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by

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ASYMMETRIC WING LOADS ON A CANBERRA AIRCRAFT DURING FLIGHT IN TURBULENCE

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SUMMARY

This is a short study of the asymmetric load on the wing of a Canberra aircraft in turbulence. The asymmetric part is separated from the symmetric part as far as is possible with the available data. The relationship of the asymmetric part to the rolling acceleration is studied.

* Replaces RAE Technical Report 72164 - ARC 34296

CONTENTS

1 INTRODUCTION

Most work to date on wing loads on aircraft flying in turbulence has been concentrated on symmetric loads. This report is a start towards a study of asymmetric effects. The actual measurements were not planned with this object in mind, so the instrumentation on the aircraft was not ideal for such a study. However, it was still considered to be worthwhile to find what indications of asymmetric effects were present.

Measurements of wing root bending moment as given by a strain gauge bridge on one side of the wing were available. The procedure adopted was to remove symmetric effects in the wing root bending moment measurement by matching it with the acceleration at the centre of gravity. The analysis was confined to frequencies below 1 Hz, that is to rigid body modes, because it was felt that the study of asymmetric structural modes would have required more extensive strain-gauging.

The relationships between the asymmetric part of the wing root bending moment and the rolling acceleration and aileron angle were studied.

2 METHOD OF ANALYSIS AND RESULTS

The measurements were made in the summer of 1965 on a Canberra aircraft taking part in Project Roughrider, an investigation into various aspects of thunderstorms held in Oklahoma, USA. The flight to which they refer has been described and discussed by Burns and Harrold[1] and by Burns[2]. The instrumentation and data reduction techniques used on this flight have been given by Burns[3,4]. For the part of the flight studied, values of roll rate, centre of gravity acceleration and wing strain gauge output were available at intervals of 1/20 s over a period of 60 s.

These values were filtered to remove frequencies above 1 Hz. The results are shown in Fig.1. The gain of the filter used is shown in Fig.9.

Values of strain gauge output and centre of gravity acceleration normalised to give unit root mean square were calculated. The two variables were matched by adjusting the centre of gravity acceleration along the time axis until the mean difference between the quantities was minimised. The required lag was 0.045 s, with the centre of gravity acceleration leading. (This lag includes instrument lags.)

The difference between the two normalised quantities, with the times of the centre of gravity acceleration values adjusted for lag, is now referred to as the remanent strain.

The remanent strain, roll acceleration and unfiltered aileron angle are shown in Fig.2. The root mean square value of the remanent strain is 0.165.

The power spectra and cross spectrum of the remanent strain and the roll acceleration were calculated by means of a computer program developed by G. Miller[5]. The theory of the spectrum calculations has been given by Jenkins and Watts[6] and Blackman and Tukey[7].

The power spectra of the remanent strain and the roll acceleration are given in Figs.3 and 4. The cross spectrum is given in Fig.5. The real part, the co-spectrum, shows the convariance between the in-phase components of the variables as a function of frequency. The imaginary part, the quadrature spectrum, shows the covariance between the out-of-phase components as a function of frequency.

The squared coherence is given in Fig.6. This is a non-dimensional measure of the correlation between the two variables as a function of frequency. The associated phase spectrum is given in Fig.7. It shows how frequency components of the remanent strain lead or lag frequency components of the roll acceleration at the same frequency. The coherence is greatest in the region between 0.45 and 0.8 Hz. Another computer program was used to filter the remanent strain and the roll acceleration, frequencies below 0.45 Hz and above 0.8 Hz being filtered out. The results are shown in Fig.8. The filters used are shown in Fig.10.

Cross-spectra have been calculated by means of the Miller program for remanent strain and aileron angle, and for aileron angle and roll acceleration. The results are shown in Figs.11 to 17.

3 DISCUSSION

The asymmetric component of the wing root bending moment is small compared with the symmetric component. The root mean square of the remanent strain is smaller than the normalised strain by a factor of 0.165. This is despite indications of fairly marked asymmetric loads as shown by the pilot's rapid use of aileron.

The power spectrum of the remanent strain shows peaks at 0.6 Hz and at zero frequency. The power spectrum of roll acceleration shows peaks at 0.55 Hz and 0.2 Hz. However, the coherence squared shows only one large peak at 0.6 Hz. The two variables are most strongly correlated in this region; their behaviour at lower frequencies is not strongly correlated. In the peak region the phase spectrum is in the neighbourhood of 90°.

The filtered values of Fig.8 show the parts of the remanent strain and roll acceleration in the waveband 0.45 to 0.8 Hz, the region of strongest correlation. A resemblance between these curves can be seen which is not apparent in the plots of the variables in Fig.2. The 90° phase lag can be seen.

The power spectrum of aileron angle shows a peak at 0.2 Hz, but there is little coherence with remanent strain in this frequency region. The maximum of coherence squared between remanent strain and aileron angle is seen from Fig.13 to occur at 0.5 Hz and to be much lower than that between remanent strain and roll acceleration. The coherence squared between aileron angle and roll acceleration (Fig.16) shows roughly equal peaks at 0.2 and 0.55 Hz.

4 CONCLUSIONS

Asymmetric effects in the wing root bending moment during a flight through turbulence have been studied. Attention was confined to rigid body modes, frequencies above 1 Hz being filtered out.

The asymmetric effects were found to be small. A connection is found between the asymmetric effect and the rolling acceleration.

In any further work on this subject, much more useful information could be obtained if both wings were strain-gauged. The effect of aileron would be better understood if gauges were fitted at front and rear.

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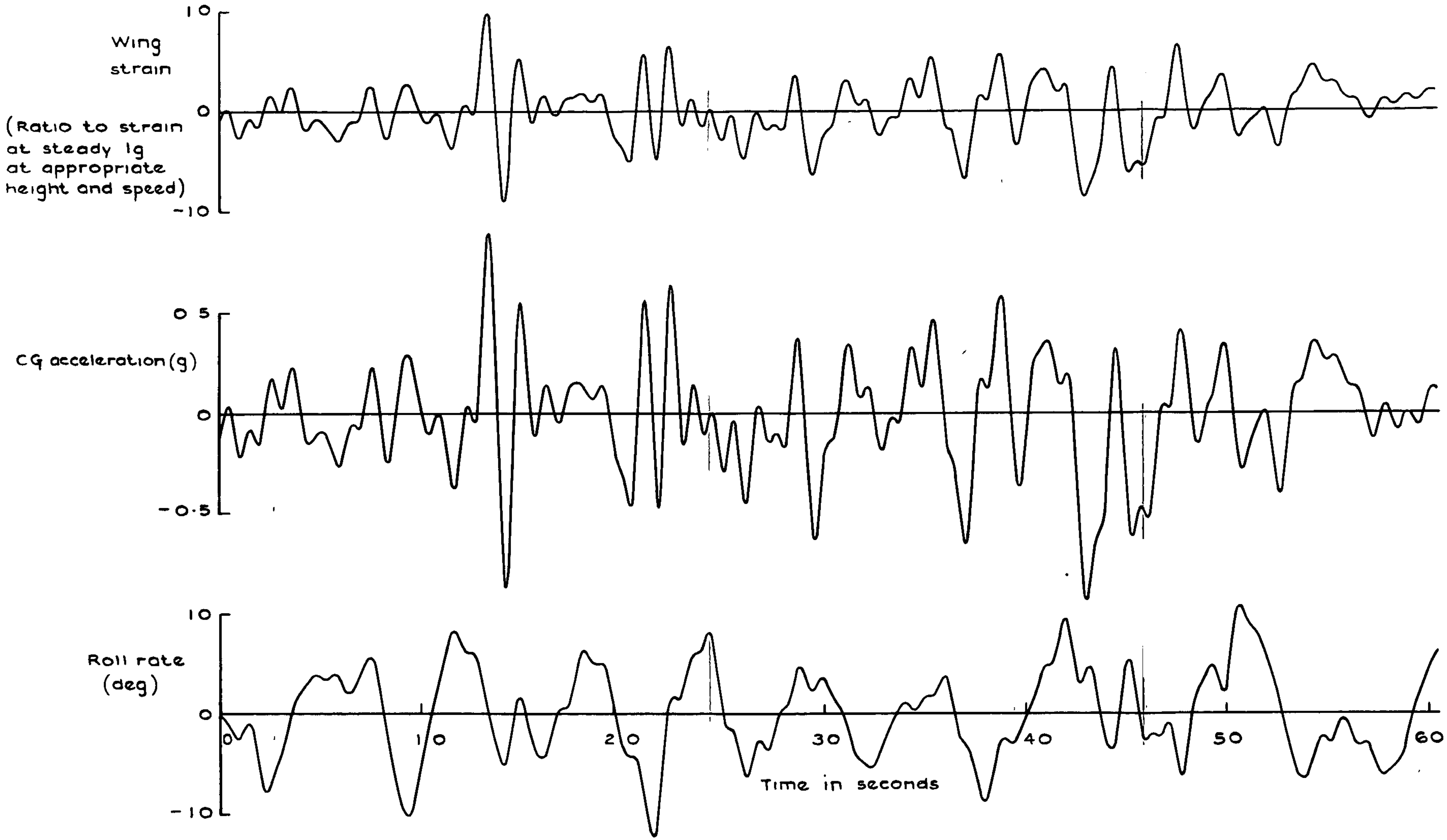

Fig.1 Roll rate, C G acceleration, wing strain gauge output after filtering to remove frequencies above 1 Hz

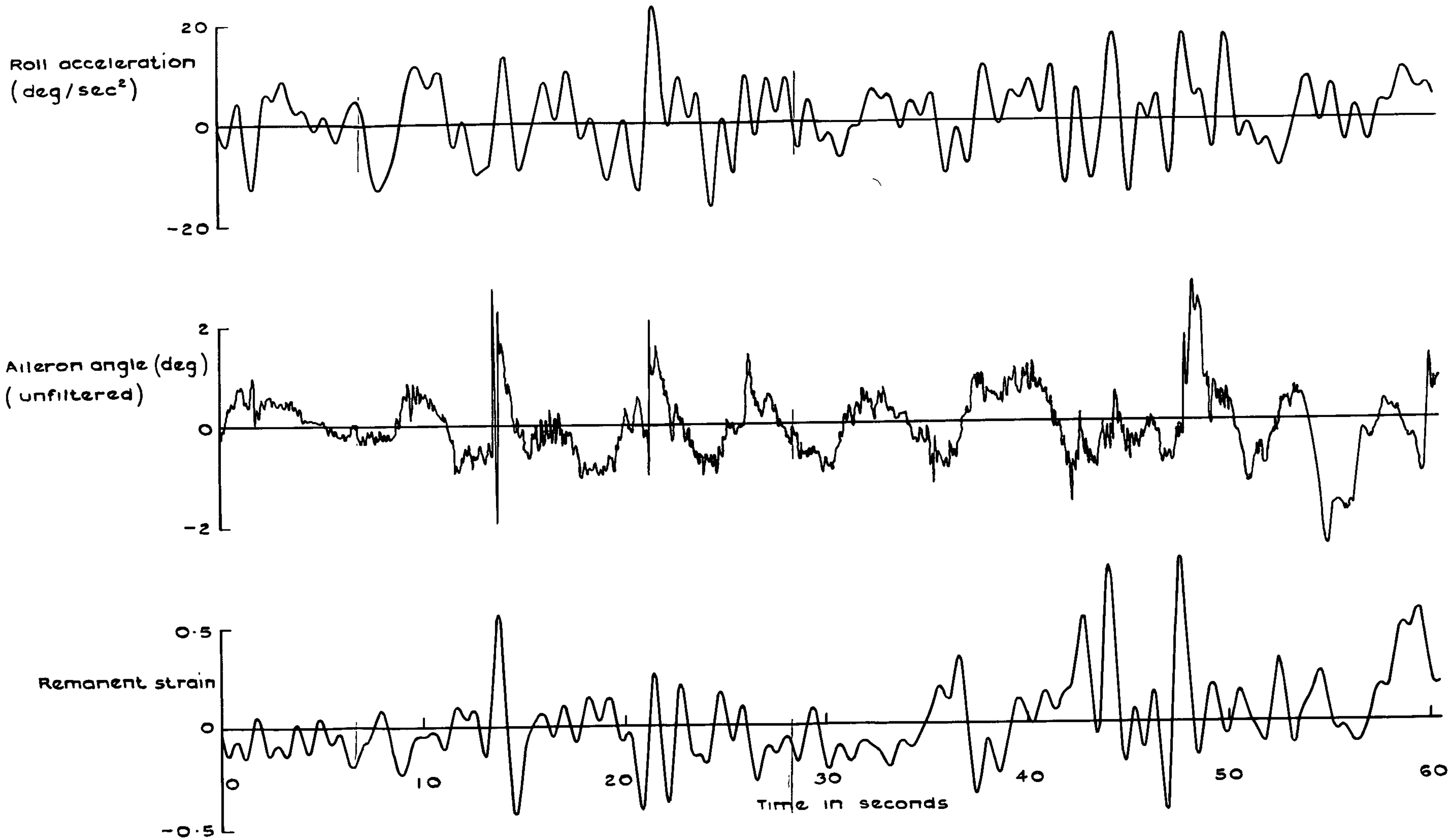

Fig. 2 Remanent strain, aileron angle (unfiltered) and roll acceleration

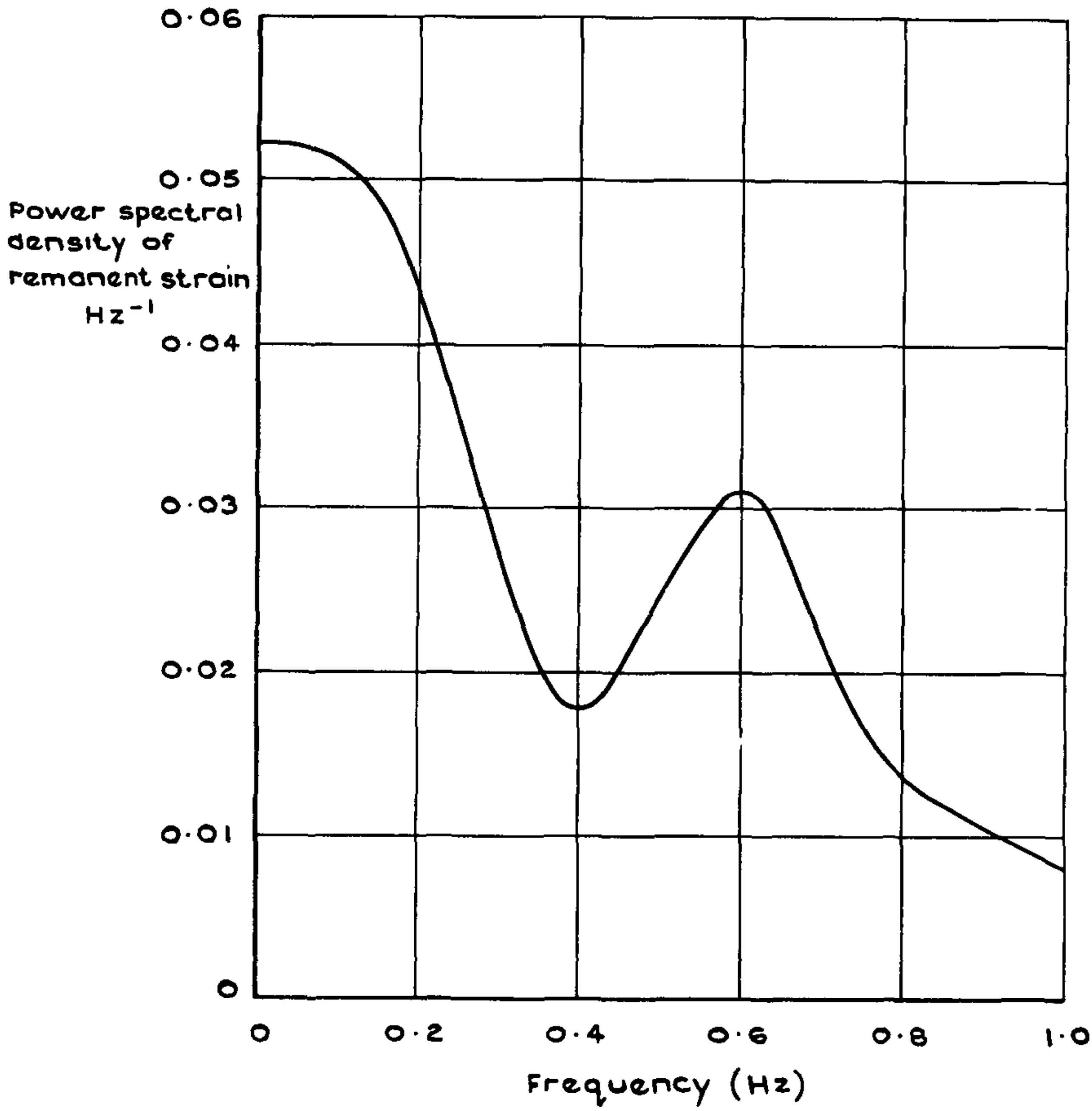

Fig.3 Power spectrum – remanent strain

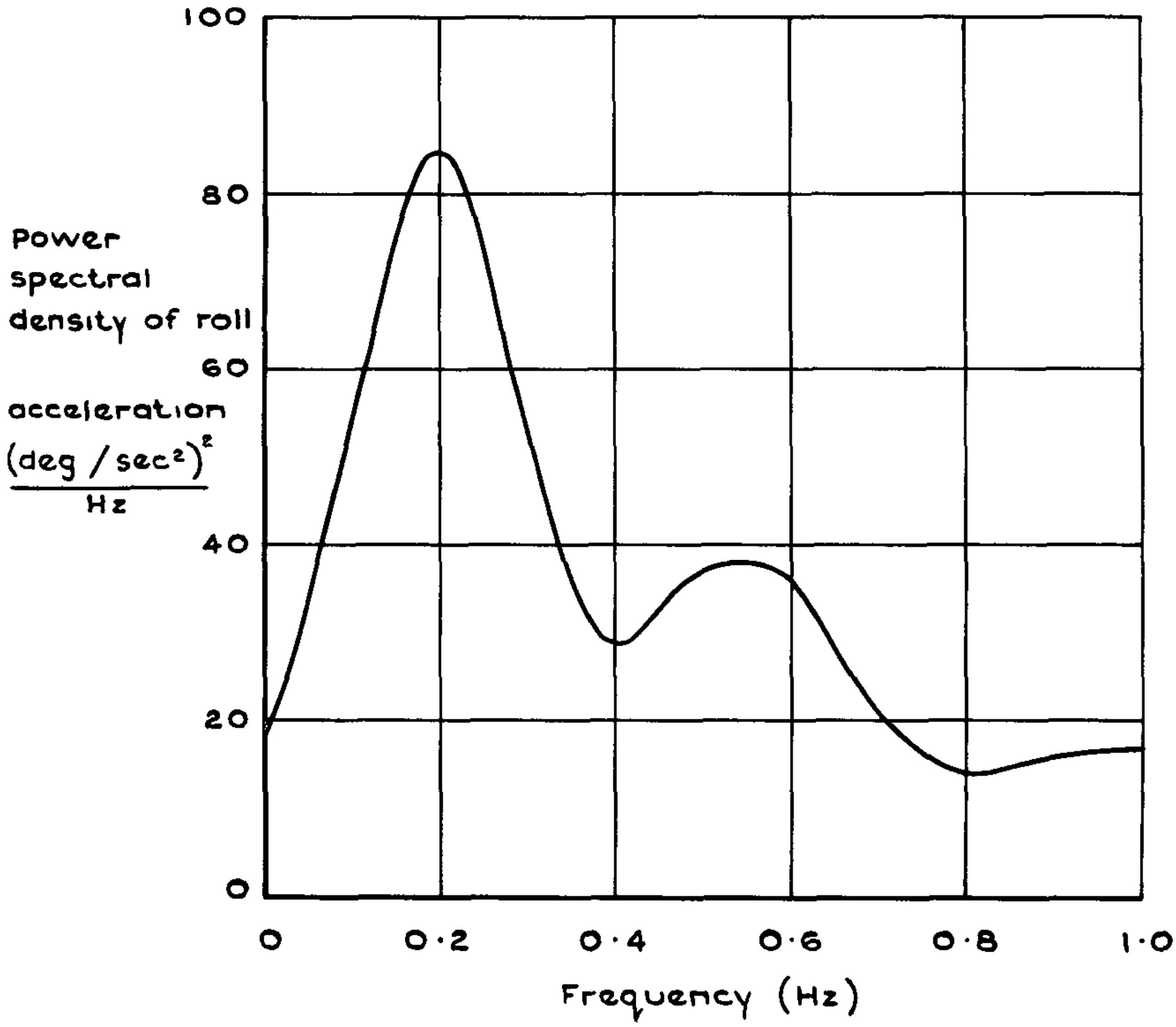

Fig. 4 Power spectrum – roll acceleration

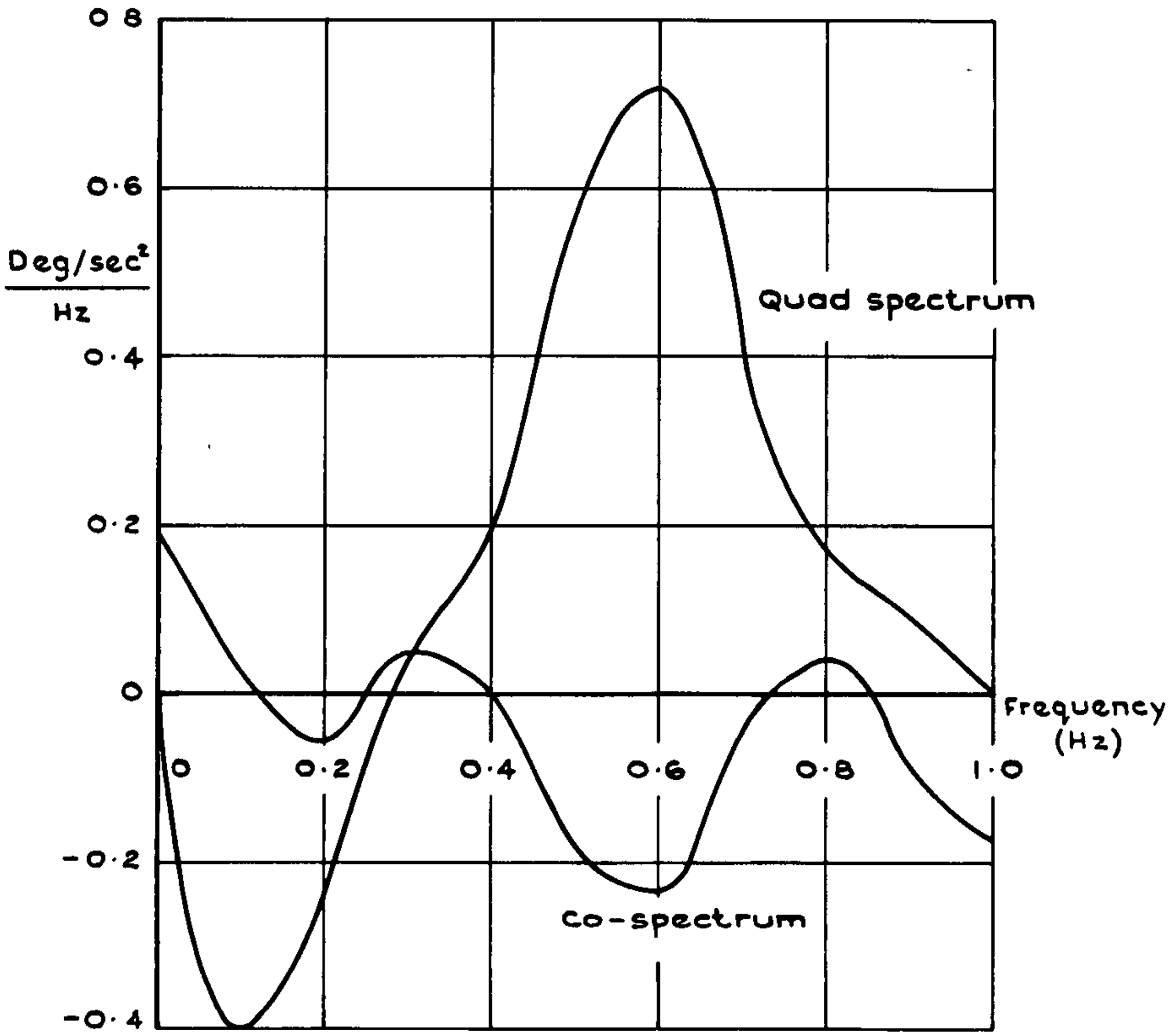

Fig. 5 Co-spectrum and Quad spectrum. Remanent strain and roll acceleration

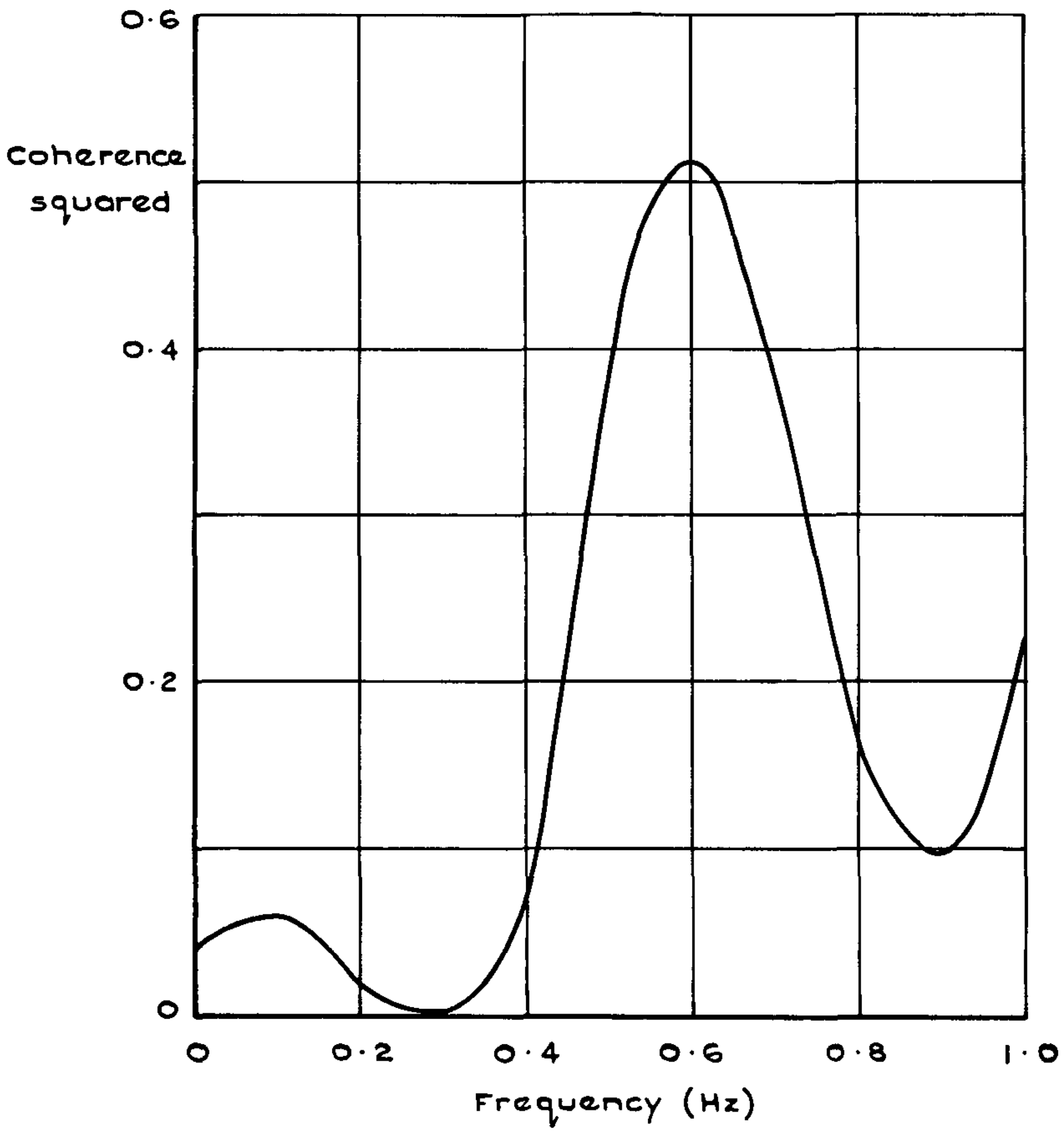

Fig. 6 Coherence squared. Remanent strain and roll acceleration

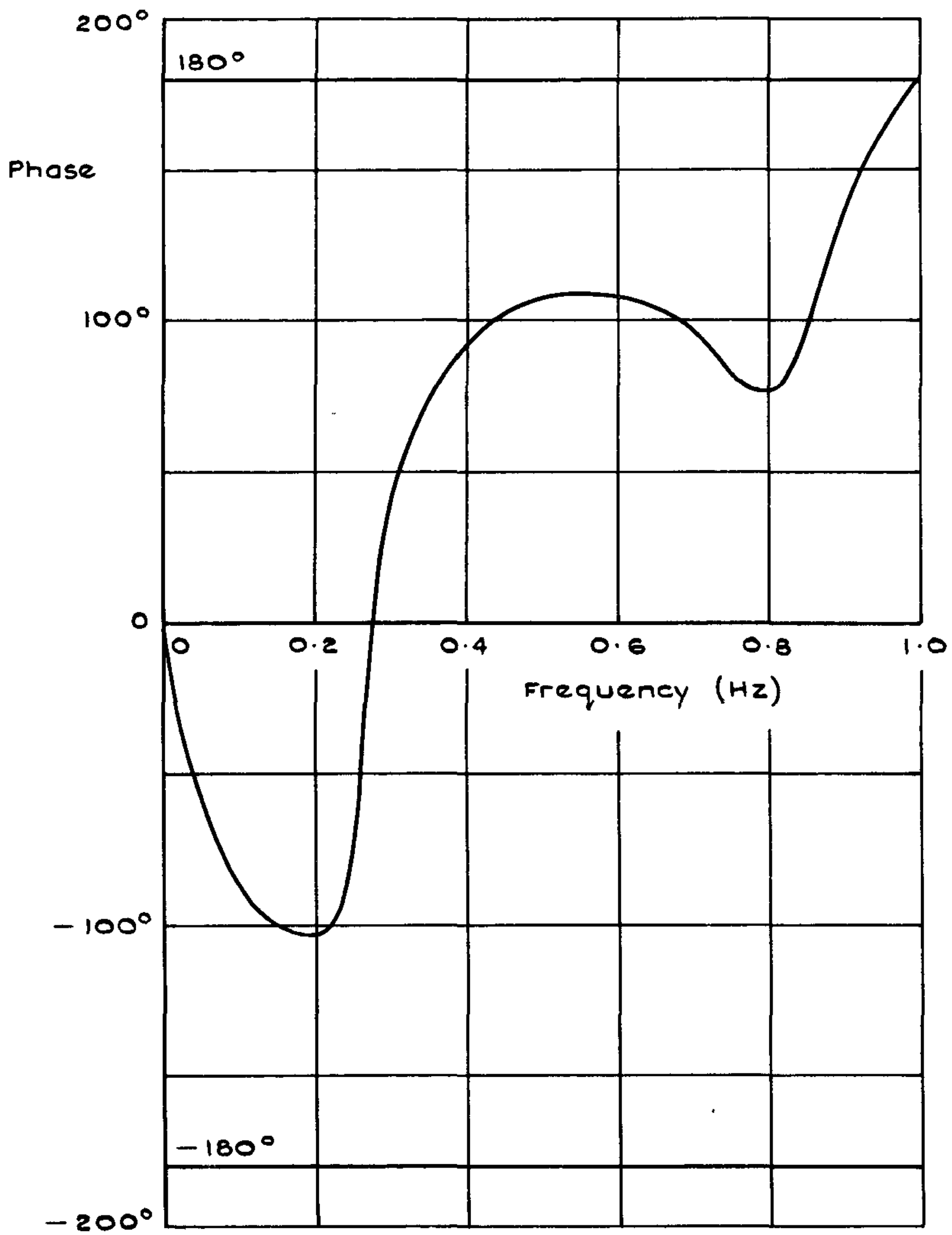

Fig.7 Phase. Remanent strain and roll acceleration

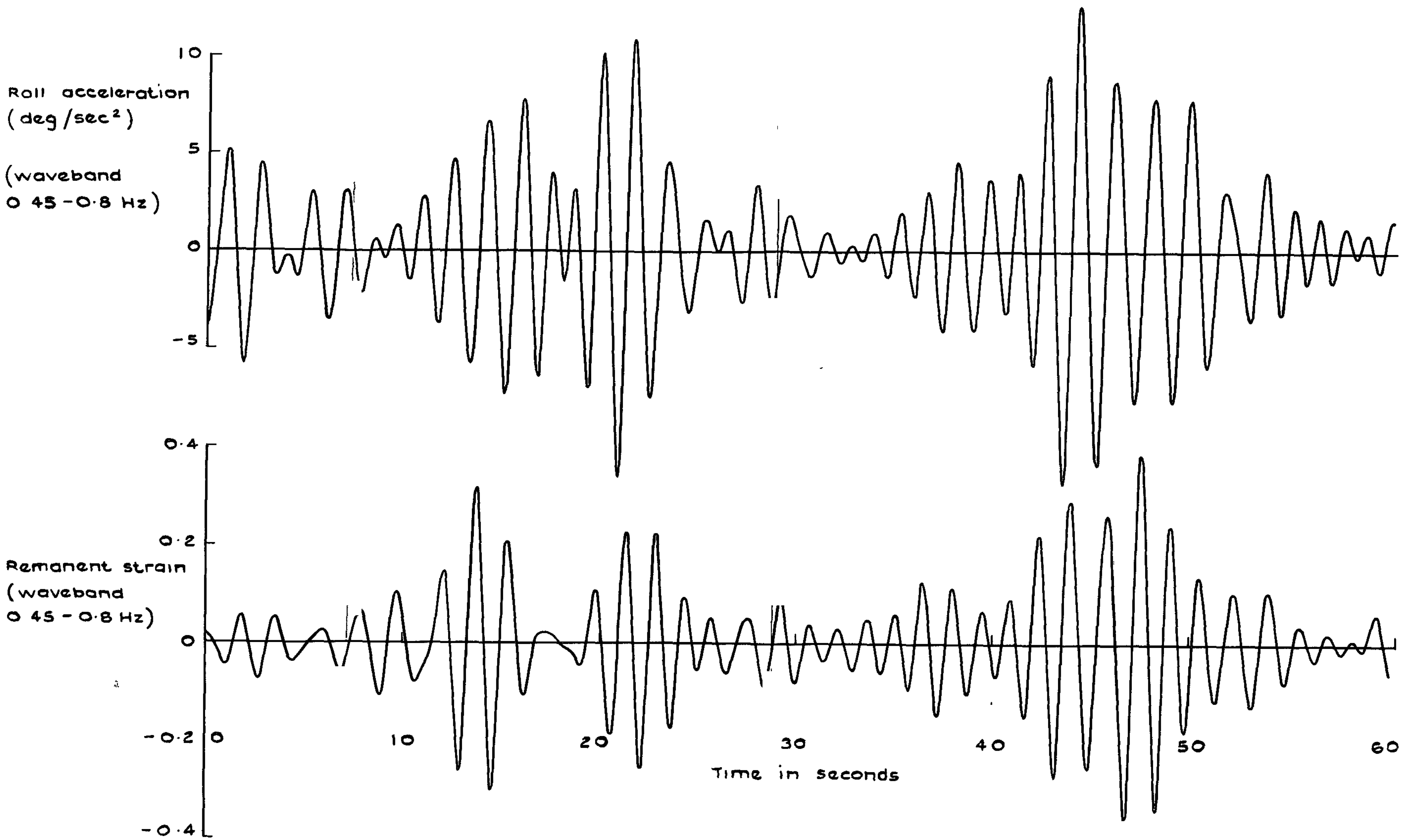

Fig. 8 Remanent strain and roll acceleration after filtering. Waveband 0·45 – 0·8 Hz

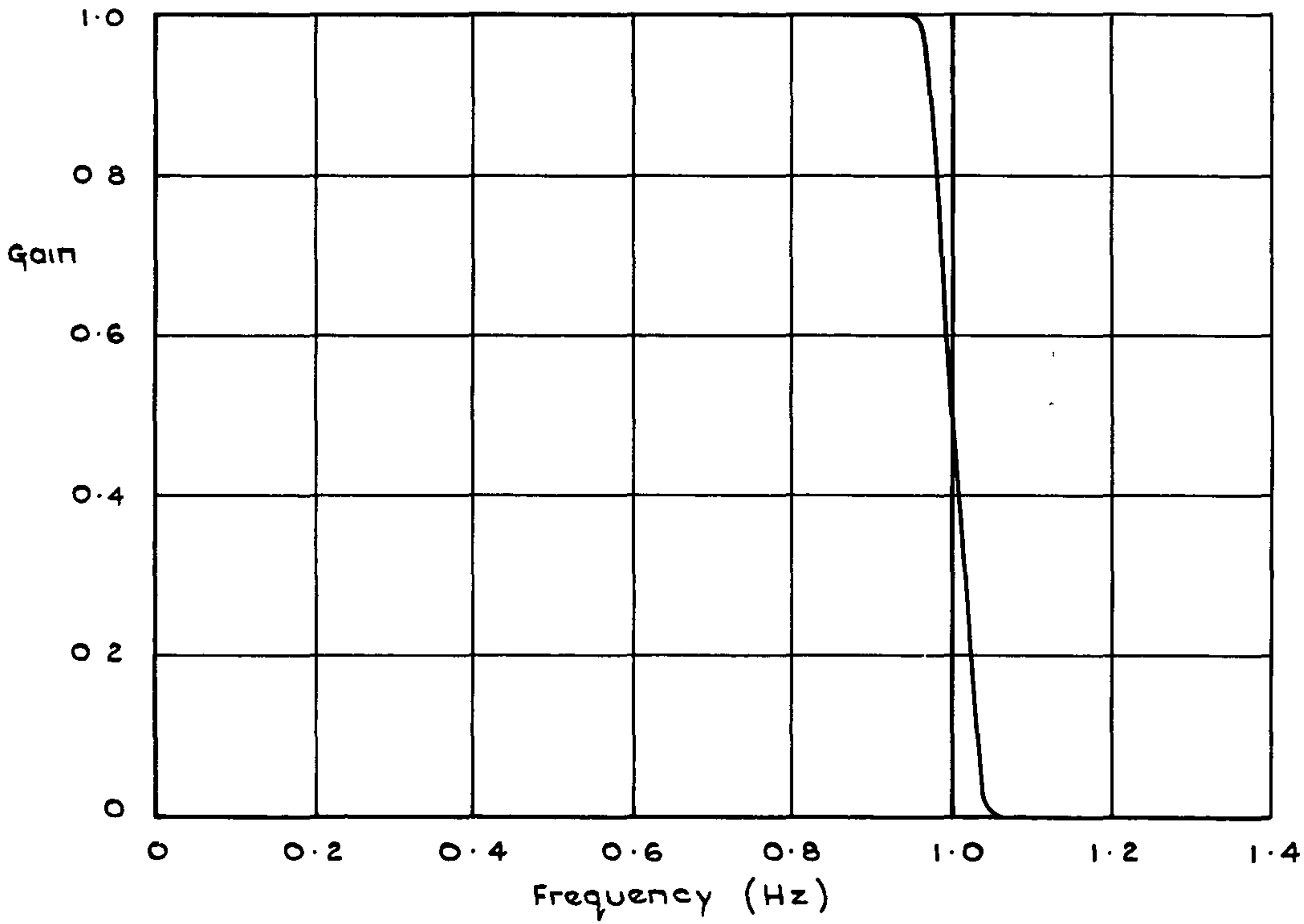

Fig.9 Filter gain. Low pass filter

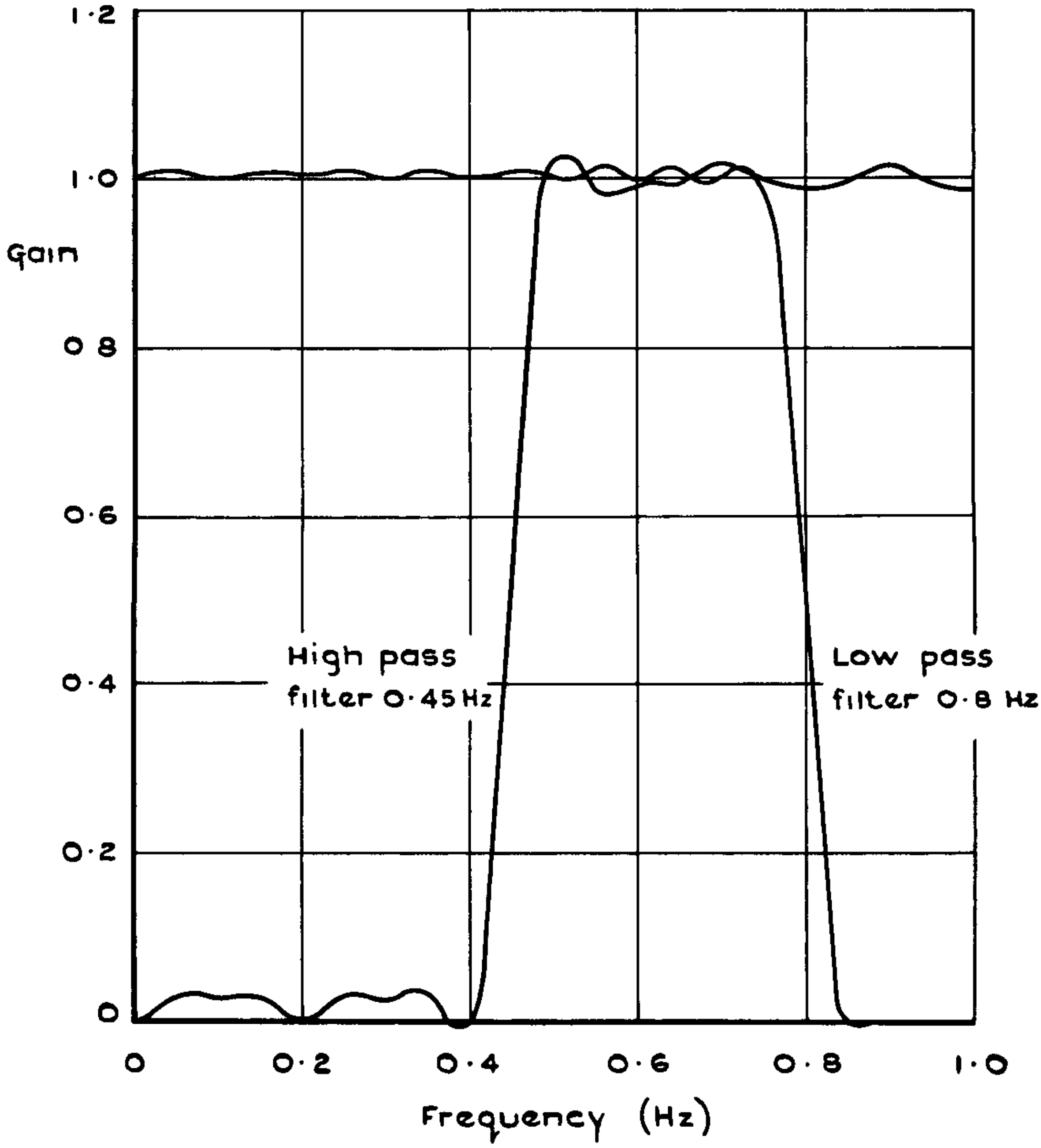

Fig. 10 High and low pass filters

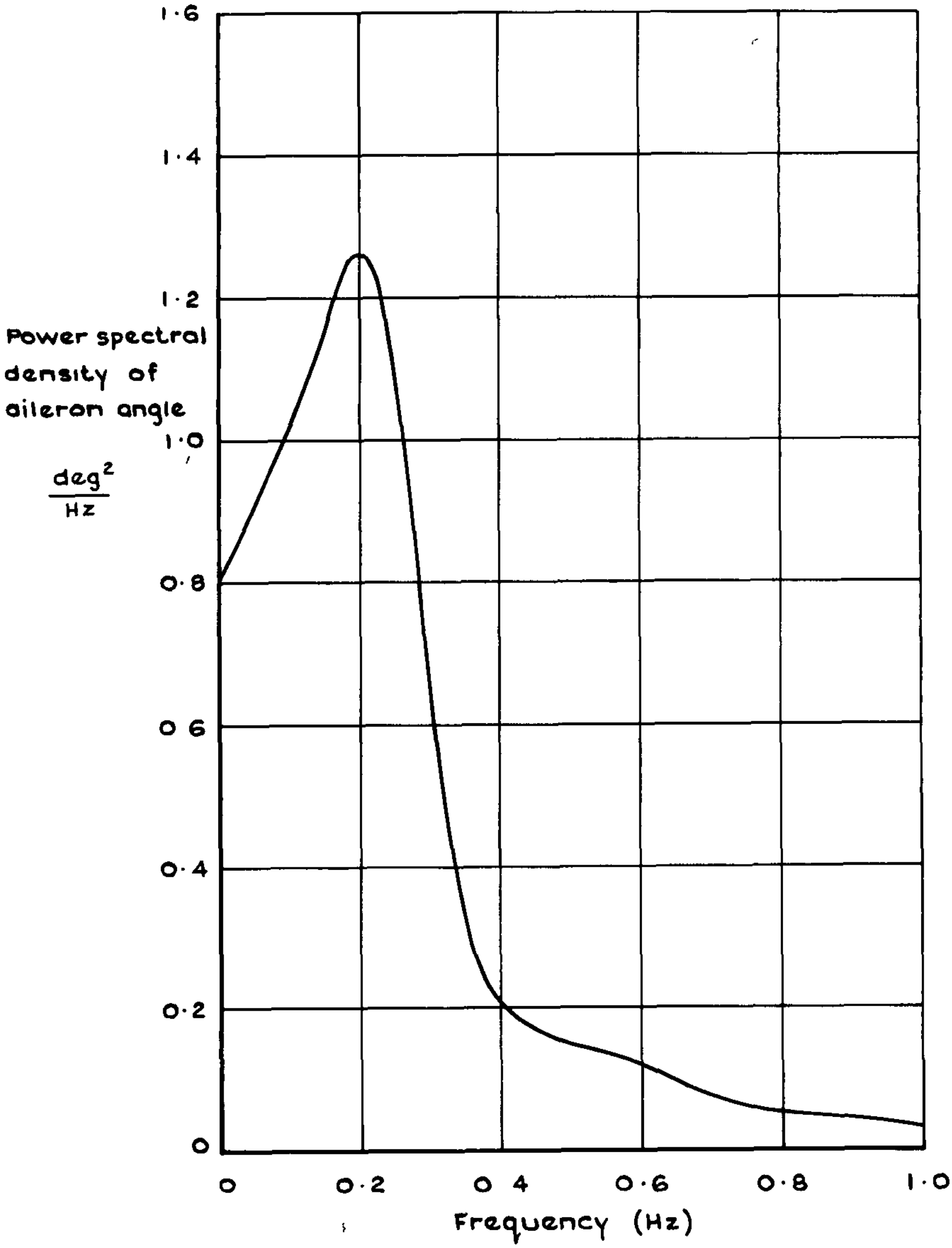

Fig.11 Power spectrum – aileron angle

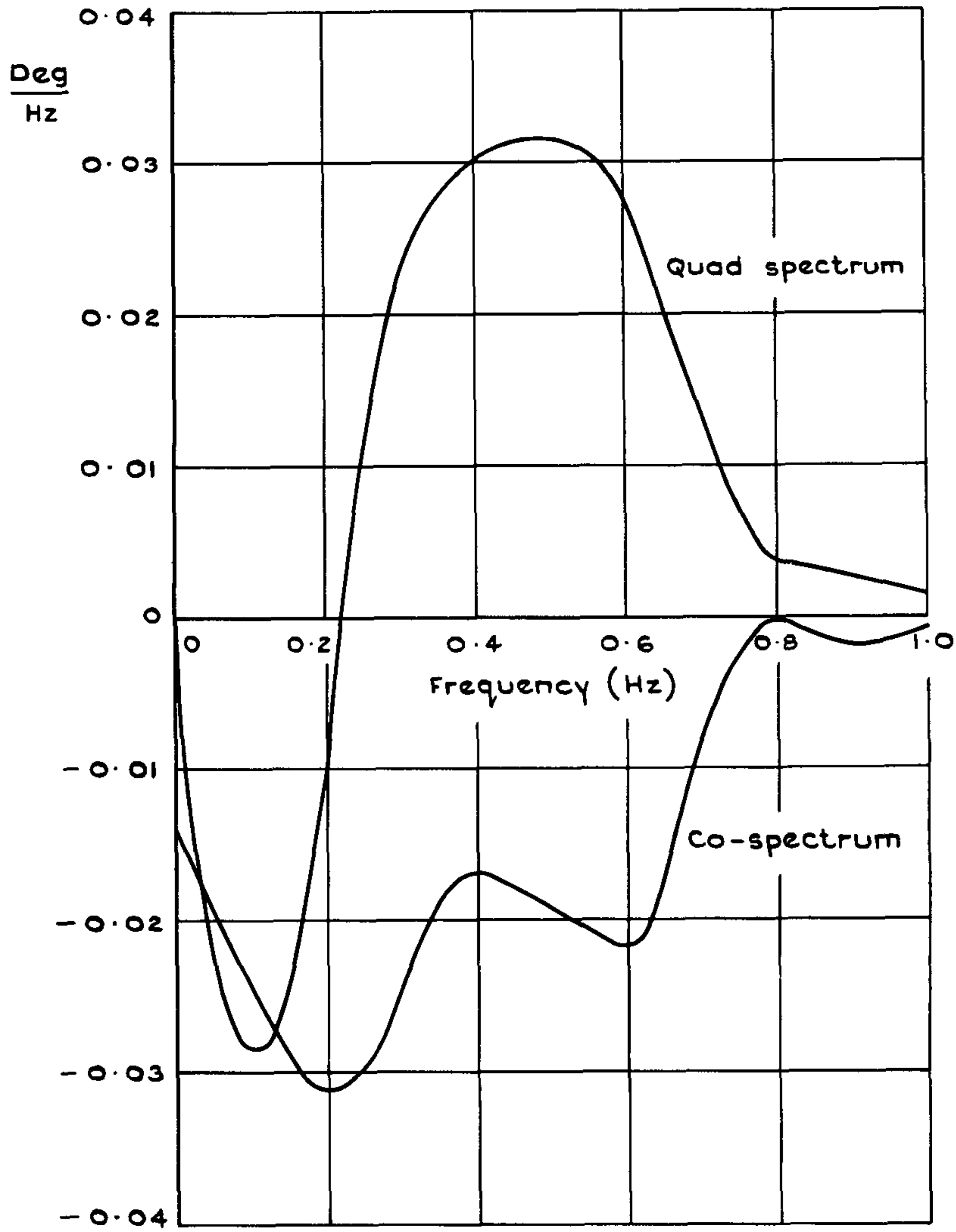

Fig. 12 Co-spectrum and Quad spectrum. Remanent strain and aileron angle

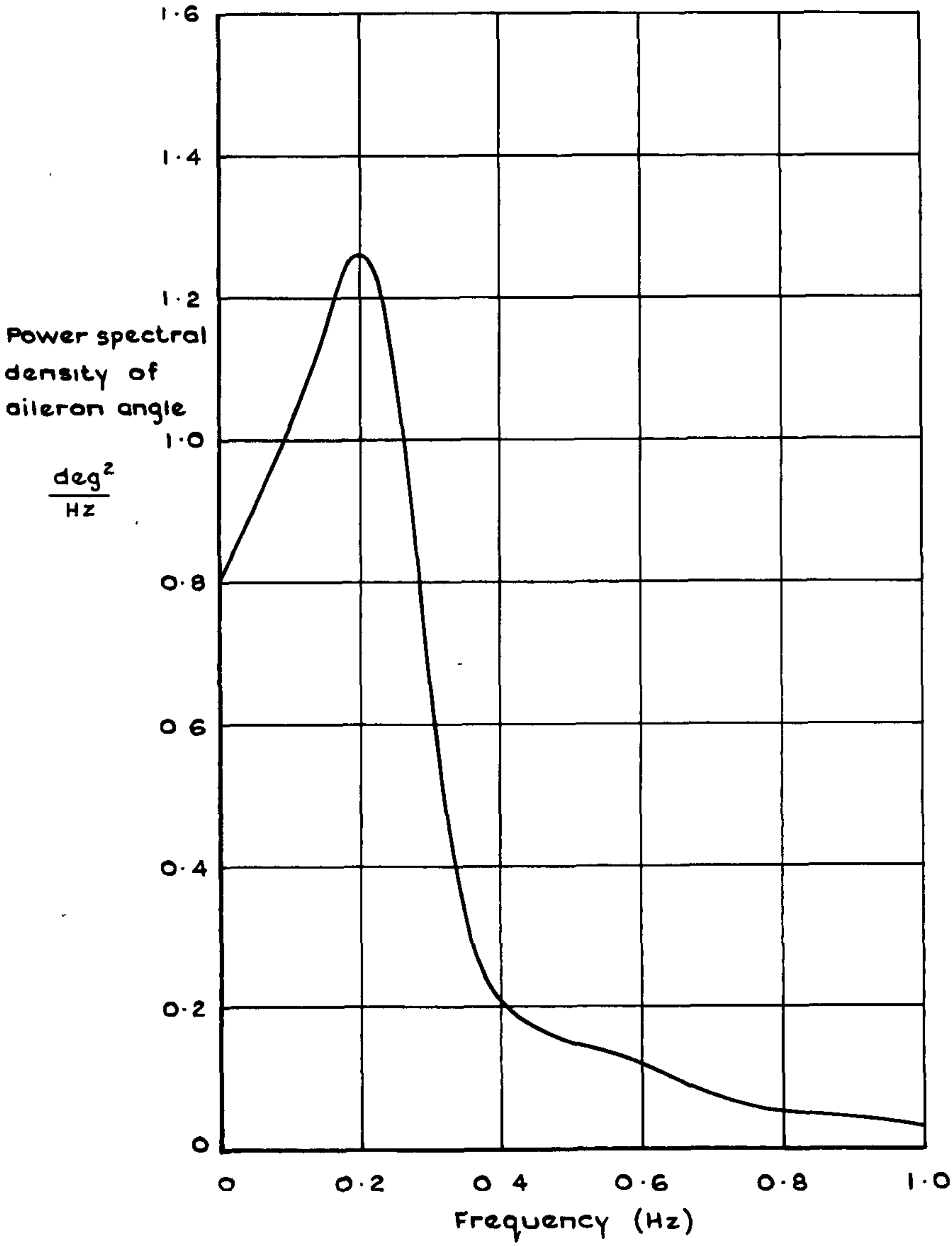

Fig.11 Power spectrum – aileron angle

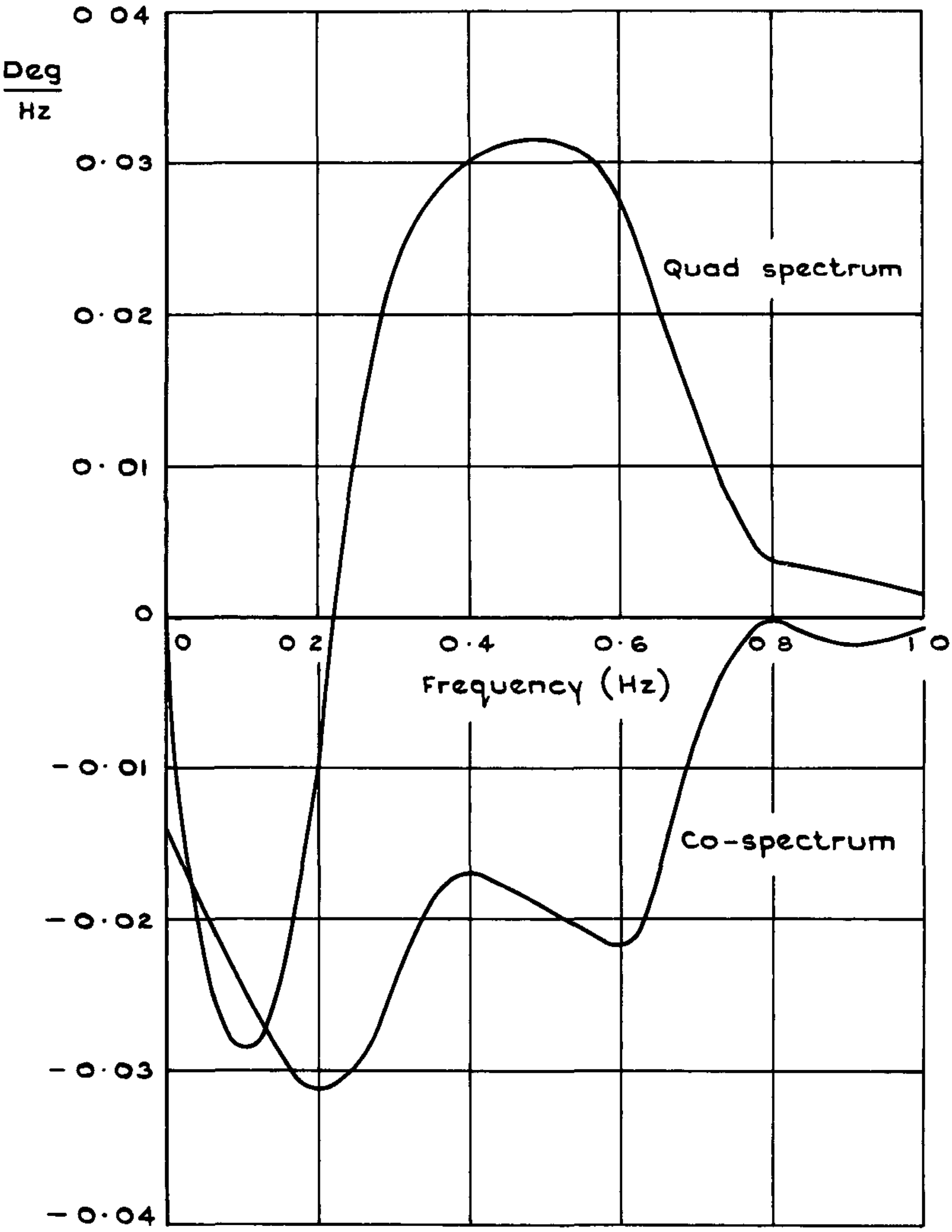

Fig. 12 Co-spectrum and Quad spectrum. Remanent strain and aileron angle

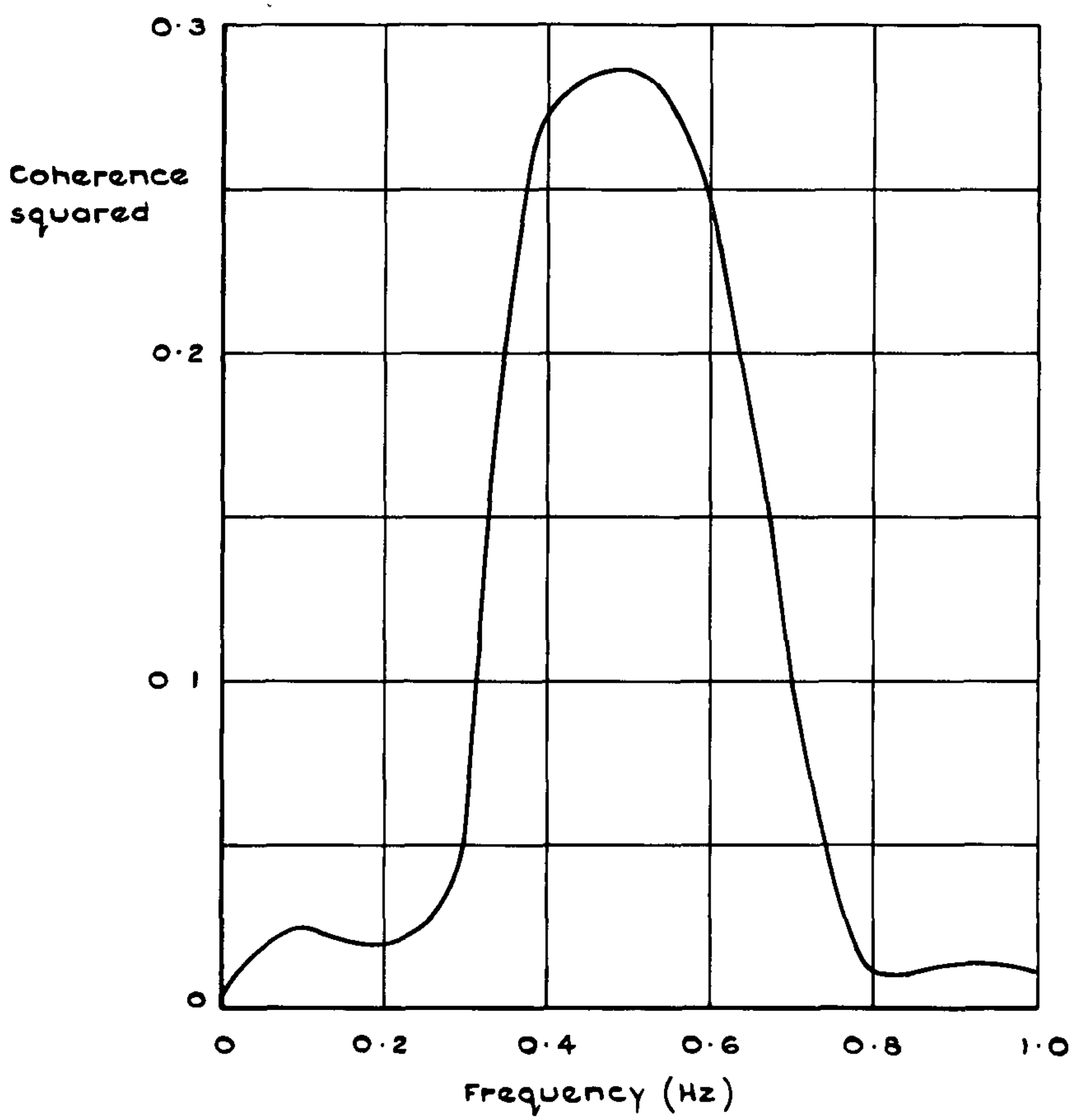

Fig.13 Coherence squared. Remanent strain and aileron angle

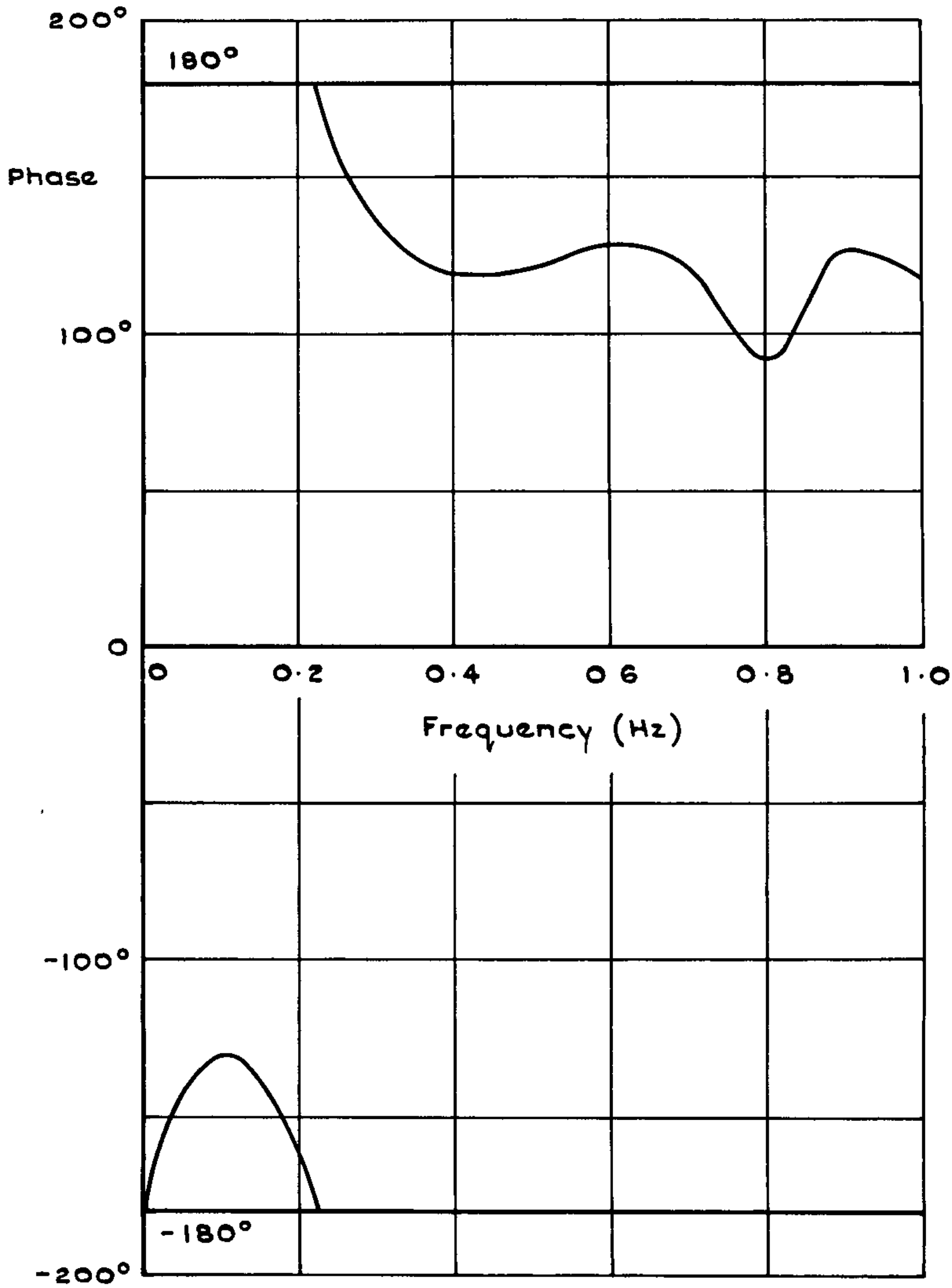

Fig.14 Phase. Remanent strain and aileron angle

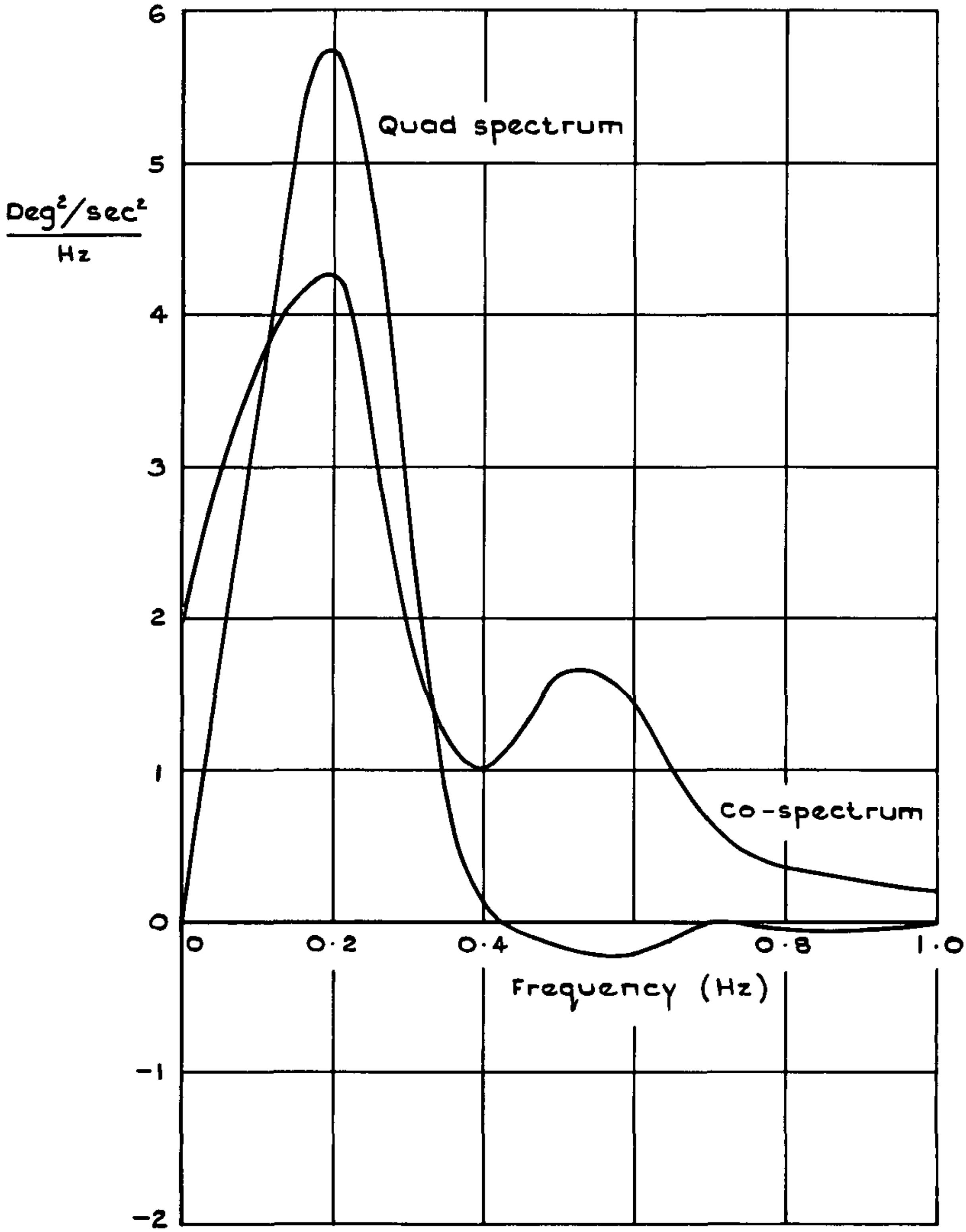

Fig. 15 Co – spectrum and Quad spectrum. Aileron angle and roll acceleration

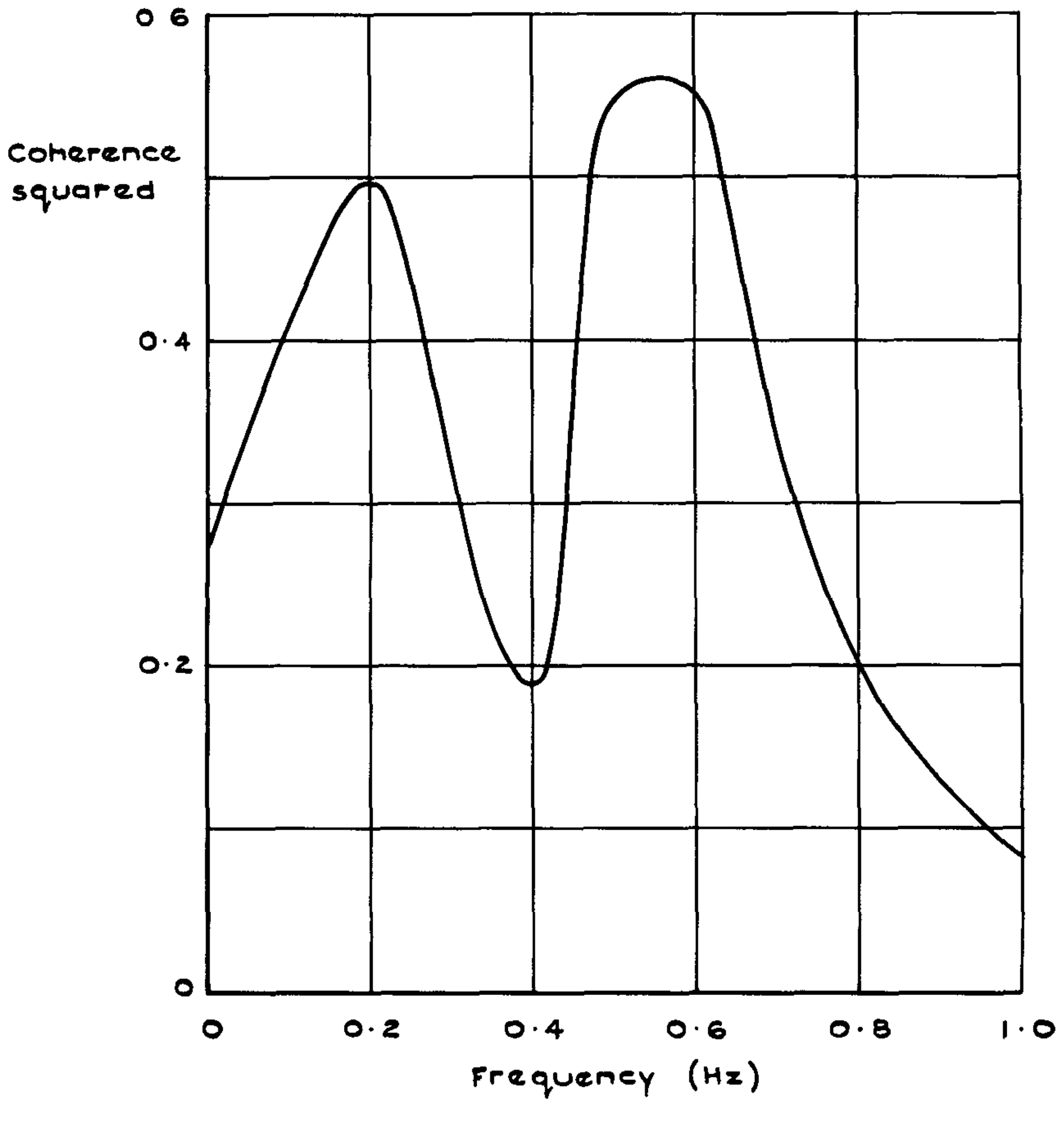

Fig.16 Coherence squared. Aileron angle and roll acceleration

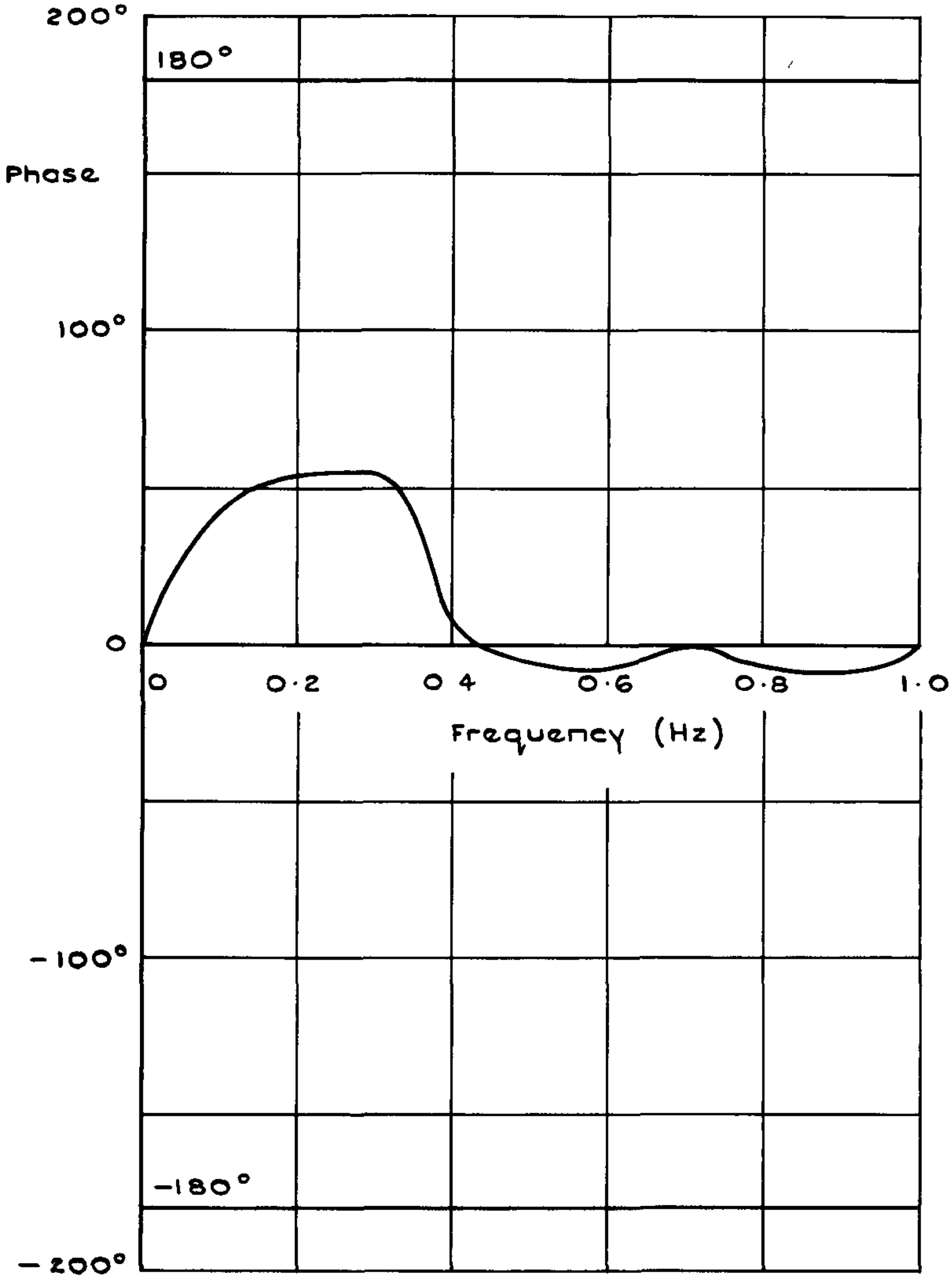

Fig. 17 Phase. Aileron angle and roll acceleration

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