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Aircraft Structures Technical Memorandum 515

FLUTTER INVESTIGATIONS ON A TRANSAVIA PL12/T-400 AIRCRAFT (U)

by

A. GOLDMAN, C.D. RIDER and P. PIPERIAS

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FLUTTER INVESTIGATIONS ON A TRANSAVIA PL12/T-400 AIRCRAFT (U)

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A. Goldman, C.D. Rider and P. Piperias

SUMMARY

An isolated flutter incident was reported in 1986 involving violent oscillations of the rudder and tail boom. This report details the subsequent activity to find a solution to the problem, and the tests conducted to verify the effectiveness of the solution.

DSTO ARL MELBOURNE

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CONTENTS

1. INTRODUCTION

The Transavia T-400 Skyfarmer is the latest version of the twin-boom agricultural aircraft and incorporates several changes from the T-300 aircraft which has been in production since 1965.

Figure 1 shows the layout of the tail boom of the T-400 aircraft. The T-400 aircraft was first flown in 1984 and flutter clearance testing was completed that year (Ref. 1). During the flutter clearance programme, the aircraft was flown up to a speed of 160 knots and shown to be free from flutter, using what were considered at the time to be adequate means of excitation in flight.

In a subsequent ferrying flight in weather conditions which would not normally be experienced during agricultural work, an incident occurred which is believed to have been a limited amplitude flutter of the rudder and tail boom at a frequency around 3.5 Hz.

The Transavia test pilot, in subsequent tests, found that he could induce a similar oscillation by applying more than 50 percent rudder actuation in a series of quick jabs in alternate directions.

At this stage ARL was approached for assistance.

2. PROPOSED SOLUTION

The most obvious solution to a control surface flutter problem is to mass balance the control surface. This is especially the case when the control surface in question has no mass balance at all, and relies on the high frictional damping of the long control cables to prevent flutter under normal operating conditions.

Reliance on frictional damping has proved satisfactory on the earlier aircraft which have been operating for the past 20 years without incident. This earlier model, the T-300, has a tail boom bending frequency of 5 Hz.

Such a mass balance was fitted to the rudder of the T-400 using a single lump mass of 1.6 kg on a 250mm arm located on the inner side of each rudder. This gave a zero static balance.

3. FIRST FLIGHT TESTS

The aircraft, with the two mass balanced rudders, was flown from Sydney to Moorabbin airport for instrumentation by ARL staff. Accelerometers were located at eight positions on the starboard tail. These locations are listed in Table 1.

Figure 2 shows a block diagram of the instrumentation.

On the first flight, at an indicated air speed of 110 knots, the pilot was able to induce a limit-cycle oscillation of the tail by means of violent pedal oscillations. The vibration was self-sustaining and was only controlled by the pilot replacing his feet on the pedals to provide a restraining force.

Figure 3 shows the recorded data at 110 knots from the accelerometers on the fin and rudder. The amplitude indicated is acceleration measured in units of "g", "g" being the acceleration due to gravity and approximately equal to 9.8 metres/sec^2. The displacement is readily derived knowing that the frequency is approximately 4 Hz. The relationship between acceleration and displacement is:-

$D = A / 4\pi^2 f^2$ where
D is displacement
A is acceleration
f is frequency

The upper two traces show that the rudder oscillations applied, corresponding to 120 millimetres peak-to-peak amplitude measured at the trailing edge, were inadequate to overcome the frictional damping. When the applied amplitude exceeded 250 millimetres, the oscillations became self-sustaining as shown by the two lower traces.

The flight tests were suspended pending further investigations of the adequacy of the mass balance system.

4. GROUND VIBRATION TESTS

In order to evaluate the effectiveness of the mass balance weights attached to the rudders, a ground vibration test was undertaken. This demonstrated that the zero static balance was insufficient to prevent the rudder from moving in the wrong direction when subjected to large amplitude vibrations in the lateral direction at the boom bending frequency.

Figure 4 shows the two mode shapes of concern.

An additional mass of approximately 500 gms was attached to the existing mass to correct this deficiency. The change in lateral bending frequency in the fundamental mode was not detectable. The frequency of the second lateral bending mode also remained constant at 13.5 Hz. However, the resonant frequency of the mass balance arm itself was measured at 14 Hz vertically and 16.6 Hz horizontally. This was considered to be too low as there was some concern about the effectiveness of the mass balance in controlling the mode at 13.5 Hz, and a resonant frequency of 16.6 Hz in the mass balance arm could possibly cause problems. The requirement is that the frequency be at least 1.5 times the highest frequency that it may couple with (Ref. 2).

The hopper was loaded in stages up to 550 Kg. No significant change in the position of nodal lines was measured.

Because of the low frequency of the second lateral bending mode, some consideration was given to stiffening the boom in the lateral direction. The vertical bending modes have a higher frequency because of the large inverted V fairing along the top of the boom. Several methods were tried, in the laboratory on a spare tail assembly, including the use of stay wires from the tailplane tips to a point along the boom. None of the stiffeners worked well enough to be considered, and the stay wires, although very effective, were unacceptable.

A redesign of the mass balance system was suggested using two concentrated masses on stiffer arms placed on opposite sides of the rudder. On fitting the redesigned mass balanced rudder, the modal analysis indicated that the nodal line of the 13.5 Hz mode was still aft of the rudder hinge and the rudder would operate to attenuate the mode.

5. FLIGHT TESTS

Because the vibration mode causing the flutter problem had not been excited on previous flight tests (Ref. 1) when the excitation method had relied on turbulence and stick raps, a better form of excitation was considered necessary.

Violent pilot activation of the controls is not permitted above 110 knots for this aircraft and the flight test called for speeds up to 160 knots. An in-flight flutter exciter was required. In order to keep the system simple and safe, a small compressed air bottle of approx 1 litre capacity was used as the power source and was charged to 600 KPa with standard industrial compressed air. A small air drill was fitted with an eccentric mass, and the drill was attached to the tail boom using a bolt and two metal straps. Discharge of air from the bottle was by means of a solenoid valve controlled by a switch in the pilot's cabin. A single charge of air was enough to rotate the drill over a frequency range starting at approximately 18 Hz and falling to zero after approximately 10 seconds. On the ground this was seen to excite all the bending and torsion modes of the tail boom adequately. Figure 5 shows the exciter attached to the aircraft.

A series of flights was flown as listed in Table 2. Only one test point could be achieved on each flight because of the need to recharge the air bottle, and because it was considered prudent to analyse the data before proceeding to the next test point. Accelerometers were located at the positons indicated in Table 1.

The aircraft was flown with hoppers empty as the ground vibration tests had not indicated any significant differences, and a hopper full of powder may have added some frictional damping.

Analysis was carried out after each flight, and the series of flights was spread over four consecutive days.

6. ANALYSIS

After each test point, the recorded data were fed into a 4 channel Fast Fourier Transform (FFT) spectrum analyser.

Spectra were obtained of the acceleration of each location for a one minute period of flight relying on turbulence input plus the exciter store. Also, for the flights up to 120 knots, the response to pilot input to the rudder pedals was captured.

7. RESULTS

In Figure 3 it will be seen that it required a considerable input on the rudder to initiate a self-sustaining flutter. The amplitudes indicated on Fig. 3, and all other similar figures are in acceleration units.

Using the relationship shown in para. 3 it will be seen that it was necessary to oscillate the rudder through more than 250 mm peak-to-peak amplitude measured at the trailing edge. In the upper two traces of Figure 3 it will be seen that an amplitude of approximately 120 mm was inadequate excitation.

For dynamic balance of the inertia forces it is necessary to consider the acceleration experienced by the mass balance and the control surface, (Ref. 3). Referring to Figure 6, which represents the first bending mode of the tail boom, it will be seen that, for dynamic balance, the inertia force on the massbalance weight will need to equal the inertia force on the rudder.

The acceleration experienced by each component is approximately proportional to the distance of the centre of gravity of each from the centre of rotation of the mode under consideration.

Thus $m_b \; v \; L \; J \; m_r \; v \; (L + x + y)$

m_b is mass of balance weight
m_r is mass of rudder

If L is large, at least 10 times, compared with x and y the static balance is satisfactory. In this case, the centre of rotation of the rudder hinge is such that L is approximately 4 times x or y. Hence the need to consider the mode shape when balancing control surfaces.

Following the fitting of adequate mass balance to the rudder, it will be seen from Figures 7 to 11 that it was not possible to excite this mode of flutter with rudder oscillations up to 800 mm in amplitude. These amplitudes, of course, are in absolute terms and include the fin motion.

The large response, measured at most locations and test points, at a frequency of approximately 5 Hz, is a mechanical vibration originating at the engine. The vibration is non-sinusoidal as it also gives rise to the harmonics at 10, 15 and 20 Hz.

Figure 7 to 15 also show the results of FFT frequency analysis of the fin/rudder and tailplane/elevator combinations. The elevator and tailplane locations were included to ensure that no problems had been introduced in the vertical plane by the addition of the rudder mass balance system.

On flight 3 the tape recorder installed to record tailplane and elevator response failed to operate. The problem was corrected for all subsequent flights, and the indications from analysis of the data from flight 2 were such that it was not considered necessary to repeat that test point.

At no speed was there any indication of a mode of vibration becoming unstable or losing damping. The phase relationship between the fin and rudder shows some undesirable features around 13 Hz in flights 1 to 3 and again in flight 9. However, the associated vibration levels are so low that it is not considered to be a reliable indicator of a problem. That the exciter operated sufficiently to shake the structure was confirmed by the pilot's observation. The response to the exciter is only a fraction of that excited by the pilot's pedal operations at the lower speeds. However, it does indicate that the turbulence present in the atmosphere was equal to the exciter store. It would be unwise to consider the use of an exciter able to produce larger dynamic forces of a magnitude similar to the pedal oscillations described earlier.

8. CONCLUSIONS

The problem of tail boom/rudder flutter at 4 Hz in the T-400 aircraft has been satisfactorily solved using a simple split mass balance system. The aircraft has been flown to 160 knots and the use of all reasonable means of excitation has demonstrated that all modes of vibration have adequate damping.

This incident and the subsequent test programme highlight the questionable practice, followed in the past, of not using mass balanced control surfaces where there is a long control cable route which introduces high frictional damping. A loss of this damping, brought about by cable failure close to the control surface, would make the aircraft prone to serious flutter. Regular maintenance inspections have apparently prevented such an occurrence on the T-300 aircraft which have been in service for many years.

The problem of adequate excitation in flutter clearance flight testing is still present. In this case the use of a simple exciter goes some way towards ensuring that an input is provided to excite the structure. Whether pedal oscillations of the amplitude required to excite the flutter in the aircraft, when flown with the inadequate mass balance, are considered too violent for regular test procedures remains a point for discussion. No attempt has been made to induce any other form of flutter by oscillating other control surfaces at similar amplitudes.

REFERENCES

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A. Goldman and S. Galea, ARL-STRUC-TM-400, March 1985.

2. Advisory Circular - Means of Compliance with FAR 23.629, Flutter.
Department of Transportion, F.A.A., Washington, August 1979.

3. Mass-balancing of Aircraft Control Surfaces.
H. Templeton, Chapman & Hall, London 1979.

TABLE 1

Location of accelerometers for test flights

Rudder trailing edge	10 mm from trailing edge
Rudder leading edge	430 mm from trailing edge
Fin hinge line	530 mm from trailing edge
Fin/boom joint	1050 mm from trailing edge

The above 4 signals were recorded on one tape recorder.

Elevator trailing edge	150 mm from trailing edge
Elevator leading edge	370 mm from trailing edge
Tailplane hinge line	425 mm from trailing edge
Tailplane front spar	790 mm from trailing edge

The above 4 signals were recorded on one tape recorder.

TABLE 2

Test flight schedule

Flt	Date flown	Air Speed	Condition	Excitation
1	1 Mar 88	80 knots	Clear sky	Pedal Oscillations - 4 Hz Turbulence - 1 minute Exciter store - 10 secs
2	1 Mar 88	90 knots	Clear, calm	As above
3	2 Mar 88	100 knots	Clear, calm	As above
4	2 Mar 88	110 knots	Clear, calm	As above
5	2 Mar 88	120 knots	Clear, calm	Turbulence - 1 minute Exciter store - 10 secs
6	3 Mar 88	130 knots	Gusty	As above
7	3 Mar 88	140 knots	Gusty	As above
8	3 Mar 88	150 knots	Gusty	As above
9	4 Mar 88	160 knots	Low cloud	Exciter store - 10 secs Turbulence - 25 seconds

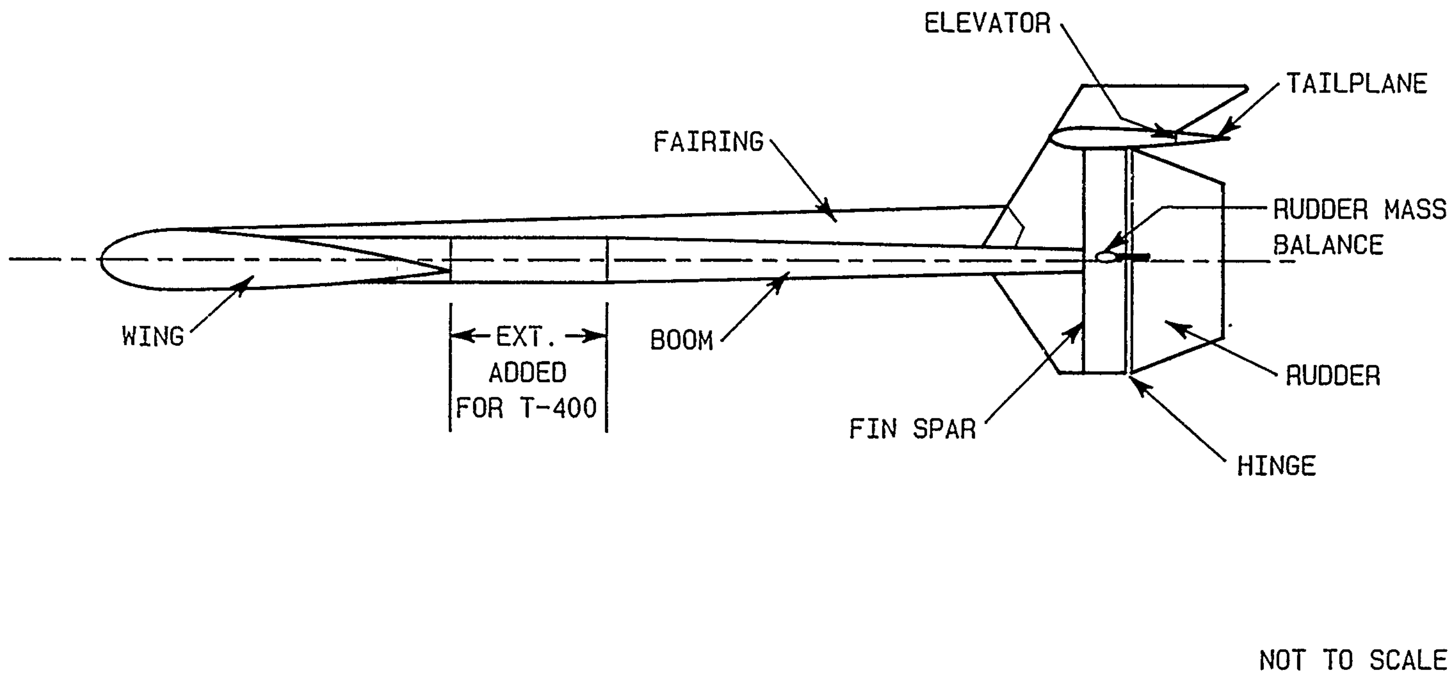


FIG 1. LAYOUT OF WING-BOOM-TAIL OF T-400

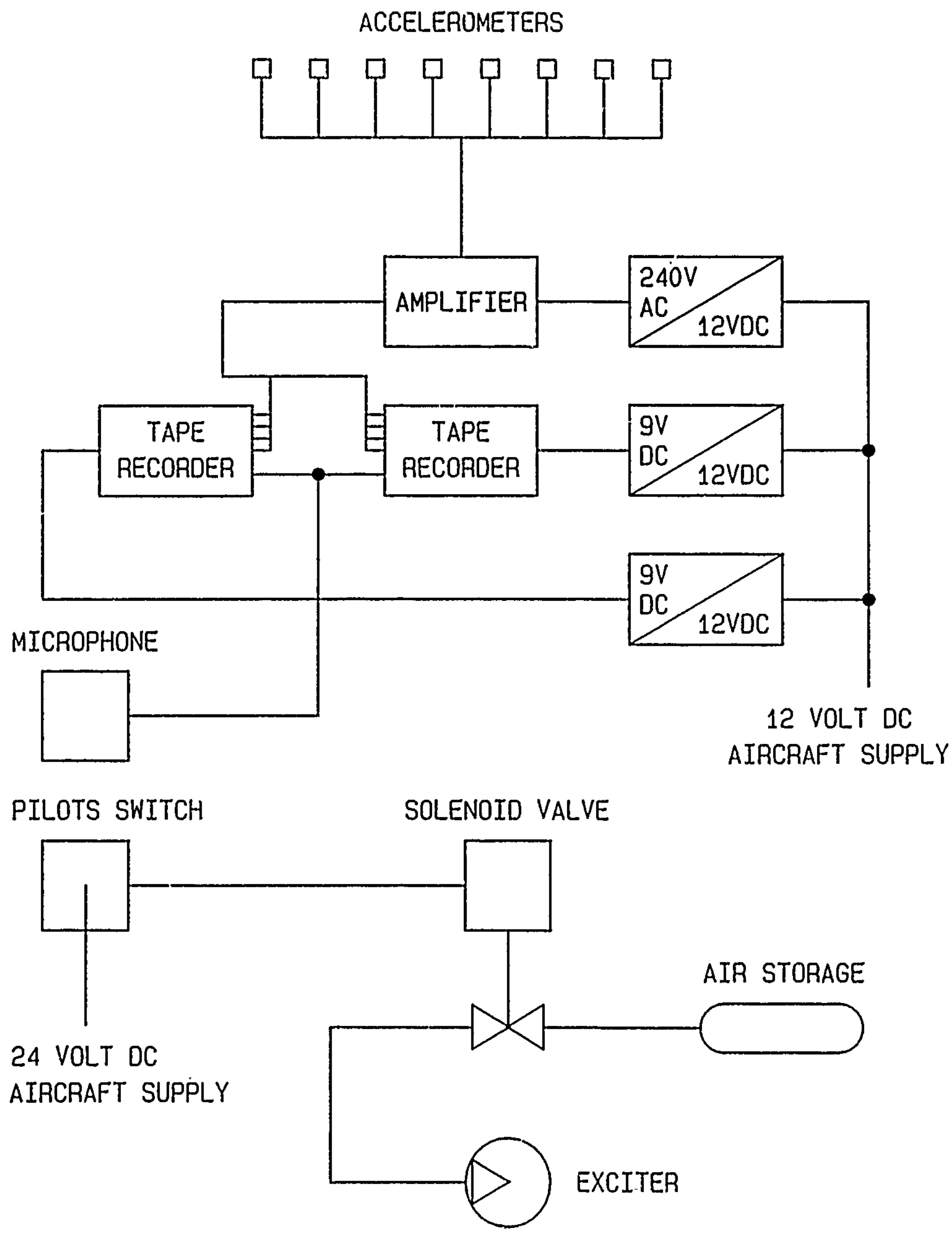


FIG 2. BLOCK DIAGRAM OF FLIGHT TEST INSTRUMENTATION

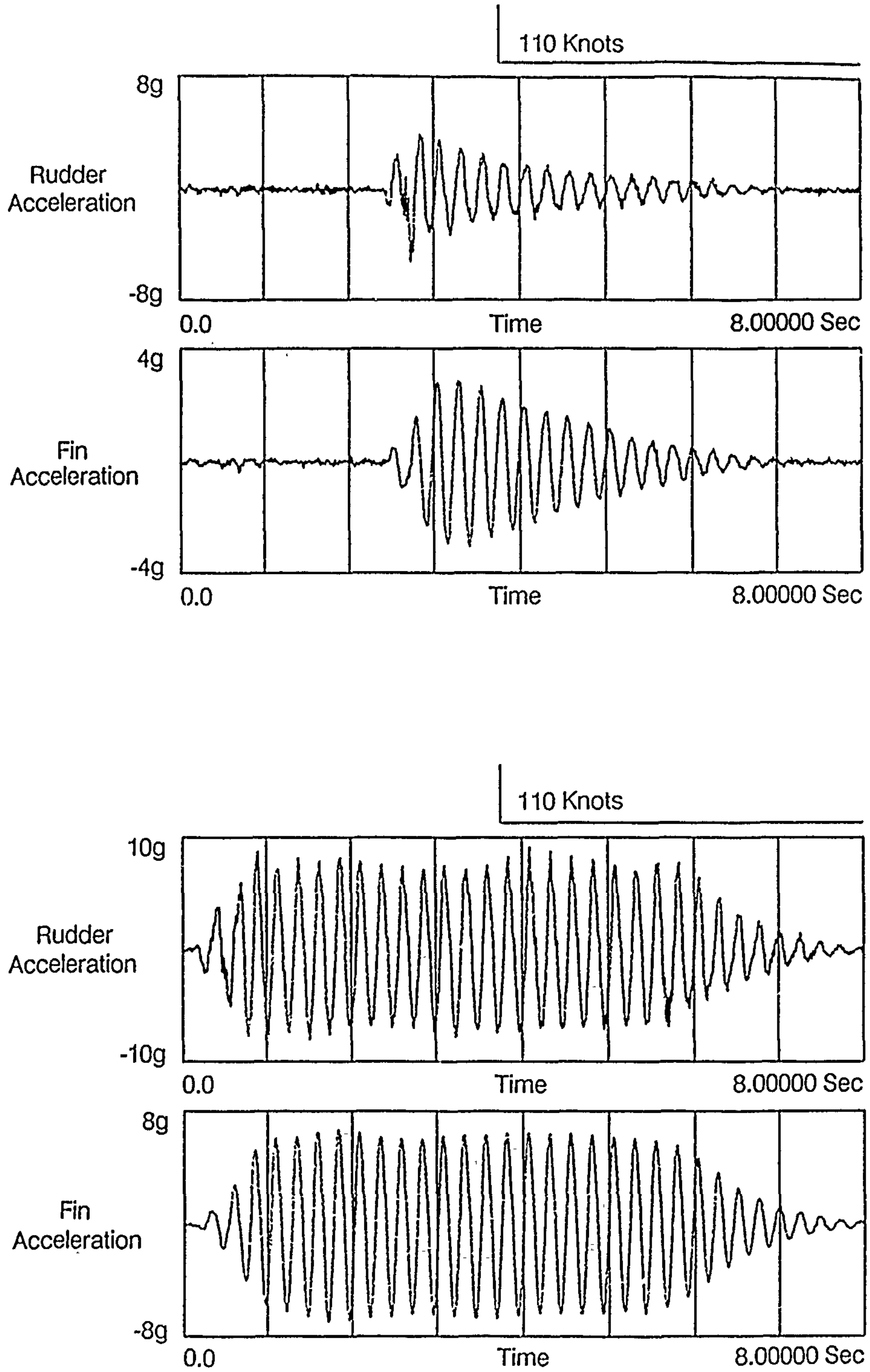
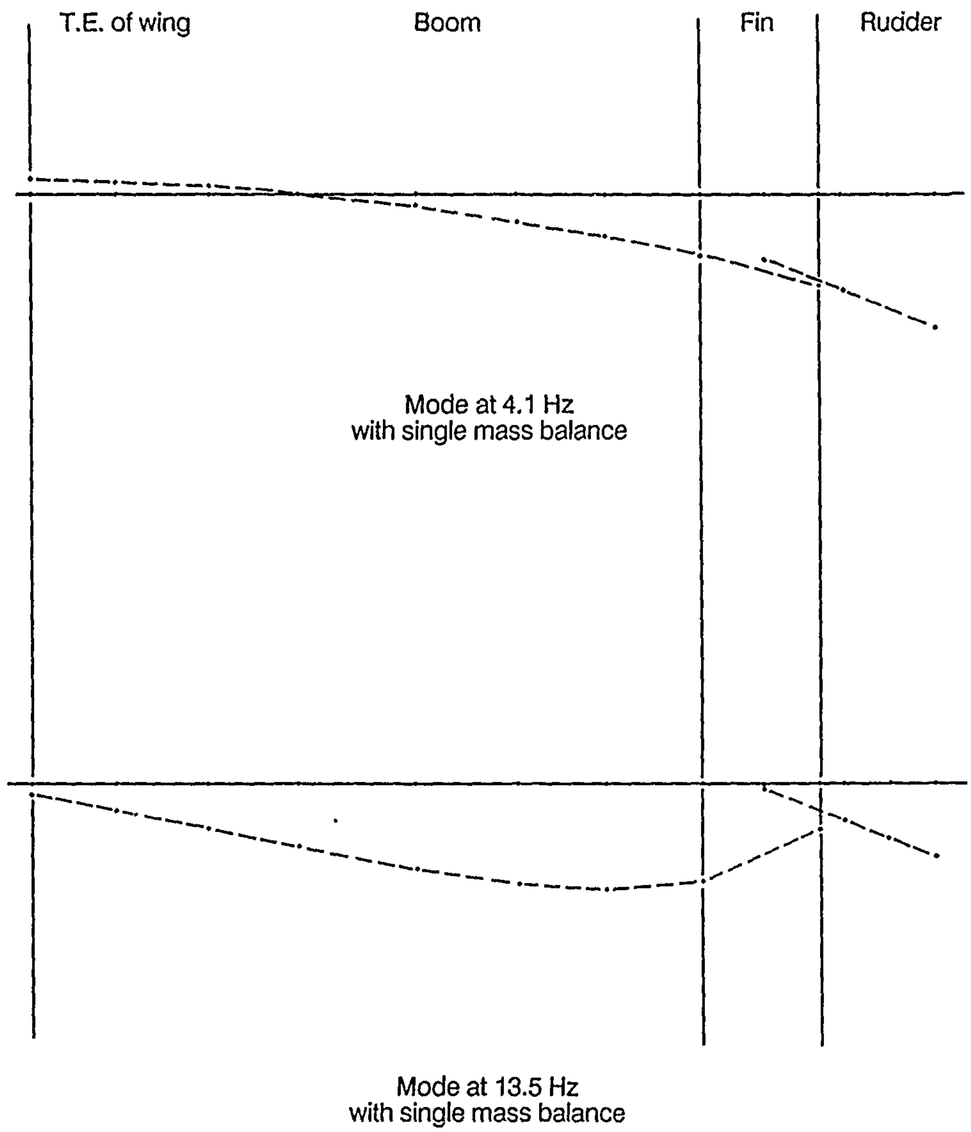


FIG 3. FLIGHT AT 110 KNOTS WITH INADEQUATE MASS BALANCE



Do not scale

FIG 4. LATERAL MODES OF VIBRATION

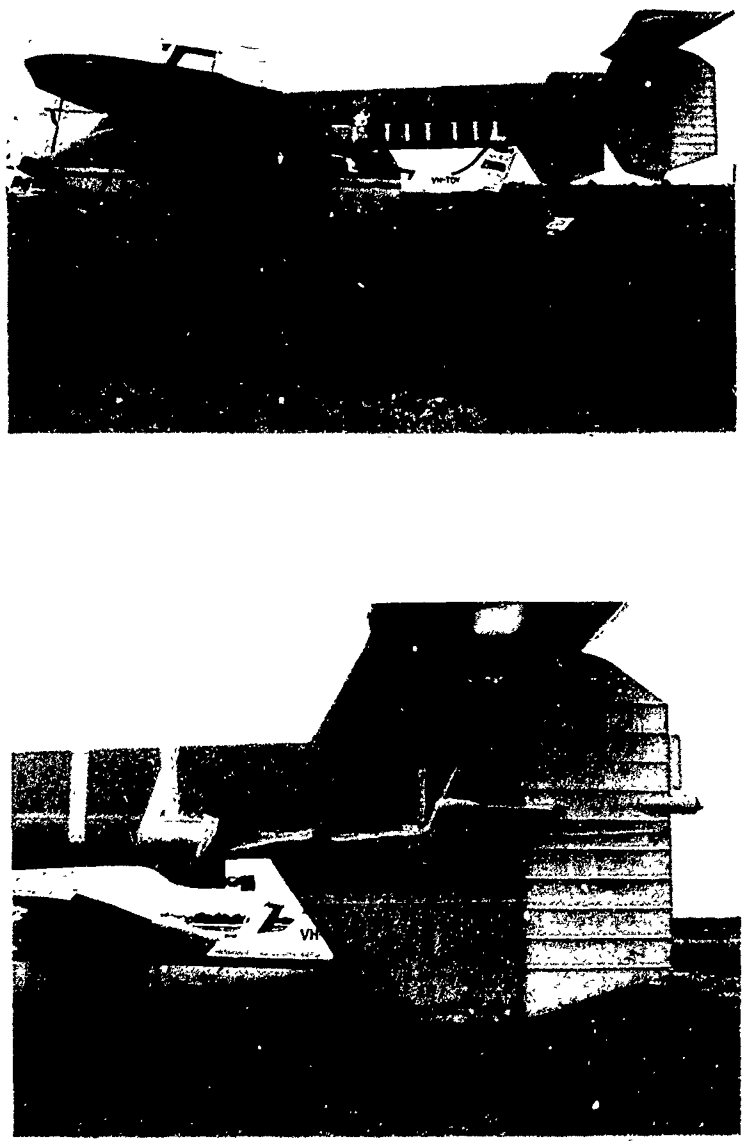
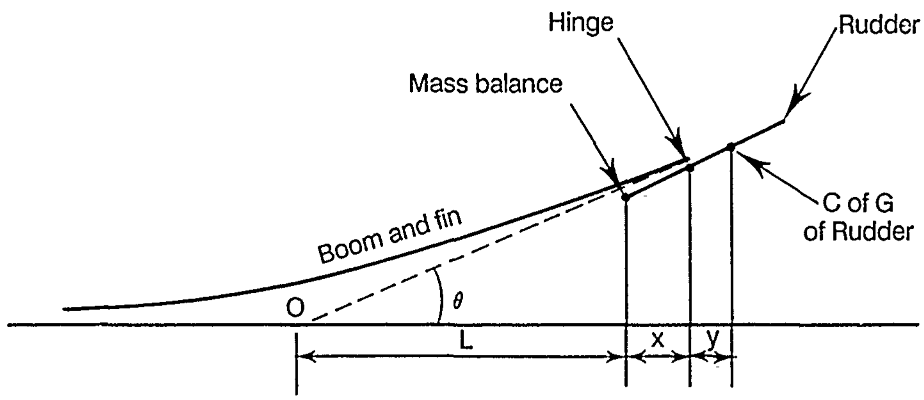


FIG 5.   PL12/T-400 SKYFARMER WITH EXCITER ATTACHED



O is the effective centre of rotation of the rudder hinge.

FIG 6. BENDING MODE AT 4 Hz

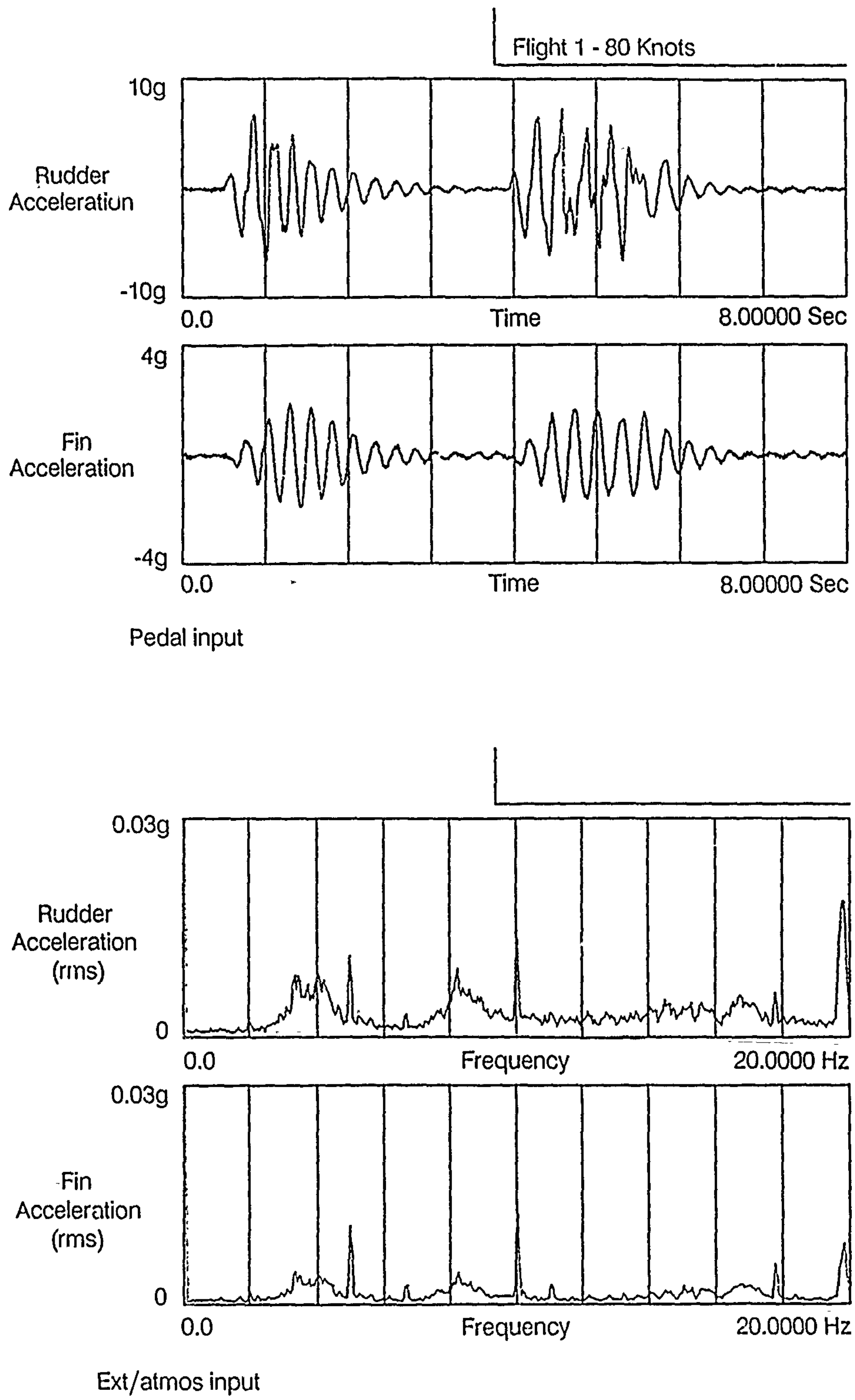


FIG 7a. FLIGHT 1 - 80 KNOTS

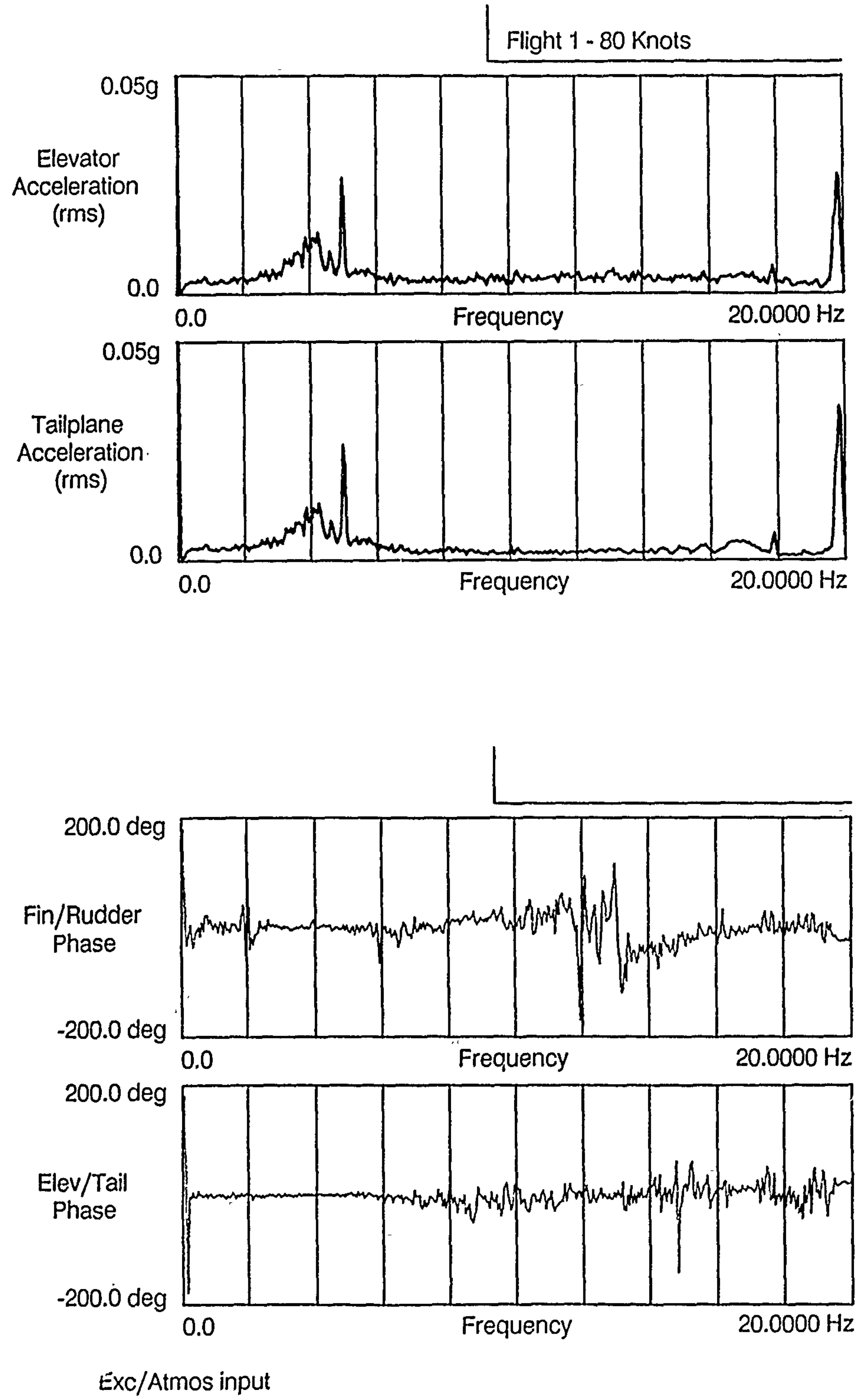


FIG 7b. FLIGHT 1 - 80 KNOTS

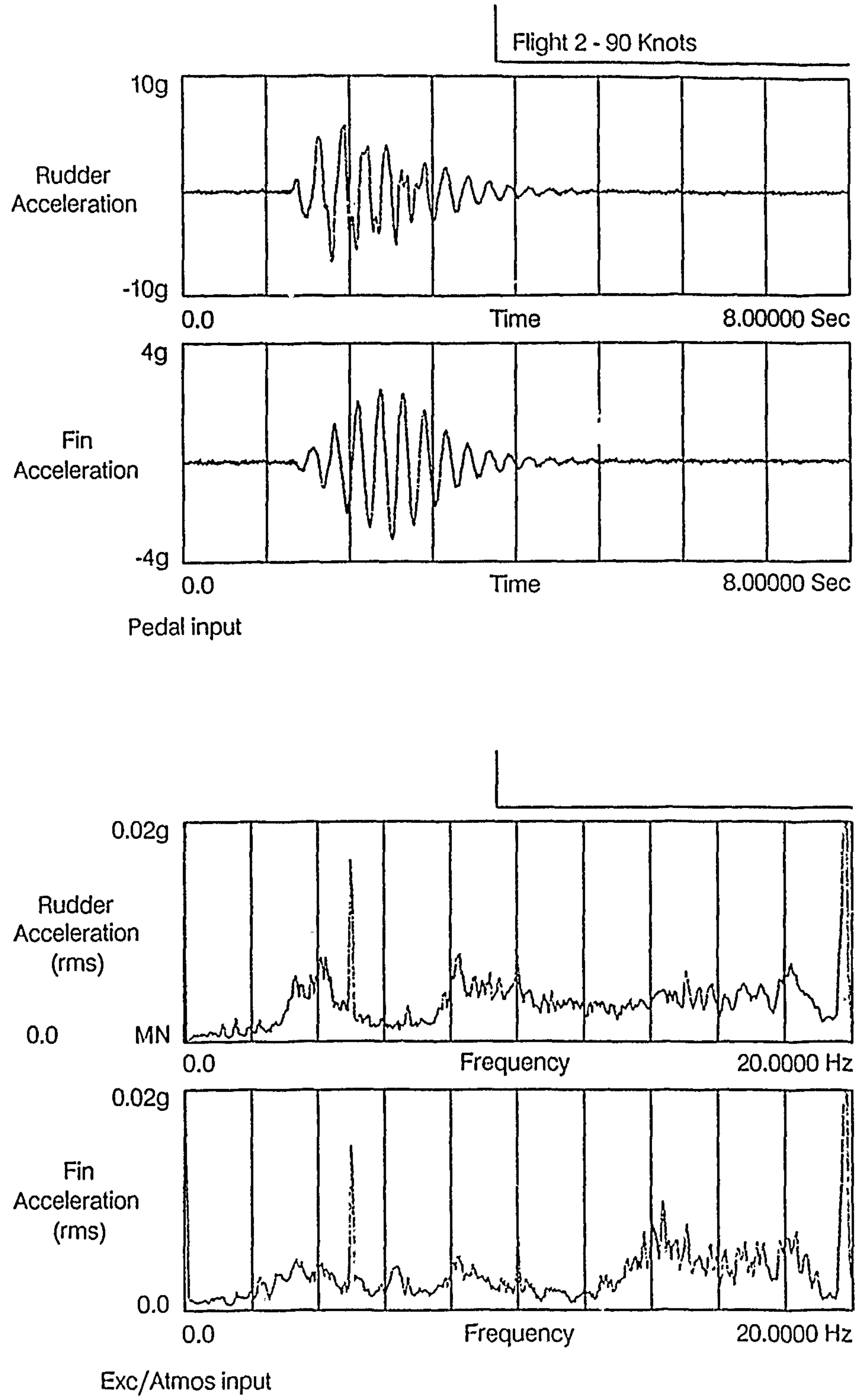


FIG 8a. FLIGHT 2 - 90 KNOTS

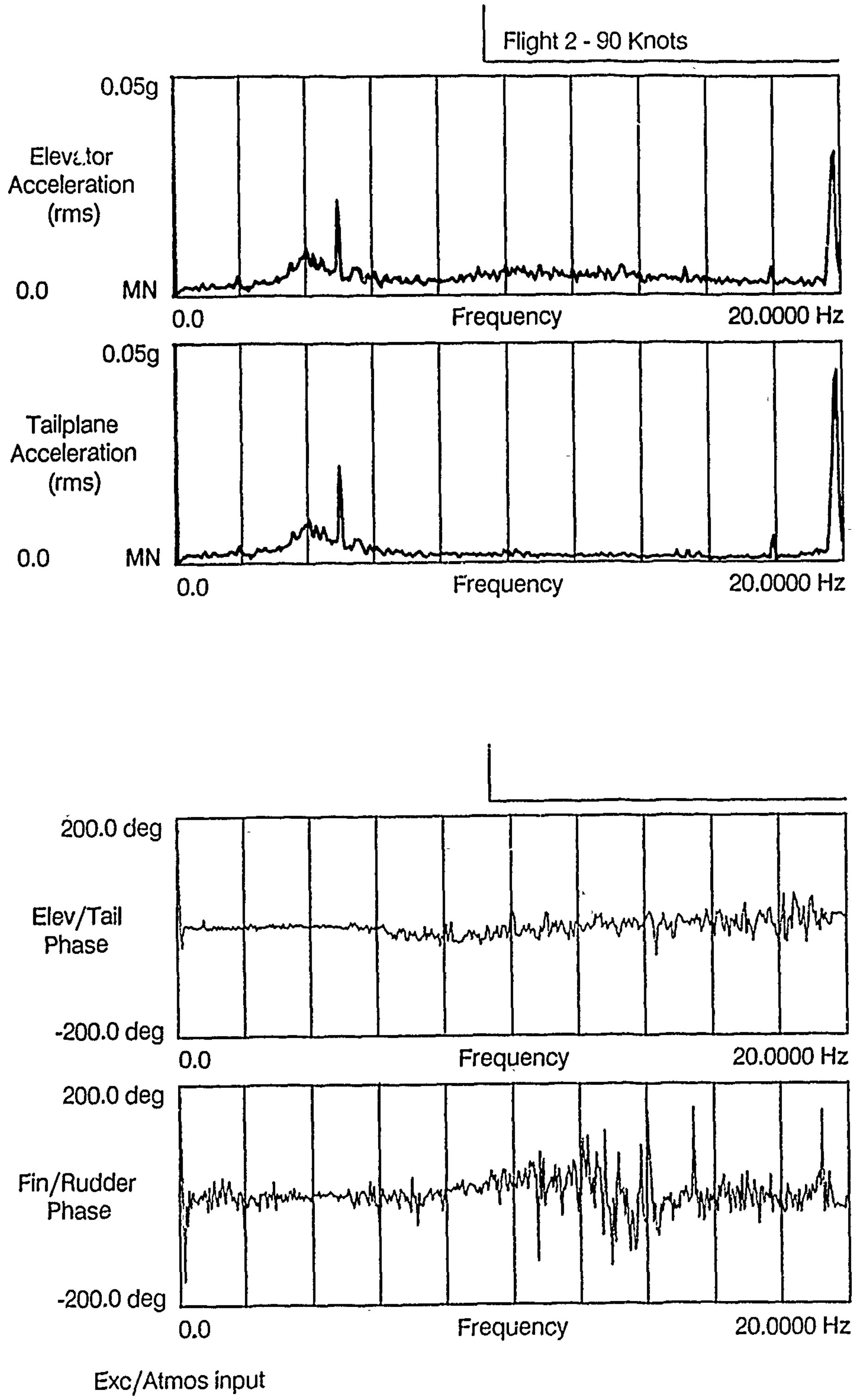


FIG 8b. FLIGHT 2 - 90 KNOTS

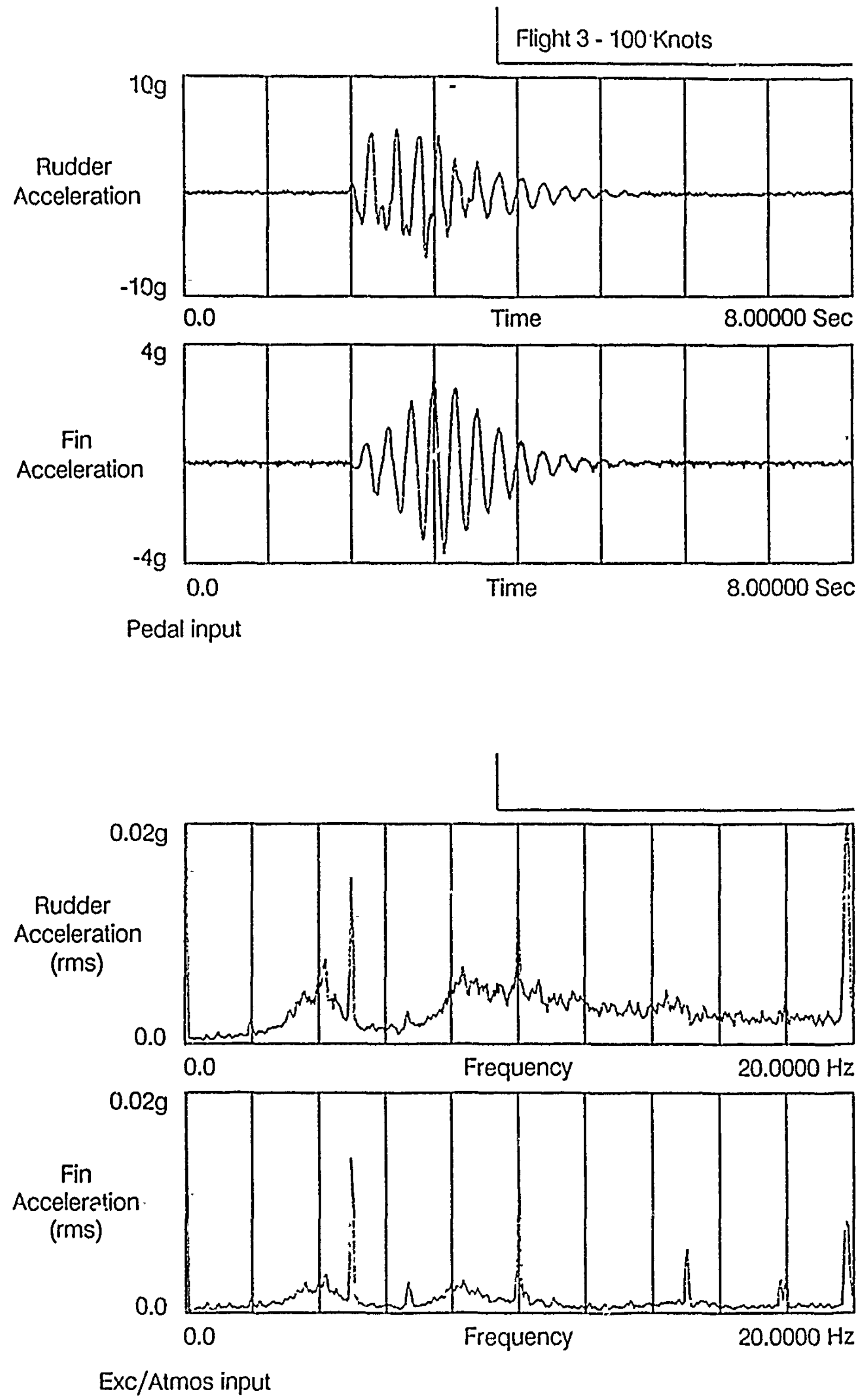


FIG 9a. FLIGHT 3 - 100 KNOTS

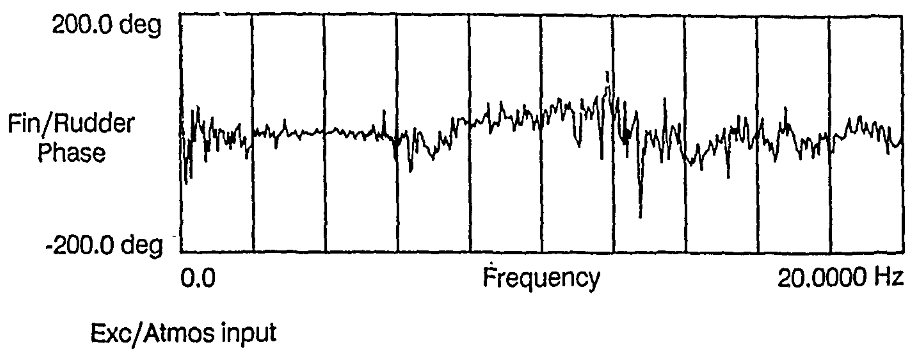


FIG 9b. FLIGHT 3 - 100 KNOTS

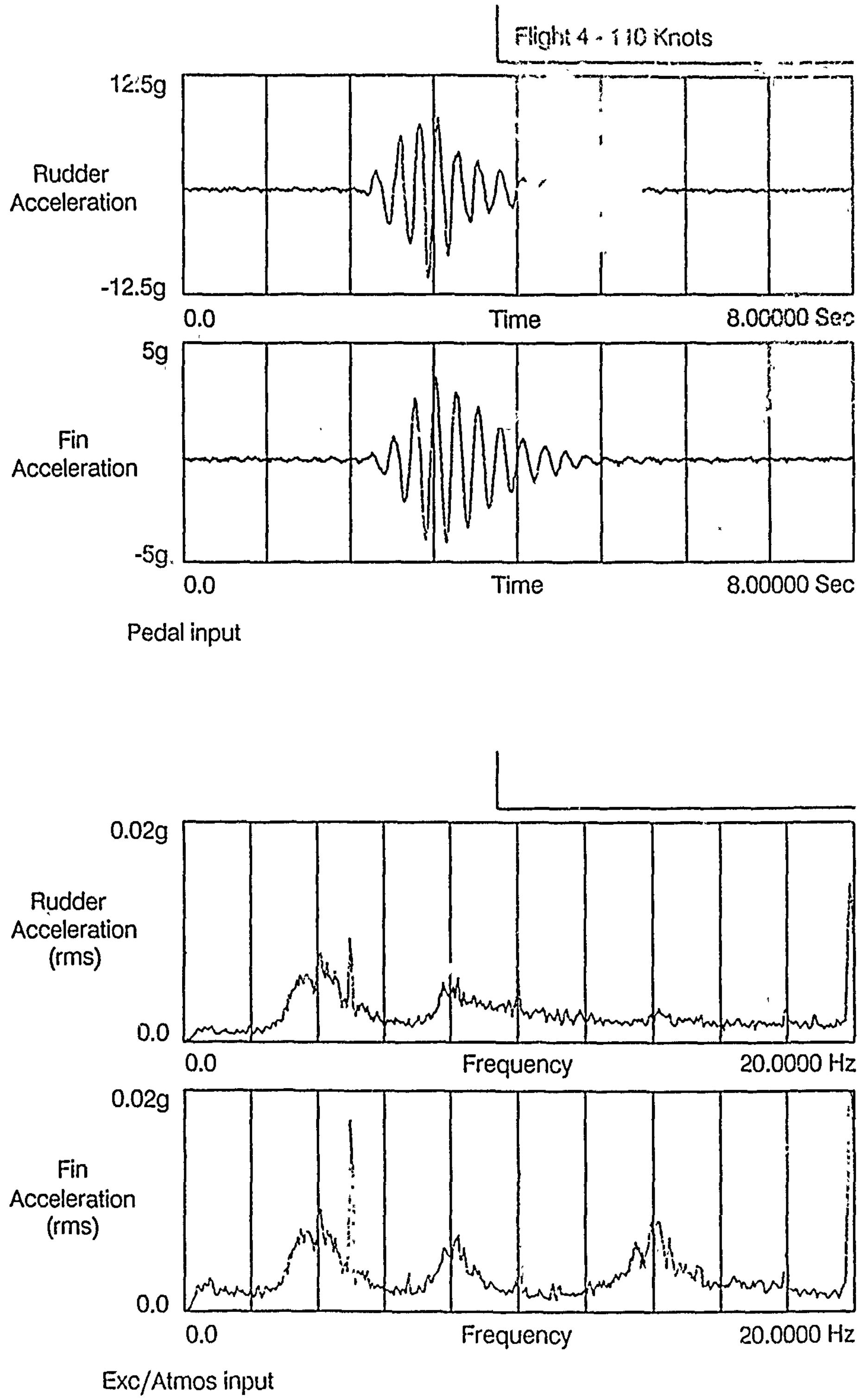


FIG. 10a. FLIGHT 4 - 110 KNOTS

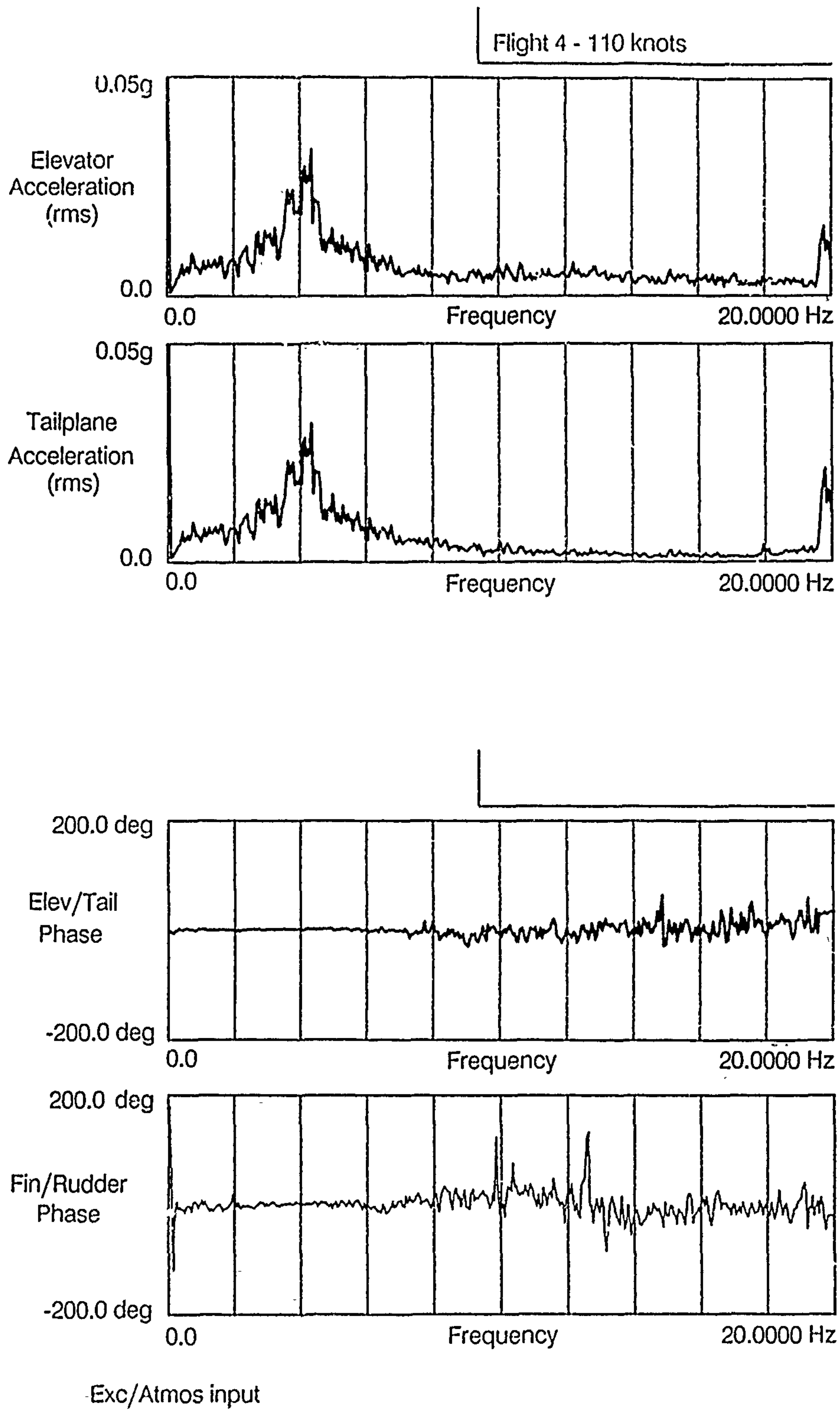


FIG 10b. FLIGHT 4 - 110 KNOTS

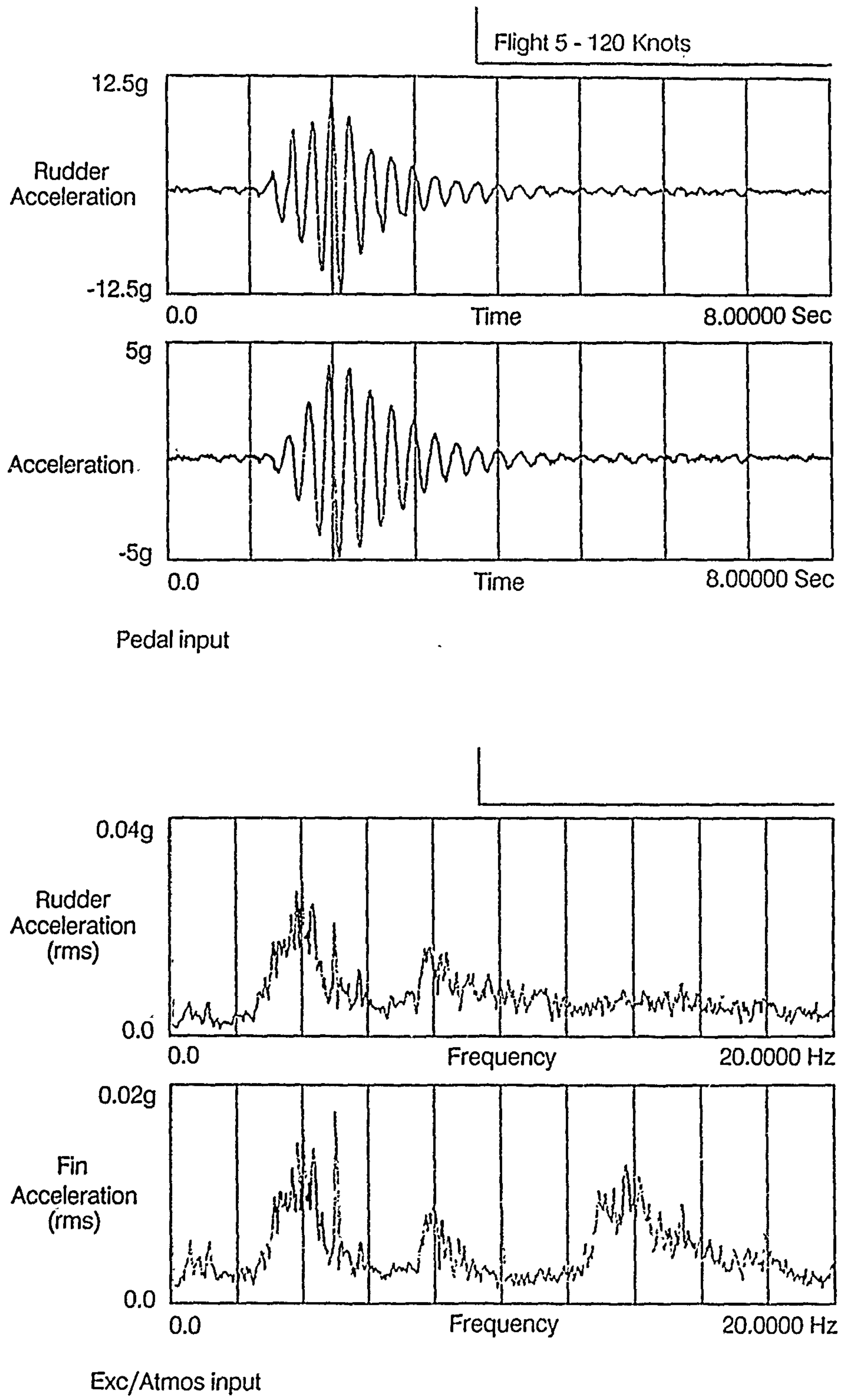
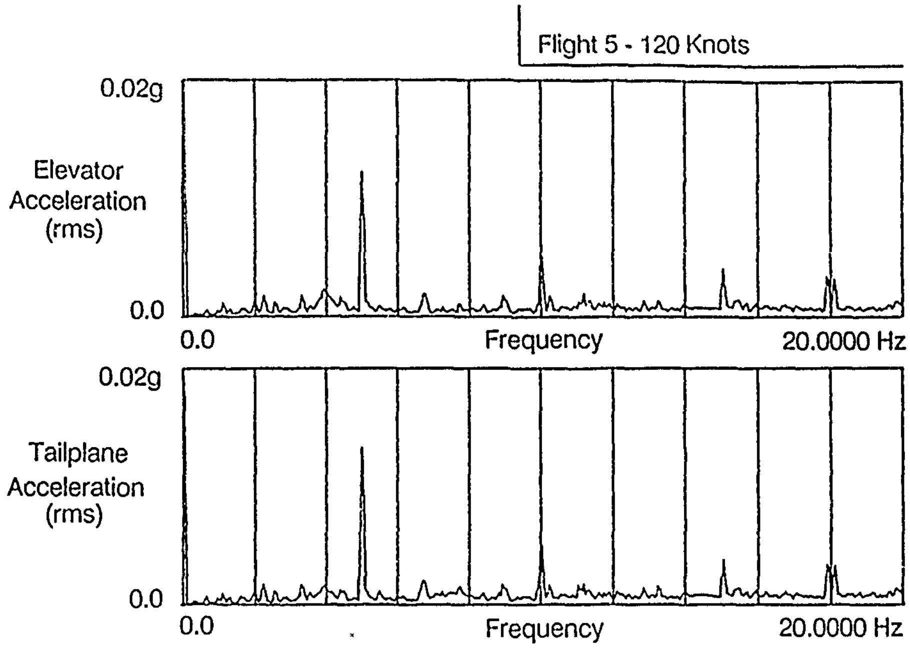
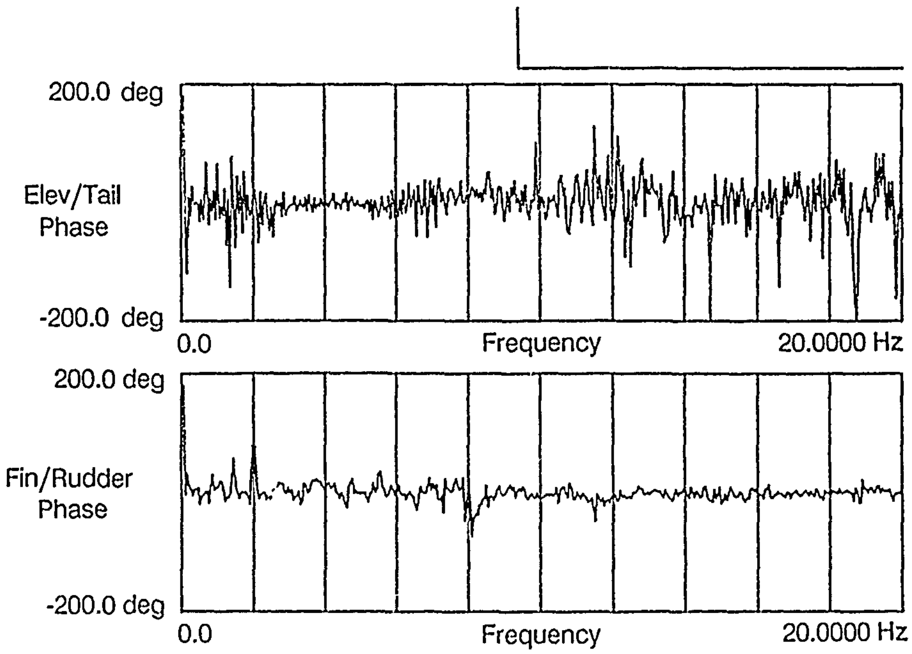


FIG 11a. FLIGHT 5 - 120 KNOTS





Exc/Atmos input

FIG 11b. FLIGHT 5 - 120 KNOTS

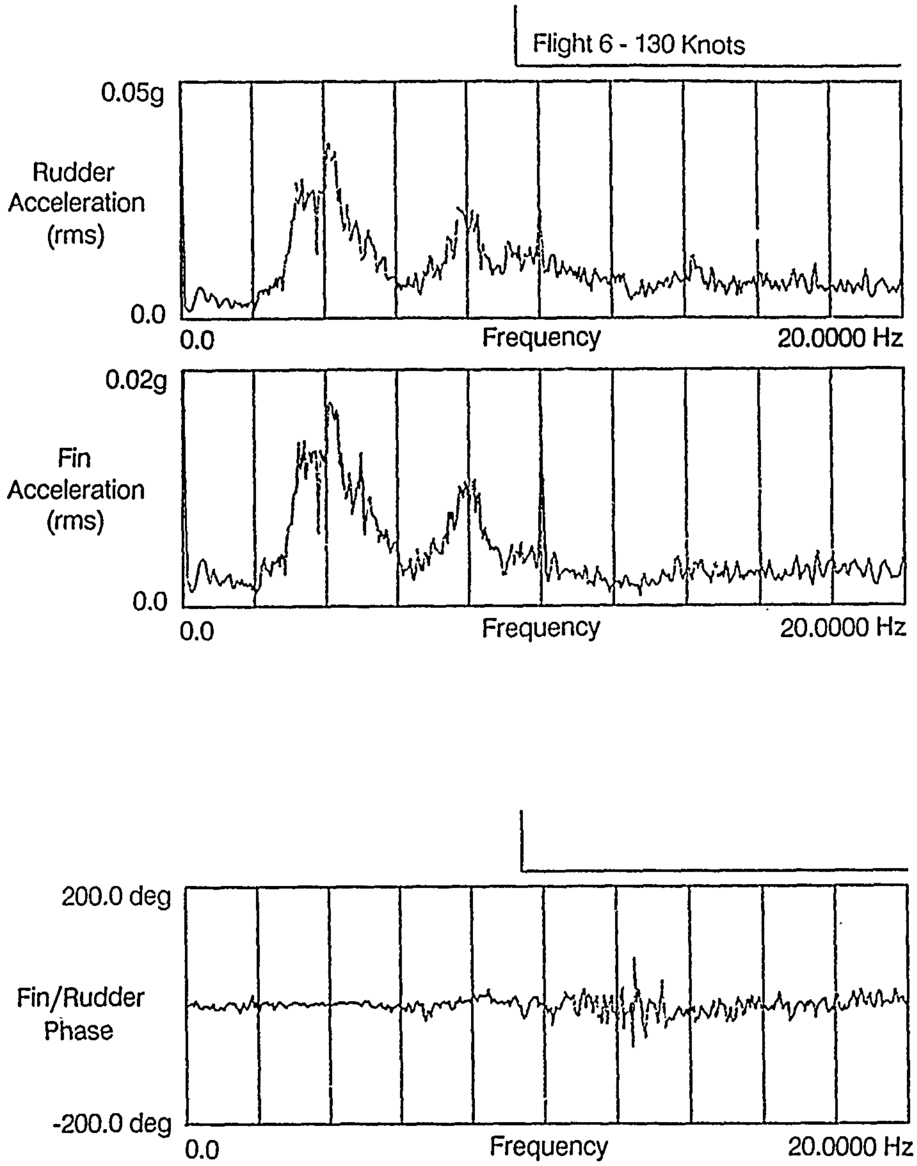
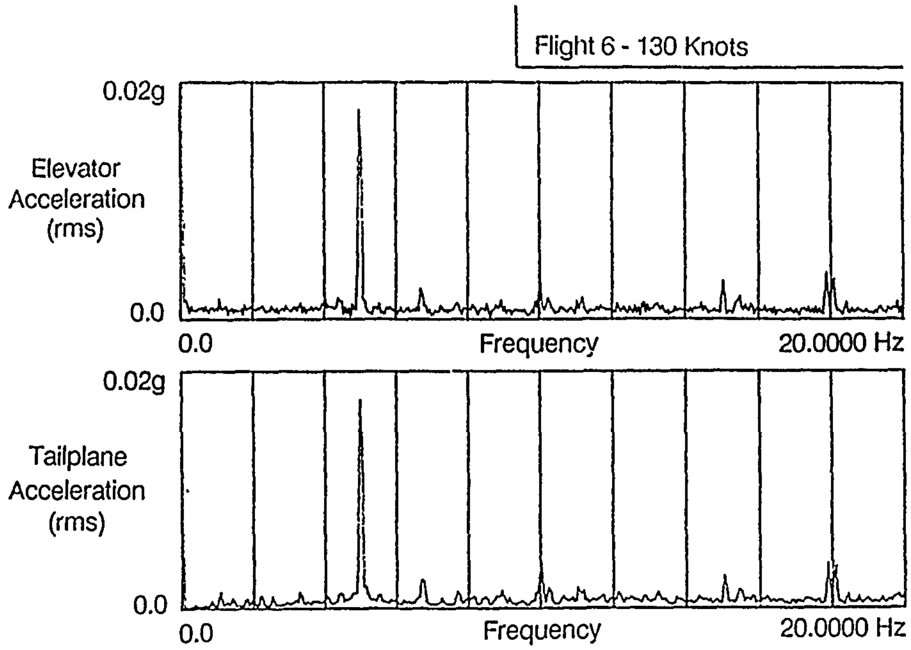
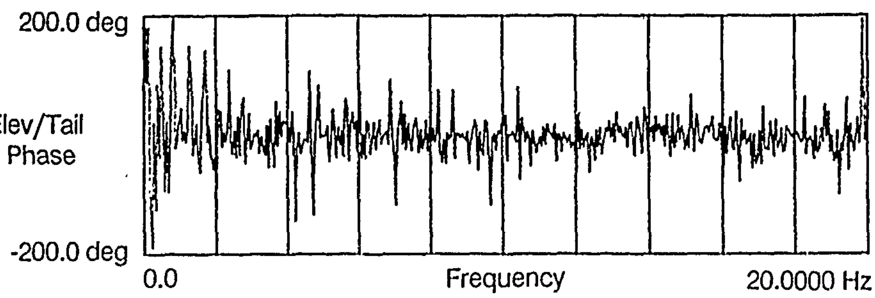


FIG 12a. FLIGHT 6 - 130 KNOTS



Exc/Atmos input



Exc/Atmos input

FIG 12b. FLIGHT 6 - 130 KNOTS

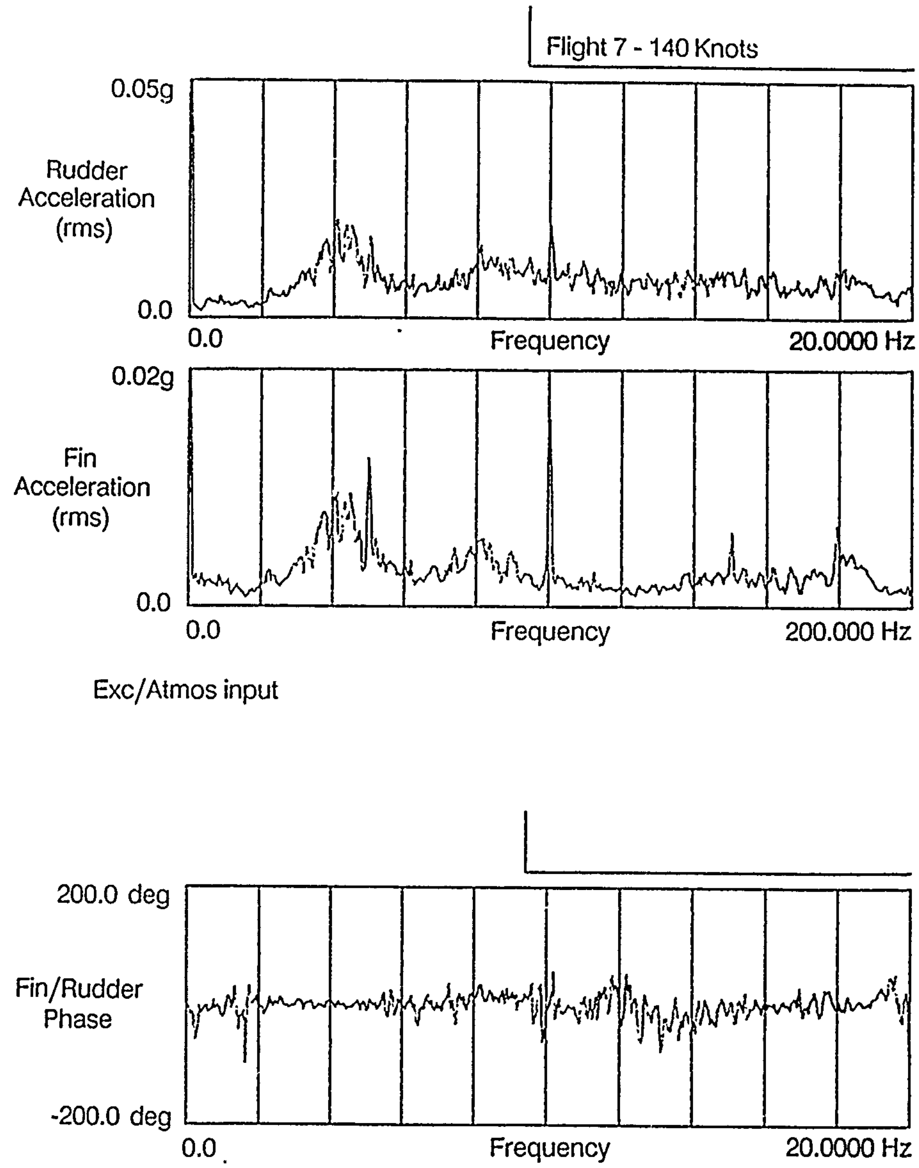


FIG 13a. FLIGHT 7 - 140 KNOTS

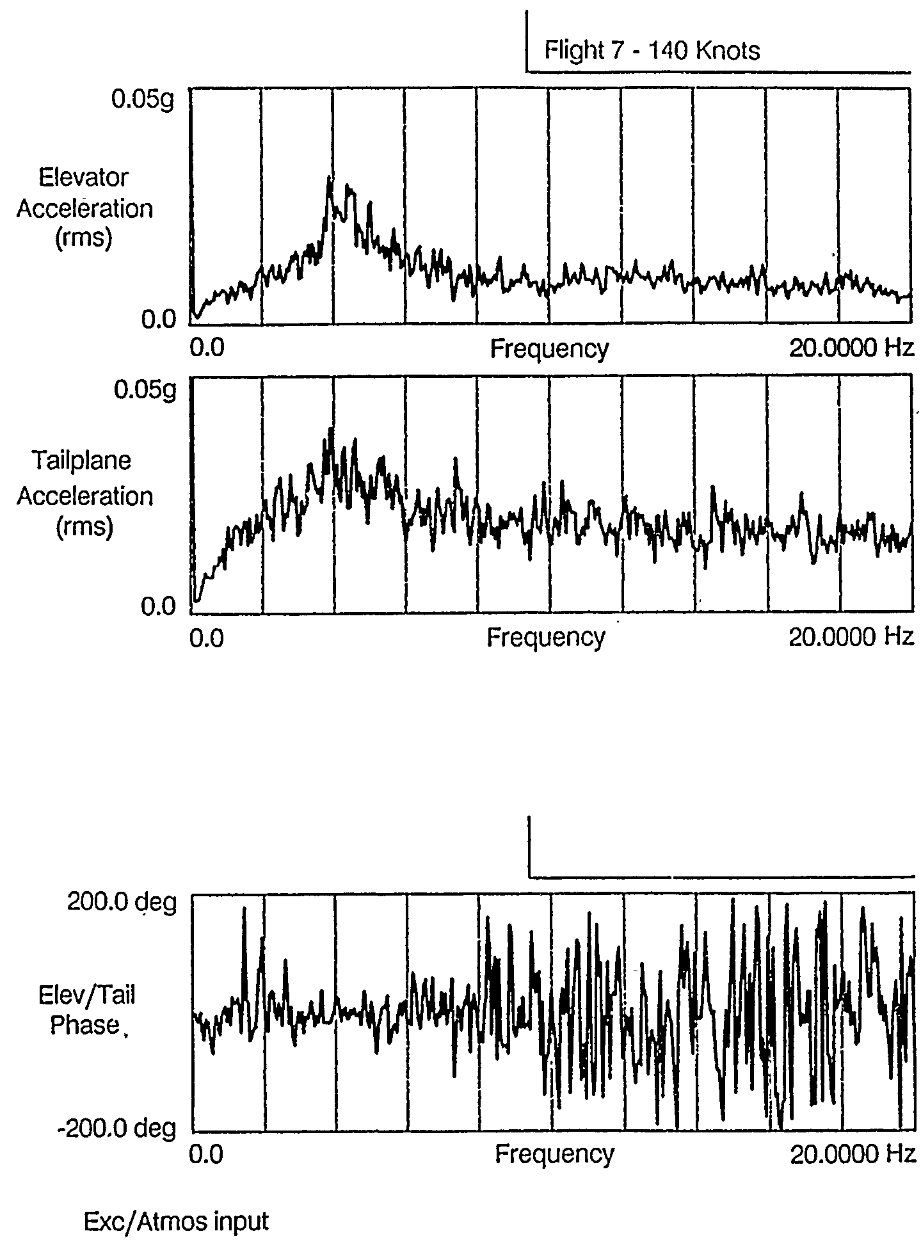


FIG 13b. FLIGHT 7 - 140 KNOTS

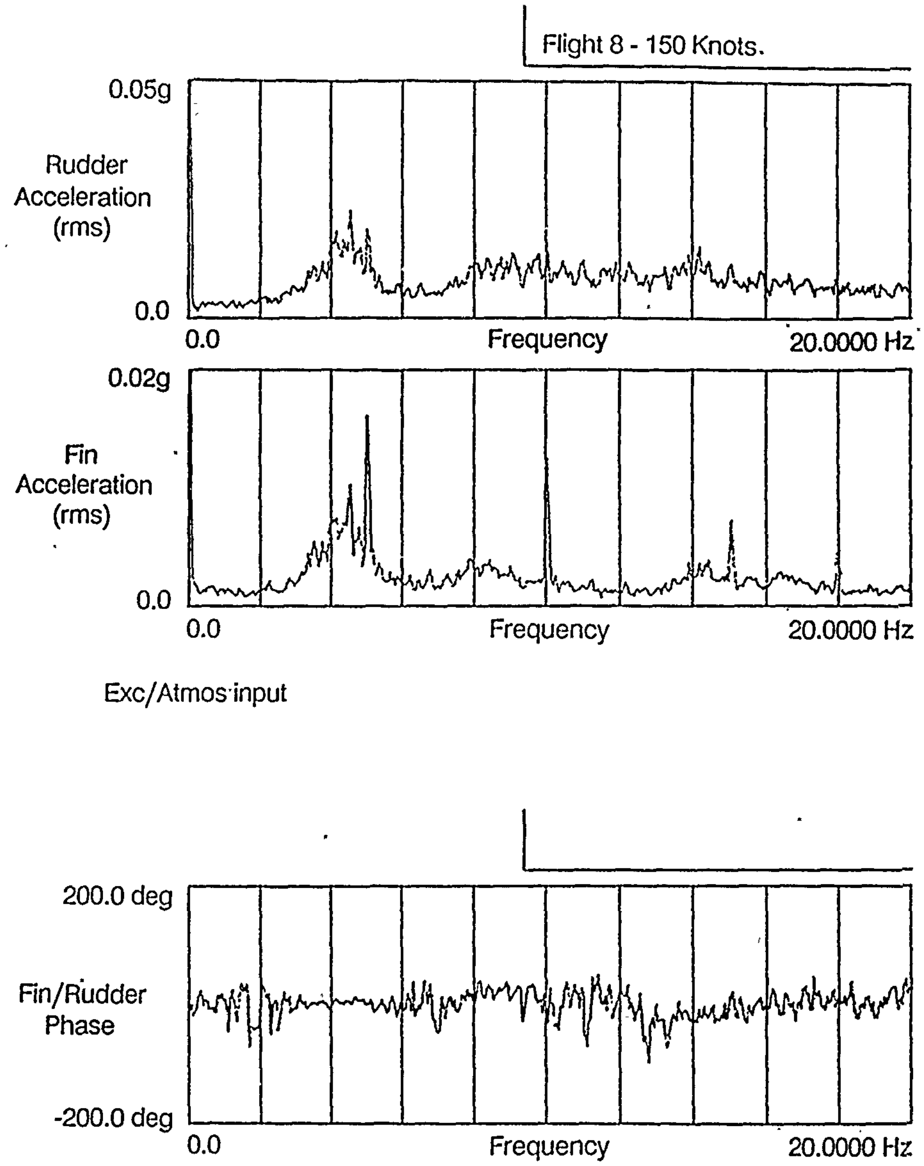


FIG 14a. FLIGHT 8 - 150 KNOTS

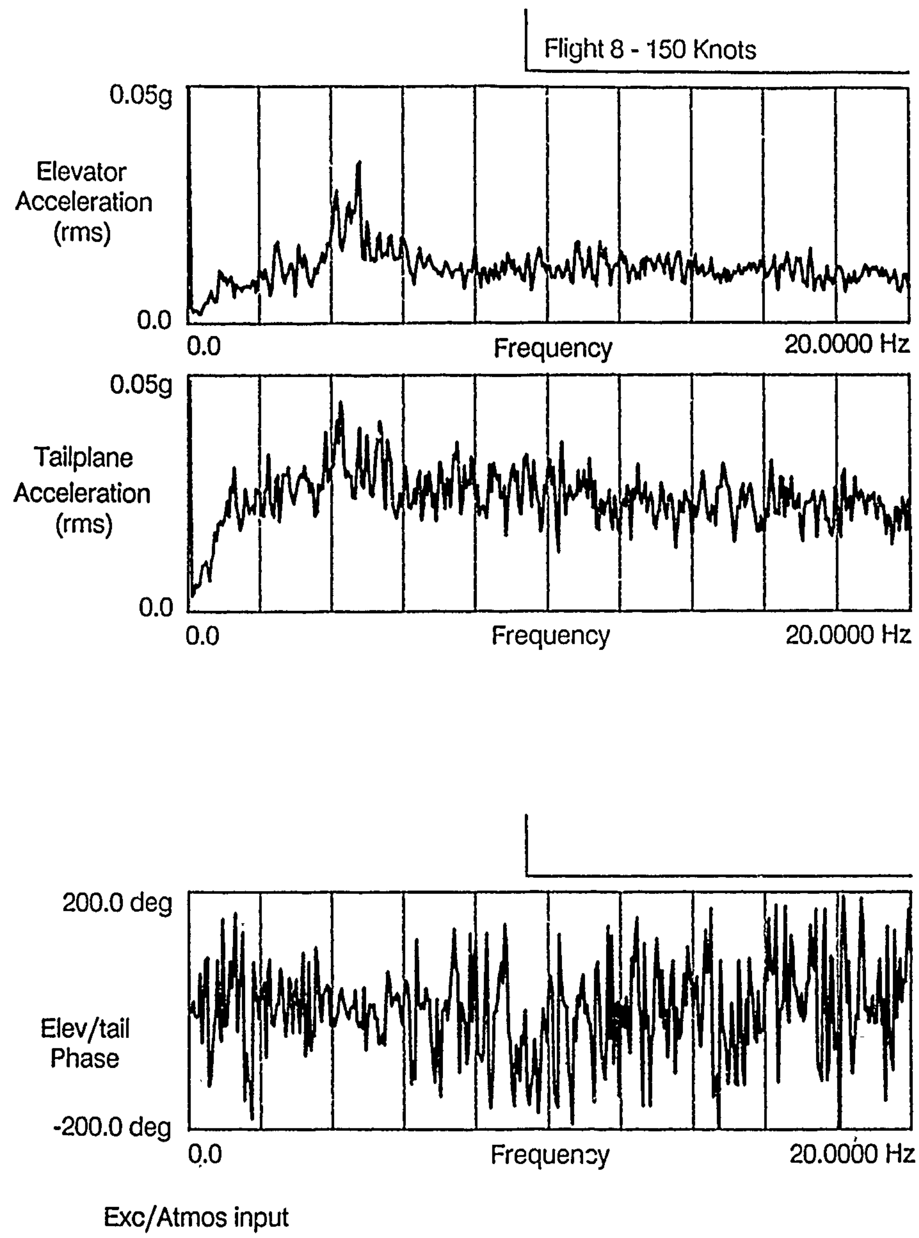


FIG 14b. FLIGHT 8 - 150 KNOTS

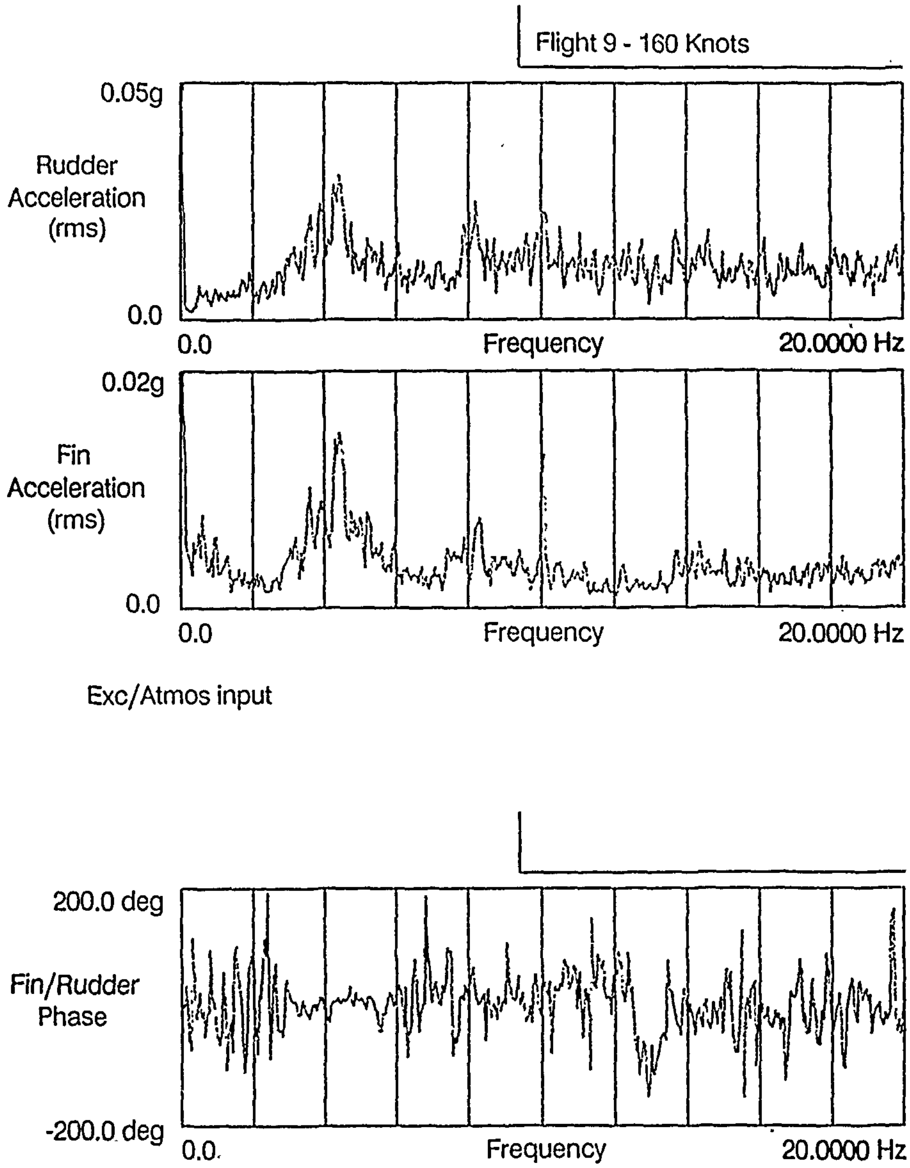


FIG 15a. FLIGHT 9 -160 KNOTS

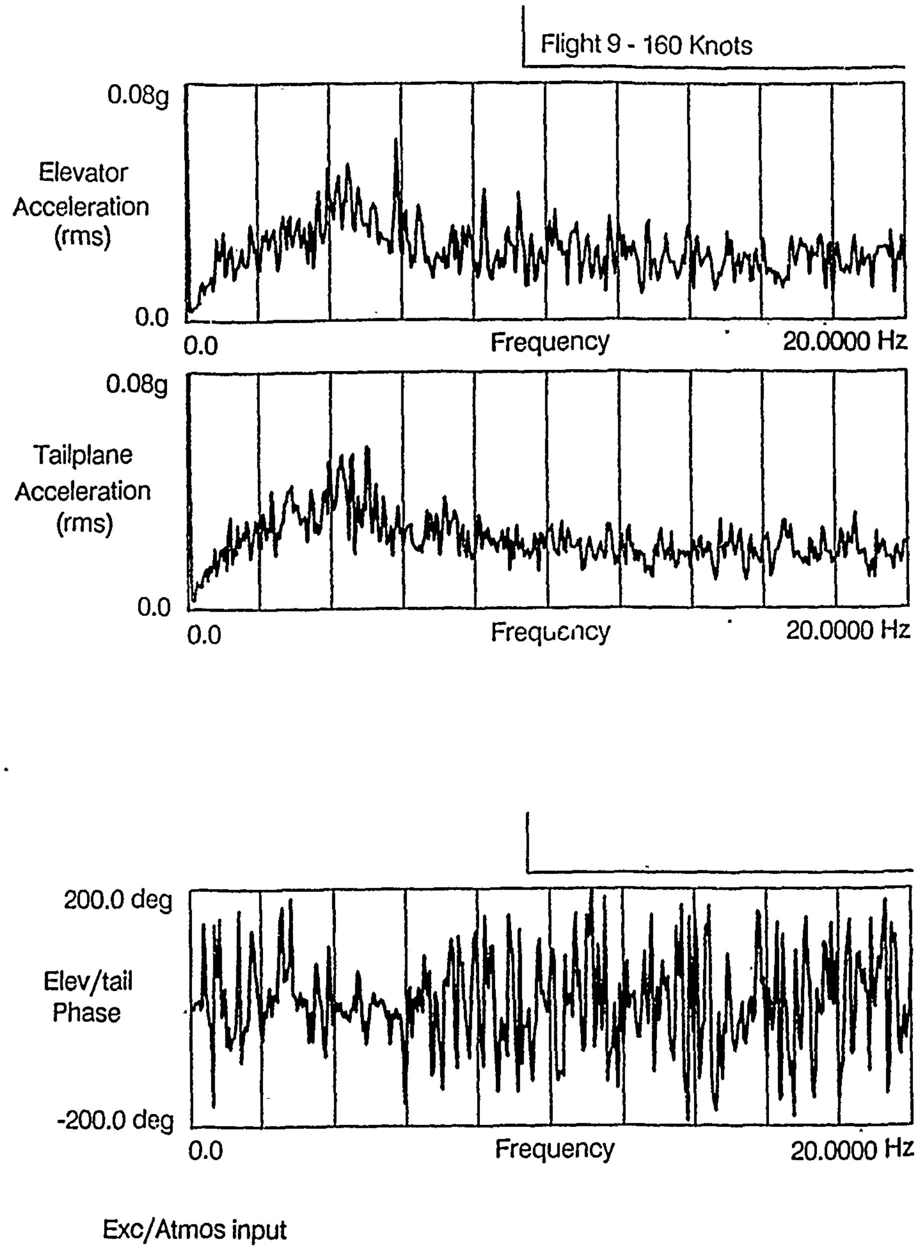


FIG 15b. FLIGHT 9 - 160 KNOTS

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16. ABSTRACT
An isolated flutter incident was reported in 1986 involving violent oscillations of the rudder and tail boom. This report details the subsequent activity to find a solution to the problem, and the tests conducted to verify the effectiveness of the solution. Keywords;

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