NATIONAL TRANSPORTATION SAFETY BOARD
Vehicle Recorder Division
Washington, D.C. 20594

February 23, 2016

Flight Data Recorder

Group Chairman's Factual Report
By Charles Cates

1. EVENT SUMMARY

Location: New York, New York
Date: March 05, 2015
Aircraft: MD-88
Registration: N909DL
Operator: Delta Air Lines
NTSB Number: DCA15FA085

On March 5, 2015, about 1102 eastern standard time (EST), a Boeing MD-88, N909DL, operating as Delta Air Lines flight 1086, was landing on runway 13 at LaGuardia Airport, New York, New York, and exited the left side of the runway, contacted the airport perimeter fence, and came to rest with the airplane nose on an embankment next to Flushing Bay. The 127 passengers received either minor injuries or were not injured, and the 3 flight attendants and 2 flight crew were not injured. The airplane was substantially damaged. Flight 1086 was a regularly scheduled passenger flight from Hartsfield-Jackson Atlanta International Airport (ATL) operating under the provisions of 14 Code of Federal Regulations (CFR) Part 121. Instrument meteorological conditions (IMC) prevailed, and an instrument flight rules (IFR) flight plan was filed.

2. FLIGHT DATA RECORDER GROUP

A flight data recorder (FDR) group was convened on March 10-11, 2015.

Chairman: Charles Cates
Aerospace Engineer
National Transportation Safety Board

Member: David Gherman
Aircraft Maintenance Technician
Delta Air Lines

Member: John White
Staff Engineer
Air Line Pilots Association

Member: Nathan Rohrbaugh
Air Safety Investigator
Federal Aviation Administration

Member: Cassandra Johnson
Mechanical Engineer
National Transportation Safety Board

3. FDR Carriage Requirements

The event aircraft, N909DL, was manufactured and received a certificate of airworthiness on August 13, 1987, per Federal Aviation Administration (FAA) records. It was operating such that it was required to be equipped with an FDR that recorded, at a minimum, 22 parameters, as cited in Title 14 *Code of Federal Regulations* Part 121.344.

4. DETAILS OF FDR INVESTIGATION

The National Transportation Safety Board (NTSB) Vehicle Recorder Division received the following FDRs:

Recorder Manufacturer/Model: **Lockheed 209F**
Recorder Serial Number: **4117**

Recorder Manufacturer/Model: **Avionica Mini-QAR MKII**
Recorder Serial Number: **8048**

4.1. Lockheed 209F Description

The 209F records aircraft data in a digital format on to six separate tracks of magnetic tape. It is configured to read 64 12-bit words of digital information from the Flight Data Acquisition Unit (FDAU) every second. It then writes the data on to the tape in groups of 64 words. Each grouping of 64 words (each second) is called a subframe. Each subframe has a designated 12-bit synchronization (sync) word identifying it as subframe 1, 2, 3, or 4, written as the first word in the subframe. The data stream is “in sync” when successive sync words appear at proper 64 word intervals. Each data parameter (for example, altitude, heading, airspeed) has a specifically assigned word and bit location within the subframe.

Approximately the last 25 hours of operational data are retained on the recording medium. The recording occurs in a cyclical fashion, with the oldest data being erased and then the current data from the FDAU being recorded in its place.

4.1.1. Recorder Condition

The FDR was examined upon receipt and was found to be in good condition. Upon removal, the magnetic tape was found to be undamaged. The data were transcribed from the tape medium to computer hard drive for analysis using the NTSB’s laboratory equipment. The accident flight was located during the transcription.

4.1.2. Recording Description

The FDR recording contained approximately 25 hours of data. Timing of the FDR data is measured in subframe reference number (SRN), where each SRN equals one elapsed second. The flight duration was approximately 1 hour and 40 minutes. The parameters evaluated for the purpose of this report appeared to be in accordance with the federal FDR carriage requirements.

4.1.3. Engineering Units Conversions

The transcribed data were converted from the recorded binary values to engineering units. The engineering unit conversions used for the data contained in this report are based on documentation from Delta Air Lines, the aircraft operator. Where applicable, the conversions have been changed to ensure that the parameters conform to the NTSB's standard sign convention that climbing right turns are positive (CRT=+).[1]

4.2. Avionica Mini-QAR MKII Description

The Mini-QAR (Miniature Quick-Access Recorder) MKII is a solid state data recorder used primarily as a data source for airline Flight Operational Quality Assurance (FOQA) programs. Depending on the amount of memory installed, the recorder has the ability to record as much as 400 hours of flight data. In the installation on the accident aircraft, the QAR recorded the same 64 word per second (wps) data stream from the FDAU as the FDR. The QAR memory is not intended to be crash protected.

4.2.1. Recorder Condition

The QAR was examined upon receipt and was found to be in good condition. The data were extracted normally with the Avionica Ruggedized Service Unit (RSU), and the manufacturer's recommended procedure.

4.2.2. Recording Description

The QAR recording contained approximately 119 hours of data. Because it records the same stream as the FDR, the QAR data is functionally equivalent to the FDR data for the accident flight. However, due to issues with data signal dropouts from the magnetic tape in the FDR, the quality of the QAR recording is marginally better than the FDR. For this reason, the QAR data was used to generate plots and perform analysis work.

4.2.3. Engineering Units Conversions

The same conversions are used for both the FDR and QAR.

Table A-1 in appendix A lists the FDR/QAR parameters verified and provided in this report. Additionally, appendix A table A-2 describes the unit and discrete abbreviations used in this report.

4.3. Issues in Recorded Data

During the group data validation activities, intermittent issues with several parameters were noted in the accident flight recording.

4.3.1. FDAU Synchro Issues

In the recording, one pitch trim, rudder position, aileron position, control wheel position, and engine EPR values displayed invalid data at simultaneous times during different points

[1] CRT=+ means that for any parameter recorded that indicates a climb or a right turn, the sign for that value is positive. Also, for any parameter recorded that indicates an action or deflection, if it induces a climb or right turn, the value is positive. Examples: Right Roll = +, Pitch Up = +, Elevator Trailing Edge Up = +, Right Rudder = +.

of the flight. See figure 5 for a plot of all invalid parameters during the event flight. Identical behavior was recorded on both the FDR and the QAR, consistent with an issue with the Flight Data Acquisition Unit (FDAU), which supplies an identical processed data stream to the FDR and QAR.

A review of flight data recorded on the QAR shows that data issues similar to those seen on the accident flight occurred sporadically and for short duration on many of the previous flights, dating back to February 20, 2014 (13 days), the earliest data available on the QAR.

A check of the maintenance history records for this FDAU was performed. The unit was installed in the accident airplane on September 23, 2014. Prior to this installation, it was removed from a different MD-88 airplane in the Delta Air Lines fleet on September 12, 2014.

The unit was removed from the previous airplane after a routine data review showed pitch trim parameters inoperative, and control wheel, aileron, and rudder positions inaccurate. Maintenance was performed on the unit and several components were replaced, and the unit was tested and re-certified for service.

The investigation team tested the FDAU to see if the abnormal behavior could be explained. The FDAU was tested using a standard Acceptance Test Procedure developed by the manufacturer of the FDAU (Teledyne), and used by Delta Air Lines to recertify FDAUs following maintenance. Visual inspections revealed nothing anomalous, however synchro signal tests revealed an intermittent error in the way the FDAU processed signals sourced from synchros.

Additional tests and troubleshooting of the FDAU determined that degradation of the chassis wiring and connections, with vibration exacerbating the issue, was the likely cause of the invalid data seen in the pitch trim, rudder position, aileron position, control wheel position, and engine EPR parameters. The invalid data intermittently output by the FDAU during the testing were consistent with invalid data recorded during the accident flight and throughout the recording by the FDR and QAR. Therefore, an evidence-based test was used as an indicator to differentiate valid and invalid data. Periods of invalid data during the flight are annotated on figure 5 in Section 4.5.

4.3.2. End of recording dropout

During the approach to landing and aircraft touchdown, it was determined that the FDAU was outputting valid data for all parameters. However, there were some individual data points following the aircraft touchdown that were invalid; likely due to aircraft vibration affecting the FDAU wiring. Additionally, all parameters (not limited to FDAU synchro parameters) except for engine speed parameters and pressure altitude became invalid during the accident sequence, prior to the recorders losing power. This was determined to be due to damage sustained by the aircraft electronics bay as the aircraft departed the runway and impacted terrain. Engine speed parameters continued to record for about 20 seconds after other parameters became invalid. Invalid data during the approach, touchdown, and accident have been removed from the plots for clarity.

4.3.3. Brake pressure

The data group also discovered a problem in the data with the recorded right brake pressure. When the brake pressure was expected to be 0 psi, for example with the landing gear stowed, the recorded value was consistently offset to about 900 psi. It could not be determined whether the 900 psi was a static offset, or if there was a 900 psi deadband in the sensing system. Therefore, the pressure transducers were taken to their manufacturer (Ametek) and tested with a standard test procedure.

As expected, the right brake pressure transducer failed its test, and the 900 psi was determined to be a static offset output from the transducer. The data was adjusted with this result, so all right brake pressure values referenced in this report and its attached tabular data have been adjusted.

4.3.4. Pressure altitude

In order to capture altitude at a high enough resolution over the entire range required, the pressure altitude parameter was stored as two components in different locations in the data map. The most significant part (MSP) is stored only once every 4 seconds, while the least significant part (LSP) is stored every second. To determine the combined total pressure altitude, the MSP and LSP of the parameter are concatenated and converted to engineering units. Because the MSP was stored at a lower rate than the LSP, the resultant combined parameter data often had spikes of one to three samples as the parameter value passed through a point where the LSP wrapped. These spikes have not been corrected in the plotted or tabular data. Pressure altitude is not corrected for barometric pressure.

4.4. Time Correlation

Correlation of the FDR data from SRN to the event local time, EST, was established with an offset provided by the CVR Group Chairman in the Cockpit Voice Recorder – Group Chairman's Factual Report.

Accordingly, the time offset for the event flight data from SRN to local EST is the following: EST= SRN – 388,860.7. Therefore, for the rest of this report, all times are referenced as EST, not SRN. However, previous landings are referenced as SRN, not local time.

4.5. FDR Plots and Corresponding Tabular Data

The following six figures contain FDR data recorded during the March 5, 2015 event. All the parameters listed in Appendix A are plotted.

Figures 1 and 2 contain aircraft basic parameters from the event flight. Figure 3 shows available control surfaces and aircraft systems aiding in deceleration, as well as forces recorded on the aircraft. Figure 4 shows flight controls and control surfaces. Figure 5 shows invalid parameters and periods of invalid data. Figure 6 shows engine parameters.

Figures 1 and 5 cover the entire flight, from recorder power up until recorder power down. Figure 3 covers a time period from 20 seconds before touchdown to 20 seconds after touchdown. Figure 4 covers a time period from 80 seconds before touchdown to 20 seconds after touchdown. Figure 6 covers a time period from 80 seconds before touchdown to recorder power down.

Figure 1 shows that the aircraft took off at about 9:24 am and climbed to an altitude of 33,000 ft. It stayed at that altitude on a northeasterly heading for about 40 minutes, maintaining an airspeed of about 280 knots. It then commenced a stepped descent lasting about 38 minutes including intermediate level-offs at 27,000, 10,800, 6,800, 3,800, and 2,800 ft pressure altitude.

Figure 2 begins as the aircraft passed through 1,000 ft above ground level (AGL). The aircraft was on a heading of around 130 degrees magnetic, airspeed was stable at 140 +/- 3 knots, pitch and roll attitude were stable, and flaps were configured at 40 degrees. A vertical acceleration peak consistent with main gear making initial contact with the runway occurred at 11:02:16.8, followed by a final main gear touchdown at 11:02:18.6. Nose gear touchdown occurred at 11:02:20.0, and the weight on wheels sensor also detected the aircraft on the ground at this time. (The weight on wheels system switch is linked to having weight on the nose gear).

At initial main gear touchdown, airspeed was about 133 knots, and the aircraft began to decelerate immediately after nose gear touchdown. About 6 seconds after main gear touchdown, the aircraft's heading began to deviate to the left from a heading of 131 degrees, and continued turning left for the next six seconds, reaching a heading of 114 degrees. It turned back to the right for another four seconds, to 125 degrees, before the recording of heading became invalid at 11:02:32.

Figure 3 shows the systems helping to decelerate the aircraft, including the thrust reversers, spoilers, and brakes. The first system to be applied was the thrust reversers. Both reversers were deployed and engines began advancing in power about two seconds after main gear initial touchdown. The spoilers were then fully deployed within 2.5 seconds after main gear touchdown. Brake pressure began to rise in a manner consistent with autobrake application 2.8 seconds after the main gear touchdown, about the same time as nose gear touchdown.

Engines achieved peak recorded reverse power of 2.07 EPR on the left, and 1.91 EPR on the right, between six and seven seconds after touchdown. Engine power decreased after this point. Thrust reversers were stowed nine seconds after main gear initial touchdown. The engines were both at about 1.6 EPR when the reversers were stowed.

Spoilers on the left and right were fully deployed following main gear touchdown, and remained fully deployed until the recording became invalid. The left spoiler position became invalid at 11:02:26, and the right at 11:02:32.

Brake pressure began to rise at approximately the same time as gear weight on wheels transitioned to true. Only left brake pressure recorded a rise; however this is consistent with autobrake application on the aircraft. When autobrakes are applied, both the left and right brakes receive equivalent brake pressure, but the pressure is only recorded on the left. Left brake pressure reached a peak of 3,000 psi, and dropped off eight seconds after initial pressure rise, consistent with autobrakes being disengaged. Autobrakes can be disengaged by applying manual braking through the toe brakes. This occurred at about the same time as the thrust reversers were stowed. At about the same time, longitudinal acceleration jumped from -0.3g to -0.04g. Following the disengagement of the autobrakes, right brake pressure increased to 1161 psi, and both brake pressure readings became invalid at 11:02:33.

Figure 4 is a plot of flight controls and control surfaces during the approach and landing. As the aircraft passed through 1000 ft AGL, the autopilot was engaged, and the aircraft's heading, pitch, roll, and descent rate were stable. Control surfaces followed their commanded inputs. As the aircraft passed through about 220 ft AGL, the autopilot was disengaged. Between that time and touchdown, the aircraft roll varied from +3 to -4 degrees, with the control wheel and aileron countering the roll. At main gear touchdown, the elevator was decreased and pitch decreased gradually over four seconds until nose gear touchdown. As the heading started to deviate to the left, right rudder was applied to a peak of 23 degrees, and as heading continued to deviate the control wheel was turned as much as 81 degrees to the right.

Figure 5 shows periods of invalid data from the FDAU during the course of the flight in the six parameters affected by the FDAU issue. At recorder power-up, all parameters were valid. The parameters were invalid from 9:11:30 to 9:14:59, again from 9:16:54 to 10:05:39, and for a third stretch from 10:06:23 to 10:13:12.

Figure 6 is a plot of engine parameters during the approach through the time of recorder power down. The engine speed traces stayed valid even after other data had become invalid due to damage sustained by the aircraft electronics bay during the accident sequence. Based on engine N2, engine 2 went sub-idle, indicative of engine shutdown, at 11:02:53.

These figures are configured such that right turns are indicated by the trace moving toward the bottom of the page, left turns towards the top of the page, and nose up attitudes towards the top of the page.

The corresponding tabular data used to create these six plots are provided in electronic comma separated value (*.csv) format as Attachment 1 to this report.

Figure 1. Plot of basic parameters during entire flight.

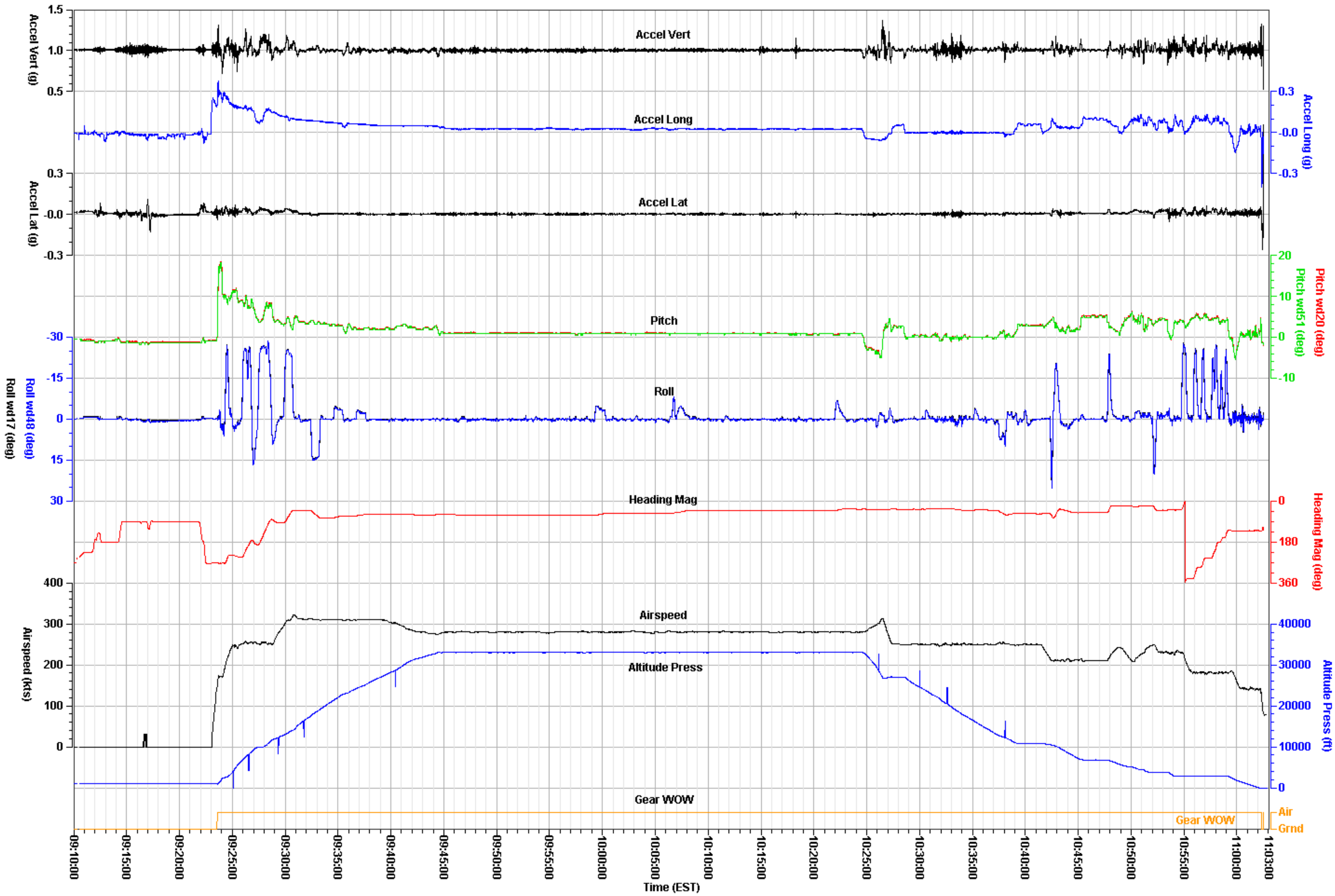


Figure 2. Plot of basic parameters during final approach and landing.

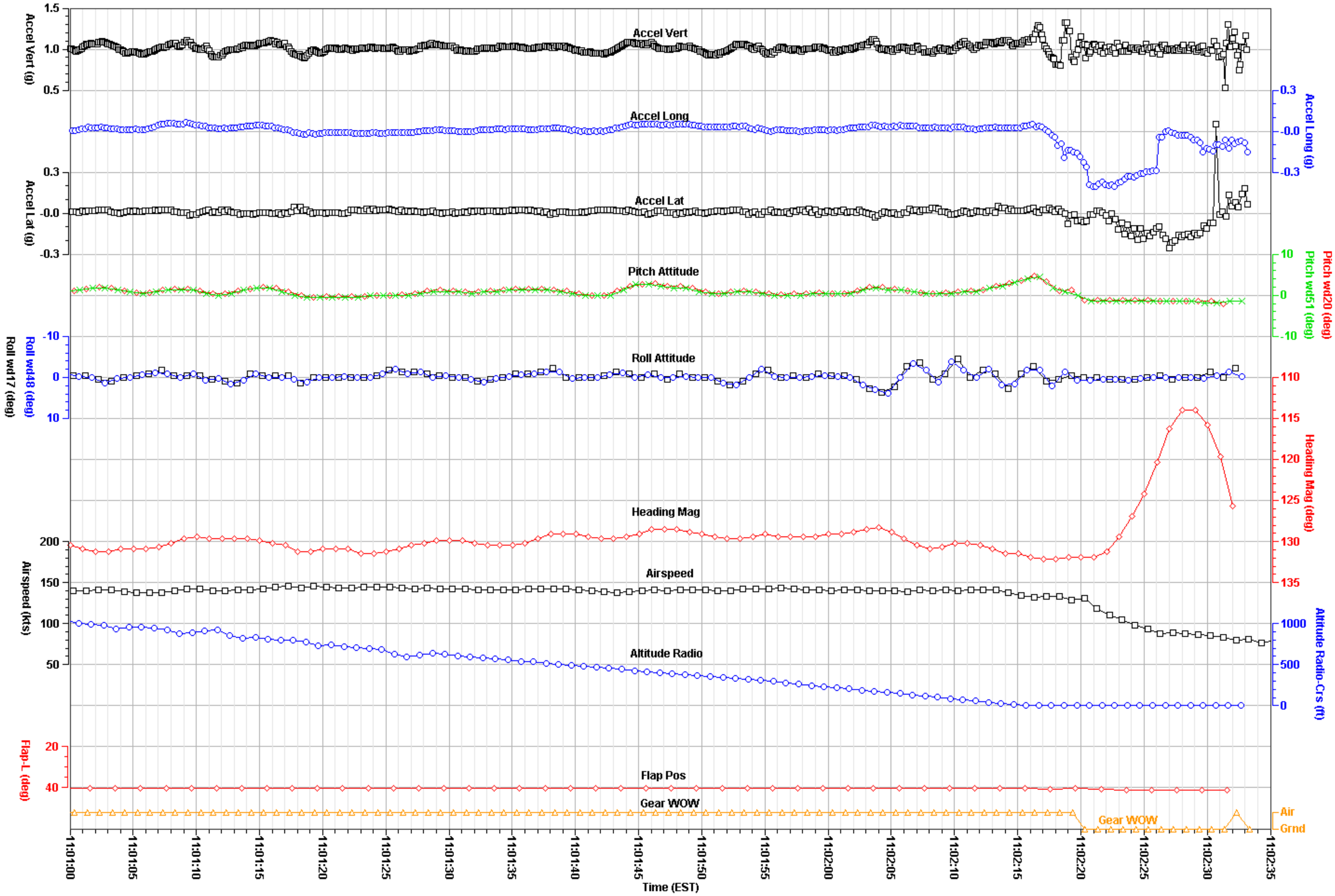


Figure 3. Plot of deceleration aids and forces around the time of landing.

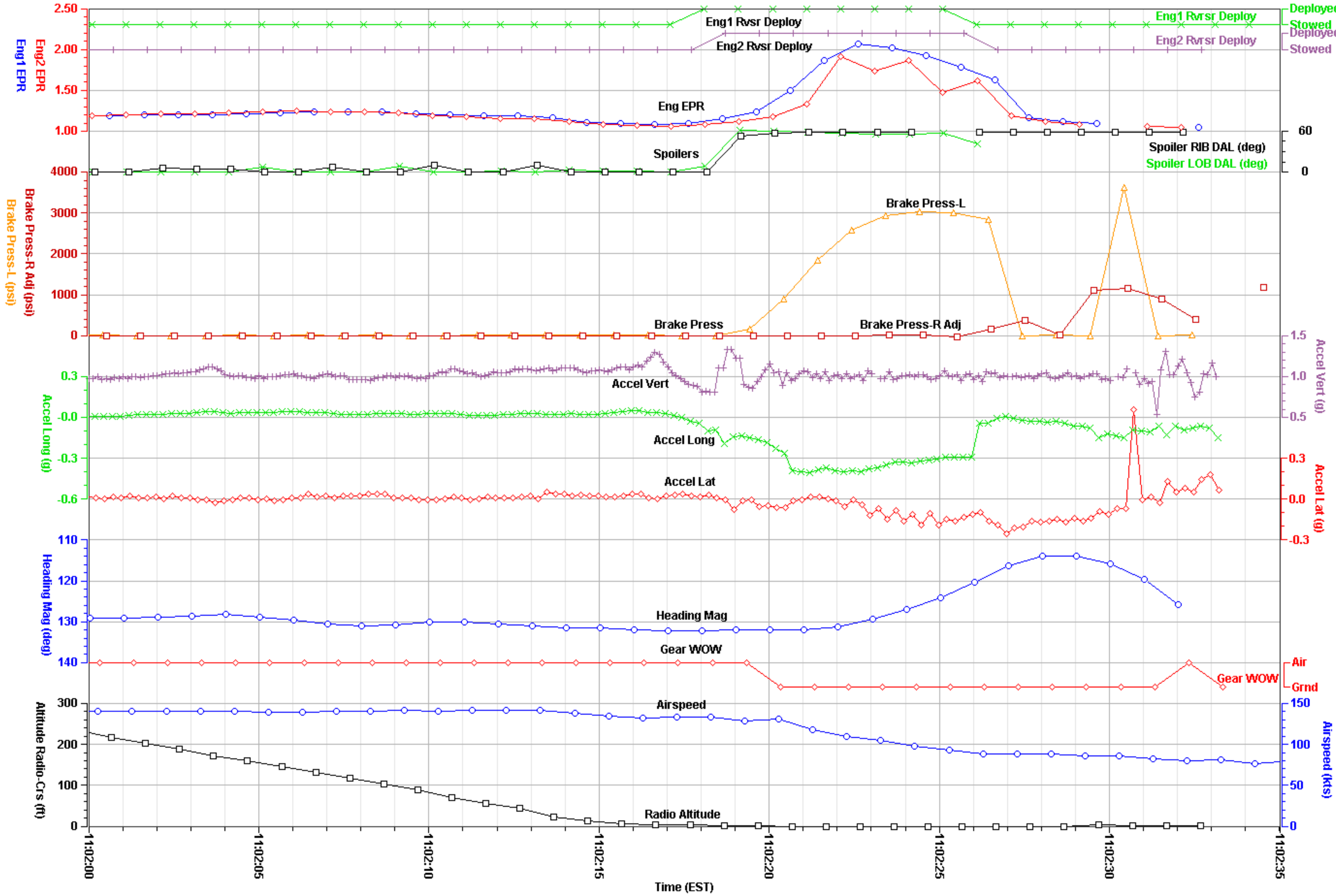


Figure 4. Plot of flight controls during final approach and landing.

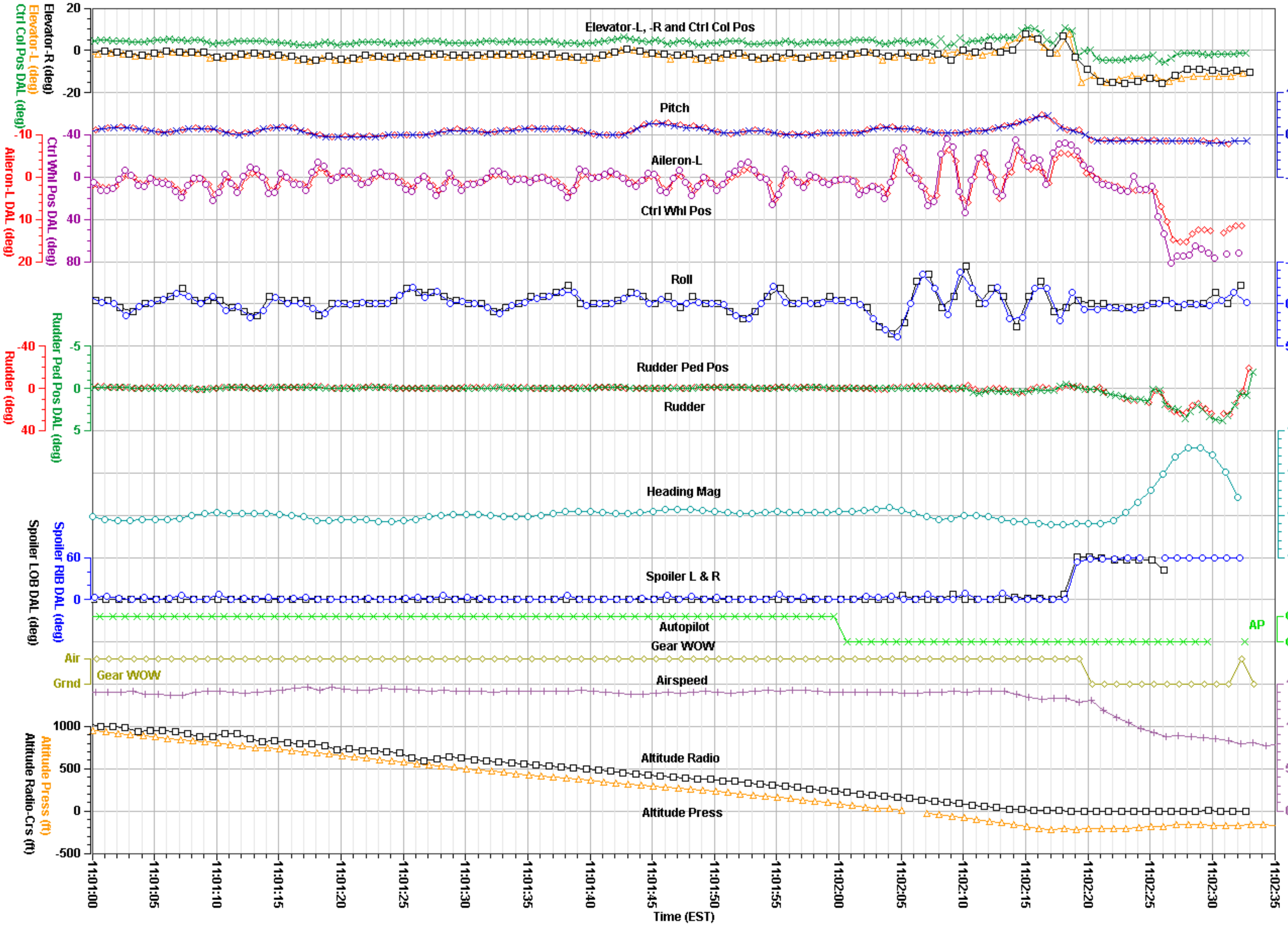


Figure 5. Parameters exhibiting intermittent invalid behavior during accident flight.

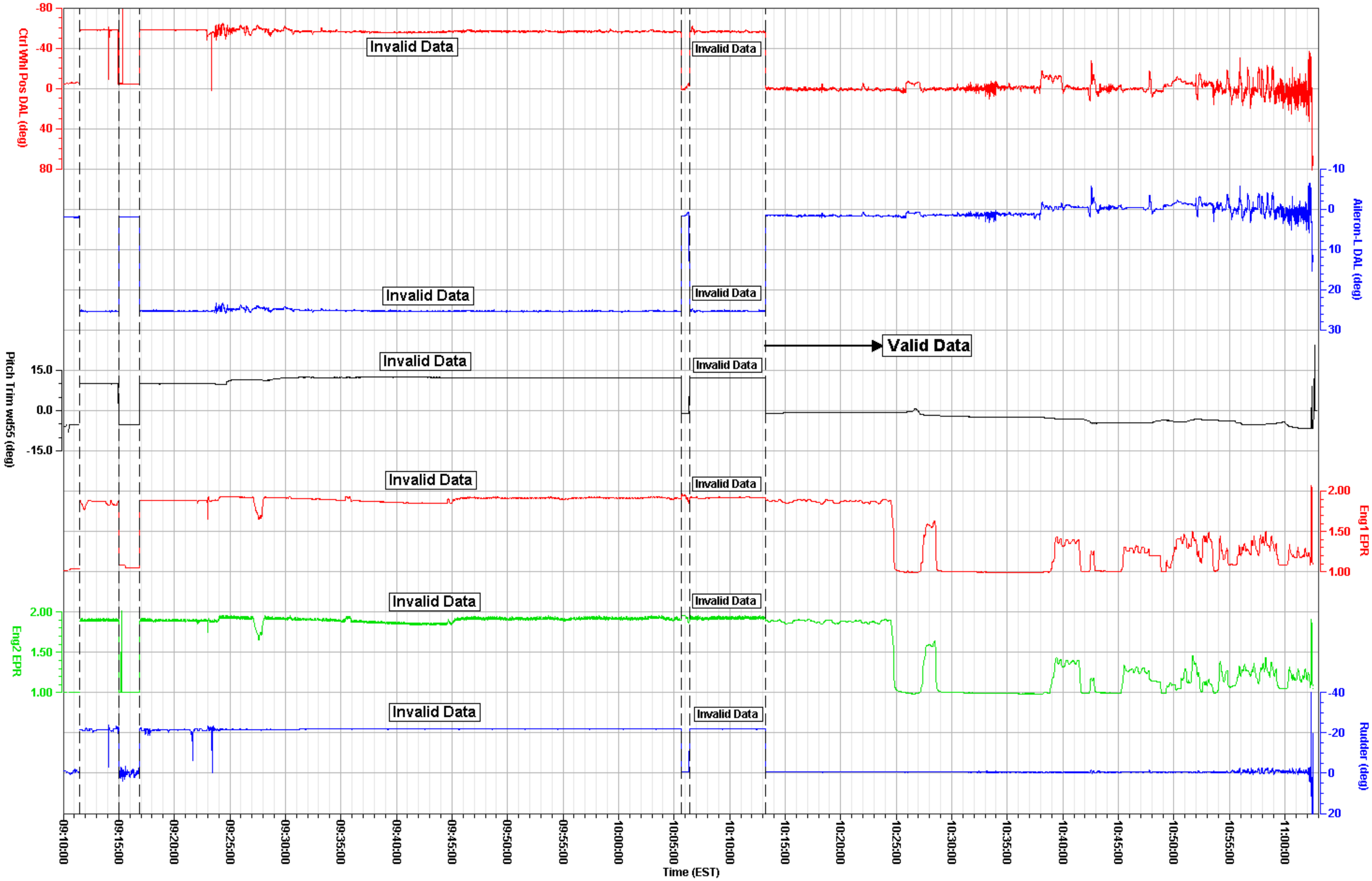
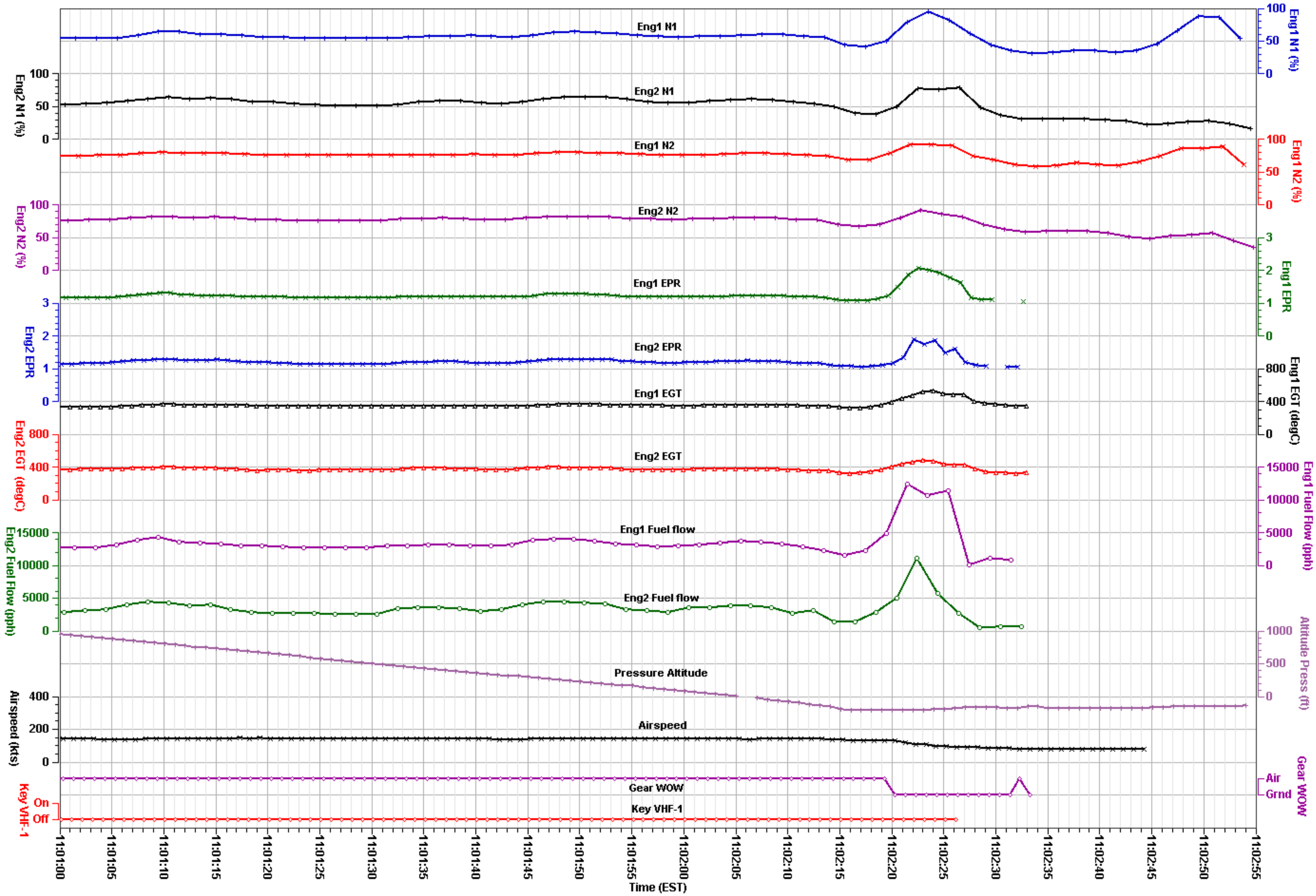


Figure 6. Plot of engine parameters during final approach and landing.



APPENDIX A

This appendix describes the parameters provided and verified in this report. Table A-1 lists the parameters and table A-2 describes the unit and discrete abbreviations used in this report.

Table A-1. Verified and provided FDR parameters.

Parameter Name	Parameter Description
1. Accel Lat (g)	Lateral Acceleration
2. Accel Long (g)	Longitudinal Acceleration
3. Accel Vert (g)	Vertical Acceleration
4. Aileron-L DAL (deg)	Left Aileron Position
5. Airspeed (kts)	Airspeed
6. Altitude Press (ft)	Pressure Altitude
7. Altitude Radio (ft AGL)	Radio Altitude
8. AP (discrete)	Autopilot Engaged
9. Brake Press-L (psi)	Left Main Gear Brake Pressure
10. Brake Press-R Adj (psi)	Right Main Gear Brake Pressure
11. Ctrl Col Pos DAL (deg)	Control Column Position
12. Ctrl Whl Pos DAL (deg)	Control Wheel Position
13. Elevator-L (deg)	Left Elevator Position
14. Elevator-R (deg)	Right Elevator Position
15. Eng1 EGT (degC)	Engine 1 Exhaust Gas Temperature
16. Eng1 EPR (ratio)	Engine 1 Engine Pressure Ratio
17. Eng1 fuel flow (pph)	Engine 1 Fuel Flow
18. Eng1 N1 (%)	Engine 1 Fan Speed
19. Eng1 N2 (%)	Engine 1 Core Speed
20. Eng1 Rvsr Deploy (discrete)	Engine 1 Thrust Reverser Deployed
21. Eng2 EGT (degC)	Engine 2 Exhaust Gas Temperature
22. Eng2 EPR (ratio)	Engine 2 Engine Pressure Ratio
23. Eng2 fuel flow (pph)	Engine 2 Fuel Flow
24. Eng2 N1 (%)	Engine 2 Fan Speed
25. Eng2 N2 (%)	Engine 2 Core Speed
26. Eng2 Rvsr Deploy (discrete)	Engine 2 Thrust Reverser Deployed
27. Flap-L (deg)	Left Flap Position
28. Gear WOW (discrete)	Gear Weight on Wheels
29. Heading Mag (deg)	Magnetic Heading
30. Key VHF-1 (discrete)	Left VHF Radio Keyed
31. Pitch (deg)	Pitch Angle
32. Pitch Trim (deg)	Pitch Trim Angle
33. Roll (deg)	Roll Angle
34. Rudder (deg)	Rudder Position

Parameter Name	Parameter Description
35. Rudder Ped Pos DAL (in)	Rudder Pedal Position
36. Spoiler LOB DAL (deg)	Left Outboard Spoiler Position
37. Spoiler RIB DAL (deg)	Right Inboard Spoiler Position

NOTE: This FDR records pressure altitude, which is based on a standard altimeter setting of 29.92 inches of mercury (in Hg). The pressure altitude information presented in the FDR plots and in the electronic data has not been corrected for the local altimeter setting at the time of the event.

Table A-2. Unit and discrete abbreviations.

Units Abbreviation	Description
AGL	above ground level
deg	degrees
degC	degrees Celsius
discrete	discrete
ft	feet
g	g
grnd	ground
hrs	hours
in	inches
kts	knots
min	minutes
psi	pounds per square inch
sec	seconds

NOTE: For parameters with a unit description of discrete, a discrete is typically a 1-bit parameter that is either a 0 state or a 1 state where each state is uniquely defined for each parameter.