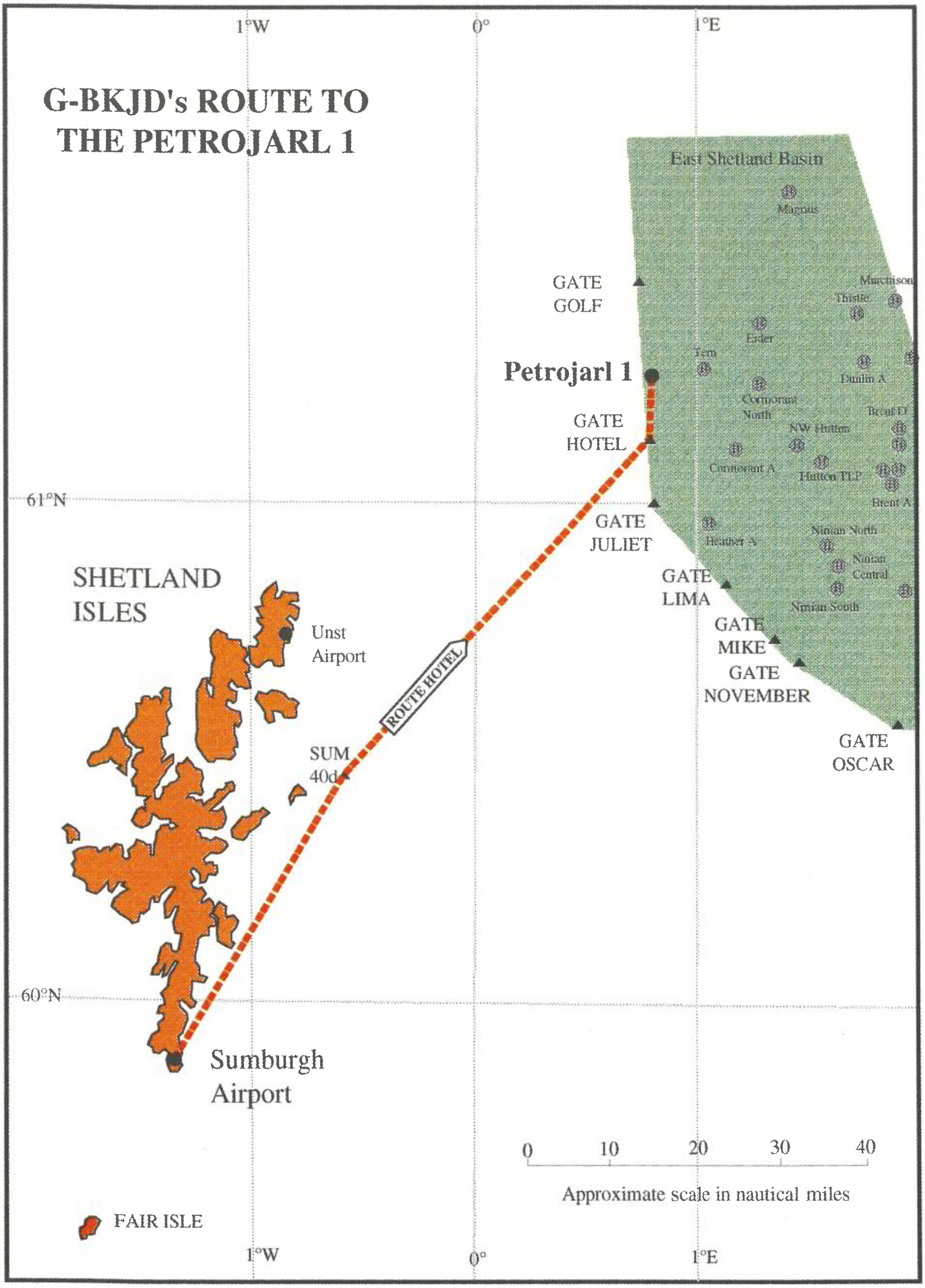

G-BKJD's ROUTE TO
THE PETROJARL 1
1°W
0°
1°E
East Shetland Basin
Magnus
Murchison
Thistle
Eider
Cormorant North
NW Hutton
Cormorant A
Hutton TLP
Brent A
Heather A
Ninian North
Ninian Central
Ninian South
GATE GOLF
Petrojarl 1
GATE HOTEL
61°N
GATE JULIET
GATE LIMA
GATE MIKE
GATE NOVEMBER
GATE OSCAR
SHETLAND ISLES
Unst Airport
ROUTE HOTEL
SUM 40d
60°N
Sumburgh Airport
0 10 20 30 40
Approximate scale in nautical miles
FAIR ISLE

G-BKJD FLIGHT SYSTEMS

1. Flight Controls

1.1 General

The Bell 214 has conventional, hydraulically-powered, collective, cyclic and yaw controls. The range of longitudinal cyclic stick movement is ± 13° which is equivalent to a stick top travel range of 11 inches.

1.2 Automatic Stability Control Systems

The Bell 214 uses both a stability and control augmentation system (SCAS) and an attitude/altitude retention system (AARS). The SCAS reduces pilot workload by improving short-term stability and handling qualities throughout the flight envelope. The AARS provides the pilot with a hands-off cruise flight capability.

The SCAS is a three axis (pitch, roll and yaw) limited authority stabilisation system using a series of electromechanical actuators. Each axis of the system utilises signals from rate gyros and control motion transducers to provide drive signals to the actuators. Each axis consists of dual electronic channels driving a single actuator. The dual channels provide inherent hardover protection in that both channels must agree on a command before the actuator can respond. A disagreement between the two channels is detected by a monitor which disengages the affected axis.

The AARS is a two axis (pitch and roll) system. The three modes available are attitude hold, heading hold and altitude hold. The attitude of the helicopter may be trimmed after AARS engagement by either beep trim function or trim release function. Controls for both methods of retrimming the helicopter are located on the cyclic stick grips. Beep trim is activated by a five position 'coolie hat' switch whereas trim release is activated by pressing and holding the trim release switch. As soon as the trim release switch is released, the AARS will hold the current attitude. The 'beep trim' authority in pitch is a nominal 3°/sec of stick movement which is equivalent to 11.5%/sec of the total range of stick travel.

AARS is normally operated in conjunction with SCAS. When a SCAS pitch or roll channel is disengaged, the AARS will partially assume the SCAS function for that axis. There will then be additional movements in the cyclic as the system makes minor attitude corrections.

1.3 Elevator control

The aircraft is fitted with a Fly-By-Wire (FBW) elevator which improves the handling qualities of the helicopter by maintaining a relatively flat pitch attitude during power and centre of gravity changes in flight. The elevator is powered by two independent systems; each system has its own control amplifier and actuator. A third airspeed transducer is used by both systems' amplifiers in a voting capacity such that an airspeed disagreement greater than 20 kt will cause the affected system to disengage and allow the other system to control the elevator. At low airspeeds the elevator is motored to the parked position. It does not move from this position until the airspeed rises above 60 kt and returns to the parked position as airspeed reduces below 45 kt.

2. Flight instruments

The aircraft is equipped with one main and one standby attitude indicator for each pilot. The main attitude director indicators (ADI) are remote indicators for the twin attitude gyros. The ADIs are capable of 360° pitch indication but the gyros are limited to 82° nose-up and 82° nose-down pitch. Each ADI provides a sphere-type display of the helicopters pitch and roll attitude. Gradations in pitch are marked on the sphere for each degree above and below 0° pitch to ±10°. Beyond ±10° there are gradations every 5° and identifying numerals at ±30° and ±60° pitch. Within the ADI display, lateral and vertical commands from the flight director system are displayed by steering bars.

The flight director provides flight path guidance to the pilots, particularly during IMC flight. It has nine modes of operation, each of which can be coupled to the AARS for hands-off flight path control. There is a go-around mode which is associated with going around from an abandoned ILS or VOR instrument approach. The mode is not applicable to going around from an abandoned visual approach or unstabilised hover.

Each pilot has an airspeed indicator and a radio altimeter within his flight instrument group. The airspeed indicators (ASI) are standard pitot-static instruments with markings from 0 to 180 kt. The indicators are unreliable below approximately 40 kt and are subject to sideslip errors. Each ASI is connected to one of three pitot-static sensing systems; the right side ASI to the right pitot tube and vice-versa. A third central pitot tube is connected to an airspeed transducer which provides an electrical signal of airspeed to other systems and computers.

The radio altimeters have height markings between 0 and 2,500 feet and a moveable index which can be set to any height. As radio height is reduced below the index height, a warning light illuminates and an audio warning sounds unless the rate of descent is greater than 3,000 feet per minute. (This feature suppresses nuisance warnings when the aircraft moved over the edge of elevated helidecks thereby causing an almost instantaneous reduction in radio height.)

3. Weather radar

The aircraft was equipped with a Sperry 'ColoRadar' weather radar. The display was centrally mounted on the instrument panel and capable of displaying navigational waypoints in addition to colour coded returns from rain-bearing clouds.

AIRCRAFT MANUFACTURER'S TAKE OFF AND CLIMB PROCEDURES

1. Flight Manual Procedures

The aircraft manufacturer specified the normal take-off procedure in Section 2 of the CAA approved supplement to the Aircraft Flight Manual (document BHT-214ST-FMS-CAA-8). This procedure was (verbatim):

1. Hover at five foot skid height. Note torque and pitch attitude.

2. Pilot - Announce beginning of maneuver, increase torque to 10 percent above required hover power and lower nose to 10 degrees below hover attitude. Complete the maneuver smoothly and within approximately two seconds. Maintain torque and attitude.

   Copilot - Start clock on signal and count seconds out loud to critical decision point (CDP). Time to CDP to be determined from figure 1-4.

   NOTE

   Do not exceed transmission torque, MGT or Ng limits.

3. Accelerate the helicopter to V_{TOSS} and at 50 feet AGL, accelerate to V_Y. Climbing and accelerating from V_{TOSS} to V_{MIN} IMC (65 KIAS) is permitted under IMC.

4. Select climb power and airspeed.

On page 2-19 of the same document the after take off checks were itemised as follows:

AFTER TAKEOFF

Rotor RPM - 100%

Hover power - Check ENGINE 2 torque within 5% of ENGINE 1. Check torque required to hover at 5 feet skid height. Observe both anti-ice lights extinguished.

Cyclic control - Apply forward cyclic to accelerate smoothly.

NOTE

> During takeoff, pitch attitude must be adjusted commensurate with power application to prevent entering the AVOID areas of height-velocity diagram. Power limit for takeoff is power required to hover IGE plus an additional increment of 10% torque (not to exceed engine limits).

Collective pitch - Adjust as desired after reaching climbout airspeed.

OPERATING COMPANY'S TAKE OFF AND CLIMB PROCEDURES

The following passages which relate to take-off, climb and go around procedures have been copied from the Operator's Operations Manual, Part 5 entitled 'BELL 214ST OPERATING PROCEDURES'. The spelling, punctuation, layout and abbreviations closely follow that used in the Manual.

OPERATIONS MANUAL AMENDMENT A.L.55

The current amendment A.L.55 contains new information regarding Offshore Take-off and Landing Profiles. This information has been produced by the CAA and is required to be incorporated in the Operations Manuals of all Offshore Operators.

It is important to note that this information is provided for guidance and consideration only. It is not intended that these profiles should be a substitution for good airmanship and sound judgement in maximising the safety of operations to and from offshore elevated platforms.

The introduction contained in Part 2 Section 1 Para 1.15.1 is worthy of emphasis:

"Due to the considerable number of variables associated with offshore take-off and landings, each take-off and landing may require a slightly different profile to account for these variations. The Aircraft Commander must exercise judgement in selecting what he considers to be the best profile. Factors such as aircraft weight, wind speed, turbulence, deck size, deck elevation and orientation, obstructions, power margins, platform gas turbine exhaust plumes etc. will influence both the take-off and landing."

In particular, for the landing, additional considerations such as the need for a clear go-around flight path, visibility and cloudbase etc will affect the Commander's decision on the choice of landing profile. The following general advice is for guidance and consideration only, it should be modified taking into account the relevant factors noted above. No attempt should be made to slavishly follow these ideal profiles as they merely represent profiles to be used for the "idealised" scenario."

Signed

Operations Manager

CHECK LISTS (cont'd)

1.5.7 After Take-Off/Go Around

During the first 500 feet of the take-off or go around the NHP should monitor the Flight Instruments to ensure the correct climb profile is maintained. It may be that the workload is sufficiently high during this period due to ATC clearances and the proximity of other traffic that it will be inappropriate for the HP to call for the After Take-Off check even when above 500 feet. Nothing shall prevent the HP carrying out any action included in these checks however, so that when he is able to call for the check it will be sufficient for the NHP to confirm that the action has been taken. Throughout this phase of flight the NHP will monitor to ensure that the HP conforms to the ATC clearance.

1.6.1 Crew Duties, Take-offs and Landings

a. Commander

When the commander is not the Handling Pilot (HP) he retains the authority on any take-off to instruct the HP to reject. Additionally the point at which the aircraft is committed to a take-off onshore is his decision, and he should call "committed". Offshore, the cyclic input remains the committal point.

b. Handling Pilot

The HP will expect the NHP to carry out the duties listed below for the different take-offs and landings. His brief for each take-off, and landing must include stating the type of take-off and the relevant decision point. Any action or procedure not covered by normal operating procedures should be briefed. NOP's need not be briefed.

Group A Take-off: The HP will call "rotating". If he initiates a reject he should call "rejecting".

Onshore Landing: All onshore approaches should be planned so that in the event of a single engine failure a running landing can be accomplished.

Offshore Landing: The HP will indicate the direction of overshoot and call committed.

c. Non Handling Pilot

The HP must rely on the NHP to monitor the engine instruments during all critical phases of flight, and advise him accordingly.

All Take-Offs: NHP calls both engines responding, and monitors T's & P's, calls TQ in the hover.

Group A Take-off: Calls CDT monitors Ts & Ps on engine instruments.

All Landings: Monitors T's & P's, engine instruments and calls TQ above 60%.

All Single Engine Landings and Rejects: Calls TQ, Ng and MGT.

SECTION 3

3.7 OFFSHORE PLATFORM PROCEDURES

Refer to Operations Manual Part 2, Section 1, Paragraph 1.15 for general considerations.

From flight test results and HAPS modelling of other helicopter types, it appears that the following take-off and landing profile is the ideal for the Bell 214ST, when using a 1'D' size deck particularly when operating close to maximum all up weight with a low relative wind speed.

3.7.1 Take-off Profile

a. Initially hover at approximately 5 ft, note torque, carry out hover checks.

b. Descend to low hover or adopt the hover attitude with the main wheels in contact with the deck and with the rotor tips as coincident as possible with the deck edge, taking into account factors such as turbulence over the deck edge and the availability of visual cues.

c. When ready for departure, smoothly apply up to 20% torque increase, above that noted in a. above, in approximately 1.5 seconds (not exceeding the take-off power rating).

d. Ideal TDP is 25 ft but may be modified taking into account factors such as power margin, turbulence, visual cues, rate of climb etc.

NOTE 1: The maximum static height, before visual cues become unacceptable is 40 ft. This coincides with the height achieved during the "ballooning" effect, following a reject at 25 ft and when operating at light weight.

NOTE 2: Avoid the tendency to drift forward during the climb to TDP.

e. Normal AEO Take-off after TDP: At TDP rotate the helicopter to approximately 12° nose down to initiate forward acceleration. At V_{toss} reduce the nose down attitude but continue the acceleration to V_y.

f. Engine Failure Recognition before TDP: Carry out a rejected landing and cushion the touchdown.

g. Engine Failure Recognition at or after TDP:

i If an engine failure is recognised at or after TDP aim to maintain the collective position and continue to rotate nose down to a maximum of 20° at a rate of approximately 10°/sec. Only when this attitude has been approximately achieved adjust the collective to ensure Nr is maintained at 99-100% (transient droop to 95%).

NOTE 3. Having committed the helicopter to a continued take-off it is important to attain the ideal attitude in order to give the best chance of missing the deck edge. Any lowering of the collective during the initial pitch nose down will reduce deck edge clearance.

NOTE 4 As the wind speed increases the nose down attitude on rotation may be reduced, such that at 40 knots wind speed only approximately 10° nose down is required to clear the deck and accelerate to V_{toss}

ii When clear of the deck and with positive airspeed rotate the nose up at approximately 5°/sec to stabilise at V_{toss}. When established in the climb smoothly accelerate to V_y.

COMMENTARY BY THE METEOROLOGICAL OFFICE ON THE CONDITIONS RELEVANT TO THE PETROJARL INCIDENT OF 6 DECEMBER 1994

The meteorological conditions seen as particularly unusual and extreme in this case were the turbulence and the vertical wind shear. The very severe turbulence levels were reported explicitly by the crew of the helicopter. The high vertical wind shear is supported by the fact that during the second go-around, although the airspeed experienced by the helicopter was rather low, and the windspeed observed on the ship itself was low, the helicopter appeared to those on the ship to be moving fairly steadily in the downwind direction. The purpose of this note is to confirm the existence of these conditions, quantify them if possible, and comment on the causes.

The conditions as experienced were the combination of large scale effects and small scale effects. By large scale we mean meteorological variations on the scale of 10km (5nm) or more and small scale means between 1km and 10km. Turbulence comprises variability on even smaller scales than the 1km scale and although we cannot specify the exact nature of turbulence in the way we can specify larger scales of motion, relationships between the intensity of turbulence and variables represented on the 1km scale are well established. We will consider the effects of the different scales separately, starting with the large scale.

Figure E-1 is a wind speed cross section covering the entire helicopter flight from Sumburgh to PETROJARL. Thus the x-axis on the figure is distance from Sumburgh and the y-axis is height above sea level. The continuous lines on the plot are contours of wind speed as forecast by the UK Met Office Limited Area Model (LAM). These show that wind speed was increasing the further north one travelled, and that wind speed was stronger at 2000 feet than at the surface. Various numbers shown on the plot indicate actual observations of wind from a variety of sources. Those nearest the y-axis are from the pilot balloon ascent made at Lerwick starting at 1715 GMT. These are very similar to what would have been experienced by the helicopter during its ascent out of Sumburgh, and suggest rather benign conditions. Those near the x-axis of the plot are surface observations from various offshore installations in the area. They confirm that surface wind speed was generally increasing as one progressed further north. The figure of 16.8 was that at PETROJARL itself, and was the average windspeed for the hour between 1715 GMT and 1815 GMT. Generally speaking wind observations for meteorological purposes are averaged over 10 minutes. As will be shown later the wind at PETROJARL underwent considerable variations in this hour. Given that the intention in Figure E-1 is to show large scale features it seems appropriate to use the 1 hour mean.

Of the remaining observations, all except one are from the helicopter itself, while the other is obtained by tracking clouds in satellite images. Both of these observation types are measurements averaged over significant horizontal distance, and these averaging scales are indicated by the arrows. It is difficult to specify the exact altitude at which the cloud motion wind pertains - it is generally accepted to be the wind at approximately cloud base but cloud base was varying over the area represented by the observation. The importance of the cloud motion wind on this plot is that it confirms the helicopter winds, which is important as they are the only source of information above the surface at PETROJARL. The observations from the helicopter itself were derived by the AAIB. The observations at about 2000 feet were on the outbound flight to PETROJARL, that at 1000 feet is the average wind for the return to Sumburgh. Because winds were obtained using slow response navigation data, reliable winds could only be obtained during the essentially straight and level portions of flight.

There is a theoretical limit to the maximum increase in westerly wind component as one moves northwards (in the northern hemisphere). For each kilometre flown northward the westerly wind component can increase by 0.126 m/s (at a latitude of 60 degrees north). In more conventional units this means that for every nautical mile flown northwards the westerly wind component can increase by .4536 knots. Given that PETROJARL was 68 nautical miles north of Lerwick, where a well observed wind of 20 knots pertained at around 2000 feet, a wind in excess of 50 knots was possible at PETROJARL at that altitude.

Another factor which came into play was that the windspeed was decreasing at all levels. However, in this situation the windspeed drops faster at the surface than at higher levels. This means that strong vertical windshear, on the large scale, was becoming increasingly likely during the period for which the helicopter was in flight.

One conclusion from Figure E-1 was that there was a vertical windshear of about 26 knots (42 knots minus 16 knots) in about 2000 feet. Note that here we have simply subtracted the wind speeds. In principle what would have made the landing difficult would have been the vector wind shear, and this would have exceeded 26 knots in 2000 feet. However, in this case the winds were near enough parallel that the vector wind shear would have been dominated by the difference in wind speed. Although the vertical wind shear between the surface and 500 feet (the maximum height during the go-arounds) would have been less than this, because windspeed is often found to vary logarithmically in the boundary layer the shear would have been much greater than the figure of 6.5 knots which would result from linear interpolation.

It is considered useful to comment on the probability of such a vertical wind shear, by reference to Crossley (1962) ("Extremes of Wind Shear", Met Office Scientific Paper No 17). According to this such a wind shear occurs 30% of the time. However, he was considering all altitudes in generating this statistic and most of the well documented examples of strong vertical wind shear occurred near the jet stream. Thus it may well be that such a wind shear is much more unusual within the lowest 2000 feet.

Figure E-2 is a temperature cross section for the same domain as Figure E-1. Again the continuous lines are contours from the LAM while the numbers are direct observations, from the same sources as in Figure E-1. Temperature is important because it has a significant bearing on levels of turbulence. As would be expected, the contours indicate temperature decreasing with increasing altitude, but the data from the helicopter tell us that the lapse rate was much steeper than the model was implying. Indeed, the lapse rate is extremely close to the dry adiabatic and in some cases appears to exceed it. This means that the atmosphere was close to being unconditionally unstable, that is to say, initially small amplitude disturbances would be expected to grow. The helicopter temperatures pertain to the initial descent towards PETROJARL.

A possibility that cannot be ruled out is that near the surface there was a temperature inversion. The cold air associated with the microburst (see below) is the most obvious mechanism for such a low level temperature inversion. Such an inversion would have had the effect of suppressing mixing, which would in turn have allowed stronger vertical wind shear than would have been possible in a well mixed layer. However, apart from the circumstantial evidence of the strong vertical wind shear, there is no direct evidence for such an inversion. The temperature of 8.0 on Figure E-2 was not for PETROJARL itself but for North Cormorant at 61.1N, 1.1E, hence this does not rule out the possibility of a small scale low level temperature inversion.

The commonly used measure of the likelihood of conditions leading to turbulence is the Richardson Number, Ri. The lower Ri, the more likely turbulence is and the greater is the likely intensity of the turbulence. Ri is the ratio of the stability to the square of the vertical wind shear. Thus severe turbulence can be expected when either the temperature profile indicates instability or there is very strong vertical wind shear or both. In the case of the large scale conditions, as indicated in Figures 1 and 2, both of these conditions are met and severe turbulence should be expected. Here the word severe should be taken in the qualitative sense and not related to a resulting vertical acceleration. Such relationships between turbulence severity and resulting vertical acceleration can only be applied to a specified aircraft type of a specified weight flying at a specified airspeed in a specified configuration, none of which conditions are likely to have much relevance to the PETROJARL incident.

It should also be commented that the effect of turbulence on an aircraft is likely to be strongly dependent on the direction in which the aircraft is flying. Turbulence associated with low Ri will comprise rolls in which there is considerable variability in wind in the downwind direction but much less variability in the crosswind direction. Thus an aircraft flying upwind or downwind will "feel" much worse turbulence than one flying crosswind at the same airspeed. In addition, as mentioned earlier, the effect of turbulence is sensitive to airspeed. From these two statements it follows that the turbulence conditions for the helicopter en-route to PETROJARL could have been almost identical to those to be experienced while attempting to land and during the go-arounds, but the effect of the turbulence regimes on the helicopter in its different phases of flight could have been very different.

In fact there is considerable evidence that due to small scale effects, the turbulence and wind shear regimes local to PETROJARL and at the time of the incident were even more demanding than the large scale effects would cause. A cumulonimbus cloud (Cb) was noted as being a mile or so north of PETROJARL as the helicopter approached, and its presence has been confirmed on satellite imagery. The sequence of imagery from the geostationary satellite METEOSAT suggests that the Cb was quite mature by the time of the incident, and therefore it is reasonable to suppose that there was at least one downdraft associated with the Cb. An intense downdraft is frequently referred to as a microburst and it is relevant to ascertain how applicable the microburst concept is to the PETROJARL incident. The most reliable quantitative data available to validate the concept is the wind data from PETROJARL itself, and these are shown in Figures 3 and 4. The dot-dashed lines show the wind speed (Figure E-3) and direction (Figure E-4) for the period from 1715 GMT to 1815 GMT. Note that these data have been digitised manually from the anemograph records: this process has some quantisation limitations which are visually apparent but do not affect the logic of what follows.

As noted earlier, the Cb affecting the incident was moving quite rapidly; a speed of 14.5 m/s (29 knots) combined with a direction of 290 degrees was obtained for the satellite derived cloud motion. Associated with a downburst are divergent winds at the surface, as Figure E-5 shows. As the Cb moved past PETROJARL, the winds experienced at the ship would carry in both speed and direction; the strongest winds would be expected as the cloud approached and there would be a rapid change in wind direction as the Cb swept past. In order to confirm this quantitatively a very simple model of a microburst was used, coupled to an assumption that the microburst itself was moving as indicated by the satellite imagery.

The microburst model used was a single ring vortex model, as described in Robinson (1991) ("The modelling of turbulence and downburst for flight simulators" University of Toronto Institute for Aerospace Studies (UTIAS) Report No 339). This is the simplest model used in flight simulators; in practice today more sophisticated models are used. Various parameters are needed to specify the model; these were chosen so that the mean square vector difference between the model simulation and that observed at PETROJARL was minimised. In addition to the wind specified by the model it was assumed that there was a large scale wind field, both components of which were varying linearly with time.

The dashed lines on Figures 3 and 4 show the simulated wind sequence. Qualitatively, the agreement with the observed wind sequence is very good and clearly semi-quantitative use could be made of the model. It had been hoped that the model would enable the enhancement to the vertical windshear caused by the microburst to be quantified. However, the model predicts that this enhancement is negligible. This arises partly from the simplicity of the model, partly from the fact that the model was intended to more correctly simulate horizontal windshear, and partly from the fact that minimising the mean square vector error over a period of one hour forces model parameters to be chosen which mean that small scales are underrepresented.

Nevertheless, the application of the model confirms that the microburst can be used to explain a considerable part of the wind variability that was observed at PETROJARL. Clearly at the time of the incident, PETROJARL was experiencing the effects of the outflow from the Cb. Such outflows are inherently very turbulent, and this would be added to the fact that the large scale flow would support very severe turbulence levels. It is likely that had the landing attempts been made either, say 20 minutes earlier or 20 minutes later, when the Cb would have been much further from PETROJARL, there would have been lower turbulence levels and less vertical windshear.

Microbursts are driven by any of three physical mechanisms; precipitation loading, evaporation and melting. Precipitation loading means that the weight of the precipitation in the column of air forces downward motion. The strong radar echo suggests that this was certainly a factor. Evaporation acts by cooling the air mass, thus increasing its density and causing downward motion. The air at the surface was well below saturation, as indicated by the humidity observations (not shown), so evaporation was also a factor. Melting acts in the same way as evaporation, again through cooling the air. The freezing level was at about 2000 feet, so this mechanism would also have been significant. Thus all the mechanisms which drive a microburst were operating and an intense microburst could be expected.

Strong convection, with which most microbursts are associated, occurs most commonly in climatic regimes where there is considerable convectively available potential energy. The most well known area where this occurs is in the USA. An additional factor contributing to the occurrence of microbursts is the uniformity of the underlying surface. In the presence of a highly variable underlying surface, convective instability will be released sooner, and with less dramatic consequences, than will be the case when the underlying surface is highly uniform. This is part of the reason why microbursts are relatively uncommon over the UK land area. However, over the sea the underlying surface is essentially uniform, so it reasonable to suppose that a microburst is more likely to be found over the sea than over land.

It is worth putting the PETROJARL microburst into an international perspective. The maximum horizontal wind change at low level, as derived from the model used above, was only 11.4 m/s or approximately 23 knots. This can be contrasted with the microburst involved in the US AIR flight 1016 (DC9) accident at Charlotte, North Carolina on 2nd of July 1994 in which the maximum horizontal wind change was 60 knots. However no comparison is possible in the vertical wind shear. For a helicopter, vertical wind shear is much more important relative to horizontal wind shear than is the case for a fixed wing aircraft.

R.W. Lunnon
Meteorological Office

WIND SPEED CROSS SECTION (Knots)

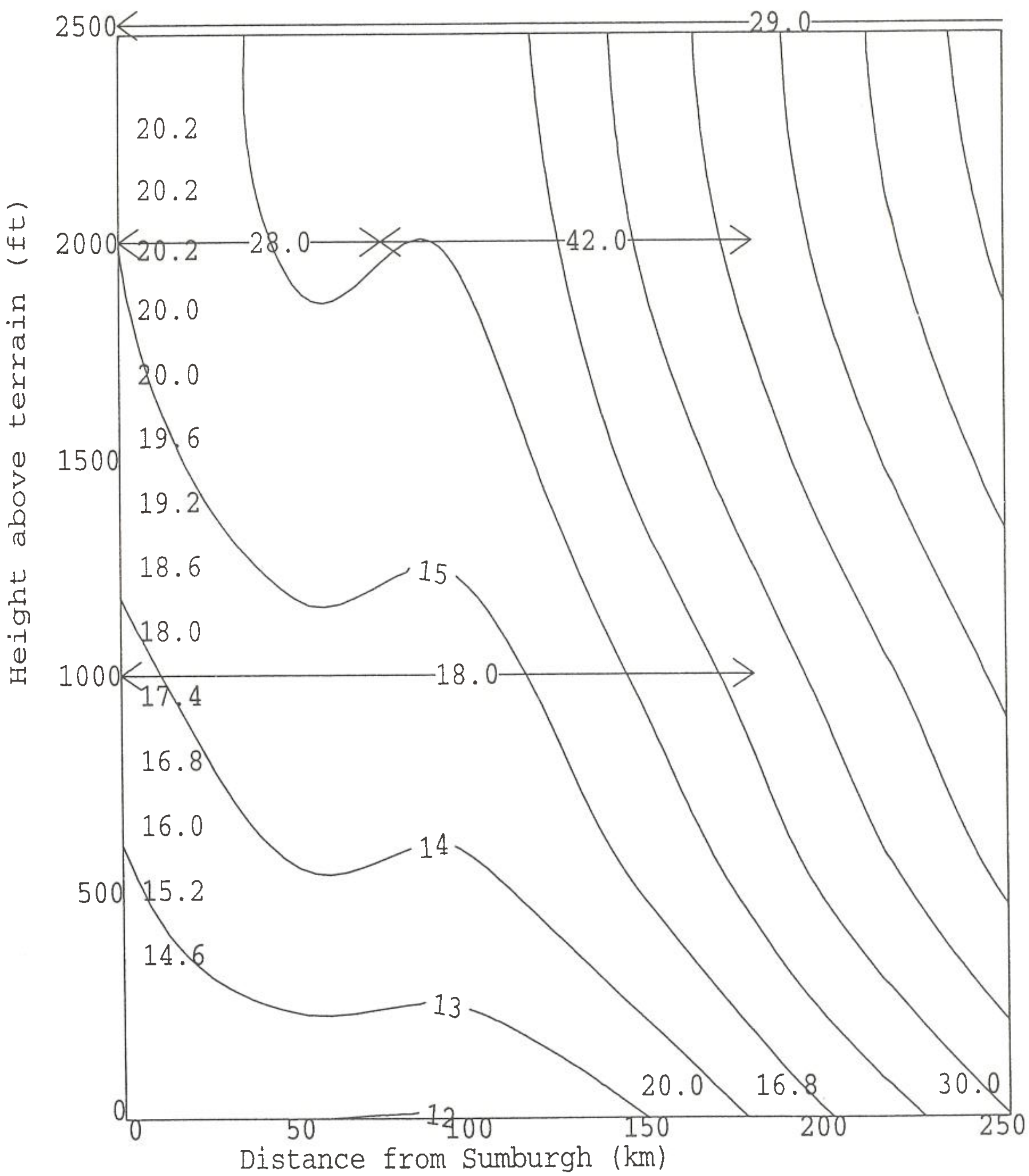


Figure E-1

TEMPERATURE CROSS SECTION (°C)

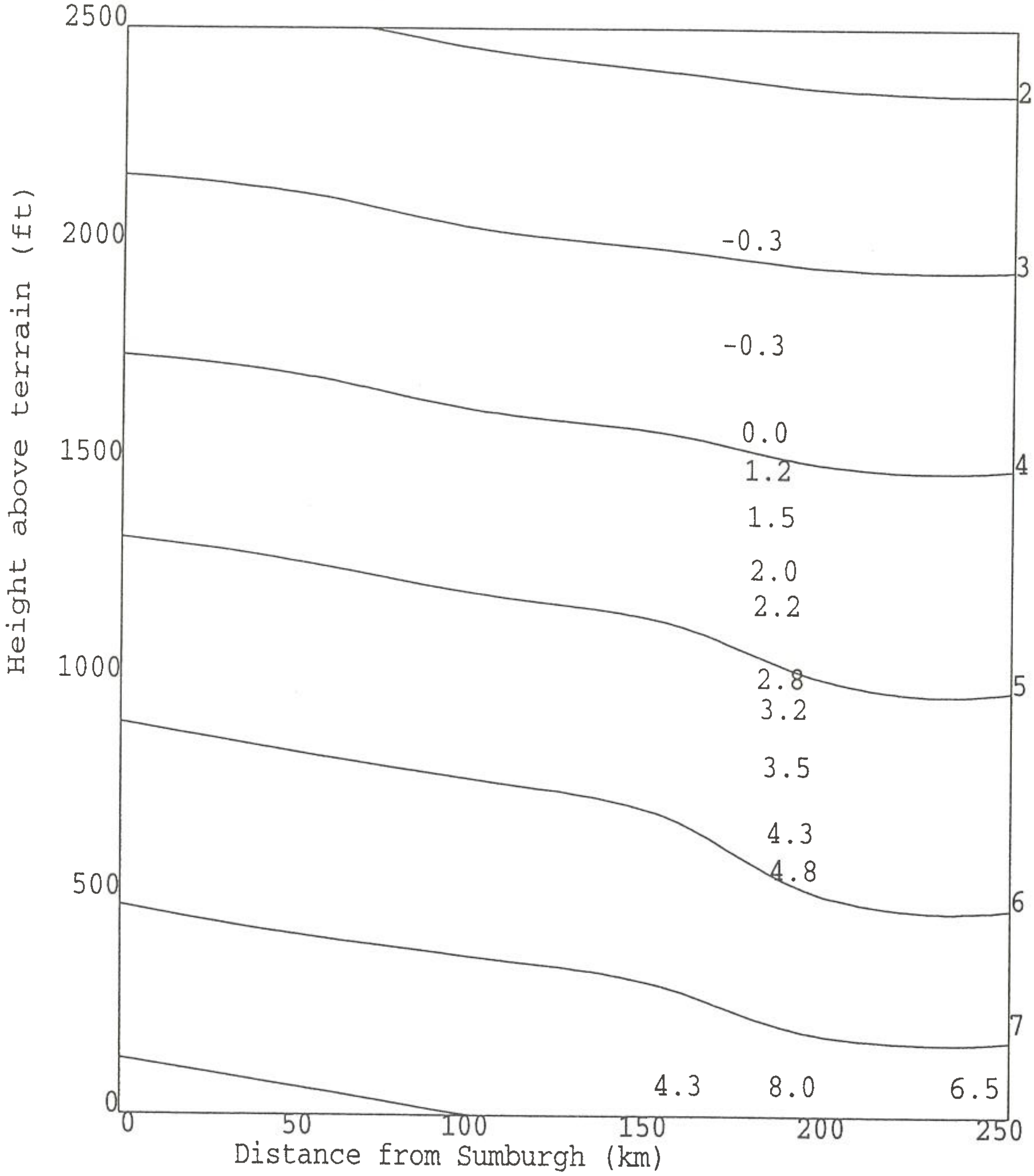


Figure E-2

WIND SPEED SEQUENCE FOR PETROJARL (m/s)

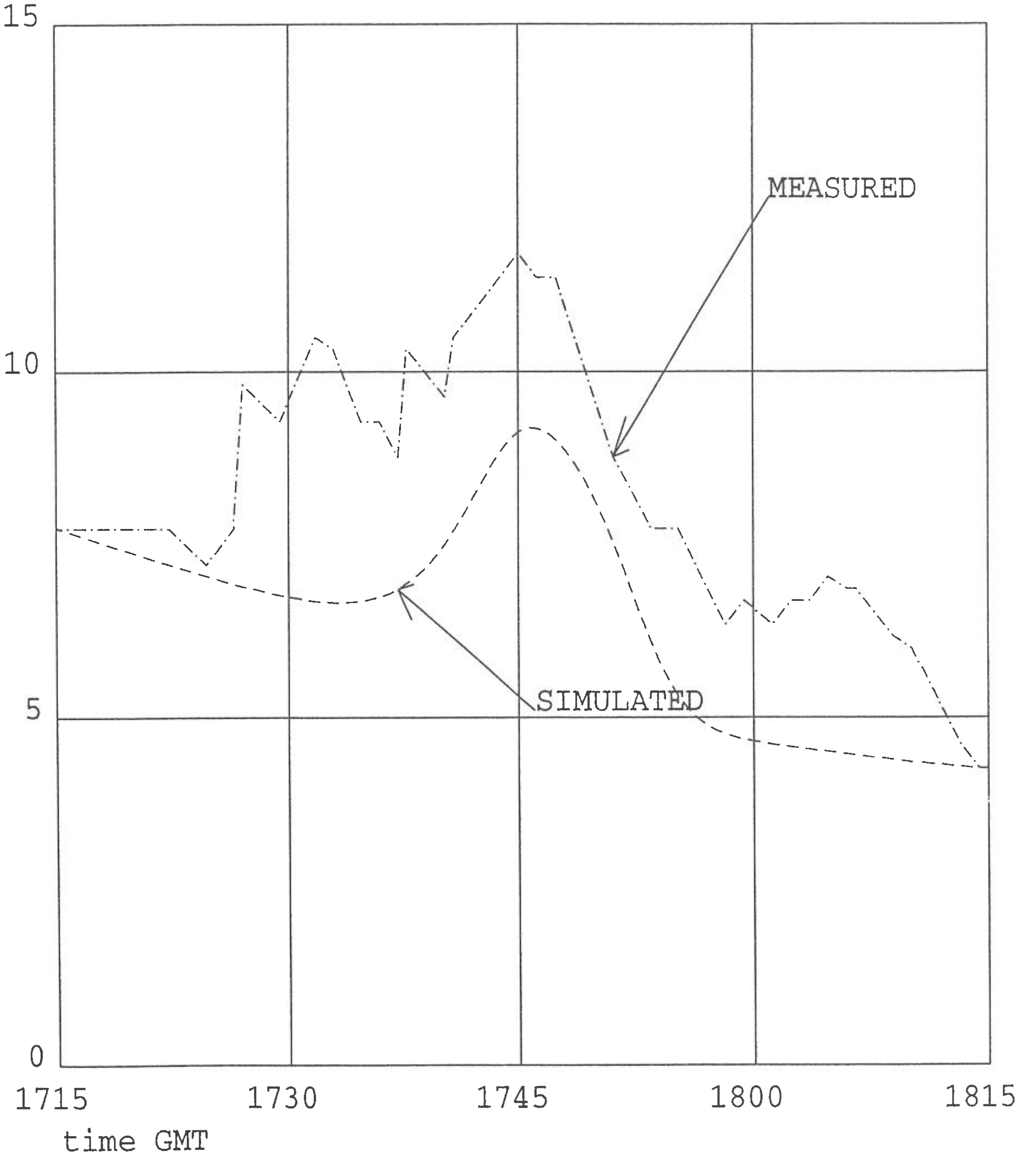


Figure E-3

WIND DIRECTION SEQUENCE FOR PETROJARL (degrees)

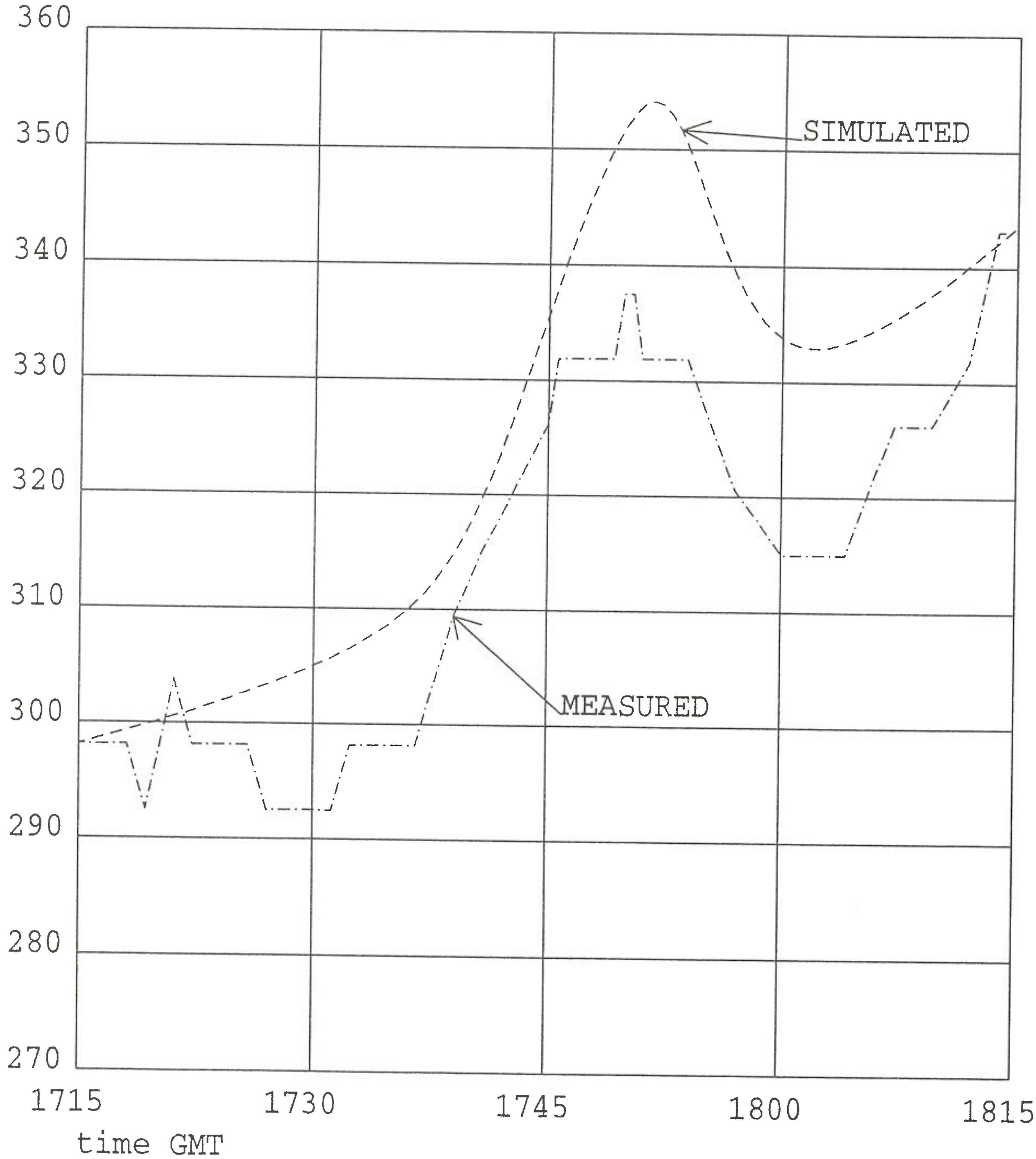


Figure E-4

OUTFLOW MICROBURST AS USED IN MODELLING DESCRIBED IN TEXT.
(Reproduced from "The Downburst" by T. Fujita, University of Chicago)

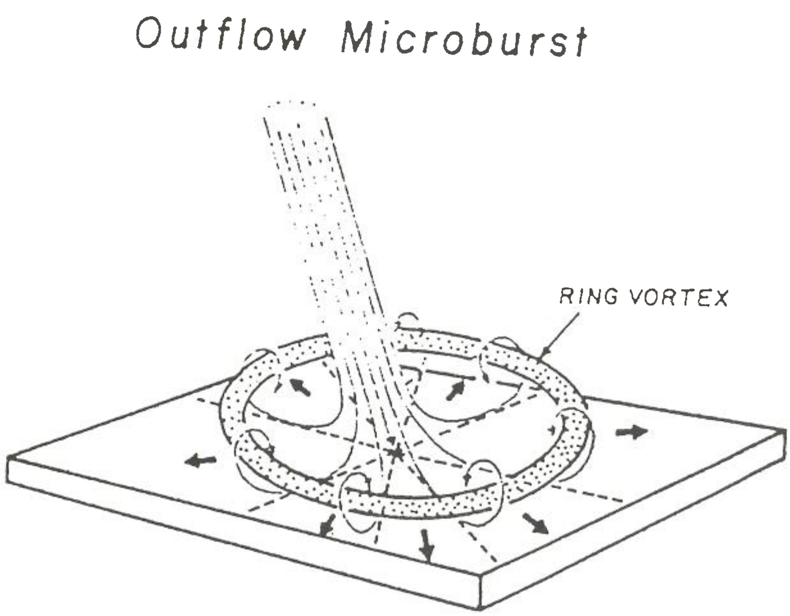


Figure E-5

BELL 214ST G-BKJD INCIDENT NEAR PETROJARL-1 on 6 DECEMBER 1994

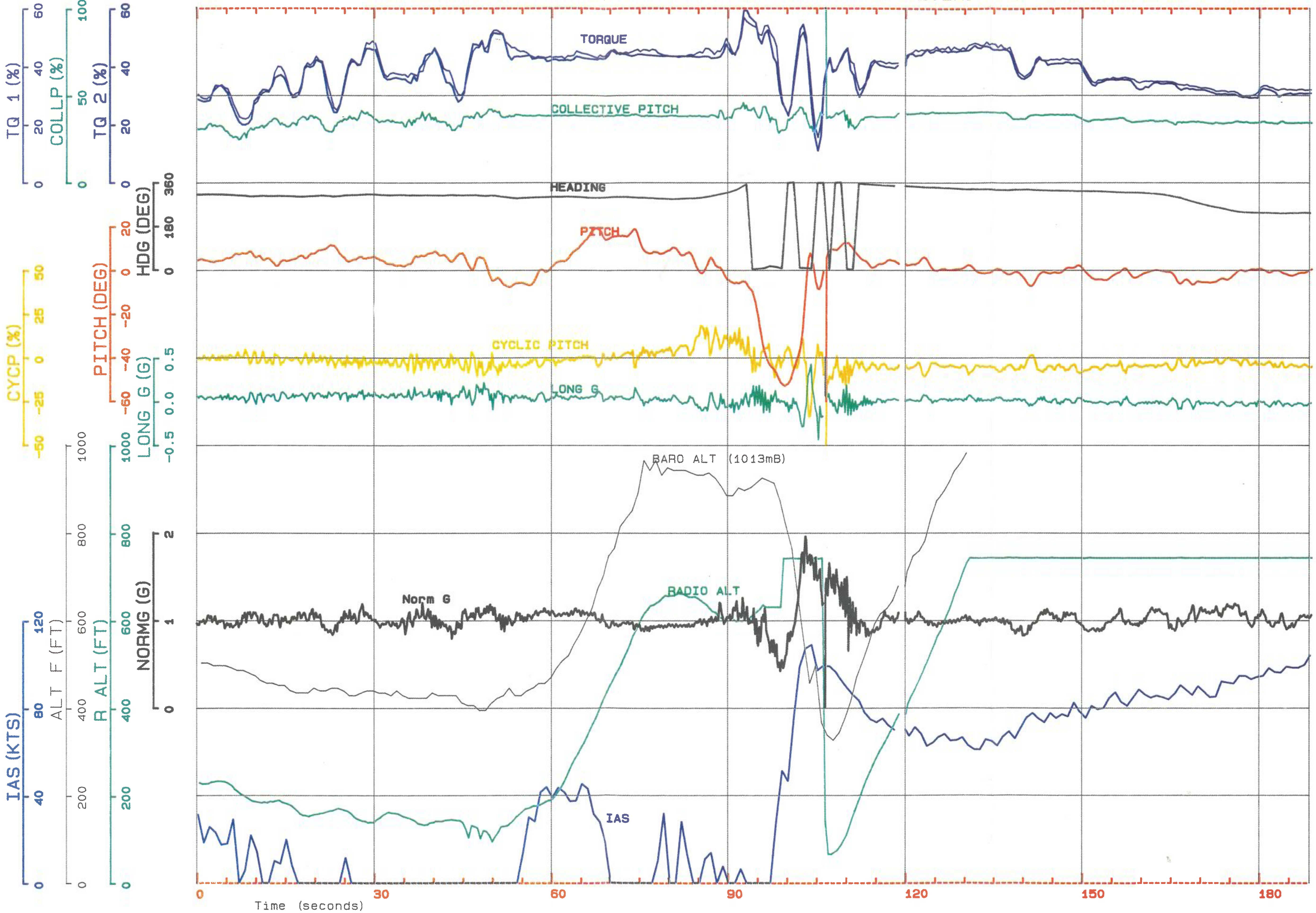


Figure F-1

Expanded FDR Plot of Time Versus Helicopter Pitch Atttitude and Longitudinal Cyclic Stick Position

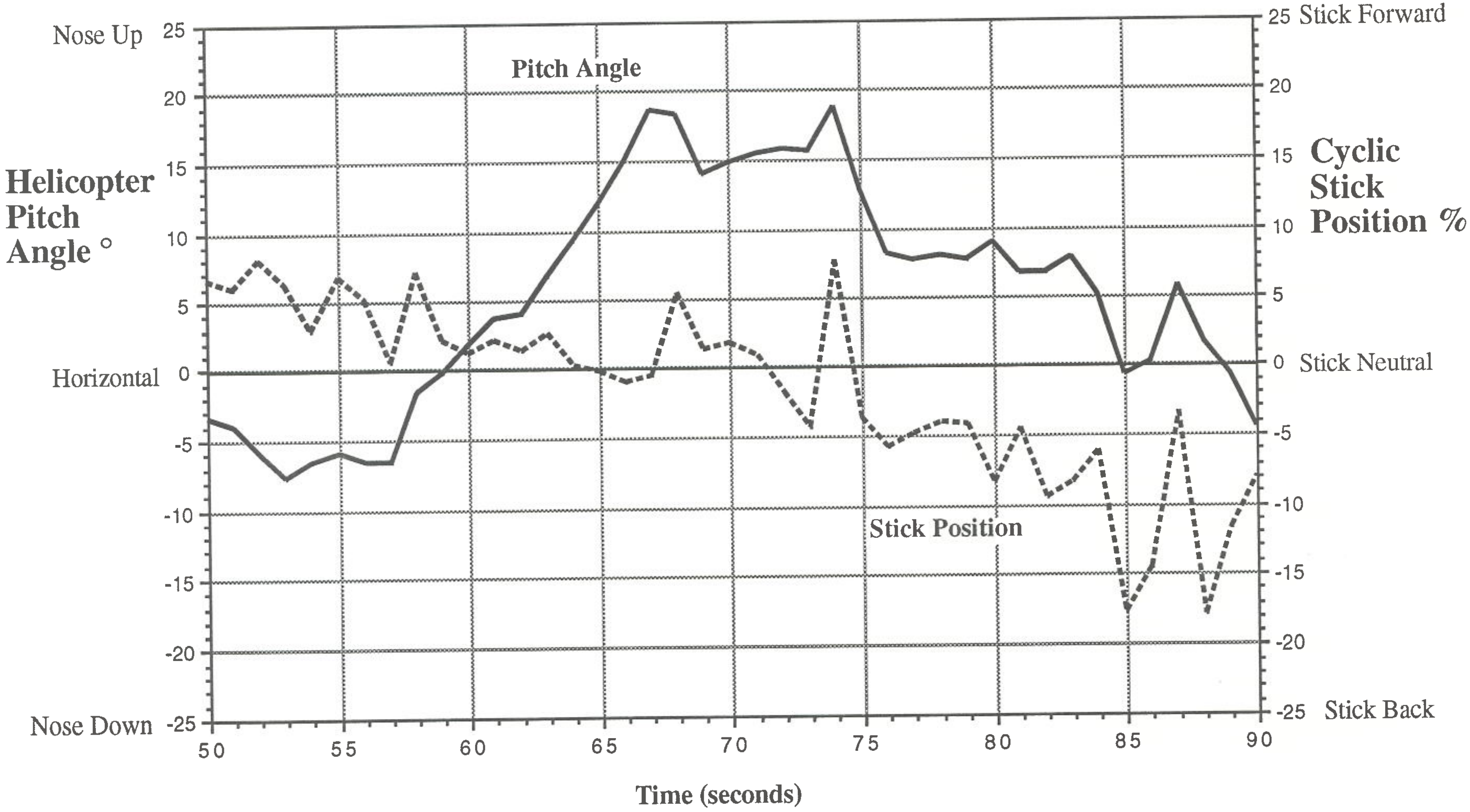


Figure F-2

TABLE OF ACCELERATIONS

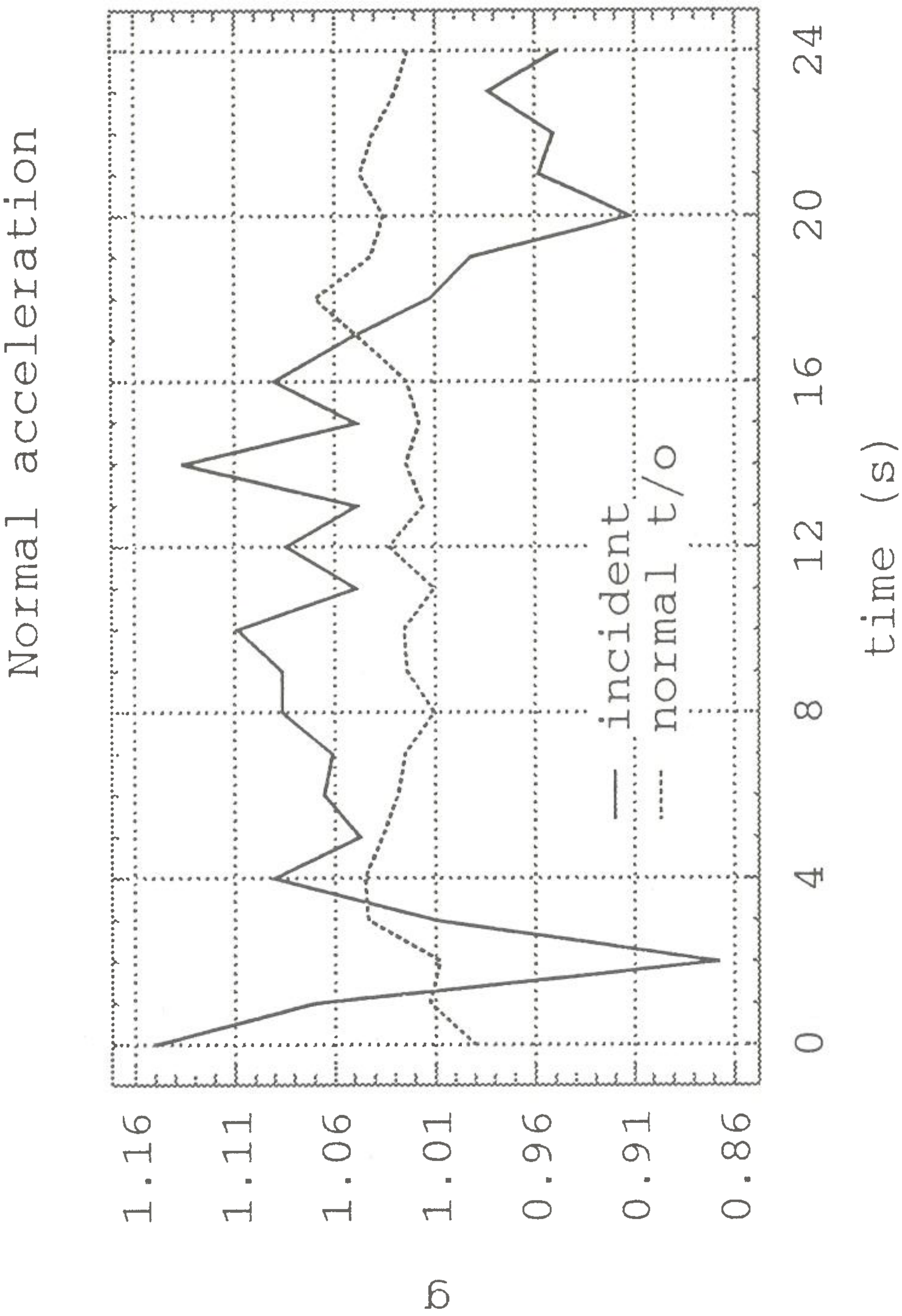
CALCULATION OF EARTH RELATED HELICOPTER ACCELERATIONS DURING FIRST 40 SECONDS OF TRANSITION

ELAPSED TIME SECS	AIRCRAFT PITCH ANGLE DEGREES	AIRCRAFT RADIO ALTITUDE FEET	INDICATED AIRSPEED KNOTS	AIRCRAFT AXIS NORMAL ACC'N (g)	AIRCRAFT AXIS LONGITUDINAL ACC'N (g)	*TRUE VERTICAL ACC'N (g)*	*TRUE HORIZONTAL ACC'N (g)*	*SMOOTHED RATE OF CLIMB (feet/min)*
0	-3.4	108	0	1.15	-0.09	*1.15*	*-0.03*	*182*
1	-4.0	130	0	1.07	0.12	*1.06*	*0.20*	*420*
2	-6.0	132	0	0.87	0.07	*0.86*	*0.16*	*716*
3	-7.7	144	0	1.01	-0.01	*1.00*	*0.12*	*562*
4	-6.6	158	0	1.09	0.07	*1.07*	*0.20*	*766*
5	-6.0	170	14	1.05	0.07	*1.03*	*0.18*	*608*
6	-6.6	174	30	1.07	0.03	*1.05*	*0.15*	*382*
7	-6.6	177	28	1.06	0.00	*1.05*	*0.12*	*250*
8	-1.6	183	42	1.09	0.10	*1.08*	*0.12*	*312*
9	-0.2	190	44	1.09	-0.01	*1.09*	*0.00*	*414*
10	1.8	198	39	1.11	0.06	*1.11*	*0.02*	*680*
11	3.8	217	44	1.05	0.06	*1.05*	*-0.01*	*1048*
12	4.0	242	42	1.08	0.05	*1.08*	*-0.03*	*1486*
13	6.8	272	38	1.05	0.04	*1.05*	*-0.09*	*1584*
14	9.3	296	38	1.14	0.07	*1.13*	*-0.12*	*1570*
15	12.0	321	46	1.05	0.05	*1.04*	*-0.17*	*1554*
16	15.0	350	43	1.09	0.05	*1.07*	*-0.24*	*1620*
17	18.7	377	32	1.05	0.06	*1.02*	*-0.28*	*1790*
18	18.3	410	28	1.01	0.12	*1.00*	*-0.21*	*1718*
19	14.1	436	19	0.99	0.01	*0.96*	*-0.24*	*1700*
20	14.9	462	0	0.91	0.06	*0.90*	*-0.18*	*1554*
21	15.5	488	0	0.96	0.06	*0.94*	*-0.20*	*1602*
22	15.8	516	0	0.95	0.06	*0.93*	*-0.20*	*1700*
23	15.7	547	0	0.98	0.02	*0.95*	*-0.24*	*1802*
24	18.8	578	0	0.95	0.04	*0.91*	*-0.27*	*1840*
25	12.7	608	0	0.94	0.06	*0.93*	*-0.15*	*1580*
26	8.1	626	0	0.93	0.00	*0.92*	*-0.14*	*1180*
27	7.7	637	0	0.93	0.01	*0.93*	*-0.11*	*760*
28	8.0	646	10	0.92	0.02	*0.92*	*-0.11*	*660*
29	7.7	659	32	0.91	0.00	*0.90*	*-0.12*	*420*
30	9.0	658	0	0.96	0.03	*0.95*	*-0.12*	*340*
31	6.8	663	0	0.92	0.07	*0.92*	*-0.04*	*60*
32	6.8	662	28	0.95	-0.01	*0.94*	*-0.12*	*-60*
33	7.8	655	12	0.93	-0.02	*0.92*	*-0.14*	*-160*
34	5.1	655	0	0.93	0.04	*0.93*	*-0.04*	*-300*
35	-0.7	647	0	0.98	-0.08	*0.98*	*-0.06*	*-360*
36	0.2	637	11	1.01	-0.07	*1.01*	*-0.08*	*-660*
37	5.8	622	14	0.99	0.10	*0.99*	*0.00*	*-740*
38	1.7	610	0	1.04	-0.07	*1.04*	*-0.10*	*-660*
39	-0.7	604	8	1.07	-0.03	*1.07*	*-0.01*	*-360*
40	-4.6	604	0	1.02	-0.06	*1.03*	*0.02*	*-120*

NOTES:

1. Time zero represents the start of the transition and as defined by the control inputs
2. Data in normal type indicates recorded data
3. Data in intalics indicates calculated data derived from the recorded data
4. Rate of climb smoothed by running average of 3 data points

Figure F-3



Normal acceleration
incident
normal t/o
time (s)
g
1.16
1.11
1.06
1.01
0.96
0.91
0.86
0
4
8
12
16
20
24

Figure F-4

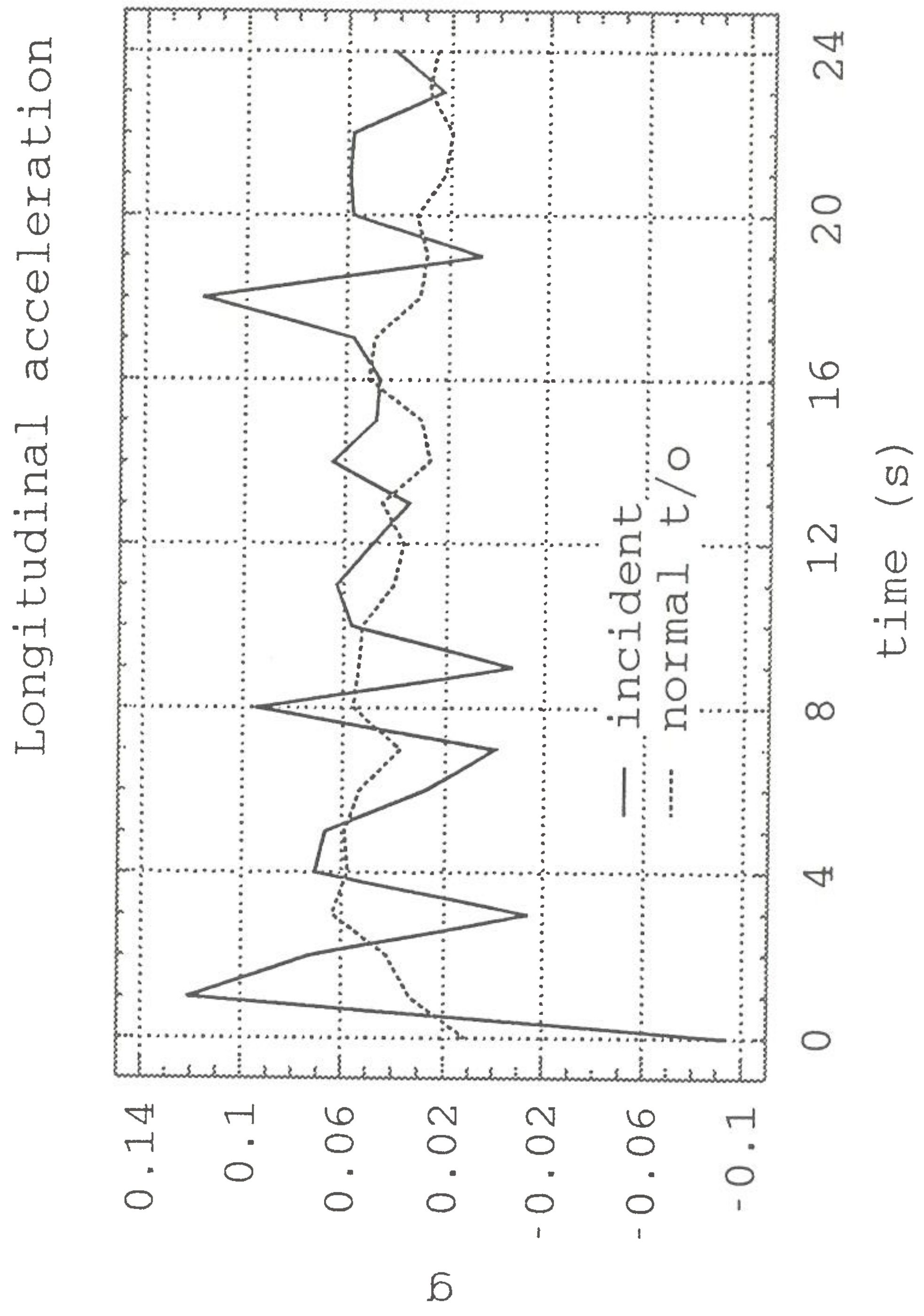

Longitudinal acceleration
g
0.14
0.1
0.06
0.02
-0.02
-0.06
-0.1
0
4
8
12
16
20
24
time (s)
incident
normal t/o

Figure F-5

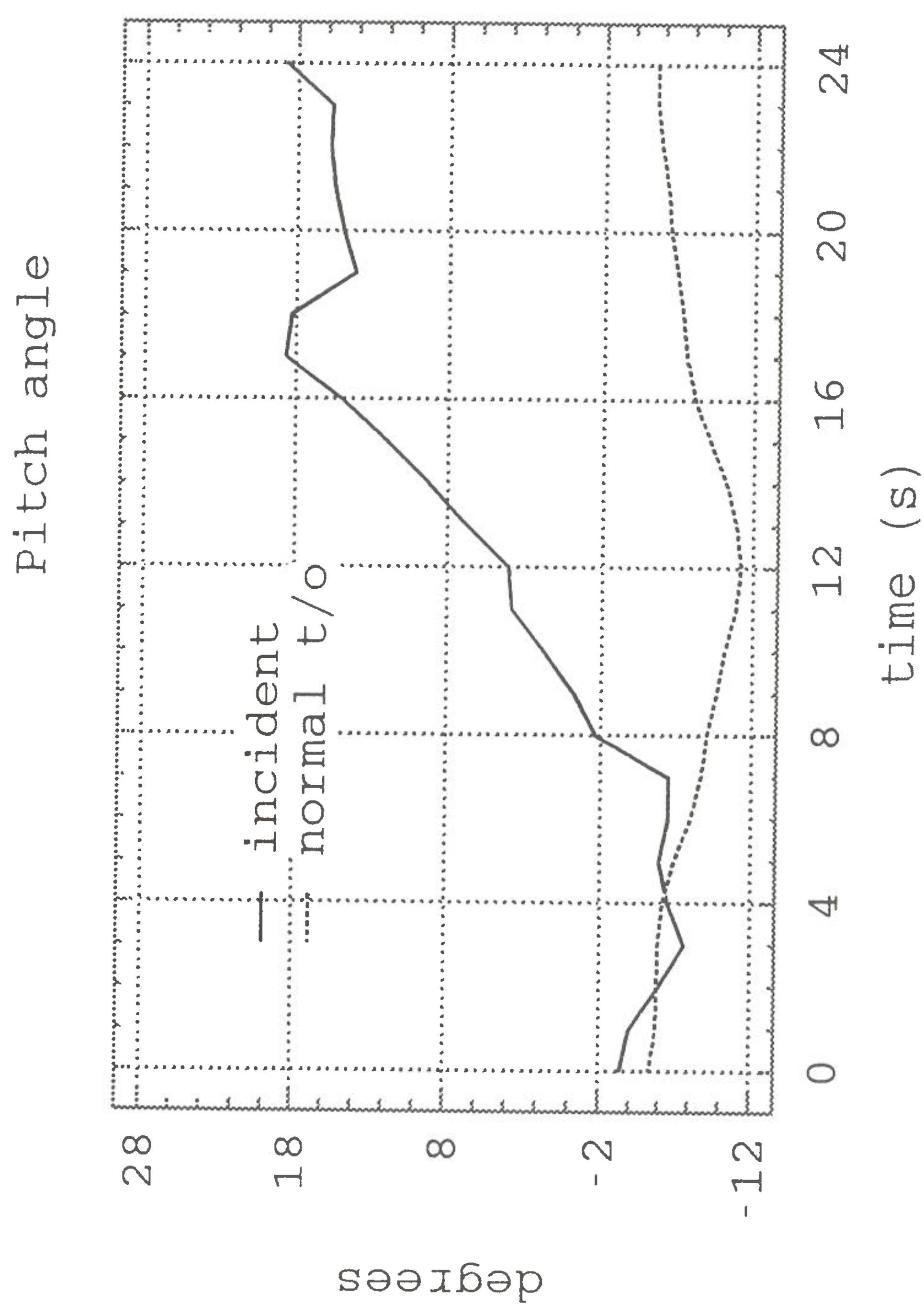

Pitch angle
incident
normal t/o
time (s)
degrees
28
18
8
-2
-12
0
4
8
12
16
20
24

Figure F-6

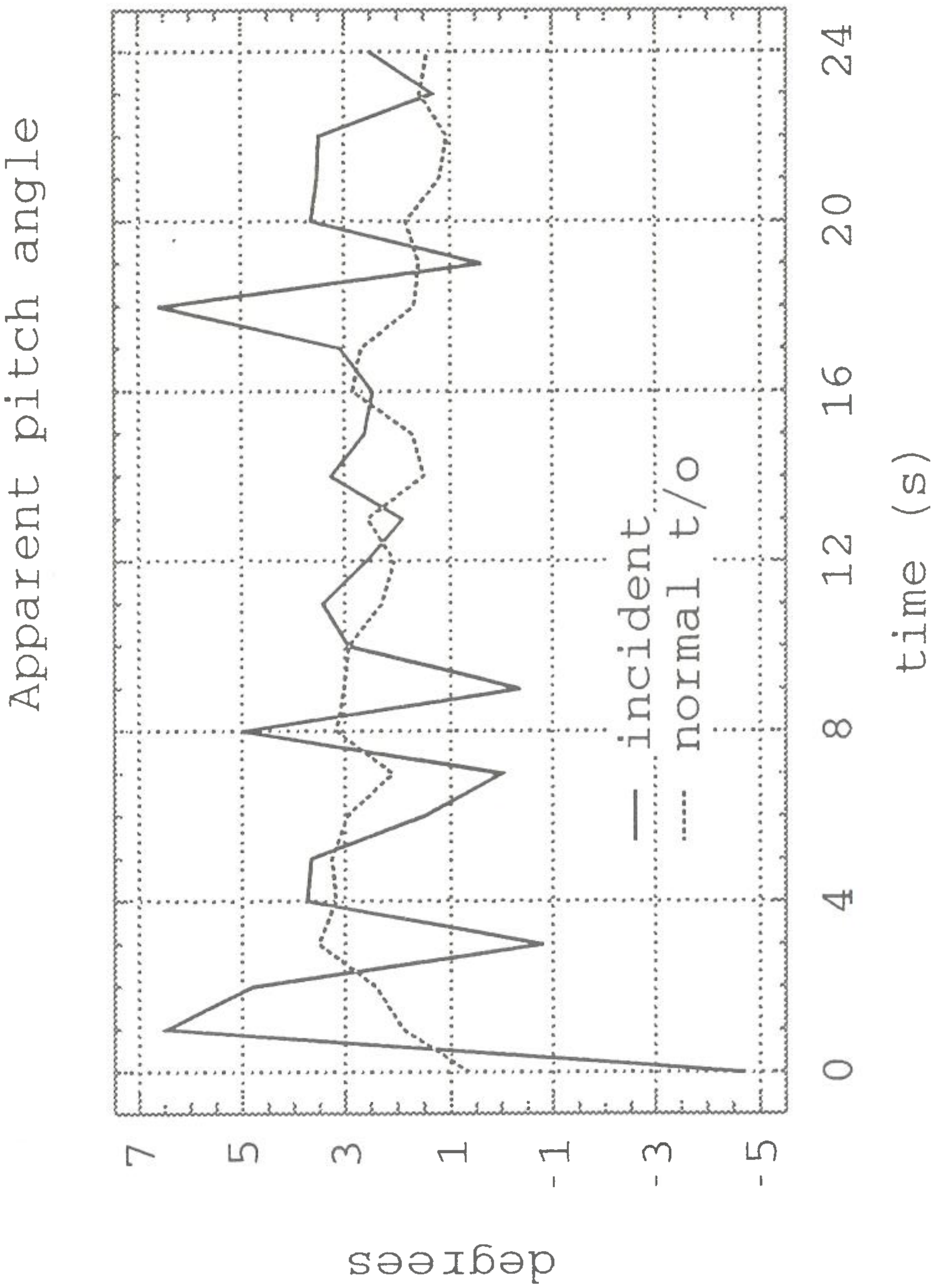


Figure F-7

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