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Notes on the Dynamic Response of an Aircraft to Gusts and on the Variation of Gust Velocity along the Flight Path
with
Special Reference to Measurements in Lancaster P.D. 119

By

ANNE BURNS, B.A.

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COMMUNICATED BY THE PRINCIPAL DIRECTOR OF SCIENTIFIC RESEARCH (AIR),
MINISTRY OF SUPPLY

Reports and Memoranda No. 2759[*]
September, 1949

Summary.—A collection of records showing the time histories of strains and accelerations at various parts of a *Lancaster* flying in turbulent air is presented and discussed. The records include specimens taken in cloud at moderate altitudes and in clear air at low altitudes. Two points of interest regarding the response of the aircraft to gusts are brought to light :—

(i) The amount of fundamental oscillation excited by a gust appears to be affected to a marked extent by the variation of gust velocity across the span.

(ii) The amount of oscillation excited does not appear to show any marked decrease as the airspeed of the aircraft is increased. Some decrease in the oscillation excited might be expected due to increase in aerodynamic damping.

An attempt is made to deduce the variation of gust velocity along the flight path from the measured response of the aircraft. The results indicate that a large up-gust is often closely followed by a large down-gust and *vice versa.*

1. *Introduction.*—In June, July and October, 1947, and March, 1948, a number of flights were made in *Lancaster* P.D.119. During these flights records of strains and accelerations were obtained while flying in turbulent air. The primary object was to test recording equipment rather than to obtain information on the strains and accelerations. Some interesting records were obtained incidentally, however, and in view of the paucity of experimental data on this subject the records have been collected and are discussed.

Examination of the records is divided into two parts : the first deals with the dynamic response of the aircraft to the imposed gusts, with particular reference to the effects of spanwise variation of gust velocity and of damping. In the second part, an attempt is made to deduce the time history and magnitude of the gusts from the measured response of the aircraft. A point of interest in the curves of gust velocity against time is that a large up-gust tends to be preceded by a large down-gust and *vice versa.*

2. *Description of Flights, Equipment and Records.*—2.1. *Description of Flights.*—The flights made from June to October, 1947, were carried out over Southern England. Gusty conditions were encountered flying through small convective clouds (cumulus) at altitudes between 1,000 and 5,000 ft. A few penetrations were made at altitudes up to 10,000 ft into large cumulus cloud, but not into cumulo nimbus.

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[*] R.A.E. Report Structures 47, received 12th December, 1949.

The flights in March, 1948, were made in Kenya. Gusty conditions were obtained in clear air flying low with 200 to 500 ft clearance over a range of hills. The turbulence was probably caused by a mixture of convective currents and of eddy currents due to the deflection of the wind over the hills.

On all these flights the aircraft was controlled manually while records were being taken.

2.2. *Description of Equipment.*—Miller recording equipment was used to obtain synchronised records of strains and accelerations at various positions on the aircraft. These positions are shown in Fig. 1. Accelerometers were fitted at ten stations along the wing and fuselage to measure normal acceleration. Strain-gauges were fitted at four stations along the wing to measure the bending moment. During most of the flights only six of the accelerometers and strain-gauges could be selected for recording at any one time. In a few of the earlier flights eleven accelerations and strains could be recorded simultaneously. The accelerations due to airscrew and engine vibration were filtered out electrically as otherwise they obscured the recording of the less rapidly varying accelerations due to turbulent air. (See Fig. 2 for examples of acceleration records with and without filtering). Records of strain did not require any filtering. The filtering of the accelerations was adjusted so that at least 95 per cent of full response was obtained at 10 c.p.s. Above this frequency the response fell off rapidly, about 33 per cent of full response being obtained at 30 c.p.s.

2.3. *Description of Records.*—The records shown in Figs. 2 to 14 are reproductions of the originals with base lines and scales added. Horizontal distance represents time, and vertical deflection of the traces from their respective base lines represents change of acceleration or strain from the level flight ($1g$) value. There are three different time scales on these records—5 in./sec (Fig. 2), 1 in./sec (Figs. 3, 7, 8 and 9) and 0·6 in./sec (Figs. 4 to 6 and 10 to 14). The vertical scales used for acceleration and strain vary from trace to trace on any one record as well as from record to record. When viewing the records it is important to bear this in mind or a false impression of the degree of turbulence may be obtained; for example, the high sensitivity used in the records of Fig. 3 gives an impression of severe turbulence whereas the maximum acceleration recorded on the main spar near the centre of gravity is in actual fact only $1{\cdot}5g$ ($0{\cdot}5g$ above straight and level).

3. *Dynamic Response of Aircraft to Gusts.*—It is immediately apparent from the records that the same accelerations are not recorded at every part of the aircraft. Some differences are due to the rolling and pitching accelerations of the aircraft and these are discussed in Appendix I. The main differences in acceleration are caused by oscillations of the wing and fuselage and of these the fundamental wing fuselage oscillation at 3·2 c.p.s.[1] predominates. It can be detected in almost all the records but shows up very clearly in the strain records of Fig. 12. Other oscillations occasionally excited are the first harmonic of the wing at approximately 6·5 c.p.s. (*see* Fig. 3d) and a fuselage flexural oscillation at approximately 7 c.p.s. (*see* Fig. 5). Asymmetrical oscillations of the wing do not appear to be excited even by asymmetrical gusts (*see* Fig. 6—the asymmetrical loading in this example is caused by the oblique entry of the aircraft into a down gust, the port wing entering shortly before the starboard. The asymmetry of the loading is aggravated by the gust velocity being greater on the starboard side than the port).

3.1. *The Effect of Spanwise Variation in Gust Velocity on the Amount of Fundamental Oscillation Excited.*—A peculiar feature of the response of the aircraft to gusts is the varying amount of fundamental oscillation excited by gusts of a similar severity. The variation in amount of fundamental oscillation excited does not appear to be due to different rates of build-up of the gusts since a moderately sharp-fronted gust in one case excites little fundamental and in another quite a marked amount (*see* Fig. 7). The explanation probably lies in the variation of gust velocity along the wing. It can be shown theoretically that if the total increase of wing lift due to two gusts is the same, but in one case the increase of lift is concentrated near the wing tips and in the other near the wing root, then more fundamental oscillation is excited in the first case than in the second. The indication of the records is that such variation of gust intensity across the span does occur and is affecting the amount of oscillation excited.

Another peculiarity shown in the records which is probably explained by spanwise variation in gust velocity is the not uncommon occurrence of a sustained fundamental oscillation unaccompanied by any marked disturbance of the aircraft as a whole (*see* Fig. 13). This is probably caused by small local disturbances of air near the wing tips which are too small noticeably to affect the motion of the aircraft as a whole, but by virtue of their concentration on the outer wing are effective in exciting the fundamental oscillation.

Emphasis has been laid on the indications in the records that spanwise variation of gust velocity affects the amount of oscillation excited because there is a possibility that standard methods of calculation (R. & M. 2221) may, by not allowing for this effect, underestimate the dynamic loads induced by gusts.

3.2. *The Effect of Damping on the Dynamic Response of the Aircraft to Gusts.*—It is not possible to estimate the value of the aerodynamic damping coefficient from the die-away of the fundamental oscillation because small gusts and disturbances which are occurring all the time in turbulent air do not allow a clean die-away of the oscillation from which to estimate the magnitude of the damping.

At normal cruising speeds the damping is not sufficiently heavy to prevent fundamental oscillations of large amplitude being built up by gusts occurring in quick succession. The oscillations from one gust can be superimposed on the oscillations excited by a previous gust before these are damped out (*see* example in Fig. 5).

The aerodynamic damping varies directly with the airspeed so that the effect of damping on the dynamic response of the aircraft might be expected to become more pronounced with increase of airspeed. Fig. 3 shows the effect of speed on the response. The aircraft was flown at an altitude of 6,500 ft through the same bank of cloud at airspeeds varying from 100 to 240 kt I.A.S. It was not possible to follow exactly the same flight path at each speed but the records give some indication of the response at different speeds. The fundamental oscillation is excited at all speeds and there is no tendency for the response of the aircraft to become less oscillatory owing to the increase of aerodynamic damping with velocity (*i.e.*, the damping does not tend to become aperiodic and the motion sluggish with increased air speed).

4. *Data on Gusts.*—No direct measurements of gust velocities were obtained, but information on the magnitude and time history of the gusts has been deduced from the recorded response of the aircraft, by a method described in Appendix II.

Plots of vertical gust velocity along flight path are shown in Figs. 17 and 18. The gust velocities have been deduced from records taken in severe clear air turbulence in Kenya.

One point of interest is that large up-gusts are usually preceded by moderate or large down-gusts and vice versa. The distance between the maximum up-gust velocity and down-gust velocity may be as short as 250 ft, with the consequence that the aircraft is moving in the opposite direction to the second gust as it enters it. The opposing velocity of the aircraft may persist until the second gust has reached its maximum velocity with the result that no relief in load is obtained due to the vertical velocity of the aircraft. In fact the aircraft may experience a load larger than would be calculated for a gust of the same magnitude if no allowance were made for the vertical velocity of the aircraft.

The shapes of the gusts shown in Figs. 17 and 18 vary considerably. In the case of the more severe gusts (velocities greater than 30 ft/sec), the velocity builds up in distances varying from 100 to 350 ft. The maximum gust velocity is not sustained for any appreciable distance but dies away almost immediately in distances again varying from 100 to 350 ft.

Figs. 19a, 19b, 19c and 19d, show types of variation in gust velocity which may occur across the wing span. These figures have been deduced from the actual variation met with along the flight path. It appears that in severe turbulence the variation over the wing span may be as much as 30 ft/sec, the aircraft being subjected to an up-gust on one wing and a down-gust on the other.

5. *Conclusions.*—The records of accelerations and strains at various stations along the wing and fuselage of a *Lancaster* when flying in turbulent air, bring to light the following two points of interest regarding the response of the aircraft.

(a) The amount of fundamental oscillation excited does not appear to be solely dependent on the magnitude and rate of build-up of the gusts encountered: it is thought that variation in gust velocity across the span is affecting the amount of oscillation excited to a marked extent.

(b) Records taken at various air speeds ranging from 100 knots to 240 knots do not show any decrease in the amount of oscillation excited. A decrease might have been expected due to the increase of aerodynamic damping with speed.

Plots of vertical gust velocity along the flight path deduced from the recorded accelerations show that a severe gust (velocity greater than 30 ft/sec) is frequently preceded by a moderate or severe gust in the opposite direction. When this occurs the aircraft hits the second gust much harder than if the second gust occurred alone. The gust velocities of the severe gusts build up in distances varying from 100 to 350 ft: when they have reached their maximum they are not sustained but die away again in from 100 to 350 ft. The gust velocity across the wing span is far from uniform and can vary by as much as 30 ft/sec, gust velocities of opposite sign occurring on the port and starboard wing and on the wings and fuselage.

REFERENCES

No.	*Author*	*Title, etc.*
1	.. ..	Resonance of Lincoln I RE.232 and Lancaster VI ND.673. S.M.E. Test Note 3208. November, 1945.
2	D. Williams	Dynamic Loads in Aeroplanes under Given Impulsive Loads. A Simplified Method of Calculation. September, 1946. R. & M. 2221.

APPENDIX I

The Determination of Accelerations Due to Roll and Pitch of the Aircraft in Turbulent Air

Angular accelerations in pitch produce differences in the accelerations measured at the nose and tail. Fig. 15a shows an enlargement of these accelerations at the nose and tail and Fig. 15b the difference between them. The difference in acceleration of the nose and tail due to pitch is small and tends to be obscured by the difference due to oscillations of the structure. The dotted line in Fig. 15b is a rough estimate of the angular acceleration in pitch. This is found to be very small both in this case (less than $0 \cdot 2$ radn/sec^2) and in other records.

Angular accelerations in roll have been estimated (Fig. 16) from accelerations measured at the front spar behind the port outer engine and at the front spar behind the starboard outer engine. Fig. 16 shows the largest angular acceleration ($1 \cdot 35$ radn/sec^2) measured during this series of test flights.

APPENDIX II

Method of Obtaining Vertical Gust Velocity from the Recorded Response of the Aircraft

An estimation is first made of the vertical accelerations of the aircraft as a whole. Use is made of two vertical accelerations, one measured at station 5 on the front spar in the fuselage and one measured at station 4 on the front spar behind the port engine. The accelerations measured at station 5 contain components due to the fundamental oscillation but none due to roll or pitch. On the other hand the accelerations measured at station 4 contain components of roll but little fundamental since station 4 is near the fundamental node. From the two accelerations it is possible to eliminate components due to rolling of the aircraft and fundamental oscillation. Higher frequency oscillations can be meaned out by eye leaving only the acceleration of the centre of gravity.

To obtain the vertical gust velocity from the aircraft acceleration, the following assumptions have been made :—

1. All changes in wing loading are due to the vertical velocity of the gust relative to the aircraft. In actual fact some variation in wing loading will be due to movement of the controls by the pilot and to changes in horizontal gust velocity.

2. It is assumed that the attitude of the aircraft remains constant and that no rolling occurs

3. The gust velocity along the wing span is assumed to be uniform. This assumption is not valid as has already been discussed (sections 3.1 and 4). Its use, however, enables an estimation to be made of the average gust velocity along the wing span.

4. The Wagner effect is neglected.

5. It is assumed that the total loss or gain of height of the aircraft over the period of time during which the time history of the gusts is to be determined is zero. For the short periods of time (15 sec) for which the time history of the gusts have been determined this assumption is not justified. Any error, however, merely shifts the base line of the gust velocity-time curve and in no way alters the general conclusions of this note.

The vertical gust velocity v at any instant is given by

$$v = \frac{2ngw}{\alpha\rho V} + u,$$

where ng is the incremental vertical acceleration of the aircraft measured from the straight and level value,

w is the wing loading,
α is the slope of the lift curve,
ρ is the density of air at sea-level,
u is the vertical velocity of the aircraft,
and V is the rectified airspeed.

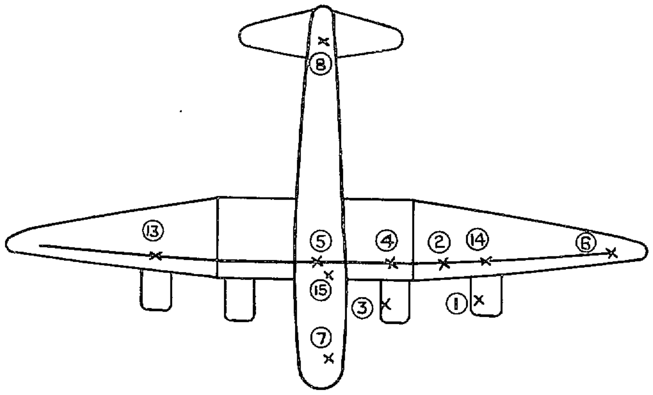
Putting in numerical values as follows :—

$w = \dfrac{53{,}000}{1{,}297}$ lb/sq ft (mean weight of aircraft during flights = 53,000 lb)

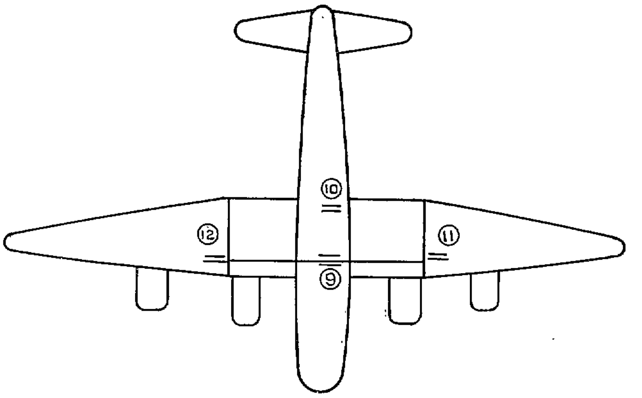
$V = 160$ knots,

we find $v = 27 \cdot 3n + u.$

The only quantity still to be determined is u, the vertical velocity of the aircraft. This has been obtained by integrating the vertical acceleration of the aircraft. The constant of integration, *i.e.*, the initial vertical velocity of the aircraft at zero time, is determined from the condition that the aircraft does not gain or lose height (assumption 5).



(a) ACCELEROMETER POSITIONS



(b) STRAIN GAUGE POSITIONS

ACCELEROMETER POSITIONS

① OUTER PORT ENGINE FRONT INNER FOOT

② FRONT SPAR FRONT FACE BETWEEN INNER & OUTER PORT ENGINES

③ INNER PORT ENGINE FRONT INNER FOOT

④ FRONT SPAR AFT FACE AT INNER PORT U/C CASTING

⑤ FRONT SPAR AFT FACE BOTTOM BOOM AT FUSELAGE CENTRE LINE

⑥ FRONT SPAR FRONT FACE NEAR WING TIP – 18" INBOARD FROM AILERON END RIB

⑦ FORWARD FACE OF MAIN BULKHEAD BETWEEN BOMB AIMER & PILOT

⑧ HEAVY FRAME JUST FORWARD OF TAIL TURRET

⑬ FRONT SPAR FRONT FACE AT OUTER STARBOARD ENGINE

⑭ FRONT SPAR FRONT FACE AT OUTER PORT ENGINE

⑮ 18" FORWARD OF FRONT SPAR MID FUSELAGE (USED AS A CHECK ON ⑤)

STRAIN GAUGE POSITIONS

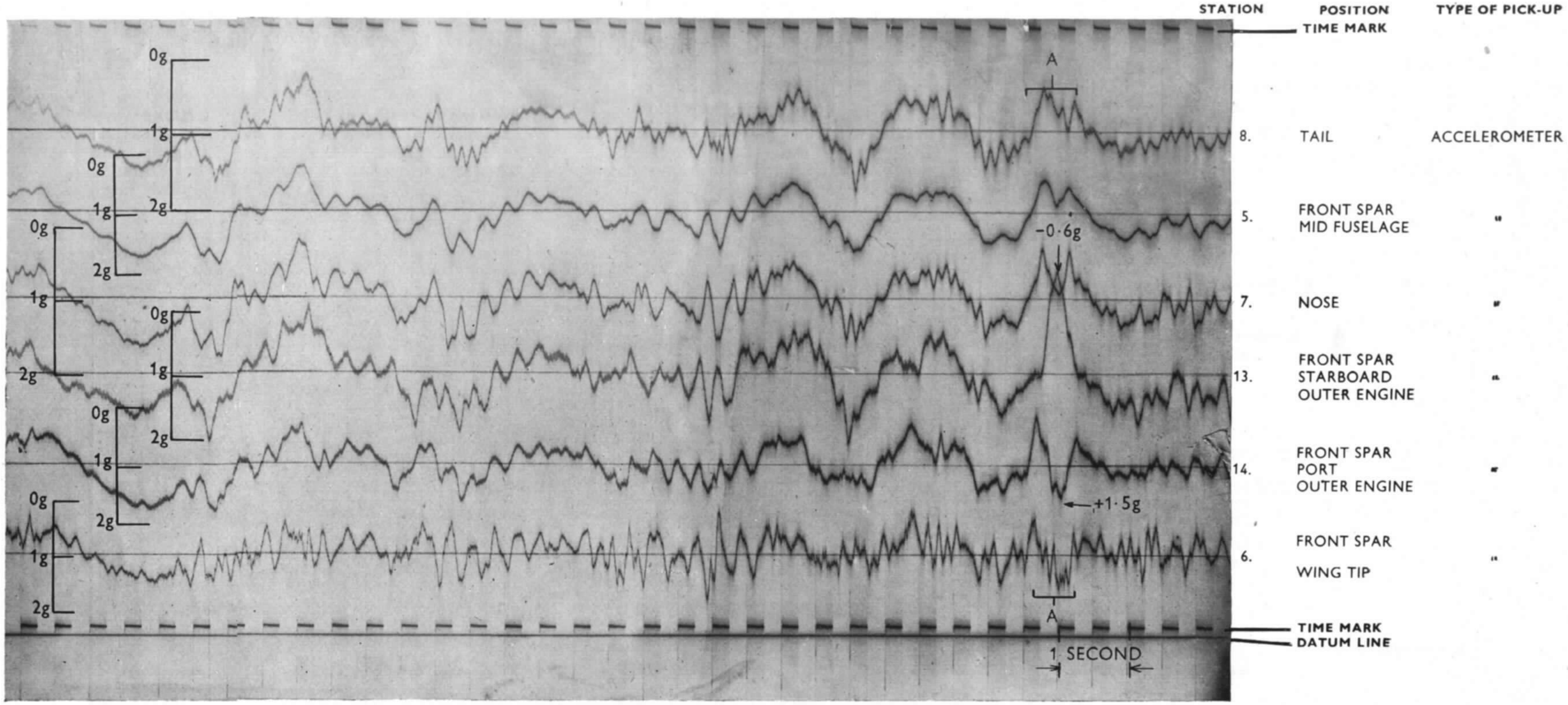
⑨ FRONT SPAR TOP BOOM AFT FACE NEAR CENTRELINE OF AIRCRAFT

⑩ REAR SPAR LOWER BOOM FRONT FACE, 18" TO PORT OF CENTRELINE OF AIRCRAFT

⑪ LOWER SPAR BOOM JUST OUTBOARD OF THE INNER ENGINE PORT SIDE

⑫ LOWER SPAR BOOM JUST OUTBOARD OF THE INNER ENGINE STARBOARD SIDE

FIG. 1 (a & b). Accelerometer and strain-gauge positions.



NOTE: NO ASYMMETRICAL OSCILLATIONS ARE EXCITED BY ASYMMETRICAL GUST LOADING AT 'AA' THE ASYMMETRICAL LOADING IS DUE TO THE PORT WING ENTERING THE GUST BEFORE THE STARBOARD WING. THE GUST VELOCITY IS GREATER ON STARBOARD SIDE

DATE OF FLIGHT — MARCH, 23rd 1948
ALTITUDE — 5000 ft ABOVE M.S.L.
200 - 500 ft ABOVE GROUND LEVEL

I.A.S. — 160 KNOTS
LOCALITY — KENYA

FIG. 6. Accelerations measured in severe turbulence example of asymmetrical wing loading.

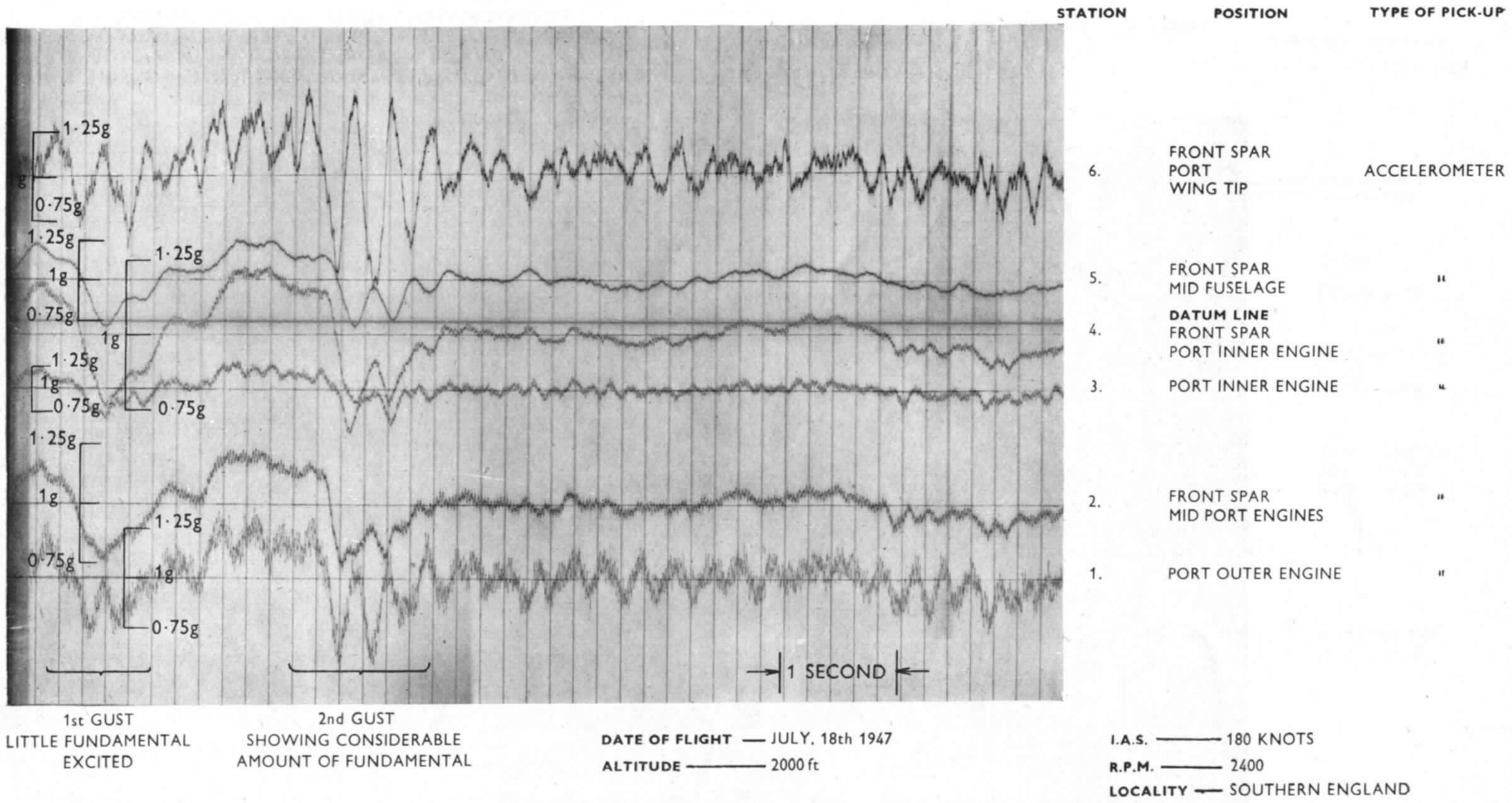
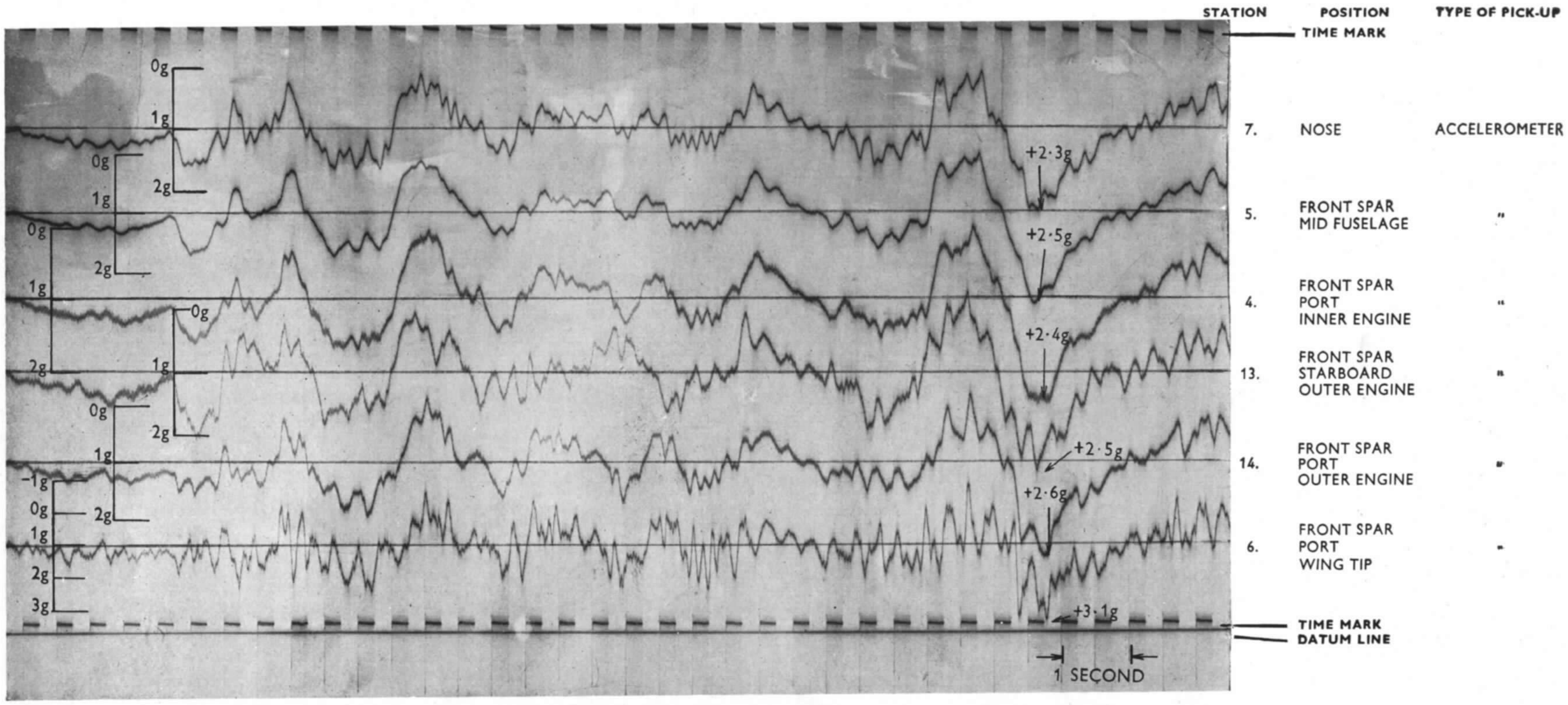


FIG. 7. Acceleration records of two light gusts showing varying amounts of fundamental oscillation excited.



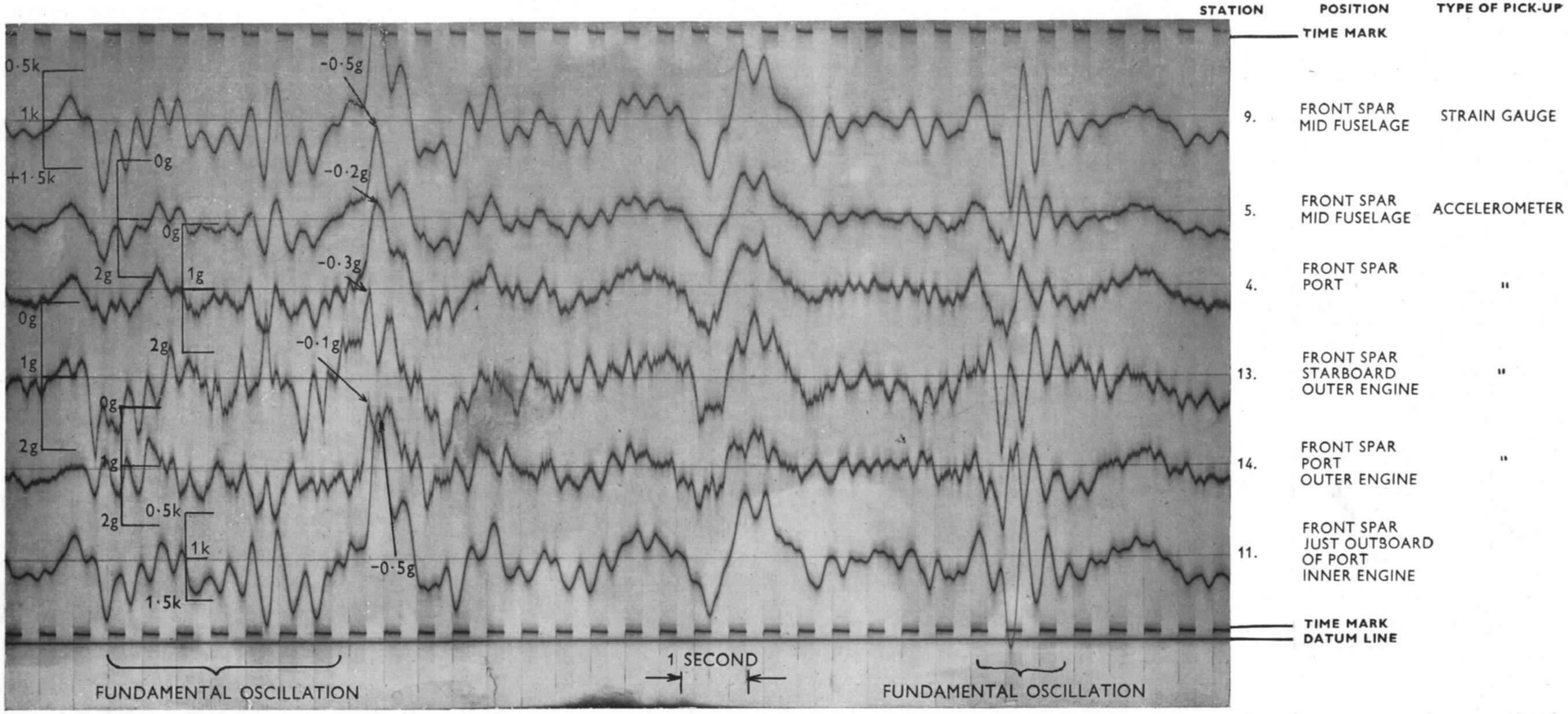
DATE OF FLIGHT ——— MARCH, 23rd 1948

ALTITUDE ——— 5000 ft ABOVE M.S.L.
200 - 500 ft ABOVE GROUND LEVEL

I.A.S. ——— 160 KNOTS

LOCALITY ——— KENYA

FIG. 11. Accelerations measured in severe turbulence.



NOTE: STRAIN SENSITIVITY, THE SCALE IS EXPRESSED IN TERMS OF 'k'.
THE CHANGE OF STRAIN BETWEEN STRAIGHT AND LEVEL FLIGHT AT
160 KNOTS AND PULLING OUT OF A DIVE AT 200 KNOTS APPROX.
WITH FUEL LOAD AS AT TIME OF RECORD

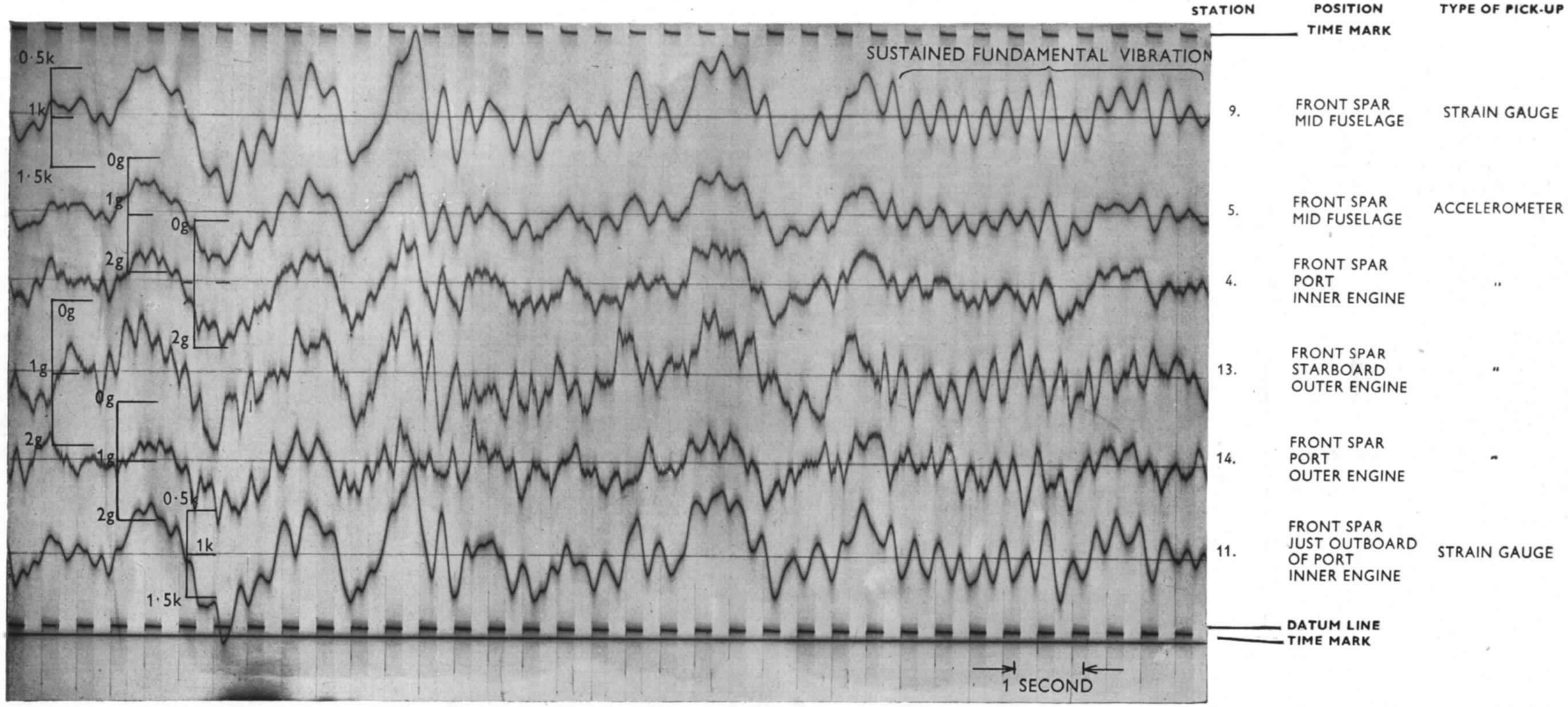
DATE OF FLIGHT — MARCH, 23rd 1948

ALTITUDE — 5000 ft ABOVE M.S.L.
200 - 500 ft ABOVE GROUND LEVEL

I.A.S. — 160 KNOTS

LOCALITY — KENYA

FIG. 12. Strains and accelerations measured in severe turbulence.



NOTE: STRAIN SENSITIVITY, THE SCALE IS EXPRESSED IN TERMS OF 'k'.
THE CHANGE OF STRAIN BETWEEN STRAIGHT AND LEVEL FLIGHT AT
160 KNOTS AND PULLING OUT OF A DIVE AT 200 KNOTS APPROX.
WITH FUEL LOAD AS AT TIME OF RECORD

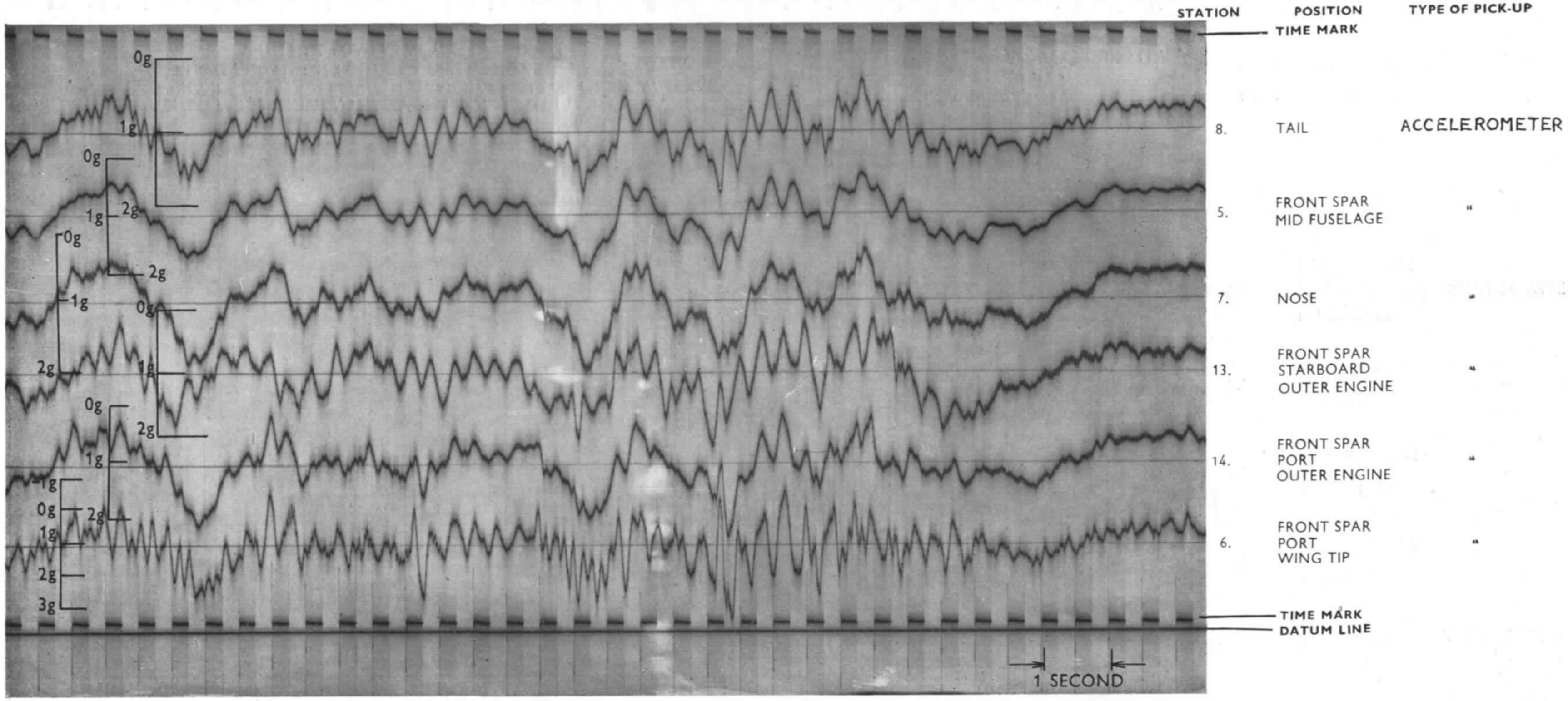
DATE OF FLIGHT — MARCH, 23rd 1948

ALTITUDE ——— 5000 ft ABOVE M.S.L.
200 - 500 ft ABOVE GROUND LEVEL

I.A.S. ——— 160 KNOTS

LOCALITY — KENYA

FIG. 13. Strains and accelerations measured in severe turbulence example of sustained fundamental vibration.



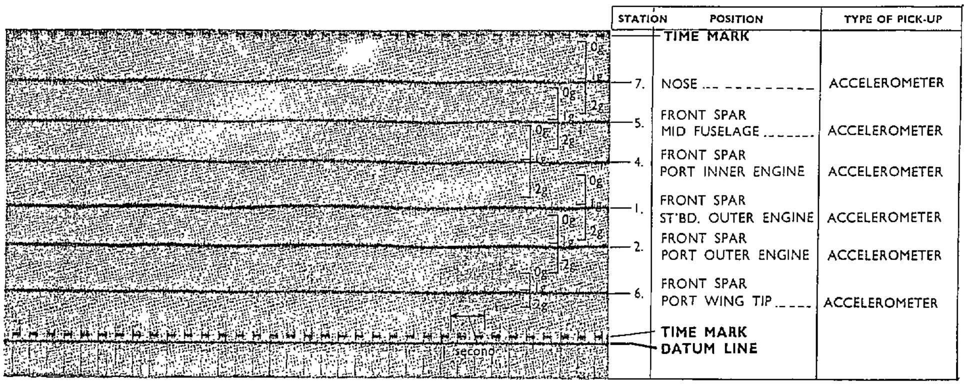
DATE OF FLIGHT — MARCH, 23rd 1948

I.A.S. — 160 KNOTS

ALTITUDE — 5000 ft ABOVE M.S.L.
200 - 500 ft ABOVE GROUND LEVEL

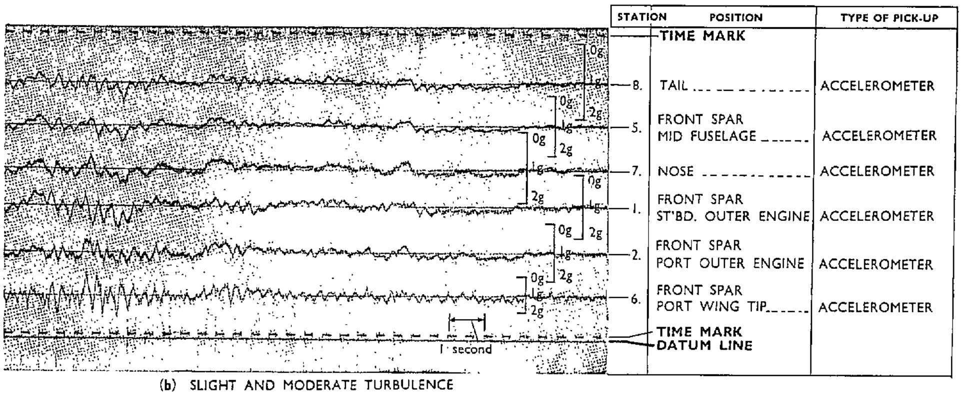
LOCALITY — KENYA

FIG. 14. Accelerations measured in severe turbulence.



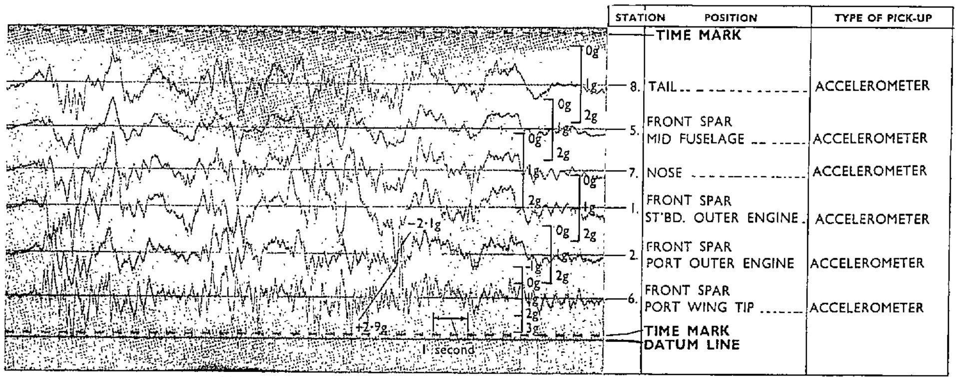
STATION	POSITION	TYPE OF PICK-UP
	TIME MARK	
7.	NOSE	ACCELEROMETER
5.	FRONT SPAR MID FUSELAGE	ACCELEROMETER
4.	FRONT SPAR PORT INNER ENGINE	ACCELEROMETER
1.	FRONT SPAR ST'BD. OUTER ENGINE	ACCELEROMETER
2.	FRONT SPAR PORT OUTER ENGINE	ACCELEROMETER
6.	FRONT SPAR PORT WING TIP	ACCELEROMETER
	TIME MARK DATUM LINE	

(a) SMOOTH AIR



STATION	POSITION	TYPE OF PICK-UP
	TIME MARK	
8.	TAIL	ACCELEROMETER
5.	FRONT SPAR MID FUSELAGE	ACCELEROMETER
7.	NOSE	ACCELEROMETER
1.	FRONT SPAR ST'BD. OUTER ENGINE	ACCELEROMETER
2.	FRONT SPAR PORT OUTER ENGINE	ACCELEROMETER
6.	FRONT SPAR PORT WING TIP	ACCELEROMETER
	TIME MARK DATUM LINE	

(b) SLIGHT AND MODERATE TURBULENCE



STATION	POSITION	TYPE OF PICK-UP
	TIME MARK	
8.	TAIL	ACCELEROMETER
5.	FRONT SPAR MID FUSELAGE	ACCELEROMETER
7.	NOSE	ACCELEROMETER
1.	FRONT SPAR ST'BD. OUTER ENGINE	ACCELEROMETER
2.	FRONT SPAR PORT OUTER ENGINE	ACCELEROMETER
6.	FRONT SPAR PORT WING TIP	ACCELEROMETER
	TIME MARK DATUM LINE	

(c) SEVERE TURBULENCE

DATE OF FLIGHT — MARCH 23rd, 1948
ALTITUDE — 6000 ft ABOVE M.S.L.
1200 - 1500 ft ABOVE GROUND LEVEL
I.A.S. — 160 KNOTS
LOCALITY — KENYA

FIG.4a, b & c. ACCELERATIONS RECORDED IN VARIOUS DEGREES OF TURBULENCE

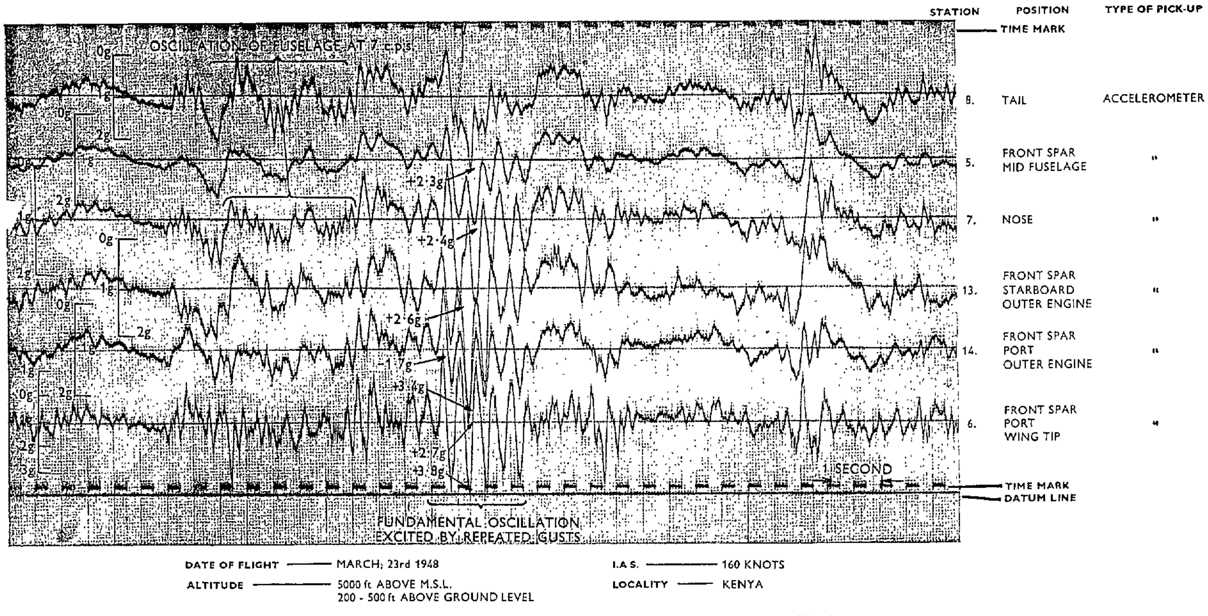
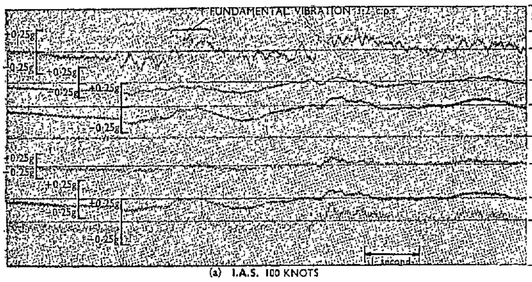
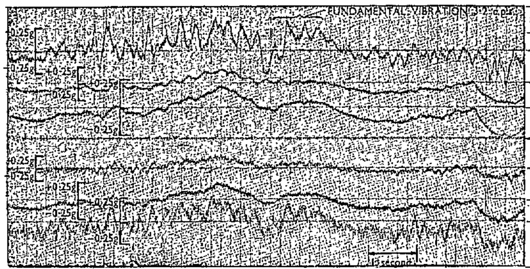


FIG. 5. Accelerations measured in severe turbulence example of severe fundamental oscillation.



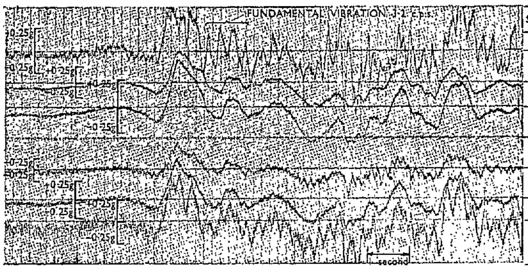
STATION	POSITION ON PORT WING	TYPE OF PICK-UP
6	FRONT SPAR WING TIP	ACCELEROMETER
5	FRONT SPAR MID FUSELAGE	ACCELEROMETER
4	FRONT SPAR BEHIND INNER ENGINE	ACCELEROMETER
	DATUM LINE	
3	INNER ENGINE	ACCELEROMETER
2	FRONT SPAR MID ENGINES	ACCELEROMETER
1	OUTER ENGINE	ACCELEROMETER

(a) I.A.S. 100 KNOTS



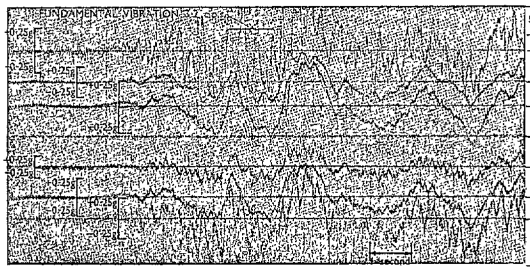
STATION	POSITION ON PORT WING	TYPE OF PICK-UP
6	FRONT SPAR WING TIP	ACCELEROMETER
5	FRONT SPAR MID FUSELAGE	ACCELEROMETER
4	FRONT SPAR BEHIND INNER ENGINE	ACCELEROMETER
	DATUM LINE	
3	INNER ENGINE	ACCELEROMETER
2	FRONT SPAR MID ENGINES	ACCELEROMETER
1	OUTER ENGINE	ACCELEROMETER

(b) I.A.S. 120 KNOTS



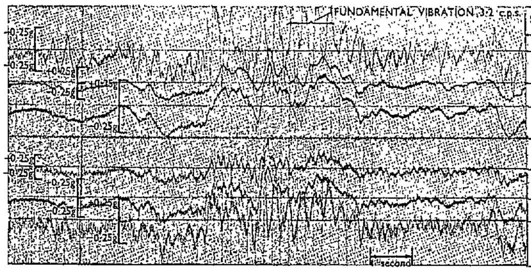
STATION	POSITION ON PORT WING	TYPE OF PICK-UP
6	FRONT SPAR WING TIP	ACCELEROMETER
5	FRONT SPAR MID FUSELAGE	ACCELEROMETER
4	FRONT SPAR BEHIND INNER ENGINE	ACCELEROMETER
	DATUM LINE	
3	INNER ENGINE	ACCELEROMETER
2	FRONT SPAR MID ENGINES	ACCELEROMETER
1	OUTER ENGINE	ACCELEROMETER

(c) I.A.S. 160 KNOTS



STATION	POSITION ON PORT WING	TYPE OF PICK-UP
6	FRONT SPAR WING TIP	ACCELEROMETER
5	FRONT SPAR MID FUSELAGE	ACCELEROMETER
4	FRONT SPAR BEHIND INNER ENGINE	ACCELEROMETER
	DATUM LINE	
3	INNER ENGINE	ACCELEROMETER
2	FRONT SPAR MID ENGINES	ACCELEROMETER
1	OUTER ENGINE	ACCELEROMETER

(d) I.A.S. 200 KNOTS



STATION	POSITION ON PORT WING	TYPE OF PICK-UP
6	FRONT SPAR WING TIP	ACCELEROMETER
5	FRONT SPAR MID FUSELAGE	ACCELEROMETER
4	FRONT SPAR BEHIND INNER ENGINE	ACCELEROMETER
	DATUM LINE	
3	INNER ENGINE	ACCELEROMETER
2	FRONT SPAR MID ENGINES	ACCELEROMETER
1	OUTER ENGINE	ACCELEROMETER

(e) I.A.S. 240 KNOTS

DATE OF FLIGHT — JULY 29th, 1947
R.P.M. — 2600
ALTITUDE — 6500 ft
LOCALITY — SOUTHERN ENGLAND

FIG.3. ACCELERATIONS FLYING AT VARYING AIR SPEEDS INTO SAME BANK OF CLOUDS

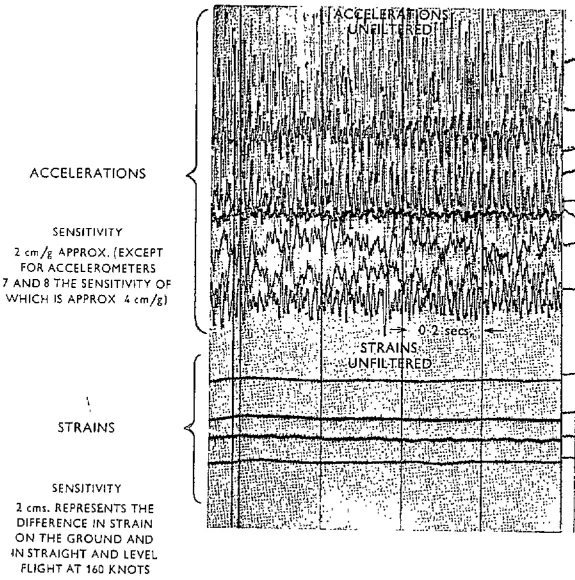


FIG. 2a. Sample of record obtained with no filtering of engine and air-screw accelerations.

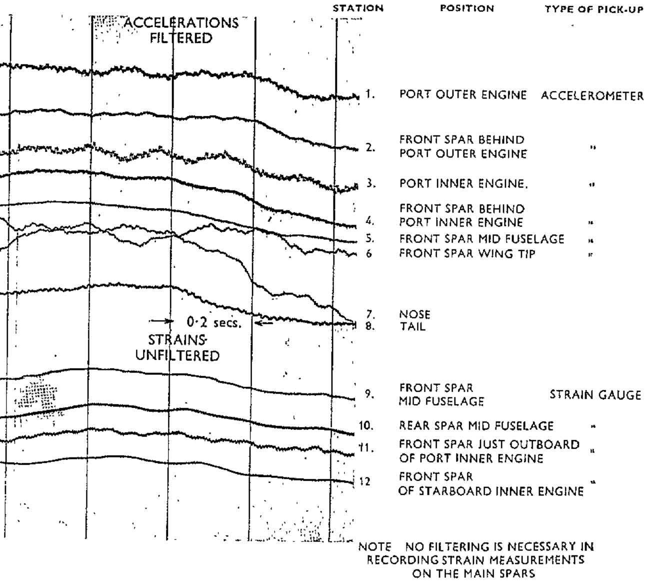


FIG. 2b. Sample of record obtained a few seconds later using filter for accelerations.

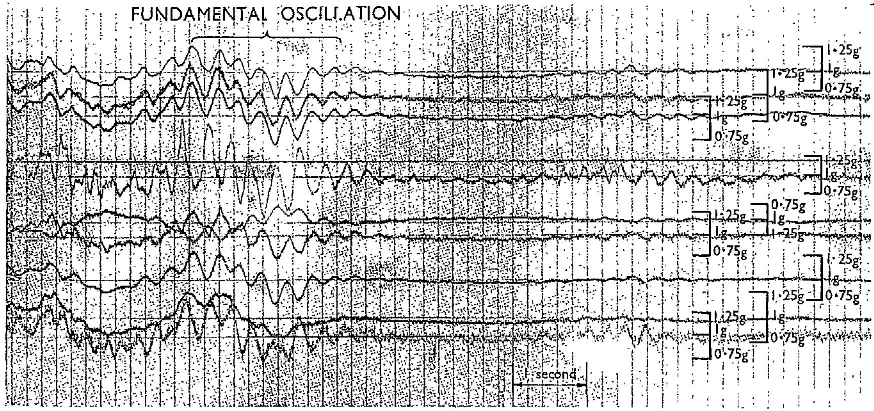


FIG.8

STATION	POSITION	TYPE OF PICK-UP
12.	FRONT SPAR JUST OUTBOARD OF STARBOARD INNER ENGINE	STRAIN GAUGE
11.	FRONT SPAR JUST OUTBOARD OF PORT INNER ENGINE	STRAIN GAUGE
10.	REAR SPAR MID FUSELAGE	STRAIN GAUGE
DATUM LINE		
6.	FRONT SPAR PORT WING TIP	ACCELEROMETER
5.	FRONT SPAR MID FUSELAGE	ACCELEROMETER
7.	NOSE	ACCELEROMETER
9.	FRONT SPAR MID FUSELAGE	STRAIN GAUGE
2.	FRONT SPAR BETWEEN PORT INNER AND PORT OUTER ENGINES	ACCELEROMETER
1.	PORT OUTER ENGINE	ACCELEROMETER

DATE OF FLIGHT—OCTOBER 30th, 1947 **LOCALITY**—SOUTHERN ENGLAND
ALTITUDE—4000 feet **I.A.S.**—170 knots **R.P.M.**—2400

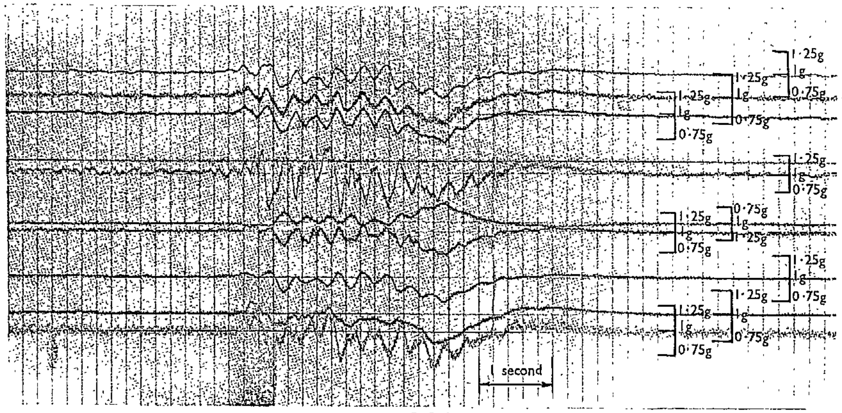


FIG 9

STATION	POSITION	TYPE OF PICK-UP
12.	FRONT SPAR JUST OUTBOARD OF STARBOARD INNER ENGINE	STRAIN GAUGE
11.	FRONT SPAR JUST OUTBOARD OF PORT INNER ENGINE	STRAIN GAUGE
10.	REAR SPAR MID FUSELAGE	STRAIN GAUGE
DATUM LINE		
6.	FRONT SPAR PORT WING TIP	ACCELEROMETER
5.	FRONT SPAR MID FUSELAGE	ACCELEROMETER
7.	NOSE	ACCELEROMETER
9.	FRONT SPAR MID FUSELAGE	STRAIN GAUGE
2.	FRONT SPAR BETWEEN PORT INNER AND PORT OUTER ENGINES	ACCELEROMETER
1.	PORT OUTER ENGINE	ACCELEROMETER

DATE OF FLIGHT—OCTOBER 30th, 1947 **LOCALITY**—SOUTHERN ENGLAND
ALTITUDE—4000 feet **I.A.S.**—170 knots **R.P.M.**—2400

FIG.8 & 9. STRAINS AND ACCELEROMETERS MEASURED WHEN FLYING IN AND OUT OF SMALL CUMULUS CLOUD

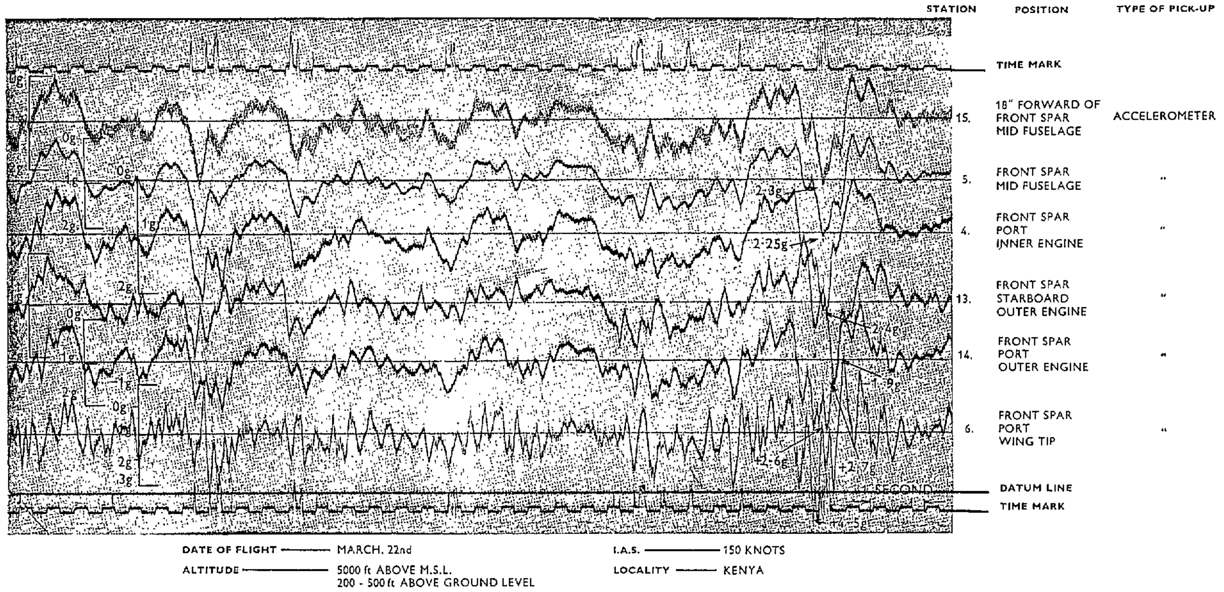


FIG. 10. Accelerations measured in severe turbulence.

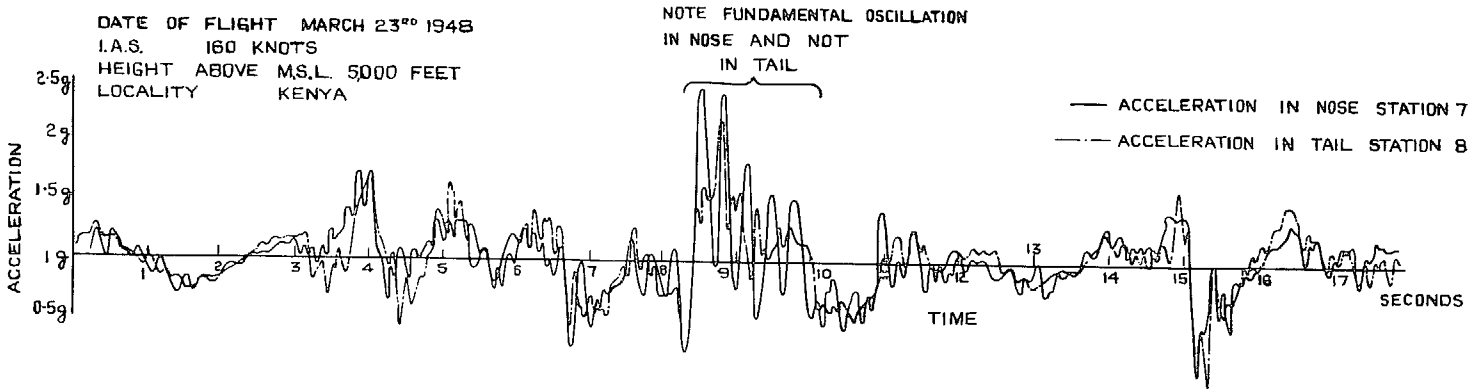


FIG 15 (a) ACCELERATIONS OF NOSE & TAIL

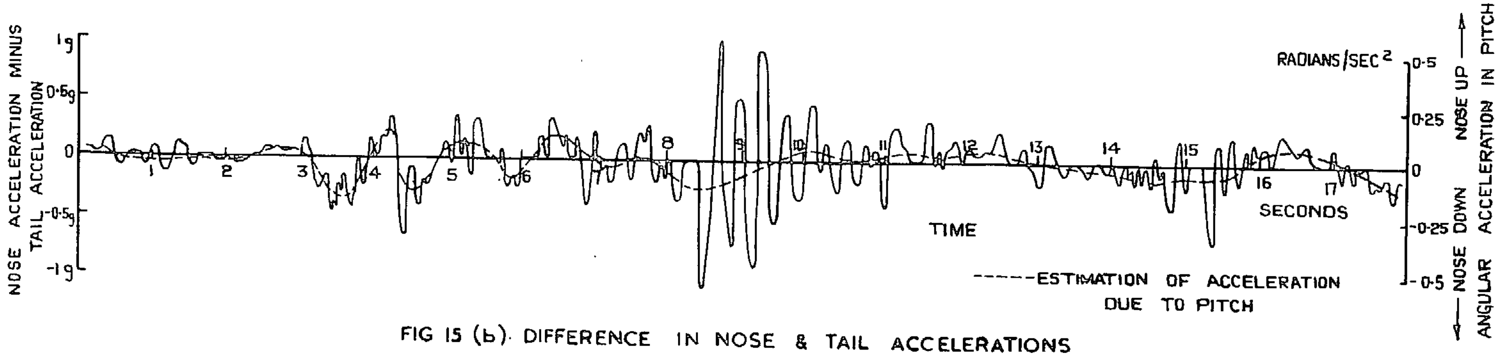


FIG 15 (b). DIFFERENCE IN NOSE & TAIL ACCELERATIONS

Fig. 15 (a & b). Pitching acceleration of aircraft in severe turbulence obtained from nose and tail accelerations.

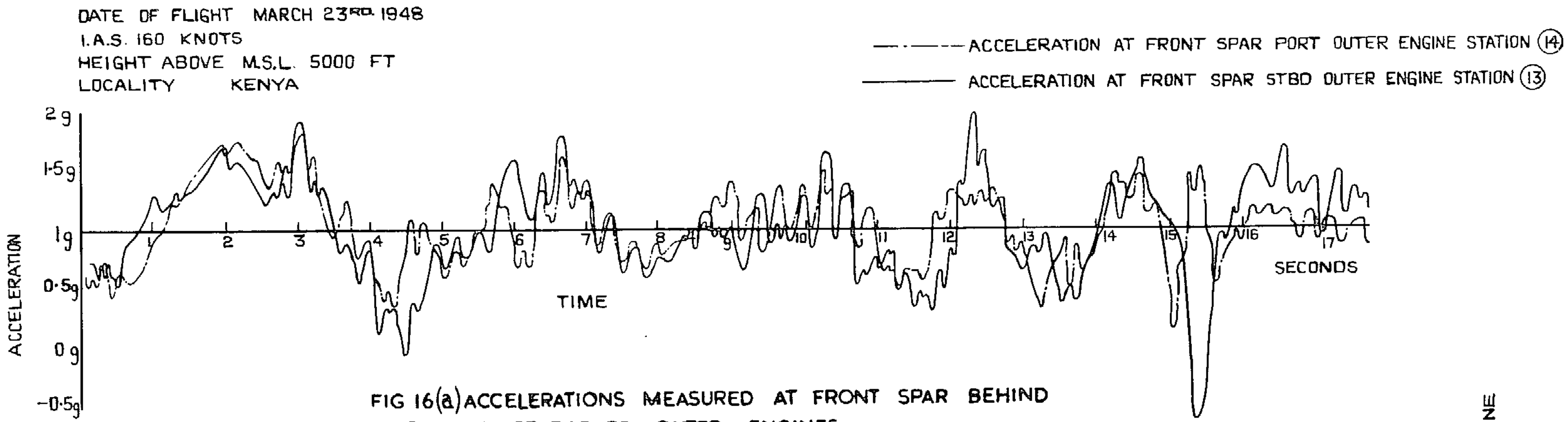


FIG 16(a) ACCELERATIONS MEASURED AT FRONT SPAR BEHIND PORT & STARBOARD OUTER ENGINES

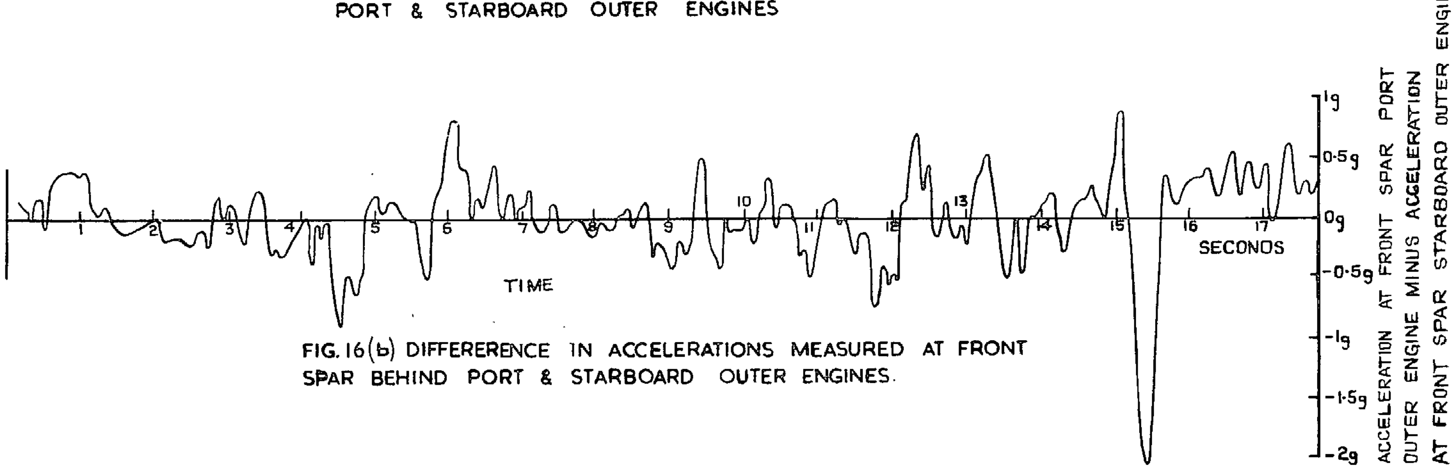


FIG. 16(b) DIFFERERENCE IN ACCELERATIONS MEASURED AT FRONT SPAR BEHIND PORT & STARBOARD OUTER ENGINES.

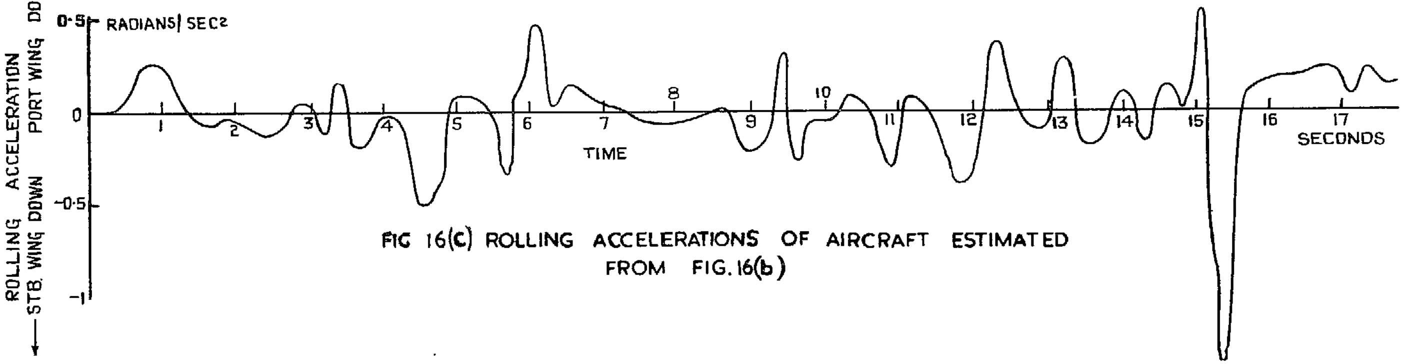


FIG 16(c) ROLLING ACCELERATIONS OF AIRCRAFT ESTIMATED FROM FIG. 16(b)

FIG. 16 (a, b & c). Rolling acceleration of aircraft in severe turbulence obtained from port and starboard wing accelerations.

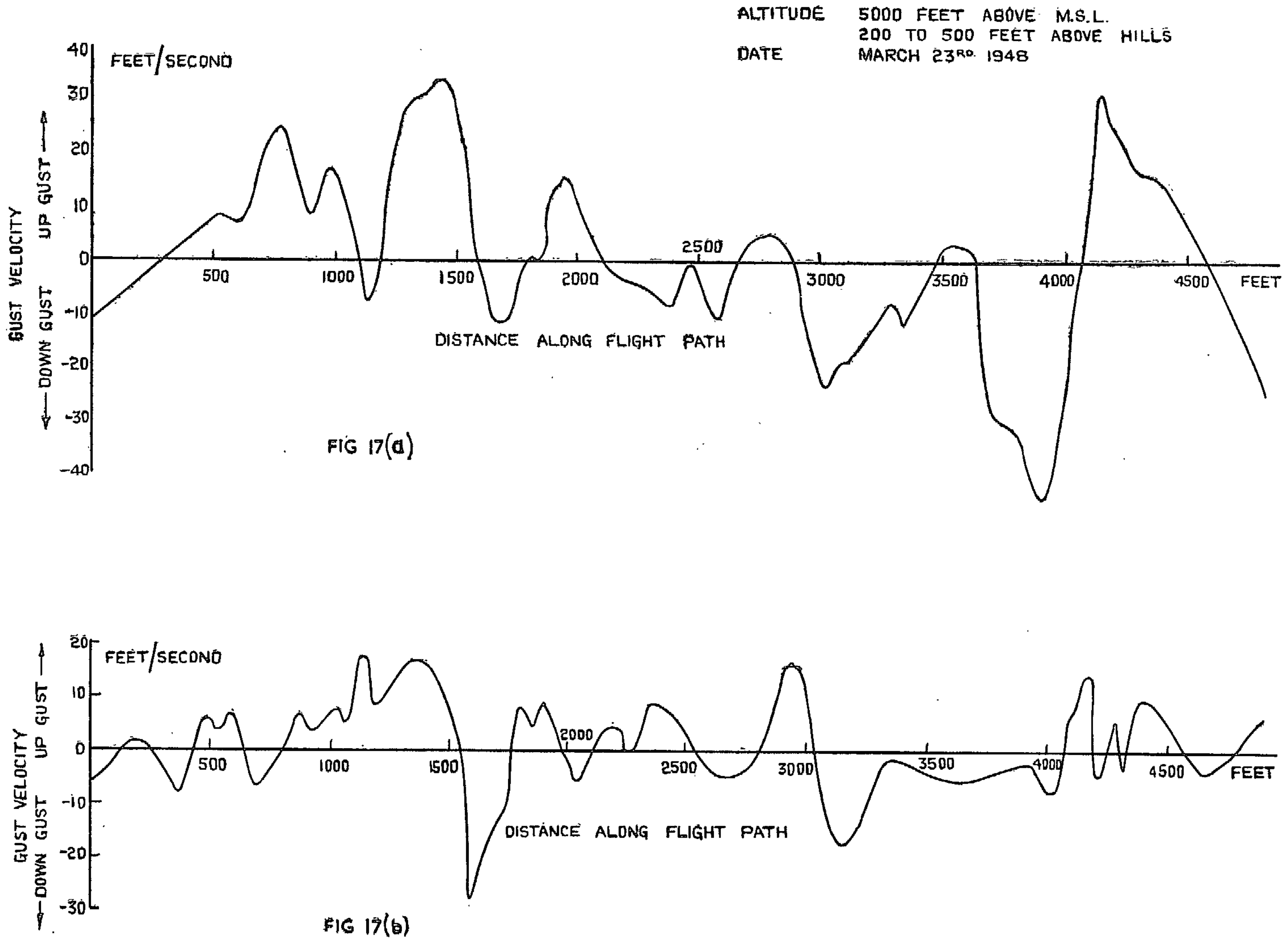


FIG 17(a)

FIG 17(b)

FIG. 17 (a & b). Plots of gust velocity along flight path from record taken in Kenya in severe turbulence.

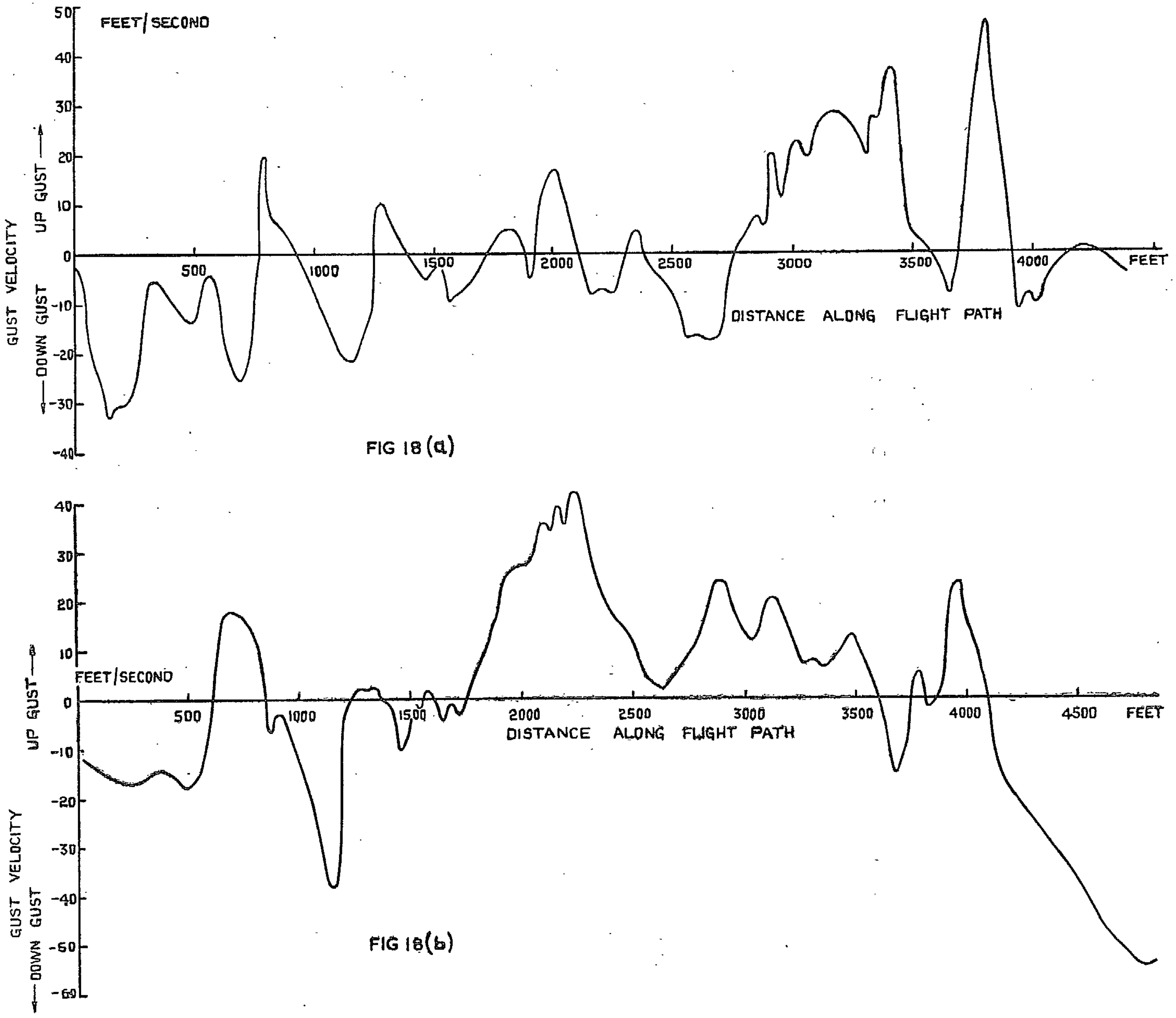


Fig. 18 (a & b). Plots of gust velocity along flight path from records taken in Kenya in severe turbulence.

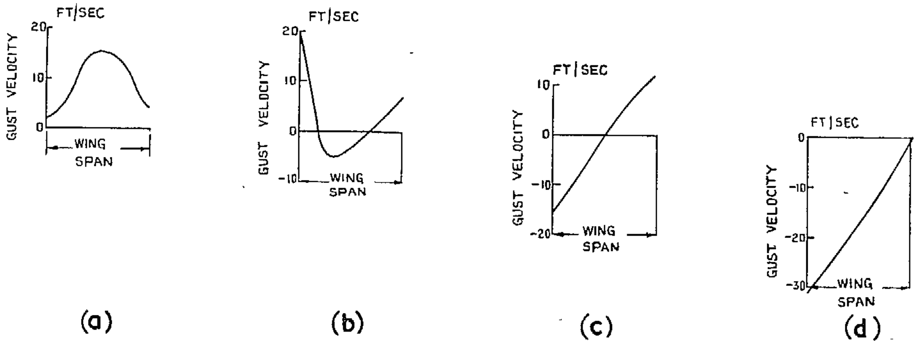


FIG. 19. Possible distributions of gust velocity across the wing span deduced from gust distribution along the flight path.

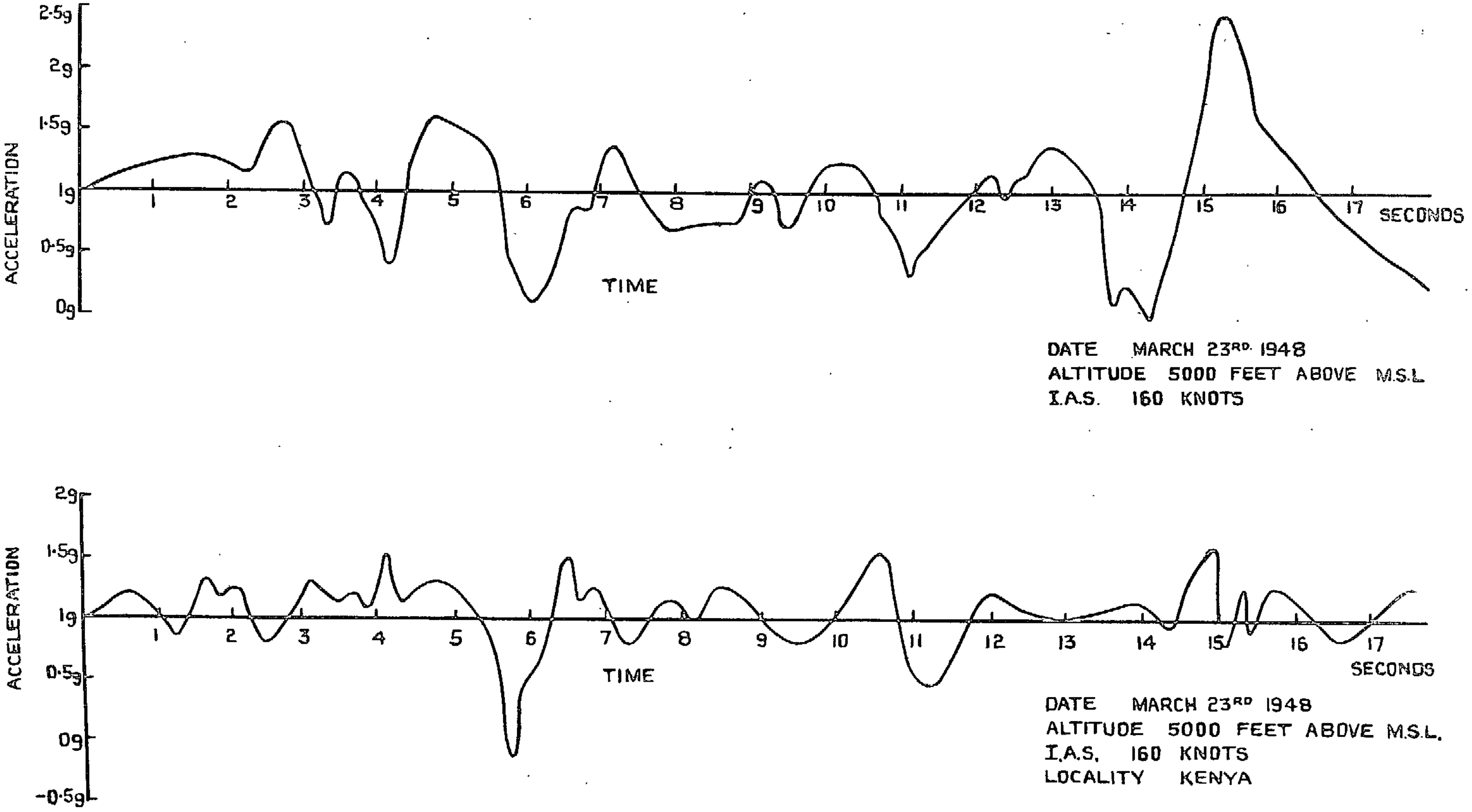
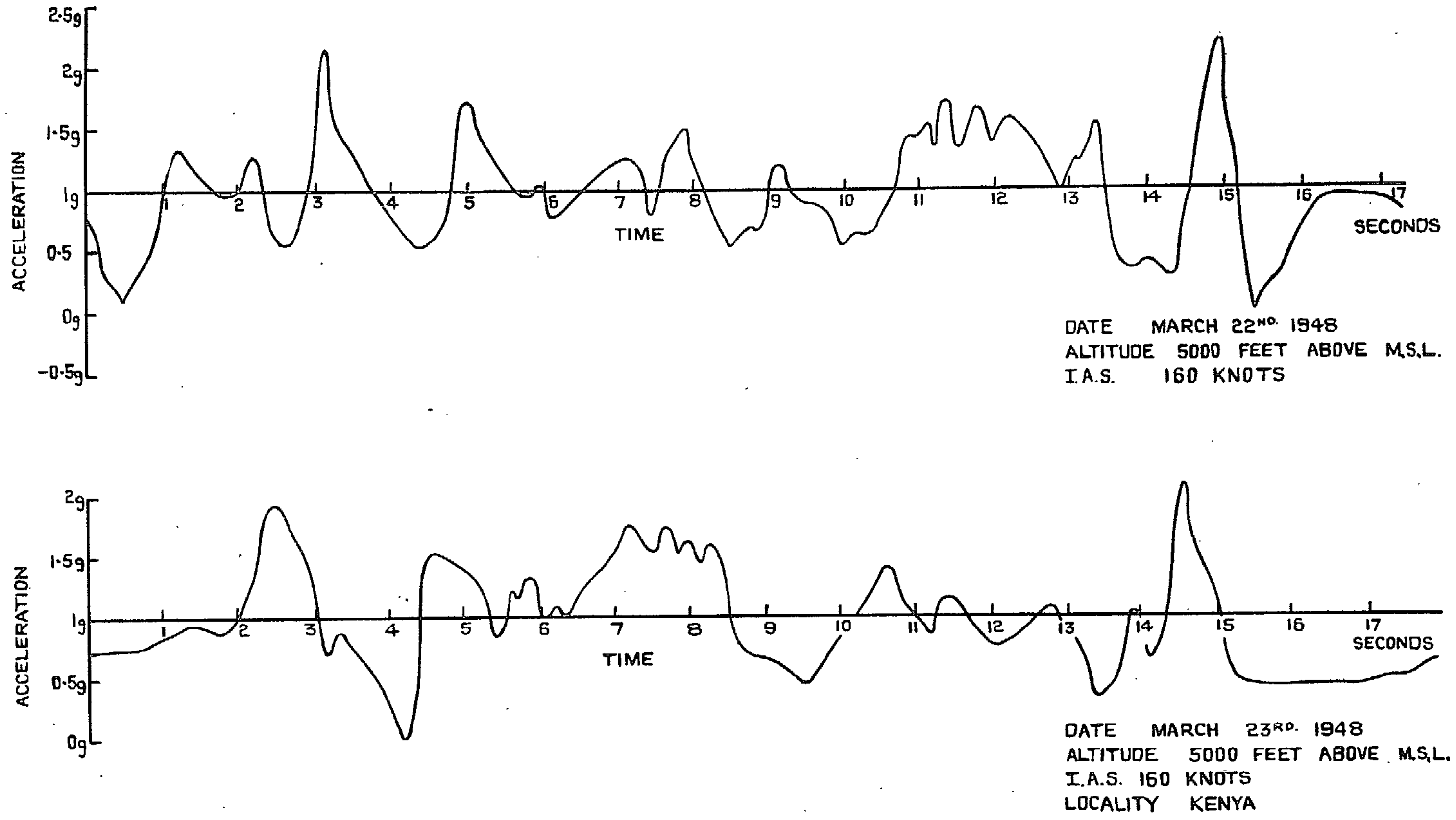


FIG. 20. Normal acceleration of aircraft as a whole deduced from records taken in severe turbulence.



DATE MARCH 22ND. 1948
ALTITUDE 5000 FEET ABOVE M.S.L.
I.A.S. 160 KNOTS

DATE MARCH 23RD. 1948
ALTITUDE 5000 FEET ABOVE M.S.L.
I.A.S. 160 KNOTS
LOCALITY KENYA

FIG. 21. Normal acceleration of aircraft as a whole deduced from records taken in severe turbulence.

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