

# National Transportation Safety Board

Office of Research and Engineering

Washington, DC 20594



DCA22FA082

## **ELECTRONIC DEVICES**

Specialist's Factual Report

January 25, 2023

## **A. ACCIDENT**

Location: Jolon, CA  
Date: February 16, 2022  
Time: 09:58 pacific standard time (PST)  
UAS: Joby Aero Inc. JAS4-2, N542AJ

## **B. ELECTRONIC DEVICES SPECIALIST**

Specialist Sean Payne  
Sr. Engineer  
National Transportation Safety Board (NTSB)

## **C. DETAILS OF THE INVESTIGATION**

A group was not convened. The NTSB Vehicle Recorder Division received the following electronic device and files:

Recorder Manufacturer/Model: SanDisk Extreme 128GB microSD card  
Recorder Serial Number: 1283YXDSY11R  
Associated Device: GoPro HERO (Forward Facing)

Recorder Manufacturer/Model: SanDisk Extreme 128GB microSD card  
Recorder Serial Number: D361YFHJ70QZ  
Associated Device: GoPro HERO MAX (Spherical Capture)

Recorder Manufacturer/Model: High Resolution Recorder (Joby Aero Inc.)  
Recorder Serial Number: TRN 0575

Recorder Manufacturer/Model: Kingston 120GB SSD  
Recorder Serial Number: 50026B778270B64A  
Associated Device: High Resolution Recorder (Joby Aero Inc.)

Recorder Manufacturer/Model: Samsung 500GB M2 SSD  
Recorder Serial Number: S3EUNB0J600225D  
Associated Device: Flight Test Instrumentation Data Acquisition (DAQ) Module

## 1.0 Device Description

### GoPro HERO

The GoPro HERO is a compact, lightweight, POV digital camera enclosed in a ruggedized housing that allows the camera to be mounted in a variety of positions using an array of supported accessories.<sup>1</sup> Depending on the model, the camera supports 5K HD at various frame rates as well as other lower quality recording resolutions at higher frame rates.<sup>2, 3</sup> The camera can be set to record still images simultaneously or independently of a video stream. The latest models employ a digital stabilization method. Metadata used for the stabilization system can be exploited for use in accident investigation. In addition, some models can record GPS data and can provide a track history of the device. The camera supports recording to microSD cards.<sup>4</sup> A built in Wi-Fi module allows users to connect to the camera either via an accessory remote control or via a smart phone app that permits camera control and image transfer.<sup>5</sup>

### GoPro HERO MAX

The GoPro Hero Max is a 360-degree format camera that lets you capture fully immersive, panoramic footage. The device has two lenses and two independent image sensors. The Hero Max captures can capture 360-degree video in up to 4K resolution and a frame rate of 60 frames per second (fps). It also has built-in stabilization, voice control, and a mobile app for editing and sharing footage. The Hero Max is waterproof up to 16 feet and offers a range of accessories for different applications.

### Joby Aero Inc. High Resolution Recorder (HRR)

The High Resolution Recorder (HRR) is a Joby Aero Inc data module designed to capture network traffic files. The HRR is [REDACTED] installed units. [REDACTED]

[REDACTED] The system records to internal commercial off the shelf (COTS) flash storage. Files are recorded in a proprietary file type (PCAP) that can be decoded to engineering units by Joby. Some design considerations had been included to ensure files are written properly in

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<sup>1</sup> POV – Point of View Shot – A photography technique that records the character’s viewpoint from a singular camera location mounted in a manner that represents the character’s field of view.

<sup>2</sup> 5K – A resolution format of 5120 x 2880 pixels comprises the most common format.

<sup>3</sup> HD – High Definition – A resolution generally consisting of greater than 480 lines of horizontal resolution.

<sup>4</sup> SD – Secure Digital – a standard for nonvolatile memory card used in portable devices.

<sup>5</sup> Wi-Fi – A local area wireless technology that allows electronic devices to exchange data over a network.

the scenario of an abrupt loss of power. These [REDACTED] HRRs were collocated on the vehicle at the time of the accident. The information in this report covers the span port HRR.

## **Flight Test Instrumentation DAQ Module (DAQ)**

The Flight Test Instrumentation Data Acquisition module (DAQ) is designed to record onboard telemetry information. This information includes vibration and strain gauge information. Detailed information was not requested for the DAQ as data was unable to be recovered (discussed in section 1.1 below).

### **1.1 Data Recovery**

#### **GoPro HERO**

The microSD card from the GoPro HERO is pictured in figure 1. The device appeared intact, with evidence of some slight external physical damage. The device was examined under a digital stereo microscope for cracks and other signs of damage. Only areas of nominal wear and small portions of abrasive damage in the edge areas of the package were detected with the visual inspection. The device was attempted to be readout with a forensic write blocker and failed to mount. The device was then re-examined using an x-ray machine. The x-ray examination produced no obvious defects, however, x-rays are typically ineffective at showing damage to the memory's internal silicon die.

The microSD card was sent to a third-party lab for subsequent evaluation. The third-party lab reported back that they were unable to recover data.

No data was recovered from this device.



**Figure 1.** Photo of microSD card from the GoPro HERO camera, as received.

## **GoPro HERO MAX**

The microSD card from the GoPro HERO MAX is pictured in figure 2. The device appeared intact, with evidence of some slight external physical damage. The device was examined under a digital stereomicroscope for cracks and other signs of damage. Only areas of nominal wear and small portions of abrasive damage in the edge areas of the package were detected with the visual inspection. The device was read out with a forensic write blocker and the memory was successfully accessed. The memory contained a number of image recordings consistent with capturing flight test operations. The last file present on the card was corrupted and unplayable. The NTSB lab employed a software process used for corrupted file recovery and was able to copy and play back the file successfully. The camera manufacturer's supplied software was used to facilitate playback, and screen captures were generated for use in the investigation and this report. The repaired file was provided to Joby Aero Inc for further analysis and use in the generation of their party submission.



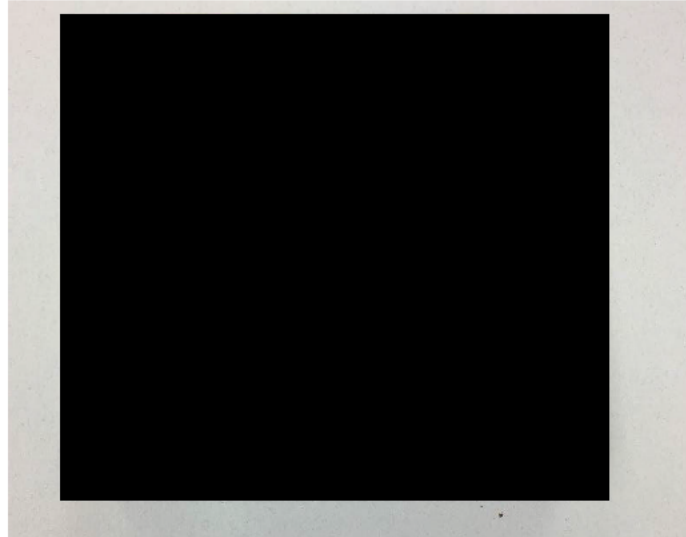
**Figure 2.** Photo of microSD card from the GoPro HERO MAX camera, as received.

## **Joby Aero Inc. High Resolution Recorder (HRR)**

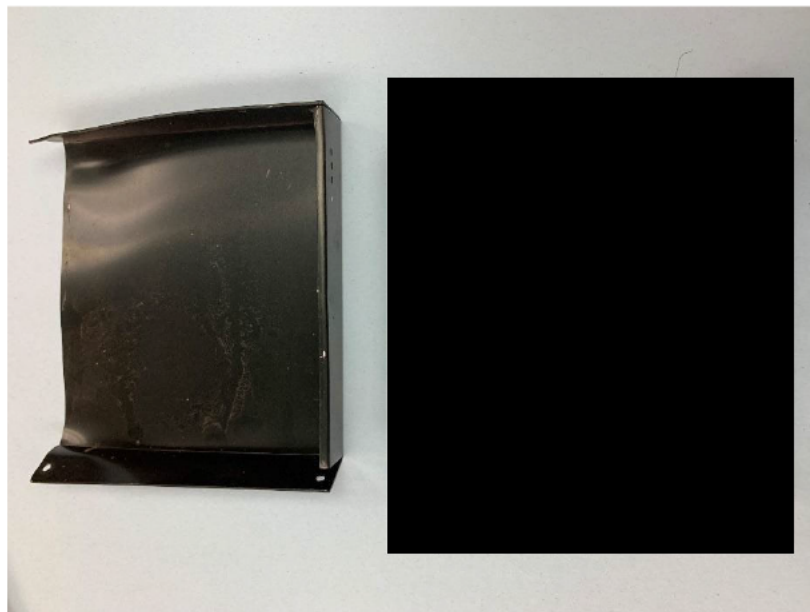
The device is pictured in its arrival condition in figure 3 and, with the top cover removed, in figure 4. The device exhibited deformation damage, specifically the area around the device's ports were damaged. An examination of the device's main board revealed numerous broken pins and subcomponents. Figure 5 is a photo of the device's SSD in its mounting location. The SSD was removed and cleaned. The device was examined with a stereomicroscope for damage. No obvious damage was noted. The device was connected to a write blocker and was accessed successfully.

A number of recording files were copied from the device. These files were in a raw packet capture format and could be decoded by Joby Aero Inc. These files were dispatched to Joby Aero Inc for a processing attempt. This process produced

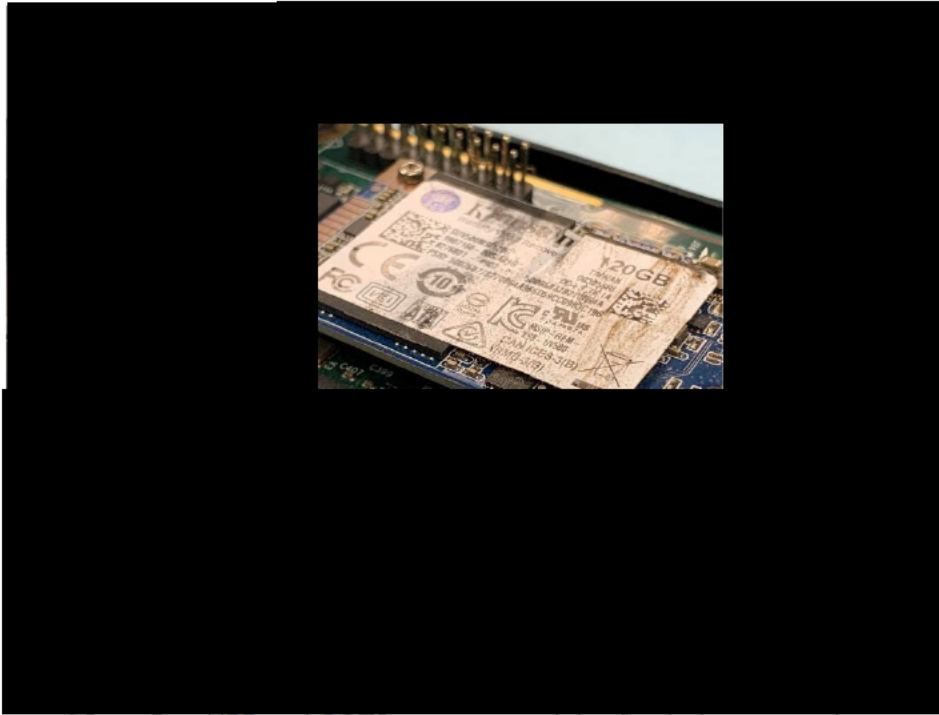
irregular results and instead, a forensic image file of the SSD was captured by the NTSB lab and dispatched to Joby Aero Inc for processing. This was successful and Joby Aero Inc provided a mirror of the recovered data in comma separated value (CSV) format to the NTSB.



**Figure 3.** Photo of span port HRR as received.



**Figure 4.** Photo span port HRR after being opened.



**Figure 5.** Photo of Span Port HRR and COTS memory module after being opened.

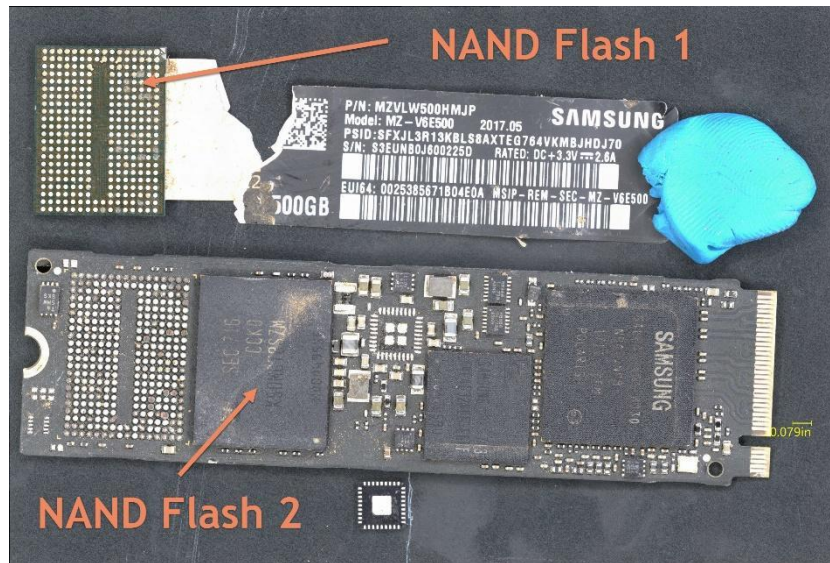
### **Flight Test Instrumentation DAQ Module**

A M2 style SATA SSD associated with the DAQ module was received. Figure 6 shows the arrival state of the DAQ module. The figure shows one of the two NAND flash memory chips had separated from the host board. In most instances, SSDs comprised of multiple NAND flash chips employ some method of striping which means the complete dataset is likely shared between the two chips. A separate controller is used by the SSD to organize and address the data shared between the two chips.

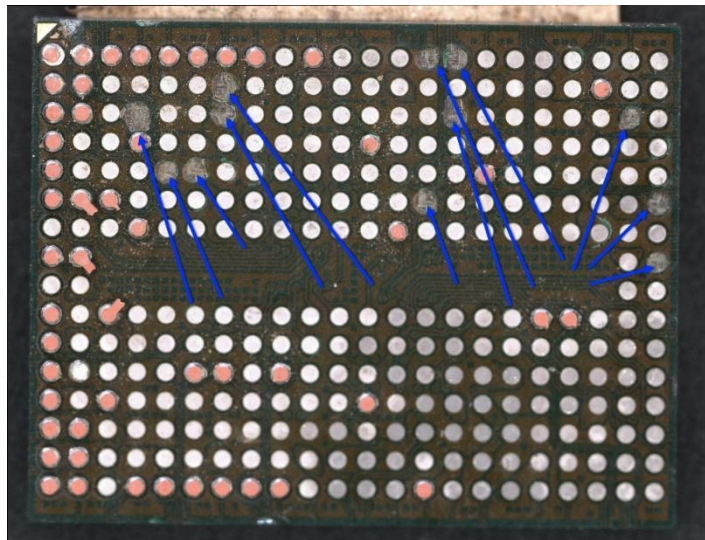
Figure 7 is a microscope image of the back side of the chip that contains the ball grid array (BGA) style connections. Blue arrows note in the figure areas where the BGA style connections were mechanically damaged. These areas show damage to the flash chip's BGA pads. The pads facilitate connection to the chip's internal architecture.

Due to the damage to the device, the difficulty of the repair, and the success of data capture from the high-resolution recorder, data recovery was not pursued for this device.

No data was recovered from the device.



**Figure 6.** Photo of M2 SATA drive from the DAQ, as received. Both NAND flash chips are labeled.



**Figure 7.** Stereoscopic microscopy photo of damage to BGA pads on NAND flash chip 1.

## 1.2 Recording Description

### GoPro HERO

No data was recovered from this device.

### GoPro HERO MAX

The accident event was captured in a 6 minute, 41 second recording. Joby documents report that the position of the HERO MAX is roughly equivalent to eye level when seated at the operator's position. The recording captured the earlier portions of the test point, through the flight test anomaly and ended after N542AJ

had entered into a departure from controlled flight but prior to impact with terrain. The file was both processed independently by the NTSB and also made available to Joby.

Imagery from this camera position is discussed in the Video Study, which can be found in the public docket for this accident.

### **Joby Aero Inc. High Resolution Recorder**

Data extracted from the .PCAP files from Joby were converted for a time period between 17:45:00.000 PST, and the loss of data at 17:58:12.340 PST. Data outside this timeframe, and previous flight data, was not evaluated by the NTSB.

### **Flight Test Instrumentation DAQ Module**

No data was recovered from this device.

## **1.3 Time Correlation**

Data from the HRR was recorded in Universal Coordinated Time (UTC) and was assumed to be correct. The data was offset -28,880 seconds to bring it in alignment with Pacific standard time (PST) which was the local time of the accident.

Timing information for the GoPro HERO MAX is discussed in the Video Study, which can be found in the public docket for this accident.

## **1.4 Data**

### **Joby Aero Inc. High Resolution Recorder**

Figure 8 is a plot of event related parameters which illustrate the chronology of the accident sequence. Selected parameters for the entire portion of the data converted by Joby are plotted. Data began around 09:45:00 PST and persisted until the loss of HRR data around 09:58:12.340 PST.

Figure 9 is a plot of event related parameters which illustrate the chronology of the accident sequence. The plotted time interval is between 09:57:00 PST and the loss of HRR data around 09:58:12.340 PST.

Figure 10 is a plot of basic parameters which illustrate the chronology of the accident sequence. The plotted time interval is between 09:57:20 PST until 9:57:40 PST. The data describes a region in which airspeed increased from approximately [REDACTED] knots to approximately [REDACTED] knots true airspeed. The plot shows the response of motor torque, motor speed and variable pitch actuator position during this timeframe. The motor speed here crosses over [REDACTED] rpm for this portion of the plot.

Figure 11 is a plot of event related parameters which illustrate the chronology of the accident sequence. The plotted time interval is between 09:57:40 PST until 09:57:55 PST. The plotted data shows the airspeed climbing from approximately [REDACTED] to [REDACTED] knots true airspeed as the aircraft continues to descend in slight nose low and right bank attitude. A horizontal line indicates a variable pitch actuator position of [REDACTED] degrees. Values for variable pitch actuator position remain near this value for the duration of this plotted time interval. No obvious oscillations in the data were noted in the parameters for variable pitch actuator angle, motor speed or motor torque.

Figure 12 is a plot of event related parameters which illustrate the chronology of the accident sequence. The plotted time interval is between 09:57:55 PST until the loss of HRR data around 09:58:12.340 PST. A horizontal line is illustrated at [REDACTED] degrees variable pitch actuator position. Airspeed in this plot is increasing from about [REDACTED] to [REDACTED] knots true airspeed as the aircraft continues in a shallow nose down pitch attitude. Values for variable pitch actuator position are shown reduced until approximately 09:58:10 PST when airspeed climbs above [REDACTED] knots true. The remainder of this data is shown in closer detail in figure 13.

Figure 13 is a plot of event related parameters for the time interval between 09:58:10 PST until the loss of HRR data around 09:58:12.340 PST.

The vehicle was in a shallow dive with a pitch angle of roughly 2 degrees nose down. The vehicle was in a right bank (approximately 19 degrees right roll), its heading changing through 118 degrees magnetic and coming to the southeast. As the shallow dive continued and the vehicle's true airspeed increased to approximately [REDACTED] knots, the right bank and shallow nose down pitch remained.

A horizontal line is illustrated at [REDACTED] degrees variable pitch actuator position. Around 09:58:10 PST, the value for station 3 variable pitch actuator position diverges from the other stations. Values for variable pitch actuator position for the remaining stations remained in a slight increasing trend toward approximately [REDACTED] degrees, but with no obvious diverging trend. At this time, values for motor speed across all stations exhibited a slight decreasing trend (just above [REDACTED] rpm), while tilt linkage angle position for all stations remained around zero degrees.

Around 09:58:11 PST, values for blade pitch angles on station 3 showed a divergent trend, peaking locally around 09:58:11.450 PST. At the same time, values for station #3 motor RPM showed similar characteristics. Prior to this moment, tilt linkage angle for all stations remained nearly steady around zero degrees, until approximately this time, in which values for station 3 tilt linkage angle began to diverge. Milliseconds later, values for tilt linkage angle on stations 4 and 1 increased significantly in amplitude.

Milliseconds later, around 09:58:11.473 PST, values for motor speed for station 4 increased rapidly. Data ended for motor speed at station 4 at 09:58:11.783 PST. This time is marked as vertical line on the plot. Shortly thereafter, around 09:58:12.029 PST, motor speed for station 6 diverged and then ramped up rapidly until data loss for that station occurred at 09:58:12.209 PST.

The end of the dataset shows values for motor torque were recorded as a wide range of values. The vehicle's position indicated roll remained approximately 20 degrees right and the vehicle had begun to pitch nose down. All data ended at 09:58:12.340 PST.

## 1.5 Parameters Provided

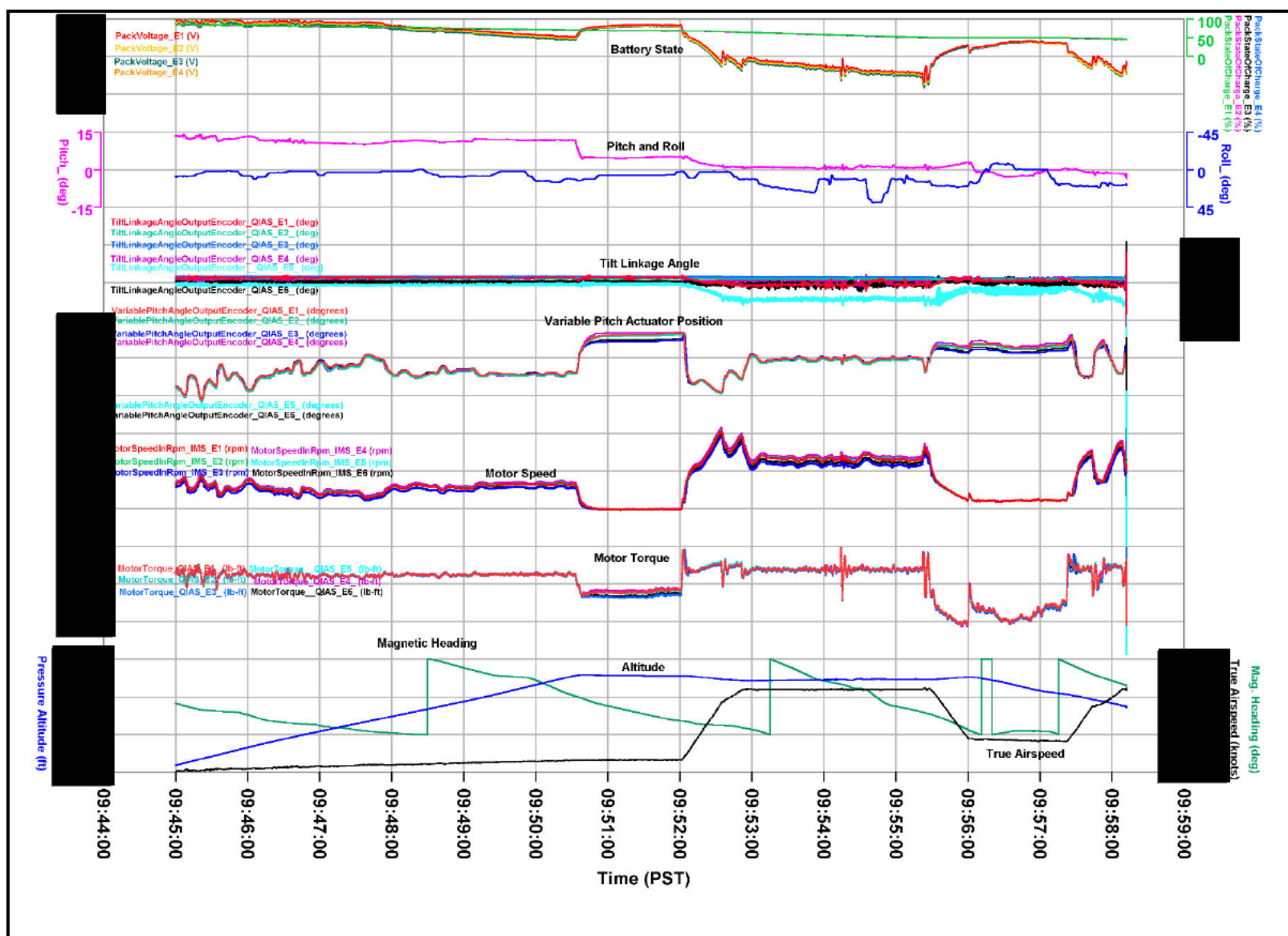
### Joby Aero Inc. High Resolution Recorder

Table 1 describes data parameters provided by the GPS device. Date, Time, Latitude, Longitude, and GPS Altitude are recorded by the device. Groundspeed and Track are derived from the recorded parameters.

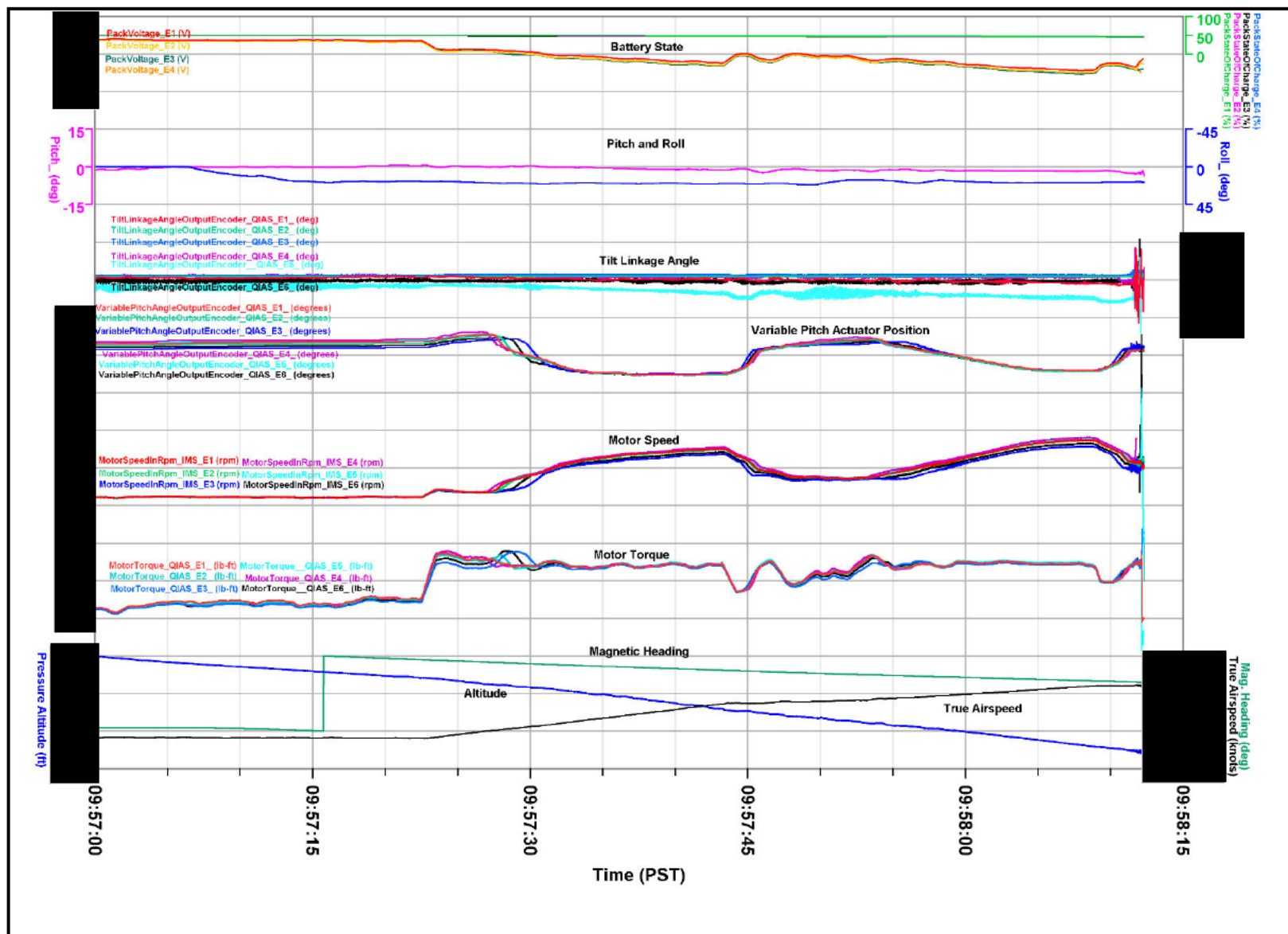
**Table 1.** GPS Data Parameters.

| Parameter Name                                | Parameter Description                              |
|-----------------------------------------------|----------------------------------------------------|
| Date                                          | Date for recorded data point (MM/DD/YYYY)          |
| Time                                          | Time (UTC) for recorded data point (HH:MM:SS)      |
| Latitude (deg)                                | Recorded Latitude (degrees)                        |
| Longitude (deg)                               | Recorded Longitude (degrees)                       |
| Pressure Altitude (ft)                        | Pressure Altitude (feet)                           |
| True Airspeed (knots)                         | True Airspeed (knots)                              |
| Motor Torque_QIAS_E# (ft*lb)                  | Motor Torque- Station # (ft*lb)                    |
| MotorSpeed_IMS_E# (rpm)                       | Motor Speed - Station # (rpm)                      |
| VariablePitchAngleOutputEncoder_QIAS_E# (deg) | Blade Pitch Angle at Linkage - Station # (degrees) |
| TiltLinkageAngleAngleOutputEncider_QIAS_E#    | Actuator Lead Screw Position - Station # (degrees) |
| Magnetic Heading (deg)                        | Magnetic Heading (degrees)                         |
| Pitch_(deg)                                   | Pitch (degrees)                                    |
| Roll_(deg)                                    | Roll (degrees)                                     |
| PackVoltage_E# (V)                            | Battery Pack Voltage - Pack # (Volts)              |
| PackStateOfCharge_E# (%)                      | Battery Pack Charge State - Pack # (percent)       |

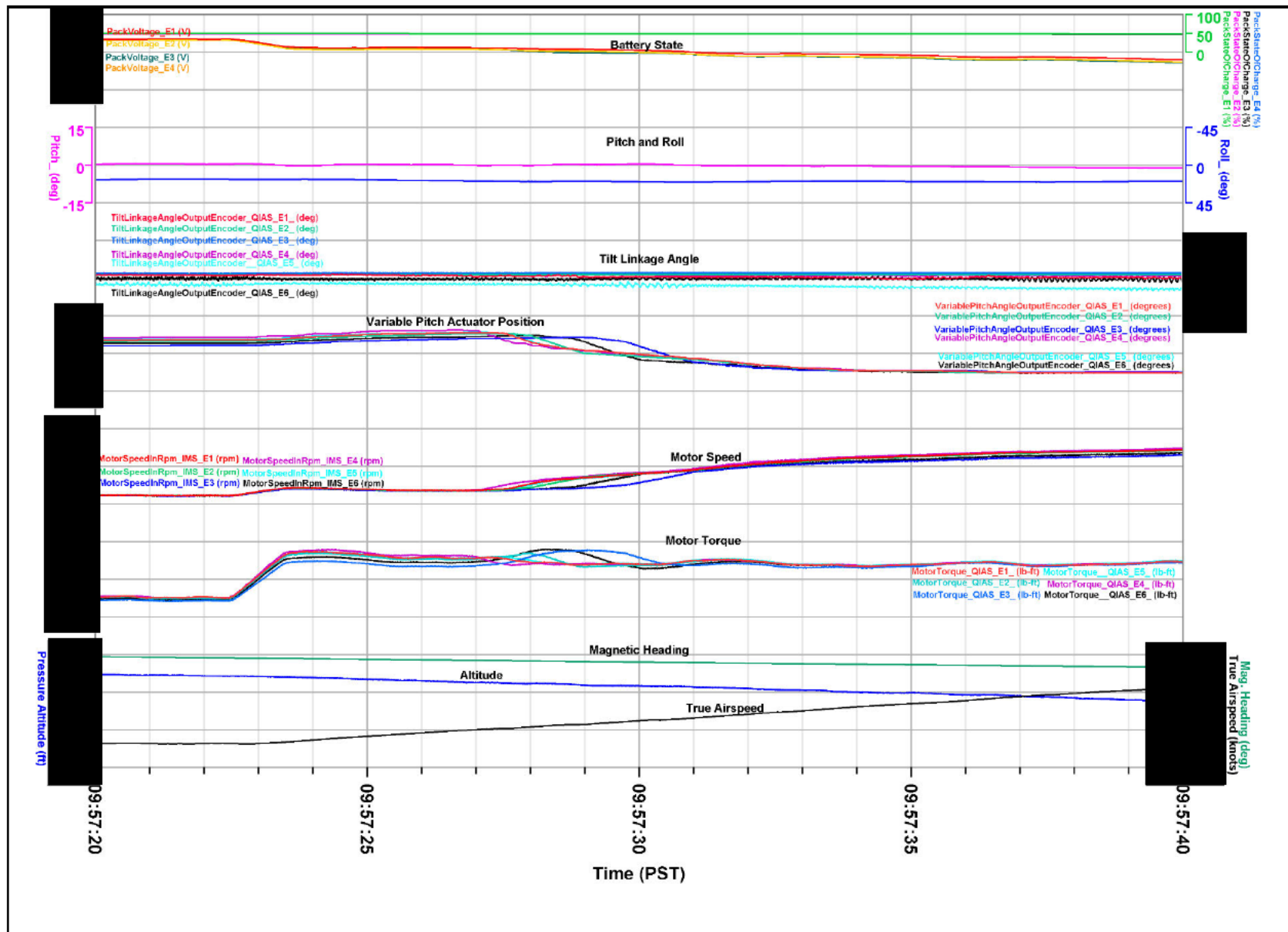
The corresponding tabular data used to create figures 8 to 13 are provided in electronic comma separated value (CSV) format as attachment 1 to this report.



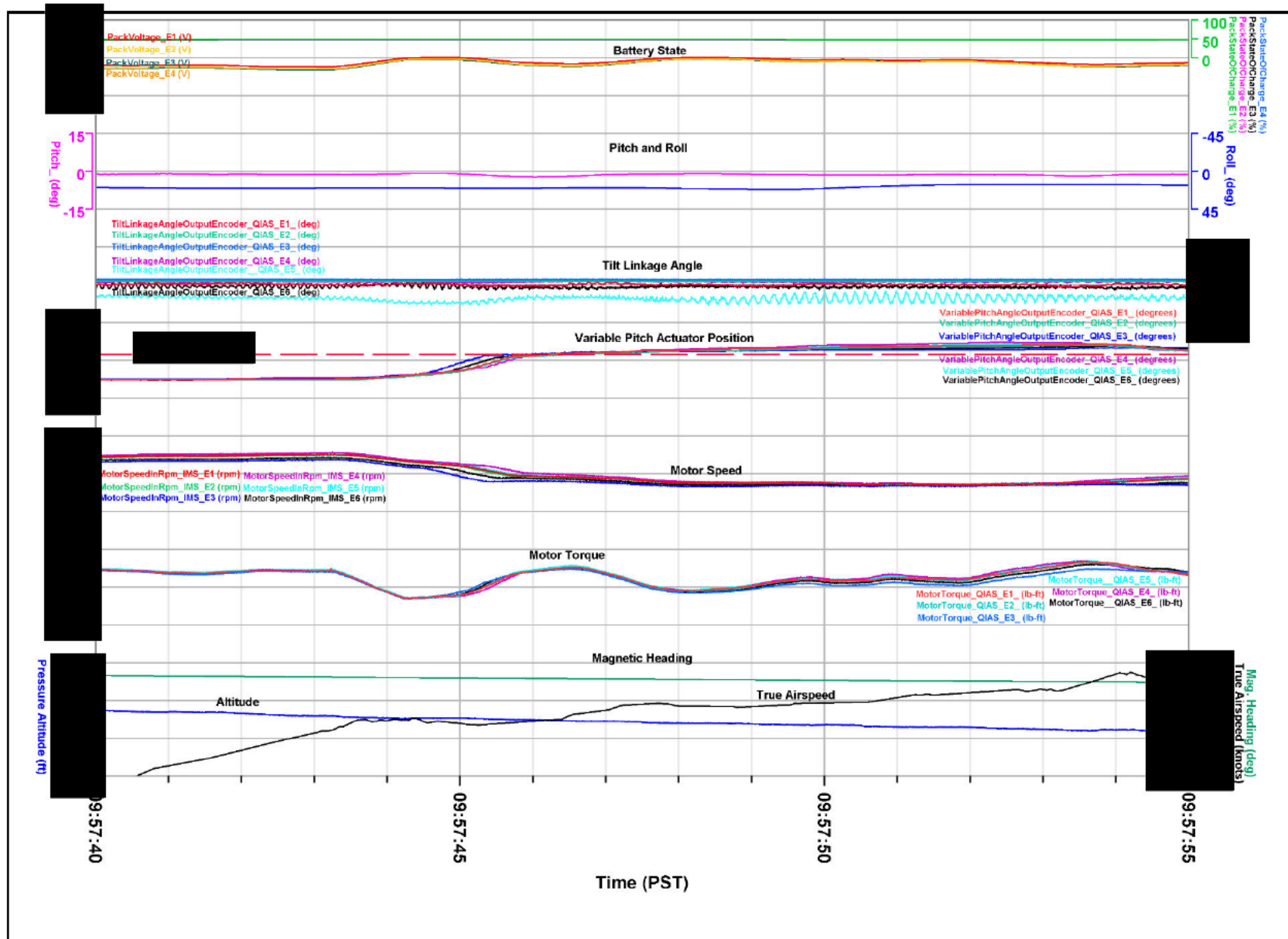
**Figure 8.** Plot of HRR data for select parameters from approximately 09:45:00 PST to the end of data at 09:58:12.340 PST.



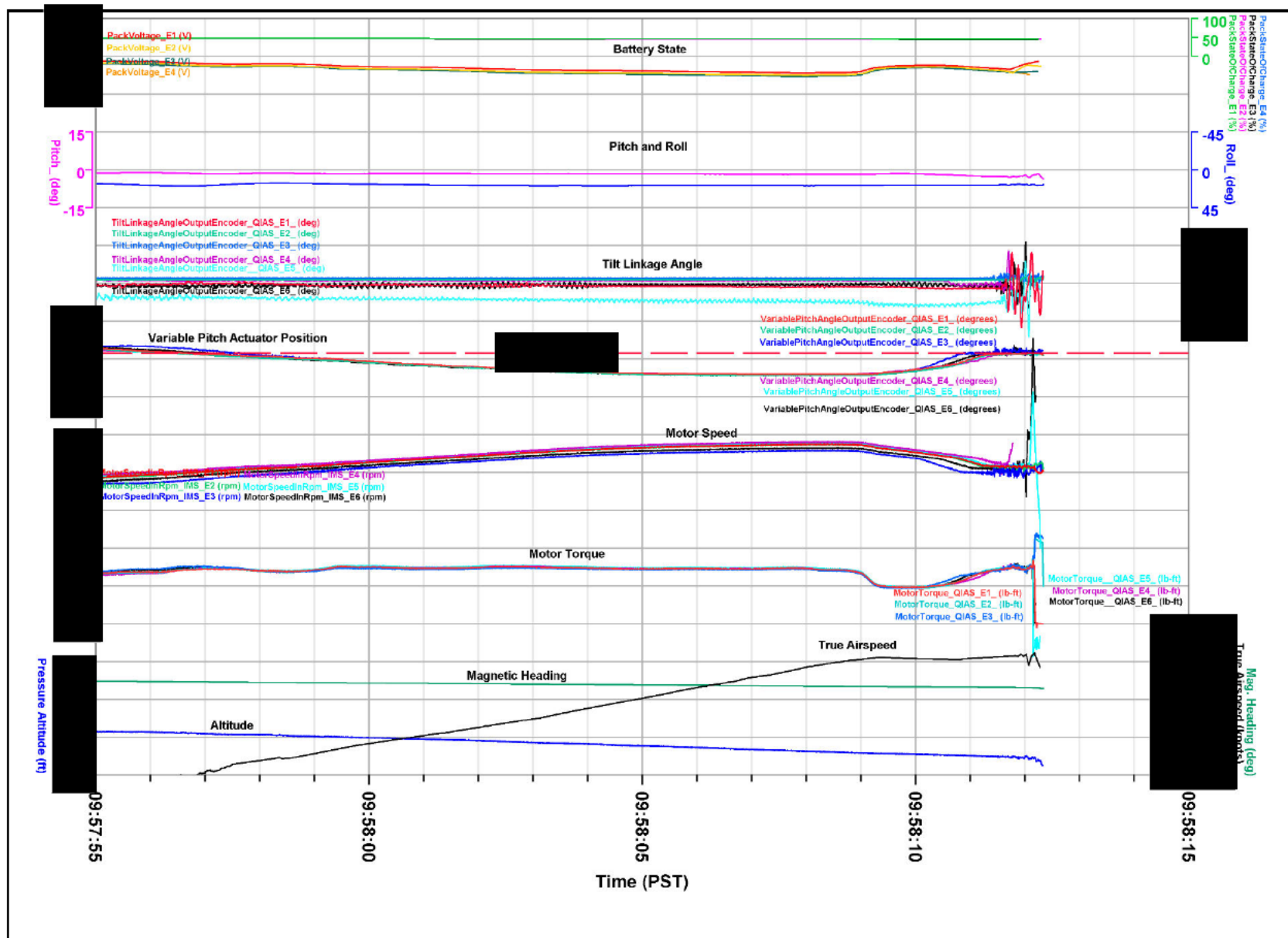
**Figure 9.** Plot of HRR data for select parameters from approximately 09:57:00 PST to the end of data at 09:58:12.340 PST.



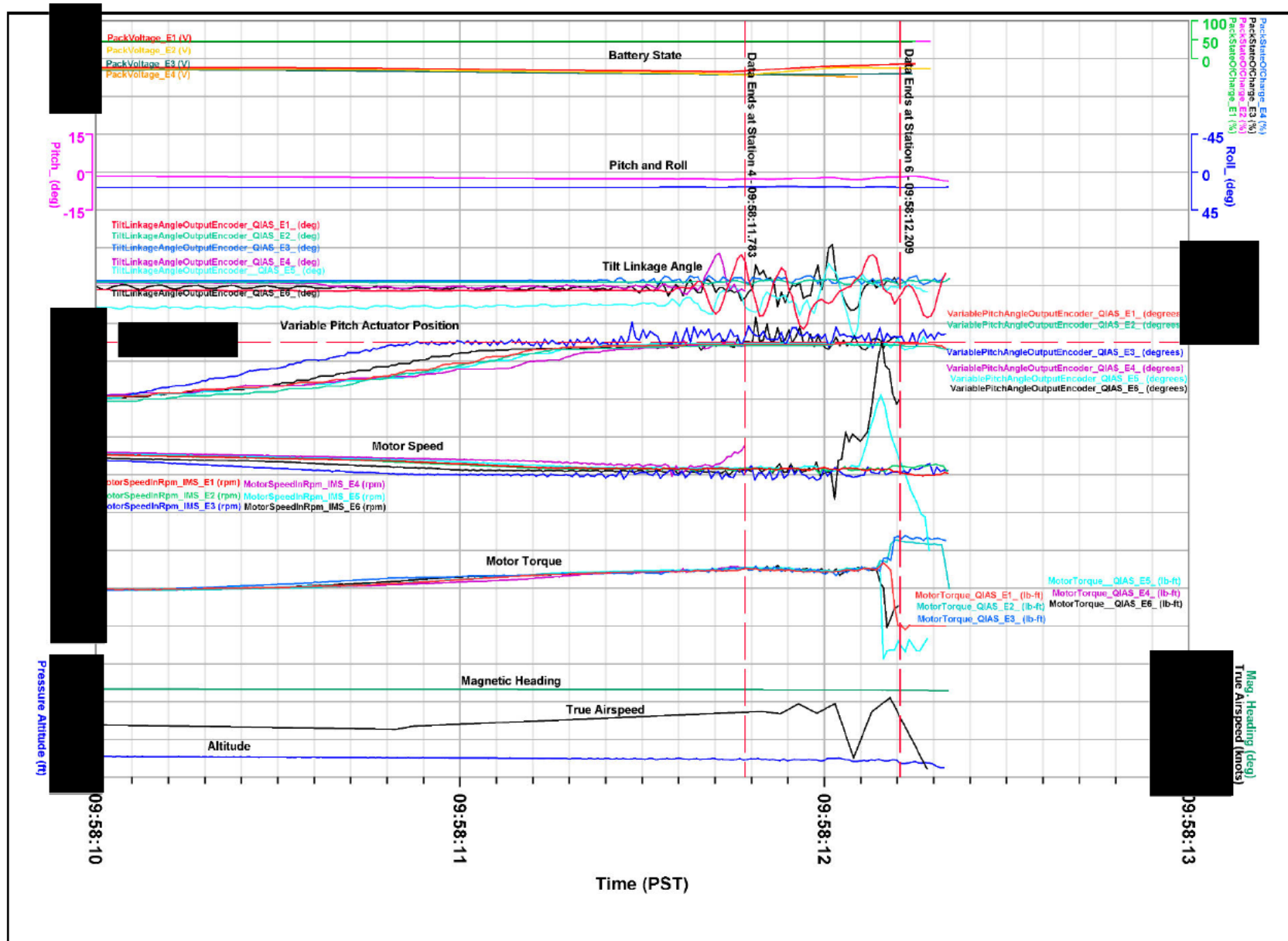
**Figure 10.** Plot of HRR data for select parameters from approximately 09:57:20 PST to the end of data at 09:57:40 PST.



**Figure 11.** Plot of HRR data for select parameters from approximately 09:57:40 PST to 09:57:55 PST.



**Figure 12.** Plot of HRR data for select parameters from approximately 09:57:55 PST to the end of data.



**Figure 13.** Plot of HRR data for select parameters from approximately 09:58:10 PST to the end of data.