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Civil Aircraft Airworthiness Data Recording Programme

Hard Landings Encountered by Subsonic Civil Jet Aircraft

by

The CAADRP Special Events Working Party

(Co-ordinated by G. B. Hutton)

Structures Dept., R.A.E., Farnborough

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CIVIL AIRCRAFT AIRWORTHINESS DATA RECORDING PROGRAMME

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SUMMARY

A number of jet aircraft in normal airline service were fitted with recorders producing continuous trace records of 14 parameters. Throughout the recording period, representing 11462 scheduled airline flights, the records were searched for unusual occurrences, and each one studied to determine its nature and, where possible, factors contributing to its cause.

This Report describes a selection of events which involved hard landings occurring on two types of aircraft during the period December 1965 to October 1969. The event descriptions include comments, most of which mention contributory causes of the hard landings. A particular study is made of the normal CG acceleration at touchdown and of aircraft manoeuvres during the flare.

It is shown that all the hard landings followed abnormal flare manoeuvres.

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* Replaces RAE Technical Report 70187 - ARC 33031

CONTENTS

1 INTRODUCTION

The object of the Civil Aircraft Airworthiness Data Recording Programme is a systematic study of the normal operational flight of civil transport aircraft. A small number of aircraft in regular airline service are fitted with analogue paper trace recorders which collect data in the form shown in Fig.1. Additional parameters have been introduced since the start of recording and the whole programme is described fully elsewhere[1].

From time to time unusual or extreme events (Special Events) are noted and this Report contains a selection of such events comprising hard landings. Accident investigation summaries[2] show that during five years up to the middle of 1968 heavy landings were a major or contributory cause of ten of the 130 reported civil aircraft accidents. The hard landings presented in this Report were all manual landings and occurred on two types of passenger-carrying subsonic jet aircraft in scheduled airline service (i.e. excluding training and test flights) during the period December 1965 to October 1969. The aircraft are denoted Types D and E and two aircraft of each type were instrumented. The recording period covered by individual aircraft ranged from two years to three years five months; Type D completed 4161 landings and Type E 7301 landings.

The Special Events are presented in the form of a reproduction* of the original record, together with information about the event and comments which represent the opinion of a Working Party comprising members of RAE, ARB, Board of Trade, CI Data Centre, Meterological Office and the airline concerned.

Special events relating to other aspects of flight are the subjects of earlier Reports and Technical Memoranda.

2 NOTE ON SELECTION OF SPECIAL EVENTS

After the photographic record has been developed it is examined and annotated by the airline concerned. It is then scrutinised by a member of the Working Party for Special Events, and finally examined in detail at the Data Centre (CI Data Centre) during routine analysis. There are thus at least three stages in which a Special Event occurring during a recorded flight may be detected. It should be noted, however, that it is not normally possible to relate the frequency of Special Events to the frequency of operational occurrences.

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*Definition is necessarily lost in photographic reproduction of records; comments are frequently based on observation from the original records. Values quoted are also measured from these.

It is not possible to lay down a hard and fast guide as to what is regarded as an unusual or extreme event, but the following is a summary of the type of occurrences looked for in the search:

(a) Normal CG (centre of gravity) acceleration increments of about ±1.0 g or larger while airborne.

(b) Rapid and large changes in height or airspeed.

(c) Excessive application of any flight control.

(d) Infrequent operational events, such as abandoned take-offs, missed approaches, engine failures, engine-out landings, etc.

(e) Unusual oscillations on any of the traces.

(f) Exceedances of operational limitations such as maximum operating speeds.

For the purpose of this Report landings regarded as being eventful were those which contained an incremental CG acceleration of 0.8 g, or above, relative to the 1 g datum.

Despite the fact that each record is examined at least three times, it is unlikely that every unusual event will be detected; this is particularly true of certain of the operational events, such as engine failure. Hence, any frequencies derived from these data should be treated with caution; nevertheless it is considered that a very high proportion of hard landings, as defined above, have been detected. It is intended that frequency data will be summarised in one form or another from time to time, and will be based on the information contained in the full routine analysis programme.

3 SPECIAL EVENTS

Fig.1 shows a sample of a normal flight and landing to familiarise the reader with recorded parameters.

The events have been grouped according to aircraft type as follows:

Figs.2 to 16, aircraft Type D.

Figs.17 to 38, aircraft Type E.

In each group the events are presented in the order in which they occurred.

4 MEASUREMENTS

Presented in Table 1 are measurements of the more important parameters relevant to the hard landing problem taken from the original record of each event. In some cases certain measurements were unobtainable for various reasons, such as traces obscuring each other at the point of interest, the trace being too faint to identify with certainty or the parameter not being monitored at the time. The following measurements are tabulated:

(a) Aircraft weight to nearest 100 kg.

(b) Touchdown speed relative to Target Threshold Speed. The Target Threshold Speed is partly dependent upon the wind speed near the ground at the time of the approach. This information was not available for many events particularly for Type E aircraft. However, the simpler system of Target Threshold Speed selection on this aircraft (see section 5.3) allowed a reasonably accurate assessment of its value to be made (see section 5.3.2).

(c) Height above the airfield at the start of engine power reduction. This information was available from Type D aircraft recordings only and was deduced from the change in barometric height from the start of power reduction to touchdown. These heights above the airfield are not corrected for errors due to ground effect and airspeed and probably have a systematic deviation from the true height.

(d) Flare type. Reference to aircraft flare are with regard to the motion of the aircraft in response to the pilot's action upon the elevator control. The start of the flare is recognised by the aircraft pitching nose upwards (the nose-up attitude being maintained until touchdown) accompanied by a rise in CG acceleration (also often maintained until touchdown).

Landing flare manoeuvres are grouped subjectively into five types. There is no well defined boundary dividing all types and that which best describes the flare of a few landings may be debatable. The five types are designated C, I, L, N and R and are shown diagrammatically in Fig.39 with the resulting normal acceleration histories. They are defined as follows:

Type C (Conventional manoeuvre)

The manoeuvre which reduces the rate of descent steadily over a period of about 7 sec and from a height (at the main wheels) of 40 to 60 ft before touching down at a descent rate of 1 to 3 ft/sec. The height found by the airlines to be generally most desirable differs for each aircraft type and is 50 to 60 ft for Type D and 35 to 45 ft for Type E.

Type I (Insufficient flare)

The flare is initiated at a time of more than 3 sec before touchdown but the average positive normal acceleration applied over this period is insufficient to reduce the rate of descent to an ideally low level.

Type L (Late flare)

The flare is initiated late, at a time of 3 sec or less before touchdown, insufficient time being available to reduce the descent rate sufficiently to avert a hard landing.

Type N (No flare)

No flare is applied, or is initiated so late before touchdown that the rate of descent is reduced by less than 1 ft/sec.

Type R (Rate of descent increased after flare)

On completion of a successful flare-out an increased rate of descent is re-introduced before touching down.

(e) Rate of descent at touchdown. This was estimated from radio height and normal acceleration and is accurate to within about 20%. Since a known radio height time history was essential estimates were obtained for aircraft Type E only.

(f) Total maximum normal CG acceleration increment above the 1 g datum. This is the peak value recorded and includes oscillations caused by structural vibrations of airframe modes at frequencies up to about 12 Hz. Fig.40 shows the frequency response of the instrumentation fitted in each aircraft type. The events from aircraft Type E in Fig.17 and 18, however, were obtained using the accelerometer system for Type D.

(g) Aerodynamic lift above the 1 g datum at touchdown.

(h) Rate of change of lift immediately prior to touchdown.

(i) Maximum normal acceleration increment above the 1 g datum ignoring the oscillations caused by structural vibration. Due to the recording film speed employed the mean level through the 'structural' oscillations could only be determined approximately; values are quoted to the nearest 0.05 g but all values are not necessarily to this accuracy.

(j) Angle of aircraft bank at the instant of touchdown. Positive sign indicates starboard wing down in accordance with British standard nomenclature. Recording sensitivity allowed an accuracy of no better than plus and minus one degree from the stated value.

Measurements (f), (g), (i) and (j), are given for each impact in multiple-impact landings.

Actual indicated airspeed at threshold was also measured from Type E recordings (this was unobtainable from Type D records) and is presented in Table 2 together with aircraft weight, Target Threshold Speed and speed at touchdown.

5 DISCUSSION

5.1 The component parts of the normal CG acceleration

This study assumes the overall CG acceleration envelope during the landing impact to be composed of three components, each being due to one of the following factors:

(i) Aerodynamic lift.

(ii) Structural vibration.

(iii) Undercarriage oleo load.

The CG accelerometer was situated very close to the aircraft centre of gravity and the instrument was influenced insignificantly by aircraft pitching. Accurate correlation cannot be assumed to exist between peak CG acceleration and structural loads owing to the individual components of the acceleration being generated by loading actions on different parts of the aircraft. Separation of the undercarriage load component (i.e. maximum acceleration above the lift datum ignoring structural oscillations) was accomplished but the results (see 5.5 below) are approximate owing to the lack of detail definition on the analogue records. This, however, should not be a problem on digital records with a sampling rate of at least 16/sec. This component separation technique provides more realistic data which should aid designers in catering for actual operating conditions and assist investigators in determining spheres in need of particular attention.

The oscillations superimposed upon the undercarriage load component were probably related to airframe resonance modes. The amplitude of these high frequency components varied widely from landing to landing and in the most extreme case (Fig.37) 37% of the overall peak acceleration was estimated* to have been produced by an airframe mode; possibly the first fuselage mode at about 4 Hz. Load assessments from these higher frequency oscillations on the analogue records are not possible owing to their frequencies being unresolvable and the particular mode being excited thus unidentifiable.

5.2 Acceleration response of aircraft types to landing impact

Although a peak incremental CG acceleration of 0.8 g (which includes 'structural' oscillations) was chosen as the threshold qualifying for selection as a Special Event on both aircraft types, this represents a greater rate of descent at touchdown on Type D then Type E, assuming the contribution from structural vibration on Type D to be no greater than on Type E. This is shown by drop tests (simulated landing tests), conducted by the manufacturers, on the main undercarriages of each aircraft. In these tests the undercarriage of Type D displayed an upper-mass acceleration 75% of that of Type E at the same impact vertical velocity.

5.3 Aircraft speed at touchdown

The aircraft's indicated airspeed at touchdown in each landing was measured and compared with the Target Threshold Speed by subtracting the latter from the former. These results are presented in Table 1. The methods of determining the required Target Threshold Speed differ slightly with aircraft type and are described below. Values of VAT are presented in the Flight Manuals and tabulated against aircraft weight. (In this study flap and slat geometry was assumed to be common in all landings of each aircraft type.) The variation in touchdown speed minus threshold speed, dealt with in section 5.3.2 below, is due to differing throttle closing procedures near the threshold and variations in the time from threshold to touchdown. Typically, on both aircraft types, the rate of change of airspeed after the start of throttle closure is 2-4 kt/sec

5.3.1 Aircraft Type D

Target Threshold Speed was VATo + $\frac{1}{3}$ wind speed if above 10 kt up to a maximum of VATo + 15 kt. In only seven events was Target Threshold Speed determinable as wind speed information was unavailable for the remainder. On average, the touchdown speed was 7 kt less than the Target Threshold Speed with

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*Due to the film traverse speed adopted any analysis of the higher frequency oscillations from the present CAADRP analogue records is extremely difficult and assessments made are very rough.

a standard deviation of 7.7 kt. The actual speed at threshold could not be measured as the speed generally fell continuously during the final approach and the threshold point could not be determined.

5.3.2 Aircraft Type E

For the landings in Figs.17 to 34 the Target Threshold Speed was VAT + 10 kt for all conditions. For the remaining landings (Figs.35 to 38), due to a change in operating procedure, the Target Threshold Speed was VAT + 5 in smooth conditions and when wind shear or gusts were likely, VAT + 10 kt was required. In the landings in Figs.35 to 38 the appearance of the fine airspeed trace was used to judge the gustiness of the wind and thus determine which speed was most likely required. VAT + 10 kt was assumed in cases where gusts of greater than ±5 kt amplitude were evident in the last minute of approach. Accordingly actual indicated touchdown speed relative to Target Threshold Speed was obtained for all landings except one for which aircraft weight was unavailable. The average value of touchdown speed minus Target Threshold Speed was -9 kt with a standard deviation of 6.4 kt. The airspeed during the final approach was steady to within 2 or 3 kt until the start of flare in nearly all the landings on this aircraft type as auto-throttle is usually in use. This characteristic enabled the actual airspeed at threshold also to be measured with reasonable accuracy and compared with the Target Threshold Speed and touchdown speed. These values are presented in Table 2. Additionally touchdown speed minus actual speed at threshold (i.e. speed lost in flare expressed as a negative quantity) is shown, also actual threshold speed minus Target Threshold Speed. On average the actual indicated airspeed at threshold was only ½ kt below the Target Threshold Speed, the standard deviation being 3.5 kt. The average value of touchdown speed minus threshold speed for landings with Type R flares was -22 kt, the three values being -35, -19, and -21 kt; in these landings the throttle was not closed earlier than is normal and was after the height had reduced to 50 ft, i.e. after crossing the threshold. For those landings with Type I flares the average was -7 kt with a standard deviation of 5.7 kt and those with flare Types L and N was -5 kt with a standard deviation of 10.7 kt. These values serve to illustrate the large amount of airspeed which is lost during Type R flare manoeuvres compared with that lost during other types of manoeuvre.

5.4 Types of flare manoeuvre

Section 4 defines various types of flare manoeuvre and the flare performed in each event is classified accordingly. In six events the flare was of Type I. In each case it was performed over a reasonable time period, ranging from 3 to 10 sec, but the mean level of normal acceleration was too low to reduce the rate of descent sufficiently for a light landing. In 21 events flare was initiated late in the landing process, at a time of 3 sec or less before touchdown, and is designated Type L. In three events the flare manoeuvre was of Type N. The manoeuvre began at less than half a second before touchdown (although the pilot initiated elevator movement up to about 1.3 sec before touchdown) and the rate of descent reduction, estimated from the normal acceleration, was less than 1 ft/sec. Manoeuvres of Types L and N may be a result of the pilot not being able to identify with sufficient accuracy his height above the runway.

Three events (Figs.25, 28 and 34) were regarded as possibly being intentionally firm landings due to the runway surface being covered with rain water or slush at the time; it is recommended in the flying manuals that a 'firm' or 'positive' landing be made in order to reduce the risk of loss of tyre adhesion by aquaplaning in these conditions.

The flare manoeuvre in six events was of Type R where, following a successful flare-out, the aircraft was still airborne and was then caused to descend more rapidly again. This possibly suggests that the flare was performed too briskly and/or too high and the pilot then became anxious to land the aircraft before losing an excessive amount of airspeed. One event (Fig.20) displays a flare manoeuvre which is a development of Type R. After the initial flare-out the aircraft's nose was pushed downwards and then flared again, this being repeated. The aircraft thus descended in a series of steps. It was during the third flare that the aircraft landed. This 'stepping' technique is often used in an attempt to achieve a light landing when the flare-out has been performed too high or too briskly. It is also considered in airline circles to be a useful technique when out of practice in landing the aircraft. Fig.20 possibly serves to illustrate the pilot's difficulty in such a situation in achieving a light landing and yet not taking an excessive time over the procedure and thus losing too much airspeed. The speed in this event had dropped to 124 kt by touchdown and at these low speeds elevator control effectiveness is often considerably reduced and excessive pitch angles would be required to effect sufficient reductions in descent rate to avert a hard landing.

It is clear that flare Types I, L and N would result in harder landings than would Type C (conventional flare manoeuvre) starting from the same initial descent rate but the general result of Type R manoeuvres is not so certain. For this reason a series of 42 consecutive landings was studied and the landing severities from flares of Type R were compared with those resulting from flares of Type C. This exercise is presented in the Appendix and Table 3 shows that the landings resulting from flare manoeuvres of Type R were generally more severe than those from Type C. The mean of the peak CG accelerations on impact (including contributions from structural vibrations of the lower modes) of Type R was 0.58 Δg and of Type C was 0.35 Δg.

The probable reason for Type R flare very often resulting in a hard landing is that, after re-instating the increased descent rate following the initial flare, the height, and hence time, which the pilot has remaining in which to control the aircraft's attitude and flight path is very small (in most cases less than 10 ft). A light landing will result if either (a) the aircraft's height on initiation of increased descent rate is less than 2-3 ft or (b) the height is sufficient (viz greater than about 20 ft) to allow the pilot to perform a further complete flare. If this height is below about 20 ft a light landing is very largely fortuitous.

5.5 Undercarriage loads and relative severities of second and third impacts

Presented in Table 4 for each landing impact in each event are values of maximum CG acceleration measured above the aerodynamic lift level and ignoring oscillations attributable to structural vibration modes. These values approximately represent the maximum vertical loads transmitted via the undercarriages. It can be seen that in six events (Figs.4, 5, 6, 8, 16 and 35) this load is higher on the second impact than the first, whereas in only two (Figs.5 and 8) is the overall landing severity (as indicated by the total peak CG acceleration) greater on the second impact. On aircraft Type D the most severe undercarriage vertical loads appear to be produced on the second impact. However, undercarriage drag loads may be considerably lower on the second impact depending upon the amount of wheel spin-up generated at the initial impact.

On no impact in any landing studied was there evidence of the nosewheel contacting the ground before the main wheels. There were, however, two landings which, for all practical considerations, included three-point landing impacts. These were the third impact in the landing of Fig.4 and the second impact in Fig.18. Whether or not the nosewheels were clear of the ground at impact was deduced from the aircraft pitch angle. If the angle at impact was greater than during the landing run-out the nosewheels were considered to be clear. In three landings (Figs.2, 30 and 35) this information was unobtainable, due either to the pitch attitude not being recorded or the trace being obscured by another at the point of interest.

From the foregoing it can be appreciated that events following the initial touchdown must also be monitored in order to observe the most severe landing loads.

Ref.3 demonstrates factors influencing the severity of second (and subsequent) landing impacts and shows how this might be alleviated.

5.6 Visibility conditions

Table 5 presents the visual conditions prevailing at the time of each landing, the second to last column indicating daylight or darkness and the last column the visual range (visibility) dictated by the weather conditions. The visibility was obtainable for only eight landings. None of these were critical, the visibility in the worst case being 4 nautical miles. Darkness was considered to range from half an hour after sunset to half an hour before sunrise. Of the total 37 landings 19 took place in daylight and 15 in darkness (the times of three landings were unavailable) representing a day/night ratio of 1.3:1. The ratios for the individual aircraft types were 2.1 for Type D and 0.9 for Type E. These values compare with 2.4 and 2.8 for all recorded landings during two years and one year from Types D and E respectively. This indicates that, for aircraft Type E especially, darkness is a contributory factor towards hard landings.

5.7 Crew awareness to impact severity

There is little evidence to show that pilots are able to judge the severity of a landing impact; the two cases for which any crew comment is available being too few to form any conclusions. In one event (Fig.22) on aircraft Type E on being subsequently asked to recall the landing the pilot could not remember the impact as being abnormally hard. Following another event (Fig.13), on aircraft Type D in this case, the pilot reported the landing as being 'firm' in the flight log and this is the only occasion when a flight log report was made on the severity of a landing impact during the 11462 landings covered by this study.

5.8 Effect of hard landings on the aircraft structure

Discussions with operators and manufacturers of both aircraft types revealed that it is improbable that any have suffered structural damage as a result of hard landings during scheduled flights and no reports of damage resulting from the events discussed in this Report have come to the notice of CAADRP.

6 RECOMMENDATION

A study to ascertain the factors resulting in the various types of flare manoeuvre occurring is recommended. From such a study certain piloting difficulties (e.g. visual cues) may become apparent which, if alleviated, should reduce the incidence of hard landings and render the landing phase of flight less hazardous.

Where possible, landing studies should investigate the significance of aerodynamic lift and structural vibration at touchdown and also of bounce and subsequent landings after initial touchdown.

7 CONCLUSIONS

The 37 Special Events represent the hardest landings found in nearly four years of CAADRP recording on four passenger-carrying subsonic jet aircraft. The aircraft were of two types (D and E) and in this period Type D performed a total of 4161 operational landings and Type E 7301.

The recorded normal CG acceleration at touchdown is generated from three principal sources. The respective components are separated and the overall acceleration level and two of the components (the contributions from aerodynamic lift and undercarriage load) are tabulated. This data should provide designers and design requirement authorities with an improved understanding of the nature of severe landings.

All the hard landings followed abnormal flare manoeuvres and the greater proportion (24 of the 37 landings) were caused by late flare initiation relative to the moment of touchdown, at a time of three seconds or less before touchdown. A study to ascertain the reason for these abnormal flares may lead to easing the pilot's task and alleviating the incidence of hard landings.

In a few landings where bounce occurred the maximum CG acceleration, ignoring vibration from structural modes, (i.e. the contribution from the undercarriage load) measured on the second impact was greater than on the first. Thus the initial contact with the ground on landing is not necessarily the most critical for undercarriage loading.

Appendix

It has been observed from CAADRP recordings that the flare manoeuvre preceding many landings is characterised by the aircraft being fully, or almost fully, flared followed by the descent rate being increased again, by the pilot pushing the elevator control forward, to the point of touchdown. This manoeuvre has been called Type R. It is most clearly witnessed in recordings from aircraft Type E on which radio height is recorded at altitudes below 400 to 500 ft; this gives a clear history of the aircraft's flight path with respect to time when over flat terrain. The descent rate achieved after the initial flare-out prior to pushing the aircraft's nose over again has ranged from a normal landing descent rate to a negative rate (i.e. the aircraft ascending).

The reasons for this type of flare manoeuvre occurring are not clear but it is likely that in these cases the pilot has misjudged his height above the ground during the flare and found himself still airborne when the flare was deemed complete. From this point the additional action is necessary in order to either land the aircraft at all or prevent its airspeed falling too low before touching down.

The effect of this type of manoeuvre on the severity of the subsequent landing is not so obvious as the effect of other flare types and for this reason a brief study was conducted, on aircraft Type E, in which the landing severities resulting from flare manoeuvres of this type (R) were compared with those resulting from what is considered the correct flare procedure (Type C) where the descent rate is reduced steadily over several seconds up to the moment of impact.

Details of study

Fig.39 displays diagrammatically the time histories of height and normal CG acceleration during flare manoeuvres of Types C and R and others, all of which categorise most landings recorded by CAADRP.

A recording of 42 consecutive flights was selected which contained a large proportion of landings having a flare manoeuvre of Type R. The flares of 22 landings were found to conform to Type C and of 10 landings to Type R.

The value of peak normal CG acceleration at touchdown was measured from each of the 32 landings and those resulting from flares of Type R were compared to those resulting from Type C. The values are presented in Table 3 and it is seen that the mean value for Type R is 0.58 Δg compared to 0.35 Δg for Type C. Also shown in the table is the time taken from the start of flare (deduced primarily from the pitch and CG acceleration traces) to touchdown. As would be expected the mean time taken performing Type R manoeuvre exceeds that of Type C, the time for Type R being 9.28 sec and for Type C 6.74 sec.

The main conclusion to be drawn from this study is that flare manoeuvres of Type R in general produce harder landings than Type C (the probable reasons are explained in section 5.4 of the main Report), but the study in the main Report shows that Type L manoeuvres produce the most severe landings which occur more rarely.

Table 1

RELEVANT PRINCIPAL PARAMETERS FOR HARD LANDINGS

						First impact					Second impact				Third impact			
Figure No	Aircraft weight (1000 kg)	Touchdown speed relative to target threshold speed (kt)	Height (at the main wheels) above airfield at start of power reduction (ft) (baro)	Flare type (see section 4)	Rate of descent at touchdown (ft/sec)	Total max normal acceleration increment above 1 g datum (g units)	Aerodynamic lift above 1 g datum at touchdown (g units)	Rate of change of lift immed prior to touchdown (g/sec)	Max accel increment above 1 g datum ignoring oscills due to struct modes (g units)	Angle of bank at instant of touchdown (deg)	Total max normal acceleration increment above 1 g datum (g units)	Aerodynamic lift above 1 g datum at touchdown (g units)	Max accel increment above 1 g datum ignoring oscills due to struct modes (g units)	Angle of bank at instant of touch down (deg)	Total max normal acceleration increment above 1 g datum (g units)	Aerodynamic lift above 1 g datum at touchdown (g units)	Max accel increment above 1 g datum ignoring oscills due to struct modes (g units)	Angle of bank at instant of touchdown (deg)
2	105 9	-	60	L	-	0 95	0 20	0 125	-	-	0 64	-0 22	0 5	-				
3	103 0	-12	140	L	-	0 87	0	-0 011	0 7	+ 2								
4	105 9	-15	100	L	-	1 16	0 09	0 044	0 75	0	0 80	-0 20	0 55	-4	0 43	-	-	3
5	92 2	- 9	< 50	N	-	0 75	0	0 075	0 55	+ 2	1 10	-0 05	0 65	0	0 45	-0 05	-	0
6	101 5	-	100	N	-	1 17	0	0	0 8	-	1 17	-0 25	0 8	-				
7	97 6	- 7	200	L	-	1 17	0 10	0 016	0 8	0	0 30	-0 10	0 25	0				
8	98 9	0	*175	L	-	0 70	0 20	-0 055	0 6	-10	1 22	-0 04	0 8	-5	0 60	-0 13	0 4	-9
9	98 0	+ 8	40	I	-	0 80	0 05	0 067	0 6	- 1	0 50	-0 10	0 4	-1				
10	99 9	-	< 30	I	-	1 18	0 10	0 175	0 75	-	0 63	-0 10	0 45	-				
11	99 8	-	-	R	-	0 84	-0 05	0 140	0 6	0	0 45	-0 05	0 35	0				
12	98 6	-	70	R	-	0 93	-0 08	0 095	0 7	0	0 37	-0 09	0 15	0				
13	96 8	-	50	R	-	0 93	-0 04	0 050	0 65	0								
14	102 5	-	50	R	-	0 80	0 11	0 161	0 5	0								
15	99 6	-	-	L	-	0 80	0	0 130	0 6	0	0 40	-0 20	0 3	0				
16	90 9	0	0	L	-	0 83	0 10	0 028	0 65	3	0 78	-0 12	0 6	0				
17	45 3	+ 1	-	L	8	0 98	0 25	0	0 85	0								
18	43 1	- 3	-	I	-	0 95	0 15	0 112	-	3	0 46	-0 22	-	1				
19	41 0	- 7	-	L	11	1 16	0 10	0 093	0 9	0								
20	43 0	-21	-	*R	4	0 85	0	0	0 65	- 1								
21	45 2	- 6	-	L	7	0 89	0 12	0 071	0 85	0	0 36	-0 13	0 3	0				
22	44 9	- 5	-	N	5	0 96	0 10	0 198	0 8	+ 1	0 43	-0 10	0 4	-1				
23	45 5	-12	-	L	8	0 94	0 11	0 054	0 8	+ 1	0 24	0	0 2	0				
24	44 8	- 8	-	L	7	1 01	0 20	0 377	-	0	0 55	0	0 5	-3	0 29	-0 16	0 2	2
25	42 8	- 8	-	L	7	0 85	0 07	0 033	0 8	- 1	0 47	-0 14	0 4	0				
26	-	-	-	L	8	1 33	0 18	0 069	-	0	0 68	-0 08	0 6	0				
27	43 6	-20	-	R	-	0 86	-0 06	0 125	0 8	0								
28	45 8	- 4	-	L	10	1 10	0 07	-0 400	1 0	+ 5								
29	46 7	-10	-	L	6	0 80	0 13	0 028	0 7	0	0 50	-0 08	0 4	0				
30	45 8	- 2	-	L	6	1 06	0 18	0 375	0 95	0	0 45	-0 19	0 4	0				
31	43 5	- 6	-	I	-	1 10	0 10	0 121	0 7	+ 1	0 60	-0 05	0 5	0				
32	44 4	-21	-	I	6	0 94	0 04	0 035	0 8	- 2	0 37	-0 16	0 3	0				
33	44 5	- 5	-	L	-	1 02	0 20	0 051	0 85	0								
34	46 3	-12	-	I	6	0 94	0 08	0 019	0 8	+ 1	0 23	-0 12	0 15	0				
35	45 8	- 3	-	L	9	0 95	0 25	0 247	0 8	0	0 44	-0 25	0 4	0				
36	44 5	- 7	-	L	7	0 92	0 14	0	-	1	0 40	-0 11	0 3	2				
37	46 7	- 5	-	L	6	0 95	0 12	0 008	0 6	0	0 29	-0 11	0 25	0				
38	45 4	-19	-	R	7	1 02	-0 08	0 028	0 7	0								

Note - 1 * See figure for comment

2 Appropriate spaces are left blank where a second or third impact did not occur

3 A dash is inserted where the parameter was not measureable for any reason

Table 2

TARGET AND ACTUAL INDICATED LANDING SPEEDS (IAS)

AIRCRAFT TYPE E

Fig. No.	Aircraft weight (1000 kg)	1 Target threshold speed (kt)	2 Actual IAS at threshold (kt)	3 IAS at touchdown (kt)	3 minus 2 (kt)	2 minus 1 (kt)	Flare type
17	45.3	149	152	150	- 2	+3	L
18	43.1	145	147	142	- 5	+2	I
19	41.0	142	139	135	- 4	-3	L
20	43.0	145	149	124	-25	+4	R
21	45.2	149	152	143	- 9	+3	L
22	44.9	149	147	144	- 3	-2	N
23	45.5	150	145	138	- 7	-5	L
24	44.8	149	149	141	- 8	0	L
25	42.8	145	140	137	- 3	-5	L
26	-	-	145	137	- 8	-	L
27	43.6	147	146	127	-19	-1	R
28	45.8	150	148	146	- 2	-2	L
29	46.7	152	152	142	-10	0	L
30	45.8	150	148	148	0	-2	L
31	43.5	147	143	141	- 2	-4	I
32	44.4	147	143	126	-17	-4	I
33	44.5	149	148	144	- 4	-1	L
34	46.3	150	143	138	- 5	-7	I
35	45.8	150	157	147	-10	+7	L
36	44.5	144	146	137	- 9	+2	L
37	46.7	147	148	145	- 3	+1	L
38	45.4	144	146	125	-21	+2	R

Table 3

ANALYSIS OF 42 LANDINGS ON AIRCRAFT TYPE E

Flare Type C			Flare Type R		
Flight No.	Maximum normal acceleration increment abcve 1 g datum level (g units)	Time of start of flare from touchdown (sec)	Flight No.	Maximum normal acceleration increment above 1 g datum level (g units)	Time of start of flare from touchdown (sec)
1	0.35	4.6	9	0.35	6.5
3	0.20	9.0	15	0.45	9.7
4	0.65	8.5	16	0.70	9.2
5	0.40	7.5	17	0.45	5.4
7	0.33	4.0	20	0.85	15.5
8	0.20	7.4	22	0.70	11.0
12	0.31	4.4	25	0.65	8.0
13	0.35	11.5	29	0.50	10.3
18	0.35	6.2	30	0.57	10.3
19	0.30	7.7	42	0.58	6.9
21	0.20	7.7			
23	0.46	5.7			
24	0.25	7.7			
26	0.48	4.4			
27	0.37	3.8			
28	0.54	7.0			
32	0.58	6.6			
35	0.13	6.4			
36	0.36	4.3			
37	0.28	4.8			
39	0.32	12.3			
41	0.39	6.8			
MEAN	0.35	6.74		0.58	9.28

Table 4

TOTAL MAXIMUM CG ACCELERATION AND MAXIMUM CG ACCELERATION ABOVE LIFT DATUM IGNORING HIGH FREQUENCY OSCILLATIONS

Figure number	1st Impact		2nd Impact		3rd Impact		Figure number	1st Impact		2nd Impact		3rd Impact	
	Total maximum normal acceleration increment above 1 g datum (g units)	Maximum acceleration above lift datum ignoring structural oscillations (g units)	Total maximum normal acceleration increment above 1 g datum (g units)	Maximum acceleration above lift datum ignoring structural oscillations (g units)	Total maximum normal acceleration increment above 1 g datum (g units)	Maximum acceleration above lift datum ignoring structural oscillations (g units)		Total maximum normal acceleration increment above 1 g datum (g units)	Maximum acceleration above lift datum ignoring structural oscillations (g units)	Total maximum normal acceleration increment above 1 g datum (g units)	Maximum acceleration above lift datum ignoring structural oscillations (g units)	Total maximum normal acceleration increment above 1 g datum (g units)	Maximum acceleration above lift datum ignoring structural oscillations (g units)
2	0.95	-	0.64	0.72			21	0.89	0.73	0.36	0.43		
3	0.87	0.70					22	0.96	0.70	0.43	0.50		
4	1.16	0.66	0.80	0.75	0.43	-	23	0.94	0.69	0.24	0.20		
5	0.75	0.55	1.10	0.70	0.45	-	24	1.01	-	0.55	0.50	0.29	0.36
6	1.17	0.80	1.17	1.05			25	0.85	0.73	0.47	0.54		
7	0.84	0.65	0.45	0.40			26	1.33	-	0.68	0.68		
8	0.70	0.40	1.22	0.84	0.60	0.53	27	0.86	0.86				
9	0.80	0.55	0.50	0.50			28	1.10	0.93				
10	0.93	0.62	0.37	0.24			29	0.80	0.57	0.50	0.48		
11	1.18	0.65	0.63	0.55			30	1.06	0.77	0.45	0.59		
12	1.17	0.70	0.30	0.35			31	1.10	0.60	0.60	0.55		
13	0.93	0.69					32	0.94	0.72	0.23	0.27		
14	0.80	0.60	0.40	0.50			33	0.94	0.76	0.37	0.46		
15	0.80	0.39					34	1.02	0.65				
16	0.83	0.55	0.78	0.72			35	0.95	0.55	0.44	0.65		
17	0.98	0.60					36	0.92	-	0.40	0.41		
18	0.95	-	0.46	-			37	0.95	0.48	0.29	0.36		
19	1.16	0.80					38	1.02	0.70				
20	0.85	0.65											

Note: 1 Appropriate spaces are left blank where a second or third impact did not occur.

2 A dash is inserted where the parameter was not measurable for any reason.

Table 5

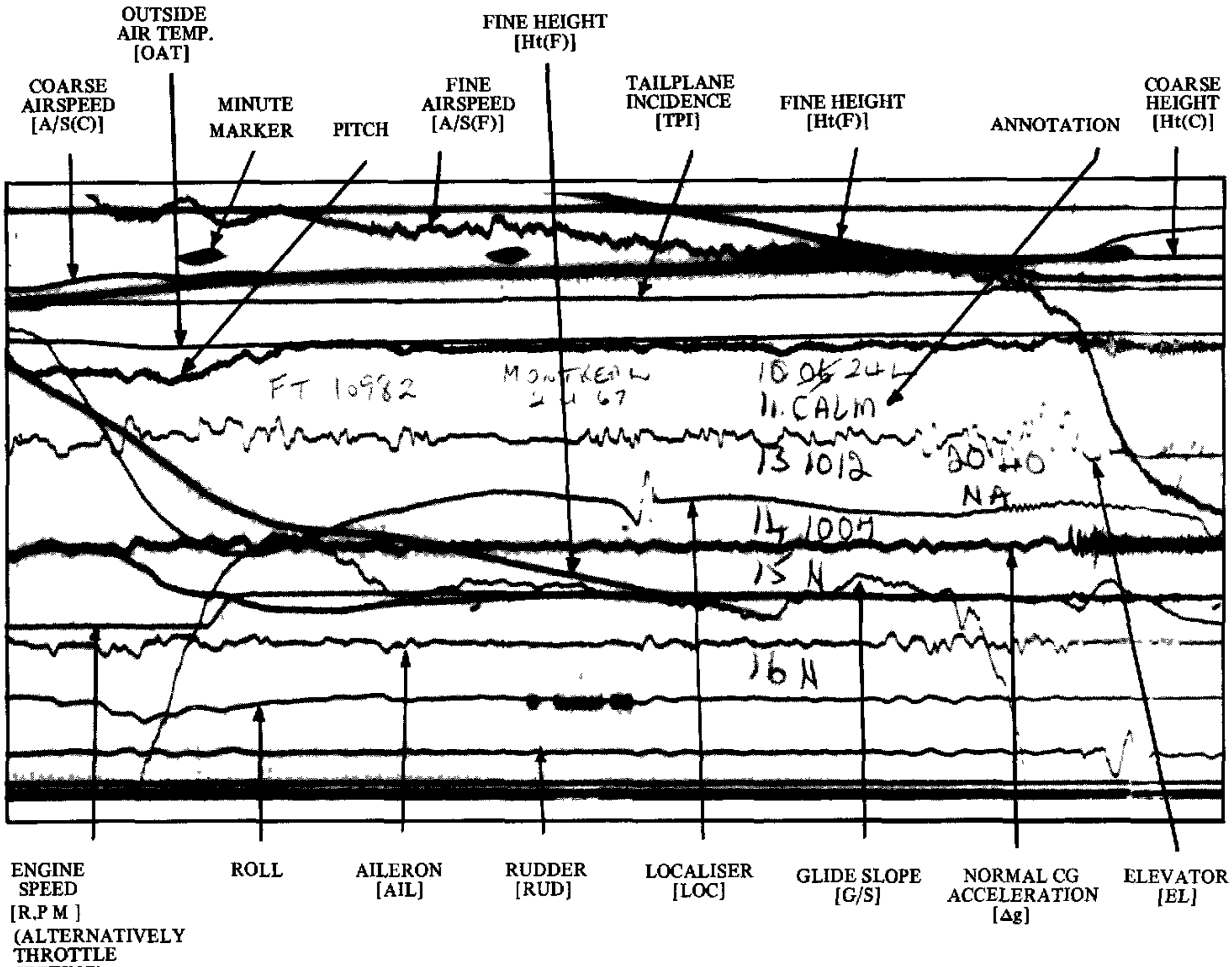
VISIBILITY CONDITIONS DURING HARD LANDINGS

Figure No.	Month	Time (GMT)	Airport	Sunrise (GMT)	Sunset (GMT)	Light (L) or Dark (D)	Visibility (NMl)
2	Dec	0108	Nassau	1144	2221	D	-
3	Nov	1925	Nassau	1126	2220	L	15
4	Feb	1755	Mont. Bay	1141	2252	L	12
5	June	0013	NY (JFK)	0926	0020	L	-
6	June	2125	Bermuda	0911	2327	L	-
7	June	0218	Mont. Bay	1035	2346	D	10
8	June	2117	Chicago	1017	0132	L	15
9	July	0031	Boston	0917	0022	L	5
10	July	2343	Chicago	1027	0126	L	-
11	July	0342	Colombo	0032	1300	L	-
12	July	1135	Tehran	0140	1545	L	-
13	Oct	1236	Prestwick	0724	1639	L	-
14	Dec	0329	Antigua	1030	2134	D	-
15	Jan	0306	Mont. Bay	1141	2252	D	-
16	July	2330 approx	Barbados	0942	2232	D	35
17	Oct	2127	Zurich	0535	1652	D	-
18	Oct	-	LHR	-	-	-	-
19	Jan	1926	LHR	0802	1622	D	-
20	July	1359	LHR	0755	1658	L	-
21	Feb	-	LHR	-	-	-	-
22	May	0748	Paris (LB)	0414	1918	L	-
23	May	1546	Brussels	0352	1925	L	-
24	June	-	LHR	-	-	-	-
25	June	1448	LHR	0349	2023	L	-
26	July	1622	Brussels	0345	1950	L	-
27	July	2121	LHR	0401	2014	D	-
28	Sept	2119	Basle	0510	1719	D	4
29	Sept	1452	Paris (ORLY)	0542	1740	L	-
30	Oct	1735	Frankfurt	0536	1650	D	-
31	Oct	2020	LHR	0650	1640	D	-
32	Nov	1724	Paris (ORLY)	0712	1602	D	-
33	Nov	1650	Frankfurt	0654	1532	D	-
34	Jan	2014	Glasgow	0838	1614	D	-
35	Apr	0750	Zurich	0437	1815	L	10
36	Apr	1851	LHR	0508	1858	L	-
37	May	2152	Amstm.	0536	1800	D	-
38	June	1018	Paris (ORLY)	0345	1956	L	-

A dash is inserted where the information was unobtainable

REFERENCES

No.	Author(s)	Title, etc.
1	The CAADRP Technical Panel	The Civil Aircraft Airworthiness Data Recording Programme. RAE Technical Report 64004 (ARC 26490) (1964)
2	International Civil Aviation Organisation (ICAO)	Aircraft Accident Digest Numbers 15-17
3	H. Hall G. B. Hutton	Operational and Theoretical Studies on the effects of pilot action on heavy landings. A.R.C. C.P. No.1119 (1969)



Note: The abbreviations in square brackets are used in Figs.2 to 38

Fig.1. Sample record

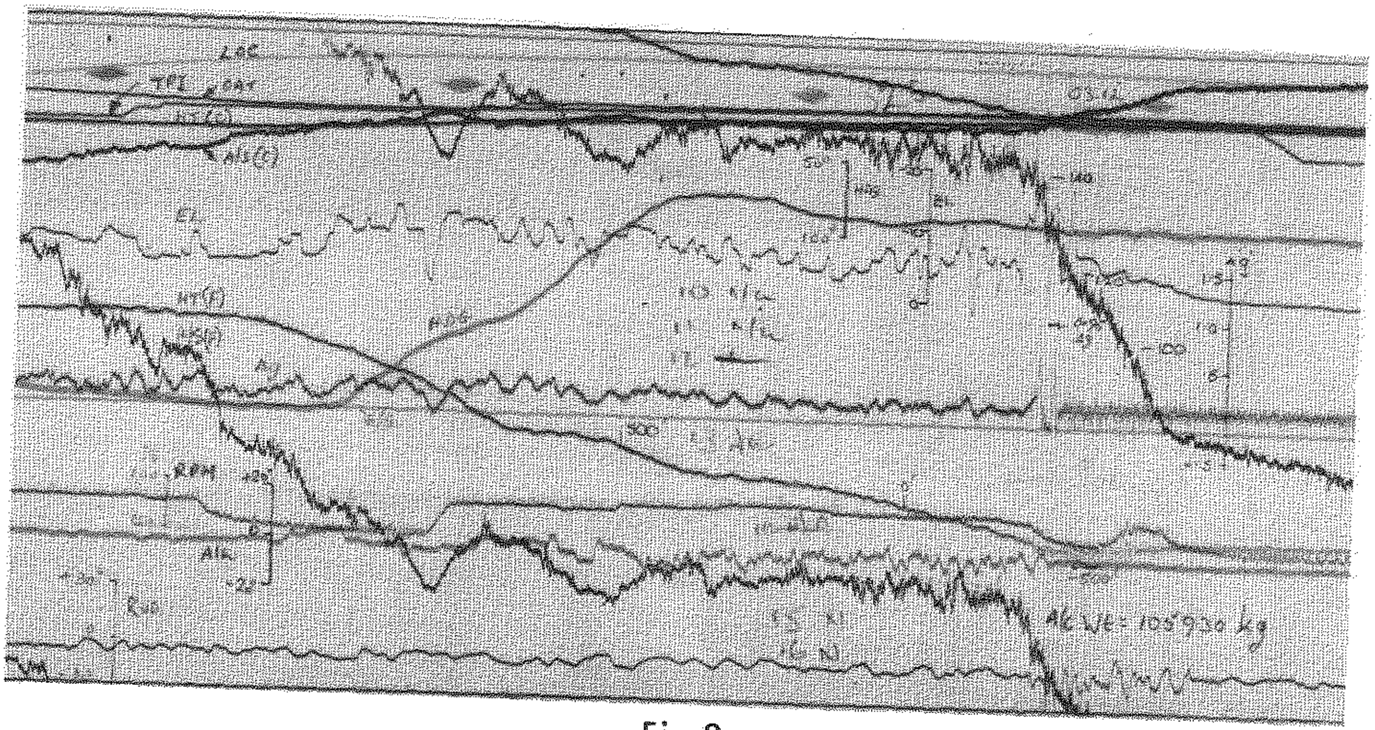


Fig.2

Information on Event in Fig.2

Aircraft Type: D

Airport: Nassau   Runway: 09

Date: December 1965   Time: 01.08 GMT

Peak CG acceleration:

1st impact: 0.95 Δg (see Comments below)

2nd impact: 0.64 Δg

Aircraft speed at initial touchdown: 138 kt ias

Comments:

During the last 10 seconds of the approach up to the start of flare the rate of descent was approximately 17½ ft/sec, estimated from the barometric height time history. This is well above the usual rate of 10 to 12 ft/sec and, as the air speed of 140 kt was correct, suggests that the aircraft was descending on a line above the correct glide slope. The glide slope deviation unfortunately was not available.

Just discernible on the original record but invisible in the reproduction opposite is a fine peak extending to 1.32 Δg. This is considered to be either spurious or of such a high frequency as to be meaningless from both structural and physiological points of view.

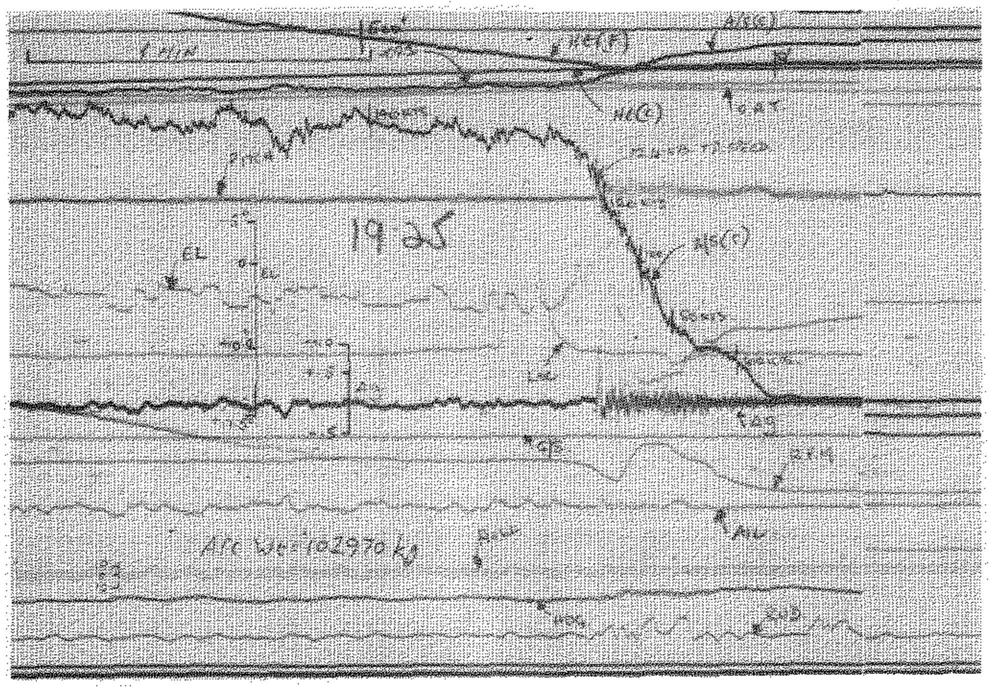


Fig.3

Information on Event in Fig.3

Aircraft Type:	D		
Airport:	Nassau	Runway:	32
Date:	November 1966	Time:	19.25 GMT
Peak CG acceleration:		$0.87\ \Delta g$	
Aircraft speed at touchdown:		124 kt ias	

Meteorological conditions:

Time (GMT)	19.00	20.00
Temp (^{o}C)	26.6	26.6
Wind	020^{o}/10 kt	360^{o}/10 kt
Visibility (Nml)	15	15
Cloud	2/8 Cu at 2300 ft	1/8 Cu at 2300 ft

Comments:

Landing performed while aircraft slightly banked. The aircraft had been oscillating in roll for a high proportion of the last three minutes of the approach, probably due to turbulent conditions.

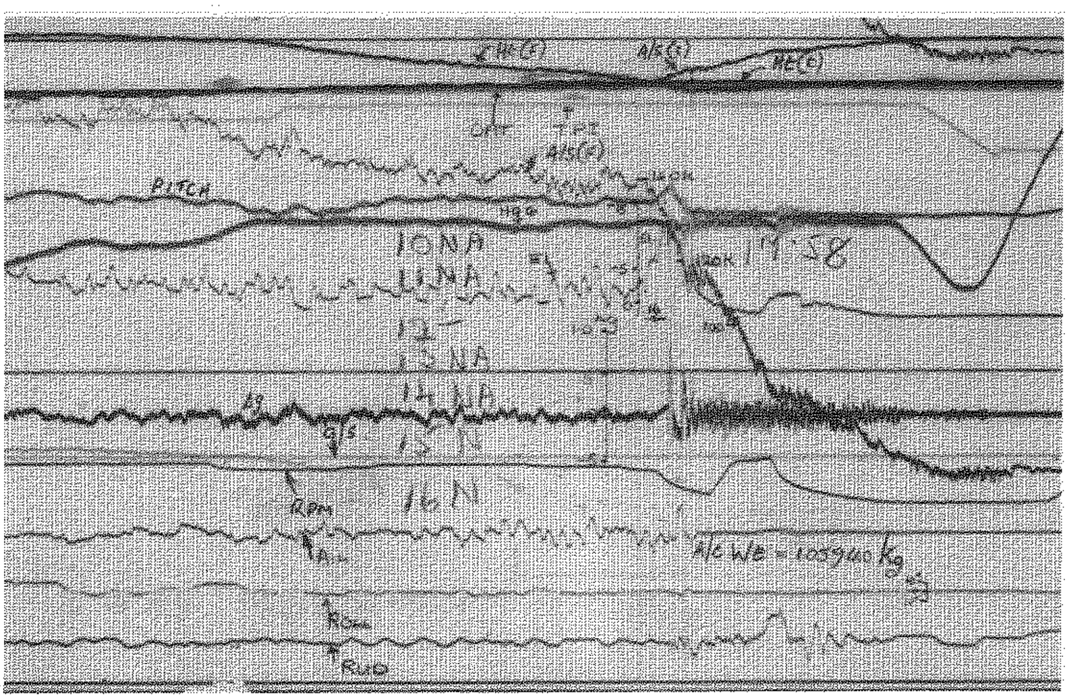


Fig.4

Information on Event in Fig.4

Aircraft Type:	D		
Airport:	Montego Bay	Runway:	06
Date:	February 1967	Time:	17.55 GMT
Peak CG acceleration:			
	1st impact:	1.16 Δg	
	2nd impact:	0.80 Δg	
	3rd impact:	0.43 Δg	
Aircraft speed at first touchdown:		130 kt ias	

Meteorological conditions:

Time (GMT)	17.00	18.00
Temp (^{o}C)	26.1	26.8
Wind	090^{o}/19 kt	090^{o}/21 kt
Visibility (Nml)	12	12
Pressure (mb)	1016.2	1015.7
Cloud	3/8 Cu Sc at 2500 ft	2/8 Cu Sc at 2500 ft
Rainfall	Nil within last 6 hours	

Comments:

An abnormal approach was followed by a heavy landing and two bounces. The second and third impacts were performed with a small degree of aircraft roll angle. Possible causes for the poor landing are as follows:-

(1) The angle of approach is low; about 2.16^{o}.

(2) Excessive power is being used to maintain the approach.

(3) Aircraft pitch-up is high to generate lift. This generates high drag.

(4) The threshold speed is 130 kt but should be 138 + 7 kt = 145 kt in the prevailing wind. This means that the aircraft is low, slow and under excessive thrust to maintain the situation.

(5) At about 100 ft there is a slight power reduction and shortly afterwards an up elevator input and a further increase in the pitch angle. This means that

(a) thrust has been reduced;

(b) drag has been increased;

(c) the aircraft is now entering the wind gradient effect.

Information on Event in Fig.4 (Contd)

The result is a sudden decay in airspeed of about 10 kt in 3 seconds.

(6) The aircraft has entered into the high sink rate associated with entry into the power-on stall.

(7) The heavy landing is inevitable. More lift is available by increasing the angle of attack but there is not enough elevator to produce it and the rate of increase of drag ensures that there is insufficient speed to provide the lift required.

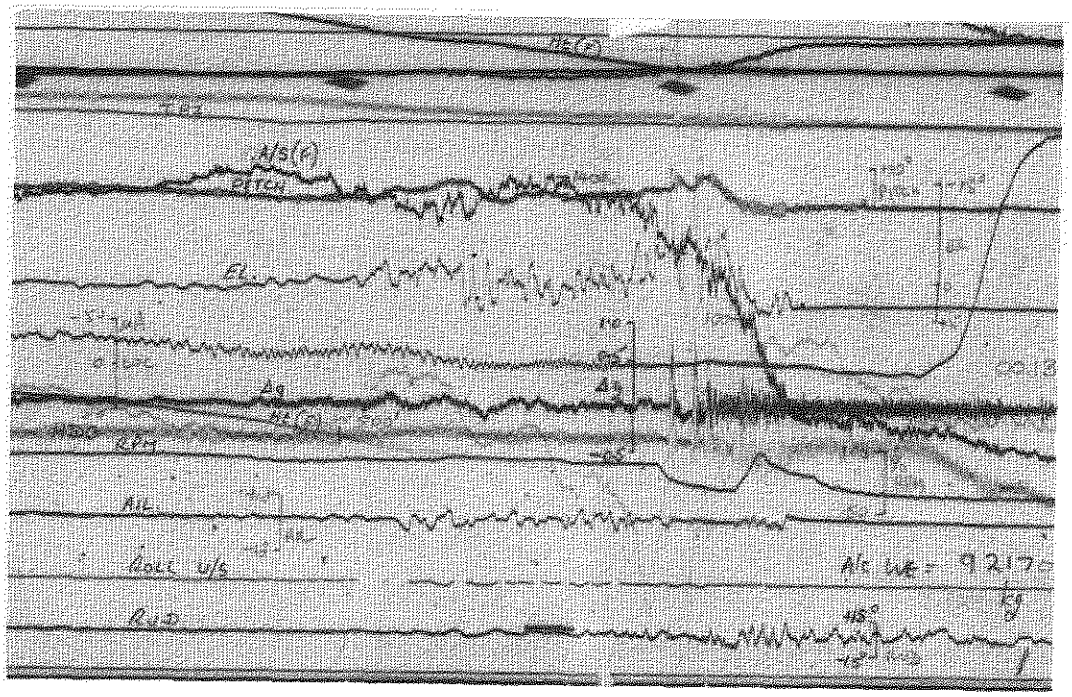


Fig.5

Information on Event in Fig.5

Aircraft Type:	D		
Airport:	New York (JFK)	Runway:	22L
Date:	June 1967	Time:	00.13 GMT
Peak CG acceleration:			
	1st impact:	0.75 Δg	
	2nd impact:	1.10 Δg	
	3rd impact:	0.45 Δg	
Aircraft speed at first touchdown:		124 kt ias	

Meteorological ground conditions:

Wind 200°/17 kt, gusting 33 kt

Comments:

Rapid oscillatory applications of elevator during landing is considered to aggravate a tendency to bounce and a gradual reduction in elevator angle is desirable[3].

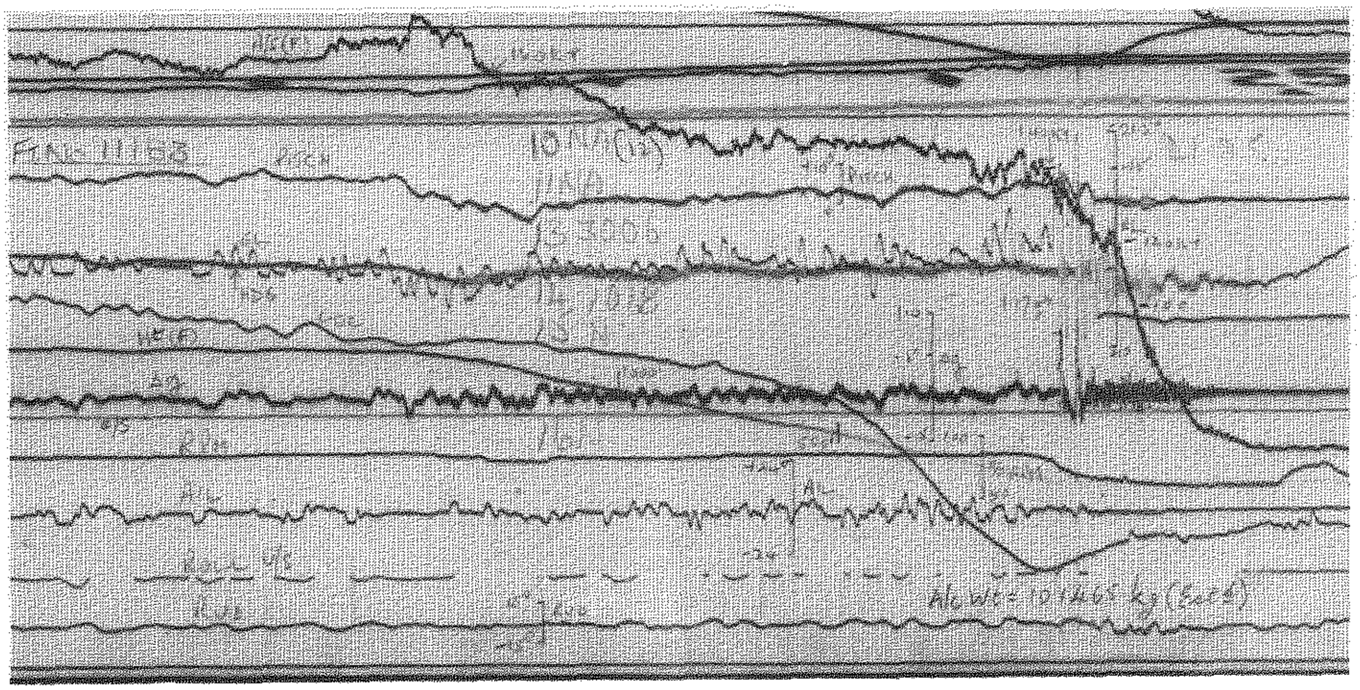


Fig.6

Information on Event in Fig.6

Aircraft Type:	D		
Airport:	Bermuda	Runway:	12
Date:	June 1967	Time:	21.25 GMT
Peak CG acceleration:			
	1st impact:	1.17 Δg	
	2nd impact:	1.17 Δg	
Aircraft speed at first touchdown:		133 kt ias	

Comments:

The flare was attempted too late and the elevator usage is similar to that in Fig.5 (see Comments appertaining to Fig.5).

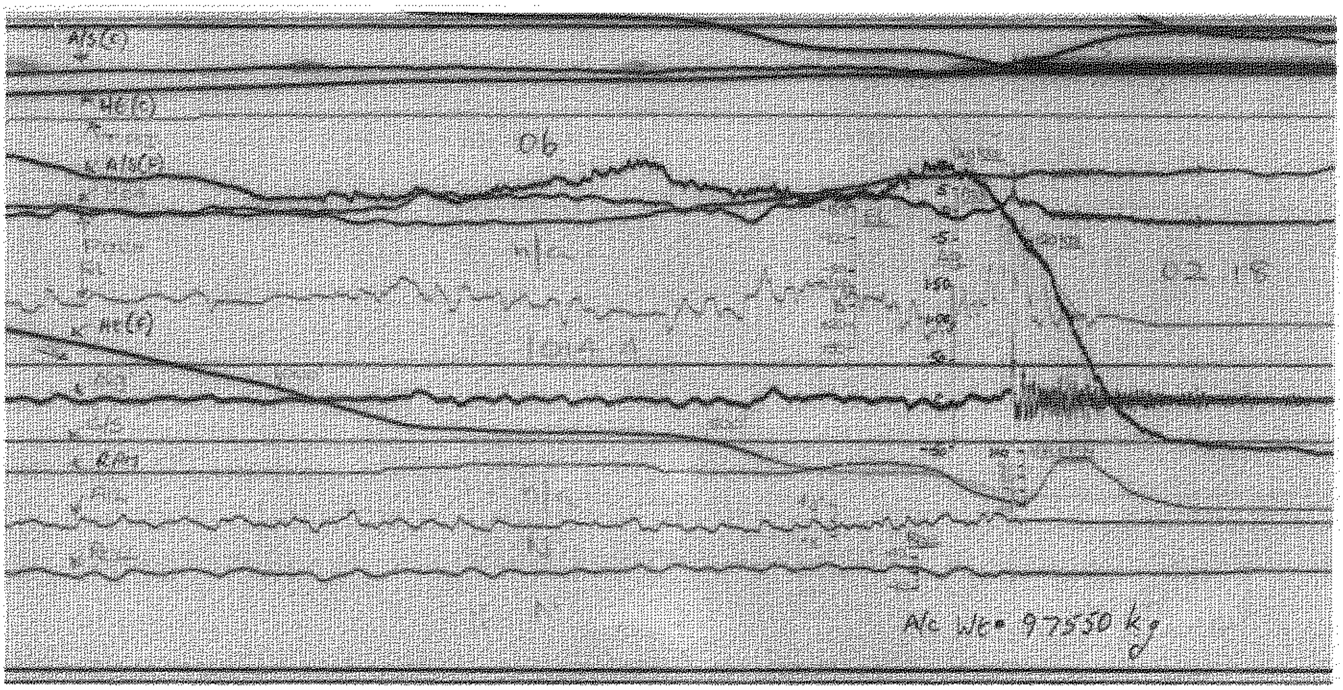


Fig.7

Information on Event in Fig.7

Aircraft Type:	D	
Airport:	Montego Bay	
Runway:	06	
Time:	02.18 GMT	
Date:	June 1967	
Peak CG acceleration:	1st impact:	1.17 Δg
	2nd impact:	0.30 Δg
Aircraft speed at initial touchdown:		125 kt ias

Meteorological conditions:

Time (GMT):	02.00	03.00
Temp (^{o}C):	23.2/21.1	22.7/20
Wind:	Calm	100^{o}/06 kt
Visibility (Nml):	10	10
Cloud:	Trace at 2000 ft, $\frac{3}{8}$ at 2700 ft	Trace at 2000 ft
QNH:	1014.9 mb, 29.97 in	1015.4 mb, 29.99 in

Comments:

Power was reduced early causing the airspeed to decrease rapidly. Also the rate of elevator application was high.

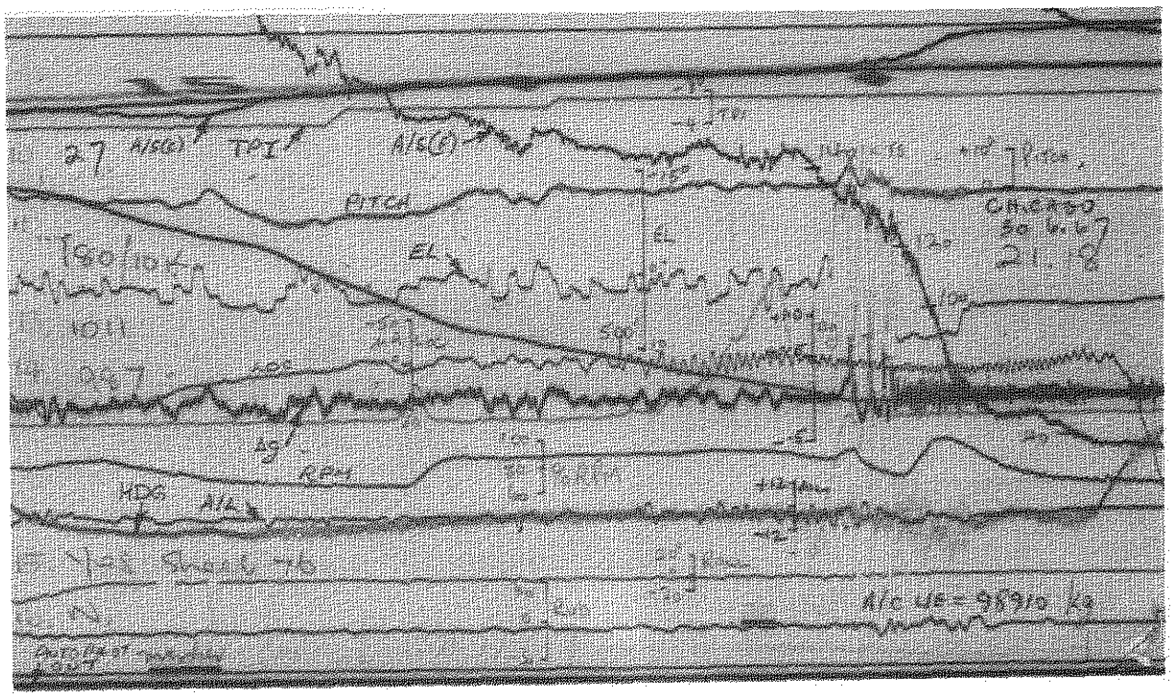


Fig.8

Information on Event in Fig.8

Aircraft Type:	D		
Airport:	Chicago	Runway:	27
Date:	June 1967	Time:	21.17 GMT
Peak CG acceleration:			
	1st impact:	0.70 Δg	
	2nd impact:	1.22 Δg	
	3rd impact:	0.60 Δg	
Aircraft speed at first touchdown:		133 kt ias	
Meteorological conditions:			

Time (GMT):	20.55	21.25	21.55
Temp (^{o}C):	30	30	30
Wind:	270^{o}/8 kt gusting 14 kt	270^{o}/7 kt gusting 14 kt	270^{o}/7 kt
Visibility (Nml):	15	15	15
Sea level pressure (mb):	1010.4	1010.4	1010.4
Cloud:	Scattered cloud at 45000 ft	Sky clear	Sky clear
Dew point (^{o}C)	17.2	16.7	17.7

Comments:

The aircraft bounced twice during the landing and the second impact was harder than the first. The throttle usage was unusual and pitch control poor. The first and third impacts were performed at a significant bank angle of about 10^{o}.

The pilot may have feared that he was about to land slightly short of the threshold and took corrective action in the last few seconds before touchdown. Gradual closure of the throttle began at a height of 175 ft but then at one second prior to the start of flare power was increased again to 90% max rpm, possibly in an attempt to gain lift and avert the short landing.

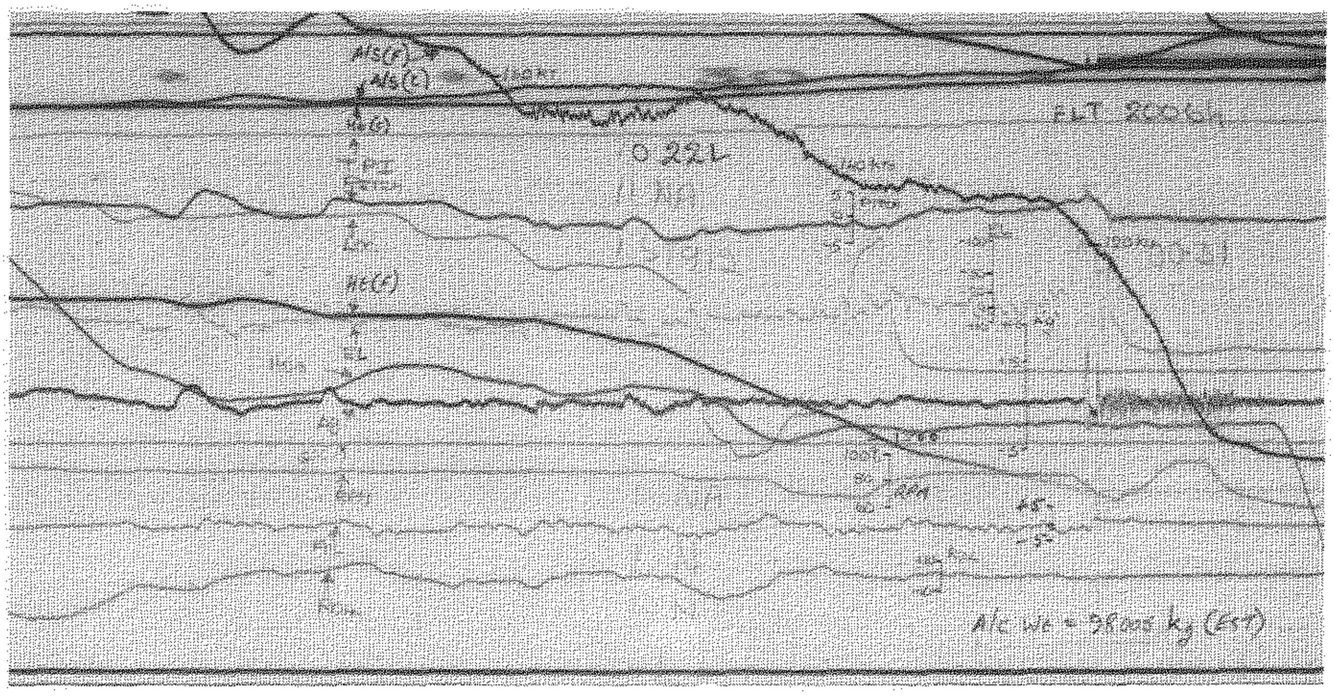


Fig.9

Information on Event in Fig.9

Aircraft Type: D

Airport: Boston

Runway: 22

Time: 00.31 GMT

Date: July 1967

Peak CG acceleration: 1st impact: 0.80 Δg

2nd impact: 0.50 Δg

Aircraft speed at initial touchdown: 124 kt ias

Meteorological conditions:

Time (GMT):	00.10	00.30	01.00
Temp (^{o}C):	25	25	25.5
Wind:	140^{o}/18 kt	180^{o}/10 kt	190^{o}/10 kt
Visibility (Nml):	5 in haze and smoke	As before	As before
Cloud:	High, thin broken cloud with few cumulus		
Altimeter:	29.88 in	29.88 in	29.88 in
Dew point:	19.5	19.5	19.5
Pressure (mb)	1012.2	1012.2	1012.6

Comments:

The flare began rather late at 1½ sec before touchdown.

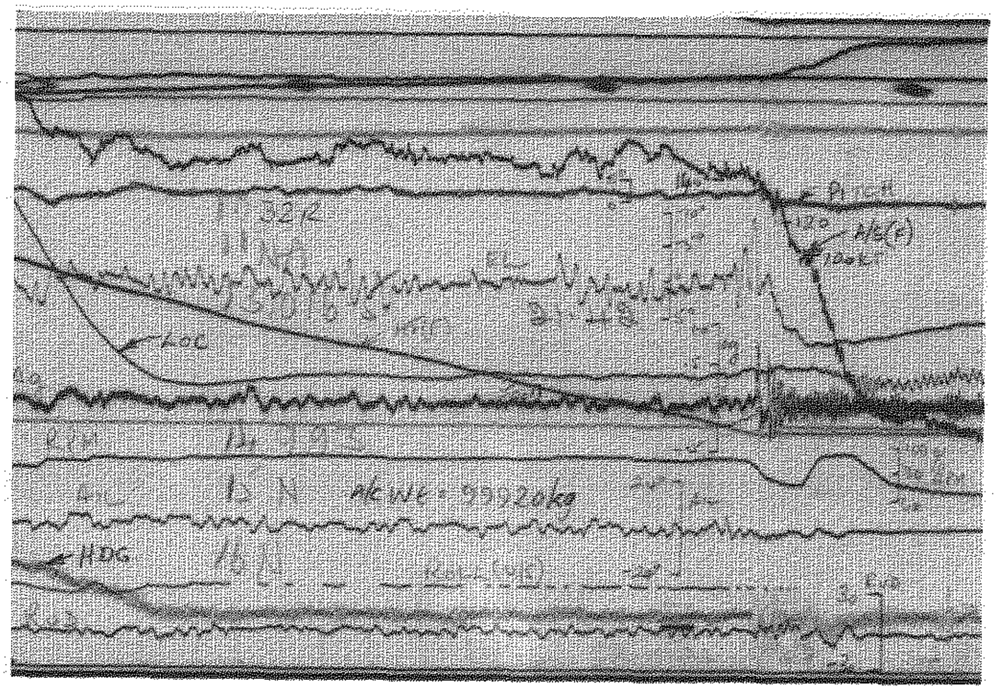


Fig.10

Information on Event in Fig.10

Aircraft Type:	D	
Airport:	Chicago	
Runway:	32	
Time:	23.43 GMT	
Date:	July 1967	
Peak CG acceleration:	1st impact:	1.18 Δg
	2nd impact:	0.63 Δg
Aircraft speed at first	touchdown:	139 kt ias

Comments:

A particularly high proportion of the total peak acceleration consists of a high frequency component.

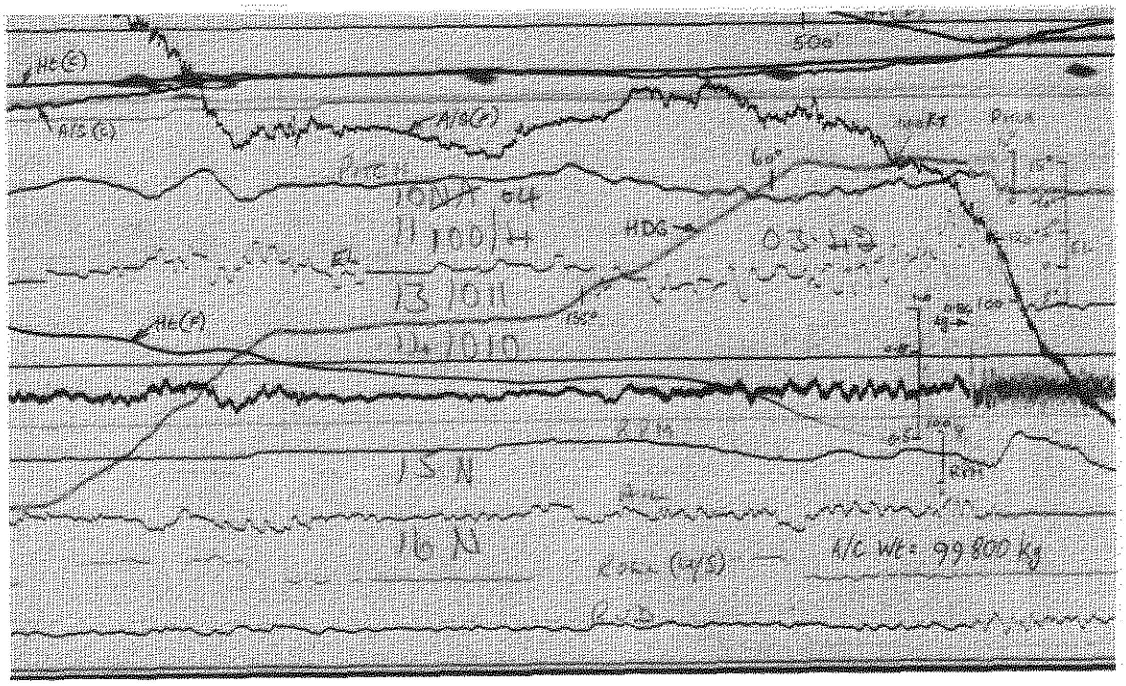


Fig.11

Information on Event in Fig.11

Aircraft Type:	D	
Airport:	Colombo	
Runway:	04	
Time:	03.42 GMT	
Date:	July 1967	
Peak CG acceleration:	1st impact:	0.84 Δg
	2nd impact:	0.45 Δg
Aircraft speed at first touchdown:		127 kt ias
Mean rate of descent during last 30 sec:		900 ft/min

Comments:

A reduction in elevator angle was applied $3\frac{1}{2}$ sec prior to touchdown resulting in a negative-going CG acceleration, the flare manoeuvre being of Type R described in section 4.

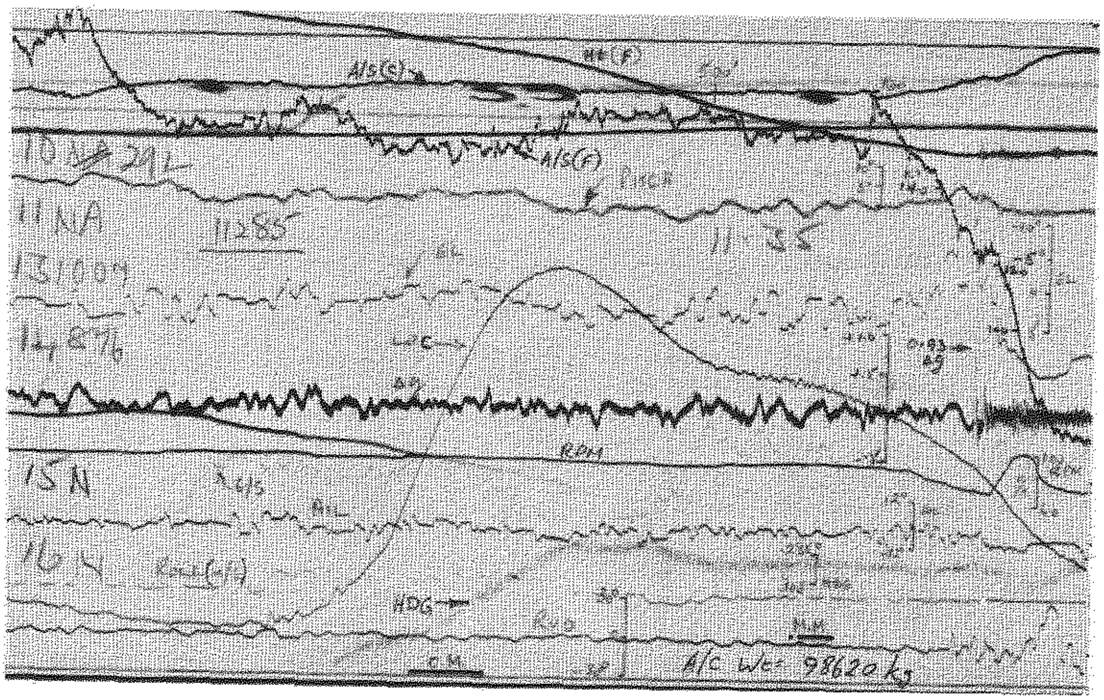


Fig.12

Information on Event in Fig.12

Aircraft Type:	D	
Airport:	Tehran	
Runway:	29	
Time:	11.35 GMT	
Date:	July 1967	
Peak CG acceleration:	1st impact:	0.93 Δg
	2nd impact:	0.37 Δg
Aircraft speed at initial touchdown:		123 kt ias

Comments:

The landing impact CG acceleration is composed very largely of an oscillating component, signifying that the landing was not performed at an abnormally high vertical velocity but that some other source produced the high peak acceleration, such as a rough runway surface at the impact point.

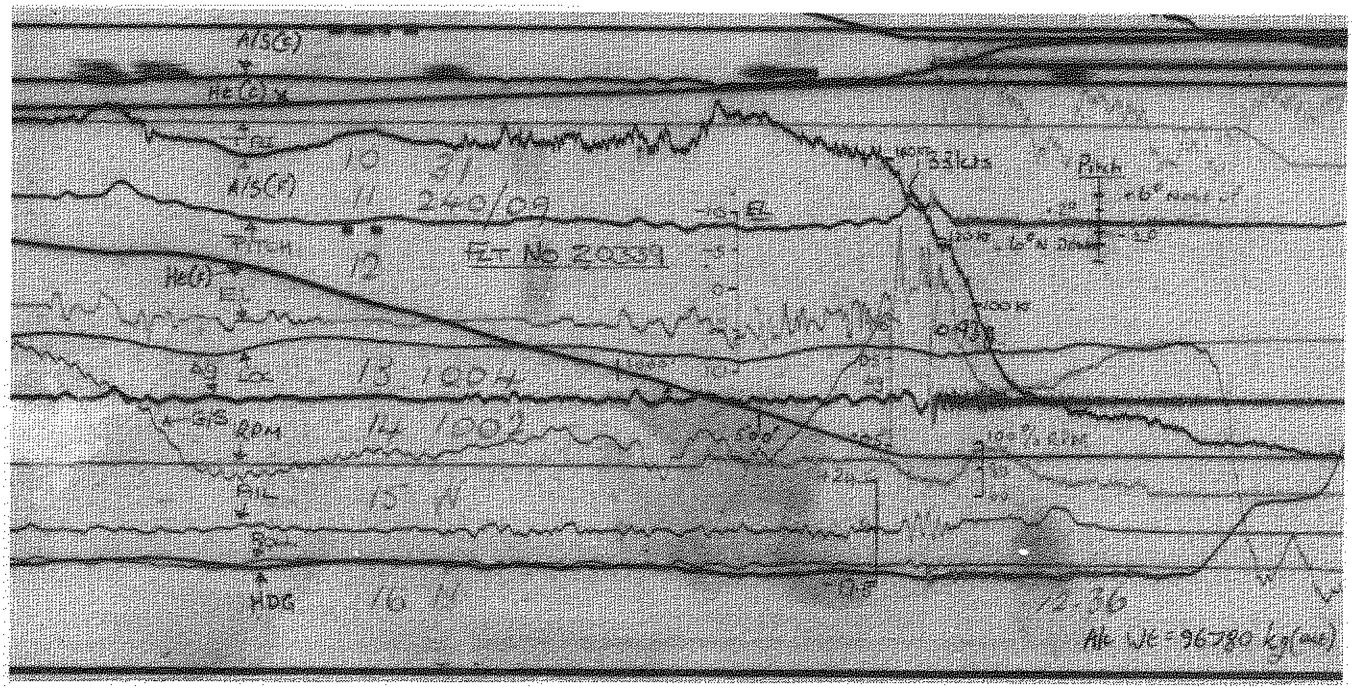

A/S(C)
HE(C)
A/S(F)
PITCH
He(F)
EL
LX
RDM
AIL
Roll
HDG
10 31
11 240/09
12
FLT No 20339
13 1004
14 1002
15 W
16 N
Pitch
12:36
A/c Wt = 96780 kg

Fig.13

Information on Event in Fig.13

Aircraft Type:	D		
Airport:	Prestwick	Runway:	31
Date:	October 1967	Time:	12.36 GMT
Peak CG acceleration:	0.93 Δg		
Aircraft speed at touchdown:	125 kt ias		

Comments:

The landing was reported in the log as being 'firm'. Six seconds prior to impact a large elevator input was applied and removed again in one continuous movement. As can be seen from the CG acceleration trace, the vertical velocity reduction achieved by the elevator application was regained in the last two seconds due to over-correction of elevator 3½ seconds before touchdown.

The landing was performed by the co-pilot.

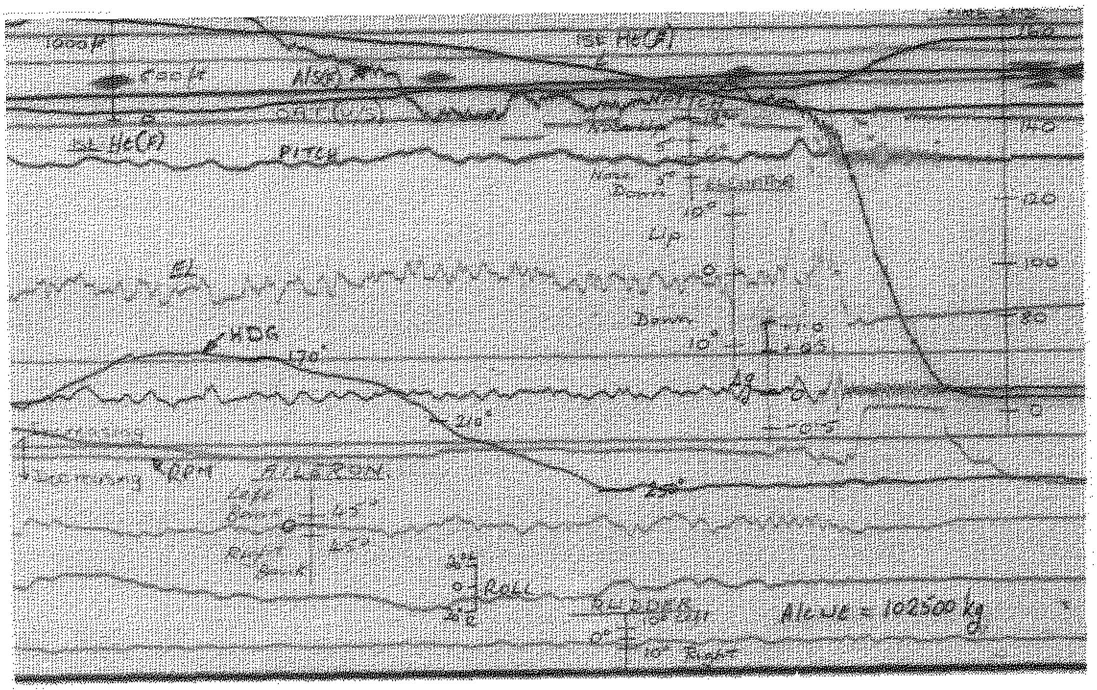


Fig.14

Information on Event in Fig.14

Aircraft Type:	D		
Airport:	Antigua	Runway:	25
Date:	December 1967	Time:	03.29 GMT
Peak CG acceleration:	0.93 Δg		
Aircraft speed at touchdown:	138 kt ias		

Comments:

The landing was performed at night on a runway which slopes slightly upward from the threshold and has no approach lighting.

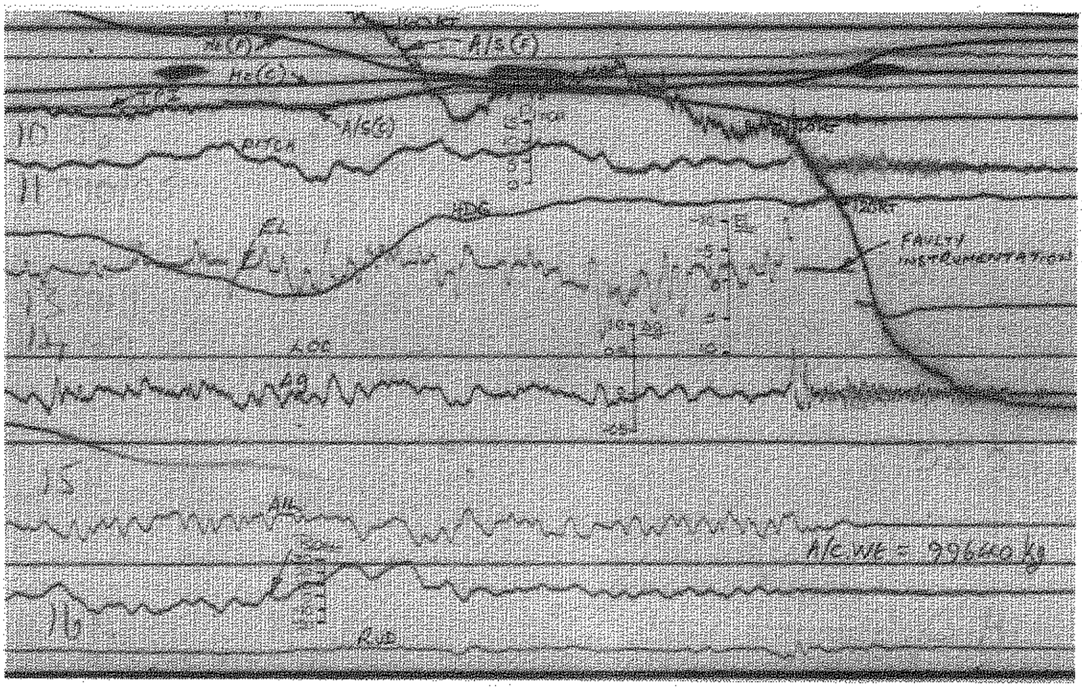

A/S(F)
A/S(C)
PITCH
HDG
EL
LOC
AIL
RUD
FAULTY INSTRUMENTATION
A/C WT = 99640 kg

Fig.15

Information on Event in Fig.15

Aircraft Type:	D		
Airport:	Montego Bay	Runway:	06
Date:	January 1968	Time:	03.06 GMT
Peak CG acceleration:			
	1st impact:	0.80 Δg	
	2nd impact:	0.40 Δg	
Aircraft speed at initial touchdown:		137 kt ias	

Comments:

The approach and landing were normal apart from the flare being left until a late stage resulting in the moderately hard landing.

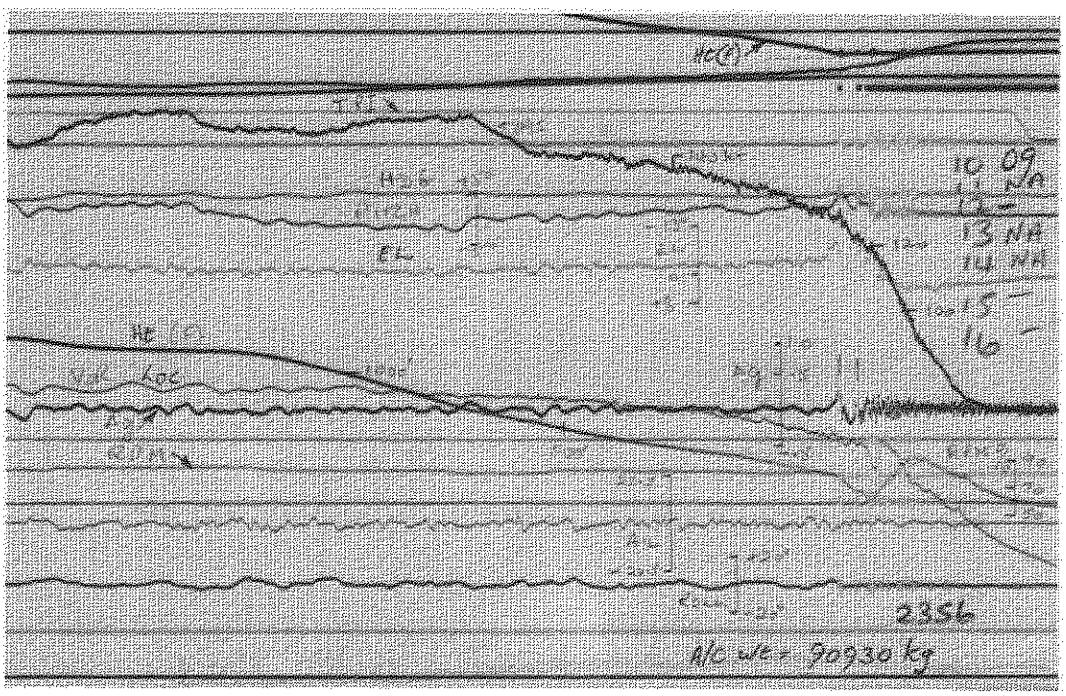


Fig.16

Information on Event in Fig.16

Aircraft Type:	D		
Airport:	Barbados	Runway:	09
Date:	July 1968	Time:	23.30 GMT (approx)
Peak CG acceleration:			
	1st impact:	0.83 Δg	
	2nd impact:	0.78 Δg	
Aircraft speed at initial touchdown		126 kt ias	

Meteorological conditions:

Time (GMT):	23.00	24.00
Temp (^{o}C):	26	26
Wind:	070/07	080/07
Visibility (Nml):	35	30
Cloud:	2/8 at 2500 ft	2/8 at 2500 ft
Dew point (^{o}C):	22	22
QNH:	1014.7	1015.6

Comments:

The aircraft pitched slowly up over last minute at constant power causing the airspeed to decrease. Power was not reduced significantly until the first touchdown.

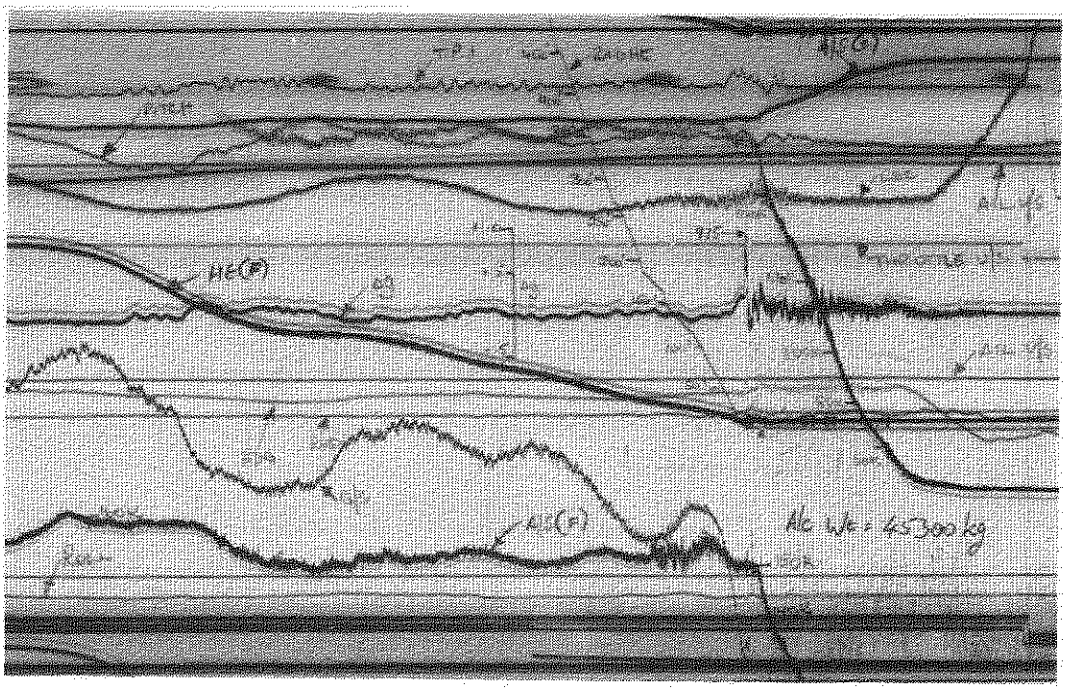


Fig.17

Information on Event in Fig.17

Aircraft Type:	E		
Airport:	Zurich	Runway:	16
Date:	October 1966	Time:	21.27 GMT
Peak CG acceleration:	0.98 Δg		
Aircraft speed at touchdown:	150 kt ias		

Comments:

Judging by the heading trace it is apparent that the landing took place in a crosswind. On landing the drifting aircraft the pilot applied rudder in order to align the aircraft with the runway. Aircraft heading was over-corrected but stability was achieved 5 seconds after touchdown.

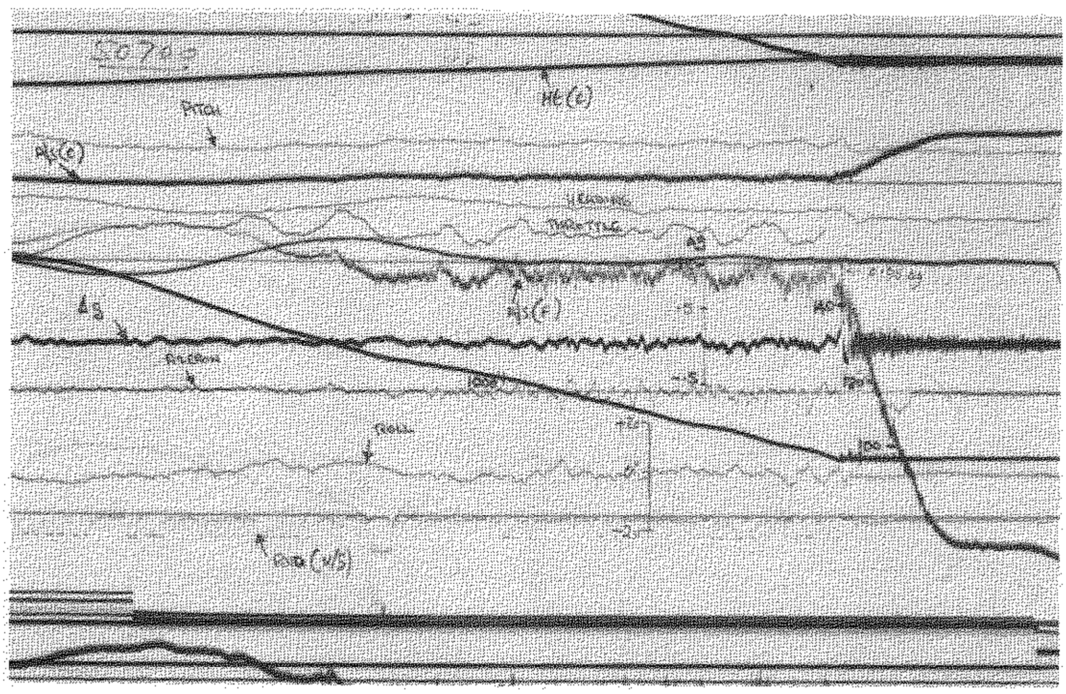


Fig.18

Information on Event in Fig.18

Aircraft Type:	E	
Airport:	London (Heathrow)	
Runway:	28L	
Time:	Unavailable	
Date:	October 1966	
Peak CG acceleration:	1st impact:	0.95 Δg
	2nd impact:	0.46 Δg
Aircraft speed at initial touchdown:		142 kt ias

Comments:

The heading and roll traces indicate that the aircraft landed in a cross-wind. It is seen from the traces that difficulty was experienced in trying to hold the aircraft level and it was landed while drifting.

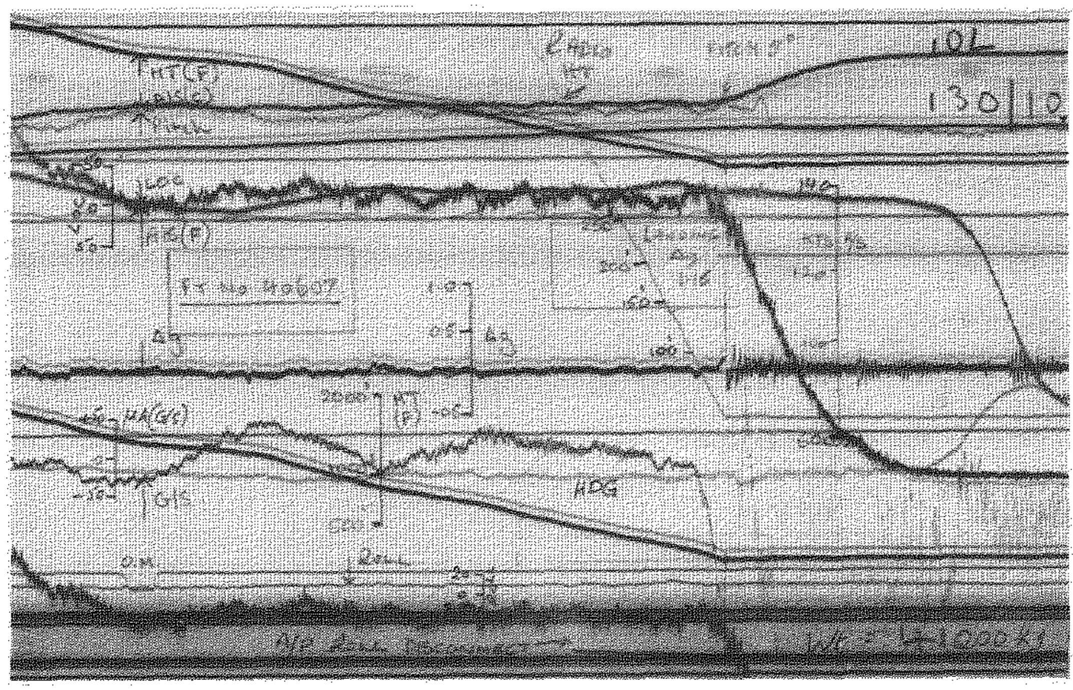


Fig.19

Information on Event in Fig.19

Aircraft Type:	E		
Airport:	London (Heathrow)	Runway:	10L
Date:	January 1967	Time:	19.26 GMT
Peak CG acceleration:	1.16 Δg		
Aircraft speed at touchdown:	135 kt		

Meteorological conditions:

Time (GMT)	19.20
Wind	130°/8 kt
Cloud	8/8 base at 1000 ft
QNH (mb)	1027
QFE (mb)	1024
Temp ($^{\circ}$C)	1
Dew point ($^{\circ}$C)	0

Comments:

Flare began late (approximately 1 second prior to touchdown) and consequently the approach descent rate of 13 ft/sec could not be reduced sufficiently for a satisfactory landing to be achieved.

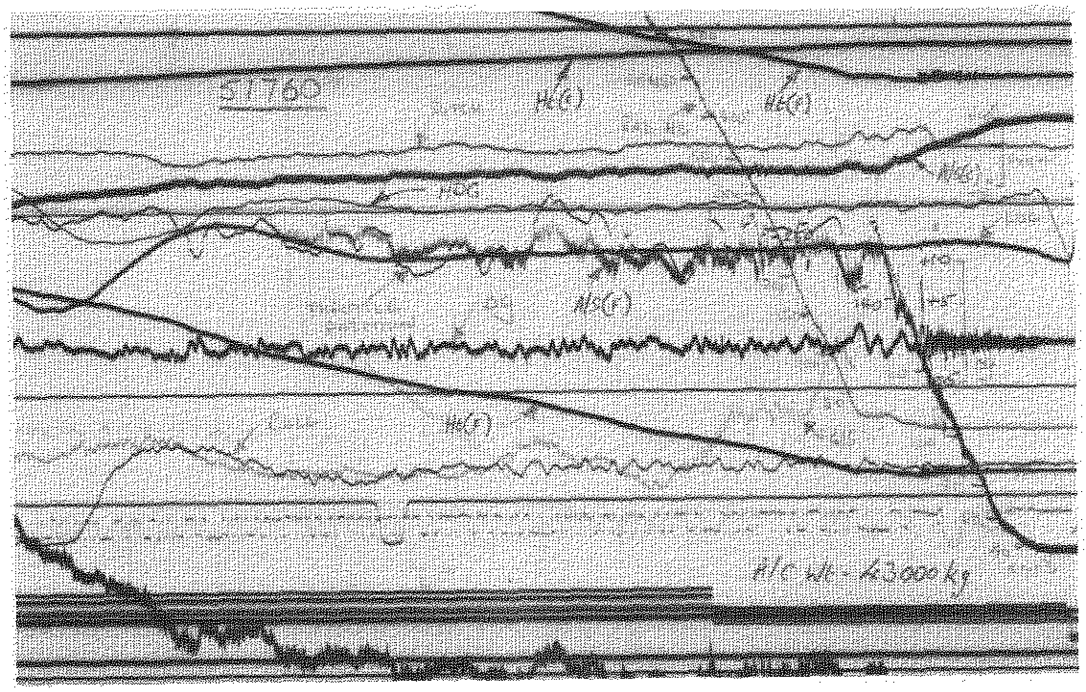


Fig.20

Information on Event in Fig.20

Aircraft Type:	E		
Airport:	London (Heathrow)	Runway:	28R
Date:	July 1967	Time:	13.59 GMT
Peak CG acceleration:	0.85 Δg		
Aircraft speed at touchdown:	124 kt		

Comments:

A poor final approach was made in gusty conditions. A complete initial flare-out was carried out at a height of 15 feet and 11 seconds before initial touchdown. The aircraft was brought down in a series of steps. This technique has been observed in other landings but resulting in impacts of lower severity (see Appendix). It may be somewhat fortuitous, however, when the aircraft lands at an instant in time corresponding with a low rate of descent in the oscillating flight path when performing this manoeuvre.

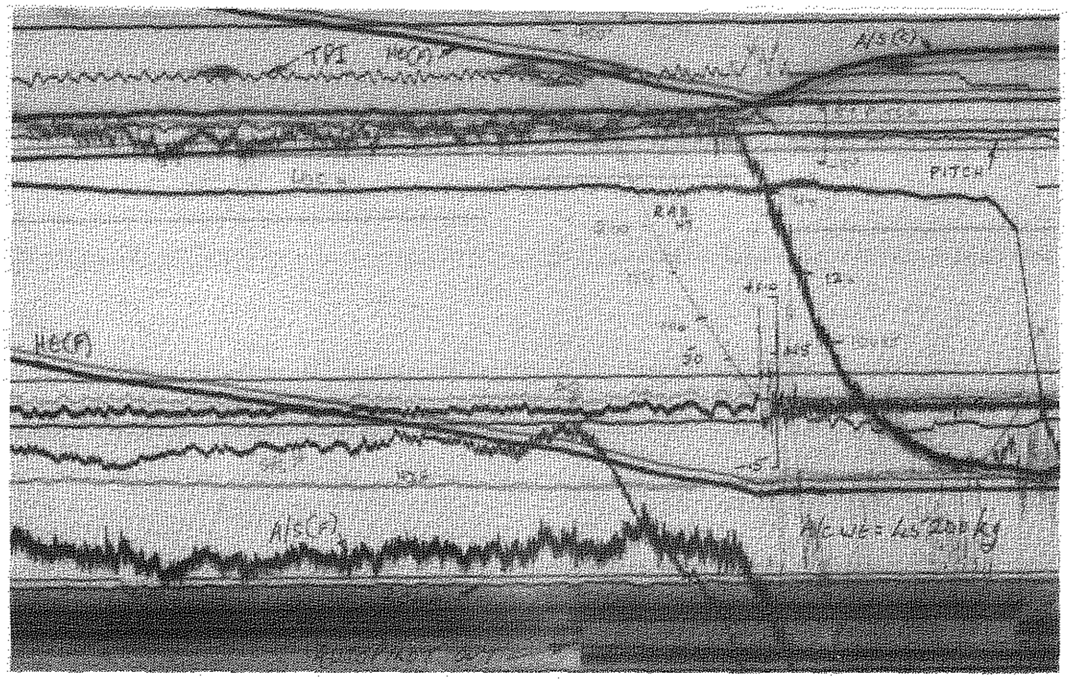


Fig.21

Information on Event in Fig.21

Aircraft Type:	E			
Airport:	London (Heathrow)		Runway:	10L
Date:	February 1968		Time:	Unavailable
Peak CG acceleration:				
	1st impact:	0.89 Δg		
	2nd impact:	0.36 Δg		
Aircraft speed at initial touchdown:		143 kt		

Comments:

The final approach descent rate is low at about 10.75 ft/sec. The heavy landing is accounted for by the late flare and consequential insufficient reduction of descent rate prior to impact. Vertical velocity at touchdown is estimated to be 7 ft/sec from normal acceleration and radio height time histories.

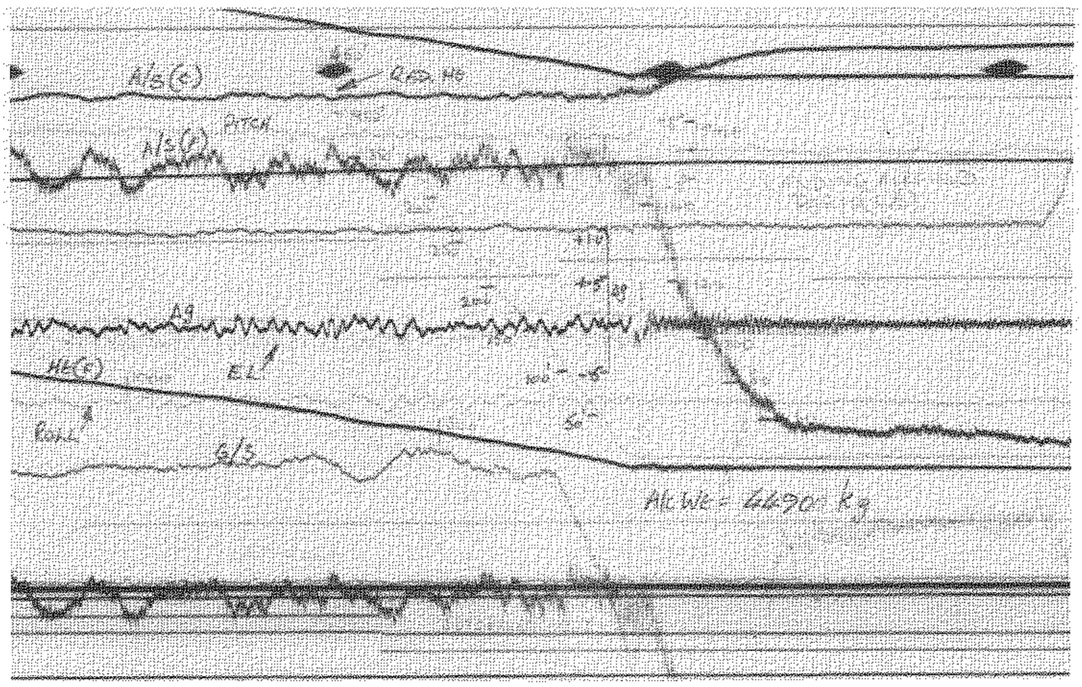


Fig.22

Information on Event in Fig.22

Aircraft Type:	E		
Airport:	Le Bourget	Runway:	Unknown
Date:	May 1968	Time:	07.48 GMT

Peak CG acceleration:

1st impact:	0.96 Δg
2nd impact:	0.43 Δg

Aircraft speed at initial touchdown: 144 kt ias

Comments:

The pilot did not recall the landing as being hard. Little or no flare was performed resulting in the aircraft touching down at the final approach descent velocity, which according to the radio height trace was fortunately low at approximately 5 ft/sec.

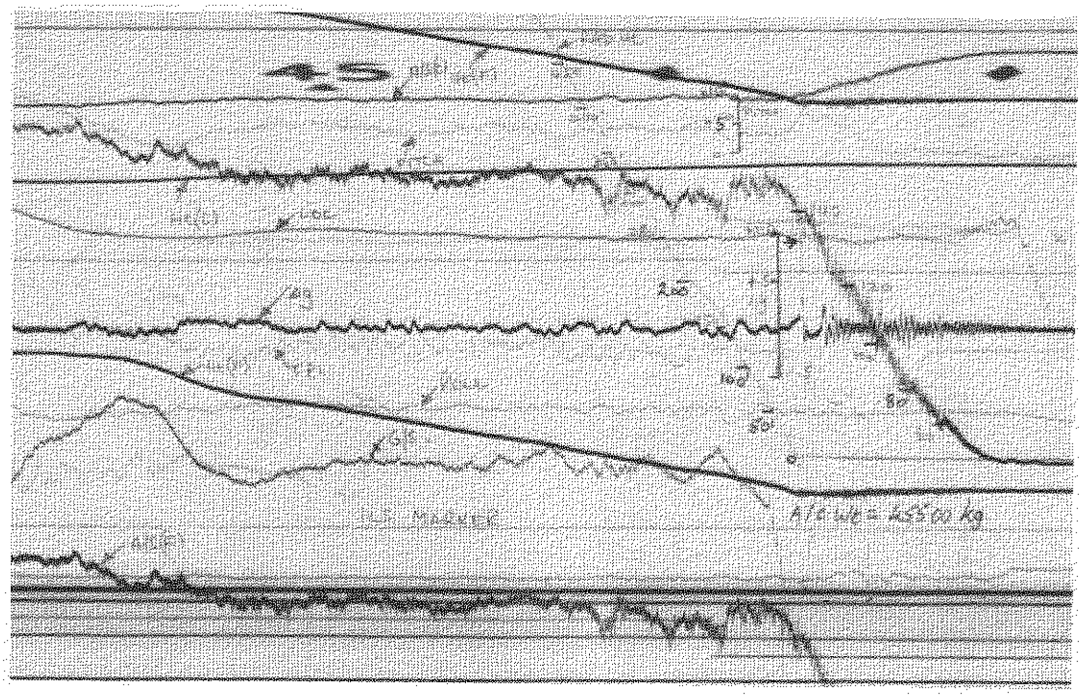


Fig.23

Information on Event in Fig.23

Aircraft Type:	E		
Airport:	Brussels	Runway:	26L
Date:	May 1968	Time:	15.46 GMT

Peak CG acceleration:

	1st impact:	0.94 Δg
	2nd impact:	0.24 Δg

Aircraft speed at initial touchdown: 138 kt

Comments:

The rate of descent at touchdown is estimated to be 8 ft/sec from the normal acceleration and radio height time histories. The pitch angle at touchdown is higher than normal at $6\frac{1}{2}^{\circ}$. The high impact Δg (a large proportion of which appears to be of high frequency) was a result of the moderately high descent rate at the moment of touchdown and the long bounce was possibly due to the high pitch angle producing a lift of 1.15 g (abs) still increasing at impact.

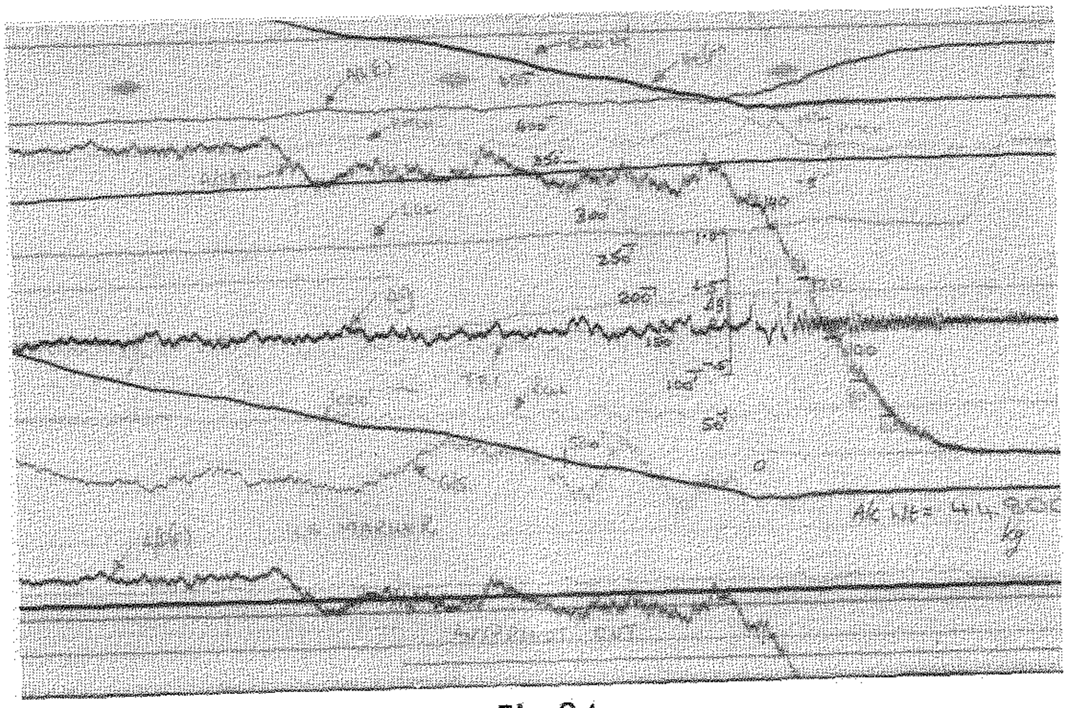


Fig.24

Information on Event in Fig.24

Aircraft Type:	E
Airport:	London (Heathrow)
Runway:	Unknown
Time:	Unknown
Date:	June 1968

Peak CG Acceleration:

1st impact:	1.01 Δg
2nd impact:	0.55 Δg
3rd impact:	0.29 Δg

Aircraft speed at initial touchdown: 141 kt ias

Comments:

The descent rate at a height of 100 ft was low (9 ft/sec) and, possibly because of this, the flare was begun late, at a height of 20 ft. The descent rate reduction was therefore small and the residual descent rate at touchdown was 7 ft/sec estimated from normal acceleration and radio height time histories.

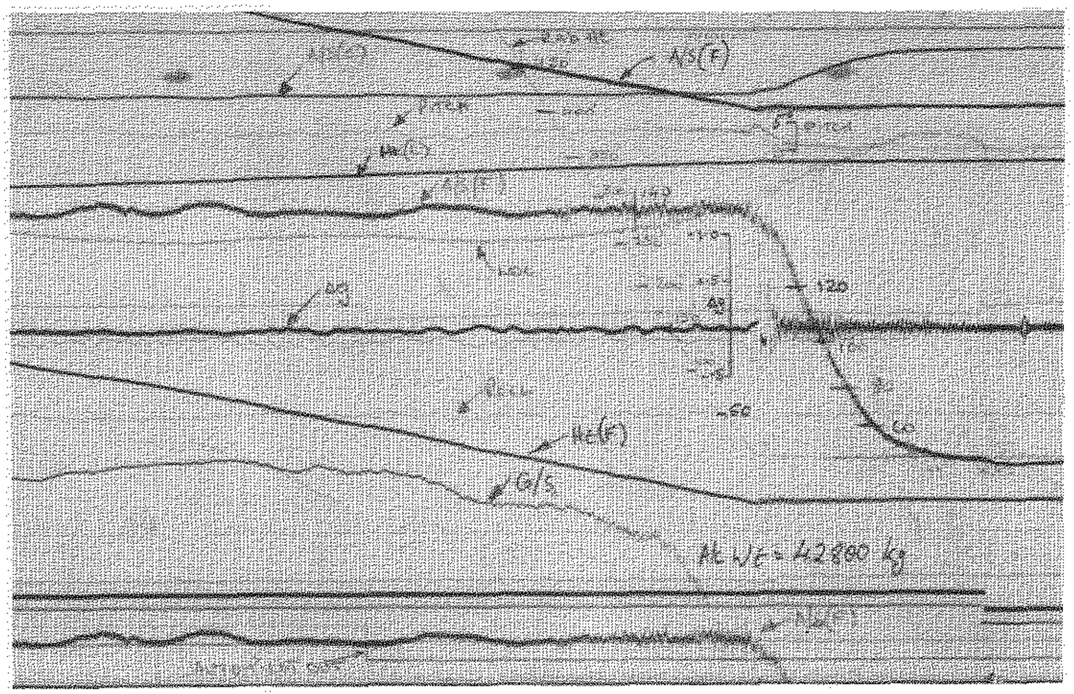


Fig.25

Information on Event in Fig.25

Aircraft Type:	E		
Airport:	London (Heathrow)	Runway:	Unknown
Date:	June 1968	Time:	14.48 GMT

Peak CG acceleration:

	1st impact:	0.85 Δg
	2nd impact:	0.47 Δg

Aircraft speed at initial touchdown: 137 kt

Meteorological conditions: Raining and thundery

Comments:

Very little flare applied. The runway was obviously wet and a firm landing may have been intentional to avoid the risk of aquaplaning.

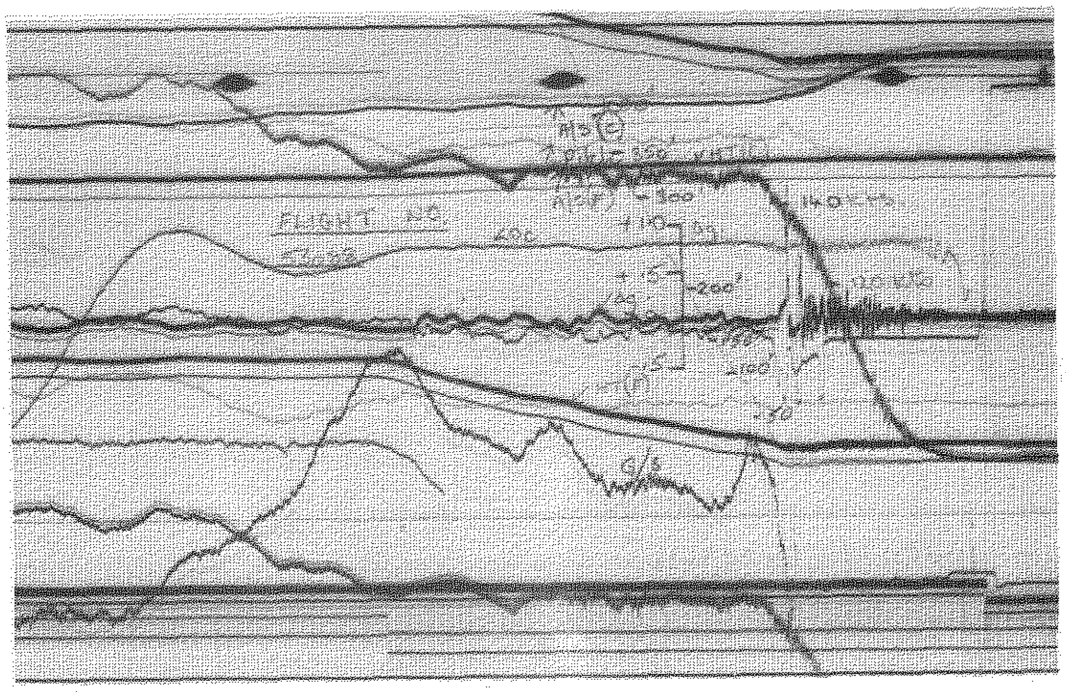


Fig.26

Information on Event in Fig.26

Aircraft Type:	E	
Airport:	Brussels	
Runway:	26	
Time:	16.22 GMT	
Date:	July 1968	
Peak CG acceleration:		
	1st impact:	1.33 Δg
	2nd impact:	0.68 Δg
Aircraft speed at initial touchdown:		137 kt ias

Comments:

Flare began late at about 1.1 sec prior to touchdown at a height of about 13 ft and reduced the descent rate from 12 ft/sec to 8 ft/sec at touchdown.

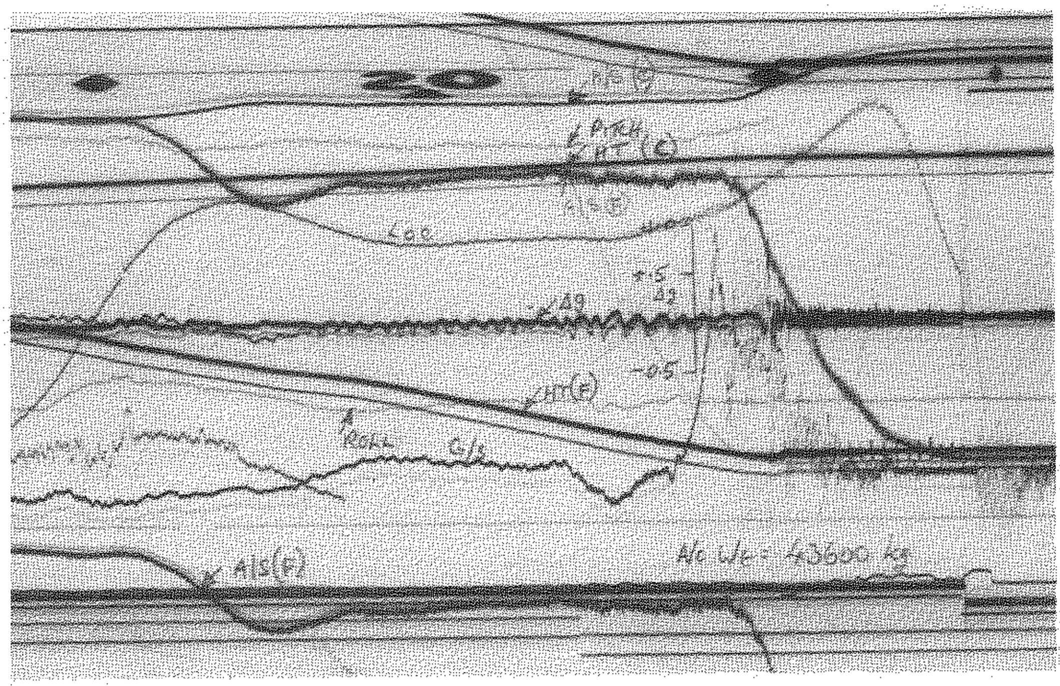


Fig.27

Information on Event in Fig.27

Aircraft Type:	E
Airport:	London (Heathrow)
Runway:	Unknown
Time:	21.21 GMT
Date:	July 1968
Peak CG acceleration:	0.86 Δg
Aircraft speed at touchdown:	127 kt ias

Comments:

Flare began very mildly at a height of about 70 ft and was continued satisfactorily until at about $1\frac{1}{2}$ sec prior to touchdown when the aircraft accelerated downward gaining approximately $2\frac{1}{4}$ ft/sec in descent velocity from some cause indeterminable from the record.

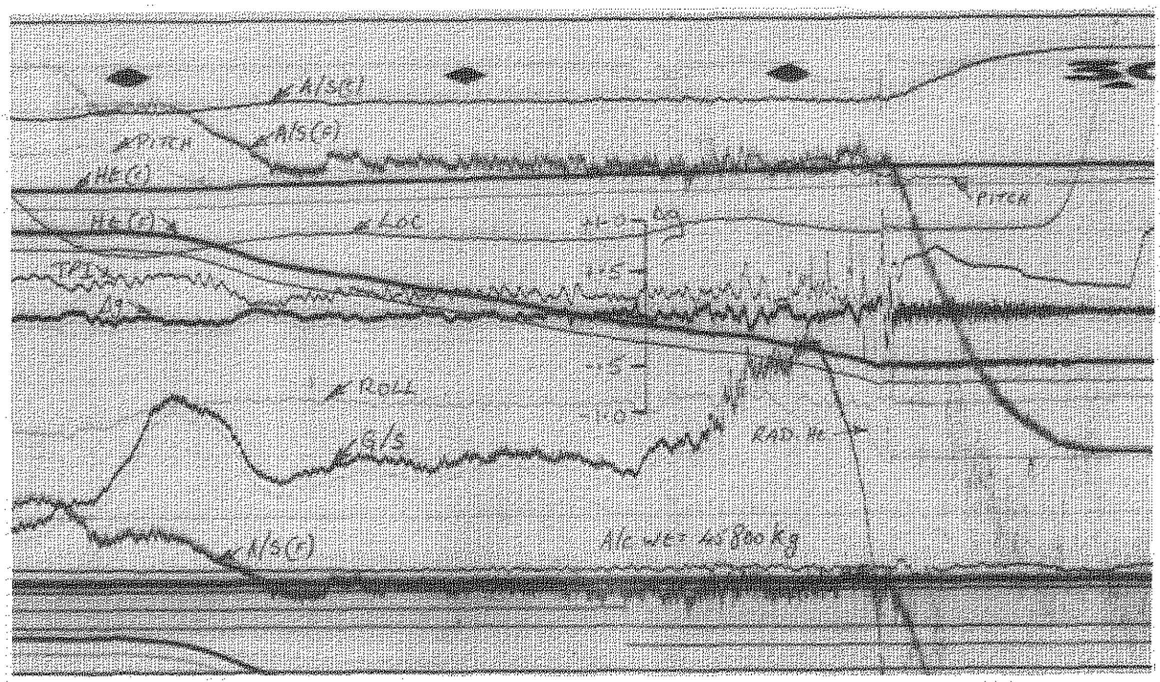


Fig.28

Information on Event in Fig.28

Aircraft Type:	E
Airport:	Basle
Runway:	16
Time:	21.19 GMT
Date:	September 1968
Peak CG acceleration:	1.10 Δg
Aircraft speed at touchdown:	146 kt ias

Meteorological Conditions:

Time (GMT):	21.20
Temp (^{o}C):	14
Wind	280^{o}/08 kt
Visibility (Nm):	4 (raining)
Cloud:	$\frac{3}{8}$ at 1000 ft; $\frac{5}{8}$ at 2300 ft; 8/8 at 8000 ft
Dew point (^{o}C):	13
QNH:	1004

Comments:

The aircraft landing weight was quite high, there was a slight tail wind component the runway was 7775 ft in length and wet and it was dark. These factors would have made it desirable to perform a firm landing but almost certainly a landing of this severity would not be intentional.

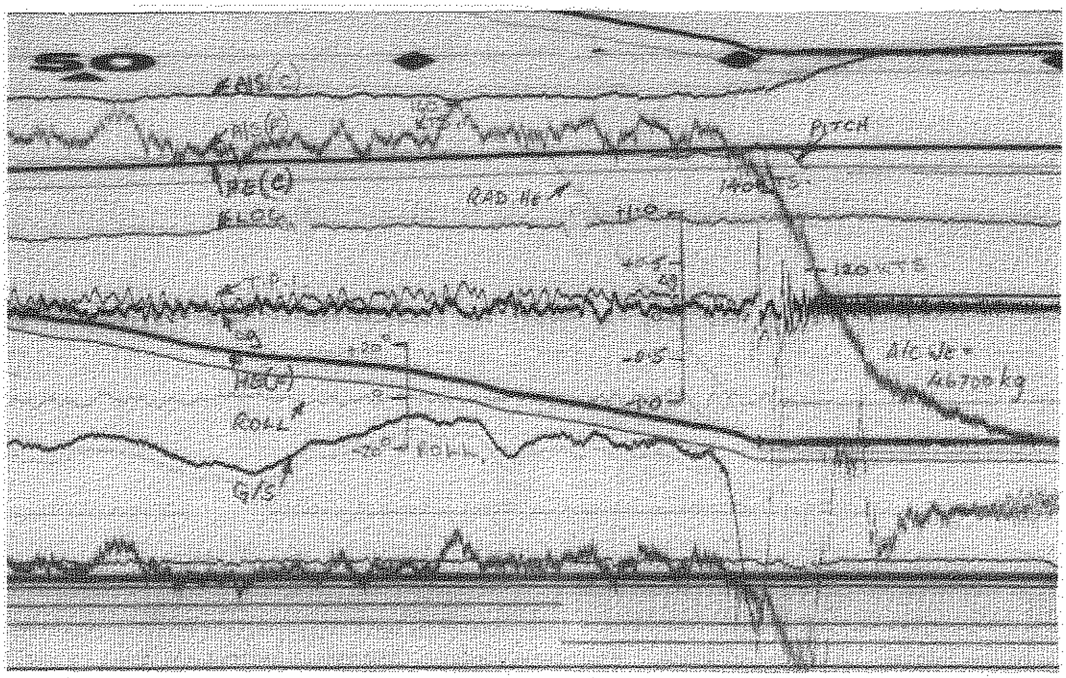


Fig.29

Information on Event in Fig.29

Aircraft Type:	E	
Airport:	Paris (Orly)	
Runway:	26	
Time:	14.52 GMT	
Date:	September 1968	
Peak CG acceleration:		
	1st impact:	0.80 Δg
	2nd impact:	0.50 Δg
Aircraft speed or initial touchdown:		142 kt ias

Comments:

The character of the airspeed trace indicates that the air was rather turbulent during the approach and landing, rendering fine control of the aircraft more difficult. The roll trace shows the aircraft to be oscillating in roll up to $\pm 4^{\circ}$ during the 10 sec prior to and during the landing.

The quoted aircraft weight is 430 kg (950 lb) above the maximum landing weight.

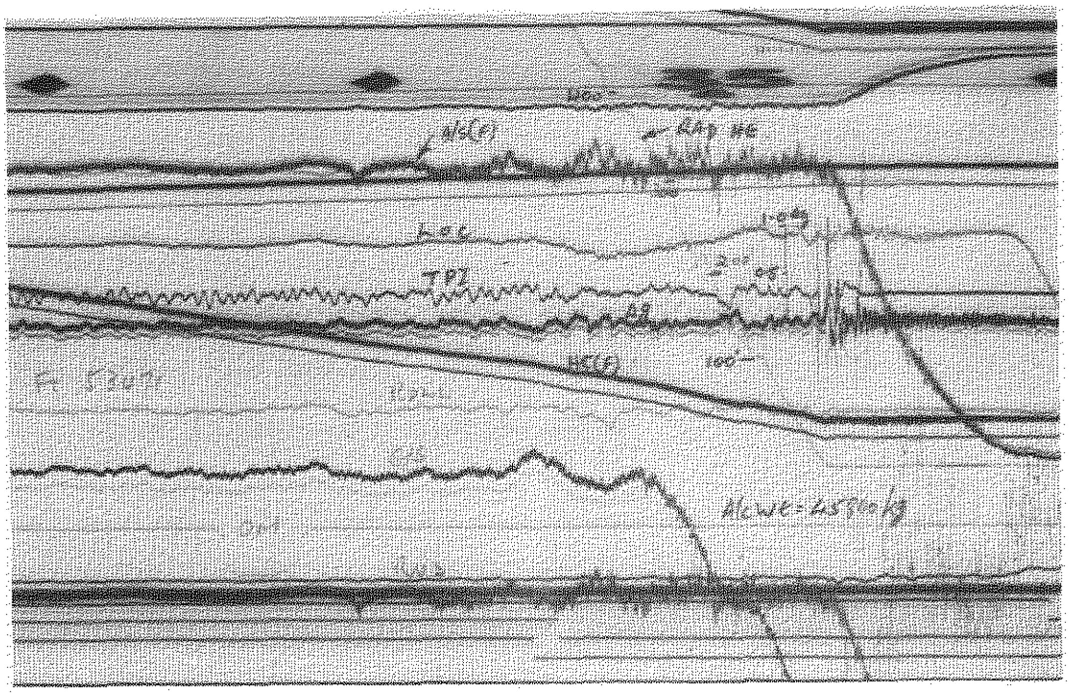


Fig.30

Information on Event in Fig.30

Aircraft Type:	E	
Airport:	Frankfurt	
Runway:	Unknown	
Time:	17.35 GMT	
Date:	October 1968	
Peak CG acceleration:		
	1st impact:	1.06 Δg
	2nd impact:	0.45 Δg
Aircraft speed at initial touchdown:		148 kt ias
Meteorological Conditions:		
Wind:	$190^{o}/09$ kt	
Comments:		

Flare did not begin until 3 sec prior to touchdown. The flare was also of an oscillatory nature, the cumulative effect during the last 3 sec being to reduce the rate of descent only by about 3 ft/sec from $11\frac{1}{2}$ ft/sec.

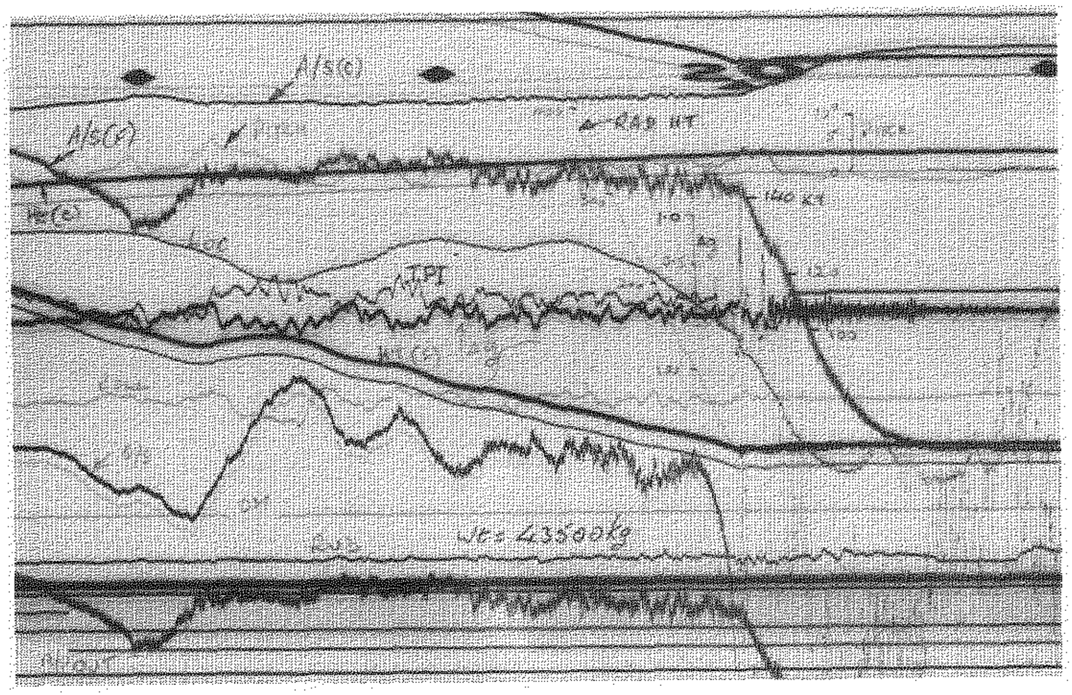


Fig.31

Information on Event in Fig.31

Aircraft Type:	E	
Airport:	London (Heathrow)	
Runway:	28	
Time:	20.20 GMT	
Date:	October 1968	
Peak CG acceleration:		
	1st impact:	1.10 Δg
	2nd impact:	0.60 Δg
Aircraft speed at initial touchdown:		141 kt ias
Meteorological Conditions:		
Wind:	260^{o}/06 kt	
Comments:		

The apparent severity of the first impact is exaggerated by the oscillatory component of the CG acceleration having a large amplitude. After smoothing out the high frequency component the maximum acceleration is reduced to approximately 0.6 Δg.

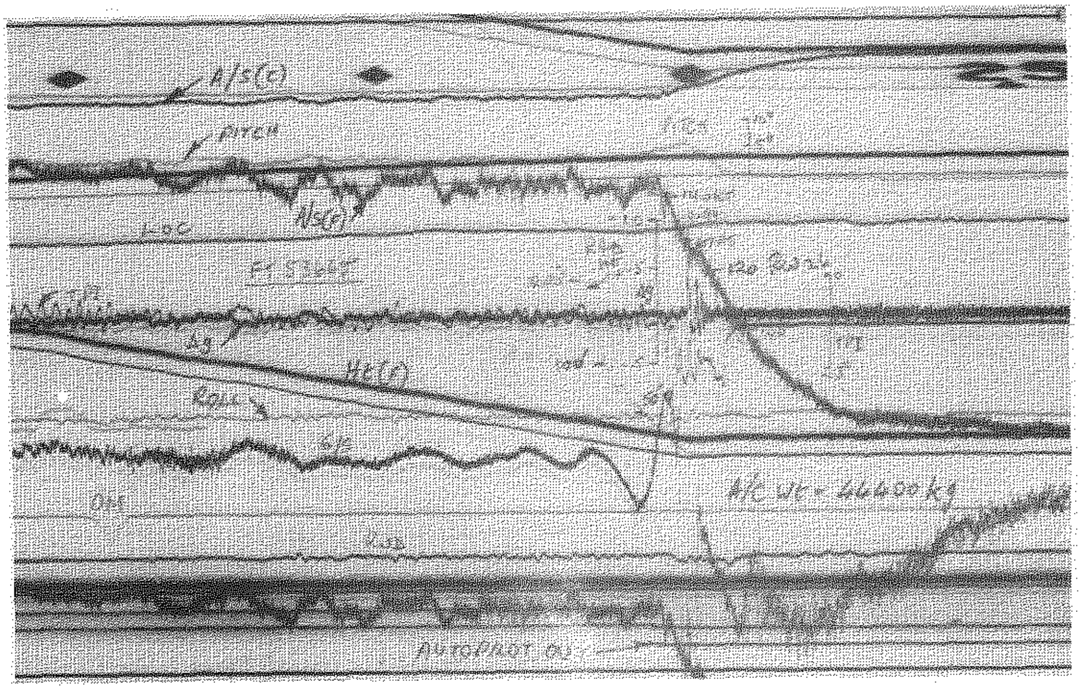


Fig.32

Information on Event in Fig.32

Aircraft Type:	E	
Airport:	Paris (Orly)	
Runway:	26	
Time:	17.24 GMT	
Date:	November 1968	
Peak CG acceleration:		
	1st impact:	0.94 Δg
	2nd impact:	0.37 Δg
Aircraft speed at initial touchdown:		126 kt ias

Comments:

The landing was intended to be an Autoland. However, at a height of 43 ft and 7 sec prior to the touchdown the autopilot disconnected itself and the pilot initiated flare at a height of 26 ft and 4.3 sec from touchdown.

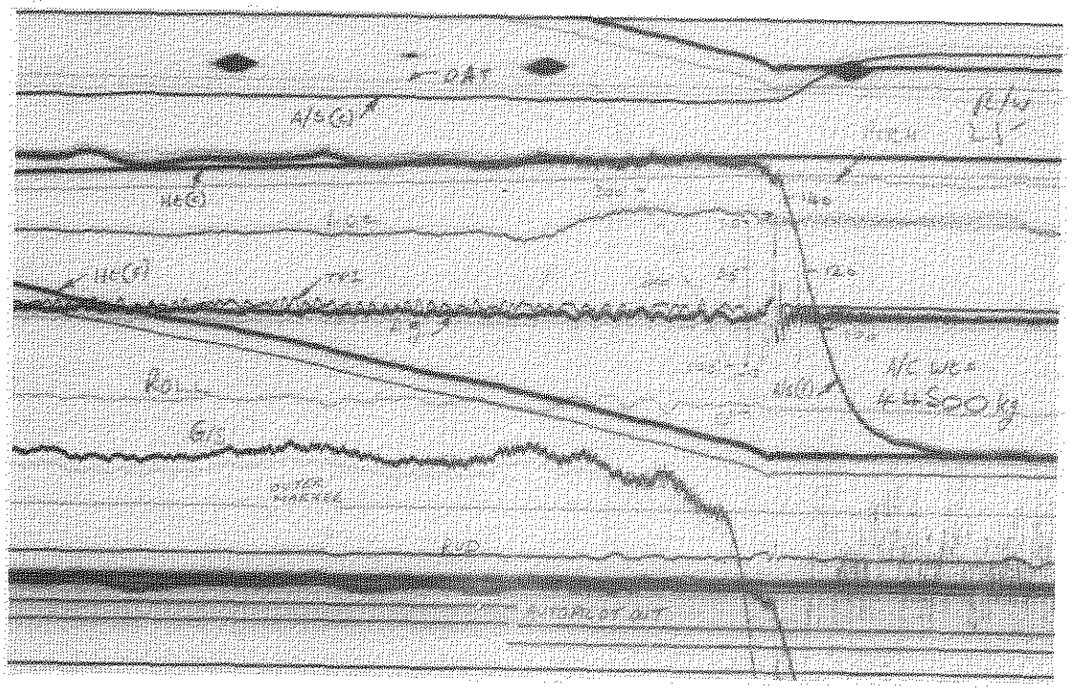


Fig.33

Information on Event in Fig.33

Aircraft Type:	E
Airport:	Frankfurt
Runway:	25
Time:	16.50 GMT
Date:	November 1968
Peak CG acceleration:	1.02 Δg
Aircraft speed at touchdown:	144 kt ias

Comments:

Late start of flare at approximately 2½ sec before touchdown.

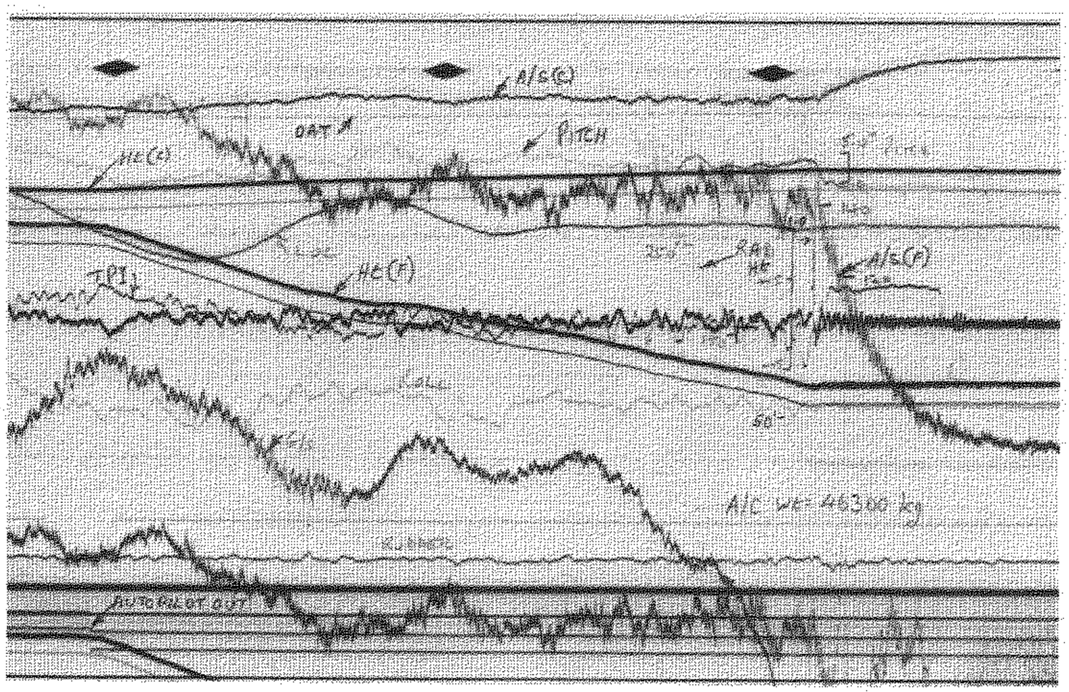


Fig.34

Information on Event in Fig.34

Aircraft Type: E

Airport: Glasgow

Runway: 06

Time: 20.14 GMT

Date: January 1969

Peak CG acceleration:

1st impact: 0.94 Δg

2nd impact: 0.23 Δg

Aircraft speed at initial touchdown: 138 kt ias

	A/c speed (ias)	Normal accel (Δg)	Pitch angle (Deg)	Descent rate (ft/sec)
At 50 ft height	135	0	4.0	13.0
At start of flare	145	0	3.1	7.2
At touchdown	137	0.94	4.4	5.7

Comments:

At the time of landing the runway had a covering of 3 mm of slush, and a firm touchdown may have been intentional to reduce the risk of aquaplaning or skidding.

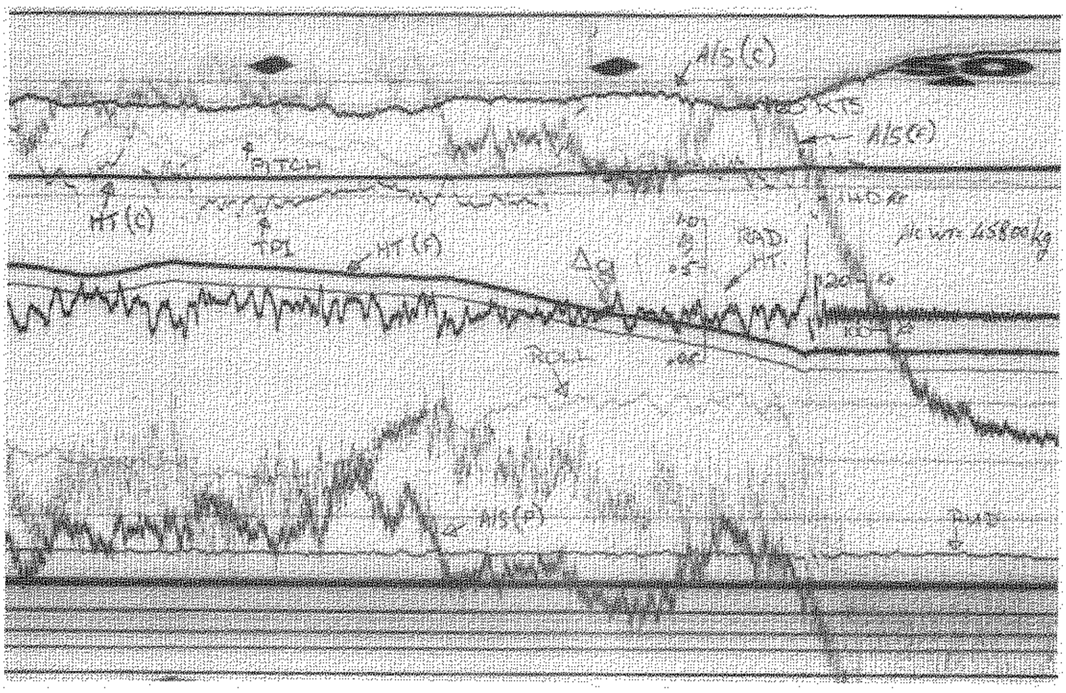


Fig.35

Information on Event in Fig.35

Aircraft Type:	E	
Airport:	Zurich	
Runway:	16	
Time:	06.50 GMT	
Date:	April 1969	
Peak CG acceleration:		
	1st impact:	0.95 Δg
	2nd impact:	0.44 Δg
Aircraft speed at initial touchdown:		147 kt ias
Meteorological conditions:		
Wind:	240°/17 kt	
Visibility:	10 Nml	
Cloud:	4/8 Cu at 3300 ft	

The meteorological Special Group reported 'Unstable air and cumulus cloud'.

Comments:

The whole approach and landing was carried out in light turbulence and a 17 kt crosswind. The fact that the meteorological Special Group reported conditions to the pilot indicates that unusual conditions were present. The record shows the flare to have started late but the turbulence and crosswind obviously produced difficulties in performing an ideal landing.

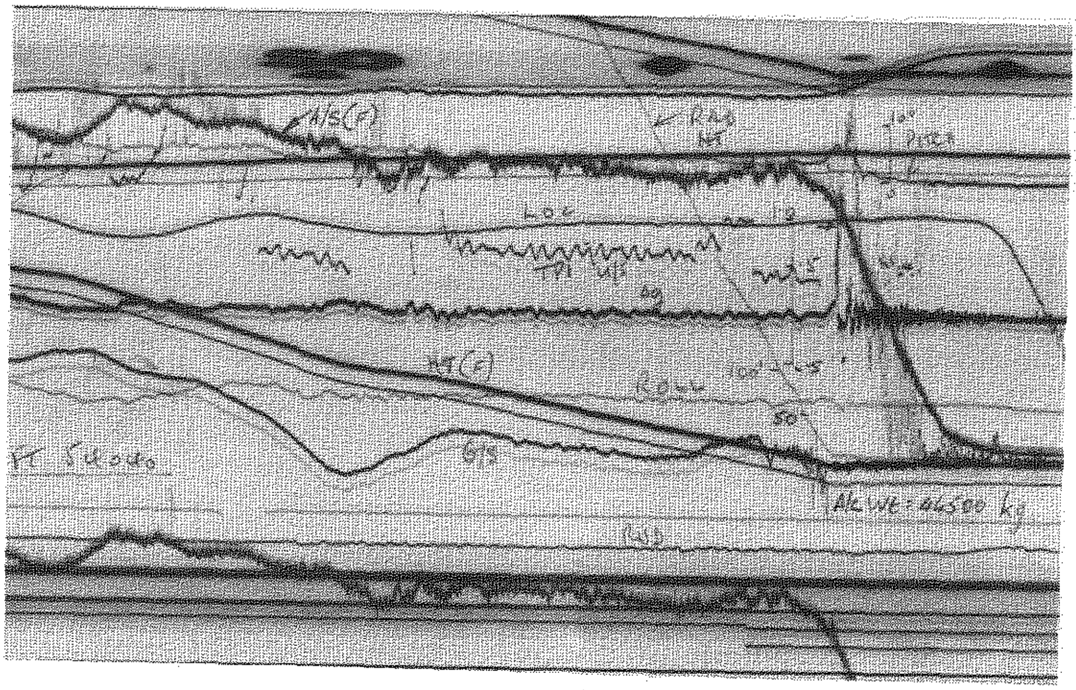


Fig.36

Information on Event in Fig.36

Aircraft Type:	E
Airport:	London (Heathrow)
Runway:	28L
Time:	18.51 GMT
Date:	April 1969

Peak CG acceleration:

	1st impact:	0.92 Δg
	2nd impact:	0.40 Δg

Aircraft speed at initial touchdown: 137 kt ias

Comments:

The flare was performed late causing the aircraft to land at a rather high descent rate of about 7 ft/sec.

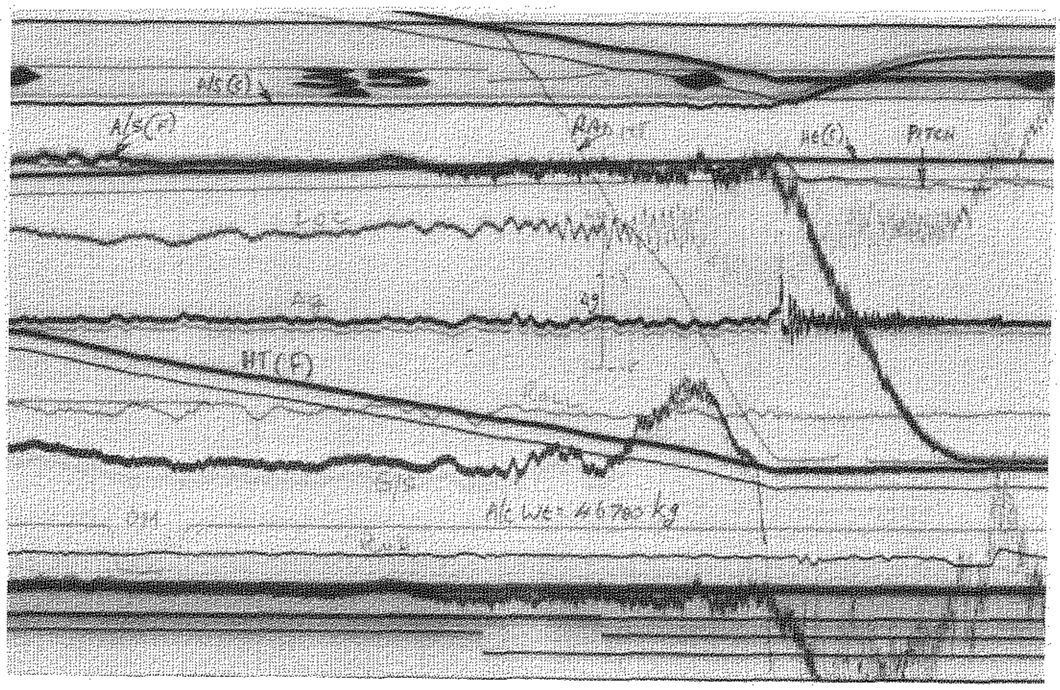


Fig.37

Information on Event in Fig.37

Aircraft Type:	E	
Airport:	Amsterdam	
Runway:	01	
Time:	21.52 GMT	
Date:	May 1969	
Peak CG acceleration:		
	1st impact:	0.95 Δg
	2nd impact:	0.29 Δg
Aircraft speed at initial touchdown:		145 kt ias

Comments:

The flare began late but the severity of the impact acceleration is exaggerated more than usually by the large amplitude of the high frequency content. Ignoring the high frequency component the maximum acceleration is about 0.48 Δg.

The 'noise' on the localiser signal, commencing half a minute before touchdown, is characteristic of this runway.

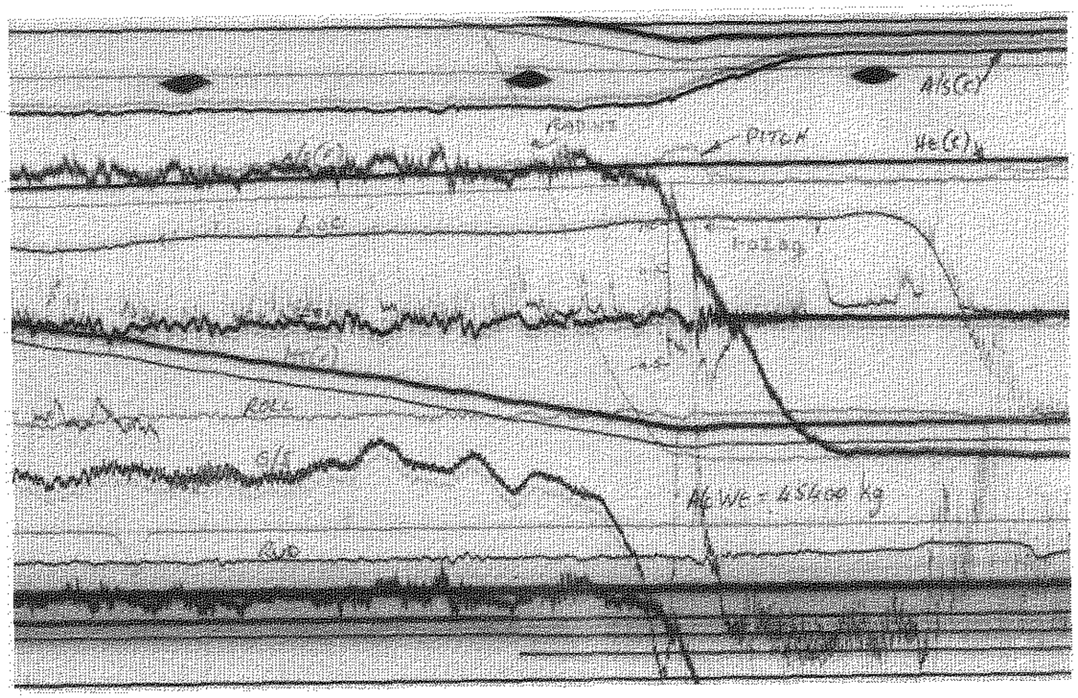


Fig.38

Information on Event in Fig.38

Aircraft Type:	E
Airport:	Paris (Orly)
Runway:	26
Time:	10.18 GMT
Date:	June 1969
Peak CG acceleration:	1.02 Δg
Aircraft speed at touchdown:	125 kt ias

Comments:

On completion of a successful flare the aircraft was still airborne and it was necessary for the pilot to initiate descent again in order to prevent the aircraft travelling too far along the runway before alighting. This flare manoeuvre is in type category R as defined in section 4 and discussed in section 5.

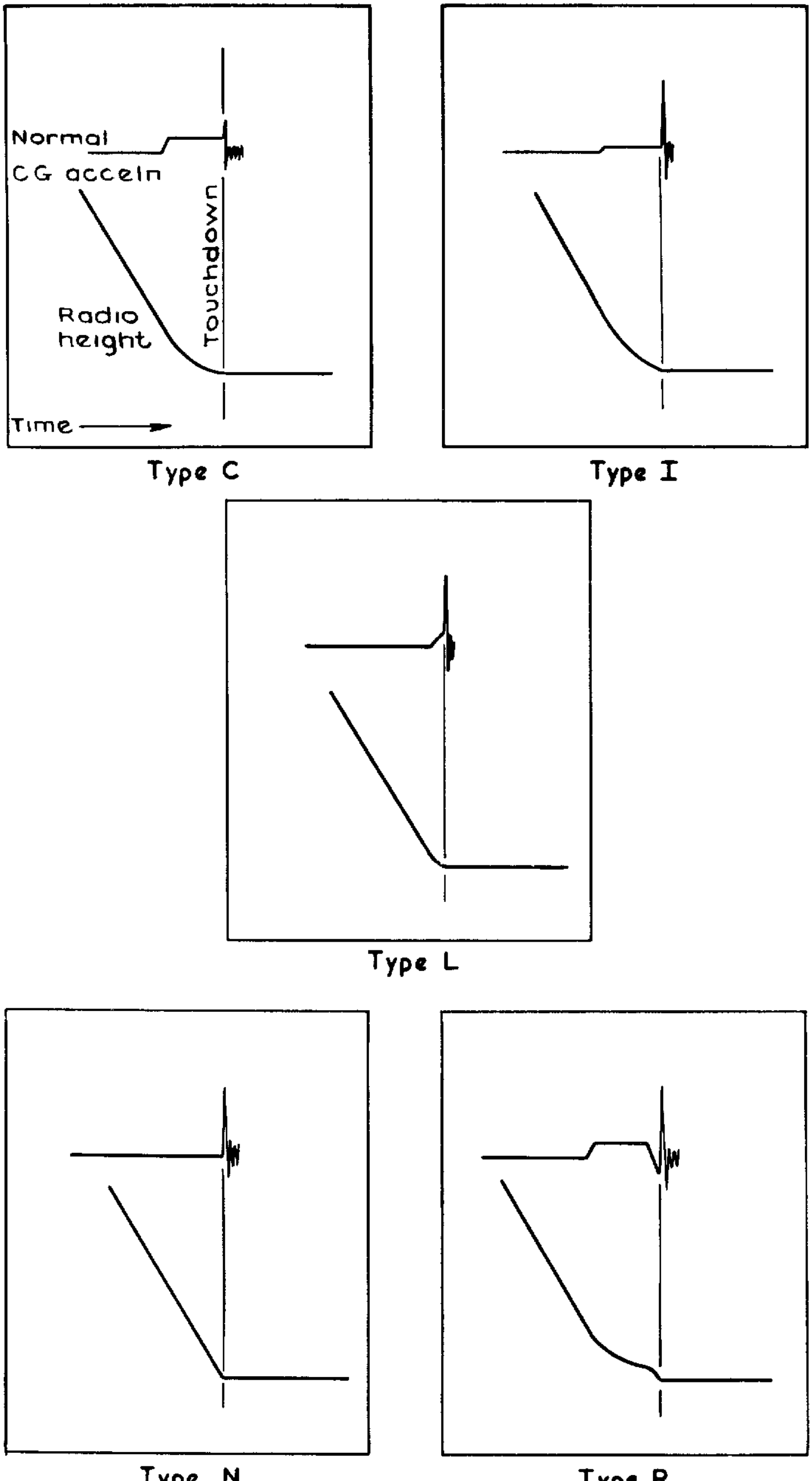


Fig. 39 Height & normal acceleration time histories during various types of flare manoeuvre

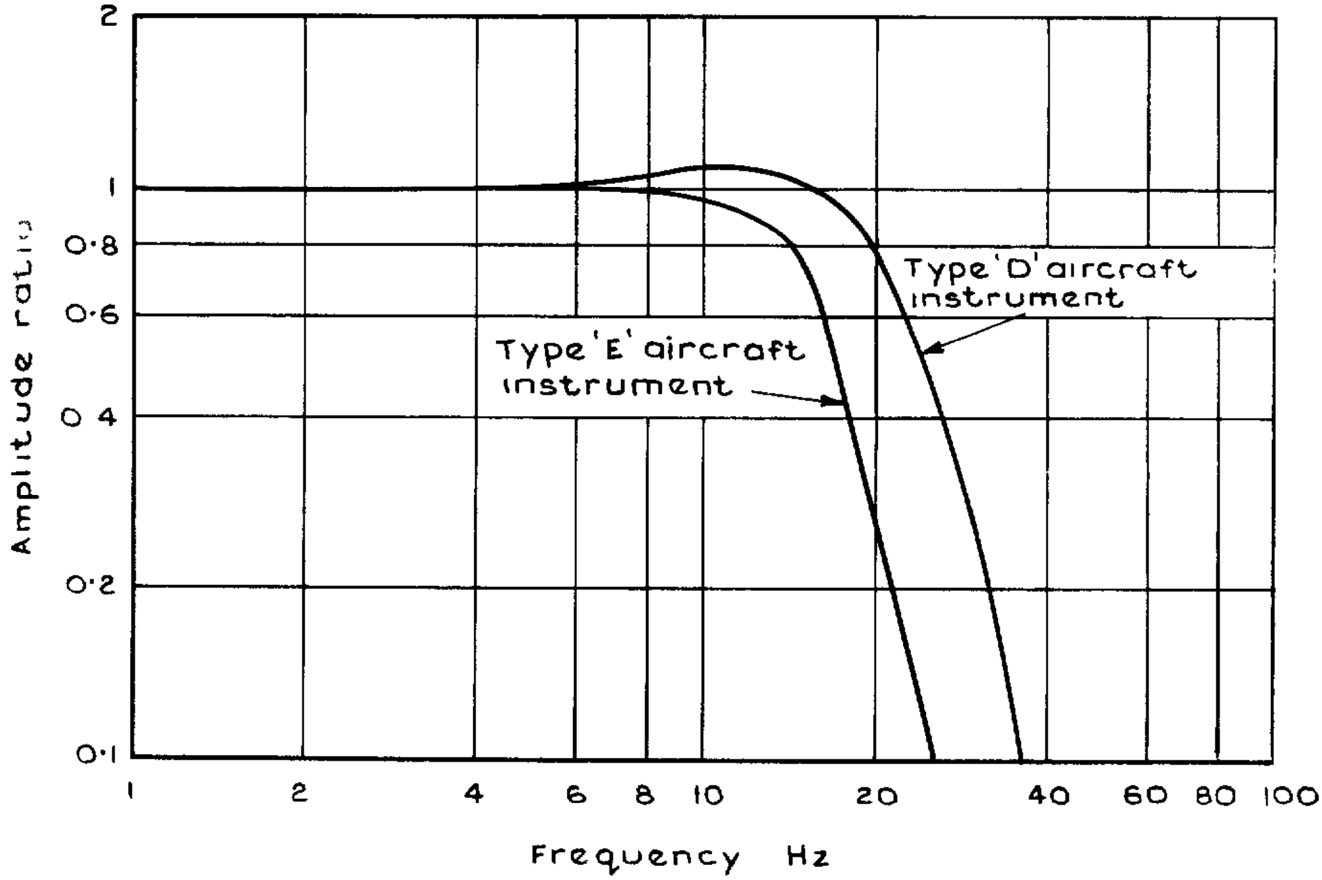


Fig. 40 Frequency response of the normal CG acceleration instrumentation

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A.R.C. C.P. No.1182
November 1970

629.13.087

The CAADRP Special Events Working Party
(Co-ordinated by G. B. Hutton)

CIVIL AIRCRAFT AIRWORTHINESS DATA RECORDING PROGRAMME HARD LANDINGS ENCOUNTERED BY SUBSONIC CIVIL JET AIRCRAFT

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It is shown that all the hard landings followed abnormal flare manoeuvres.

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