Flight Data Analysis Using Limited Data Sets

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Author Biography:

Neil Campbell graduated in 1983 with a Bachelor of Engineering degree (Electronics) from the University of Western Australia. In 1986 Neil joined the Bureau of Air Safety Investigation as a flight recorder specialist. During 1998 he was a member of the ICAO Flight Recorder Panel which developed changes to ICAO Annex 6. In February 2000, Neil joined the Corporate Safety Department of Cathay Pacific Airways Limited in Hong Kong. During 2001 and 2002 he held the position of Manager Air Safety. In December 2003 he rejoined the Australian Transport Safety Bureau as a Senior Transport Safety Investigator.

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1. INTRODUCTION

The use of computer graphics to animate Flight Data Recorder (FDR) or Quick Access Recorder (QAR) information is well known. It is a valuable investigation tool as well as a powerful medium to provide communication and education. With newer aircraft the FDR or QAR will record a comprehensive range of parameters that accurately define its performance and operation. However with general aviation aircraft, most helicopters or older-generation air transport aircraft, there may be no FDR and only a limited number of parameters will be recorded by other systems. At the Australian Transport Safety Bureau (ATSB) animations have been produced using limited data sets including:

- Radar data
- Global Positioning System (GPS) data
- Electronic control unit data (eg. engine data)
- Basic FDR parameters

The case study presented in this paper is from a Bell 407 helicopter accident.
Two sources of recorded data were available for this investigation:

- Ground-based Radar data
- Onboard Electronic Control Unit (ECU) data

2. RADAR DATA

2.1 Background

Primary radar returns are produced by radar transmissions which are passively reflected from an aircraft and received by the radar antenna. The received signal is relatively weak and provides only position information. Primary radars, which are only located near capital city airports, have a nominal range of 50 NM.

Secondary radar returns are dependent on a transponder in the aircraft to reply to an interrogation from the ground. The aircraft transmits an encoded pulse train containing the secondary surveillance radar (SSR) code and other data. Pressure altitude may be encoded with these pulses. As the aircraft transponder directly transmits a reply, the signal received by the antenna is relatively strong. Consequently, an aircraft which has its transponder operating can be more easily and reliably detected by radar. Civilian secondary surveillance radars are located along the east coast of Australia to meet the operational requirement of radar coverage from 200 NM north of Cairns to 200 NM west of Adelaide. Coverage within a 200 NM radius of Perth is also required.

A transponder-equipped aircraft is not always detected by secondary radar. This could be due to one of the following reasons:

- aircraft is outside of the range of the radar
- transponder is not switched on
- transponder is unserviceable
- loss of aircraft power to the transponder
- terrain shielding
- aircraft transponder aerial is shielded from the radar due to aircraft manoeuvring

2.2 Accuracies

The radar rotates at 16.2 RPM giving a scan rate of 3.7 seconds.

The accuracy of the radar position data is proportional to the range of the aircraft from the radar site. Typical accuracies for a monopulse SSR are:

Range Accuracy	:	± 0.05 NM RMS
Azimuth Accuracy	:	± 0.05° RMS

The overall accuracy can be affected by terrain or meteorological conditions.

The Mode C Pressure Altitude data accuracy is determined by the aircraft's encoding altimeter accuracy plus the transponder quantisation of 100 feet. An encoding altimeter can suffer from lag when experiencing high vertical speed changes.

3. ECU DATA

3.1 Background

The Bell 407 was fitted with a Rolls Royce 250-C47B turbine engine. The ECU is a component of the engine Full Authority Digital Electronic Control (FADEC) system. The ECU was located forward of the main rotor transmission (refer to Figure 1).

The ECU has a non-volatile memory (NVM) that can store engine and other parameters. When it detects an exceedance it functions as an incident recorder and is designed to store 60 seconds of data commencing 12 seconds prior to the start of the exceedance.

3.2 Parameters

The following parameters were recorded:

Mnemonic:	Name:	Units:
Timestamp	Cumulative Engine Run-time	hhh:mm:ss.sss
Nr	Rotor Speed	%
Ng (N_1)	Gas Generator Speed	%
Np (N_2)	Power Turbine Speed	%
MGT	Measured Gas Temperature	°F
Q	Torque	%
Wf	Fuel Flow	pph
NDOT	Rate of change of Ng	%Ng/sec
P1	Ambient Pressure	psi
Mode	Engine Control Mode (Automatic/Manual)	1=Auto
CP	Collective Pitch	%
PLA	Power Lever Angle	Degrees
T1	Compressor Inlet Temperature	°F

Each parameter was sampled twenty-two times covering a period of 25.2 seconds.

3.3 Sampling Rate

Each parameter was sampled every 1.2 seconds. When an exceedance occurred an additional sample of each parameter was recorded.

4. TIMING OVERLAP

Radar data is time-stamped with UTC which is synchronized with UTC obtained from GPS. ECU data is time-stamped with elapsed time relative to the initiating exceedance. As these two time sources were not synchronized it was necessary to determine by other means whether an overlap of the two data sets had occurred.

The following observations were made from the radar data:

- The final radar return was recorded at 1144:45 UTC at an altitude of 2,700 feet (Mode C).
- The latitude and longitude of the final radar return was located very near the crash site (within 0.1 NM).
- The final series of returns indicated that a substantial speed had developed.
- The initial loss of returns was probably due to terrain shielding.

- The helicopter subsequently did not climb high enough for radar returns to again be received.

The following observations were made from the ECU data:

- The recording of ECU data ceased when impact occurred.

- The ECU stored data from the last 25 seconds of flight.

- Data latency was small as the engine data recorded by the ECU was directly available and not transmitted by other systems.

Considering the above observations it was considered highly likely that the radar data and ECU data did overlap in time and that the manoeuvre leading to the development of the substantial speed, initially captured by radar, was the same manoeuvre subsequently captured by the ECU.

Pressure altitude was the only common parameter and it was used to try and correlate in time the two data streams.

5. PRESSURE ALTITUDE

5.1 Radar Mode C Pressure Altitude

Pressure Altitude referenced to 1013.2 hPa was recorded with a resolution of 100 feet. The source of the pressure altitude was an altitude encoder in the helicopter. A static source provided static pressure to the encoder. Mode C pressure altitude is monitored by ATC and in comparison with the altitude derived from the ECU it was considered to be accurate but limited by resolution. Refer to Figure 2.

As the reported QNH was 1014 hPa approximately 30 feet needed to be added to the recorded Mode C values to give pressure altitude referenced to QNH.

5.2 ECU Ambient Pressure

The ECU recorded ambient pressure which was used for fuel scheduling purposes. It was sourced from an open port on the ECU itself. The port was not connected to a static pressure line. Given its location it was susceptible to pressure fluctuations due to airflow from the main rotor.

Ambient pressure is an accurate indicator of pressure altitude as long as certain assumptions are met. One assumption is that an accurate source of static pressure is available and if so standard conversions can be used to convert pressure to altitude. This assumption was not satisfied for the ambient pressure data recorded by the ECU and corrections needed to be applied to convert it to pressure altitude. Refer to Figure 3.

5.3 ECU Pressure Altitude Offset

The highest Mode C pressure altitude recorded was 3,700 feet and the highest pressure altitude obtained from the ECU was 4,370 feet. This indicated that the ECU was over-reading by at least 670 feet.

The final pressure altitude obtained from the ECU was 870 feet. Given the small data latency expected for the ECU then this value was the approximate sea-level value allowing for the sampling interval of 1.2 seconds.

6. TIMING CORRELATION

Overlaying the Mode C and ECU pressure altitude traces showed that a good match was obtained when the ECU altitude was offset by -850 feet and the end of the Mode C trace was overlapped by the start of the ECU trace. The duration of the overlap was approximately 11 seconds. The tolerance of the duration of the overlap is considered to be ± 2 seconds. Refer to Figure 4.

7. ANIMATION OF THE ECU DATA

While computer animation is recognised as being a very useful means of assimilating large quantities of information it is also very useful when analysing limited data sets such as the ECU parameters.

The ECU data was imported by the ATSB's Hewlett Packard C3000 computer for presentation using RAPS version 5.0 software. A simulated instrument panel was developed to display key parameters in real-time. Refer to Figure 5.

While the ECU sampling interval was 1.2 seconds the frame rate of the animation was much higher eg. 100 frames/sec. Intermediate values were linearly interpolated.

Torque Instrument:

The pointer and digital display were directly driven by the ECU torque data.

MGT Instrument:

After the values in degrees Fahrenheit were converted to degrees Celsius, the pointer and digital display were directly driven by the ECU MGT data.

Ng Instrument:

The pointer and digital display were directly driven by the Ng data.

Collective Display:

The pointer and digital display were directly driven by the collective data. Rolls-Royce advised that maximum collective corresponded to a recorded value of approximately 60%.

Nr/Np % RPM Instrument:

The pointer and digital display were directly driven by the Nr/Np data.

Time:

A time counter in seconds with the zero datum at the end of the ECU recording ie. at the time of impact with the water. A value of –25.2 corresponds to the start of the ECU data.

Altimeter:

The ECU ambient pressure data (psi) was converted to pressure altitude. The pressure altitude was smoothed and used to drive the display.

Vertical Speed Indicator:

Derived from the rate of change of pressure altitude.

The animation was very useful in showing the correlation between parameters eg. the relationship between Nr/Ng due to governing. These relationships are not always evident from a data listing. It also put the data into time perspective.

8. CONCLUSIONS

Non-FDR data is becoming increasingly available from accidents involving general aviation aircraft and smaller helicopters. While these aircraft do not require an FDR they are often fitted with avionics which can store data.

Analysis of this data can be very useful to an investigation. Computer animation of these limited data sets can provide valuable information that is not readily apparent from a data listing.

Data obtained from sources other than the FDR may be inaccurate and uncalibrated and require careful analysis.

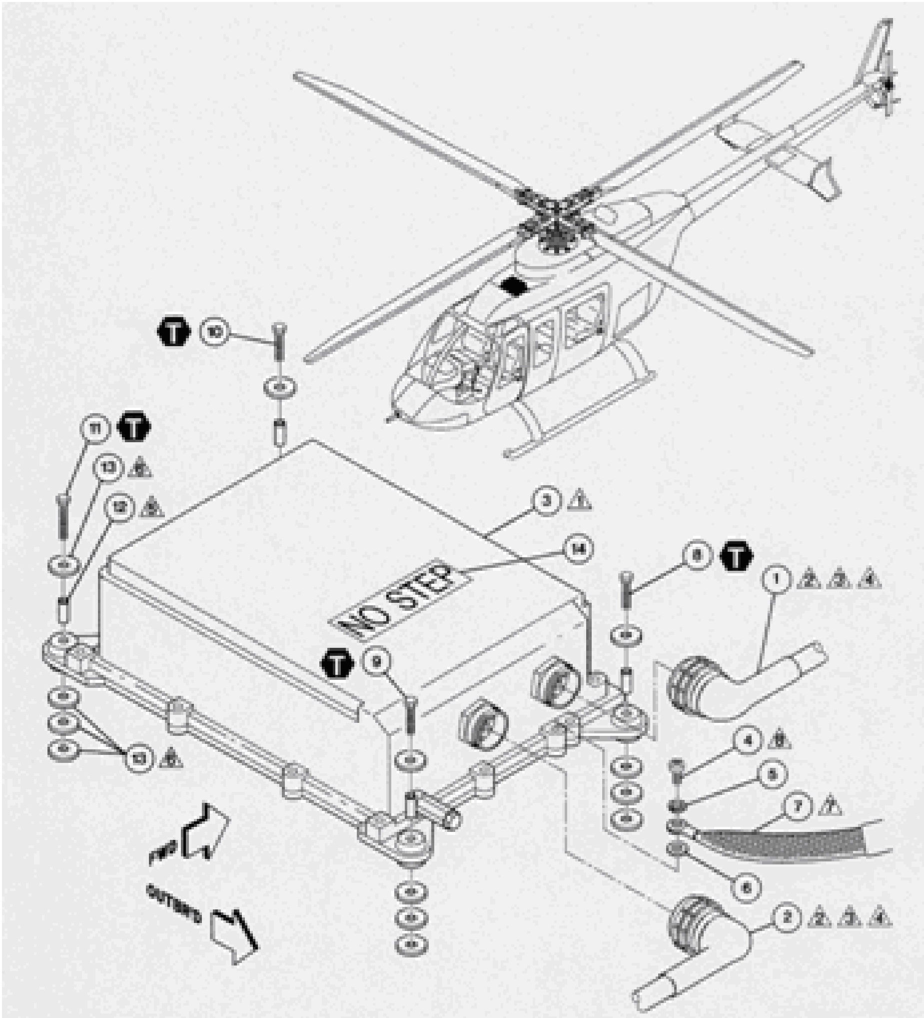

Figure 1 (1)

(1) Sourced from *"Service Bulletin 407-99-31"* Bell Helicopter Textron.

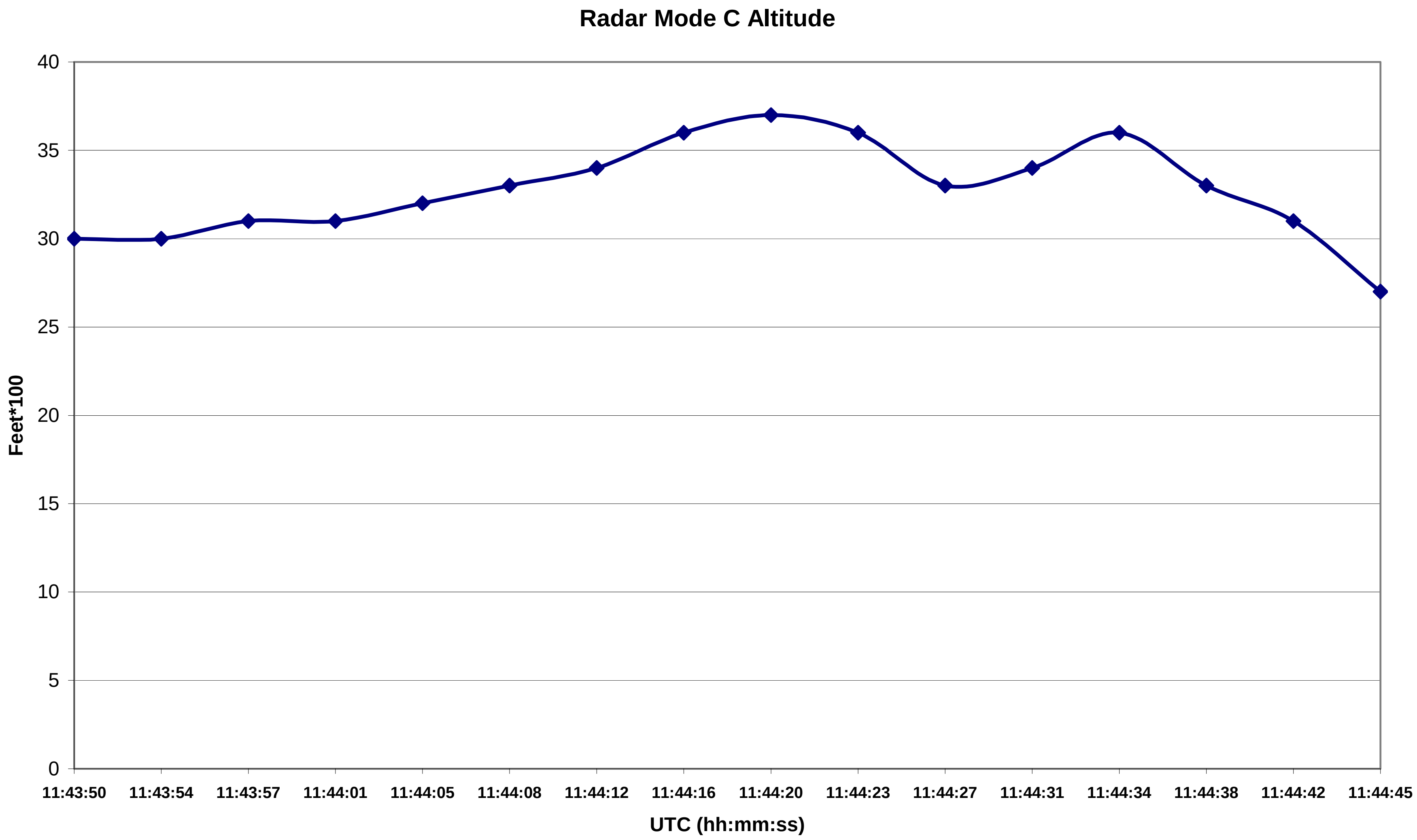
Radar Mode C Altitude
40
35
30
25
20
15
10
5
0
Feet*100
11:43:50
11:43:54
11:43:57
11:44:01
11:44:05
11:44:08
11:44:12
11:44:16
11:44:20
11:44:23
11:44:27
11:44:31
11:44:34
11:44:38
11:44:42
11:44:45
UTC (hh:mm:ss)

Figure 2

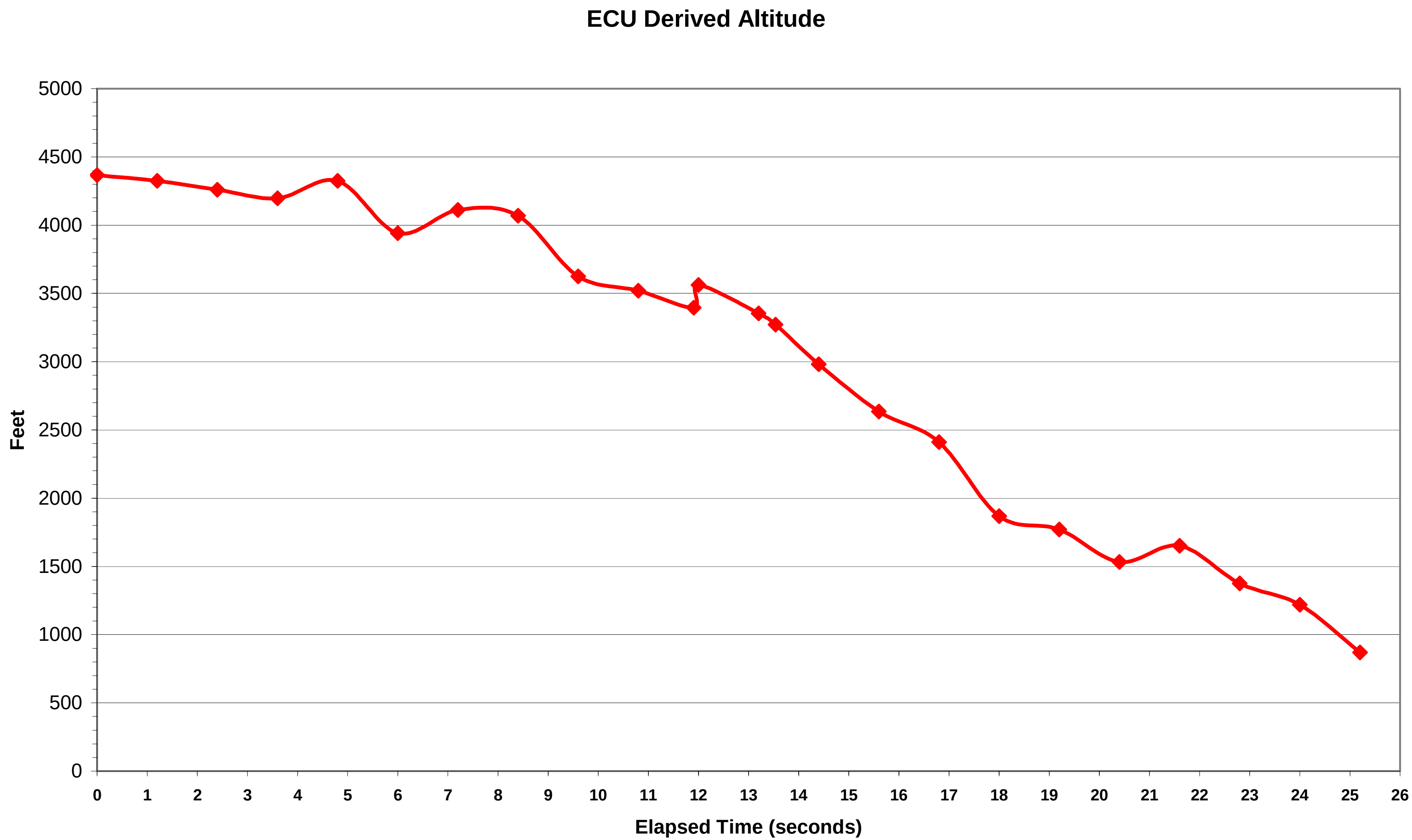
ECU Derived Altitude
Feet
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
Elapsed Time (seconds)

Figure 3

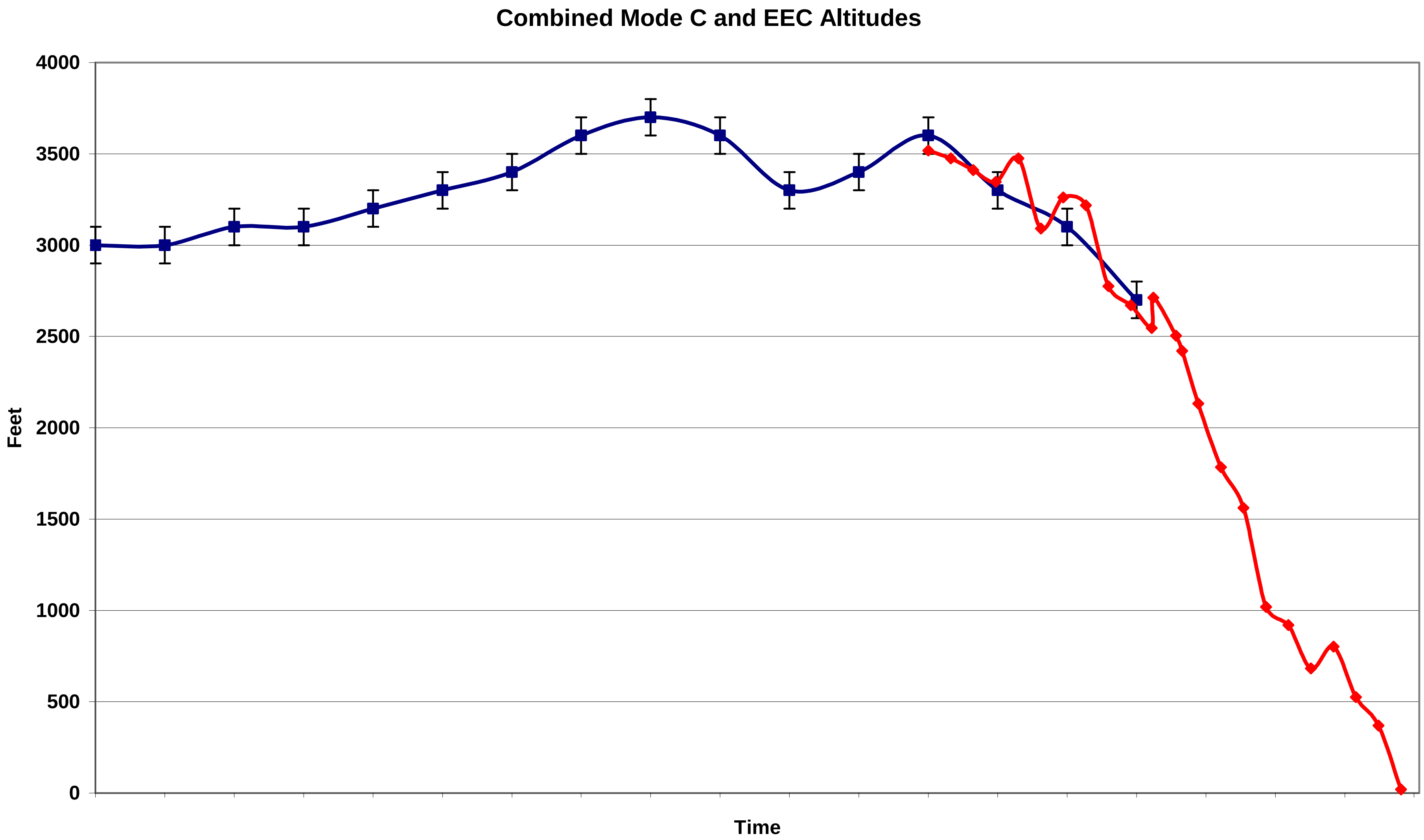
Combined Mode C and EEC Altitudes
4000
3500
3000
2500
2000
1500
1000
500
0
Feet
Time

Figure 4

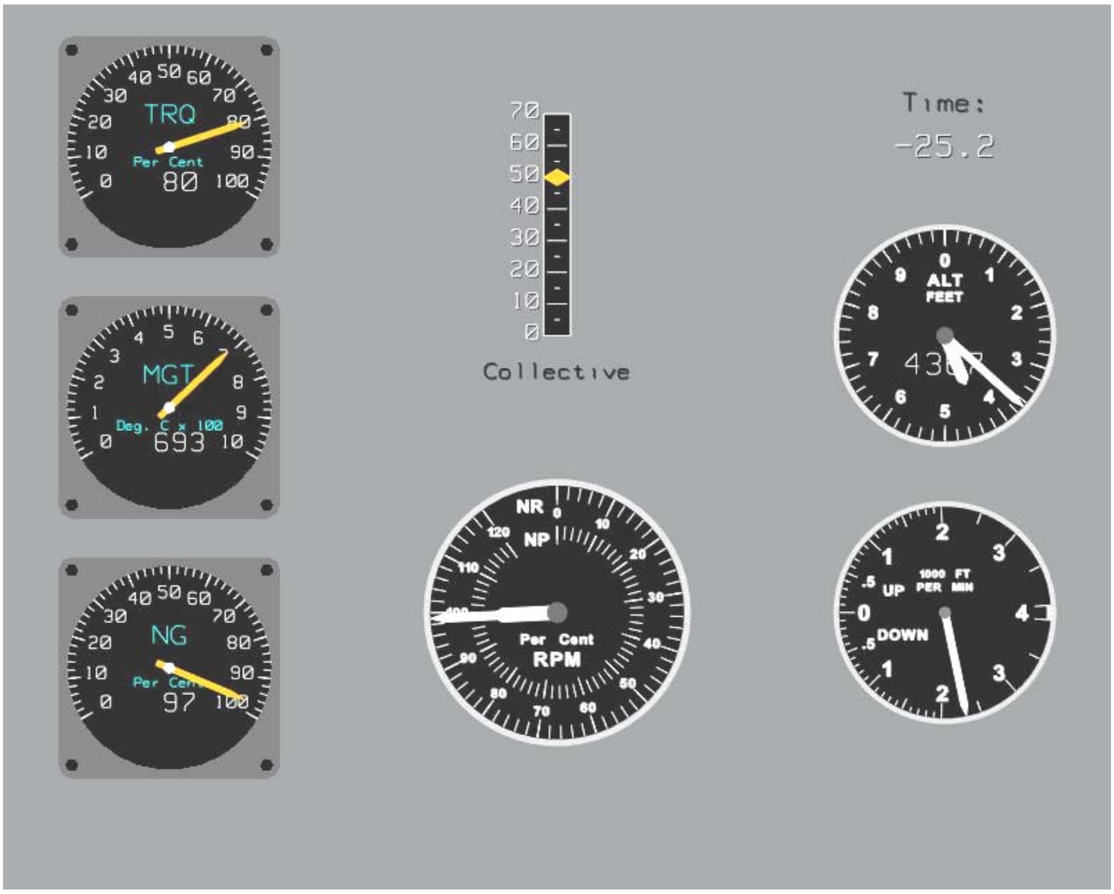
TRQ
Per Cent
80
MGT
Deg. C x 100
693
NG
Per Cent
97
Collective
Time:
-25.2
ALT
FEET
NR
NP
Per Cent
RPM
UP
DOWN
1000 FT
PER MIN

Figure 5