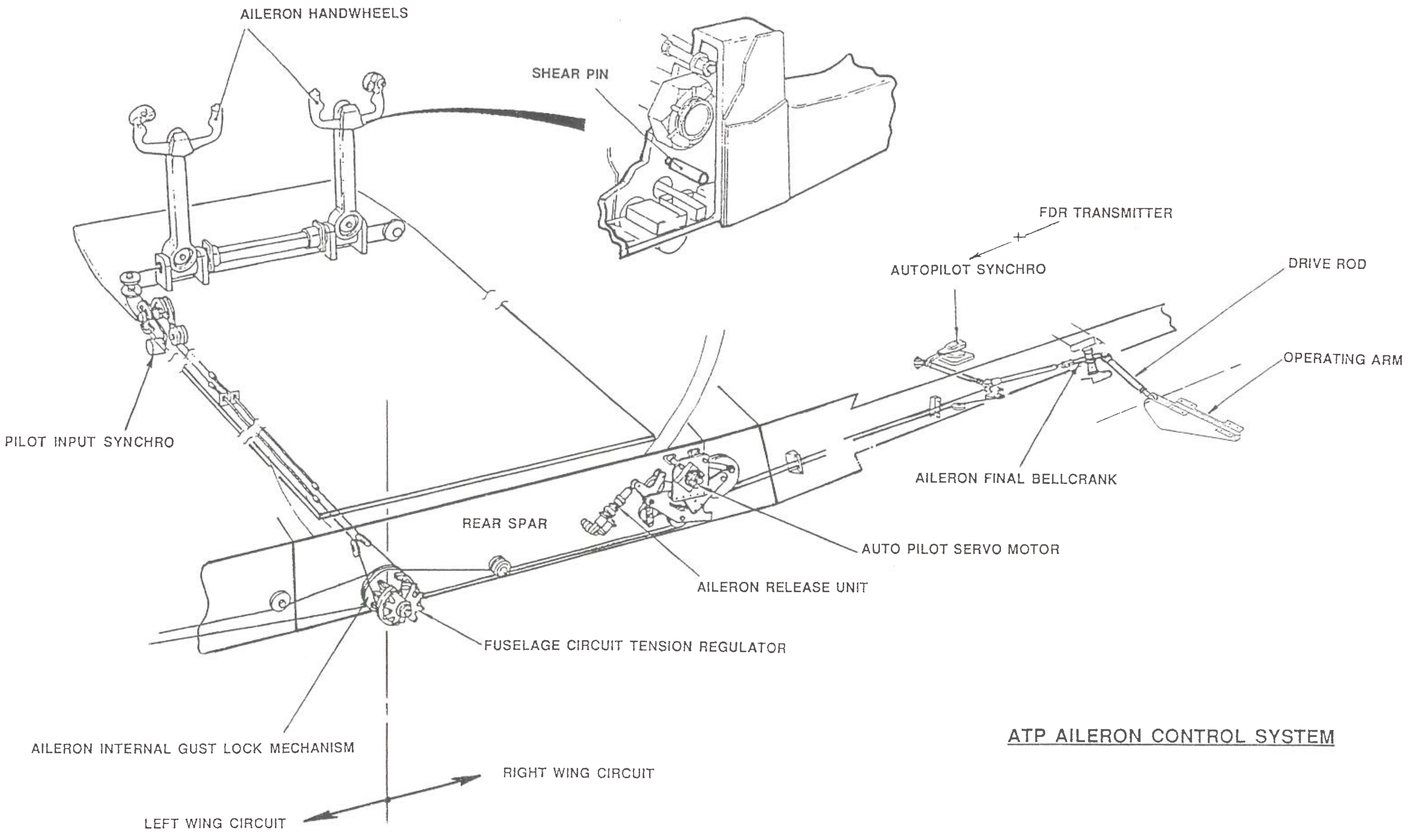
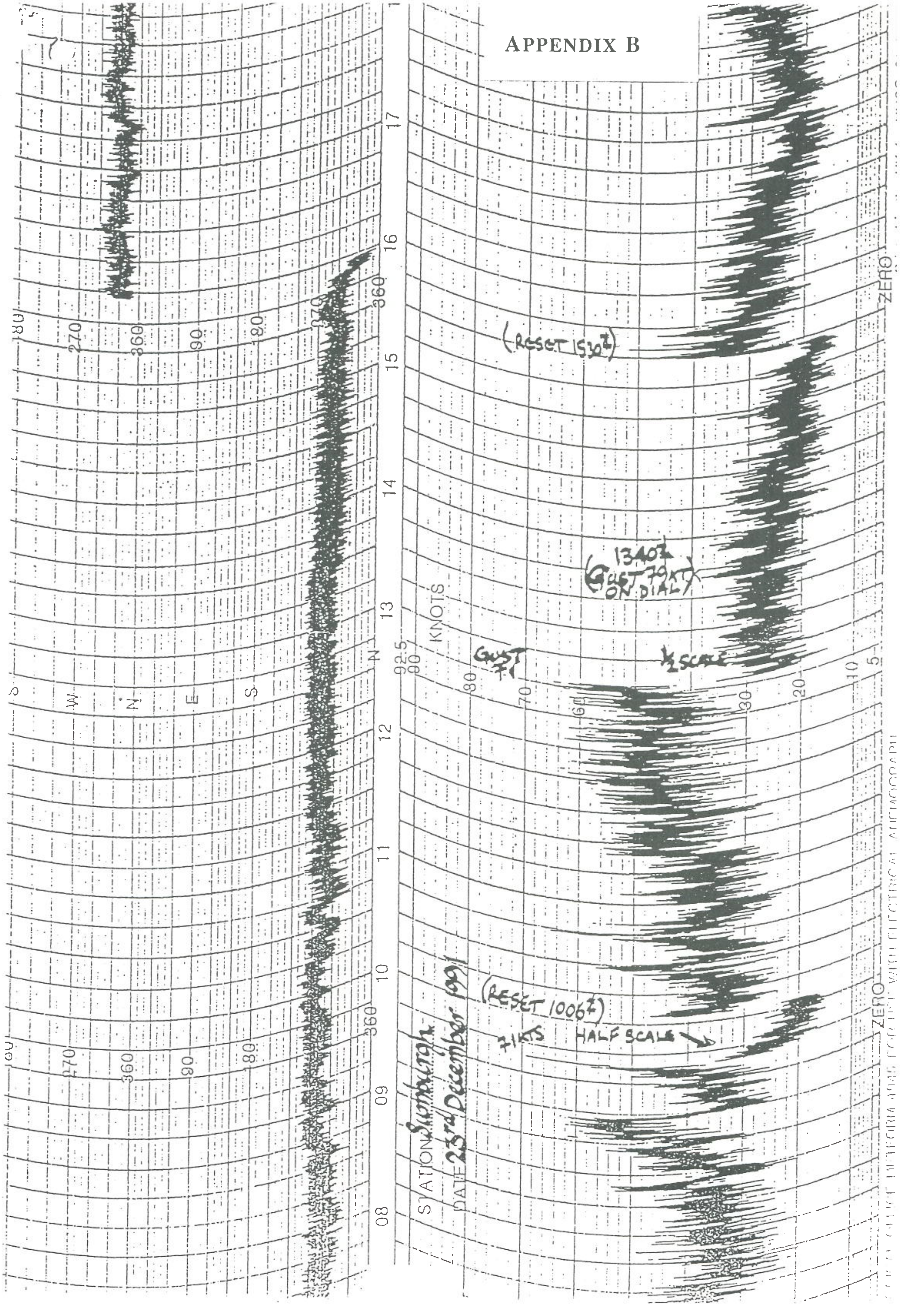
APPENDIX A



ATP AILERON CONTROL SYSTEM

APPENDIX B



STATION Sumburgh

DATE 23rd December 1991

(RESET 1530Z)

1340Z (GUST 79KT ON DIAL)

GUST 71

½ SCALE

(RESET 1006Z)

71KTS HALF SCALE

HORIZONTAL WINDSHEAR IN LOW LEVEL TURBULENT FLOW

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Short-period fluctuations and gusts are familiar features of typical surface wind anemograph records. In certain conditions such fluctuations may reveal the present of horizontal windshear of sufficient strength to be a hazard to certain types of aircraft. The purpose of this note is to describe how turbulent motion may give rise to such shears. The arguments used are based on traditional conceptual models of boundary layer flow. A case of marked gustiness in gale force winds at Sumburgh airfield, Shetland Islands, brought to our attention by Mr J J Barnett of the AAIB, is discussed as an example. Recommendations for further research are made.

Turbulent motion near the Earth's surface gives rise to a vertical displacement of air "parcels". For short displacements, each parcel may be considered to retain the velocity it possessed at its level of origin. The mixing action brings air parcels from different heights, and with different velocities, into close proximity. The process is illustrated schematically in figure 1.

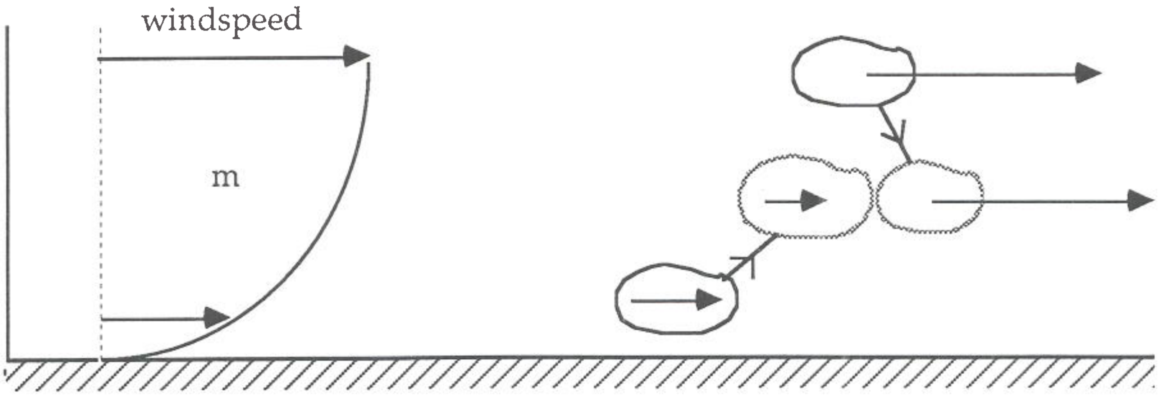


Figure 1: Schematic illustrating how vertical mixing in sheared flow gives rise to horizontal wind fluctuations

A typical boundary layer wind speed profile, with speed an increasing function of height, is shown at left; the creation of gustiness in the wind field at a mid level m, by the arrival of parcels from upper and lower levels is illustrated at right. The gustiness tends to be most pronounced when the mean wind (at 10 metres, say) is strong, and when convective instability aids the mixing process. Strong wind speeds imply strong vertical windshear and therefore a marked velocity difference between parcels originating at upper and lower levels. Convective instability will favour the mixing of parcels over a deep layer; with reference to our example, this will enable parcels with widely differing velocities to penetrate to level m . The more stable the flow, the more the vertical mixing is damped and gustiness suppressed.

Gusts in the wind field must be associated with horizontal windshear. However, because gusts are typically of short duration and are of small horizontal scale, the shear is seldom serious from an aviation point of view. Most aircraft will traverse gust events within a few seconds; consequently the associated shears have little opportunity to produce sustained changes to the ascent or descent rate of the aircraft, and are experienced more as general "bumpiness". For aviation purposes Woodfield (1990) suggests that the term windshear should be restricted to shear events of between 3-40 secs duration (as experienced by the aircraft); while those of less than 3 secs duration should be classed as turbulence.

The mechanism illustrated in figure 1 can give rise to more sustained peaks and lulls in wind speed which could represent a windshear threat. Examples may be seen in the anemometer trace reproduced in figure 2. The trace was recorded at Sumburgh airfield, Shetland on 23 December 1991 during severe gale to storm force winds (WNW 40-50 kt) and marked instability (hail showers were observed at times throughout the day). Conditions were therefore very favourable for deep vertical mixing. Isolated peaks and lulls to around 60 kt and 30 kt respectively are evident. However, these are of short duration and may be classed as turbulence according to Woodfield's criteria. Events which may be of more significance from a windshear point of view are indicated AA', BB' and CC'. At these points quite sharp transitions in wind speed of up to 16 kt occur between fairly steady flow regimes. The resolution of the trace clearly makes it difficult to be rigorous in estimating the degree of windshear. However, the transitions at AA' and BB' take place over an interval of about 50 secs, which corresponds to a horizontal distance of about 1125 m (if we assume that the structure reproduced in the trace is advected at the mean flow speed). The shear zones would be traversed in about 28 secs by an aircraft with an airspeed of 80 kt, and they therefore fall into the category of windshear rather than turbulence. Furthermore, the magnitude of the horizontal windshear is about 4m/s per 600 m which is classified as "strong" and likely to cause considerable difficulty in aircraft control according to the criteria proposed by Trunov and Turesson (1986) (table 1). It should be emphasised that the above evidence for strong windshear events comes from a very small sample of wind record on the day in question. Examination of the full record may reveal instances of more extreme events.

Intensity of windshear	Vertical windshear	Horizontal windshear	Updraft/Downdraft velocity	Effect on aircraft control
Light	0-2 m/s/30 m	0-2 m/s/600 m	0-2 m/s	Little
Moderate	2-4 m/s/30 m	2-4 m/s/600 m	2-4 m/s	Significant
Strong	4-6 m/s/30 m	4-6 m/s/600 m	4-6 m/s	Considerable difficulty
Severe	> 6 m/s/30 m	> 6 m/s/600 m	> 6 m/s	Hazardous

Table 1: Windshear intensity criteria proposed by Trunov and Turesson (1986)

From a first analysis it seems likely that the wind fluctuations seen in figure 2 are fairly typical examples of the structure of low level turbulence in conditions of strong wind and convective instability. Although local effects (generated by topography, for example) will be present, they are probably not dominant. The risk of low level windshear may therefore be widespread when such conditions apply.

Although local topography was probably not of over-riding importance on the day in question, the influence of Fitful Head, a bluff cliff rising to 1000 ft some 5 km WNW of Sumburgh airfield (upstream on the day in question), is another possible source of significant low level windshear. It is known that when the wind is directed towards a cliff edge circulations or eddies may form on the lee side, a phenomenon known as "curl over" (see figure 3 reproduced from Scorer, 1978). periodically, the eddies may be "released" from the cliff edge and move downstream, whereupon a new eddy will build in its place. A train of eddies moving downstream would produced periodic increases in surface wind where relatively fast moving air descends to the surface behind the eddies (figure 4). Scorer (1978) suggests that the eddies often contain frontal structures which result in sudden wind speed changes (rather than the more gradual changes implied by figure 4). Eddy formation is more common in stable flows, rather than in the unstable conditions characteristic of the day in question.

To conclude, the anemograph trace shown in figure 2 suggests that significant windshear events may occur at Sumburgh during conditions of high winds and marked instability. Climate data for Sumburgh suggests that mean wind speeds in excess of 34 kt effect the airfield 2.2% of the time. The likelihood of conditions similar to that depicted in figure 2 is significant, therefore, and the question of windshear risk warrants further research. In some situations the influence of Fitful Head may be important (winds in excess of 34 kt from directions 286-345° (the general direction of Fitful Head) occur 0.6% of the time. Although useful for an initial analysis, the anemograph record is clearly not sufficient for a more rigorous study. Installation of two or more digital logging anemometers (capable of 3 sec resolution, at least) would aid the assessment of the windshear risk at Sumburgh airfield.

References

Scorer, R S, 1978: *Environmental Aerodynamics,* Ellis Horwood 488pp

Trunov, O K and Turesson, L-O, 19876: *On the problem of low level windshear,* report from the Swedish Soviet working group on scientific-technical cooperation in the field of flight safety

Woodfield, A A, 1990: *Relationships between windshear severity and aircraft characteristics,* HMSO, London

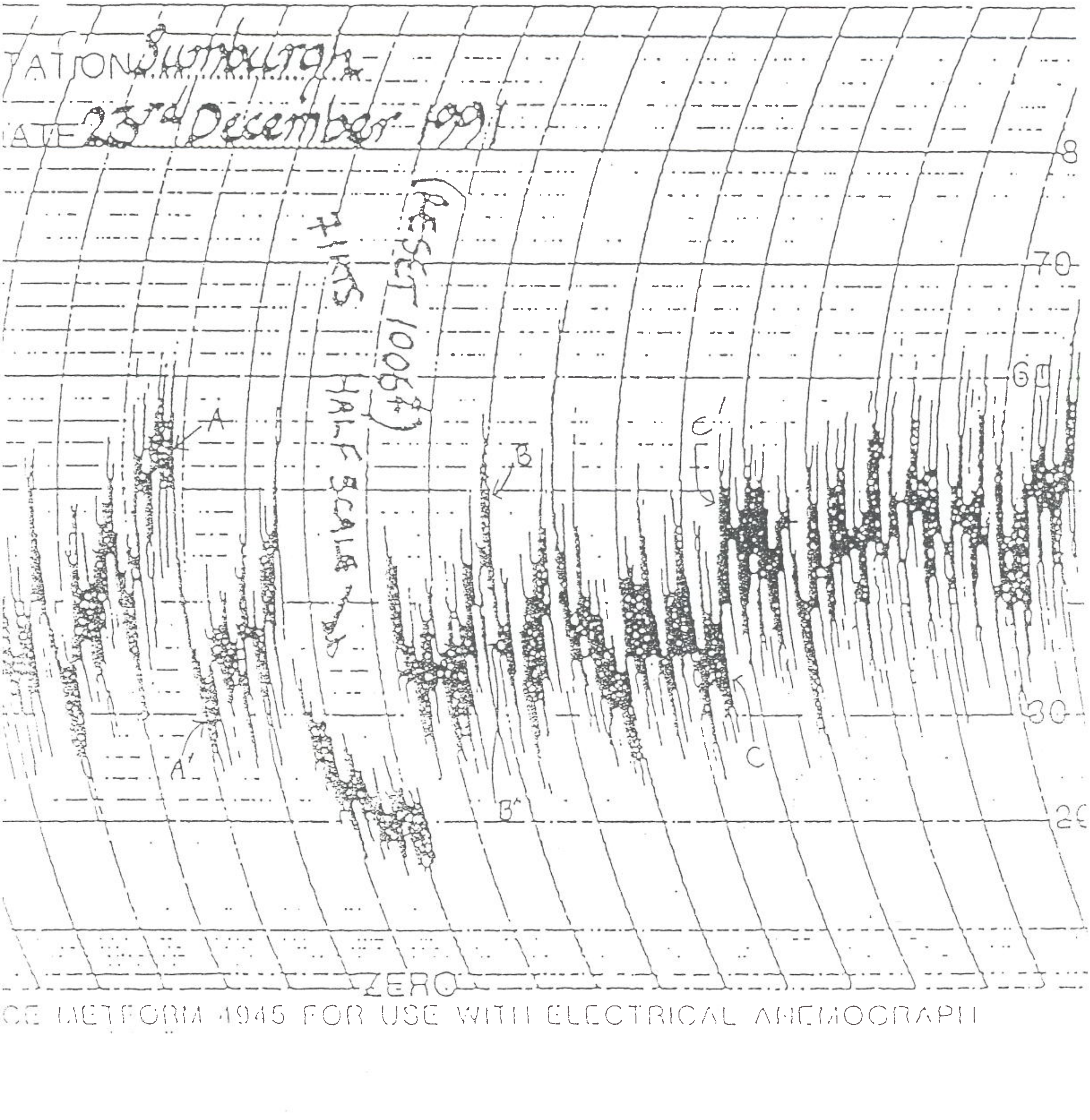


Figure 2 Section of the anemograph trace from Sumburgh airfield 23 December 1991

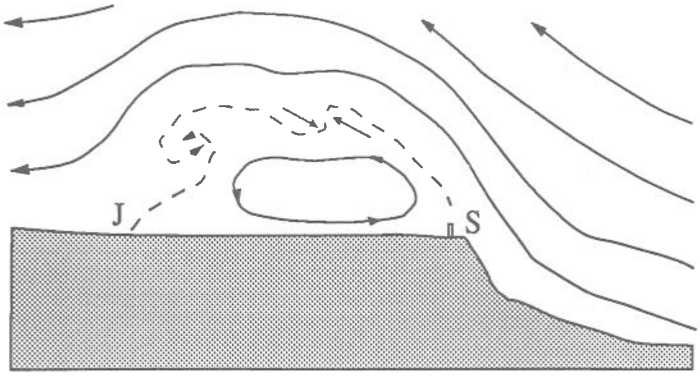


Figure 3: The formation of eddies on the lee side of a cliff top (reproduced from Scorer, 1978)

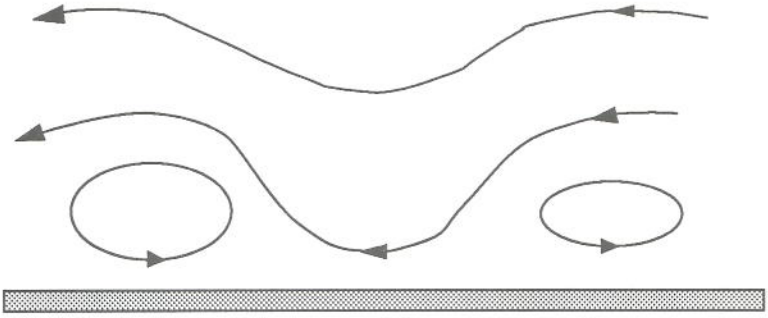


Figure 4: Fast moving air from aloft may descend to the surface between the eddies moving downstream with the mean flow (flow lines shown are relative to the eddies).

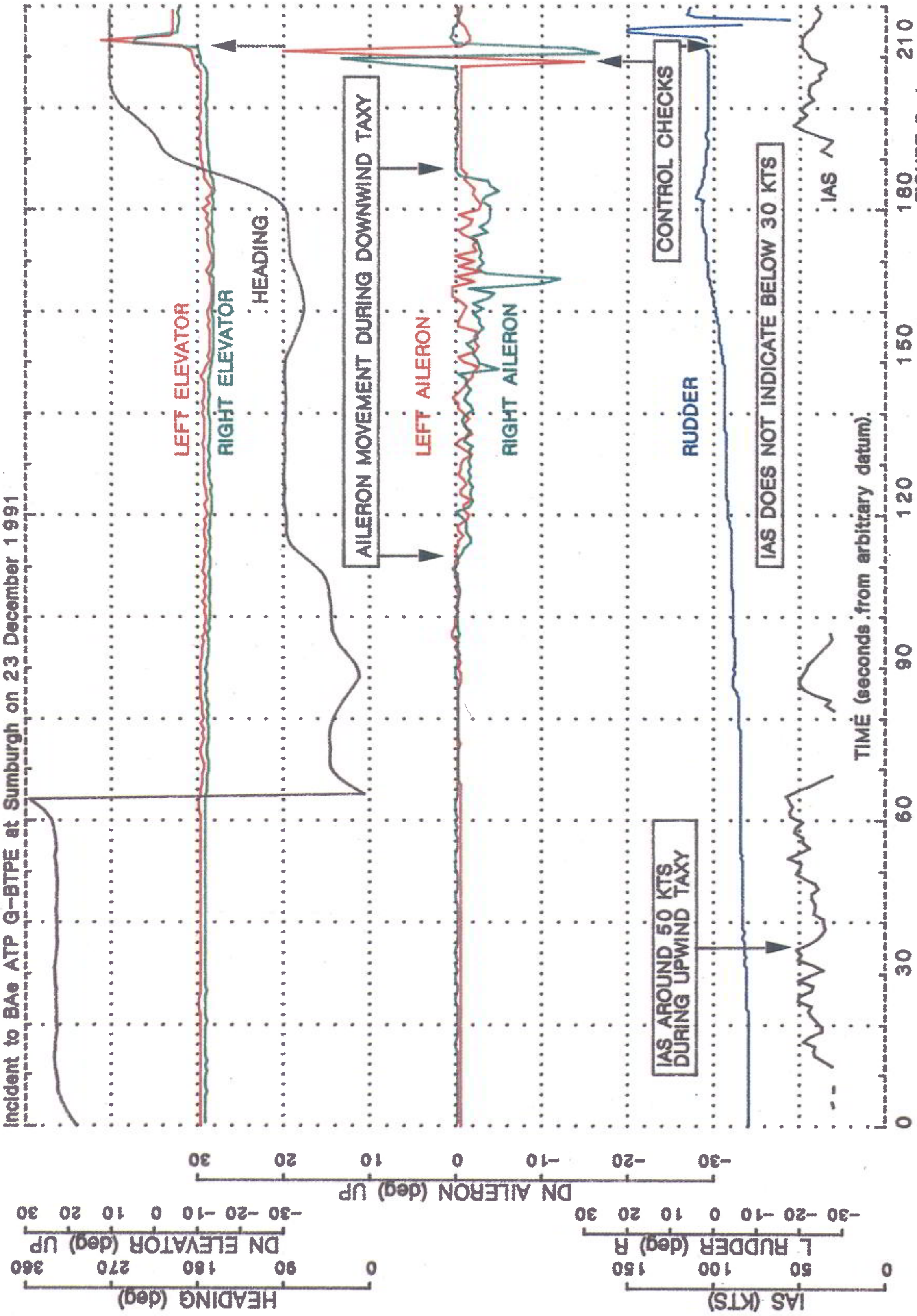

Incident to BAe ATP G-BTPE at Sumburgh on 23 December 1991
HEADING (deg)
0 90 180 270 360
DN ELEVATOR (deg) UP
-30 -20 -10 0 10 20 30
DN AILERON (deg) UP
30 20 10 0 -10 -20 -30
IAS (KTS)
0 50 100 150
L RUDDER (deg) R
-30 -20 -10 0 10 20 30
LEFT ELEVATOR
RIGHT ELEVATOR
HEADING
AILERON MOVEMENT DURING DOWNWIND TAXY
LEFT AILERON
RIGHT AILERON
CONTROL CHECKS
RUDDER
IAS DOES NOT INDICATE BELOW 30 KTS
IAS
IAS AROUND 50 KTS DURING UPWIND TAXY
0 30 60 90 120 150 180 210
TIME (seconds from arbitrary datum)

FIGURE D-1

Incident to BAe ATP G-BTPE at Sumburgh on 23 December 1991

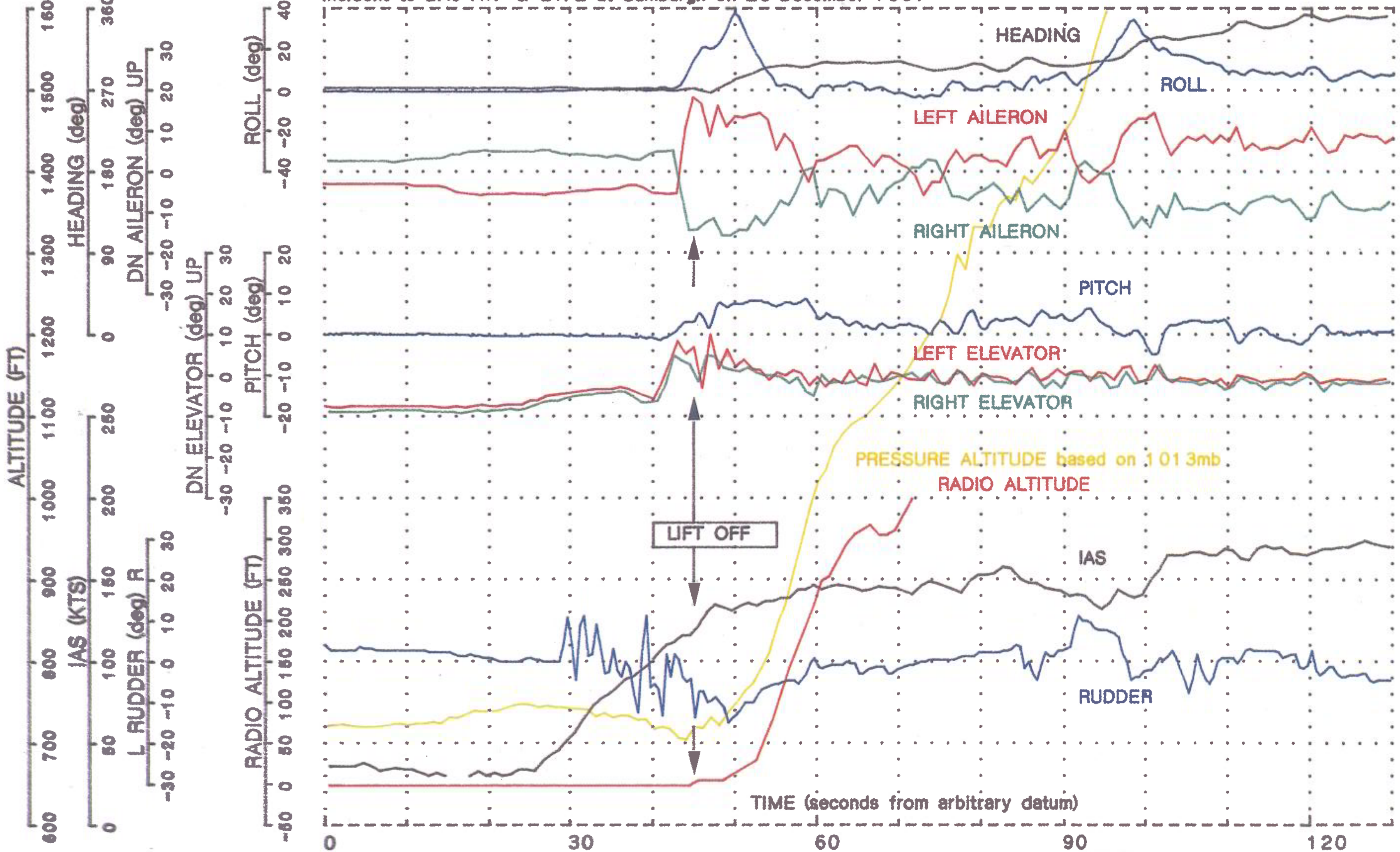


FIGURE D-2

Incident to BAe ATP G-BTPE at Sumburgh on 23 December 1991

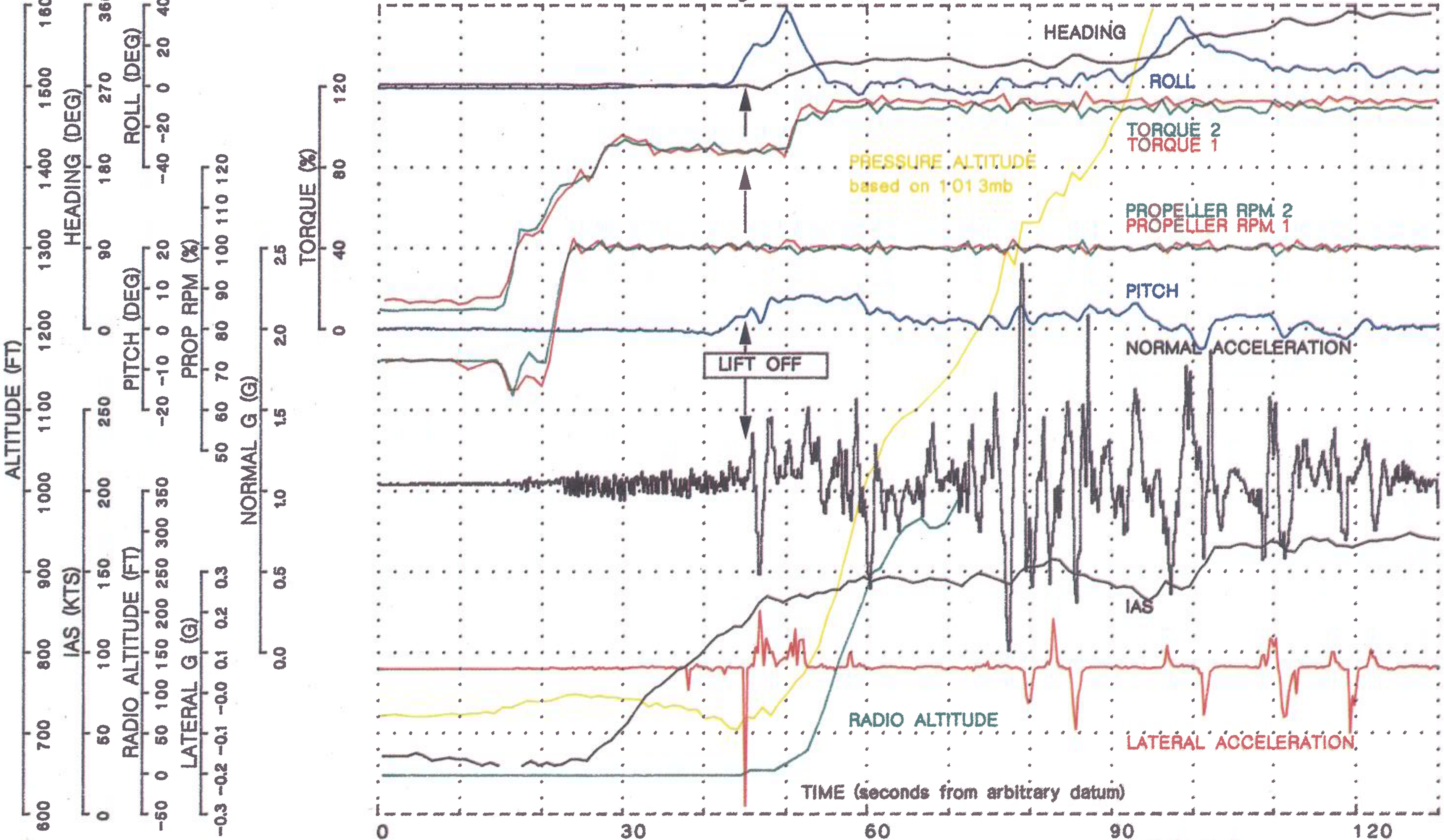
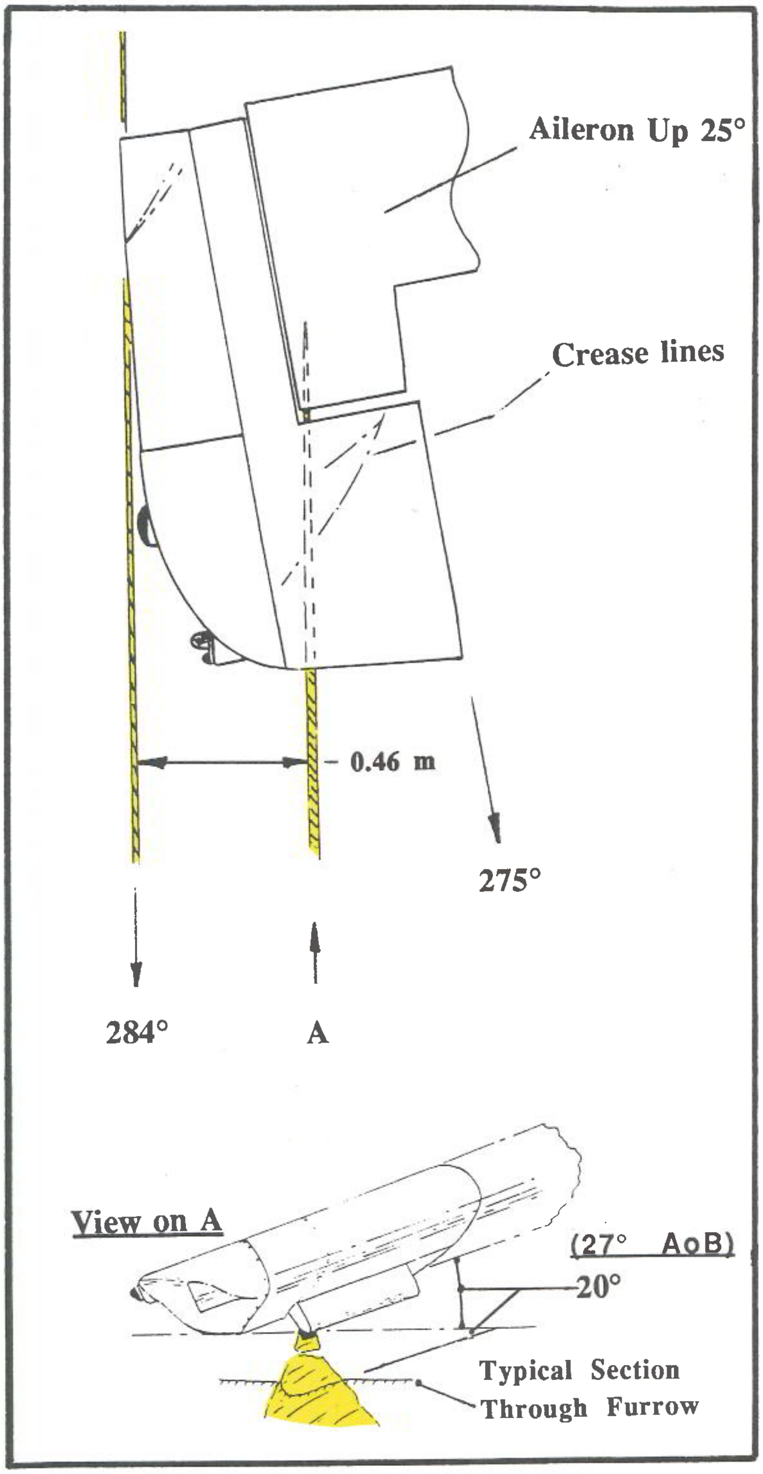
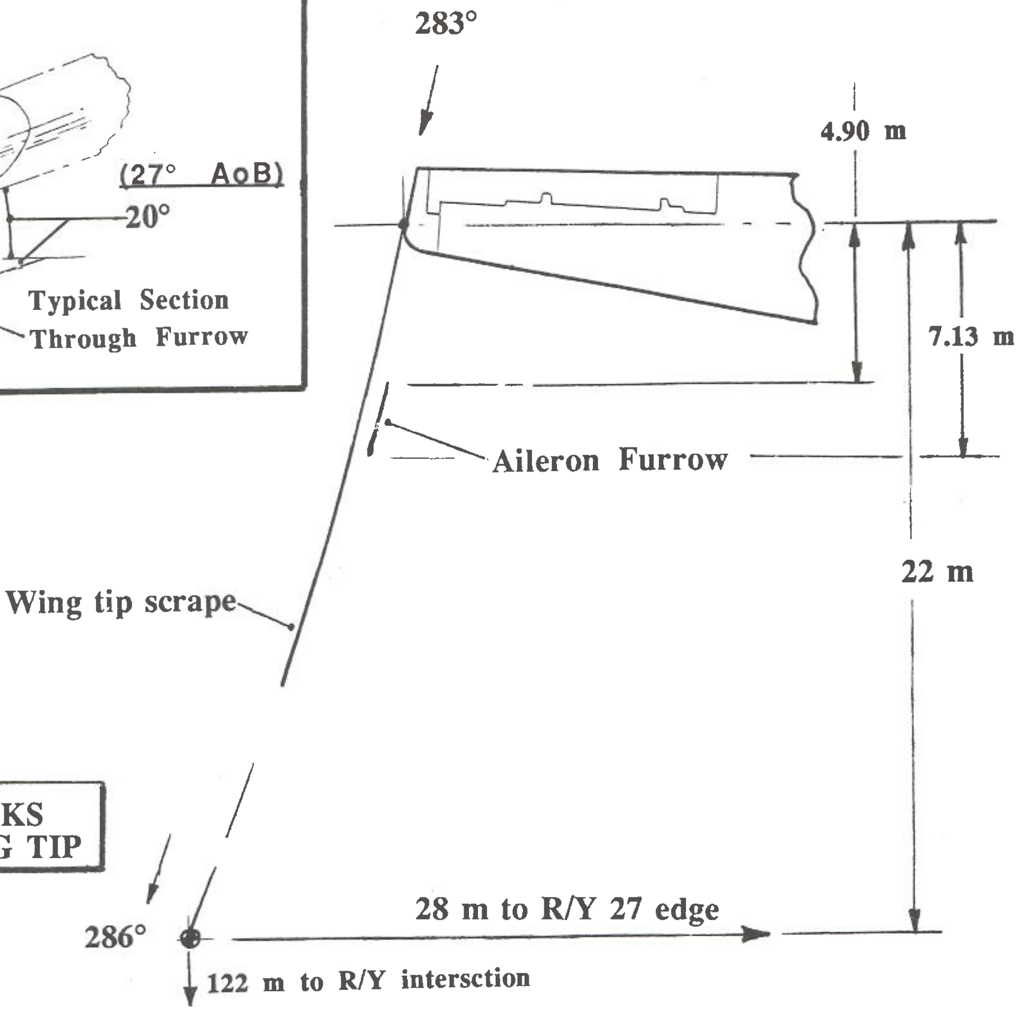


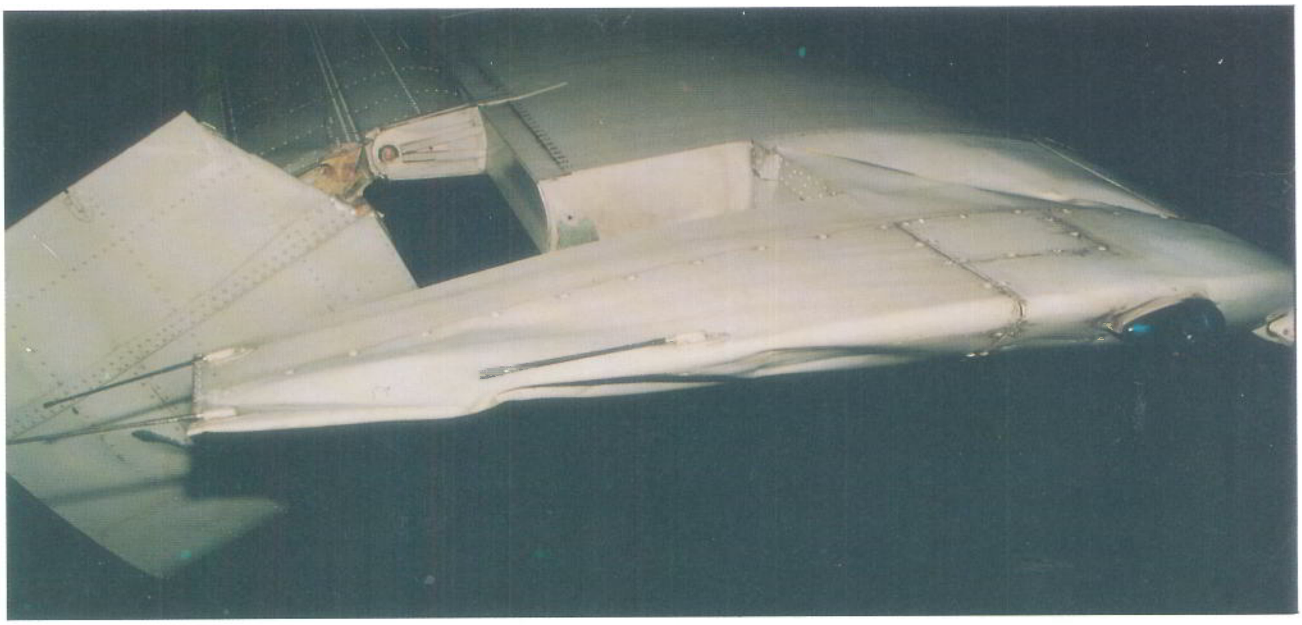
FIGURE D-3

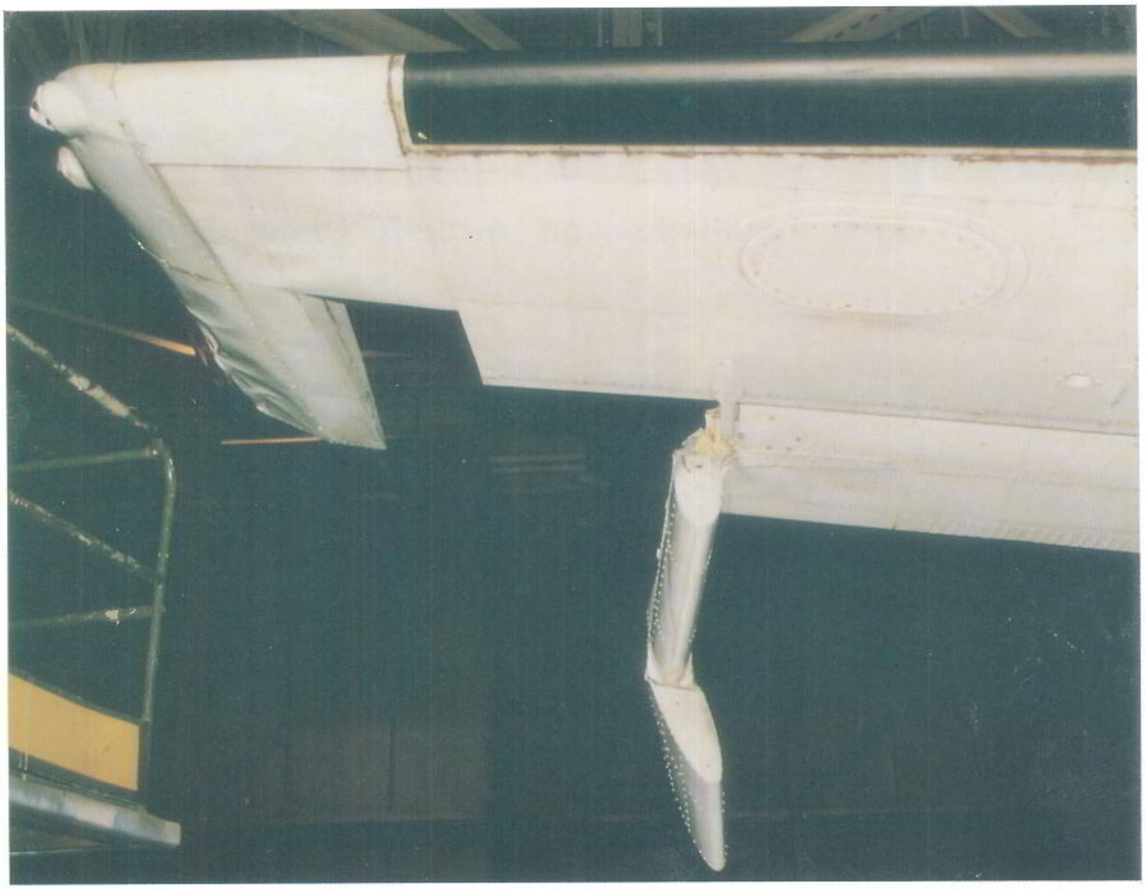
APPENDIX E



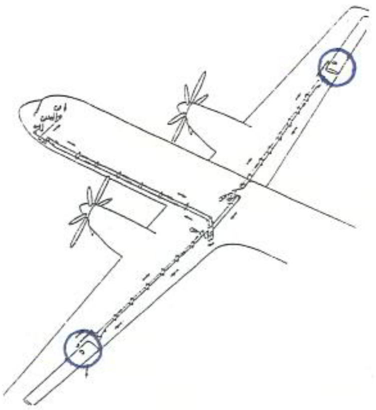


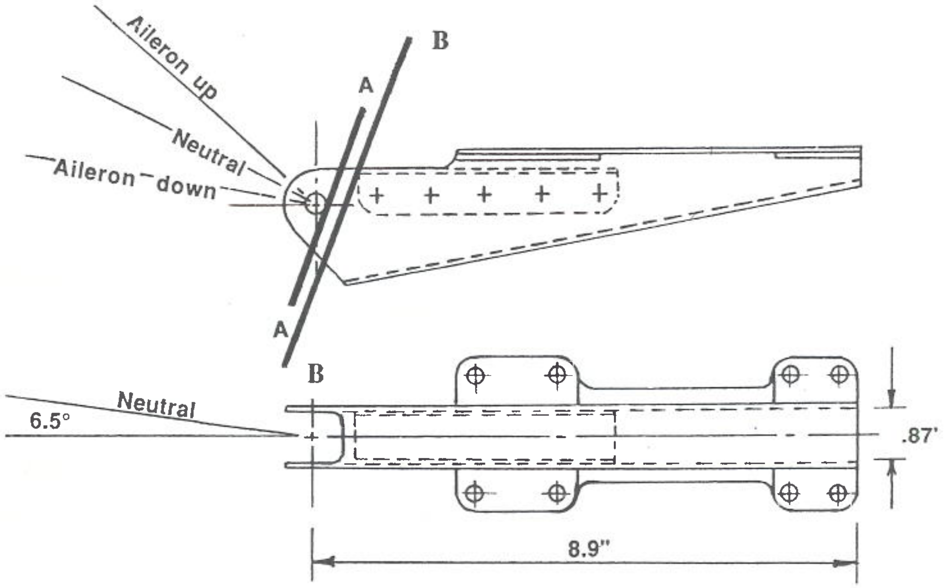
GROUND WITNESS MARKS
AND RELATION TO WING TIP

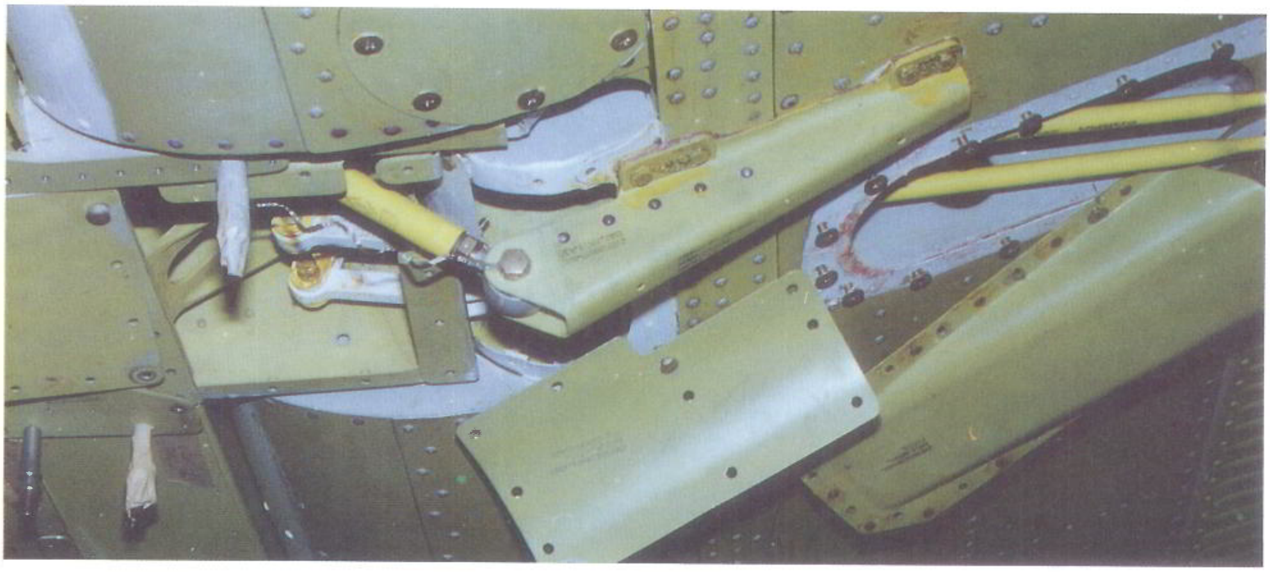




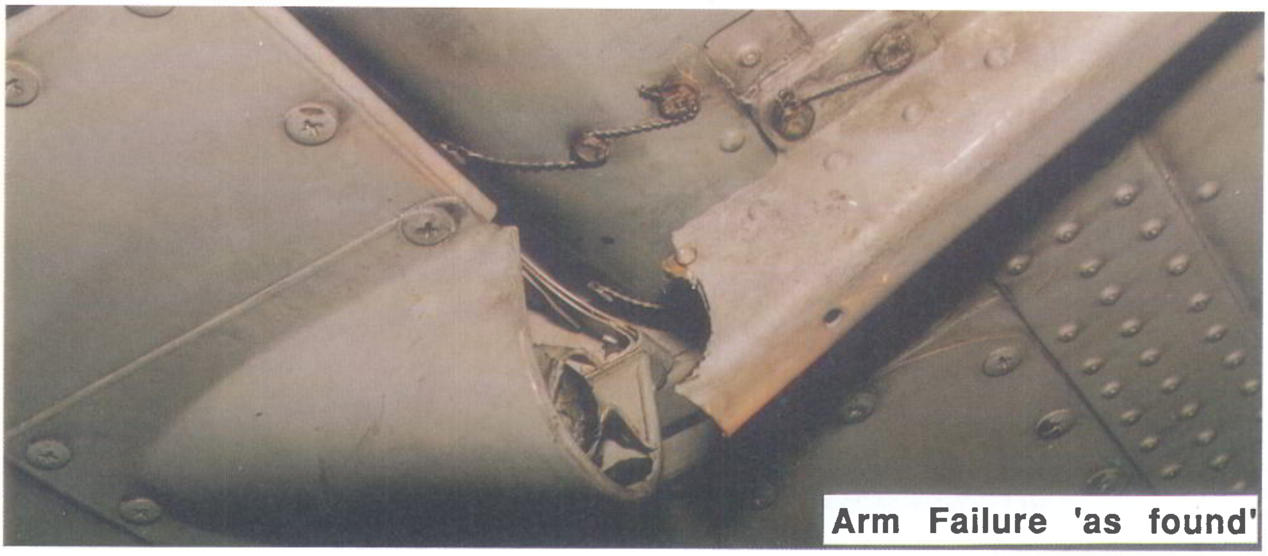
General Views of Wing Tip and Aileron Damage





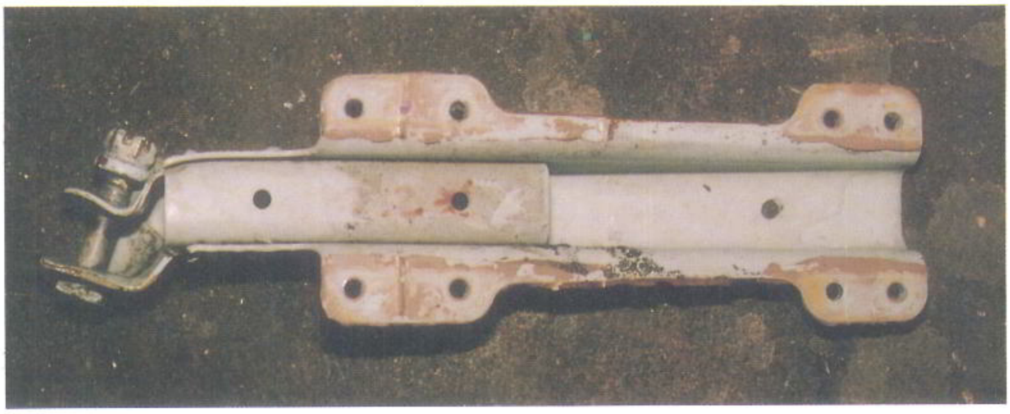


Arm Installation-on Aircraft Under Build

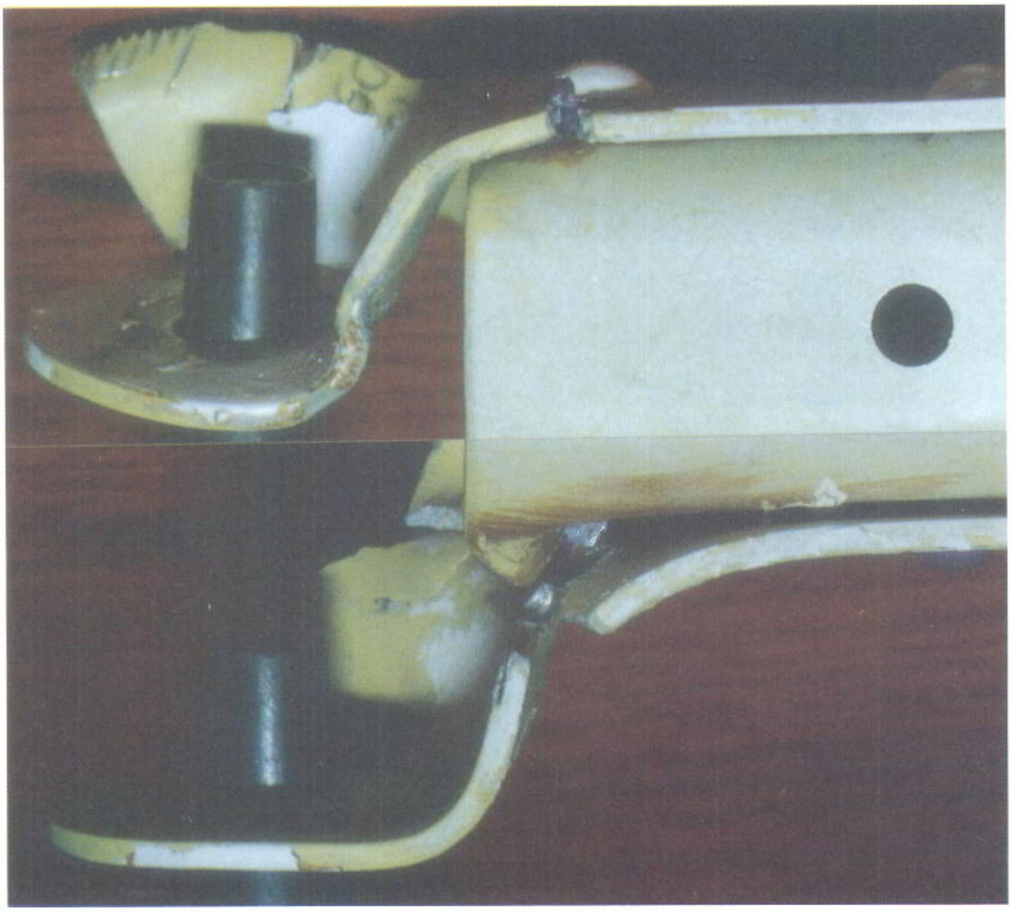


Arm Failure 'as found'

OPERATING ARM DETAILS Pt No JD576J0067



Failed Aileron Operating Arm from G-BTPE



Detail of Failure from Right Aileron Operating Arm from G-OLCD