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

October 24, 2022

Cockpit Displays – Recorded Flight Data

Specialist's Factual Report
by Sean Payne

1. EVENT

Location:	Janesville, WI
Date:	February 16, 2021
Aircraft:	Velocity Vtwin
Registration:	N13VT
Operator:	Private
NTSB Number:	CEN21FA130

2. DETAILS OF INVESTIGATION

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

Device 1:	**Garmin G3X**
Device 1 Serial Number:	**350005134**
Device 2:	**Garmin G3X**
Device 2 Serial Number:	**350005025**
Device 3:	**Garmin G5**
Device 3 Serial Number:	**011-03809-00**

2.1. Garmin G3X Device Description

The Garmin G3X is a series of displays certified to be installed on certified aircraft. The model comes in 10.6" (GDU 460) and 7" (GDU 470) display versions. The unit employs a touch-screen user interface and can be utilized as a Primary Flight Display (PFD), Multi-Function Display (MFD), Engine Monitoring Device (EDM), or a combination of all, depending on how the unit is integrated with other compatible avionics products. The unit has the ability to record data via an externally removable SD card mounted under the center of the screen, or internally on a series of non-volatile memory (NVM) chips.

If not disabled, the unit is capable of logging historical information at a variable rate of up to 10 Hertz to internal NVM. Historical logs may be copied to a standard SD card inserted into the slot provided on the front of the unit, by selecting the touchscreen option, "Copy to SD Card", in configuration mode. Data is exported in engineering units, in a comma-separated value (CSV) format.

2.1.1. Garmin G3X Data Recovery

The aircraft and avionics were recovered from a river at the accident site and the avionics were water damaged. The avionics were delivered to the NTSB Vehicle Recorder Laboratory in water to inhibit the corrosion process and facilitate possible recovery. Figure 1 is a photo of the devices shipped to the lab in a sealed cooler. Figure 2 is a photo of the devices receiving a deionized-water rinse in a bucket.

Figure 1. Photo of devices as delivered to the laboratory.

Figure 2. Photo of being rinsed in fresh water.

The two Garmin G3X displays consisted of a Primary Flight Display (PFD) and a Multi-Function Display (MFD). The units appeared identical, and the units were unmarked. Both units were disassembled and inspected. Both units' main boards were removed, cleaned and dried in a vacuum drying oven. After drying the main boards were again inspected and no obvious defects or corrosion were noted.

Garmin Ltd. was contacted and was consulted for potential data recovery strategies. Garmin did not suggest a data recovery strategy. In lieu of technical assistance, Garmin offered a working G3X device to operate as a surrogate for a potential data recovery exercise.

The surrogate G3X display was received from Garmin and disassembled. The main board of one of the accident units was installed in the surrogate device. This device booted successfully. The device was determined to be the MFD. To recover data, the unit was reprogrammed to behave like a PFD so data could be successfully extracted using menus accessible only through the G3X's configuration mode. A full complement of GPS, AHRS, CAS and engine data was recovered from this unit, however, the engine data was only from one of the two engines of the aircraft. The dataset did not indicate which engine the data was from. Data from this unit is discussed further in section 2.1.2. Figure 3 is a photo of the unit booting when connected to an external DC power supply.

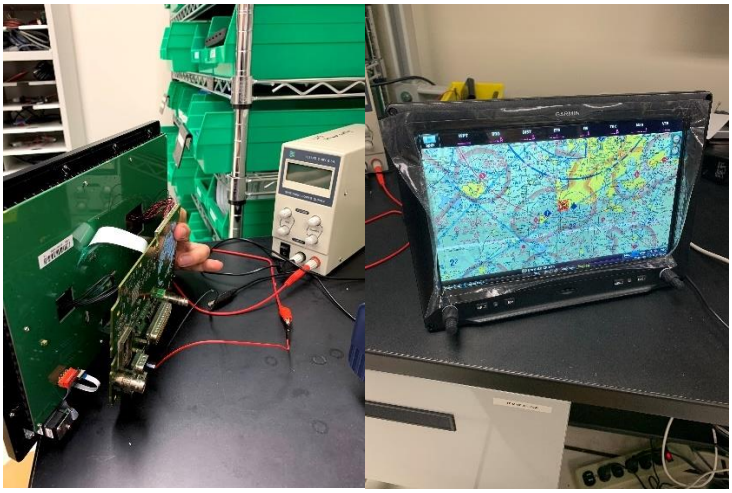

Figure 3. Photo of the MFD's main board installed in a G3X surrogate and booted.

The PFD was then elected to be downloaded as it could possibly contain data from the aircraft's other engine. The main board from the PFD was then inserted in the surrogate in a process similar described above, but it failed to boot as discussed above, Garmin did not provide any further technical assistance.

The PFD's main board was then examined for NVM chips associated with data retention. A SanDisk chip, model number SDIN8DR1-8G was identified as the source of flight data. The chip was removed from the accident PFD's main board. The chip was then imaged with two different chip imaging interfaces. In one image, a Netherlands Forensic Institute (NFI) memory toolkit was used with the appropriate adapter. In the second instance, a Sireda adapter was used in conjunction with Roadkill imaging software to create a second image. These two images were saved as back up in case the accident PFD chip was damaged attempting a transplant to the surrogate device.

The PFD chip images were examined and attempted to be converted to flight data using digital reconstruction methods. Only GPS data was able to be reconstructed. In the absence of assistance from Garmin, a solution for a digital reconstruction method was not possible at this time.

It was determined that transplanting a clone of the accident PFD chip to a working G3X main board would be attempted. For this, the chip image taken in the above description was written to a new, exemplar SanDisk SDIN8DR1-8G to create a clone of the accident PFD chip. Instead of using the surrogate main board provided by Garmin, the main board of the working accident MFD was selected to place the clone chip for readout. This was accomplished by using a computerized BGA rework station. Figure 4 is a photo of the clone of the accident PFD chip being placed on the accident MFD main board using the BGA rework station. The method proved effective and the clone of the PFD chip (now on the MFD board) was then implanted in the surrogate and booted successfully. Data was recovered by accessing configuration mode. A review of the data showed that no further engine data was recovered. Further discussion about the PFD data is discussed below.

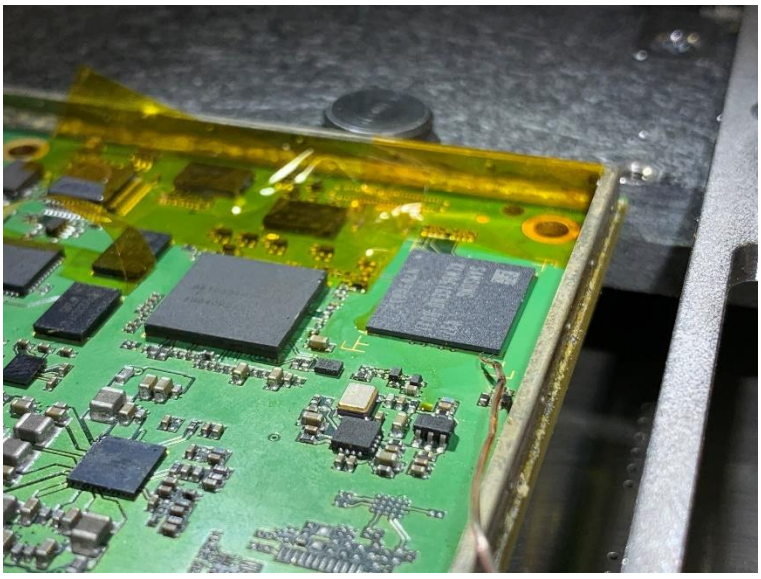

Figure 4. Photo of the clone of the accident PFD NVM chip being placed on the accident MFD main board.

2.1.2. Garmin G3X Data Description

Data extracted from both the PFD and the MFD are discussed in this report, however, the data from the two devices closely mirrored each other. In the data plots and the attachments, each parameter is labeled as being from the PFD, e.g. “ParameterName_PFD” or from the MFD, e.g., “ParameterName_MFD.”

Data recovered from the PFD began in a manner consistent with the start of the operation of the aircraft. GPS data recovered from the PFD begins just before 14:59:00 UTC and shows the aircraft near a ramp area of Southern Wisconsin Regional Airport (KJVL), Janesville, Wisconsin. The PFD data included air data, systems data, AHRS data, GPS data and limited engine data. The PFD recorded a parameter for “Engine % Power” but no other engine data parameters. The parameter “Engine % Power” appeared consistent with engine data recovered from the MFD, which is discussed below.

Data recovered from the MFD began around 15:12:00 UTC. Data from the MFD for air, AHRS, systems and GPS data appeared to be a mirror of data recovered for the same parameters from the PFD, with the exception that the MFD dataset included a number of

engine related parameters for one engine only. The kit supplier for the aircraft was contacted and stated that the MFD would record data from the right engine (engine 2) and that the PFD would record data from the left engine (engine 1).

The kit supplier offered to perform a test download of another V-Twin aircraft that had a similar avionics suite, and the NTSB requested this to be conducted. The kit supplier performed the download and supplied the NTSB lab with the data. Exemplar data from the test download showed that data from the PFD contained engine data for both the left (1) and right (2) engine. While data from the accident downloads only contained engine data on the dataset extracted from the MFD, there was no engine data contained on the subsequent download from the recovered PFD dataset.

Since it could not be conclusively determined which engine was presented in the MFD data, it was elected to label data from the MFD as “Engine B” and any reference to the missing engine data from the PFD referenced as “Engine A.” The data from the MFD persisted approximately 4 seconds longer than the dataset from the PFD.

The data extracted included a number of recorded sessions which ranged from January 15, 2021, to the accident day on February 16, 2021. The accident files were dated February 16, 2021, and the dataset from the PFD and MFD varied in parameters and length as described above.

The times were recorded in Universal Coordinated Time (UTC) and were not offset to the local time of the accident for this report.

Figure 5 is an overview of the entire GPS tracklog of the accident flight. Note that the weather and lighting conditions depicted in Google Earth are not necessarily representative of that of the accident day. This statement applies to all figures containing Google Earth plots.

Figure 6 is a depiction of the GPS tracklog showing an overview of the aircraft’s tracklog in the vicinity of KJVL, Janesville, Wisconsin. The figure depicts the aircraft’s departure from KJVL.

Figure 7 is a depiction of the GPS tracklog showing the aircraft’s departure from the traffic pattern toward the south from KJVL.

Figure 8 is a depiction of the GPS tracklog showing the aircraft’s outbound portion of flight from KJVL.

Figure 9 is a depiction of the GPS tracklog which highlights the aircraft’s attempted return toward KJVL. The wreckage location is marked with a yellow pin. Note that the data did not follow the aircraft to the accident site. In some Garmin devices where a chip recovery process is utilized, typically some amount of data is not recoverable, this could have been caused by the unit’s internal data buffering scheme.

Figure 10 is a plot of basic aircraft performance, systems and engine parameters for the entire accident recording. The data show the PFD began logging data just prior to 14:59 UTC. The data then show the aircraft was stationary until approximately 15:04 UTC when

the parameter for GPS groundspeed indicated the aircraft was moving. By approximately 15:05, data show that the aircraft had stopped moving again. Just under two minutes later, the parameter from the PFD “Engine % Power “B”” showed an increase in engine power while the aircraft was stationary, consistent with the aircraft performing a run up. The aircraft was stationary again, until data show the aircraft taxiing and subsequently beginning a takeoff roll around 15:11:30. Pitch angle increased, and the aircraft appeared to stabilize at a climb speed of about 125 knots. Around 15:12:15, data show engine rpm for engine B decreased from around 2600 RPM to 2100 RPM. Around this time airspeed began to increase to a maximum of around 156 knots and altitude to a maximum of around 2850 feet. During this interval, rpm for Engine B fluctuated above 2100 RPM. The aircraft appeared to stop its climb shortly thereafter around 15:13:25. The aircraft continued around 2800 feet until approximately 15:14:00 when the RPM for engine “B” began to show a decrease. By 15:14:10, the RPM for engine “B” had reached zero. The aircraft was now in a descent trend for the rest of the recorded dataset. Airspeed began fluctuating but had a decreasing trend for the remainder of the recording. As airspeed and altitude data began trending downward, values for pitch and roll began to become more active. In general, the trend for pitch could be described as more positive, however, the values for pitch did fall below zero at times. At the end of the recording, indicated airspeed registered as approximately 107 knots. Values for pitch seemed to fluctuate between -6 degrees nose down and positive 7 degrees nose up. Values for roll seemed to fluctuate between approximately zero degrees (level) and positive 5 degrees (left roll). The data set ended when the aircraft was about 0.5 nm from ESE the wreckage site.[1]

Figure 11 is an expanded timescale plot of basic aircraft performance, systems and engine parameters for the final portion of the accident recording.

Figure 12 is a super-expanded timescale plot of basic aircraft performance, systems and engine parameters for the end of the accident recording.

Figure 13 is a plot of basic aircraft performance parameters and all available and validated engine performance data for Engine “B” for the entire accident recording.

Figure 14 is a plot of basic aircraft performance parameters and all available and validated engine performance data for Engine “B” for the final portion of the accident recording.

Figure 15 is a plot of basic aircraft performance parameters and all available and validated engine performance data for Engine “B” for the end of the accident recording.

Figure 16 is a plot of basic aircraft performance parameters and all available and validated aircraft systems data for the entire accident recording.

Figure 17 is a plot of basic aircraft performance parameters and all available and validated aircraft systems data for the final portion of the accident recording.

[1] As noted previously, premature cessation of recorded data from an accident flight is consistent with the device’s internal data buffering scheme.

Figure 18 is a further expanded plot of basic aircraft performance parameters and all available and validated aircraft systems data for the final portion of the accident recording.

Attachment 1 is recorded data from the G3X MFD in comma-separated value format (.CSV). Appendix A is a list of parameter descriptions and unit abbreviations used in this report.

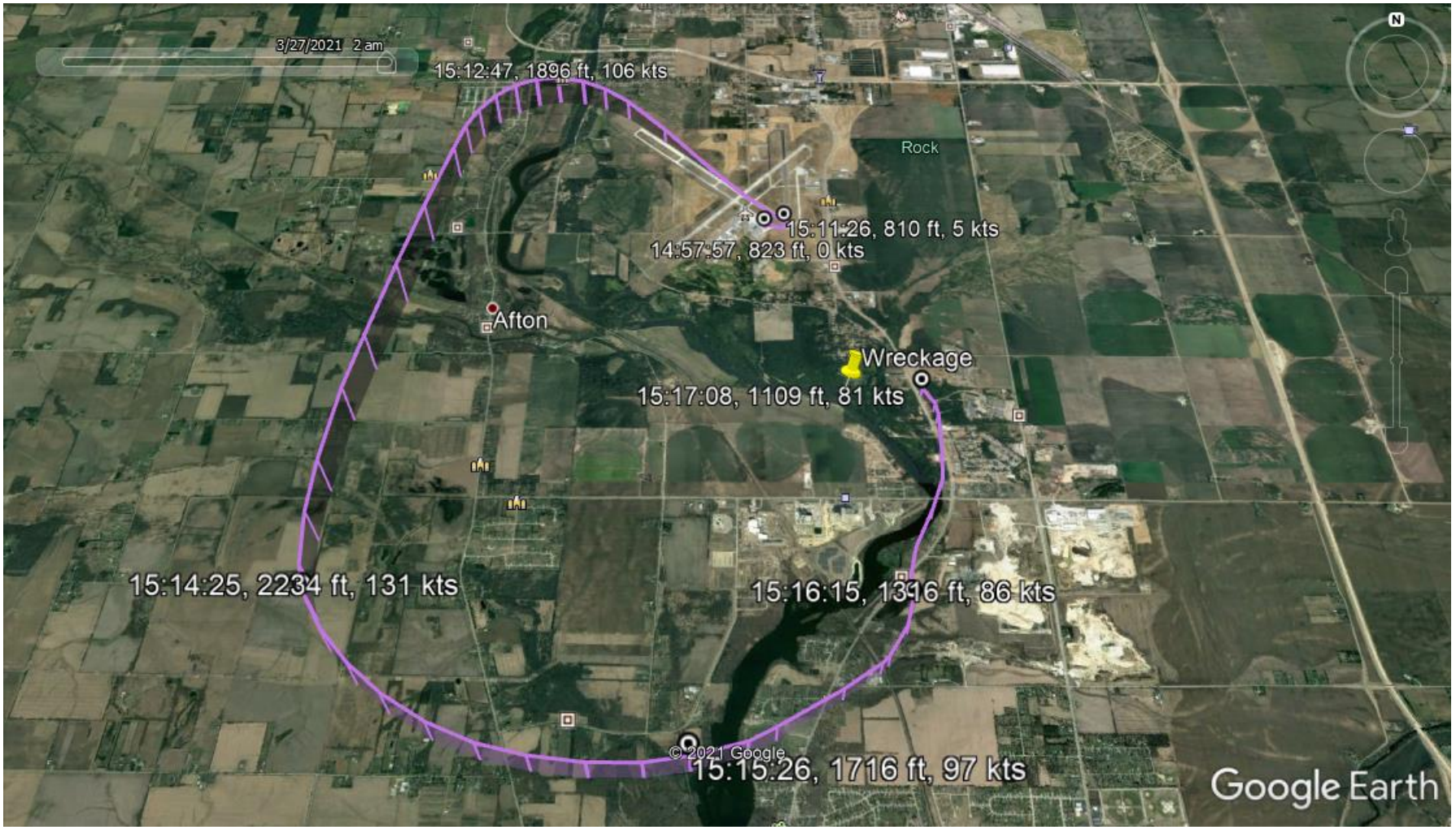

Figure 5. An overview of the tracklog recovered for the accident flight.

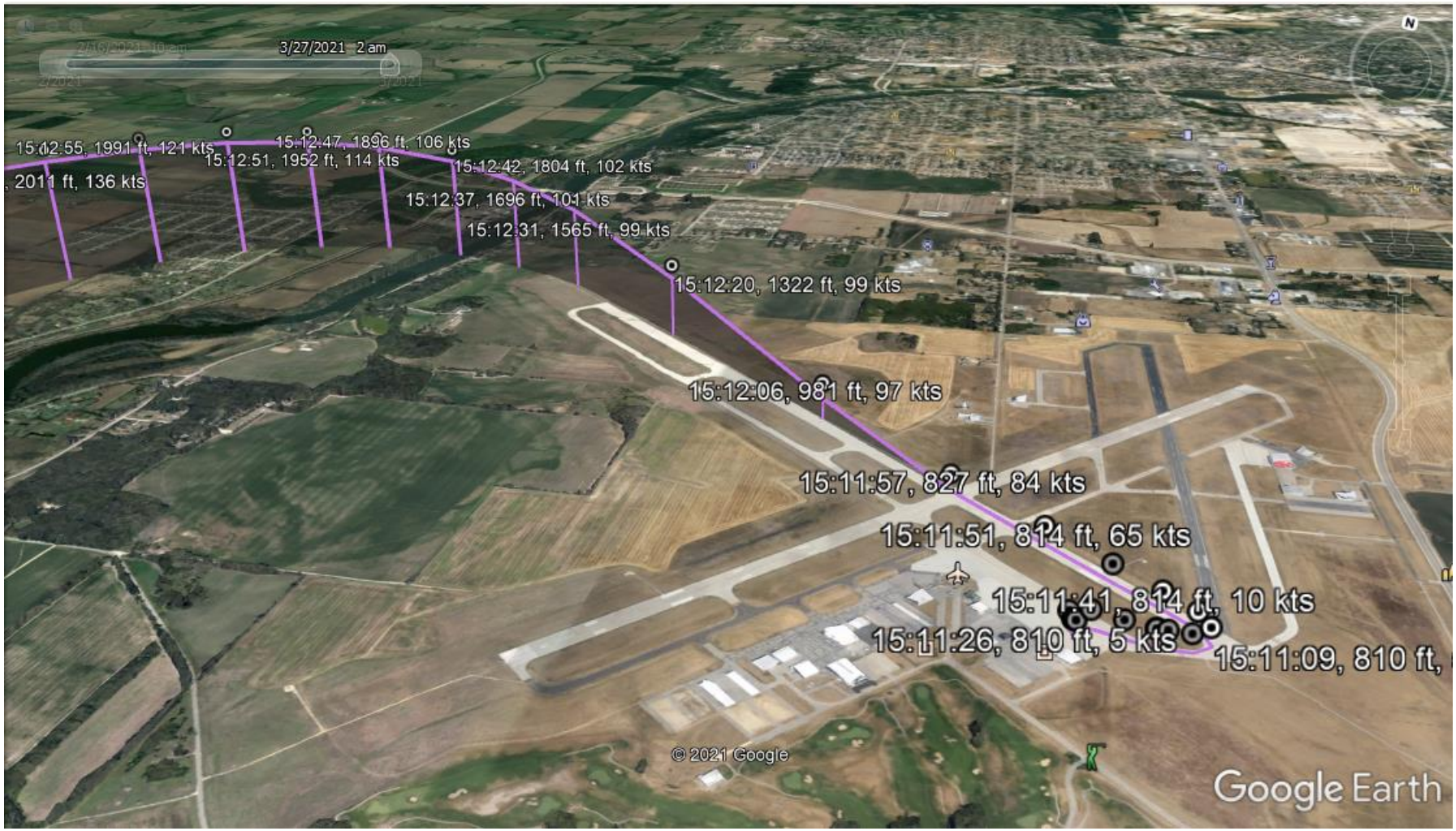

Figure 6. An overview of the aircraft's departure from JVL.

Figure 7. An overview of the aircraft's tracklog as it headed south from JVL.

Figure 8. An overview of the aircraft's tracklogs at it returned toward JVL.

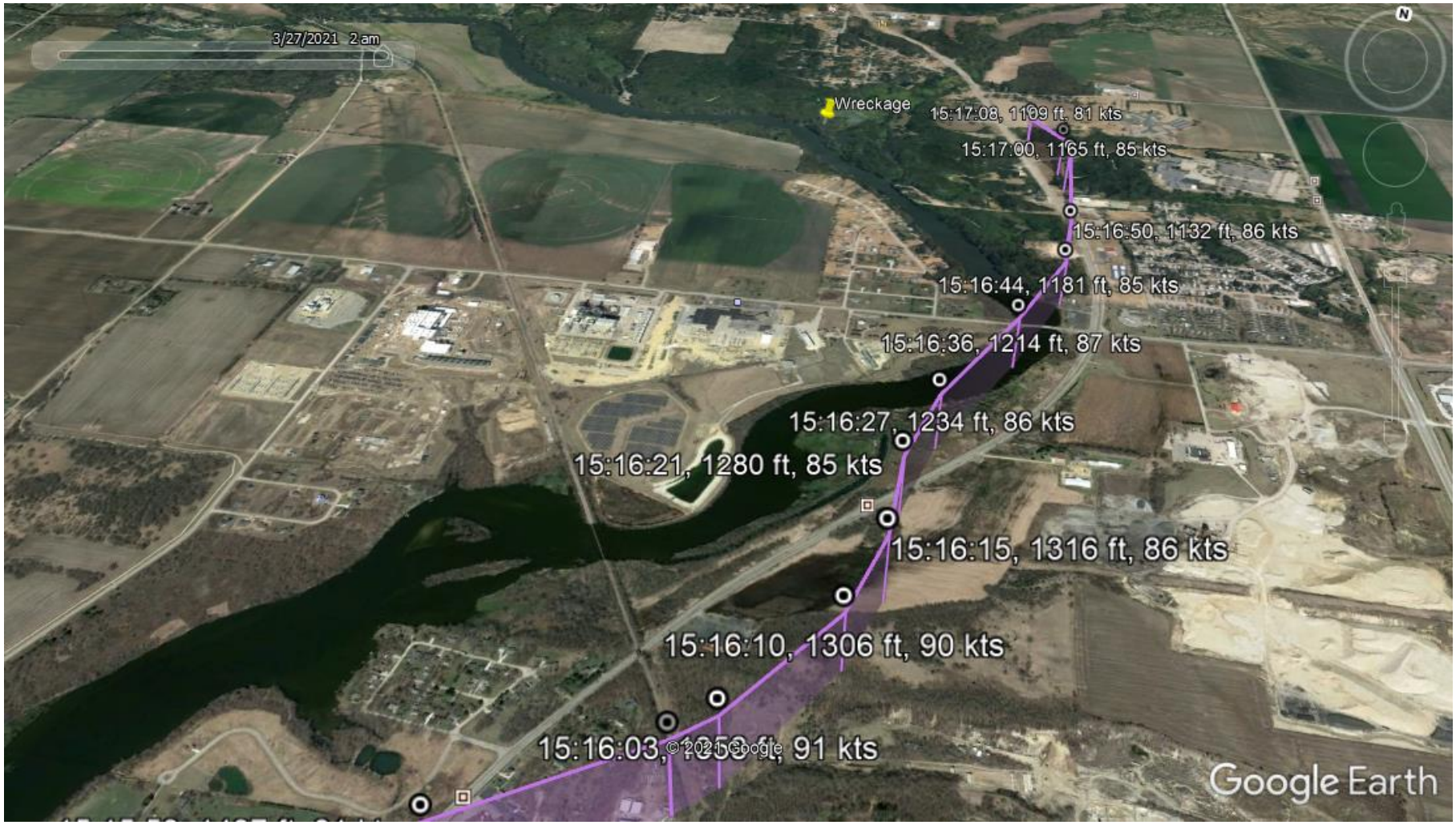

Figure 9. An overview of the aircraft's final tracklog points. The wreckage is denoted as a yellow pin.

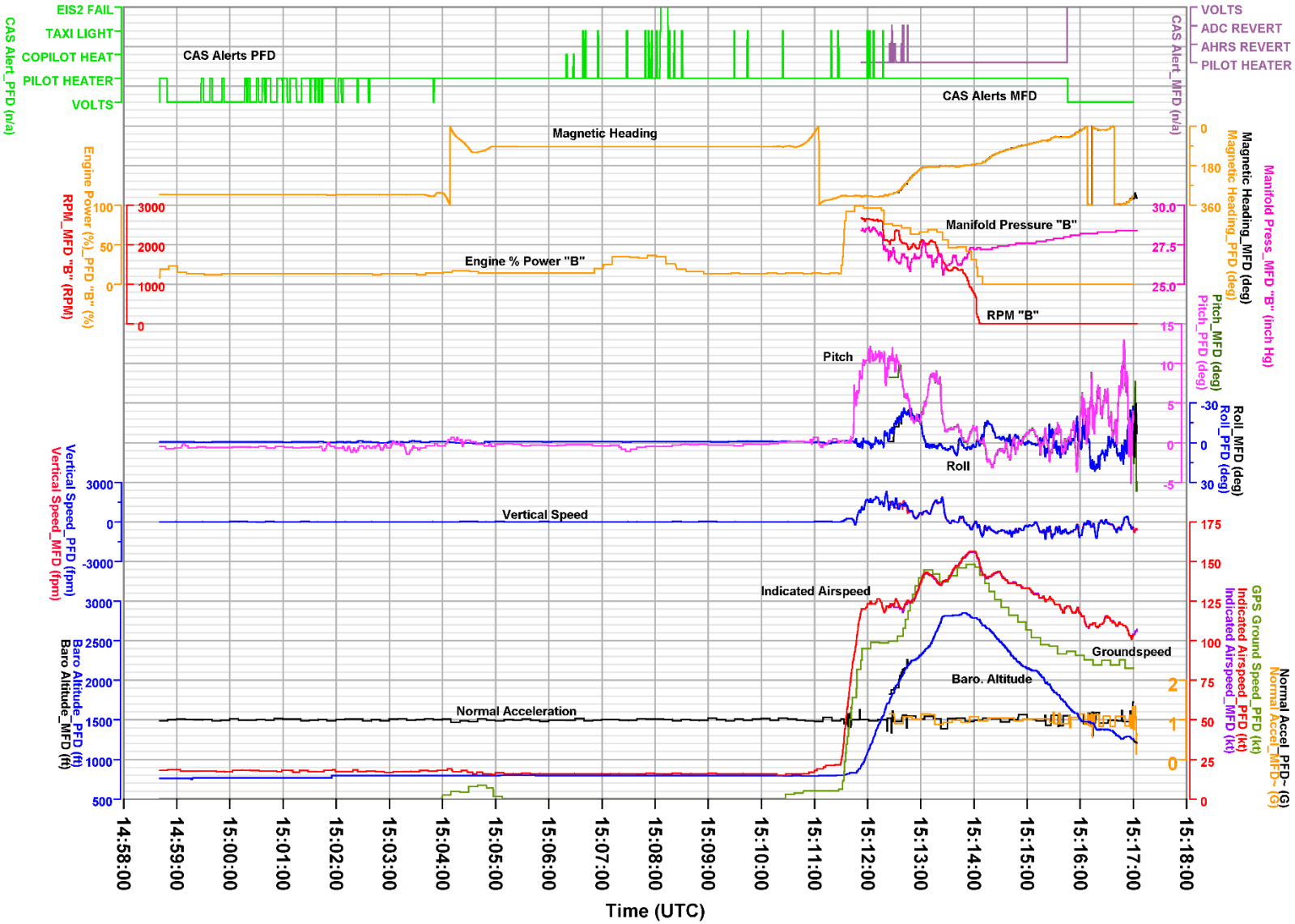

Figure 10. Basic aircraft performance, systems and engine parameters for the entire accident recording.

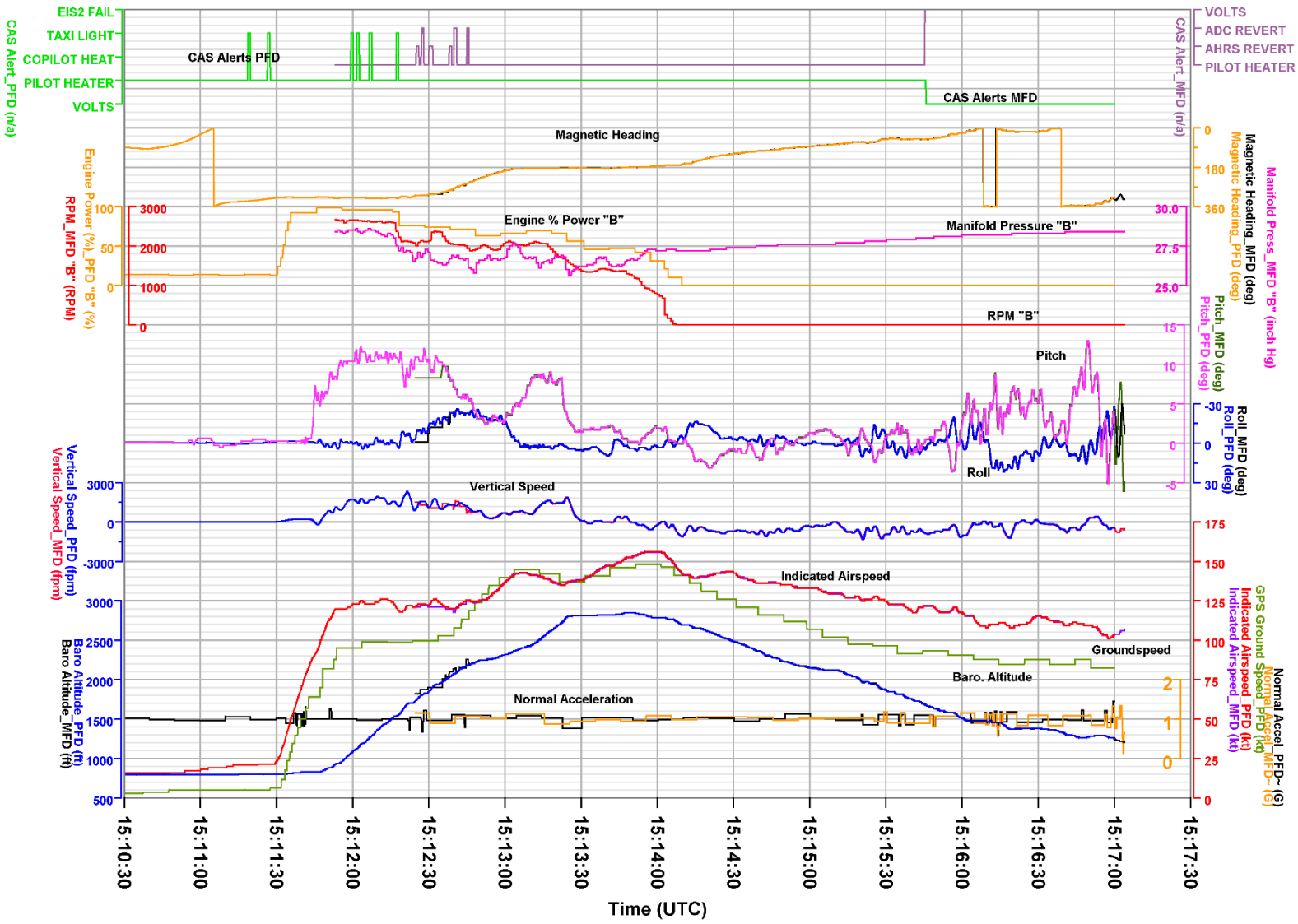

Figure 11. An expanded timescale plot of basic aircraft performance, systems and engine parameters for the final portion of the accident recording.

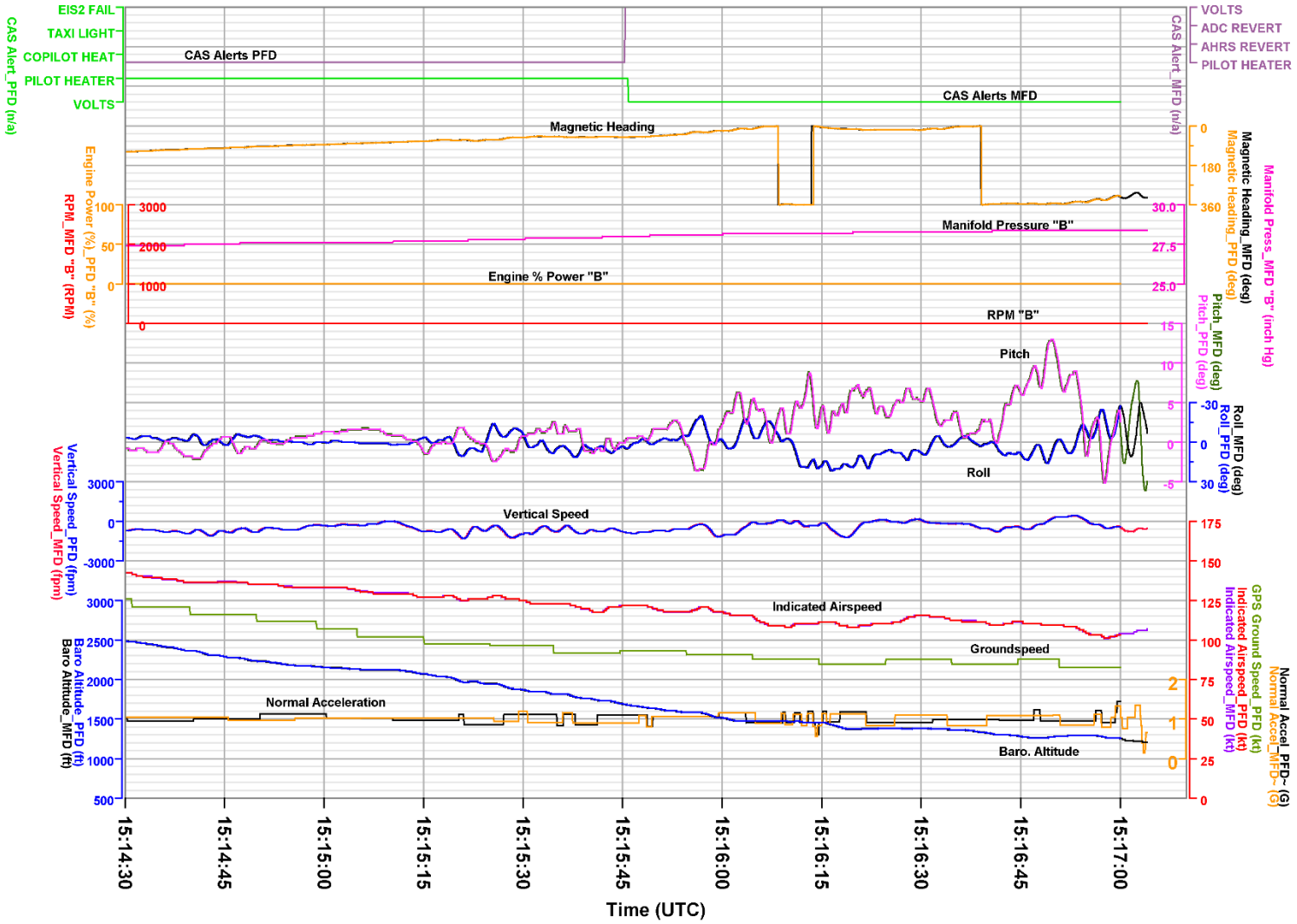

Figure 12. A super-expanded timescale plot of basic aircraft performance, systems and engine parameters for the end of the accident recording.

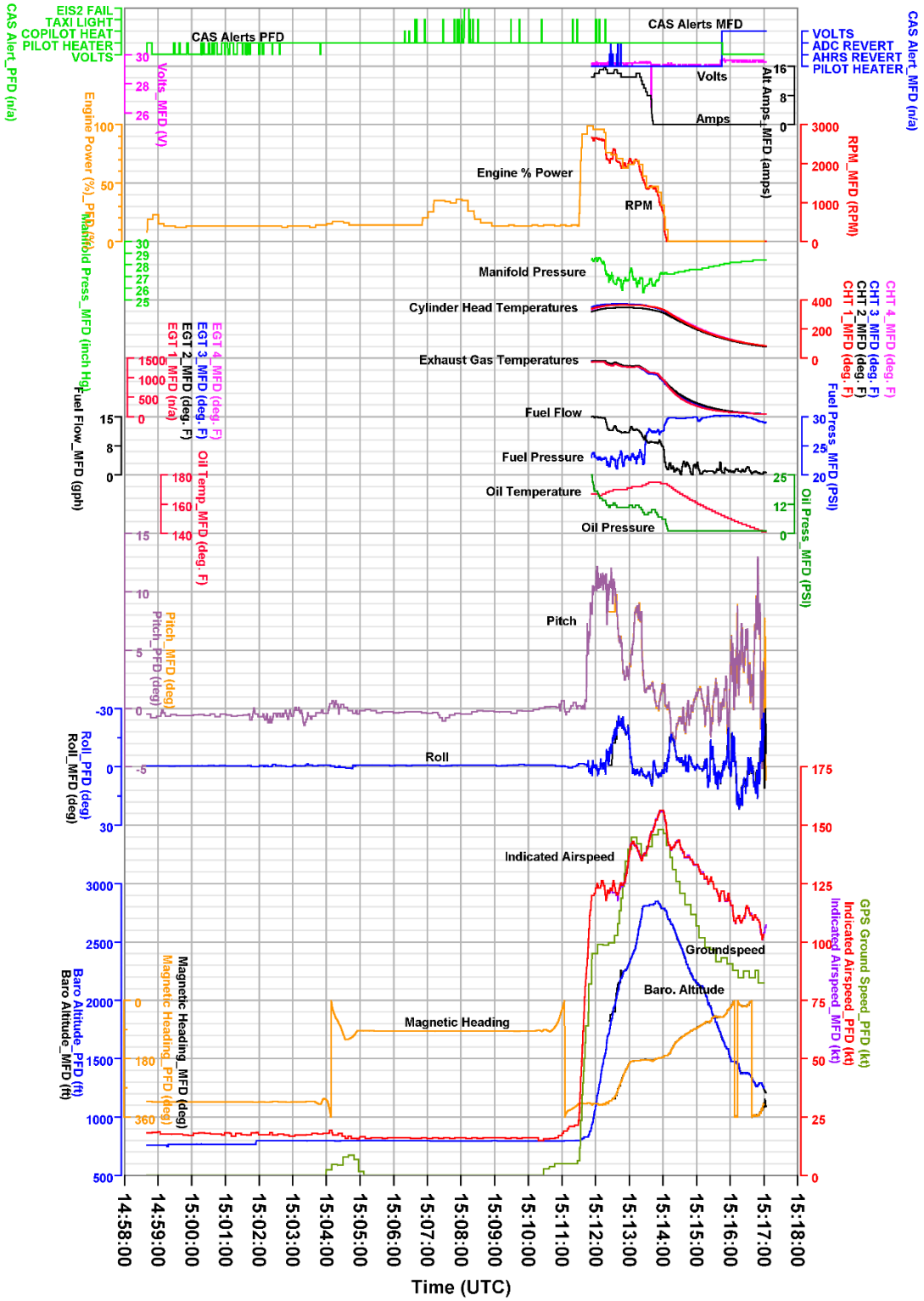

Figure 13. A plot of basic aircraft performance parameters and all available and validated engine performance data for Engine "B" for the entire accident recording.

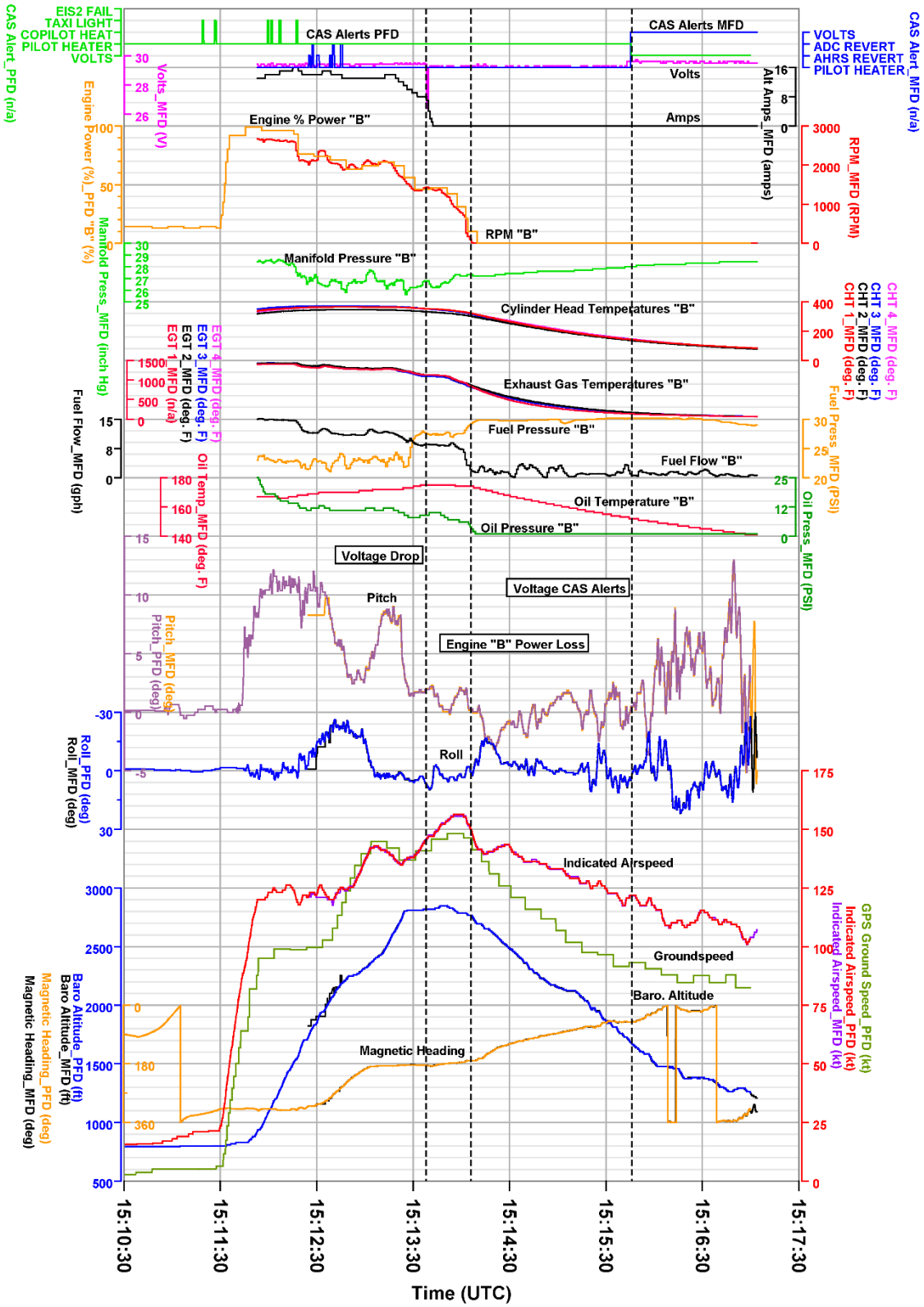

Figure 14. A plot of basic aircraft performance parameters and all available and validated engine performance data for Engine “B” for the final portion of the accident recording.

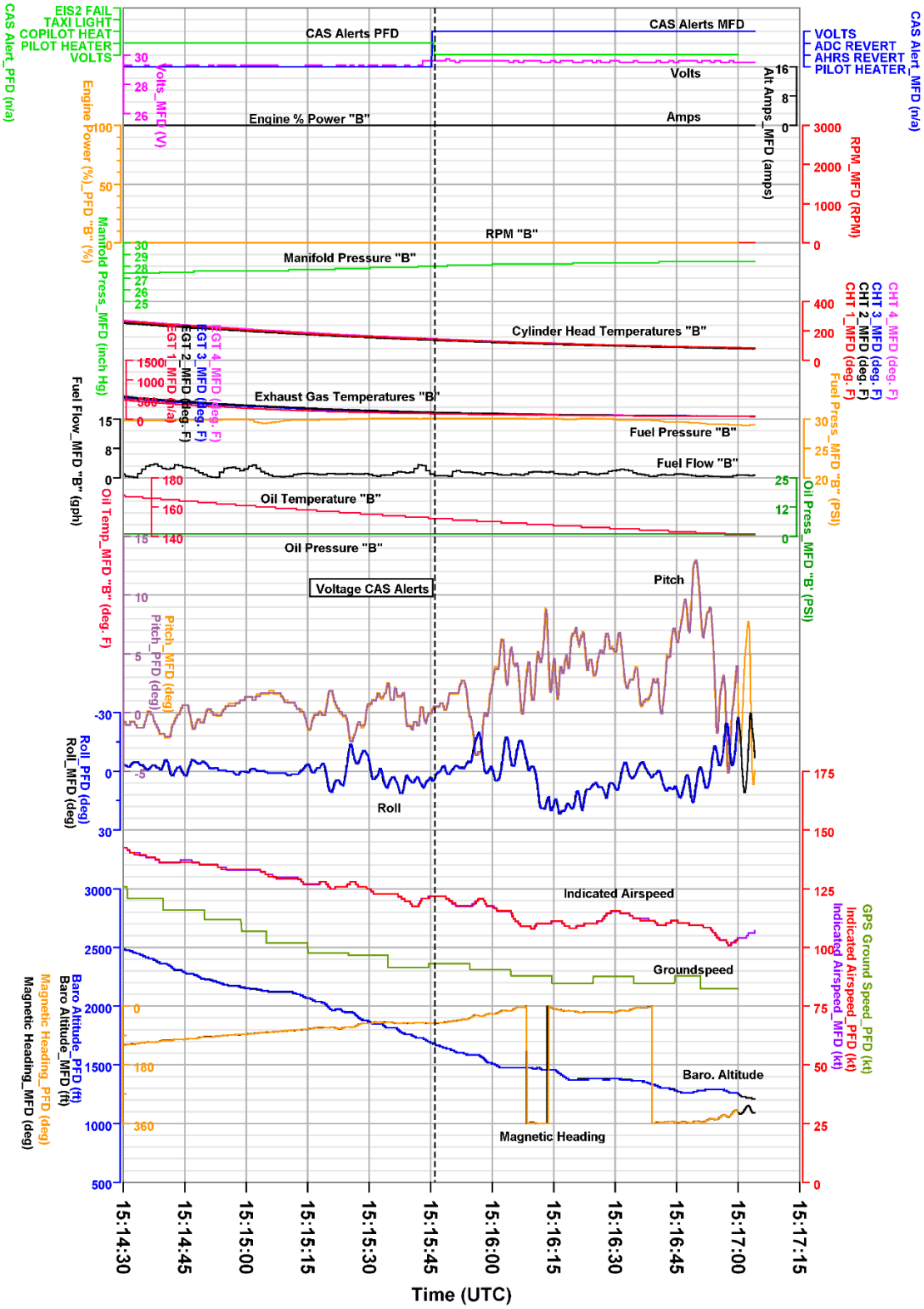

Figure 15. A plot of basic aircraft performance parameters and all available and validated engine performance data for Engine “B” for the end of the accident recording.

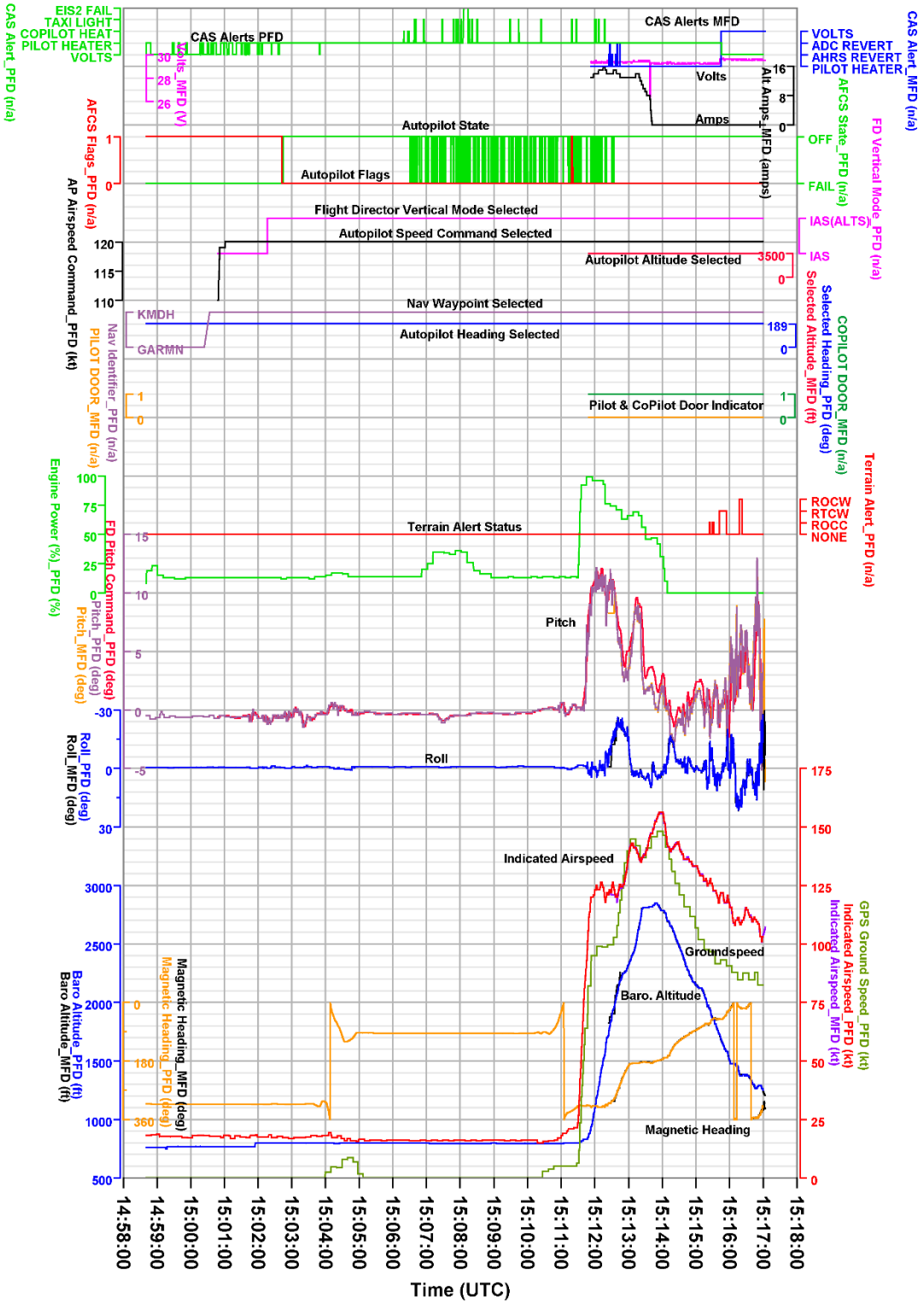

Figure 16. A plot of basic aircraft performance parameters and all available and validated aircraft systems data for the entire accident recording.

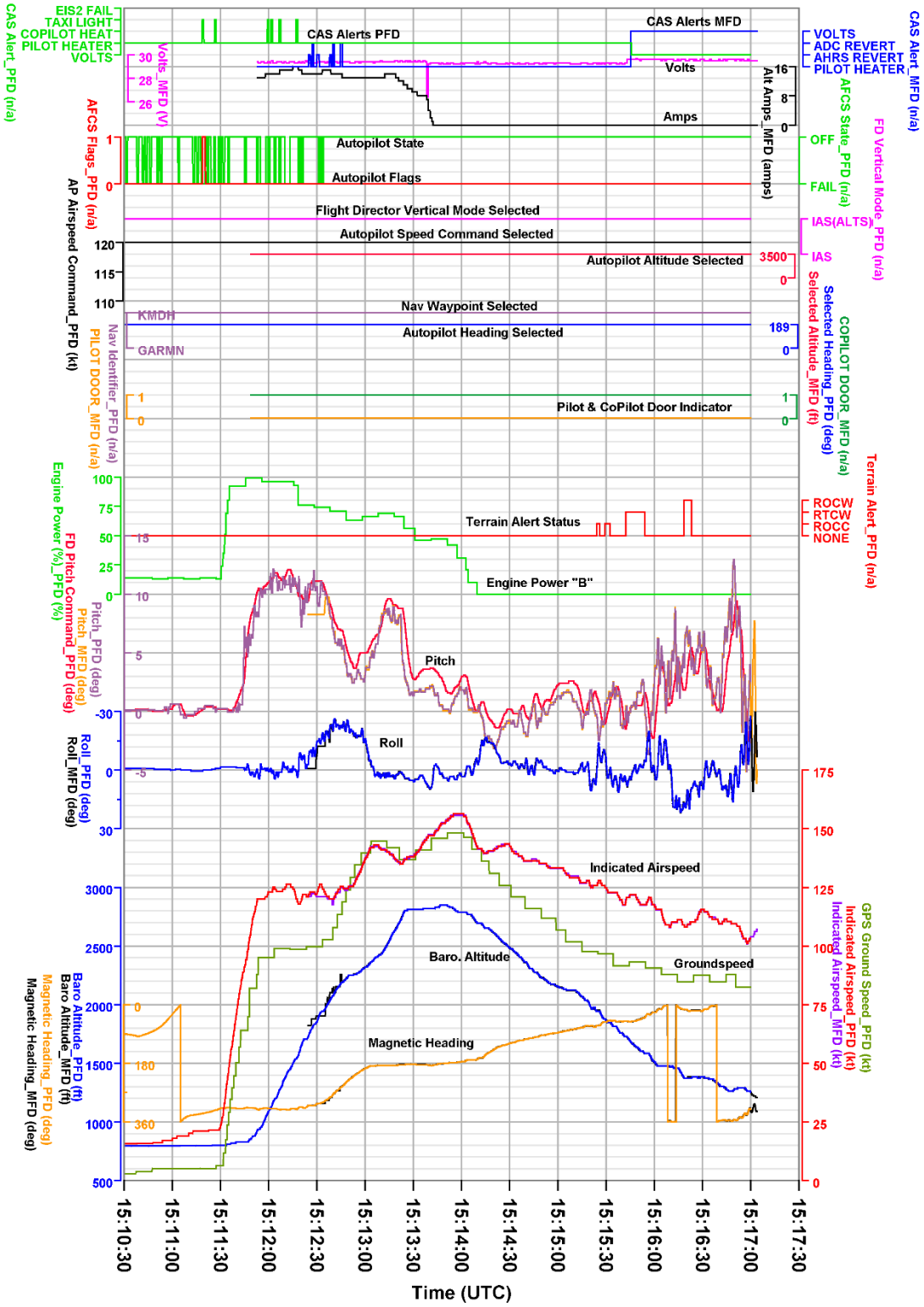

Figure 17. A plot of basic aircraft performance parameters and all available and validated aircraft systems data for the final portion of the accident recording.

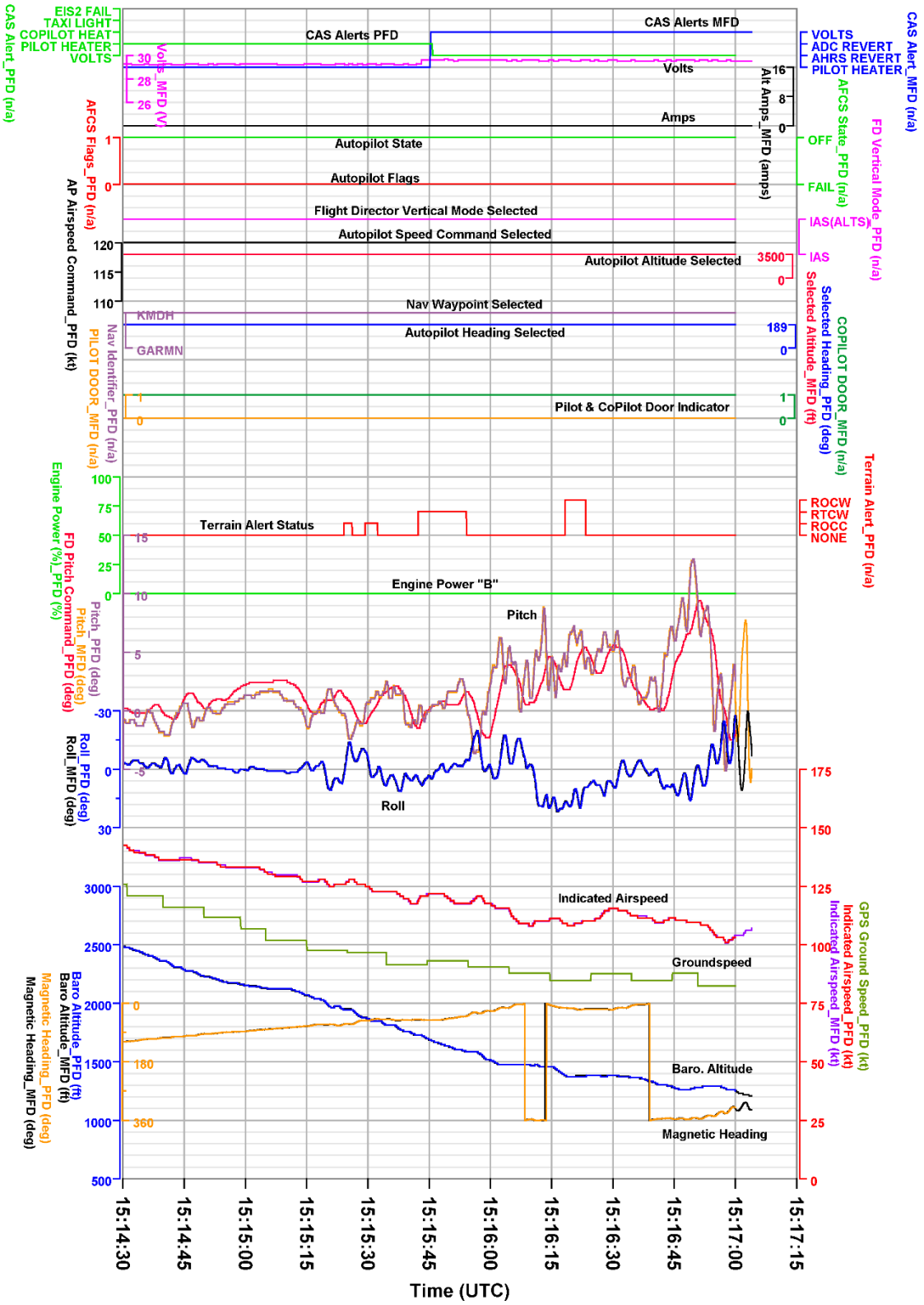

Figure 18. A plot of basic aircraft performance parameters and all available and validated aircraft systems data for the final portion of the accident recording.

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 abbreviations used in this report.

Table A-1. Verified and provided parameters.

Parameter Abbreviation (units)	Parameter Name
AFCS Flags_PFD (n/a)	AutoFlight Control State - FLAGS - Source PFD
AFCS State_PFD (n/a)	AutoFlight Control State - FLAGS - Source PFD
Alt Amps_MFD (amps)	Alternator Amperage - Source MFD
AP Airspeed Command_PFD (kt)	Autopilot Commanded Airspeed - Source PFD
Baro Altitude_MFD (ft)	Barometric Altitude - Source MFD
Baro Altitude_PFD (ft)	Barometric Altitude - Source PFD
CAS Alert_MFD (n/a)	Crew Alerting System - Source MFD
CAS Alert_PFD (n/a)	Crew Alerting System - Source PFD
CHT #_MFD - Engine "B" (deg. F)	Cylinder Head Temperature - Cylinder # - Engine "B"
COPILOT DOOR_MFD (n/a)	CoPilot Side Door Status - Source MFD
EGT 1_MFD - Engine "B" (deg. F)	Exhaust Gas Temperature - Cylinder # - Engine "B"
Engine Power (%)_PFD - Engine "B" (%)	Percent Power - Source PFD - Engine "B"
FD Pitch Command_PFD (deg)	Flight Director Pitch Command - Source PFD
FD Vertical Mode_PFD (n/a)	Flight Director Vertical Mode - Source PFD
Fuel Flow_MFD - Engine "B" (gph)	Fuel Flow - Engine "B" - Source MFD
Fuel Press_MFD - Engine "B" (PSI)	Fuel Pressure - Engine "B" - Source MFD
GPS Ground Speed_PFD (kt)	Groundspeed - Source PFD
Indicated Airspeed_MFD (kt)	Indicated Airspeed - Source MFD
Indicated Airspeed_PFD (kt)	Indicated Airspeed - Source PFD
Magnetic Heading_MFD (deg)	Magnetic Heading - Source MFD
Magnetic Heading_PFD (deg)	Magnetic Heading - Source PFD
Manifold Press_MFD - Engine "B" (in. Hg)	Manifold Pressure - Engine "B" - Source MFD
Manifold Press_MFD - Engine "B" (in. Hg)	Manifold Pressure - Engine "B" - Source MFD
Nav Identifier_PFD (n/a)	Navigational Waypoint Identifier (Sequenced) - Source PFD
Normal Accel_MFD (g)	Normal Acceleration - Source MFD
Normal Accel_PFD (g)	Normal Acceleration - Source PFD
Oil Press_MFD - Engine "B" (psi)	Oil Pressure - Engine "B" - Source MFD
Oil Temp_MFD - Engine "B" (deg. F)	Oil Temperature - Engine "B" - Source MFD
PILOT DOOR_MFD (n/a)	Pilot Side Door Status - Source MFD
Pitch_MFD (deg)	Pitch - Source MFD
Pitch_PFD (deg)	Pitch - Source PFD - Source PFD
Roll_MFD (deg)	Roll - Source MFD
Roll_PFD (deg)	Roll - Source PFD - Source PFD
RPM_MFD (RPM)	RPM - Engine “B” - Source MFD

Parameter Abbreviation (units)	Parameter Name
Selected Altitude (ft)	AutoFlight System Selected Altitude - Source MFD
Selected Heading_PFD (deg)	AufoFlight System Selected Heading - Source PFD
Terrain Alert_PFD (n/a)	Terrain Warning System Alert Status - Source PFD
Vertical Speed_MFD (fpm)	Vertical Speed - Source MFD
Vertical Speed_PFD (fpm)	Vertical Speed - Source PFD
Volts_MFD (V)	System Voltage - Source MFD

Table A-2. Unit abbreviations.

Units Abbreviation	Description
RPM	revolutions per minute
deg. F	degrees Fahrenheit
gph	gallons per hour
psi	pounds per square inch
in.Hg	Inches of Mercury
deg	degrees
fpm	feet per minute
ft	feet
kt	knots
n/a	not available
g	unit of gravitational acceleration
%	percent
V	volts
amps	Amperes