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HELICOPTER OPERATIONAL MONITORING PROJECT

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Contents

Abbreviations

AFPA	Automatic Flight Parameter Analysis
AGL	Above Ground Level
ATC	Air Traffic Control
BA	British Airways
BHL	Bristow Helicopters Ltd
CAA	Civil Aviation Authority
CAADRP	Civil Aircraft Airworthiness Data Recording Programme
FDR	Flight Data Recorder
FDS	Flight Data System
GPWS	Ground Proximity Warning System
HDG	Heading
HUMS	Health and Usage Monitoring System
IAS	Indicated Airspeed
NG1/NG2	Gas Generator RPM – Engine 1/2
NMLA	Normal Acceleration
OEI	One Engine Inoperative
QAR	Quick Access Recorder
PITCH	Pitch Attitude
RALT	Radio Altitude
ROLL	Roll Attitude
RTRPM	Main Rotor RPM
SDD	Safety Data Department
SHL	Stewart Hughes Ltd
SRG	Safety Regulation Group
T41/T42	Turbine Gas Temperature – Engine 1/2
TRQ1/TRQ2	Torque – Engine 1/2
Vno	Maximum speed in normal operation

Summary and Conclusions

Summary

Over recent years much attention has been focused on the need to improve helicopter airworthiness, and significant progress has been made through measures such as the introduction of Health and Usage Monitoring and Flight Data Recorder (HUM/FDR) systems. However the majority of fatal helicopter accidents are caused by operational factors.

Operational monitoring by the routine analysis of FDR data to detect deviations from normal, expected or flight manual practice, is a well established practice on fixed-wing aircraft. It provides continuous operational quality control with timely feedback of sub-standard practices, and produces hard information for the evaluation and improvement of procedures.

As a result of positive experience in the CAA SRG's fixed-wing FDR operational monitoring research programme and with the support of Shell Aircraft Limited, it was decided that a study should be carried out into an implementation on FDR-equipped helicopters. Stewart Hughes Limited were tasked with a project to demonstrate the potential safety and other benefits of helicopter operational monitoring, based on the analysis of an existing set of Super Puma flight data. The results of the project are presented in this report.

Conclusions

(1) The safety, operational and financial benefits of operational monitoring have been well proven in the fixed wing world.

(2) The results produced by this project have clearly demonstrated the potential of helicopter operational monitoring to improve operational practices and enhance total helicopter safety.

(3) The analysis of helicopter operational 'events' has demonstrated the capability to identify undesirable or sub-standard practices, and provide a timely feedback to crews.

(4) The statistical analysis of helicopter data has generated valuable management information for the identification of adverse operational trends, and the improvement of operational procedures.

(5) There is a very clear justification for taking further steps towards the full implementation of helicopter operational monitoring.

(6) Due to the differences in the nature of fixed-wing and helicopter operations, there are a number of issues which should be investigated further prior to any definition of, and commitment to, a helicopter operational monitoring programme.

(7) A programme definition study should be carried out, involving a consultation with helicopter operators, to specify how helicopter operational monitoring should be implemented. This should be followed by a 'live' trial to evaluate the specified implementation, and provide further evidence of the achievable benefits.

1.0 INTRODUCTION

An examination of UK large helicopter accident reports on the CAA's SDD database has indicated the following statistics on accident causes:

(1) All helicopter accidents:

- Operational: 42% (bad weather, loss of control, collision with objects etc.)
- Airworthiness: 50% (tail rotor failure, gearbox failure, engine failure etc.)
- Both: 8% (loss of control/engine failure etc.)

(2) Fatal helicopter accidents:

1. Operational: 69%
2. Airworthiness: 19%
3. Both: 12%

Helicopter Health and Usage Monitoring and Flight Data Recorder (HUM/FDR) systems have been fitted to all large UK-based civil helicopters. Experience to date has demonstrated that the HUM systems are providing real safety benefits by making a valuable contribution to the improvement of helicopter airworthiness.

The above statistics show, however, that the majority of large helicopter fatal accidents are caused by operational factors. The opportunity now exists to enhance operational safety by implementing a helicopter operational monitoring programme, utilising the acquired FDR data. Although a new concept in the helicopter world, operational monitoring is a well established practice on fixed-wing commercial aircraft, with proven benefits.

The objective of operational monitoring is to provide a tool for operational quality control and aircraft performance assessment. Exceedances of flight manual limitations, deviations from standard operating procedures or what is considered good operating practice, and other 'events', can be detected by the routine analysis of FDR data. Experience of fixed wing operators has shown that improved crew awareness of normal operating techniques and limitations due to exposure to such analysis has brought about an increase in adherence to standard operating procedures that has a direct safety benefit.

This report presents the results of a project carried out by Stewart Hughes Limited (SHL) to demonstrate the potential benefits of helicopter operational monitoring by analysing an existing set of de-identified helicopter flight data. This data is from a Super Puma helicopter operating in the North Sea, and comprises over 800 flight sectors. SHL analysed the data using a Flight Data System (FDS) analysis program on loan from the CAA Safety Regulation Group (SRG).

Section 2 of the report describes British Airways' FDR programme, which in many respects represents the 'state-of-the-art' in fixed-wing operational monitoring. Section 3 then describes the helicopter operational monitoring project which has been carried out by SHL, and Section 4 presents the results obtained. Section 5 discusses the benefits of helicopter operational monitoring and the issues associated with its implementation. Finally section 6 presents a set of recommendations on further steps towards the establishment of a helicopter operational monitoring programme.

2.0 FIXED-WING OPERATIONAL MONITORING

Operational monitoring has been carried out for many years in the fixed-wing world. Before considering helicopter operational monitoring, this section presents a review of best fixed-wing practice, as represented by the British Airways monitoring programme.

BA's current flight data recording (FDR) programme was developed in the 1970s as part of the CAA's FDR research project, CAADRP (the Civil Aircraft Airworthiness Data Recording Programme). The system has migrated from a research project into an airline safety tool and is subject to much on-going development. Although, due to its evolution over a number of years, improvements could be made on some elements of the system, the overall system is considered to represent the 'state of the art' in operational monitoring.

2.1 Concept and implementation of BA's FDR programme

The objective of BA's flight data recording programme is to extract information from recorded flight data and use this to improve the safety and efficiency of the aircraft, the airline's operations, and the operating environment (airports, Air Traffic Control, other airlines etc.). Flight data is used to monitor aircraft performance and handling, as well as engine performance and condition on all flights, and detect undesirable 'events' and trends so that corrective action is taken before incidents occur.

Flight data analysis consists of the following two stages:

(1) Primary analysis. The most common form of primary analysis is the replay of recorded flight data through a program that detects 'events' or 'exceedances' i.e. instances when the aircraft has made an excursion outside a pre-determined envelope. Table 2.1 presents a typical list of events.

(2) Secondary analysis. This is the analysis of events or exceedances to generate meaningful and easily understood information to aid the management task.

There are six main components to the implementation of British Airways' flight data recording programme:

(1) On-aircraft data recording equipment, connected to appropriate data sources. The Quick Access Recorder (QAR) with its removable magnetic tape cartridge is the system currently used on the large majority of BA aircraft.

(2) On-ground data analysis system. For engineering and operational purposes, a computer program is used to analyse the data after it has been transferred from the cartridges. British Airways' SESMA (Special Event Search and Master Analysis) is used for operational monitoring. The 'event' parameters are calculated on the introduction of the aircraft type to service by both performance engineering and pilot management, and may be refined from time to time.

(3) Management responsibility. The programme cannot be successful without an airline management which actively pursues safety to the extent that it is prepared to invest in the hardware, the software, and the personnel; but above all, is prepared to subjugate its natural disciplinary role towards its pilot workforce.

(4) Union responsibility. The pilot union must also accept its responsibilities for safety to the extent that it is prepared to co-operate fully in the self-motivating nature of an FDR programme. The emphasis must be on prevention of abnormal operations or excursions, using feedback from pilots, through the union, to management.

(5) Union/Management agreement. With the co-operation between airline management and its pilot union, an FDR agreement was negotiated with a set of rules and working procedures. In BA's procedures, the Engineering Department is responsible for collecting and analysing the data. When an event is identified, there is one 'key' person who is given the facility to identify the Captain involved. The key person must have unquestionable integrity and enjoy the trust of the union. It is probable that he or she will belong to the airline management.

(6) The Authority's responsibility. The Aviation Authority must, in the interests of improvement in air safety, provide a suitable legislative framework to allow the FDR programme, with its inherently sensitive material, to function. In other words, the Authority's role becomes one of monitoring that the pilot union and airline management are handling the FDR data in such a way that it provides an acceptable improvement in safety.

Because of the UK CAA's involvement with the development of this programme over nearly 30 years, there is a unique, close working relationship and sharing of information. This has proved that a Regulatory Authority, in recognising the safety benefits derived, can handle this sensitive information with integrity and gain the trust of all the parties involved.

2.2 Operation of the FDR programme

The QAR cartridges are removed from the aircraft daily and are transferred to the Engineering Department. From a hopper containing up to 120 tape cassettes, a robot arm feeds four replay units, each of which could be reading and analysing data from different aircraft types. The data is transferred to three mini-computers which compare aircraft operation with pre-set parameters for around 65 events. Engineering data is also analysed, and in all, approximately 100 cassettes and over 3 Gigabytes of DFDR data is successfully analysed daily in BA, representing about 95% of all flights.

When an event is detected, a graphic printout of all parameters (a 'trace') is produced for two minutes each side of the event time. This printout is completely de-identified, except for aircraft type, calendar month, departure airfield, arrival airfield, and a unique code number.

Each trace is assessed by a pilot representative from the fleet concerned and the significant ones are reviewed in detail at a monthly 'fleet meeting' by a training manager, a union representative, the 'key' manager (the only person who knows all the flight details), an FDR analyst and an aircraft performance engineer. If it seems likely that further information could be of safety value, the union representative is asked to telephone the Captain. This name is available only from the key manager using the unique code.

When telephoned, the Captain is asked if he was aware of the event and if possible, to provide further detail which could benefit others or may enable the union representative to assist or rectify his understanding. On average, only one flight in one thousand produces an event worthy of a telephone call to the Captain. If necessary, training resources will be made available to enable the Captain and crew to sort out a problem.

Monthly summary reports are produced for management, containing a month by month summary, with deltas for last 3 months compared to previous 3 months. Three monthly reports are generated and widely circulated for educational purposes. These present for each aircraft fleet:

- Numbers of events over the monitored period, divided into different groups relating to event type – e.g. ATC, Ground Support, Pilot Handling, Weather, GPWS, Operating Procedures, Flight Controls, Instruments, etc.

- A summary of the results of an event 'risk' analysis, with numbers of events in each risk category – Severe, High, Medium, Low, Minimal.

- Brief summaries of each event

A bi-monthly Operational FDR Working Group (OFDRWG) meets to discuss policy and general matters. This meeting brings together all interested parties in the BA programme plus a representative from the CAA. The group also instigates projects focusing on a particular area of operation or event, for example rotation rate on take-off and the associated occurrence of tail strikes. Data on the normal distribution of a parameter is gathered by lowering the parameter threshold to obtain an output on every flight.

2.3 Flight data analysis tools

British Airways continues to develop its flight data analysis tools and implement new tools. The comprehensive set of tools described below represents the state of the art in the 'secondary analysis' of flight data.

2.3.1 *Exceedance database and analysis – SESBASE*

SESBASE is an 'event' database that contains a summary of the details of each event detected by the SESMA program and then validated by airline staff. It can analyse events by aircraft type, event type, airfield, date, keyword etc. and present the results in a graphical format most appropriate for that particular analysis.

Within SESBASE is a risk analysis program that automatically assigns a 'severity' to every event (according to the nature of the event and the magnitude of the exceedance), and then permits a comprehensive analysis of risk; by event type, by aircraft type, by airfield and so on.

Various displays allow the user to detect trends before they become major problems. Examples of the trend analysis outputs are:

- A display of event occurrences on one aircraft fleet over a six moth period as a bar graph, with each month identified separately, and events ranked in order of total severity (i.e. the sum of the severity indices for all occurrences of each event).

- A display of the ranking of the total severity of events at each airfield used by an aircraft fleet, normalised per 1000 visits to each airfield.

- A comparison of one aircraft fleet with the whole airline, showing a trend of the factored SESMA events per 10,000 flights on a month by month basis.

2.3.2 *Flight reconstruction*

Three separate tools can be used to re-create a flight as a flight recorder trace, on flight instruments, or as a three dimensional view of the flight path

(1) Flight recorder trace. This is a display of the flight recorder trace of any selected event or flight segment, alternatively a numerical 'listing' of all parameters can be viewed. For this display British Airways uses the Flight Data Company's "GRAF for Windows 95" program.

(2) Instrument animation. This tool recreates the flight as the pilot saw it, presenting the actual flight instrument display for the aircraft type. The autopilot modes and flight director commands are displayed, and the aircraft flight path is shown as a height profile plus a God's eye view. The animation can be viewed in real time, or it can be speeded-up, slowed down or paused.

(3) Flight path visualisation. This is a 3-dimensional reconstruction of the flight path. The display can be rotated horizontally and vertically so that it can be viewed from any angle, and scaled for the most appropriate picture. The flight path, viewed from above, can be overlaid on the approach chart, showing the local environment.

2.3.3 *MAXVALS*

MAXVALS is a concept that can look at operational patterns over many thousands of flights. MAXVALS automatically records the maximum value of many flight parameters on each and every flight, and then calculates and displays the way these parameters are distributed over thousands of flights to show how a fleet of aircraft is being operated. This gives information that fills in the void between the extremes detected by the SESMA program and gives insight into 'normal' operating parameters which are very important in the design and operation of modern aircraft. Displays include tables and histograms. MAXVALS permits a detailed analysis by allowing filtering by aircraft type, airfield, flight phase and so on. MAXVALS can analyse two aircraft types simultaneously, producing overlaid histograms.

2.4 Benefits of operational monitoring

British Airways are totally convinced of the value of the flight data recording programme, and implement it on all new aircraft. Benefits include:

(1) Improved flight safety:

- by monitoring operations 24 hours a day, 365 days a year
- by detecting adverse trends in operational behaviour before incidents occur
- by detecting weaknesses in the crews, aircraft, and operating procedures
- by detecting threats from the environment, e.g. airports, Air Traffic Control, other airlines, helicopter operations etc.

(2) Enhanced flight training:

- by identifying areas where training is needed
- by monitoring the effectiveness of training
- by providing feedback to crews

(3) Improved policy making

- by providing objective evidence on which decisions can be based
- by monitoring the effect of policy changes

(4) Reduced costs:

- by monitoring fuel efficiency, crew procedures, noise violations, in-flight ATC delays, aeroplane stresses, engine efficiency and so on
- by aiding maintenance
- by enhancing safety

The safety benefits obtained are the primary justification for the FDR programme, however there are also significant cost benefits. Examples of these include:

- Very large savings from pulling an engine early, before an in-service failure
- Major savings from reducing fuel burn by identifying problems such as flaps which are not rigged correctly, or doors which are not fully closed
- Savings from the ability to predict surge from engine pressure ratios, and adjust IGVs as necessary
- Savings from reducing the number of incidents such as tail strikes
- The freeing up of simulator time, or improvement of simulator exercises, from an accurate knowledge of aircraft operations
- The ability to change procedures or the environment to minimise airframe stresses and hence maintenance, for example the improvement of an uneven runway
- The ability to provide feedback to manufacturers, enabling optimisation of the maintenance policy

Vmo Exceedance
Vmo Exceedance (Birdstrike)
Mmo Exceedance
Flap Placard Speed Exceedance
Exceedance of Flap/Slat Altitude
Exceedance of Max Operating Altitude
Approach Speed High Within 90 secs of Touch-Down
Approach Speed High Below 500 ft AAL
Approach Speed High Below 25 ft AGL
Approach Speed Low Within 2 mins of Touch-Down
Climb Out Speed Low 35 ft AGL to 400 ft AAL
Climb Out Speed Low 400 ft AAL to 1500 ft AAL
Pitch Rate High on Take-Off
Unstick Speed High
Unstick Speed Low
Tyre Limit Speed High at Take-Off
Pitch Attitude High During Take-Off
Abnormal Pitch Landing (High)
Abnormal Pitch Landing (Low)
Excessive Bank Below 100 ft AGL
Excessive Bank 100 ft AGL to 500 ft AAL
Excessive Bank Above 500 ft AAL
Excessive Bank Near Ground (Below 20 ft AGL)
Initial Climb Height Loss 20 ft AGL to 400 ft AAL
Initial Climb Height Loss 400 ft to 1500 ft AAL
Excessive Time to 1000 ft AAL After Take-Off
High Rate of Descent Below 2000 ft AGL
High Normal Acceleration on Ground
High Normal Acceleration in Flight (Flaps Up, Flaps Down)
High Normal Acceleration at Landing
Normal Acceleration: Hard Bounced Landing
Go Around
Abandoned Take-Off
Abnormal Configuration – Speed Brake with Flap
Low on Approach (Between 3 and 2 mins of Touch-Down)
Speedbrake on Approach Below 800 ft AAL (Any Flap)
Reduced Lift Margin Except Near Ground ($M > 0.3$, $M <= 0.3$)
Reduced Lift Margin at Take-Off (35 to 100 ft AGL)
Stick Shake
Early Configuration Change After Take-Off (flap)
Late Land Flap (Not in position below 500 ft AAL)
Reduced Flap Landing
Deviation Under Glideslope (below 600 ft AAL)
Deviation Above Glideslope (below 600 ft AAL)
Low Buffet Margin (above 20000 ft, $M <= 0.828$)
Low Buffet Margin (above 20000 ft, $M > 0.828$)
Flap load relief operational
GPWS Hard, Soft and False Warning

TABLE 2.1 : Listing of British Airways 757-200 events

3.0 HELICOPTER OPERATIONAL MONITORING PROJECT

3.1 Project objectives

The objectives of the helicopter operational monitoring project described in this report were to:

1. Perform a practical demonstration of the application of fixed wing operational monitoring techniques to helicopters, using an existing Super Puma flight data set.

2. Develop a set of rules for the detection of helicopter operational 'events', and generate example events from the data set to illustrate the type of information which could be generated by a helicopter operational monitoring system.

3. Based on the results of the demonstration, determine usefulness of a helicopter operational monitoring system as an operational quality control tool and management aid, and make recommendations on the implementation of such a system.

3.2 Super Puma flight data

The project analysed a set of de-identified Super Puma flight data from over 800 sectors which had been recorded for an earlier study. This, combined with the available manually entered sector details, provided a useful set of data for the evaluation of a prototype operational monitoring program.

The Super Puma data was recorded in 1987 for an operational usage analysis, aimed at confirming the time-at-condition estimations which the manufacturer used in fatigue life computations for various components. The range of recorded parameters was originally selected for health monitoring trials. However, for the usage analysis the Super Puma was fitted with a low airspeed transducer which made measurements of both local airspeed and vector angle. These measurements were then translated into longitudinal and lateral airspeed. The flight parameters contained in the database are listed in Table 3.1.

3.3 Flight data analysis tools

The helicopter operational monitoring was performed using the following tools:

3.3.1 *Flight data system*

The Flight Data System (FDS) is an analysis program produced by FDC/ATM, running on an IBM or compatible PC with an MS-DOS operating system. The FDS allows digital data available from the aircraft recorders to be converted into useful information for aircraft operations and maintenance personnel. The main functions of the program are:

- To read data from quick access and universal flight data recorders

- To convert this data into a format that the system can use

- To enable the operator to produce flight parameter lists and traces on the screen or in printed form, and produce diagrams in graph form comparing parameters

- To carry out user defined flight analyses using Automatic Flight Parameter Analysis (AFPA) rule sets

- To store data for future use

- To export AFPA results in ASCII format for use by other programs

The system is flexible and easy to use, allowing the operator to configure it with parameters necessary to produce the results that are required.

The flight data are analysed using a set of AFPA rules, with the FDS detecting and storing all rule violations. For this project rules were created to detect exceedances of Super Puma Flight Manual limitations, and deviations from standard operating procedures or what is considered good operating practice.

3.3.2 *Microsoft Office software*

The results of the FDS data analysis are stored separately for each flight, and for the analysis of large numbers of results the FDS is of little use. To enable the meaningful analysis of significant numbers of rule violations and present outputs from this the following Microsoft Office software was used:

- Excel 5.0
- Access 2.0
- PowerPoint 4.0

Excel spreadsheets were used to store the FDS results and perform statistical analyses on these. An Access database was used to store the manually entered Super Puma sector details, plus all FDS results. Screen dumps of FDS traces were imported into PowerPoint for inclusion in this report.

3.4 Information sources for the configuration of operational limits

The FDS AFPA rules encode various Super Puma operational limits and detect limit exceedances. Four sources of information have been used to define the operational limits used in this project:

(1) The Super Puma Flight Manual.

(2) A chart showing Super Puma cyclic and yaw pedal taxi limits.

(3) Bristow Helicopters Ltd (BHL) guidance material on Tiger Offshore Profiles and the Super Puma Flight Manual Supplement for Group A Operation.

(4) Representative pilot opinion on what are considered to be reasonable flight envelope limits for good operating practice.

3.5 Flight data analysis

3.5.1 *Primary analysis*

The primary analysis was performed using the FDS AFPA rules. Four sets of rules have been created:

- AFPA set 1: In flight analysis 1
- AFPA set 2: In flight analysis 2
- AFPA set 3: On ground analysis
- AFPA set 4: Calculation of flight statistics

The purpose of the rules in AFPA rule sets 1-3 are to detect 'events' in the Super Puma flight data. The rules contained in these rule sets are listed in Table 3.2. Event thresholds were set according to the following criteria:

(1) For events based on flight manual limits, the limits specified in the flight manual were used.

(2) For other events, thresholds were set at a level which gave a number of event occurrences. This was primarily done for demonstration purposes, as the objective was to generate example events to indicate the potential capabilities and benefits of helicopter operational monitoring. In any on-line system, it would be necessary to agree all event thresholds with the helicopter operators.

Rule set 4 contained a limited number of rules with low thresholds so that an output would be obtained from every flight for a statistical analysis of maximum parameter values on normal operations.

In addition to detecting events, the rules were configured to trap and disregard 'bad data'. A review of the Super Puma database showed that the AFPA rule 'bad data' trapping had to be capable of:

(1) Trapping the large quantities of bad data with corrupted parameter values present on some flights

(2) Trapping the spurious data generated prior to engine run-up and system stabilisation

All the Super Puma flight data was analysed using rule sets 1-3. In addition a one third sample of the database was analysed with rule set 4.

3.5.2 *Secondary analysis*

The results from rule sets 1-4 were imported into Excel in a two step process. The ASCII file outputs from the FDS were converted into a format in which each rule violation is stored as a separate record. The converted files were then imported into Excel using an Excel Macro. The results were also transferred to an Access database.

The main difference in the secondary analysis performed in this project and the on-line analysis of flight data is that this project involved the batch analysis of a data set comprising one years flying. In an on-line system, it is envisaged that flight data would be analysed on a daily basis.

The secondary analysis comprised the following elements:

3.5.2.1 Analysis of events

The event occurrences generated by each rule set were sorted by event type and then by the magnitude of the key parameter associated with the event. The most significant occurrences of each event were then investigated by viewing the flight parameter traces to identify the circumstances of the event.

A selection of 'interesting' events was made for inclusion in this report to demonstrate the potential of helicopter operational monitoring to identify, and provide meaningful information, operational events.

3.5.2.2 Statistical analysis

Using the analysis facilities within Excel, the following four example statistical analyses were performed:

(1) Calculation of data distributions for the maximum values of particular flight parameters during normal operations.

(2) Calculation of the distributions of maximum parameter values for parameters which had exceeded rule thresholds to create an event. These distributions represent the upper tail of the overall data distributions.

(3) Calculation of trends in event occurrences. Trends were determined by dividing the one years' data into four 3-month periods, and calculating the number of occurrences in each period.

(4) Ranking of events according to the number of occurrences, to identify the most frequently occurring events in a period.

(1) *Variable parameters*

Abbreviation	Description	Units
ALT	Pressure Altitude	feet
COLLP	Collective Pitch	deg
CYCLAT	Cyclic Pitch – Lateral	%
CYCLNG	Cyclic Pitch – Longitudinal	%
HDG	Heading	deg
IAS	Indicated Airspeed	knots
LATA	Lateral Acceleration	g
LATIAS	Lateral Airspeed (low airspeed sensor)	knots
LNGA	Longitudinal Acceleration	g
LNGIAS	Longitudinal Airspeed (low airspeed sensor)	knots
NF1	Free Turbine RPM, Engine No. 1	rpm
NF2	Free Turbine RPM, Engine No. 2	rpm
NG1	Gas Generator RPM, Engine No. 1	rpm
NG2	Gas Generator RPM, Engine No. 2	rpm
NMLA	Normal Acceleration	g
OAT	Outside Air Temperature	
PITCH	Pitch Attitude	deg
RALT	Radio Altitude	feet
ROLL	Roll Attitude	deg
RTRPM	Main Rotor RPM	rpm
T41	Turbine Gas Temperature, Engine No. 1	deg C
T42	Turbine Gas Temperature, Engine No. 2	deg C
TRPIT	Tail Rotor Pitch	deg
TRQ1	Torque, Engine No. 1	%
TRQ2	Torque, Engine No. 2	%

(2) *Discrete parameters*

Abbreviation	Description
ALTH	Altitude Hold Engaged
EVNT	Pilot Event Marker Pressed
HDGH	Heading Hold Engaged
IASH	Airspeed Hold Engaged
MLGL	Main Undercarriage Down and Locked – Left
MLGR	Main Undercarriage Down and Locked – Right
NLG	Nose Undercarriage Down and Locked
RBRK	Rotor Brake On
WS	Weight on Wheels

TABLE 3.1 : List of Super Puma flight parameters

Rule set 1

EVENT20A	High Pitch Attitude below 20 ft AGL
EVENT20B	Low Pitch Attitude below 20 ft AGL
EVENT20C	High Pitch Attitude above 20 ft AGL
EVENT20D	Low Pitch Attitude above 20 ft AGL
EVENT20E	High Pitch Rate above 500 ft AGL
EVENT20E2	High pitch rate below 500 ft AGL
EVENT21	Roll Attitude
EVENT21D	High Roll Rate above 500 ft AGL
EVENT21D2	High Roll Rate below 500 ft AGL
EVENT22A	High Rate of Descent below 500 ft AGL
EVENT22C	High Rate of Descent above 500 ft AGL
EVENT23B	Airborne Normal Acceleration (max)
EVENT23B2	Airborne Normal Acceleration (min)
EVENT72A	Low Rotor Speed – Power On
EVENT72B	High Rotor Speed – Power On
EVENT73A	Low Rotor Speed – Power Off
EVENT73B	High Rotor Speed – Power Off
EVENT74A	Excessive Lateral Cyclic Control
EVENT74B	Excessive Longitudinal Cyclic Control
EVENT74C1	Excessive Coll Pitch Control-Level Flt
EVENT74C2	Excessive Coll Pitch Control-In Climb
EVENT75A	Max Continuous Torque (2 Engines)
EVENT75B1	Max Continuous Torque #1 (OEI)
EVENT75B2	Max Continuous Torque #2 (OEI)
EVENT76A1	High Engine RPM #1 (2 Engines)
EVENT76A2	High Engine RPM #2 (2 Engines)
EVENT76B1	High Engine RPM #1 (OEI)
EVENT76B2	High engine RPM #2 (OEI)
EVENT77A1	High Engine Temp #1 (2 Engines)
EVENT77A2	High Engine Temp #2 (2 Engines)
EVENT77B1	High Engine Temp #1 (OEI)
EVENT77B2	High Engine Temp #2 (OEI)
EVENT7A	Low Airspeed above 500 ft AGL

TABLE 3.2 : List of AFPA rules

Rule set 2

EVENT79	Pilot Event Marker – in flight
EVENT80	Autopilot Engaged below 70 knots
EVENT81A	Gear not locked down below 100 ft (t/o)
EVENT81B	Gear not locked down below 500 ft (ldg)
EVENT82A	Avoid Area 1
EVENT82AAA	Avoid Area 1 value of point A
EVENT82AEE	Avoid Area 1 value of point E
EVENT82B	Avoid Area 2
EVENT82BAA	Avoid Area 2 value of point A
EVENT82BEE	Avoid Area 2 value of point E
EVENT82C	Avoid Area 3
EVENT82CAA	Avoid Area 3 value of point A
EVENT82CEE	Avoid Area 3 value of point E
EVENT82D	Avoid Area 4
EVENT82DAA	Avoid Area 4 value of point A
EVENT82DEE	Avoid Area 4 value of point E
EVENT83	VNE
EVENT84	VNO
EVENT84A	VNO2 (wt = 8350 kg or 18370 lb)
XWEIGHT	Calculated instantaneous weight (lbs)

Rule set 3

EVENT20F	Pitch Attitude on Ground – Nose Up
EVENT20G	Pitch Attitude on Ground – Nose Down
EVENT21E	Roll Attitude on Ground
EVENT23C	Normal Acceleration at Landing
EVENT76A1	High Engine RPM #1
EVENT76A2	High Engine RPM #2
EVENT78A1	High Engine Start Temperature #1
EVENT78A2	High Engine Start Temperature #2
EVENT85	Rotor brake applied at 120 rpm +
EVENT86	Tail boom overhang
EVENT87	longitudinal cyclic limit (on ground)
EVENT88A	lateral acceleration (on ground)
EVENT88B	longitudinal acceleration (on ground)
EVENT88C	normal acceleration (on ground)
EVENT89A	Taxi limit (left gear lifts)
EVENT89B	Taxi limit (right gear lifts)

TABLE 3.2 : List of AFPA rules

4.0 HELICOPTER OPERATIONAL MONITORING RESULTS

4.1 Analysis of events

20 flights with the most significant events have been selected for presentation in this report in the form of a description of the event, plus a trace showing the relevant flight parameters during the period when the event occurred. The FDS can mark the location of events on the traces with 'flags', these have been removed in all but one of the examples to improve the clarity of the traces. The 20 events were selected as:

(1) Examples of the most significant event occurrences

(2) Examples of flights with abnormal or unexplained data/manoeuvres

The events are described in the following pages, being classified according to the following six categories of operation:

(1) Engine start-up and shut-down

(2) Ground handling

(3) Take-off and landing

(4) In-flight handling

(5) Training

(6) Air test

The flight parameter abbreviations used in this section are explained in the list of abbreviations at the front of the report, and also in Table 3.1. In the flight parameter traces presented here, changes in the status of discrete parameters are indicated by changes in the thickness of the parallel lines shown at the bottom of the traces.

4.1.1 *Engine start-up and shut-down*

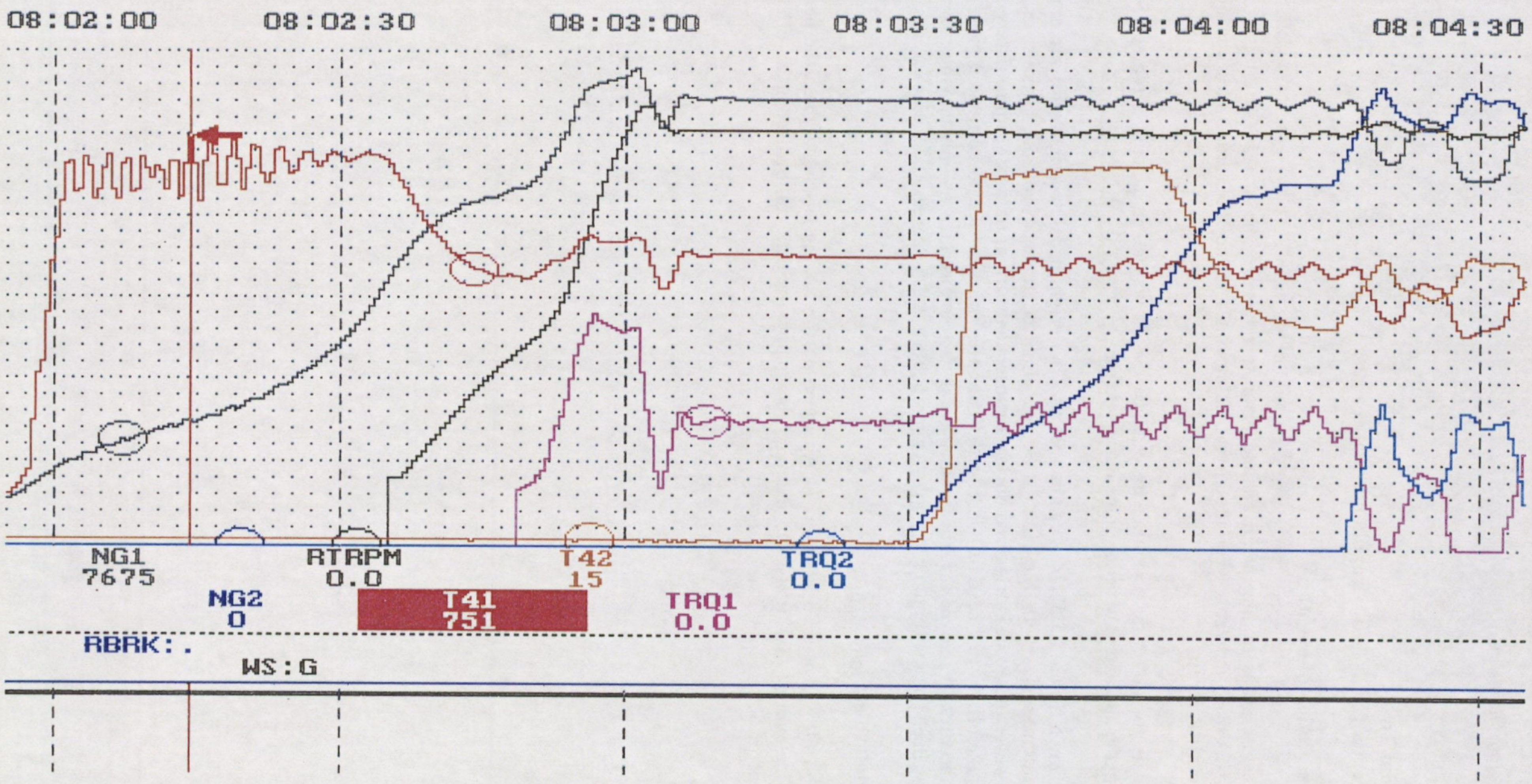
4.1.1.1 Flight No: 1

From/To: Aberdeen – Hutton Tension Leg (Fixed)
Event(s): 78A1 High Engine Start Temperature #1

Description of event:

During No.1 engine starting T41 momentarily reached a value of 751 degC, exceeding the event trigger value of 750 degC. This is not a flight manual exceedance as 750 degC is the maximum (unlimited time) limit for engine starting, the maximum transient (5 second) limit is 800 degC.

This is however an example of how the available data might be reviewed during possible fault investigations. In this case the trace shows the behaviour of No.1 engine during starting and the subsequent run-up of No.2 engine. T41 can be seen to oscillate between 634 and 751 degC whilst NG1 increases during the engine start. Then, for a period of 44 seconds whilst engine No.2 is starting, oscillations can be seen in the time histories of T41, NG1, TRQ1 and RTRPM. Maximum and minimum values of these parameters are as follows: T41: 499-532 degC, NG1: 26,947- 27,708 rpm, TRQ1: 13.1-17.6%, RTRPM: 253.4-256.4 rpm.


08:02:00
08:02:30
08:03:00
08:03:30
08:04:00
08:04:30
NG1
7675
RTRPM
0.0
T42
15
TRQ2
0.0
NG2
0
T41
751
TRQ1
0.0
RBRK: .
WS:G

Flight No: 1

4.1.2 *Ground handling*

4.1.2.1 Flight No: 2

From/To: -
Event(s): 89B Taxi limit (right gear lifts)

Description of event:

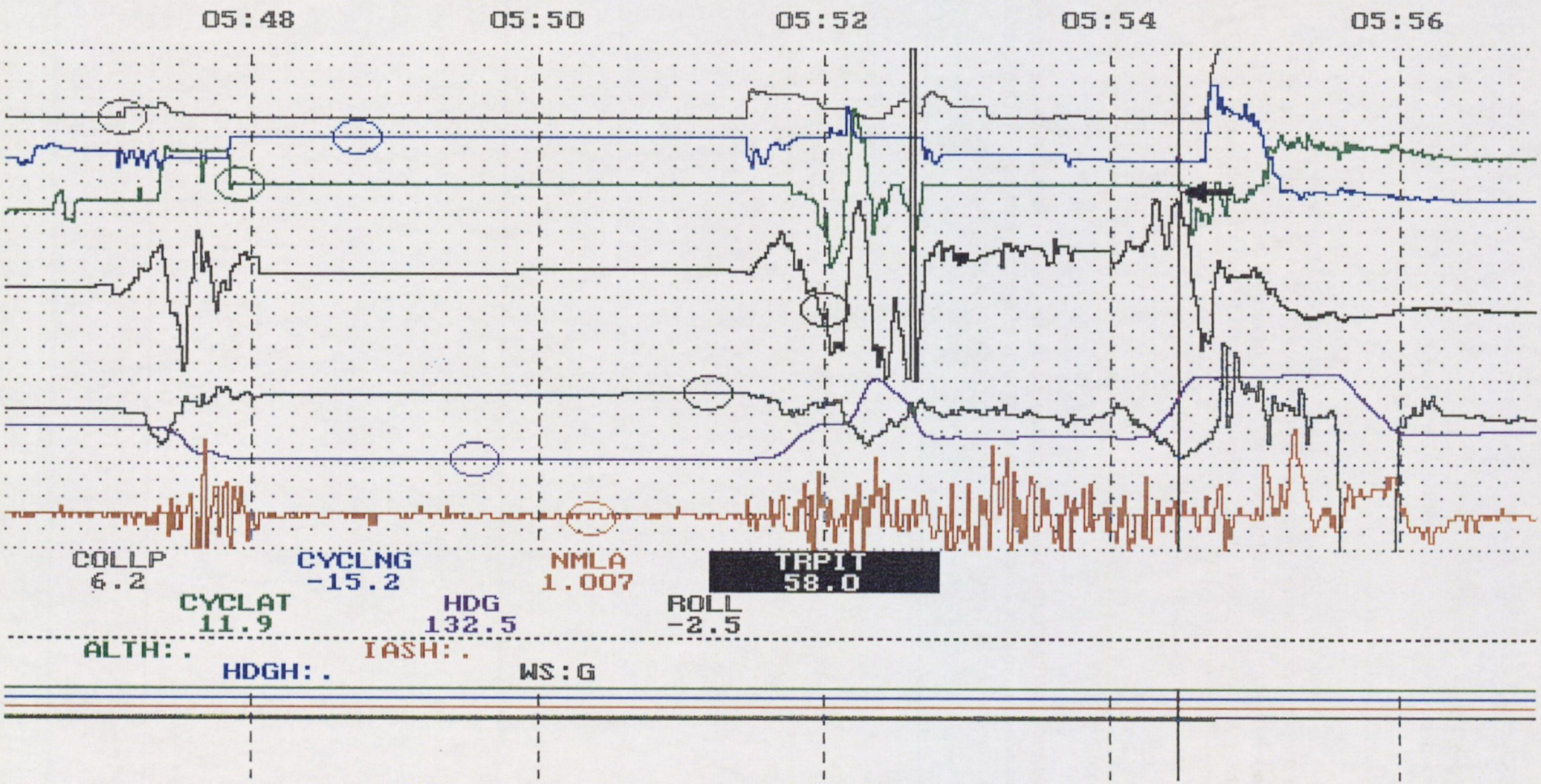
The aircraft is taxiing at an airfield prior to take-off. The increased activity in the NMLA trace indicates when the aircraft is moving and the HDG trace shows when the aircraft is turning.

A rule for detecting taxi limit exceedance events was created using a plot of Super Puma cyclic and yaw pedal limits during taxiing.

During a turn at 05:52:14 it can be seen that both right pedal and right stick are applied simultaneously, with the right stick reducing the tendency of the aircraft to roll. However the event is triggered during a subsequent turn at 05:54:28, immediately prior to take-off. In this case full right pedal is applied but there is no correlated movement of the stick. It may be that this is unnecessary as the aircraft was only moving slowly at this time. The maximum roll angle during the turn is 2.5 degrees.

Comments:

The roll-over of a Super Puma at Aberdeen during taxiing has highlighted the need to define aircraft taxi limits, this example shows how the data can be used as an effective detector of taxi limit exceedances.


05:48
05:50
05:52
05:54
05:56
COLLP
6.2
CYCLNG
-15.2
NMLA
1.007
TRPIT
58.0
CYCLAT
11.9
HDG
132.5
ROLL
-2.5
ALTH:.
IASH:.
HDGH:.
WS:G

Flight No: 2

4.1.2.2 Flight No: 3

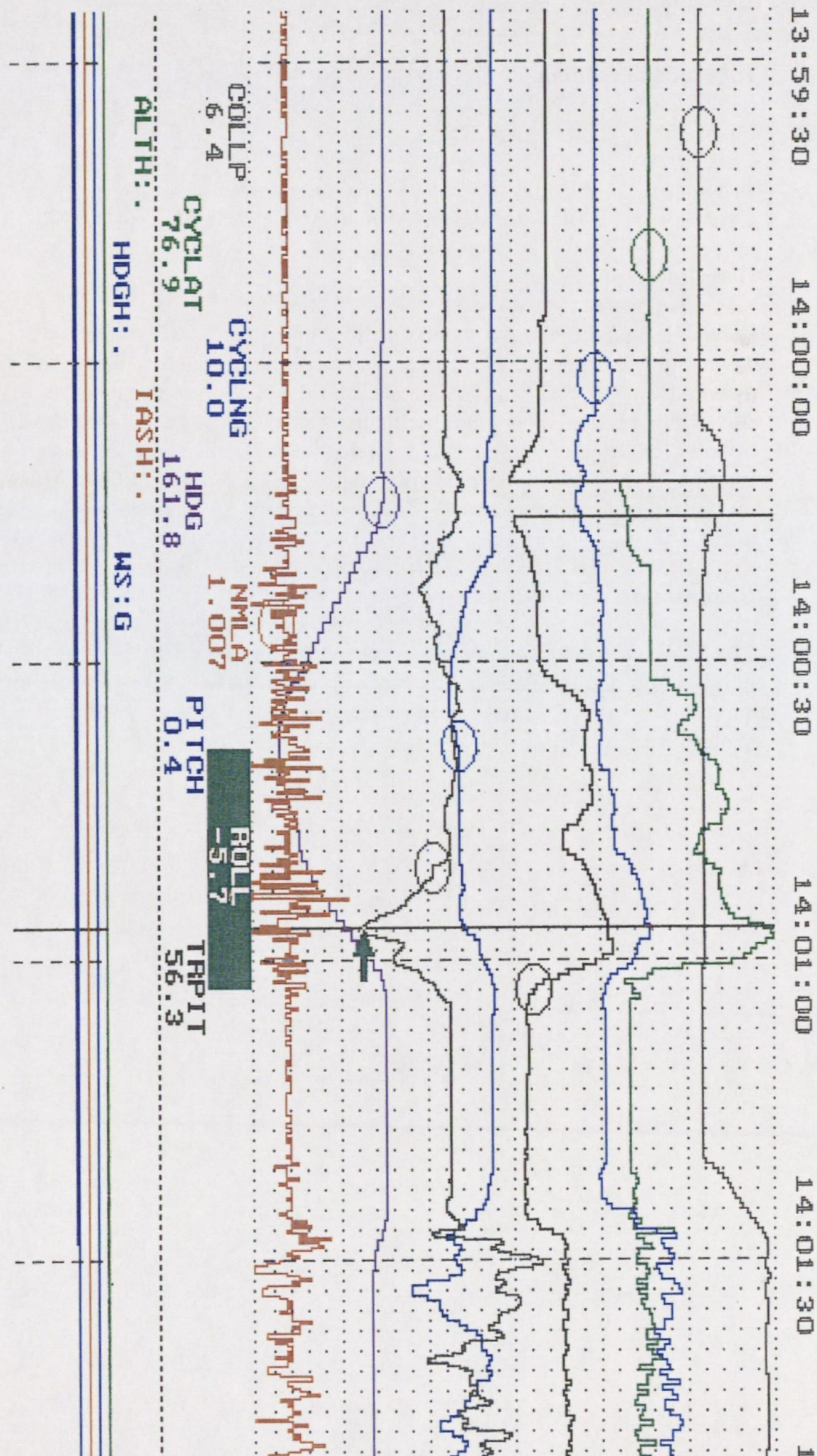
From/To: -
Event(s): 21E Roll Attitude on Ground

Description of event:

This is another example of the aircraft taxiing at an airfield prior to take-off. The aircraft commences taxiing at 14:00:06 when collective pitch is increased and forward stick applied. The aircraft makes two turns in opposite directions. The application of right pedal on the second turn causes the aircraft to roll to a maximum of 5.7 degrees, causing the roll attitude event to trigger (threshold = 5 degrees). It can be seen that just as the roll angle is approaching a maximum right stick is rapidly applied to counteract the roll.

Comments:

The increased aircraft roll in this example may be due to the fact that the aircraft was travelling at greater speed during the turn than in the previous case. Again the example demonstrates how the data can be used to monitor taxiing operations.


13:59:30
14:00:00
14:00:30
14:01:00
14:01:30
14:02:00
COLLP 6.4
CYCLNG 10.0
CYCLAT 76.9
HDG 161.8
NMLA 1.007
PITCH 0.4
ROLL -5.7
TRPIT 56.3
ALTH:.
IASH:.
HDGH:.
WS:G

Flight No: 3

4.1.3 *Take-off and landing*

4.1.3.1 Flight No: 4

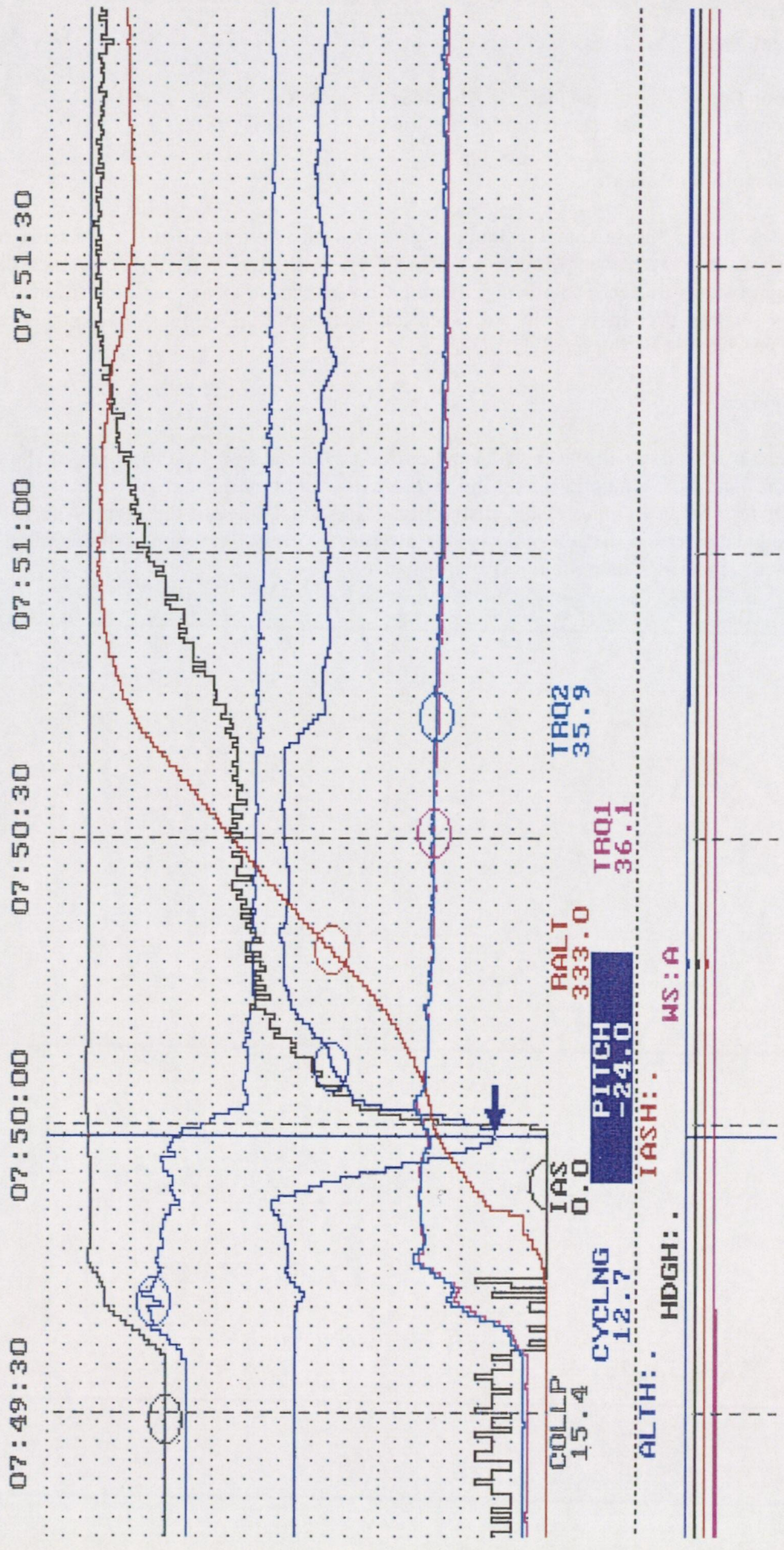
From/To: Aladdin (Mobile drilling unit) – Aberdeen
Event(s): 20D Low Pitch Attitude above 20 ft AGL

Description of event:

Following take-off from a mobile drilling unit the aircraft rotates to a maximum nose down pitch attitude of 24 degrees and accelerates rapidly. This is the greatest nose down attitude detected in the data set, and the histogram presented in Figure 4.2 at the end of this section shows that the value is at the extreme limit of the upper tail of the distribution of the pitch attitude events. The BHL guidance material recommends rotating to 8 degrees nose down, and the Super Puma Flight Manual specifies a maximum nose down attitude of approximately 15 degrees for a take-off from an airfield.

Comments:

The low combined torque values recorded during the climb suggest that the aircraft is light, in addition time and date information indicates that the take-off took place in the dark. This case appears to be an example of a rather over enthusiastic take-off manoeuvre.


07:49:30
07:50:00
07:50:30
07:51:00
07:51:30
COLLP
15.4
CYCLNG
12.7
IAS
0.0
PITCH
-24.0
RALT
333.0
TRQ1
36.1
TRQ2
35.9
ALTH: .
HDGH: .
IASH: .
WS:A

Flight No: 4

4.1.3.2 Flight No: 5

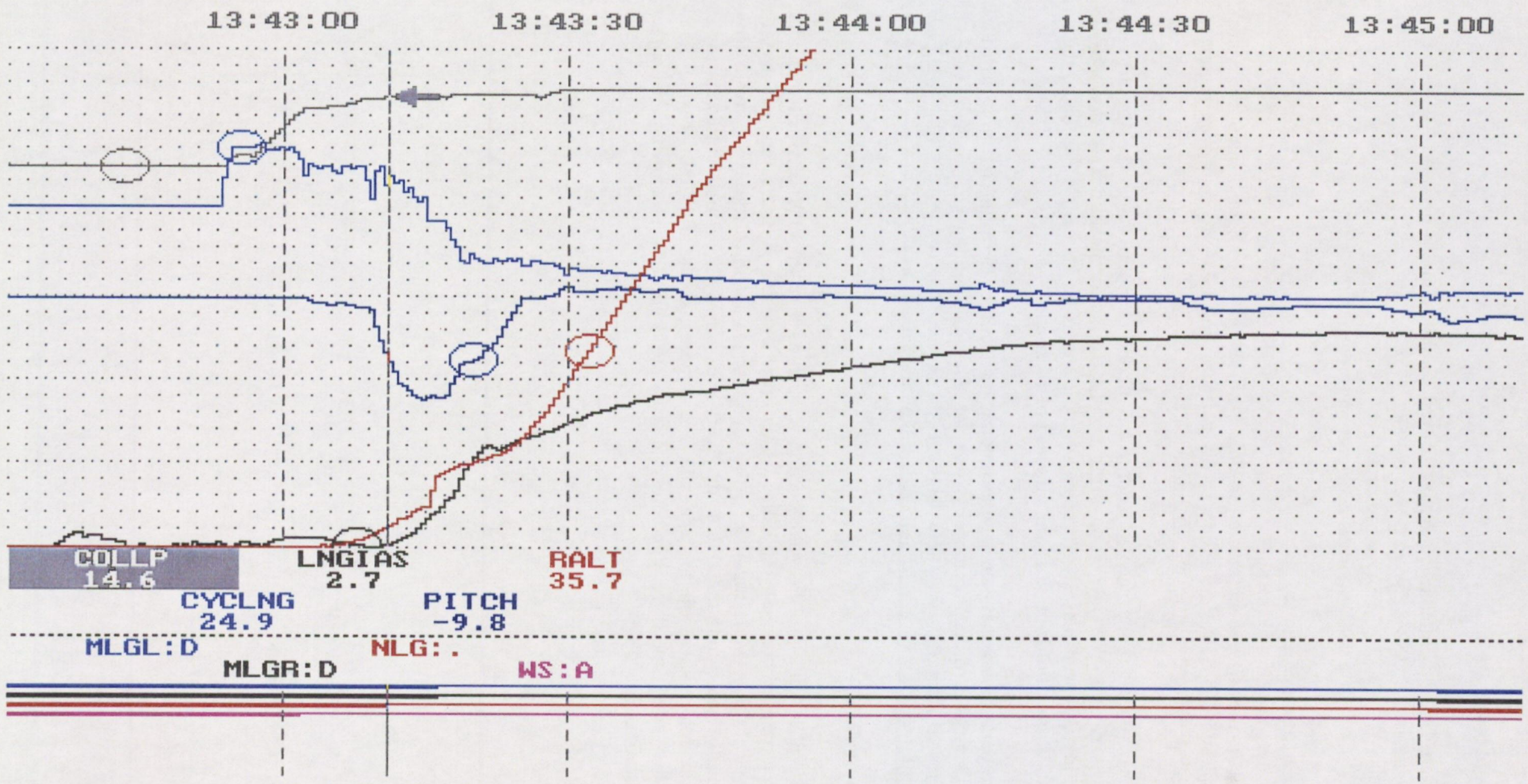
From/To: D' Constructor – Aberdeen
Event(s): 81A Gear not locked down below 100 ft (t/o)

Description of event:

This example shows that the landing gear has been retracted just as the aircraft is starting to rotate during a take-off from a rig, with the radio altimeter recording a height of only 35 feet. This is significantly lower than on any of the other flights in the data set, however there is no published guidance material defining the point at which the gear should be retracted during a take-off.

Comments:

There is no universally accepted view on the advantages or disadvantages of the early retraction of the landing gear during take-off. It could be argued that retracting the gear early represents an unnecessary distraction at a critical stage of the flight. Alternatively it might be argued that cleaning up the aircraft by early retraction of the landing gear may marginally improve take-off performance.



13:43:00
13:43:30
13:44:00
13:44:30
13:45:00
COLLP
14.6
LNGIAS
2.7
RALT
35.7
CYCLNG
24.9
PITCH
-9.8
MLGL:D
NLG:.
MLGR:D
WS:A

Flight No: 5

4.1.3.3 Flight No: 6

From/To:	Sumburgh – Stena Seawell (Mobile support vessel)	
Event(s):	82B	Avoid Area 2
	82C	Avoid Area 3
	88C	normal acceleration (on ground)

Description of event:

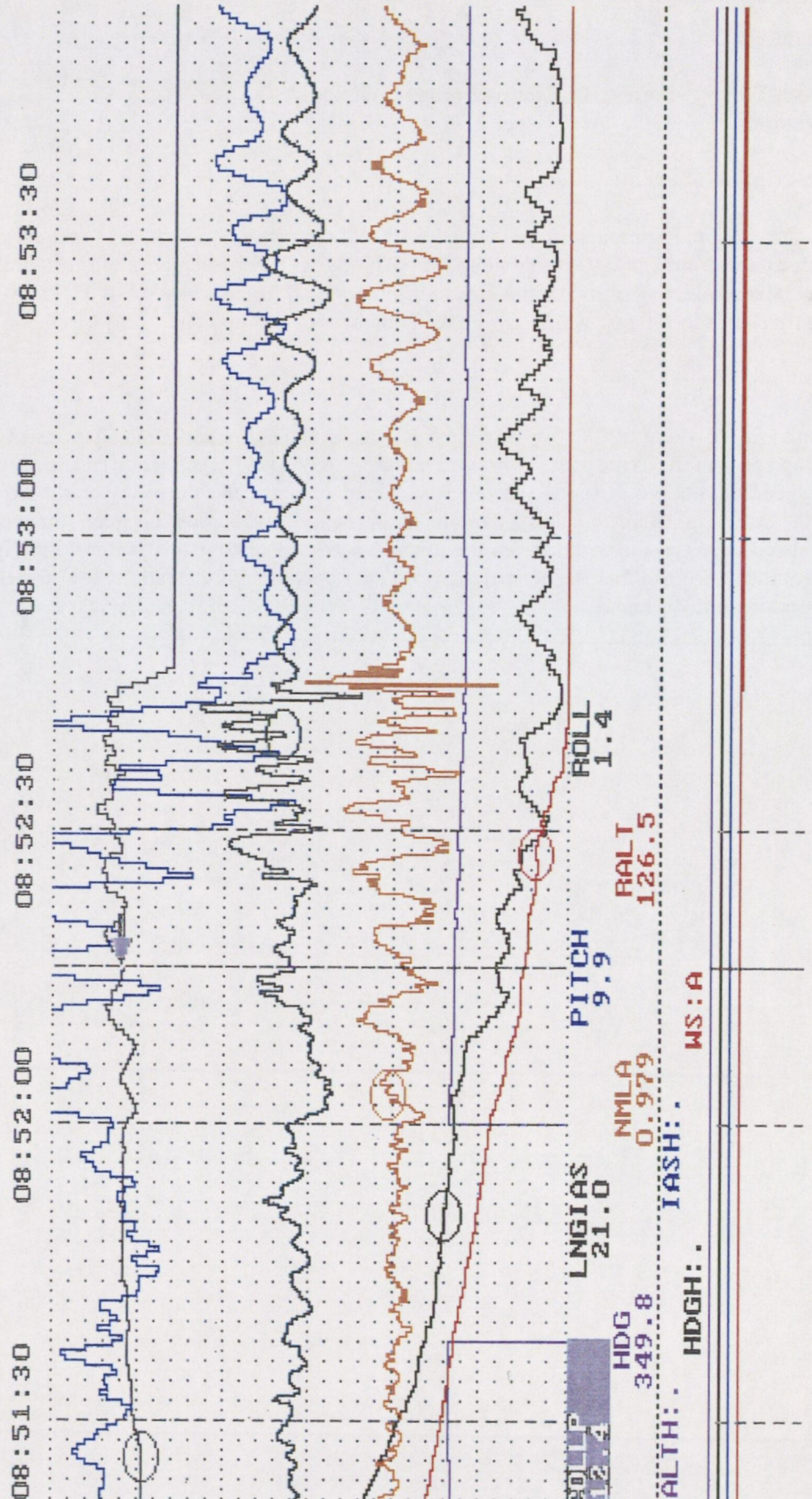
AFPA rules have been created to detect entries into the flight manual avoid area. To facilitate this it was necessary to divide the avoid area into four area segments, with separate rules detecting entries into each segment.

During the final approach to landing on a mobile support vessel the aircraft enters the flight manual avoid area at an altitude of 126 ft and airspeed of 21 knots (measured by the low airspeed sensor). After remaining in the avoid area for 17 seconds, the aircraft exits at an altitude of 52 ft and airspeed of 14 knots.

The data shows that, during the landing manoeuvre, the pilot is trying to follow the pitching and rolling motion of the vessel. The post-landing sinusoidal PITCH, ROLL and NMLA traces show the vessel's actual motion. The vessel is rolling 4 degrees with a roll period of 7 seconds, and is also pitching 2 degrees.

Comments:

Current landing profiles have been developed as a result of extensive experience, and more recently compitor modelling, to optimise a wide range of safety and performance considerations while minimising the time aircraft spend in the avoid areas. However, transitory entry into these areas may very occasionally be seen as in this approach. The main area of interest in this example is to demonstrate the ability to measure the motion of the vessel, and thereby monitor the sea state conditions under which helicopters are operating from ships.


08:51:30
08:52:00
08:52:30
08:53:00
08:53:30
COLLP 12.4
HDG 349.8
LNGIAS 21.0
NMLA 0.979
PITCH 9.9
RALT 126.5
ROLL 1.4
ALTH: .
HDGH: .
IASH: .
WS:A

Flight No: 6

4.1.3.4 Flight No: 7

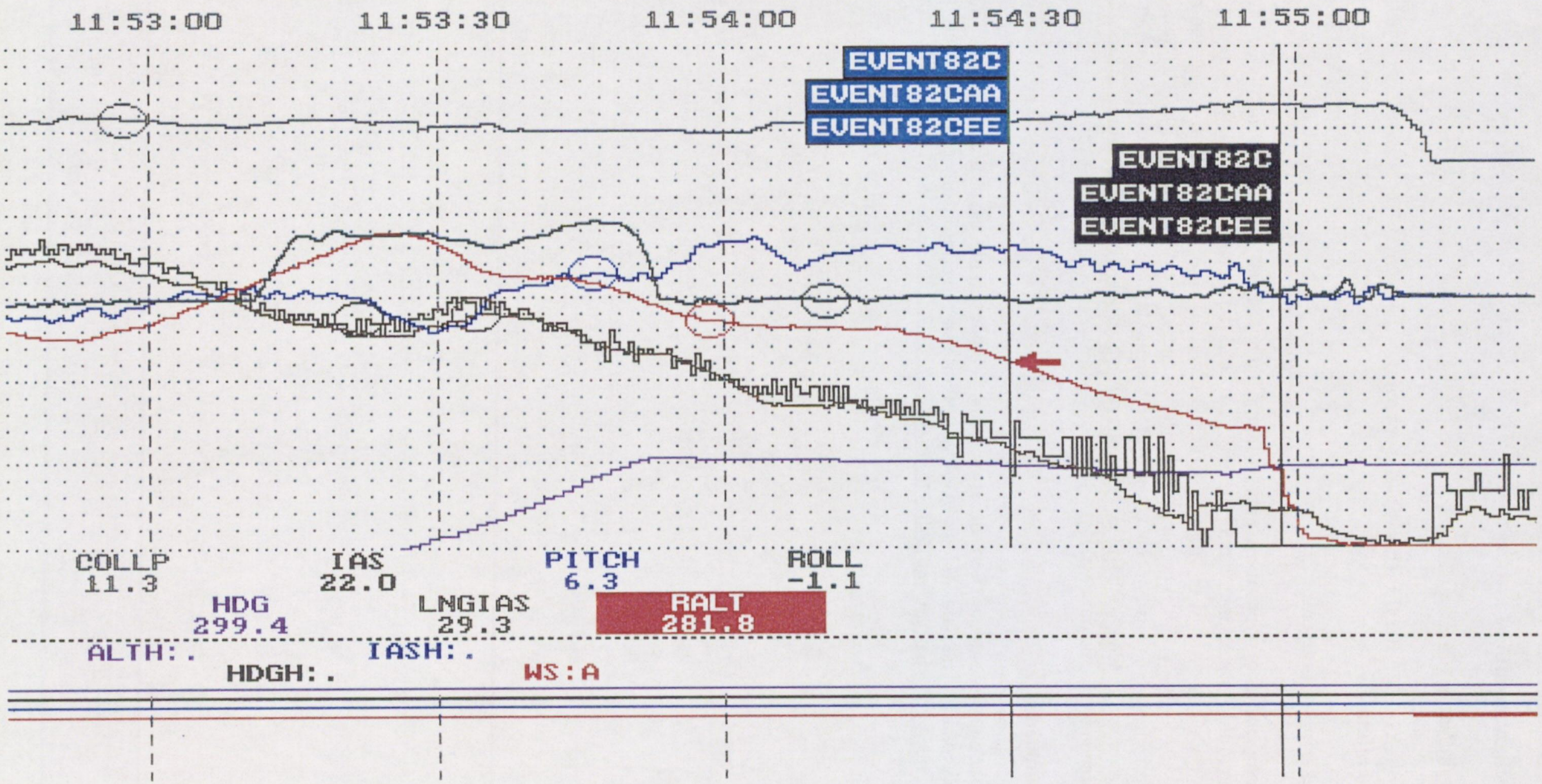
From/To: Forties B (Fixed) – Forties D (Fixed)
Event(s): 82C Avoid Area 3

Description of event:

During the final approach to landing on a rig the aircraft enters the flight manual avoid area at an altitude of 280 ft and airspeed of 29 knots. After remaining in the avoid area for 28 seconds, the aircraft exits at an altitude of 116 ft and airspeed of 11 knots. The figure shows the 'flags' which can be set to show the start and end of the event.

Comments:

It may be of value to identify manoeuvres which result in significant amounts of time being spent in the avoid area. However, monitoring of avoid areas requires accurate low airspeed data. Low airspeed sensors were fitted only for the purposes of the original data gathering exercise. This example shows good correlation between the normal airspeed data and the output from the low airspeed sensor, but this is not normally the case. It can be seen that the normal airspeed data becomes very erratic below a speed of approximately 40 knots.


11:53:00
11:53:30
11:54:00
11:54:30
11:55:00
EVENT82C
EVENT82CAA
EVENT82CEE
EVENT82C
EVENT82CAA
EVENT82CEE
COLLP
11.3
IAS
22.0
PITCH
6.3
ROLL
-1.1
HDG
299.4
LNGIAS
29.3
RALT
281.8
ALTH: .
IASH: .
HDGH: .
WS: A

Flight No: 7

4.1.4 In-flight handling

4.1.4.1 Flight No: 8

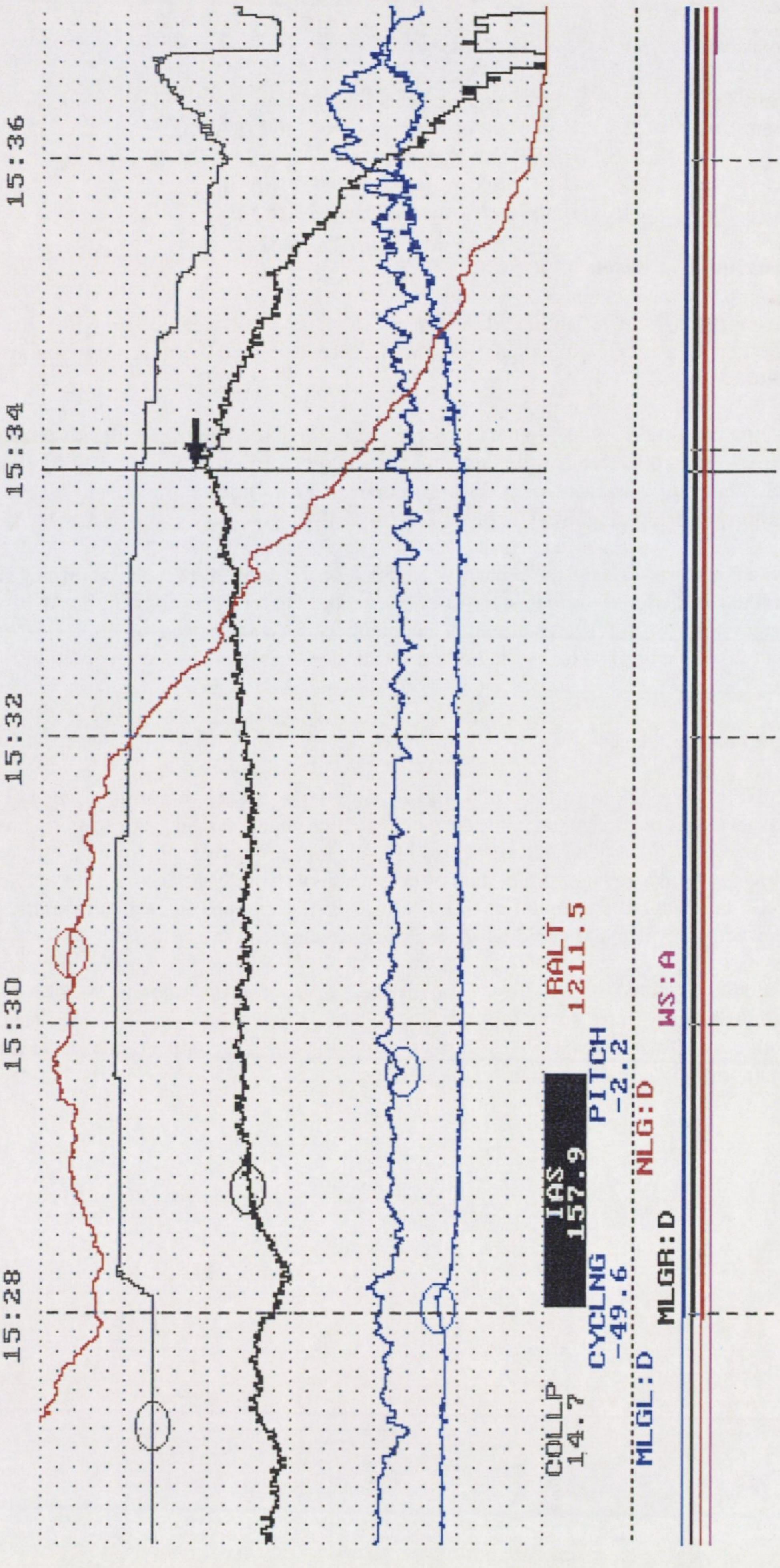
From/To: Beryl B (Fixed) – Aberdeen
Event(s): 84 VNO

Description of event:

Using the charts in the Super Puma Flight Manual, the Vno calculated for the prevailing conditions was 154 knots. It can be seen that a short duration Vno exceedance occurred during the descent to landing at Aberdeen, with a maximum IAS of 157.9 knots. During the first part of the descent the pilot has maintained an approximately constant collective pitch setting and a slightly nose down attitude, allowing airspeed to build as the aircraft descends. This is the only detected Vno exceedance in the data set.

Comments:

Although of only a short duration, this is an example of a genuine flight manual exceedance. The data also gives a clear picture of the circumstances of the exceedance, i.e. during the descent into Aberdeen airport.


15:28
15:30
15:32
15:34
15:36
COLLP
14.7
CYCLNG
-49.6
IAS
157.9
PITCH
-2.2
RALT
1211.5
MLGL:D
MLGR:D
NLG:D
WS:A

Flight No: 8

4.1.4.2 Flight No: 9

From/To:	Brae B (Fixed) – Aberdeen	
Event(s):	22A	High Rate of Descent below 500 ft AGL
	73B	High Rotor Speed – Power Off
	20C	High Pitch Attitude above 20 ft AGL
	20A	High Pitch Attitude below 20 ft AGL

Description of event:

During the descent to landing at Aberdeen, event 22A is triggered from 500 ft down to 335 ft, with a maximum calculated rate of descent of 1,004 ft/min occurring at 480 ft altitude.

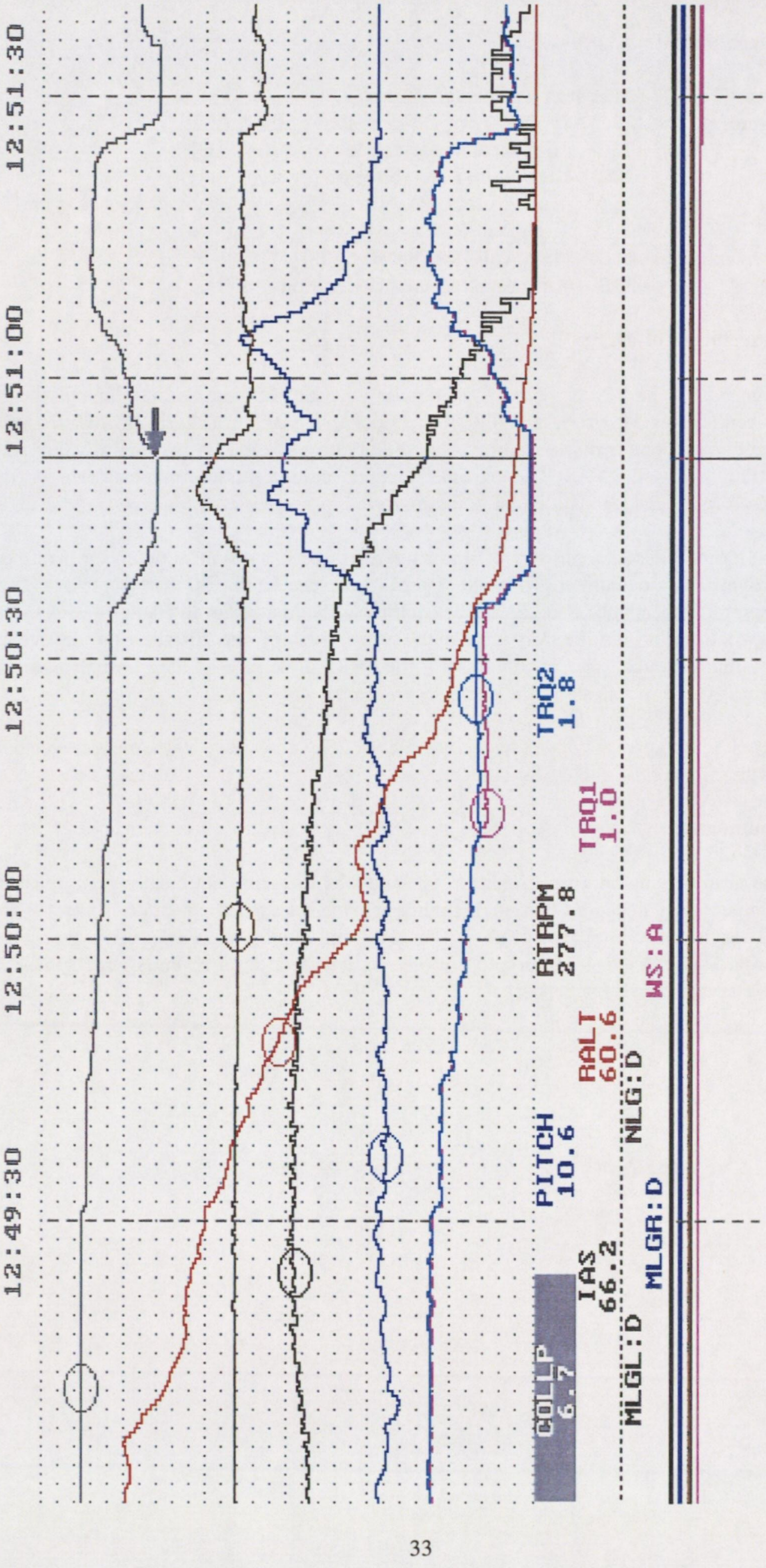
At 190 ft altitude and 122 knots IAS the pilot starts lowering the collective from 12.2 degrees. The collective is fully down and the engine torques at zero at 102 ft, 104 knots IAS. The rotor rpm rises as the aircraft commences a Quickstop manoeuvre, and peaks at 286 rpm, triggering event 73B.

The pilot starts raising the collective at 60 ft to re-apply power for the final flare to landing. The engine torques start to rise 3 seconds later. The aircraft flares to a 16.1 degrees nose up pitch attitude at a height of 19.6 ft and speed of 33 knots, causing event 20A to trigger. This is the highest event 20A maximum value recorded in the data set.

Comments:

Whilst it is not unknown for a pilot to fully lower the collective during a revenue flight, this normally occurs at an altitude much greater than 500 feet in order to initiate a rapid descent. Carrying out a low-level Quickstop, or recovering from an autorotation at low-level on a revenue flight cannot be considered good practice as it leaves no room for error. Under these conditions any failure of the engines to respond rapidly to the renewed power demand could have serious consequences.

It should be noted that there are no defined limits for the maximum nose-up pitch attitude during a flare out before landing. There is however a recommended nose pitch up limit for touch down. This data is providing the first opportunity to establish a distribution of actual maximum pitch attitudes.


12:49:30
12:50:00
12:50:30
12:51:00
12:51:30
COLLP 6.7
IAS 66.2
PITCH 10.6
RALT 60.6
RTRPM 277.8
TRQ1 1.0
TRQ2 1.8
MLGL:D
MLGR:D
NLG:D
WS:A

Flight No: 9

4.1.4.3 Flight No: 10

From/To: Aberdeen – Stavanger (Sola)
Event(s): 22C High Rate of Descent above 500 ft AGL
22A High Rate of Descent below 500 ft AGL
20E High Pitch Rate above 500 ft AGL
21 Roll Attitude
21D High Roll Rate above 500 ft AGL
21D2 High Roll Rate below 500 ft AGL
23B Airborne Normal Acceleration (max)

Description of event:

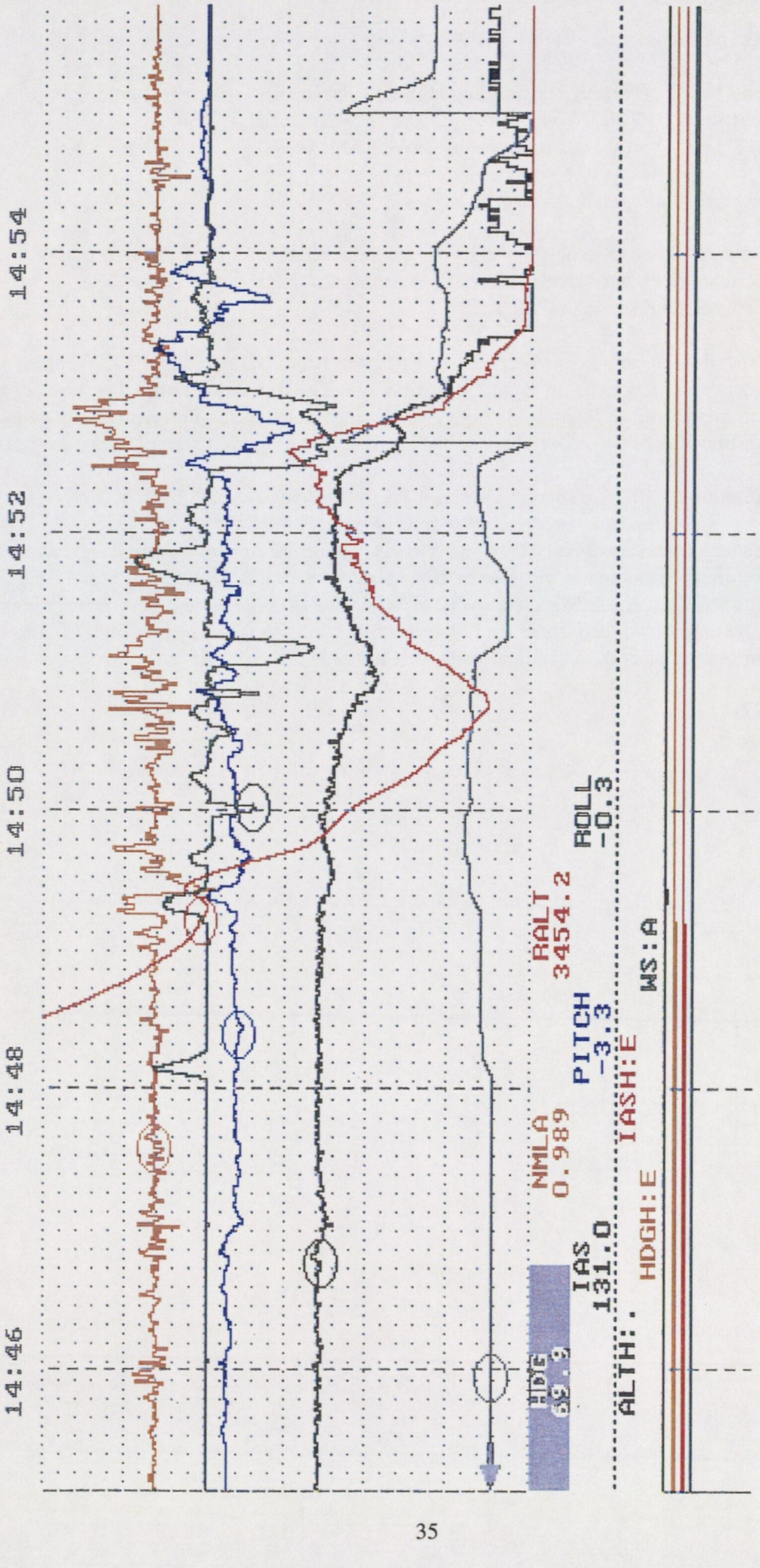
Events 22C and 22A trigger on the descent into Sola. The maximum calculated rate of descent below 500 ft was 1,630 ft/min, occurring at an altitude of 467 ft. With the exception of one training flight, this is the greatest event 22A maximum value recorded in the data set. (N.B. The barometric and radio altitude time histories correlated, therefore the RALT data is not being distorted by terrain effects).

The aircraft makes a number of sharp turns, triggering roll attitude and roll rate events. The greatest calculated roll rate is 21.1 deg/sec. This is the greatest event 21D threshold exceedance and, as can be seen from the histogram in Figure 4.3 at the end of the section, is significantly above the upper tail of the distribution of event 21D maximum values. The maximum recorded roll angle is 39.4 deg, which again is the highest value measured in the data set.

Rapid pitch changes have triggered events 20E and 23B, with normal acceleration varying from 0.72g to 1.38g.

Comments:

The aircraft was on a positioning flight and was therefore not carrying any passengers. It is generally accepted that such flights provide pilots with an opportunity for making greater use of available aircraft performance and manoeuvrability with more aggressive flying. Had the events described above been triggered on a revenue flight, these would have been a cause for concern.


14:46
14:48
14:50
14:52
14:54
HDG
69.9
IAS
131.0
NMLA
0.989
PITCH
-3.3
RALT
3454.2
ROLL
-0.3
ALTH:.
HDGH:E
IASH:E
WS:A

Flight No: 10

4.1.4.4 Flight No: 11

From/To: Hutton Tension Leg (Fixed) – Aberdeen
Event(s): 20E High Pitch Rate above 500 ft AGL
7A Low Airspeed above 500 ft AGL

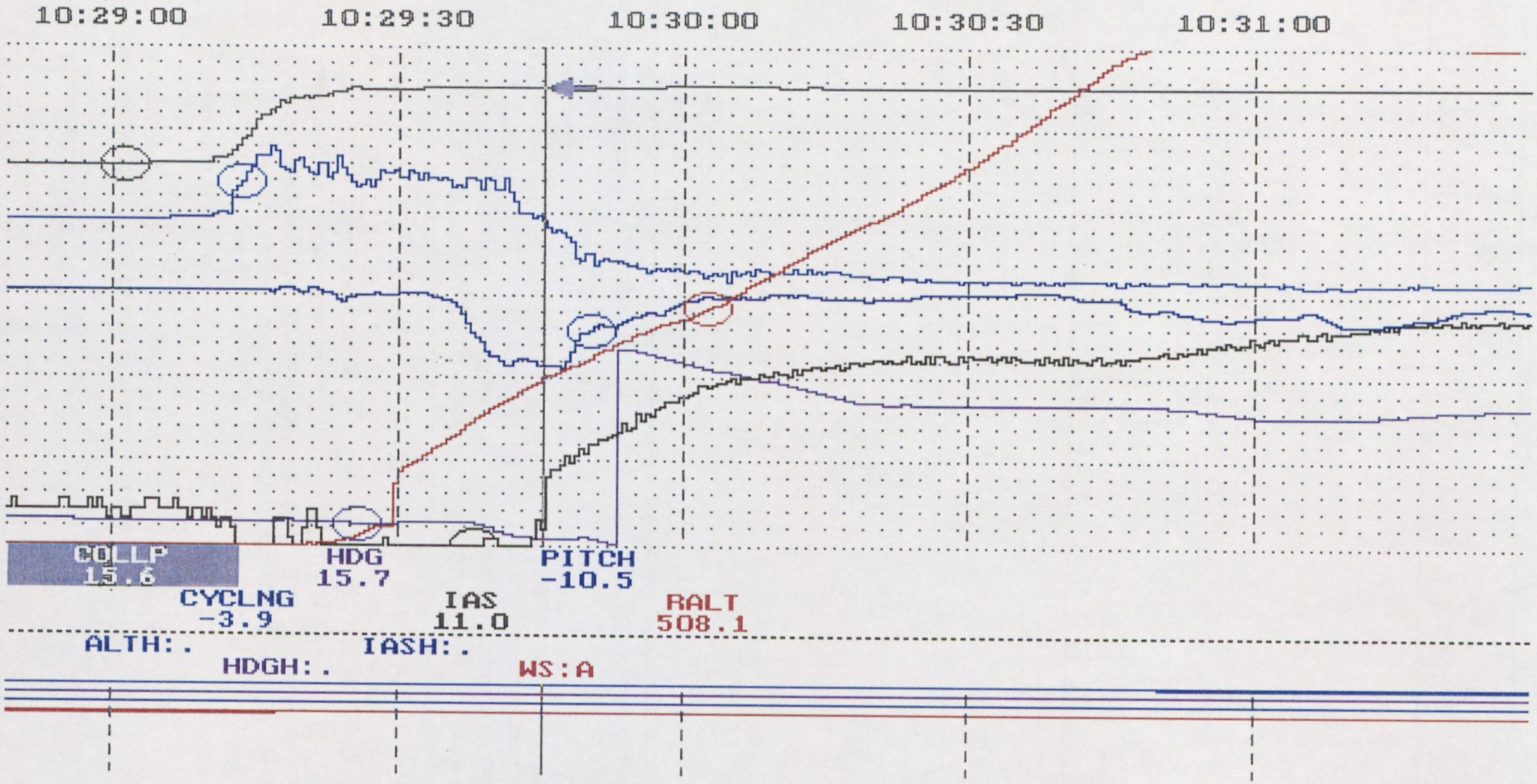
Description of event:

Following take-off from the rig the aircraft climbs to 510 ft before gaining any significant forward speed, triggering event 7A. The aircraft then makes a turn and departs in the direction of Aberdeen.

On the final approach to Aberdeen (not shown), the aircraft stops its descent at 610 ft and enters a hover, again triggering event 7A. The aircraft then pitches nose down to recommence the descent to landing, triggering event 20E. The maximum calculated pitch rate was 5deg/sec, which was the highest value found in the data set above 500 ft.

Comments:

The behaviour described above is clearly abnormal for a standard revenue flight, therefore the detected events can be considered to be valid. However it is not uncommon for aircraft to be used to photograph rigs for the oil companies. It is probable that in this example the departure and arrival flight profiles were modified to allow for photography of both the rig and Aberdeen.



10:29:00
10:29:30
10:30:00
10:30:30
10:31:00
COLLP
15.6
HDG
15.7
PITCH
-10.5
CYCLNG
-3.9
IAS
11.0
RALT
508.1
ALTH:.
IASH:.
HDGH:.
WS:A

Flight No: 11

4.1.4.5 Flight No: 12

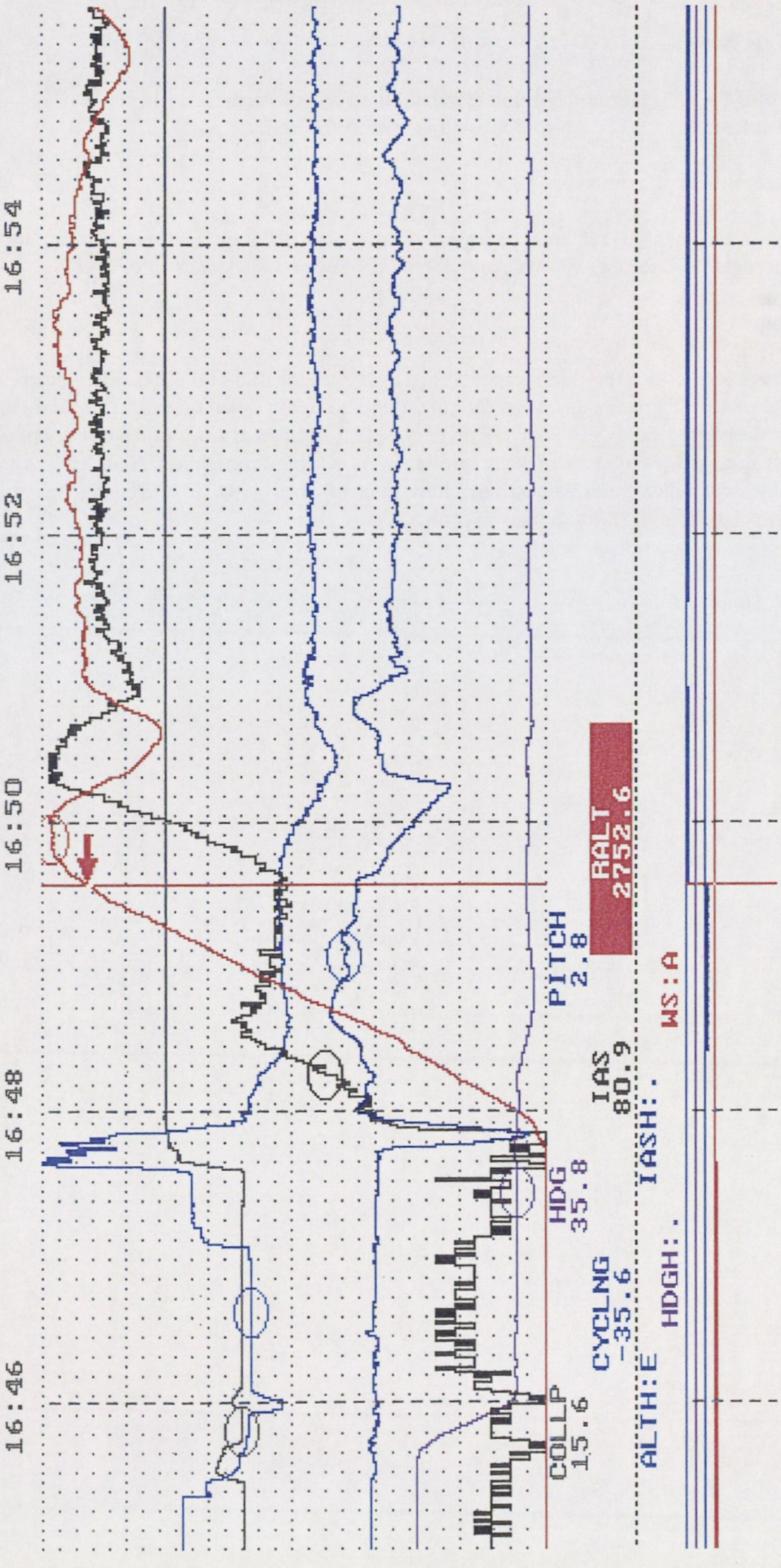
From/To: Aberdeen – North Cormorant (Fixed)
Event(s): 22C High Rate of Descent above 500 ft AGL

Description of event:

Following take-off from Aberdeen the aircraft enters a climb and accelerates to 80 knots, at which point the airspeed hold is engaged. The aircraft continues to climb at constant speed. At an altitude of 2,750 ft, whilst still in the climb, the altitude hold is engaged, disengaging the airspeed hold. The autopilot appears to push the stick forward to arrest the climb, the aircraft stops climbing, pitches to an attitude of 9 deg nose down and starts rapidly descending and accelerating to 149 knots. This triggers event 22C, with a maximum calculated rate of descent of 2046 ft/min. The stick is pulled back and, after descending over 600 ft, the aircraft starts climbing again and decelerating. The altitude hold is then disengaged and the aircraft stabilised at a height of 2,800 ft and speed of 135 knots. The altitude hold is finally re-engaged.

Comments:

Although it is only conjecture, this is a possible example of mismanagement of the altitude hold, with this being engaged too early, i.e. whilst the aircraft was still climbing at a significant rate.


16:46
16:48
16:50
16:52
16:54
COLLP 15.6
CYCLNG -35.6
HDG 35.8
IAS 80.9
PITCH 2.8
RALT 2752.6
ALTH:E
HDGH:.
IASH:.
WS:A

Flight No: 12

4.1.4.6 Flight No: 13

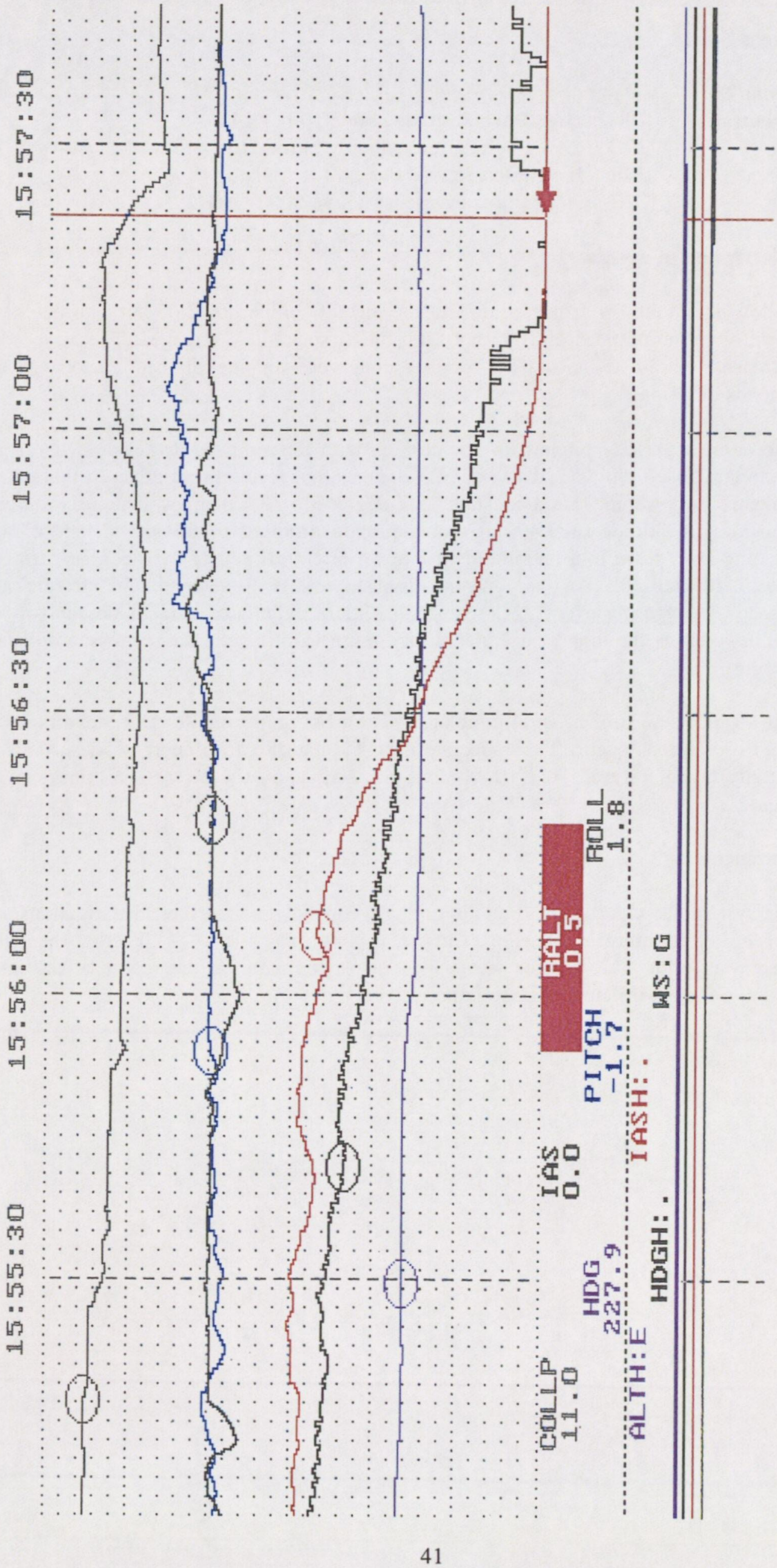
From/To: Hermod (Mobile derrick barge) – Aberdeen
Event(s): 80 Autopilot Engaged below 70 knots

Description of event:

The altitude hold remains engaged all the way through the descent to landing at Aberdeen, triggering event 80, and is only disengaged 8 seconds after landing.

Comments:

It is possible that the pilot forgot to disengage the altitude hold before commencing the descent to Aberdeen and was fighting this throughout the descent. The data may be highlighting a fairly common occurrence – that aircrew try to descend with the altitude still engaged. Whilst there were probably no serious consequences in this case, fixed wing experience has demonstrated how lack of awareness of currently engaged flight control system modes can cause accidents.


15:55:30
15:56:00
15:56:30
15:57:00
15:57:30
COLLP 11.0
HDG 227.9
IAS 0.0
PITCH -1.7
RALT 0.5
ROLL 1.8
ALTH:E
IASH:.
HDGH:.
WS:G

Flight No: 13

4.1.4.7 Flight No: 14

From/To: -

Event(s): 20C High Pitch Attitude above 20 ft AGL
20D Low Pitch Attitude above 20 ft AGL
20E High Pitch Rate above 500 ft AGL
22C High Rate of Descent above 500 ft AGL

Description of event:

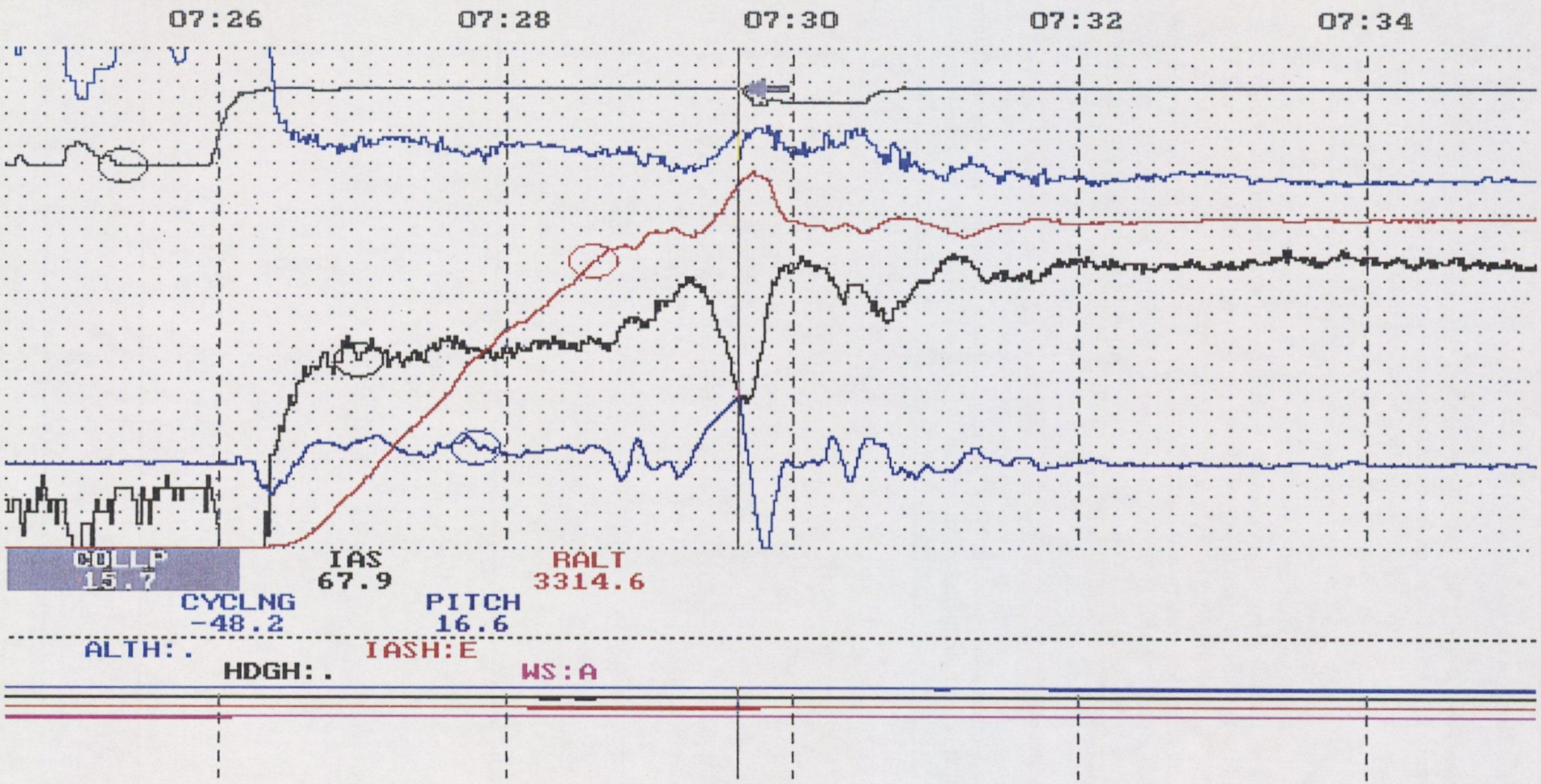
Following a take off from an airfield the aircraft climbs to 2,850 ft and enters level flight, with an airspeed of 100 knots and the airspeed hold engaged. The airspeed then increases to 120 knots and the aircraft undergoes an unexplained manoeuvre of 50 seconds duration.

The aircraft initially pitches up and climbs, with the airspeed decreasing. It reaches a maximum nose-up pitch attitude of 16.7 degrees, triggering event 20C. At this point the collective is lowered from a constant 15.7 degrees to 13.6 degrees. The aircraft reaches a maximum altitude of 3,400 ft and minimum airspeed to 66 knots, before rapidly pitching nose down to a maximum nose down pitch attitude of 21.4 degrees, triggering events 20D and 20E. At this point the airspeed hold is disengaged. The aircraft rapidly descends, triggering event 22C with a maximum calculated rate of descent of 3,450 ft/min – this is the highest calculated maximum value in the data set by a substantial margin.

The aircraft stabilises at an altitude of 2,970 ft, but some smaller altitude, airspeed and pitch oscillations occur. The collective is raised back to 15.6 degrees 53 seconds after initially being lowered. The oscillations die away and the aircraft continues in level flight.

Comments:

The system has clearly found an abnormal event, however further investigations would be required to interpret this. For example, it is not possible to say whether the detected event was pilot, autopilot or weather induced. It might be the result of the aircraft hitting a violent up-current or standing wave.



07:26
07:28
07:30
07:32
07:34
COLLP
15.7
IAS
67.9
RALT
3314.6
CYCLNG
-48.2
PITCH
16.6
ALTH:.
IASH:E
HDGH:.
WS:A

Flight No: 14

4.1.4.8 Flight No: 15

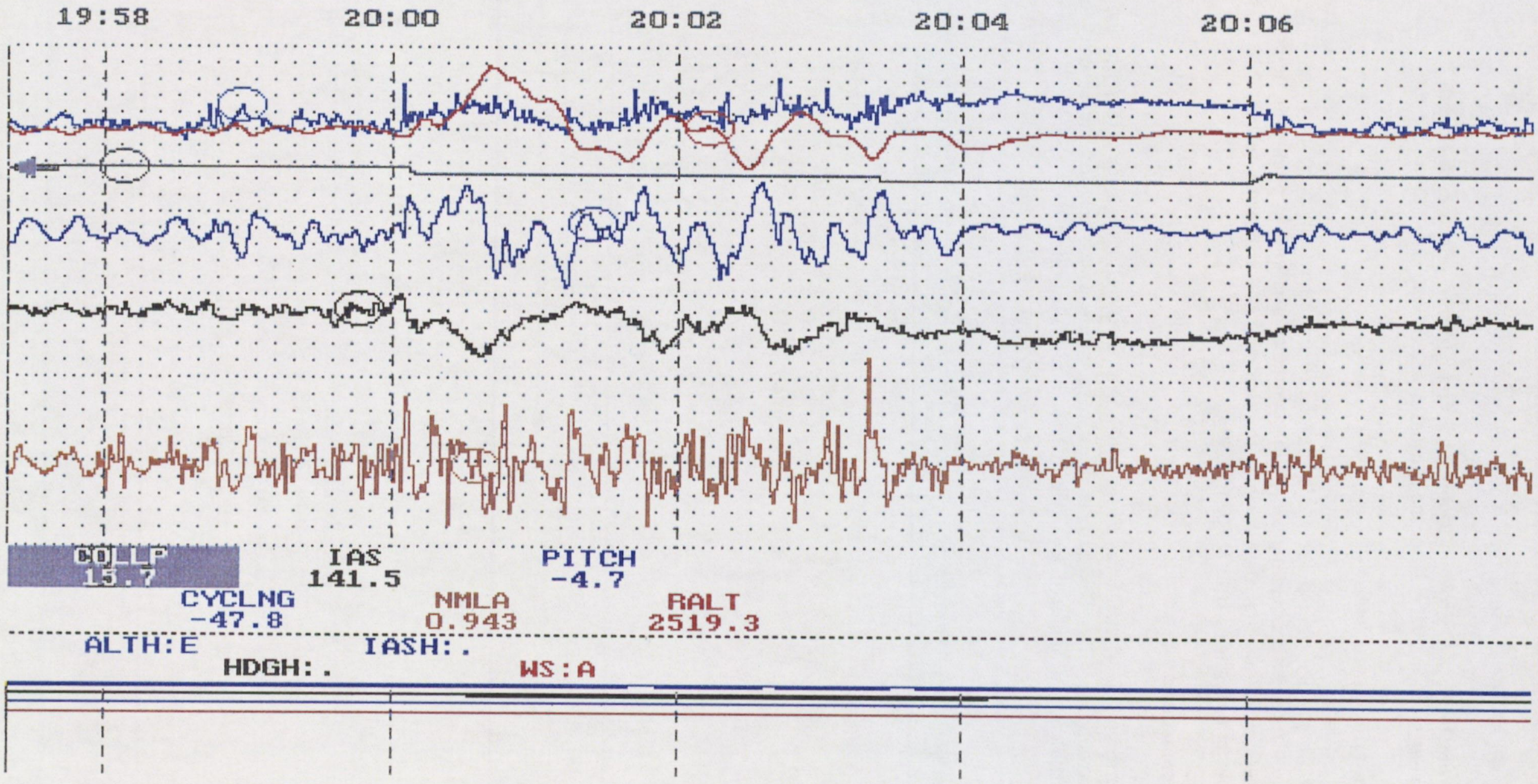
From/To: Drill Star (Mobile semi sub) – Aberdeen
Event(s): 22C High Rate of Descent above 500 ft AGL
20E High Pitch Rate above 500 ft AGL
23B Airborne Normal Acceleration (max)

Description of event:

During level flight with the altitude hold engaged the aircraft undergoes a period of rapid variations in altitude, airspeed and pitch attitude, triggering events 22C, 20E and 23B. The altitude hold is disengaged 3 times, coincident with 3 minima in the altitude trace. Altitude varies from 2,300 to 2,900 ft, airspeed from 115 knots to 150 knots, and pitch attitude from 11 degrees nose down to 5 degrees nose up. Normal acceleration varies from 0.63g to 1.66g, with these variations correlating with the pitch attitude changes.

Comments:

The aircraft appears to be flying through turbulence, and possibly has an altitude hold which is not functioning effectively.


19:58
20:00
20:02
20:04
20:06
COLLP
15.7
IAS
141.5
PITCH
-4.7
CYCLNG
-47.8
NMLA
0.943
RALT
2519.3
ALTH:E
IASH:.
HDGH:.
WS:A

Flight No: 15

4.1.4.9 Flight No: 16

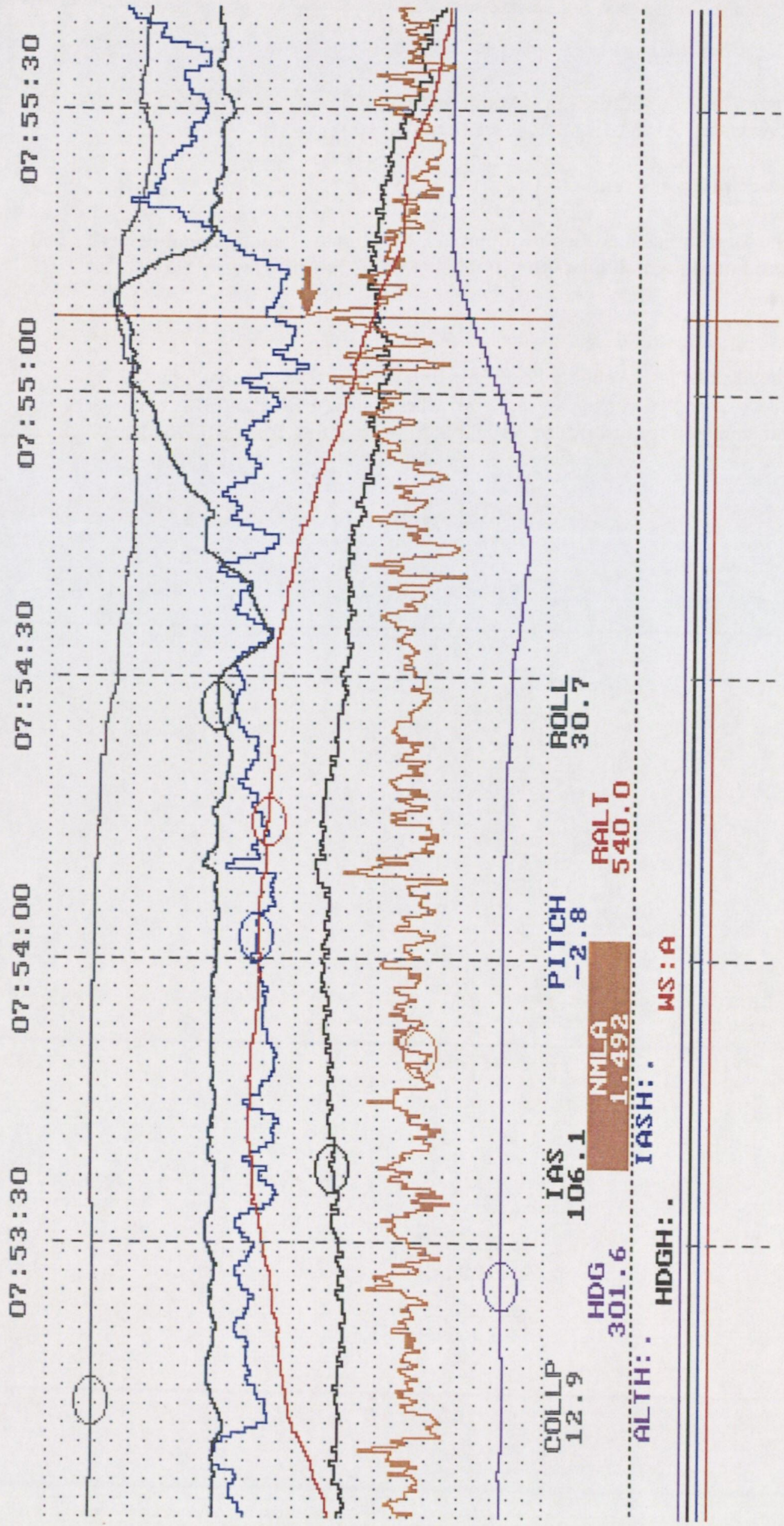
From/To: C Provine (Mobile jack-up platform) – Beatrice A (Fixed)
Event(s): 23B Airborne Normal Acceleration (max)

Description of event:

The manually entered sector details record that the flight is taking place in severe turbulence. This is highlighted by the constant variations in pitch attitude and normal acceleration during the descent to Beatrice A, triggering event 23B. Normal acceleration varied from 0.76g to 1.49g.

Comments:

Beatrice A is in the Moray Firth, which is an area well known for turbulence due to the surrounding hills. The data enables an accurate assessment of the severity of any turbulence encountered, and its effects on aircraft handling.


07:53:30
07:54:00
07:54:30
07:55:00
07:55:30
COLLP 12.9
HDG 301.6
IAS 106.1
NMLA 1.492
PITCH -2.8
RALT 540.0
ROLL 30.7
ALTH:.
HDGH:.
IASH:.
WS:A

Flight No: 16

4.1.4.10 Flight No: 17

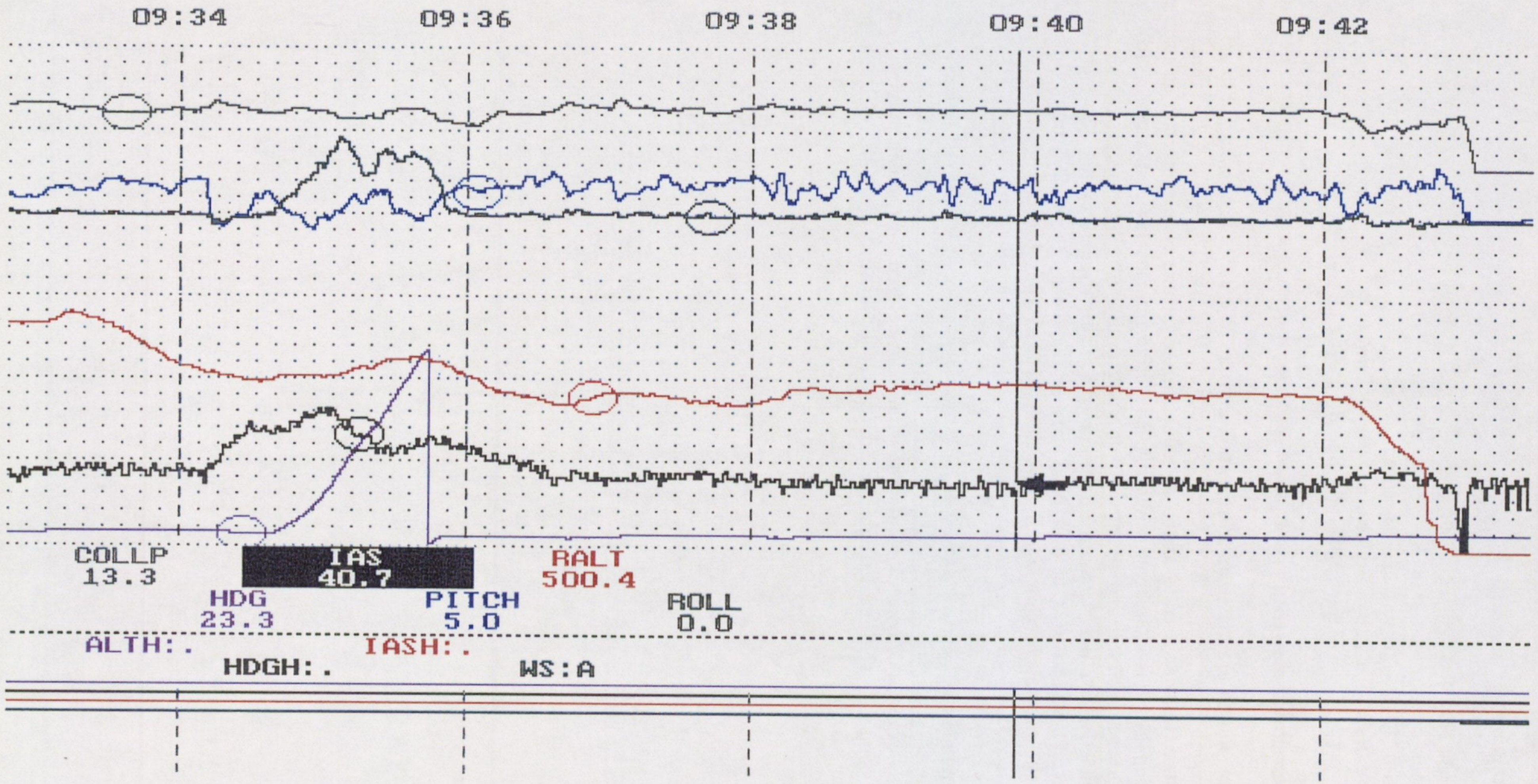
From/To: Sumburgh – Magnus (Fixed)
Event(s): 7A Low Airspeed above 500 ft AGL

Description of event:

The aircraft has made a slow approach to Magnus, maintaining a height of 500 ft and a speed of around 40 knots for 10 minutes. This has triggered event 7A.

Comments:

The aircraft has probably been forced to make a slow approach due to other traffic. The data was recorded over 8 years ago, when the East Shetland Basin was very busy and it was common for aircraft to be held at 500 ft waiting for traffic to clear.


09:34
09:36
09:38
09:40
09:42
COLLP
13.3
IAS
40.7
RALT
500.4
HDG
23.3
PITCH
5.0
ROLL
0.0
ALTH:.
IASH:.
HDGH:.
WS:A

Flight No: 17

4.1.5 **Training**

4.1.5.1 Flight No: 18

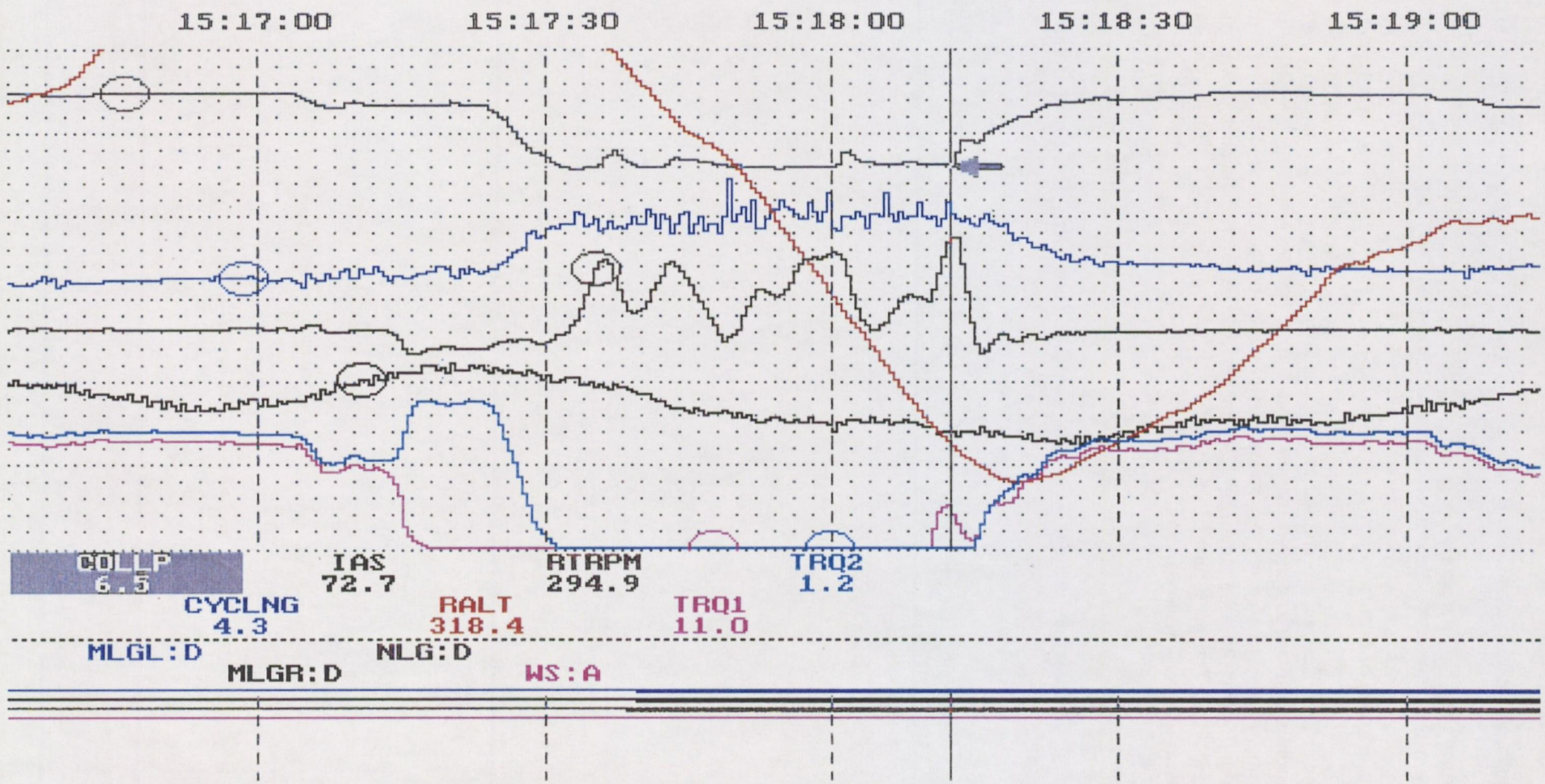
From/To: Longside – Aberdeen
Event(s): 72B High Rotor Speed – Power On
73B High Rotor Speed – Power Off

Description of event:

The pilot is practising an autorotation and the aircraft is descending with zero engine torque. Rotor rpm is fluctuating between approximately 265 and 290 rpm, with the collective being used to control this. Just before the end of the autorotation some power is applied to No.1 engine whilst the collective remains lowered. Engine No.1 torque increases to 14% and the rotor rpm rises rapidly to 295 rpm, at which point the collective is raised to control the rotor rpm. This triggers events 72B and 73B, and would have activated the overspeed alarm in the cockpit (set to 290 rpm). However the flight manual maximum transient limit of 310 rpm for power-off flight was not exceeded.

Comments:

This example demonstrates how the data could be used for training purposes, enabling a comprehensive post flight de-brief with a detailed analysis of each practice manoeuvre.


15:17:00
15:17:30
15:18:00
15:18:30
15:19:00
COLLP
6.5
IAS
72.7
RTRPM
294.9
TRQ2
1.2
CYCLNG
4.3
RALT
318.4
TRQ1
11.0
MLGL:D
NLG:D
MLGR:D
WS:A

Flight No: 18

4.1.5.2 Flight No: 19

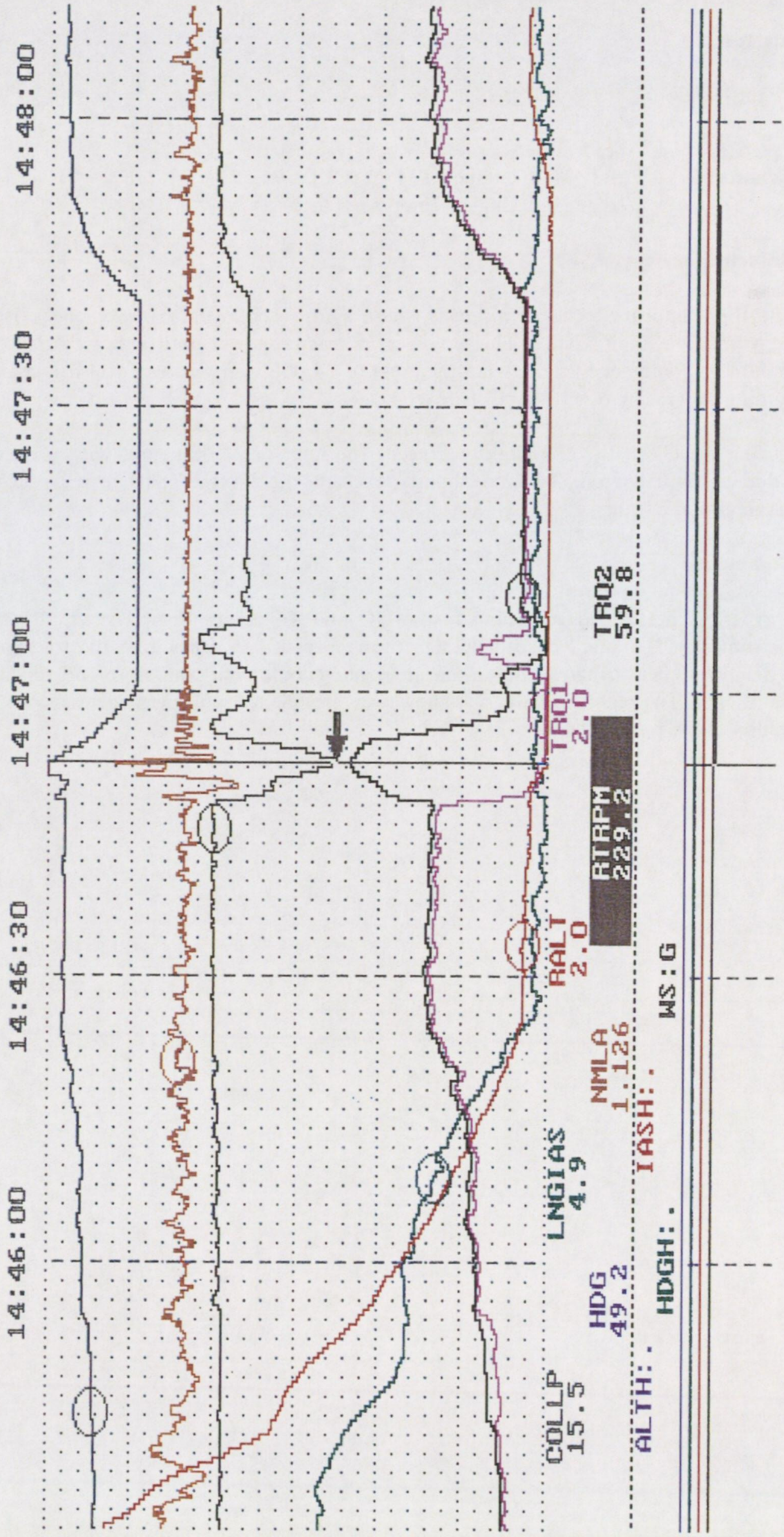
From/To: Aberdeen – Longside
Event(s): 72A Low Rotor Speed – Power On

Description of event:

The aircraft descends to a hover at 10-15 ft, a No. 1 engine failure is then simulated. It can be seen that No.2 engine torque immediately increases, and the collective is raised from 14.5 deg to 16.4 deg as the aircraft descends to the ground. The rotor rpm drops from 266 rpm to a minimum of 229 rpm just as the aircraft touches down, triggering event 72A. The peak normal acceleration on landing is only 1.13g, so the pilot has managed a very gentle landing!

Comments:

As for the previous example, the data would be very useful for a post training flight debrief.


14:46:00
14:46:30
14:47:00
14:47:30
14:48:00
COLLP 15.5
HDG 49.2
LNGIAS 4.9
NMLA 1.126
RALT 2.0
RTRPM 229.2
TRQ1 2.0
TRQ2 59.8
ALTH: .
HDGH: .
IASH: .
WS: G

Flight No: 19

4.1.6 **Air test**

4.1.6.1 Flight No: 20

From/To: Aberdeen – Aberdeen
Event(s): 76B2 High engine RPM #2 (OEI)
77B2 High Engine Temp #2 (OEI)

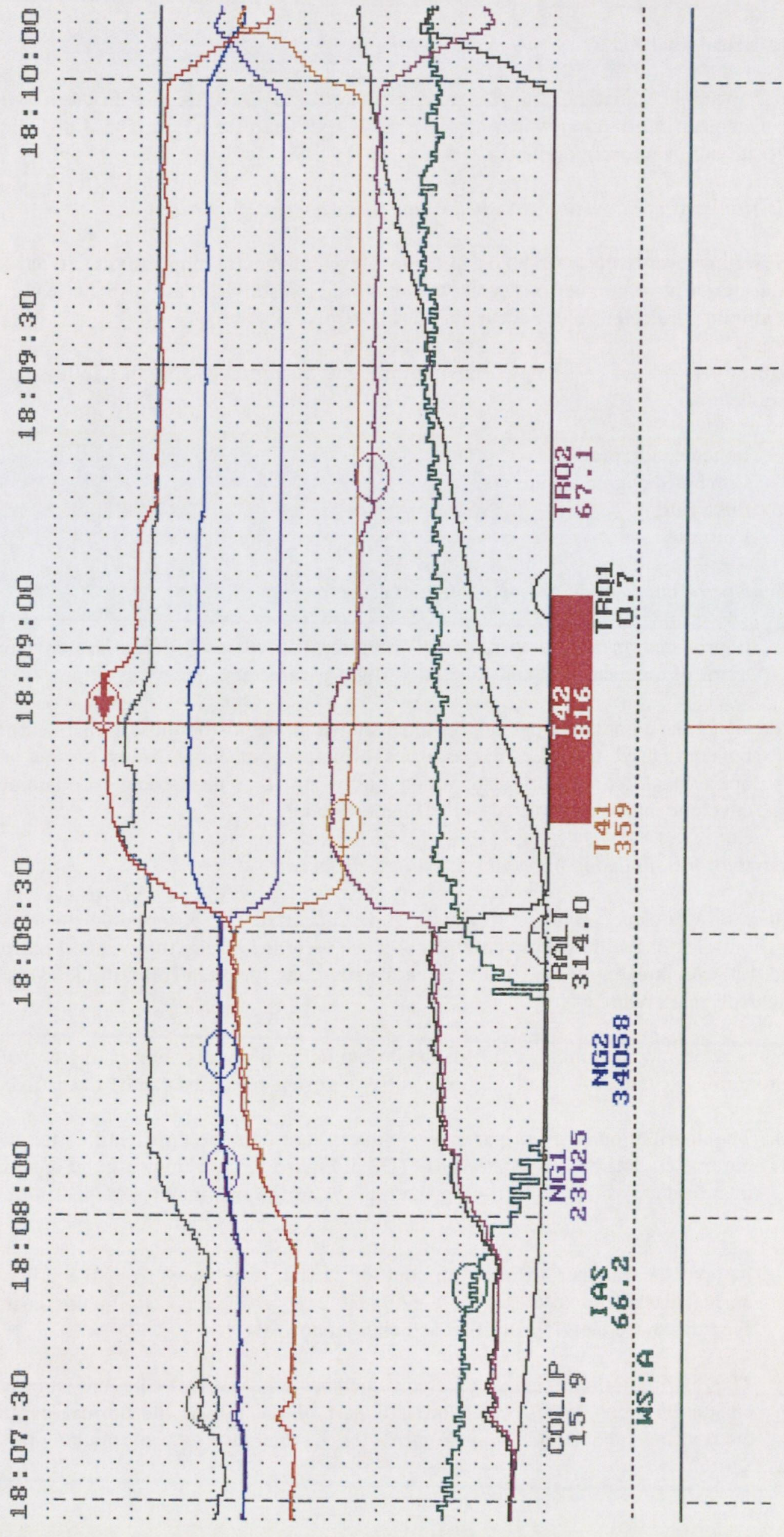
Description of event:

The flight appears to be an air test, where a max contingency power check is being performed on Engine No.2. This involves increasing power until either the NG O.E.I. maximum contingency rating (2.5 minutes) of 34,000 rpm, or the T4 O.E.I. maximum contingency rating of 810 degC, is reached.

During the check the NG slightly exceeds the limit of 34,000 rpm, with a maximum value of 34,058 rpm. T4 also slightly exceeds the limit of 810 degC, reaching a maximum of 816 deg.

Comments:

The test is performed according to the NG and T4 values displayed on the cockpit instruments. The small exceedances in the recorded data are within the tolerance for instrument measuring/reading accuracy, and could not therefore be considered significant. The recorded data, does however, provide a useful permanent record of the results of the power check.



18:07:30
18:08:00
18:08:30
18:09:00
18:09:30
18:10:00
COLLP 15.9
IAS 66.2
WS:A
NG1 23025
NG2 34058
RALT 314.0
T41 359
T42 816
TRQ1 0.7
TRQ2 67.1

Flight No: 20

4.2 Statistical analysis

Four example statistical analyses were performed to illustrate the different types of management information which can be readily extracted from a database of helicopter operational monitoring events.

4.2.1 *Distributions of maximum parameter values for normal operations*

By setting event rule thresholds at a low level and extracting maximum parameter values on a large number of flights, it is possible to establish data distributions for the maximum parameter values occurring during normal operations.

Figure 4.1 presents example maximum value histograms for the following four parameters:

- Indicated airspeed
- Combined engine torque
- Pitch rate
- Roll rate

This type of information has two potential uses:

(1) It provides an ability to quantify the aircraft's current operational envelope in terms of the measured and calculated flight parameters.

(2) Using the cumulative percentage plots shown on the histograms, it enables rules to be configured to detect exceedances of upper percentile limits of the normal operational parameter distribution, allowing the monitoring of operational envelope limits not covered in the Flight Manual.

4.2.2 *Distributions of maximum parameter values for events*

When a sufficient number of events have occurred, it is possible to establish distributions for the maximum parameter values recorded during the events. Figures 4.2 and 4.3 present example maximum value distributions for pitch/roll attitude events and pitch/roll rate events.

This type of information is useful for the investigation of events. For example, from the histograms in Figures 4.2 and 4.3, three different event scenarios can be identified:

(1) The distribution of event parameter values represents the upper tail of the overall parameter distribution (e.g. Event 21D2 in Figure 4.3). In this case the operational monitoring is simply identifying the top x% of the maximum recorded parameter values.

(2) An event parameter value is an 'outlier', being well away from the tail of the normal parameter distribution (e.g. Event 21D in Figure 4.3). In this case, the event has been clearly identified as being 'abnormal'.

(3) The distribution of event parameter values has an abnormal characteristic, with a cluster of event values which are not part of the tail of the normal parameter distribution (e.g. Event 21 in Figure 4.2). In this case, one particular operation

may be responsible for generating a large proportion of the occurrences of a particular event.

4.2.3 *Trends of event occurrences*

Little meaningful trend information can be extracted from a discrete data set from one year of flying by one aircraft. However, Figure 4.4 presents three example trend plots to illustrate the potential value of trend information for the management of operations.

The upper trend plot shows the number of sectors flown in four three-month periods during the year of operation. It can be seen that the operational tempo is fairly constant for most of the year, but with an increase in the September-November period.

The middle trend plot shows the number of sectors with occurrences of 'low airspeed above 500 ft' events. It can be seen that there is a large increase in events the September-November period. Although it is only speculation, this large increase may be caused by Air Traffic Control delays due to an increase in the volume of traffic in this period. If so, this would be useful management information.

The lower trend plot shows the occurrences of 'high normal acceleration' events. Here the trend is a 'bath tub' curve, with increased rates of occurrences in the December-February and September-November periods, and a low level of occurrences in the June-August period. It is clear that the occurrences of high normal acceleration events are weather related, with increases due to increased levels of air turbulence in the winter months.

4.2.4 *Ranking of events by number of occurrences*

The final analysis performed is a ranking of events according to the number of occurrences, as shown in Figure 4.5. Obviously the number of occurrences of an event are related to the level of the event trigger threshold. With the thresholds set for this demonstration project, the actual ranking shown in Figure 4.5 is not significant. However, for an on-line system with appropriately set event thresholds, being able to identify the most frequently occurring events in a period would help management to focus on those areas where improvements in operational practices are required.

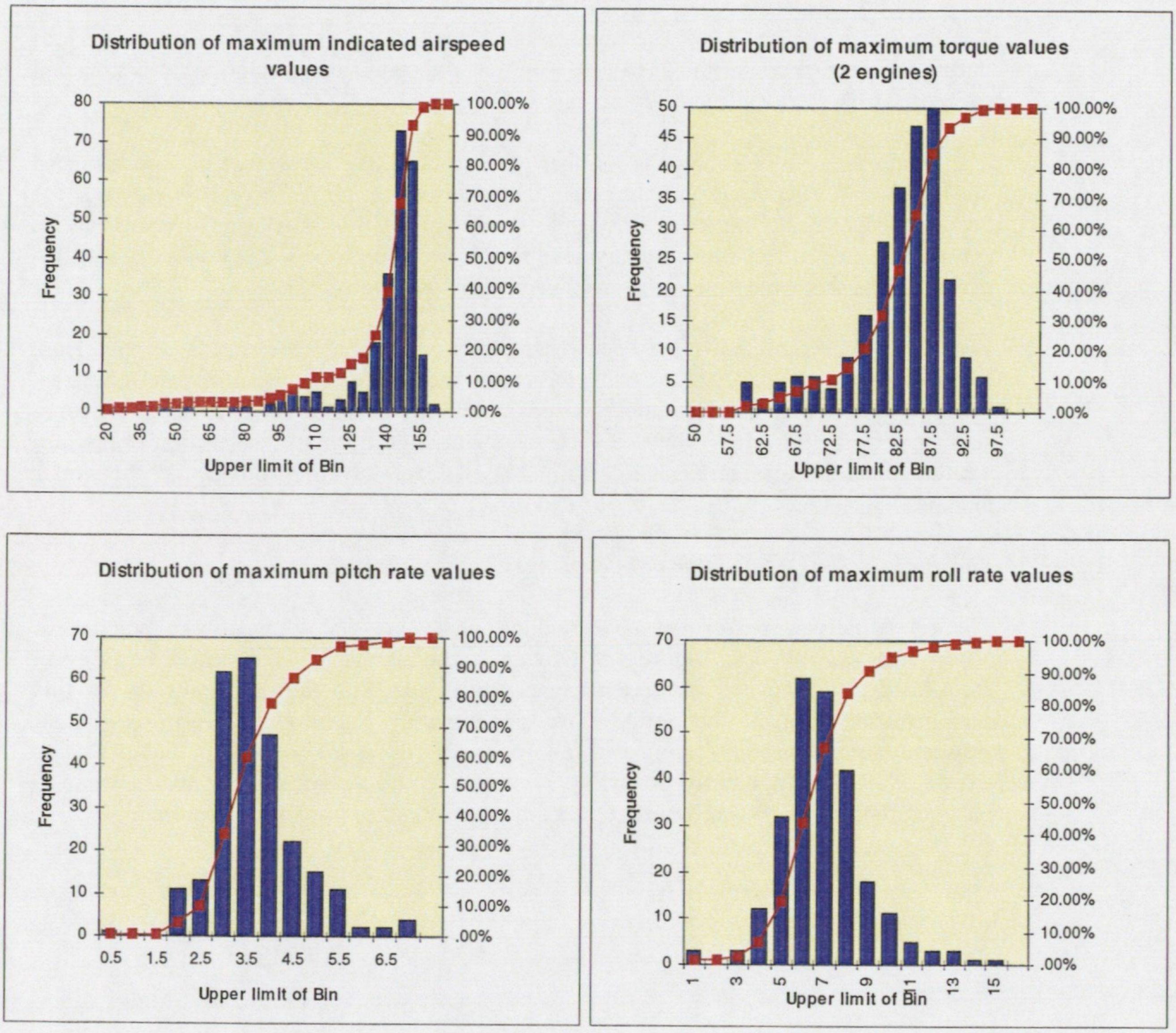

Distribution of maximum indicated airspeed values
Frequency
Upper limit of Bin
Distribution of maximum torque values (2 engines)
Frequency
Upper limit of Bin
Distribution of maximum pitch rate values
Frequency
Upper limit of Bin
Distribution of maximum roll rate values
Frequency
Upper limit of Bin

FIGURE : 4.1

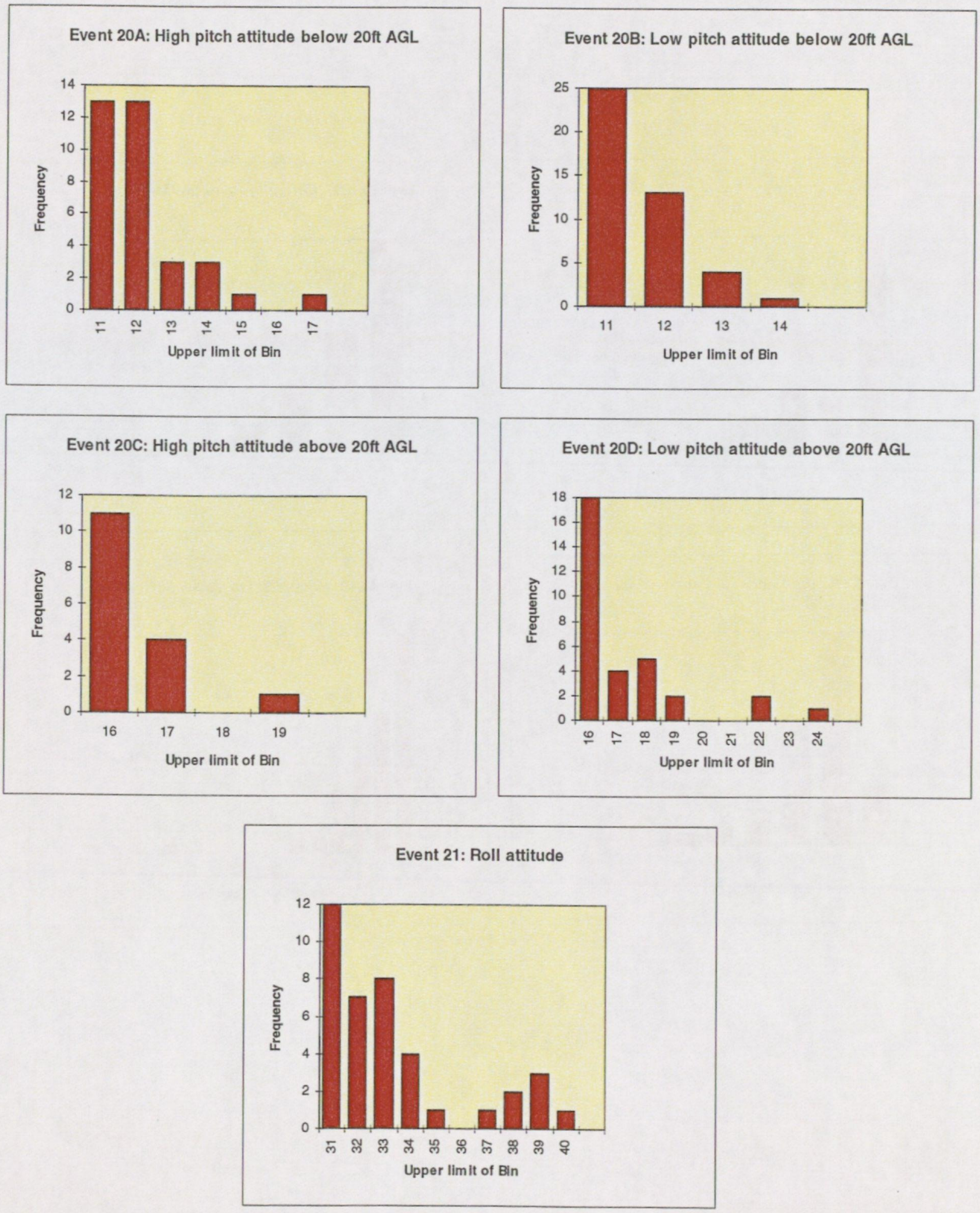
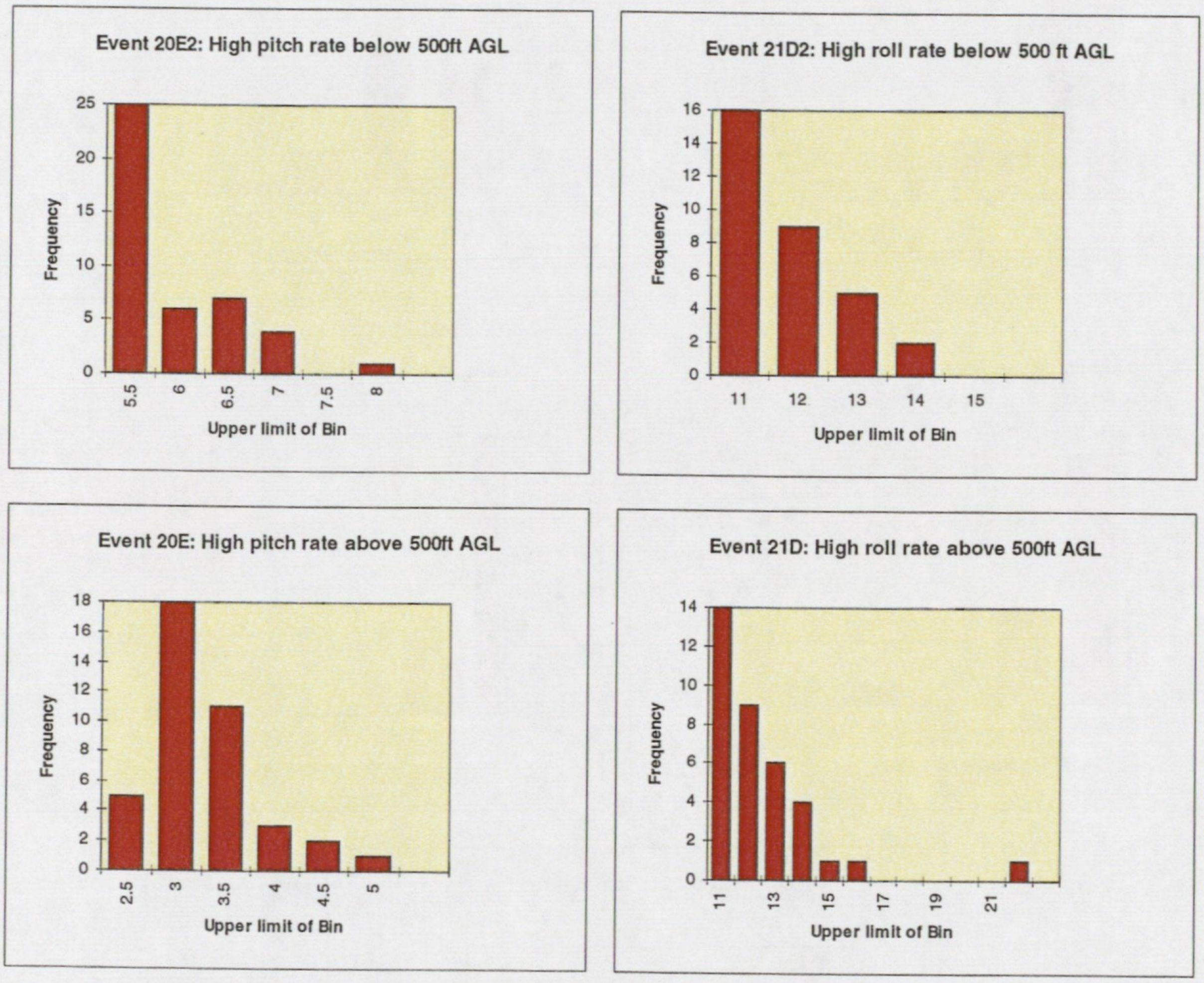
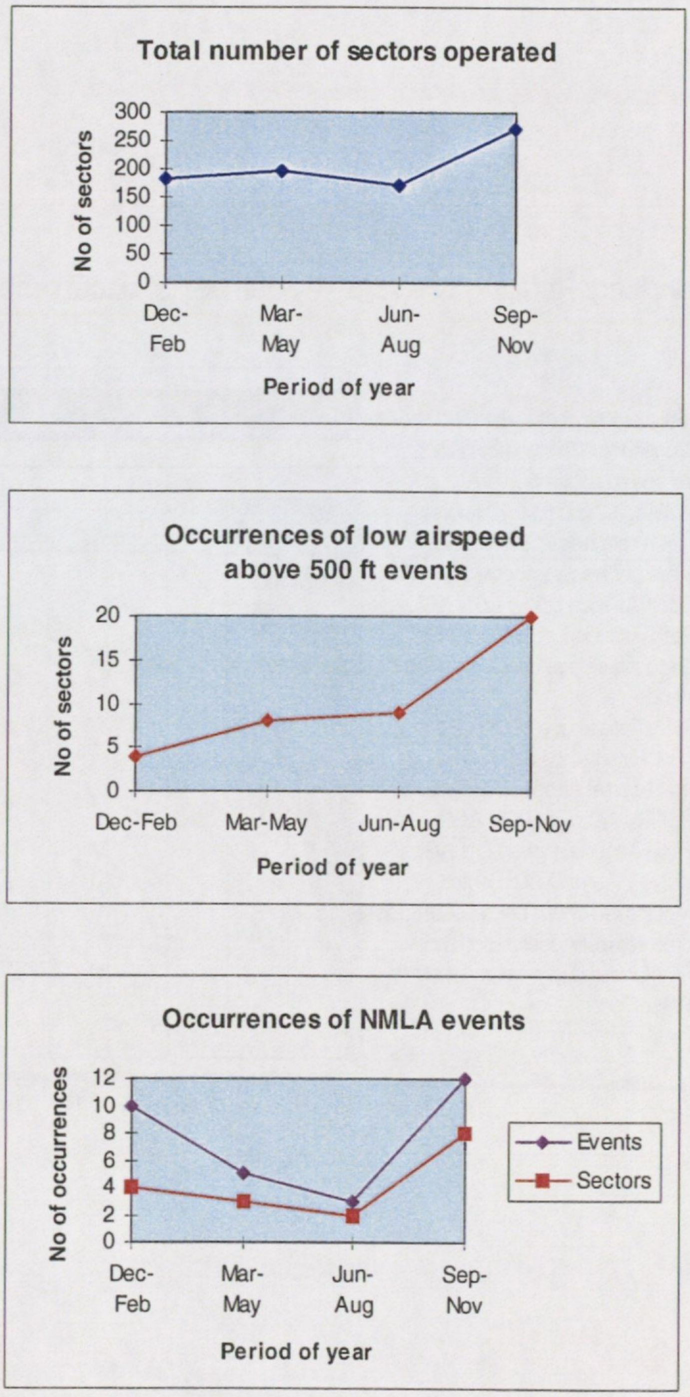

Event 20A: High pitch attitude below 20ft AGL
Frequency
Upper limit of Bin
Event 20B: Low pitch attitude below 20ft AGL
Frequency
Upper limit of Bin
Event 20C: High pitch attitude above 20ft AGL
Frequency
Upper limit of Bin
Event 20D: Low pitch attitude above 20ft AGL
Frequency
Upper limit of Bin
Event 21: Roll attitude
Frequency
Upper limit of Bin

FIGURE : 4.2



Event 20E2: High pitch rate below 500ft AGL
Frequency
Upper limit of Bin
5.5
6
6.5
7
7.5
8
Event 21D2: High roll rate below 500 ft AGL
Frequency
Upper limit of Bin
11
12
13
14
15
Event 20E: High pitch rate above 500ft AGL
Frequency
Upper limit of Bin
2.5
3
3.5
4
4.5
5
Event 21D: High roll rate above 500ft AGL
Frequency
Upper limit of Bin
11
13
15
17
19
21

FIGURE : 4.3



Total number of sectors operated
No of sectors
300
250
200
150
100
50
0
Dec-Feb
Mar-May
Jun-Aug
Sep-Nov
Period of year
Occurrences of low airspeed above 500 ft events
No of sectors
20
15
10
5
0
Dec-Feb
Mar-May
Jun-Aug
Sep-Nov
Period of year
Occurrences of NMLA events
No of occurrences
12
10
8
6
4
2
0
Dec-Feb
Mar-May
Jun-Aug
Sep-Nov
Period of year
Events
Sectors

FIGURE : 4.4

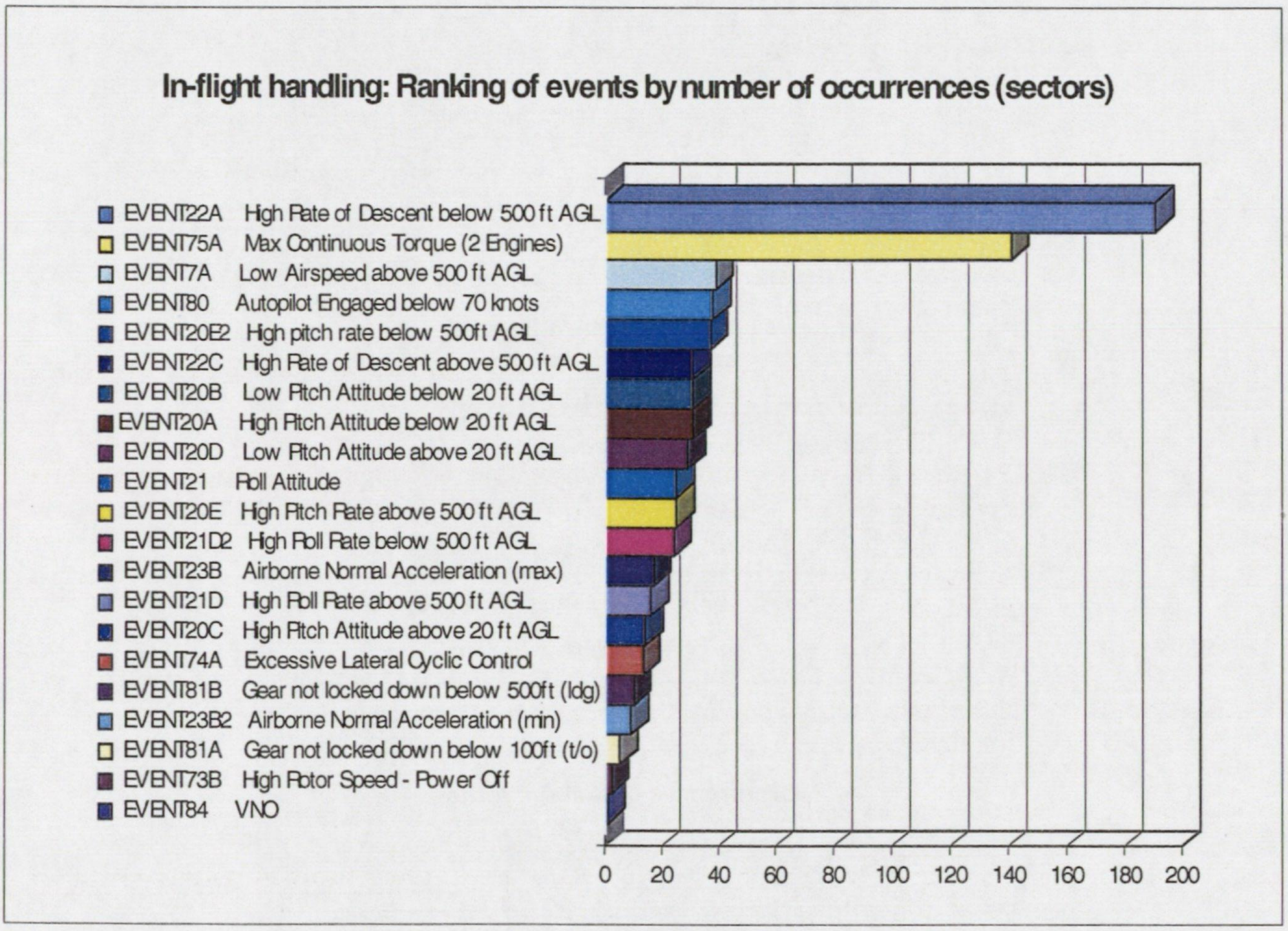

In-flight handling: Ranking of events by number of occurrences (sectors)
EVENT22A High Rate of Descent below 500 ft AGL
EVENT75A Max Continuous Torque (2 Engines)
EVENT7A Low Airspeed above 500 ft AGL
EVENT80 Autopilot Engaged below 70 knots
EVENT20E2 High pitch rate below 500ft AGL
EVENT22C High Rate of Descent above 500 ft AGL
EVENT20B Low Pitch Attitude below 20 ft AGL
EVENT20A High Pitch Attitude below 20 ft AGL
EVENT20D Low Pitch Attitude above 20 ft AGL
EVENT21 Roll Attitude
EVENT20E High Pitch Rate above 500 ft AGL
EVENT21D2 High Roll Rate below 500 ft AGL
EVENT23B Airborne Normal Acceleration (max)
EVENT21D High Roll Rate above 500 ft AGL
EVENT20C High Pitch Attitude above 20 ft AGL
EVENT74A Excessive Lateral Cyclic Control
EVENT81B Gear not locked down below 500ft (ldg)
EVENT23B2 Airborne Normal Acceleration (min)
EVENT81A Gear not locked down below 100ft (t/o)
EVENT73B High Rotor Speed - Power Off
EVENT84 VNO
0 20 40 60 80 100 120 140 160 180 200

FIGURE : 4.5

5.0 DISCUSSION OF HELICOPTER OPERATIONAL MONITORING

5.1 Benefits identified in the project

The benefits of implementing operational monitoring on fixed-wing operators have been well proven, and several of the fixed-wing benefits described in Section 2.4 would also apply to helicopters. This section comments on the benefits of helicopter operational monitoring which have been identified in the project reported here.

(1) Significant progress has been made in the improvement of helicopter airworthiness through the introduction of new health monitoring capabilities with implementation of HUM/FDR systems. The evidence in this report supports the view that parallel improvements in helicopter operational safety can be obtained by using the FDR data for helicopter operational monitoring.

(2) Safety is enhanced through improved operational awareness, with the ability to identify undesirable operating practices of which there was previously no knowledge.

(3) Helicopter operational monitoring provides continuous, real-time, operational quality control, with the ability to readily identify undesirable operational trends.

(4) The information generated by the analysis can be used to improve crew awareness of normal operating techniques and limitations

(5) Parameter traces produced from training flights would provide a useful input to a post flight de-brief, enabling a full evaluation of any practised manoeuvres.

(6) Easy access to parameter traces can assist the maintenance task, by for example aiding system troubleshooting.

(7) Much can be learned from 'normal' flying, with a new ability to quantify the operational envelope. This will provide a useful input for the on-going improvement of operational procedures.

5.2 Problems encountered in the project

Some problems and limitations were encountered during this helicopter operational monitoring project, these are briefly summarised below.

Problems/limitations encountered with the Super Puma data:

(1) There was a problem with the calibration of the tail rotor pitch data which prevented the absolute interpretation of the data in terms of actual pedal position or tail rotor blade pitch. For the purposes of the project it was assumed that the minimum tail rotor pitch value found in the data set equated to full left pedal, and the maximum value equated to full right pedal.

(2) The data from the low airspeed sensor was frequently found to be inaccurate or unreliable. As expected, the data from the standard indicated airspeed sensor was of little use below an airspeed of 40 knots. The lack of accurate low airspeed data limited the capability to detect periods of flying in the Flight Manual avoid areas.

(3) Several sectors were found to contain large amounts of bad data. In most cases these sectors were eliminated from the database.

(4) The lack of latitude/longitude position data hampered the interpretation of events by preventing tracking of the helicopter flight path, and measurement of the distance to/from a landing/take-off point at which an event occurred.

Problems/limitations encountered with the Flight Data System:

(1) The FDS has all the limitations associated with being an MS-DOS rather than a Windows program.

(2) Whilst the AFPA rule editor is easy to use, there are limitations to the sophistication of the rules which can be created.

(3) The FDS performs the flight data primary analysis task well, but the secondary analysis capabilities are limited and it is necessary to export the data to other programs for this purpose.

(4) It is not possible to import the ASCII data files created by the FDS directly into a database or spreadsheet, as the data associated with the different rule violations which occurred on a flight are merged together to create one long character string. It was therefore necessary to write a small program to convert the ASCII files into a format in which each rule violation is stored as a separate record.

(5) Because of the limitations on the volumes of data which can be analysed by the FDS at one time, it was necessary to analyse Super Puma data in 3 sets and merge the results later.

5.3 Helicopter operational monitoring implementation issues

This section identifies some of the key issues which must be considered in relation to the actual implementation of helicopter operational monitoring.

5.3.1 *Commercial issues*

Because of the differences in aircraft costs, flying rates and revenues, the implementation of operational monitoring on fixed-wing aircraft can be more easily justified on the basis of the savings achieved than it can on helicopters.

The helicopter world is extremely competitive and all operators are facing financial constraints, therefore consideration must be given to the costs of implementing helicopter operational monitoring.

Given the above two points, any practical implementation of helicopter operational monitoring should aim to maximise the financial savings which can be achieved, and minimise implementation and operating costs.

5.3.2 *Technical and operational issues*

It is more difficult to apply operational monitoring to helicopters than to fixed- wing aircraft, as fixed-wing operations are more clearly defined. For example, there is no glide path to follow on rig approaches.

To maximise the benefits of operational monitoring, this must be well targeted at the problem areas which are specific to helicopter operations.

Given the high level of manoeuvrability of a helicopter, there may be a debate between pilots, operations managers and engineers about how to define operating envelope limits for parameters for which there are no flight manual limits.

Whilst the technical feasibility of helicopter operational monitoring is not in question, there is a learning curve to be climbed in the area of the use of the results from this.

5.3.3 *Management issues*

A comprehensive implementation of helicopter operational monitoring could result in a programme with many components. The best approach may be a staged implementation, rather than trying to do everything at once.

The successful implementation of operational monitoring requires a high level of trust between pilots and management. Pilots must fully accept and participate in the programme. This implies the following requirements:

- Sensitive data must be protected by being appropriately de-identified.
- The objective of the programme should be to provide positive feedback, only in very extreme circumstances should disciplinary measures be involved.

Good management of an operational monitoring programme is essential. The ideal solution is for it to be under the control of an independent safety officer or department. To learn as much as possible from the data, following an event the safety officer should run through a flight replay with crew and allow them to talk about it.

To minimise programme costs, proper consideration must be given to the logistics of data handling prior to system implementation.

The integration of the programme with the safety reporting program BASIS, as implemented by British Airways, will need to be addressed.

5.3.4 *System implementation*

An operational monitoring programme would be implemented on helicopters equipped with HUM/FDR systems, and utilise the parameters currently recorded on the FDR. Unlike the Super Puma data analysed in this project, the FDR parameter list includes navigational data, the nature of which is dependent on the type of navigation system fitted to the particular aircraft. Separate justification would be required for any new sensors for operational monitoring, for example a low airspeed sensor.

At least for the purposes of a trial implementation, the recommended approach to operational monitoring is to use ground-based processing. It would therefore be necessary to store the FDR data on the aircraft in an easily accessible recorder, for subsequent air-ground transfer. Implementing the on-aircraft system for operational monitoring should not be a costly exercise if the proposals outlined below are adopted.

The proposed on-aircraft system implementation is based on the Stewart Hughes Limited (SHL)/Teledyne Controls HUM/FDR system fitted to helicopters operated by British International and Helicopter Service. However it is believed that the same approach would be possible for the GEC-Marconi Defence Systems (GMDS) IHUMS used by Bristow and Bond Helicopters.

On the current SHL/Teledyne HUMS/FDR the FDR data acquired by the flight data acquisition sub-system are transferred to the HUMS sub-system via an inter-CPU communications link. The HUMS then performs a decode operation to convert the FDR parameters into engineering units. Assuming ground-based processing, the proposed on-aircraft system implementation is as follows:

(1) A small HUMS software modification would be implemented to place the decoded FDR parameters into a buffer and out to a spare RS422 serial port.

(2) The FDR data would be recorded onto a compact, self contained data recorder which stores the data on industry standard Type II or II PCMCIA FLASH Memory cards. Card capacity can be selected to suit the data storage requirements, with capacities of 175 Mbytes or more now being available.

(3) A small amount of additional software would be required in the HUMS to control the process of writing the data to the card. For the SHL/Teledyne HUMS, prototype software exists for this purpose as SHL have already evaluated a PCMCIA card data recorder for HUMS.

(4) After transferring the PCMCIA card to a ground replay system, the FDR data would be downloaded via a SCSI interface which gives a high rate of data transfer (e.g. 600 Kbytes/second).

6.0 RECOMMENDATIONS

The benefits of helicopter operational monitoring which have been demonstrated in this project clearly justify taking further steps towards a programme implementation. The following recommendations are made:

A live trial of helicopter operational monitoring should be carried out with an operator to address as many as possible of the issues discussed in Section 5 prior to any full programme implementation. The key objectives of the trial should be to further demonstrate the benefits of operational monitoring, address the practicalities of a programme implementation, and investigate possible programme costs and limitations.

The live trial should utilise the on-aircraft system implementation described in Section 5.3.4. The ground based processing should be based on the same Flight Data System as used for this project.

The live trial should be preceded by a limited programme definition study to ensure that the benefits and value of the information obtained from this trial are maximised, and any negative impacts are minimised. The study would involve three main items:

(1) A consultation with helicopter operators, involving:

- A briefing on the concept of helicopter operational monitoring, and the results of this project.
- A definition of the trial programme's objectives and scope, including the numbers and types of helicopter involved.
- An analysis of the parameters to be recorded, the event rules and rule thresholds to be implemented, and the form of the outputs to be generated.
- A review of the proposed on-aircraft and ground-based system implementations.
- A discussion of the operation and management of the trial system, including the participation and support of pilots, data security, the logistics of data handling, the management and reporting of system information, and liaison with the CAA.

(2) The specification of all elements of the helicopter operational monitoring system to be trialed, including system hardware, software, operation and management.

(3) An assessment of the costs of the trial and also the estimated costs of a full implementation of helicopter operational monitoring.