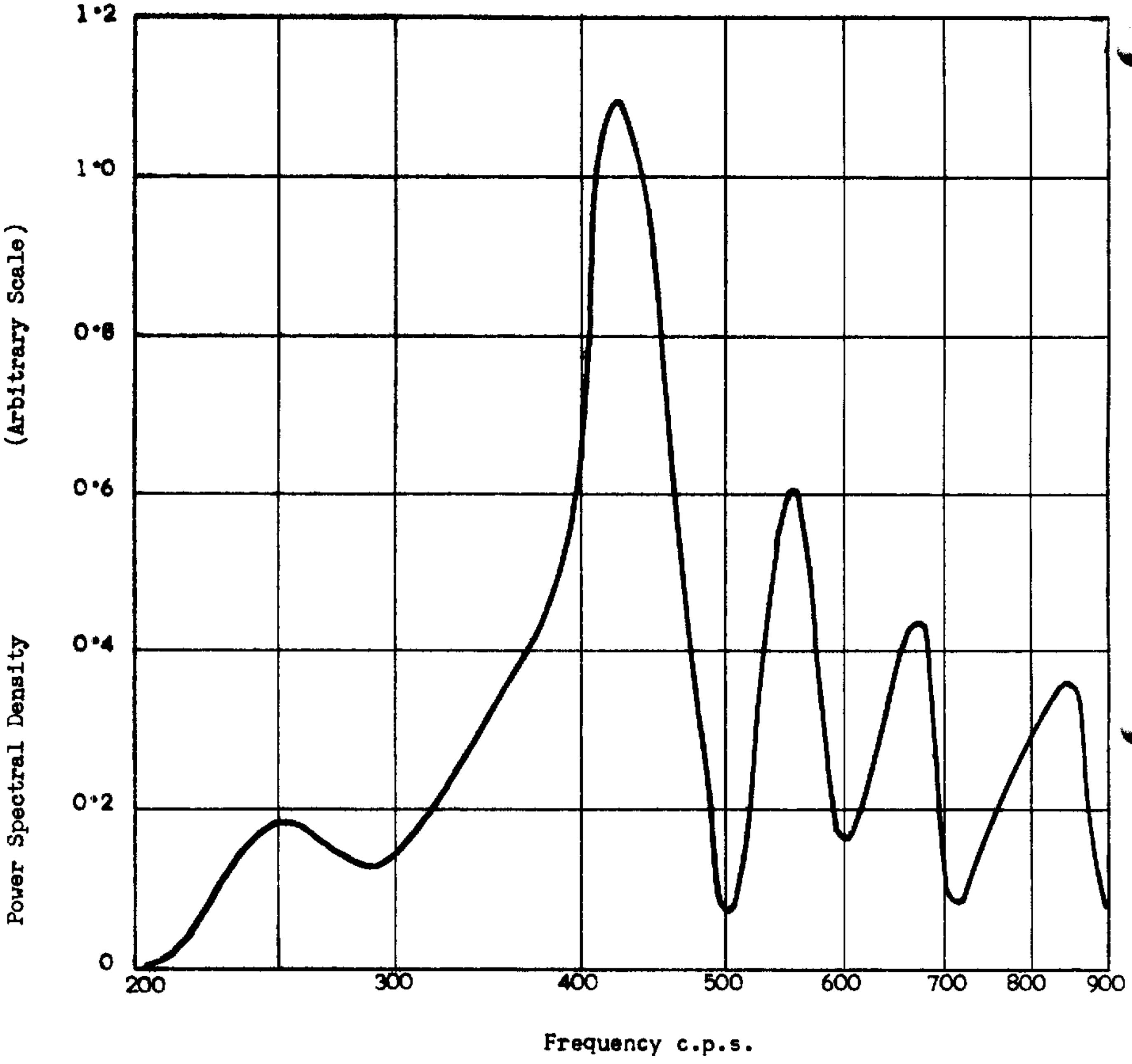

Figure 3 - Power Spectral Density of Strain in Tailplane Panel

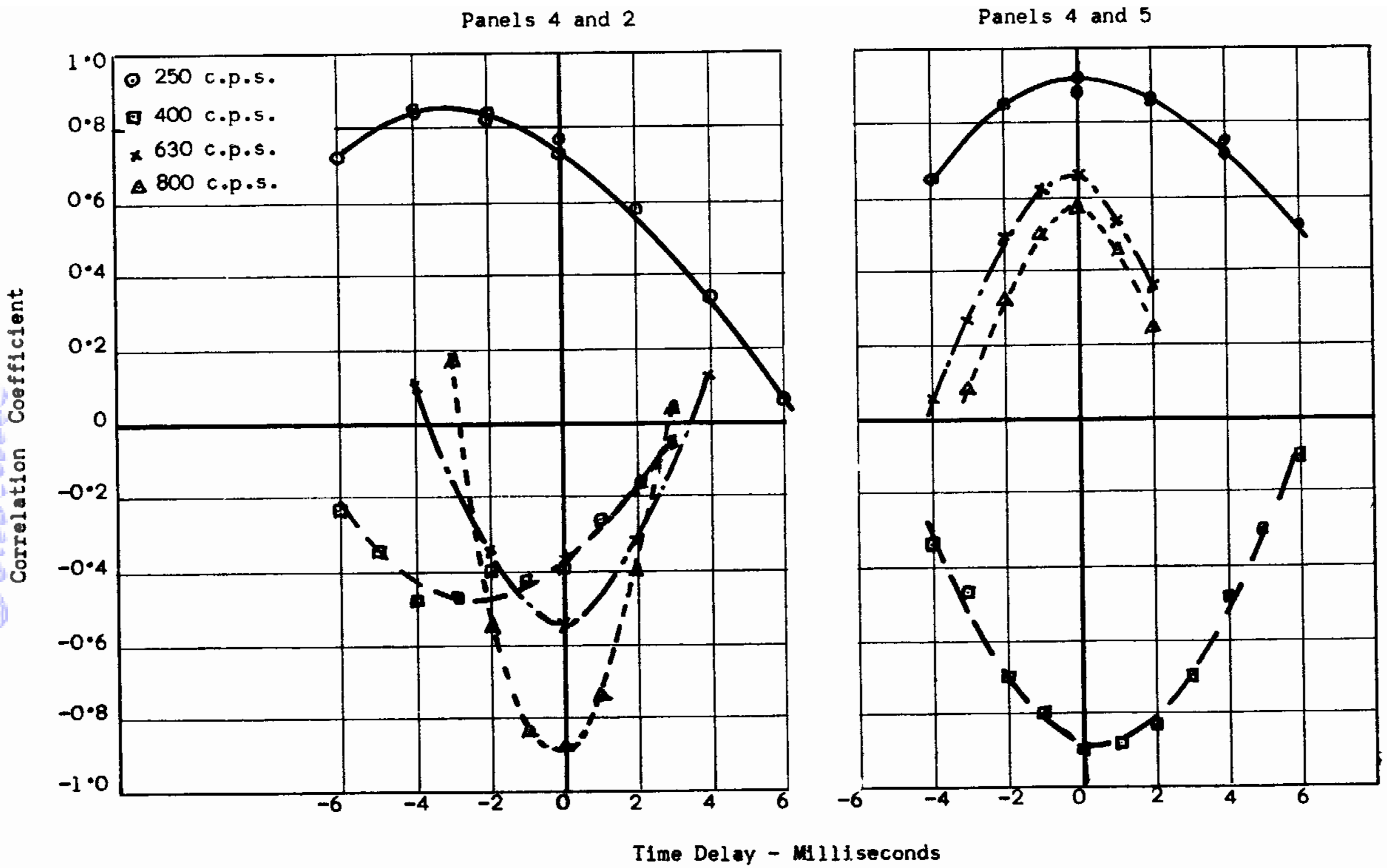

Figure 4 - Correlation of Panel Strains in Chordwise Direction

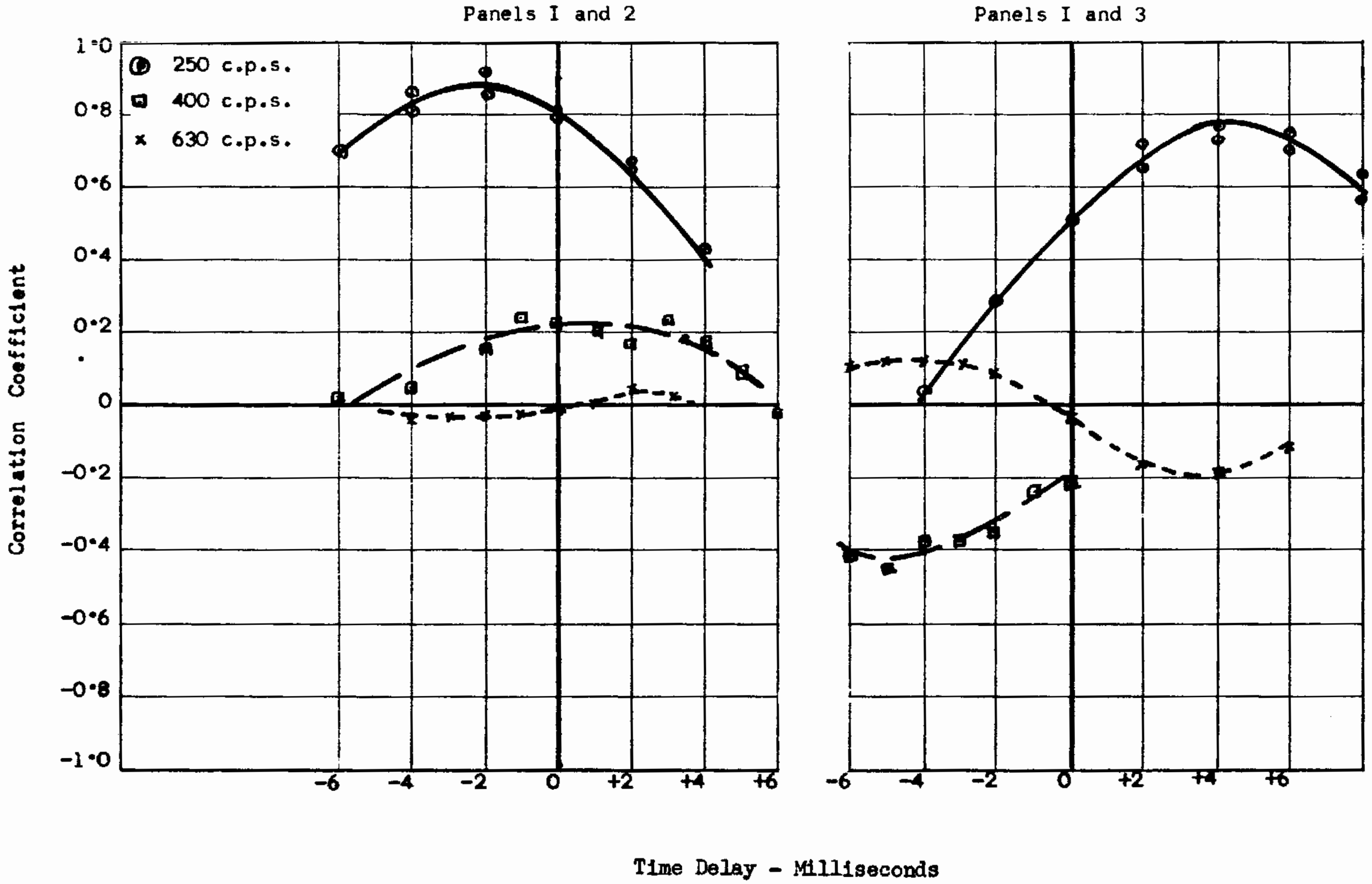

Figure 5 - Correlation of Panel Strains in Spanwise Direction