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Normal Accelerations Measured in the Cockpit and at the C.G. of a Jet Transport Aeroplane during Flight through Rough Air

by

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NORMAL ACCELERATIONS MEASURED IN THE COCKPIT AND AT THE C.G. OF A JET TRANSPORT AEROPLANE DURING FLIGHT THROUGH ROUGH AIR

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SUMMARY

Normal accelerations covering frequency range between 0 and 10 cps have been measured in the cockpit and at the C.G. of the Comet 3B aircraft during flight at 230 knots through rough air at an altitude of 2000 ft. The rms acceleration in the cockpit was found to be about 15% less than that at the C.G. The reasons for this are investigated.

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1 INTRODUCTION

The accelerations experienced, during flight through rough air, in the cockpit of an aeroplane which has a long slender fuselage are likely to differ appreciably from those experienced at the aeroplane's centre of gravity[1]. A number of accidents and incidents which have occurred on the present day 'big jet'[2] in such conditions have increased the interest in the study of this aspect of flight dynamics. The cockpit acceleration environment is of interest from two points of view; possible physiological effects on the pilot and as a possible cause of malfunctioning of the cockpit instruments. Since little data is readily available, some measurements, which were made for a different purpose on the De Havilland Comet 3B, have been analysed. These consist of measurements of the normal acceleration in the cockpit and at the centre of gravity (C.G.). In the analysis, particular attention has been paid to the frequency content of these accelerations, and to the way in which it is related to the normal modes of vibration of the aircraft's structure.

2 DETAILS OF THE FLIGHT MEASUREMENTS

The data discussed here were measured in the De Havilland Comet 3B aeroplane, a photograph of which is shown in Fig.1. This aeroplane has a fuselage which is the same size as, but is of different stiffness to that of the Comet 4, and has the same wings as the Comet 4B. Comets 4 and 4C have wings of larger span which have fuel pods mounted on them. The fuselages of the Comets 4B and 4C are 7 ft 6 inches longer than those of the 3B and 4. The aircraft weight during the test was 43600 kgs.

The data analysed were obtained as a continuous trace record of normal acceleration in the cockpit and at the C.G. during a five minute run at 230 knots through rough air at a height of 2000 ft. The aircraft was in the 'clean' configuration and was under the manual control of the pilot. Examination of the trace record of elevator angle shows that such movements as occurred were slow and small.

The cockpit accelerometer was mounted 6 ft behind the pilots' seats and was displaced 2 ft 6 inches from the starboard side of the fuselage centreline. The C.G. accelerometer was within 1 ft of the actual centre of gravity of the aeroplane. Both instruments were mounted on the level of the cabin floor and were rigidly attached to primary structure. The actual instruments used were of the type described in Ref.3 and were such that the overall frequency response of the system comprising the accelerometer, demodulator and recording galvanometer was flat between zero and 12 c/s and the phase lag was linear with frequency over this range.

3 THE RESULTS OBTAINED

Examples of the time-histories of accelerations which were measured in the cockpit and at the C.G. are shown in Fig.2. From these it is apparent that the cockpit acceleration contains a component at around 4 c/s which is not readily apparent in that at the C.G., whilst the latter has components at around 2 c/s and 8 c/s which are not readily visible in the record obtained from the cockpit instrument.

To show more clearly the contributions of different frequency bands, spectral densities of the two accelerations have been computed from readings taken at 1/32 second intervals during the first 75 seconds of the measured time-histories. These spectra are shown in Fig.3. The spectral density of normal acceleration in the cockpit is less than that at the C.G. for frequencies below 1 c/s due to rigid body pitching of the fuselage. Dynamic aeroelastic effects begin to appear at about 1 c/s and are mainly responsible for the differences between the spectra at frequencies higher than this. Frequencies between 1 c/s and 2 c/s contribute more to the acceleration at the C.G. than to that in the cockpit but between 2 c/s and 7 c/s this situation is reversed. The relative contributions to the overall acceleration of the different aeroelastic modes, which are represented by the (larger) peaks in the measured spectra, can be seen in Fig.4. From this it is deduced that if the effects of the aeroelastic mode at about 2 c/s were removed from the C.G. acceleration, its rms would be reduced by about 20%. The actual rms due to this mode alone is about 65% of the total rms of 0.166g. Even if aeroelasticity did not occur, there would still be some acceleration spectral density at the higher frequencies due to rigid body motion. The 2 c/s mode contributes little to the acceleration experienced in the cockpit. The effect of removing the modes between 2.5 c/s and 7 c/s from the latter would be to reduce its rms by about 10%. The rms acceleration due to the mode at about 4 cps alone is about 45% of the total rms of 0.142g which was measured in the cockpit. The contribution of modes with frequencies greater than 7.5 c/s is small.

The way in which the differing response of the cockpit and C.G. are reflected in the average frequencies at which given acceleration levels are exceeded (crossed with positive slope) is shown in Fig.5. The data used in preparing this figure are those for the whole of the run. The probability distributions are not quite Gaussian and are slightly skew. The relationship between the distributions for the cockpit and C.G. accelerations, shows that there were a larger number of crossings of acceleration levels near the steady flight value in the cockpit than at the C.G., but a smaller number of crossings of the higher incremental acceleration levels, as would be expected[4,5] from their spectral densities.

4 DISCUSSION OF THE AEROELASTIC RESPONSE OF THE AIRCRAFT

With the aid of information on the normal modes of vibration of Comet aircraft which has been supplied by the manufacturer (Fig.6), it has been possible to determine which aeroelastic modes are responsible for the various peaks in the measured acceleration spectra shown in Fig.3. No aeroelastic information is available which relates directly to the Comet 3B aircraft used in the present tests. That shown in Fig.6, in the form of sketches of the deflection of the fuselage centreline in the first 5 symmetric modes, relates to theoretical estimates and measured ground resonance data for the Comet 4 (with wing fuel pods empty) and to theoretical estimates for the Comet 4B. Except where shown, there are no noticeable differences between the shapes given from the 3 sets of data as far as the fuselage deflection is concerned. The test aeroplane has the same wings as the Comet 4B but a fuselage 7 ft 6 inches shorter, it being equal in size but not in stiffness to that of the Comet 4. Precise agreement between the present measurements and this aeroelastic data would not, therefore, be expected.

A detailed examination of Figs.3 and 6 shows that:

(a) The difference between the cockpit and C.G. acceleration spectra between 1 c/s and 2 c/s is due to mode A, which is primarily the fundamental bending mode of the wing.

(b) The peak in the cockpit acceleration spectrum at around 4 c/s, which is much more pronounced there than in that for the C.G., is due to mode B, which is the fundamental bending mode of the fuselage.

(c) The peaks in the spectra at about 5.7 c/s are mainly produced by mode C, in which tailplane bending is predominant.

(d) The peaks in the spectra which occur at 7.2 c/s and 9.3 c/s are probably due to modes D and E. Which peak should be assigned to which mode cannot, however, be decided with certainty on the basis of measurements at only two points on the fuselage.

5 CONCLUSIONS

Measurements made on the Comet 3B aircraft, flying at 230 knots through rough air at a height of 2000 ft, show that the normal acceleration in the cockpit is somewhat less than that at the C.G., having an rms about 0.9 times that of the C.G. acceleration. This is due to the differing contributions, at these two points, of the first three modes of the aircraft response; the contribution of higher modes is negligible. In the first mode, rigid body pitching decreases the acceleration at all points ahead of the C.G., and thus in the cockpit. The second mode, which is the first aeroelastic one, is basically the wing fundamental bending mode (at about 2 c/s) which contributes very little to the acceleration in the cockpit but increases the rms C.G. acceleration by some 20%. The third mode, the fuselage fundamental at about 4.5 c/s, which from ground resonance tests appears to have a large cockpit to C.G. amplitude ratio (about 5) contributes appreciably, as would be expected, to the rms acceleration in the cockpit, (increasing it by about 10%) but does not make a noticeable contribution to that at the C.G. However, as the excitation of this mode does not appear to be large, the increase in cockpit acceleration due to it is not very great and the total rms cockpit acceleration remains less than that at the C.G.

As the aeroelastic response to atmospheric turbulance of a given mode depends on its damping and excitation, which in turn depend on the speed and height at which the aircraft is flying, these effects would have to be taken into account in any extrapolation of the present results to flight conditions which differ appreciably from those in which they were obtained.

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Fig.1 Test aeroplane

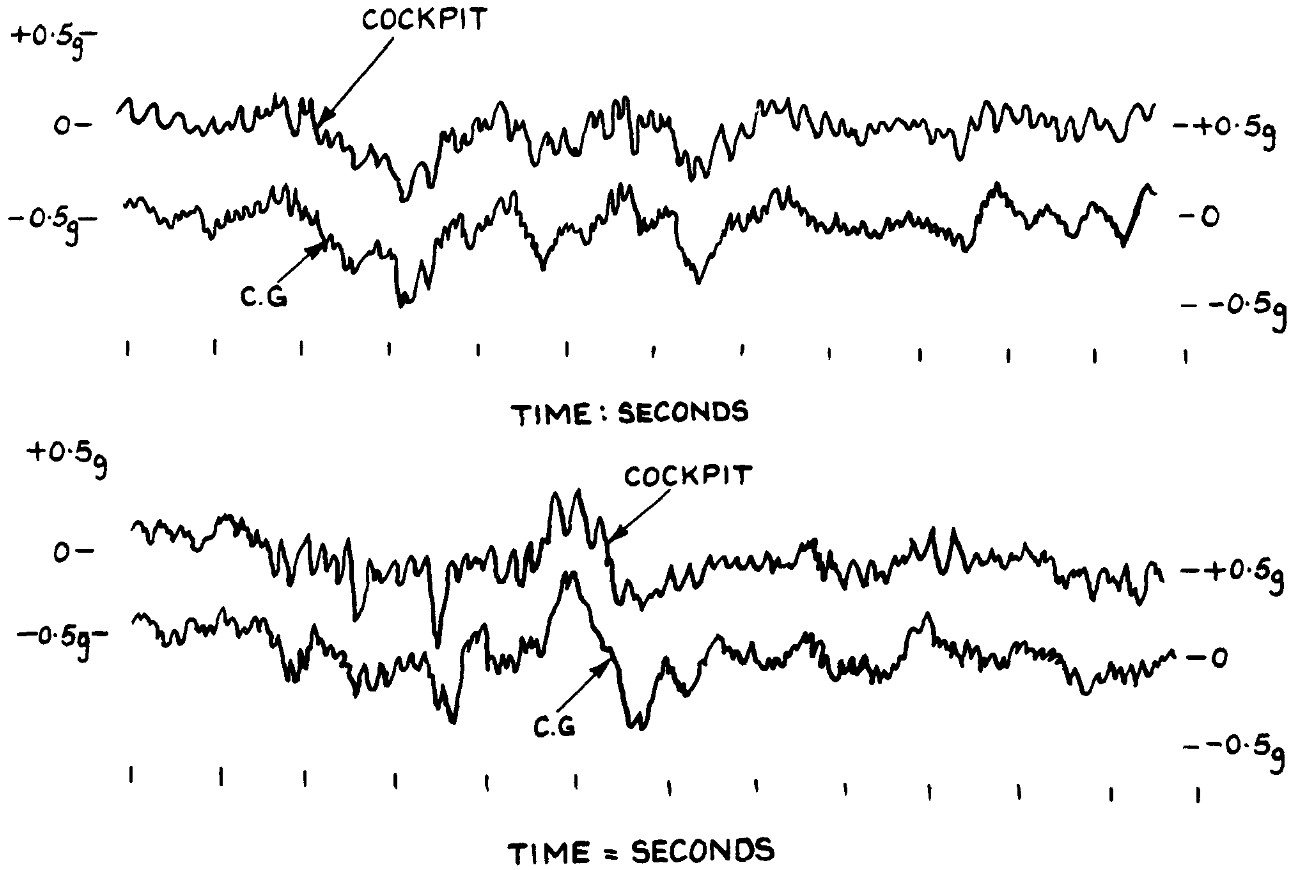

FIG. 2 EXAMPLES FROM TIME – HISTORIES OF NORMAL ACCELERATIONS MEASURED IN THE COCKPIT AND AT THE C.G.

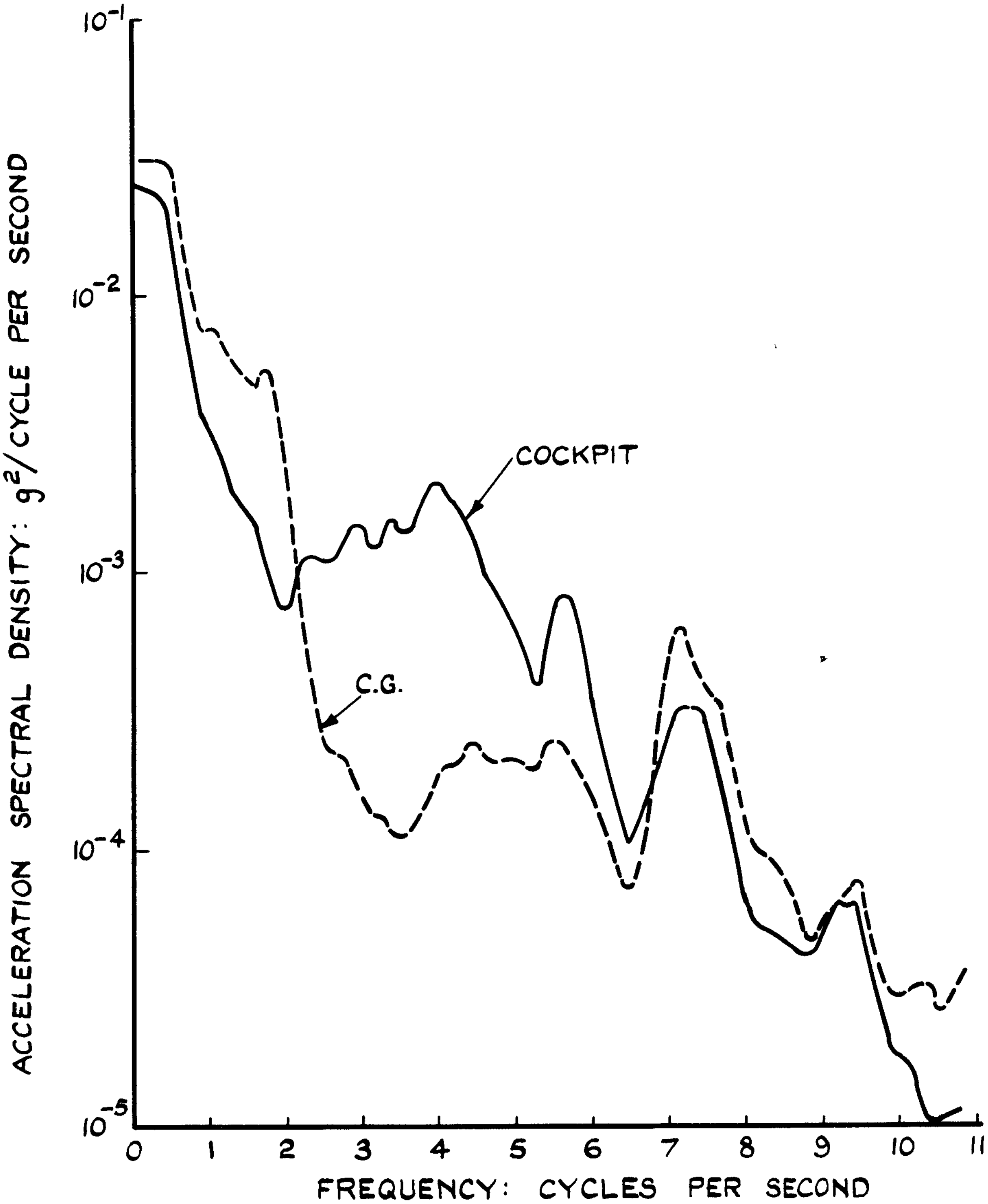

FIG. 3 SPECTRAL DENSITIES OF NORMAL ACCELERATIONS IN THE COCKPIT AND AT THE C.G.

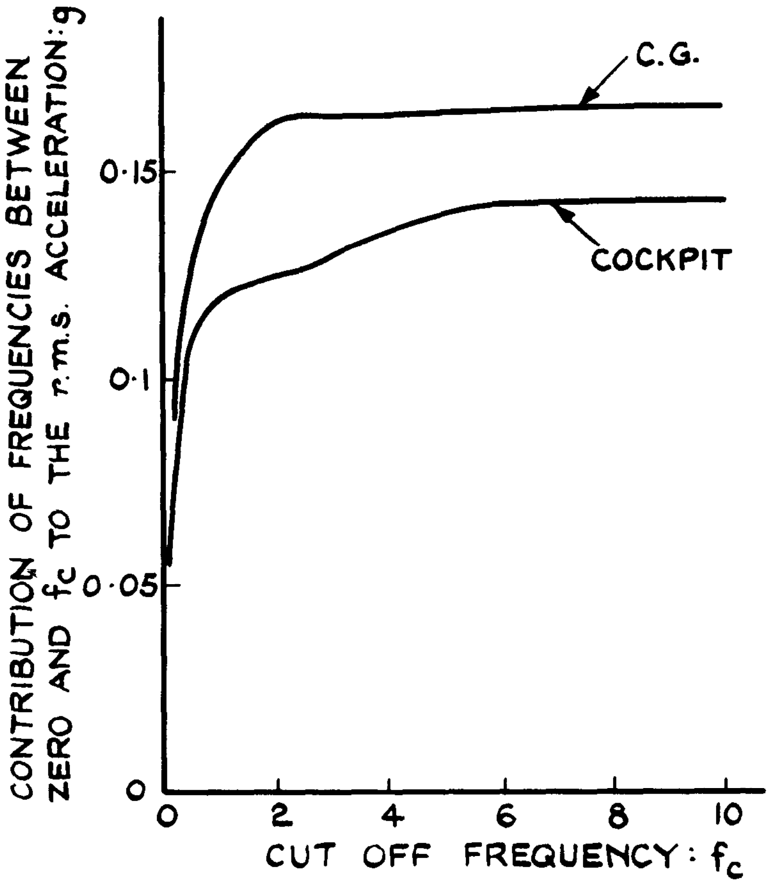

FIG. 4 THE CONTRIBUTION OF THE HIGHER FREQUENCIES TO THE r.m.s. ACCELERATION.

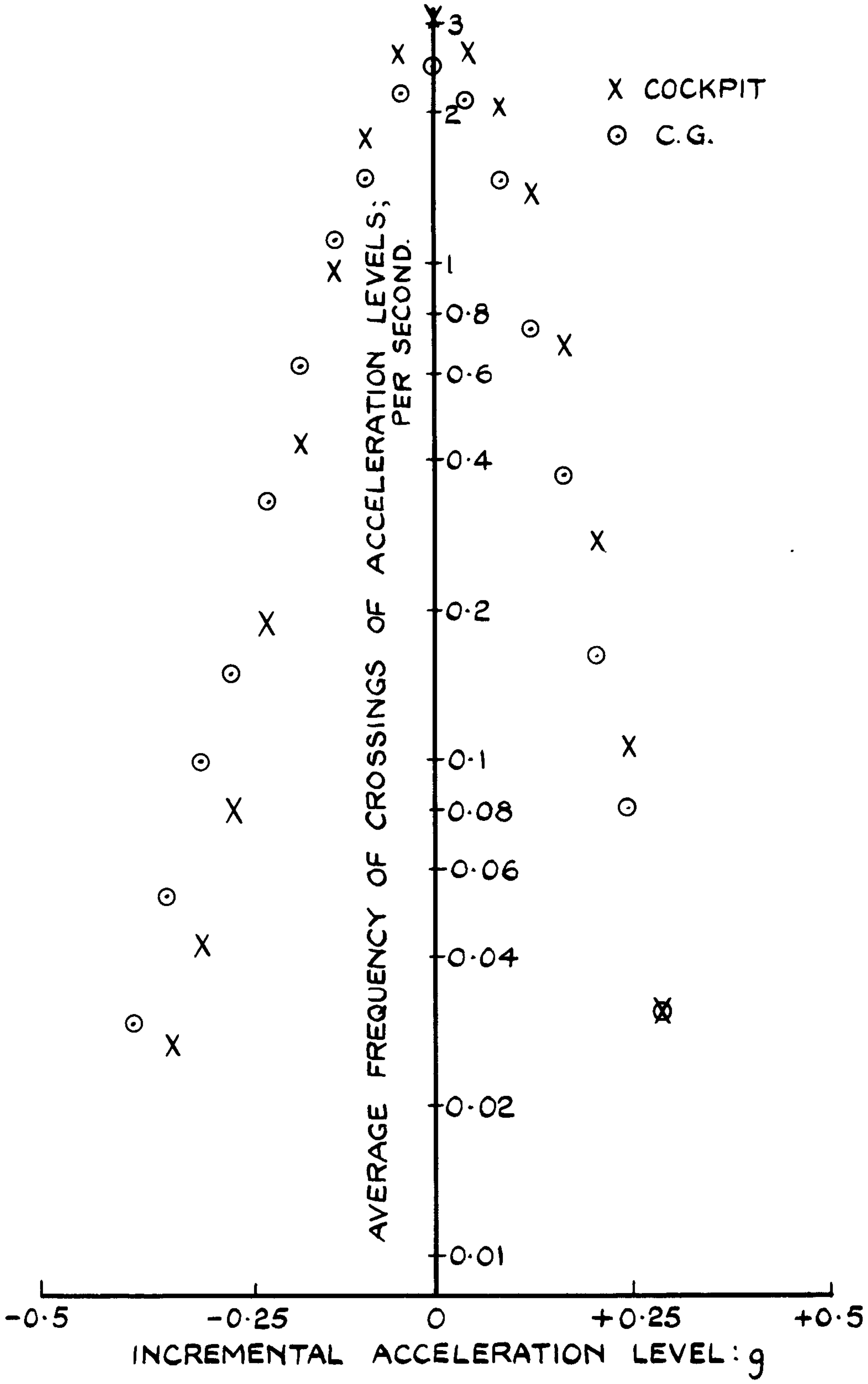

FIG. 5 AVERAGE FREQUENCIES AT WHICH ACCELERATION LEVELS WERE EXCEEDED IN THE COCKPIT AND AT THE C.G.

NATURAL FREQUENCIES (c/s)

MODE	COMET 4 THEORY	COMET 4 GROUND RESONANCE TEST	COMET 4B THEORY
A	2·0	2·1	1·8
B	4·5	4·6	4·4
C	6·6	6·2	6·9
D	8·4	7·7	9·5
E	8·6	8·8	8·4

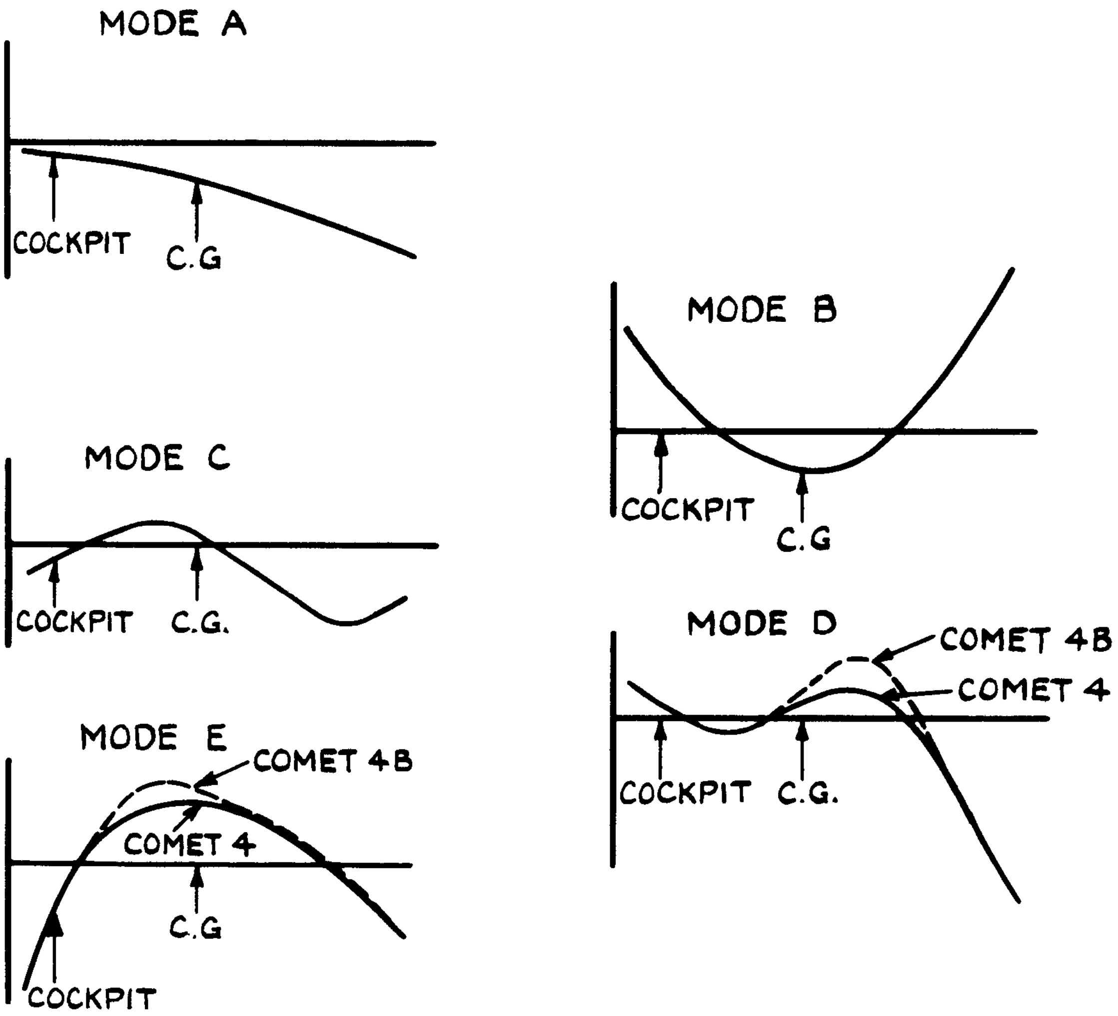

FIG. 6 SKETCHES OF THE DEFLECTION OF THE FUSELAGE CENTRELINE OF COMET AIRCRAFT IN THE FIRST FIVE SYMMETRIC MODES OF VIBRATION.

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