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

December 13, 2017

Flight Test Data Recorder

Group Chairman's Factual Report
By Charles Cates

1. EVENT SUMMARY

Location:	Italy, Texas
Date:	July 6, 2016
Aircraft:	Bell 525
Registration:	N525TA
Operator:	Bell Helicopter
NTSB Number:	DCA16FA199

On July 6, 2016, an experimental Bell 525 helicopter, N525TA broke up in flight and impacted terrain near Italy, Texas. The two pilots onboard were fatally injured and the helicopter was destroyed. The flight originated from Arlington, Texas, as a developmental flight test and was conducted under the provisions of 14 *Code of Federal Regulations* (CFR) Part 91. Visual meteorological conditions prevailed at the time of the crash.

2. FLIGHT DATA RECORDER GROUP

A flight test data recorder group was convened at Bell Helicopter's Arlington, Texas location on July 7-10, 2016 and created an initial review of data from all possible sources. The group reconvened on September 8, 2016 to download the helicopter monitoring unit using Bell's dedicated ground station.

Chairman: Charles Cates
Mechanical Engineer, Data Recorder Specialist
National Transportation Safety Board

Member: Brett Howard
Associate Tech Fellow Aircraft Development, Flight Technology
Bell Helicopter

Member: Kim Malone
Chief Flight Test Data Ops & Technical Computing
Bell Helicopter

Member: Dennis Barbini
Flight Test Engineer
Federal Aviation Administration

3. DATA RECORDING SYSTEMS

The event aircraft, N525TA, was an experimental flight test demonstration rotorcraft operating under the provisions of 14 CFR Part 91. The aircraft was outfitted with the capability to carry a pilot and copilot with no passengers. Accordingly, it was not required to be equipped with a flight data recorder (FDR) under §91.609. When certified with the planned number of passenger seats, the aircraft will be required to be equipped with a FDR, and an FDR was installed but not operational at the time of the crash. More details on the FDR can be found in section 4.2 of this report.

Although the aircraft was not required by statute to be equipped with a FDR, it was heavily instrumented with several aircraft and ground based recording systems, both production and flight test based, including a streaming telemetry system, helicopter monitoring unit, avionics recorders, and primary flight display/multi-function display recording capability.

4. DETAILS OF FLIGHT TEST DATA INVESTIGATION

The National Transportation Safety Board (NTSB) Vehicle Recorder Division received the following components with flight data recording and storage capabilities:

Recorder Manufacturer/Model:	**Simmonds Precision Products Vigor Helicopter Monitoring Unit (HMU)**
Recorder Serial Number:	**0006**
Recorder Manufacturer/Model:	**L3 SRVIVR Cockpit Voice/Flight Data Recorder (CVFDR)**
Recorder Serial Number:	**009-01029**
Recorder Manufacturer/Model:	**128 GB Solid State Drive (SSD) from aircraft high speed avionics bus**
Recorder Serial Number:	**TW-032GYJ-55085**
Recorder Manufacturer/Model:	**4 SD memory cards**
Recorder Serial Number:	**unknown**
Recorder Manufacturer/Model:	**Zodiac Aerospace RSM storage module 128 GB**
Recorder Serial Number:	**052405-112012**

4.1. Simmonds Precision Products Vigor HMU Description

The Vigor HMU is the recording component of a helicopter Health and Usage Management System (HUMS) which is planned to be included on production Bell 525 helicopters. The recorder is connected to a variety of accelerometers throughout the aircraft and the avionics bus to provide vehicle health monitoring and diagnostics and usage management data to helicopter operators. Accelerometer power is provided by the HMU, and vibration data is recorded at rates up to 10,000 Hz.

The HMU has a proprietary interface and the data is contained on an internal Compact Flash (CF) card in a proprietary file structure. Processing data from the CF card requires a dedicated ground station for readout and analysis of the data.

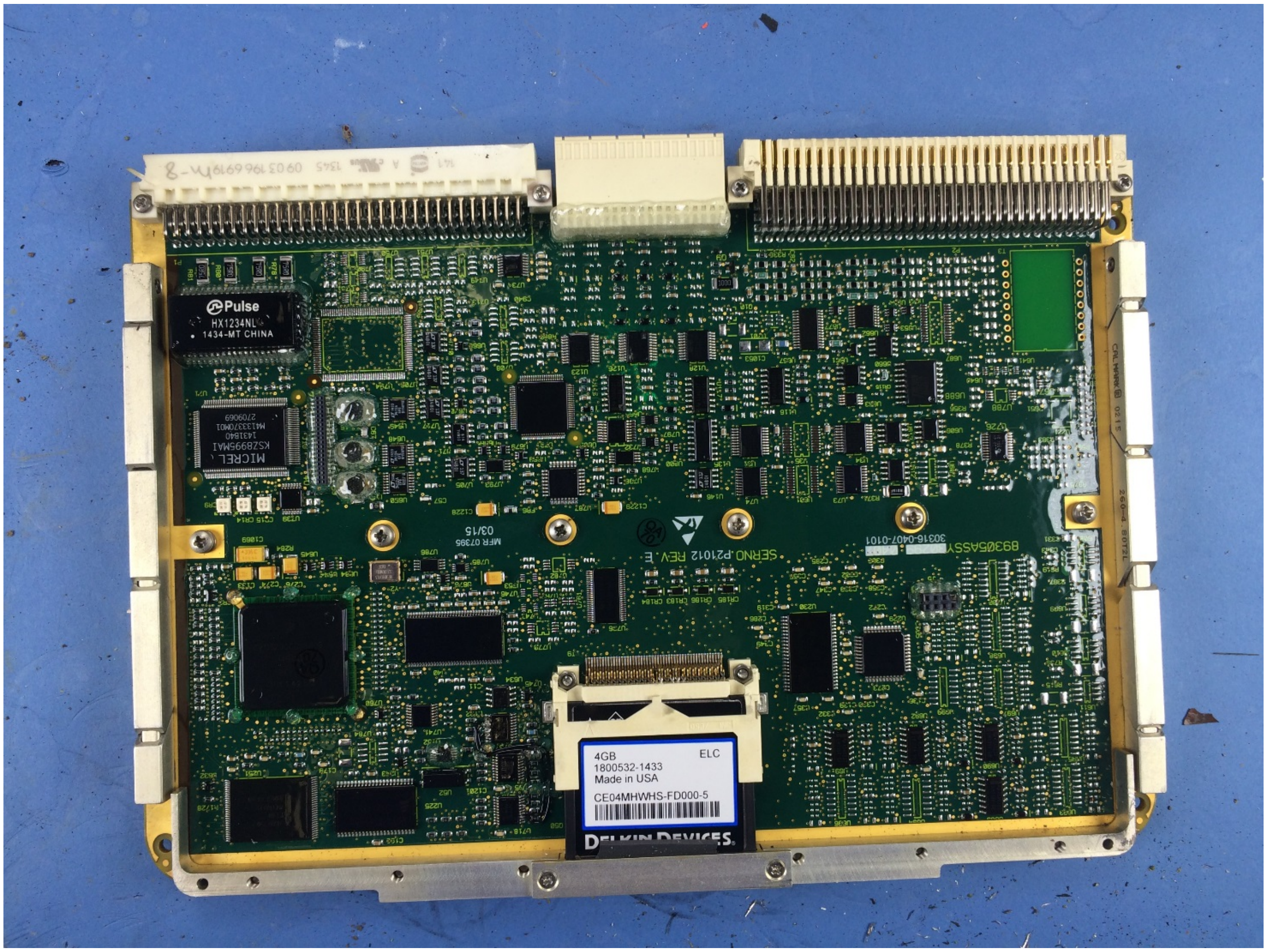
4.1.1. Vigor HMU Condition

The Vigor HMU was damaged in the event by mechanical impact forces. No thermal or other fire-related damage was evident. The extent of the damage is shown in the as-received picture of the HMU, in figure 1.

The manufacturer provided instructions for removal of the internal CF card to the NTSB. The unit was disassembled at the NTSB's vehicle recorder laboratory using the manufacturer's instructions and the memory board and CF card were found to be undamaged, as shown in figure 2. The card was removed and a forensic copy of the card was created without difficulty.

Figure 1. Exterior of Vigor HMU as-received.

Figure 2. HMU processor board with attached CF card.



4.1.2. Vigor HMU Recording Description

The flight test data recorder group reconvened at Bell Helicopter's facility on September 8, 2016, for the purpose of downloading the HMU data. The CF card from the event helicopter HMU was installed in a surrogate HMU in Bell Helicopter's HMU ground station, a part of their helicopter simulation lab, and downloaded without difficulty. Bell's standard test download procedures were used to extract the data to a set of proprietary processing and analysis software tools. The data files were left on the card after the download.

The card was found to contain 303 files, 23 of which were dedicated flight data files. The flight data was time stamped from June 15, 2016 to July 6, 2016. The remainder of the files were various setup, configuration, and other proprietary files.

The HMU data is designed to be used when the helicopter is in service for vibration trend monitoring, fault detection, exceedance recording, aircraft and engine logbook recording, and as part of an operator's maintenance program. Because of the maturity level of the flight test avionics software, not all required data from the ARINC bus was available to the HMU for full trending capabilities. This was a known limitation with the software version, which is planned to be updated prior to the certification of the aircraft.

The recording contained vibration data for airframe and engine assemblies and components. All of the data was mirrored in other recorded data, so the data from the HMU is not further discussed in this report.

4.2. L3 SRVIVR CVFDR

The L3 SRVIVR is a solid state recorder with the ability to record at least two hours of four channel digital audio data as well as at least 25 hours of flight data on solid state memory modules. For more details on the Cockpit Voice Recorder (CVR) functionality, see the Cockpit Voice Recorder Specialist's Factual Report, available in the case docket.

4.2.1. Recorder Condition

Upon arrival at the laboratory, it was evident that the exterior of the CVFDR had sustained significant structural damage, as shown in figure 3. The outer case was removed and the interior crash-protected case did not appear to have any heat or structural damage, as shown in figure 4. The memory board within the crash–protected case was checked for heat or structural damage and none was found, as shown in figure 5. The data was successfully downloaded from the crash-survivable memory using hardware and software provided by the CVFDR manufacturer.

Figure 3. L3 CVFDR as received.

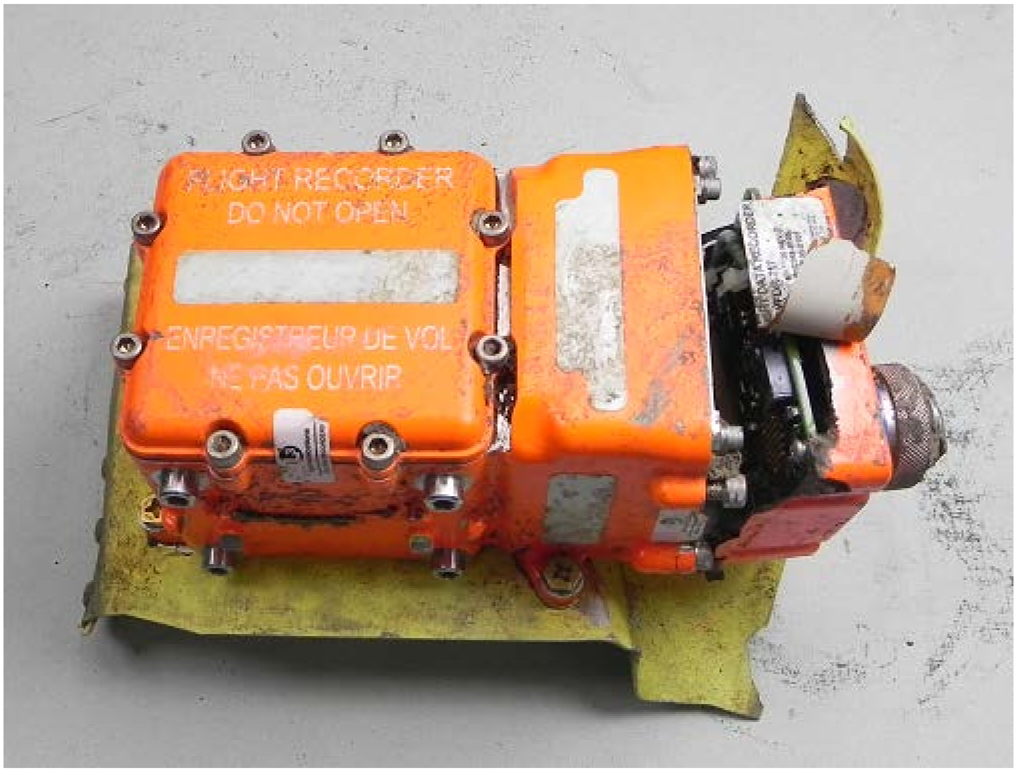
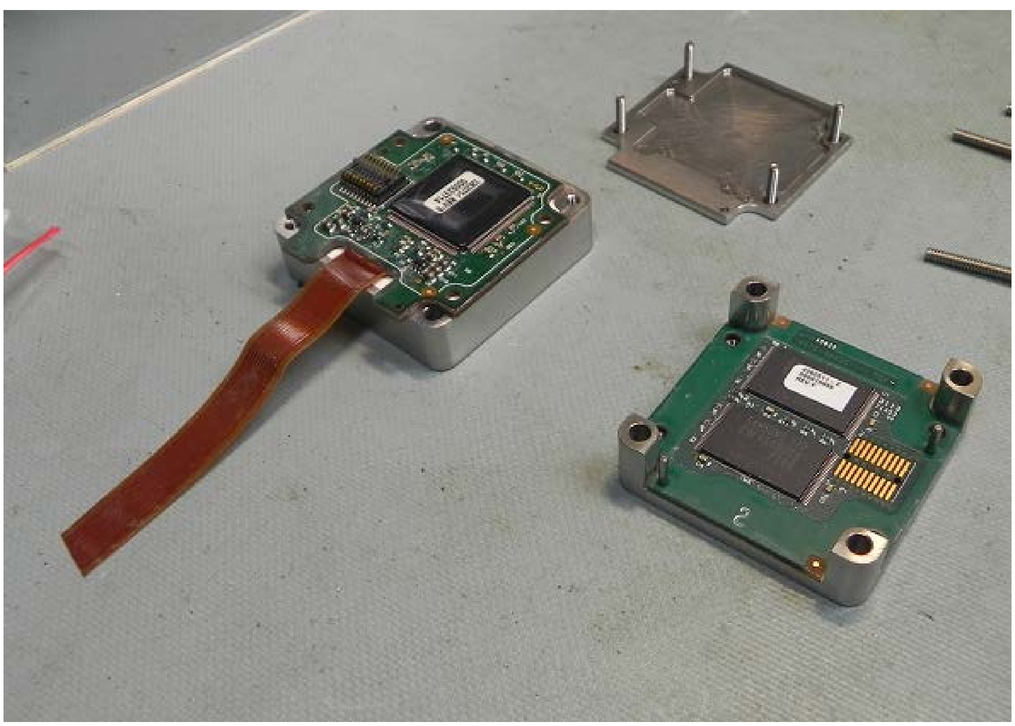


Figure 4. Crash survivable memory unit removed from unit.

Figure 5. Component and memory board inside crash survivable memory unit.



4.2.2. Recording Description

The data download file was reviewed and determined to be blank. The data pattern was consistent with a factory format, indicating that the FDR may not have been receiving data or fully configured in the helicopter.

4.3. SSD from aircraft high speed avionics bus

A 128 GB solid state hard drive was found in the wreckage. The hard drive was determined to be from a Panasonic Toughbook computer that recorded comprehensive diagnostic data from the aircraft high speed avionics bus. The hard drive stored all available data from the avionics system, including some data that was not recorded by the aircraft telemetry system.

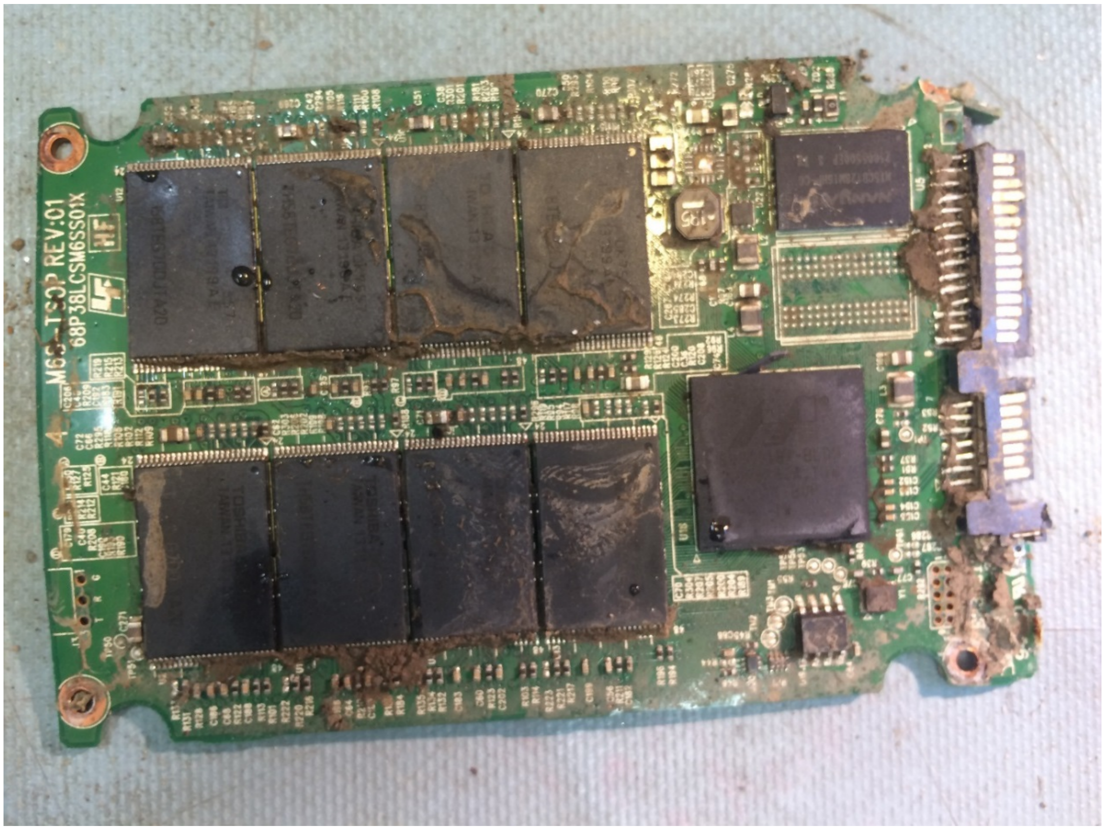
4.3.1. Recorder Condition

Upon arrival at the laboratory, it was evident that the drive had been subject to severe impact forces and sustained significant structural damage, as shown in figure 6. The structural damage included crushing and bending of the hard drive case. The unit also showed signs of fuel contamination and had dirt and mud packed in to the drive connectors and breaches in the drive casing, but no signs of thermal damage or sooting.

Disassembly of the drive revealed further damage to the solid state memory modules, including cracking across several modules and drops of fuel contaminating the board and memory modules. There was also fuel contaminated dirt and mud stuck to the board in several places and packed around several of the memory modules and drive connectors. A photograph of the drive’s main board is shown in figure 7. An attempt to recover the hard drive was made, however due to the extent of the damage, no data could be recovered from the hard drive.

Figure 6. Solid state hard drive from avionics bus recorder, as-received.

Figure 7. Memory board of solid state hard drive.



4.4. SD Memory Cards

Four SD memory cards were recovered from the aircraft primary flight displays (PFD) and multi-function displays (MFD). Some of the cards had the ability to record 1 Hz data from the avionics system. Because all of the data recorded were available at a higher rate from other sources, data from these cards are not documented further in this report.

4.5. Zodiac Aerospace RSM storage module 128 GB Description

The Zodiac Aerospace RSM storage module was the data storage medium of the flight test recorder system installed on N525TA. The module consists of a ruggedized solid state hard drive with 128 GB capacity and an integrated E-SATA download interface. The data recorded on this drive was typically downloaded after each test flight and was the primary data source for Bell’s flight test analysis team.

Data stored on the RSM module was sourced from the following sensors and aircraft systems:

- Flight test strain gauges placed in the fuselage, main rotor, tail rotor, engine, and engine mounts.
- Production accelerometers in the drive system, rotors, and engine/auxiliary power unit (APU).
- Flight controls data bus including ARINC-429/1553/RS-232/RS-485.
- Hydraulic system temperatures, pressures, and flows.
- Production and flight test air data systems including temperatures and pressures.
- Both engines, all engine control channels of temperatures, pressures, speeds, gearboxes, and shafts.
- Flight test temperature readings in the aircraft skin.
- Avionics and flight displays systems.

In all, the data stream contained 3,078 total measurements and 5,282 parameters including derived readings. Each parameter was sampled and recorded by the data system between 31 and 4,000 times per second.

The data stream recorded by the RSM was also transmitted via a telemetry stream to a ground station at Bell’s flight test facility for real time analysis and recording. The two recordings were compared and found to be of an equivalent duration, meaning that the RSM recording and the telemetry stream stopped simultaneously. The data from the RSM itself was deemed to be more reliable due to the fact that it did not suffer from telemetry stream dropouts.

4.5.1. Recorder Condition

The RSM module was ejected from the helicopter during the crash sequence, and was found apart from the main aircraft wreckage. The module was found in good condition, with no apparent impact or thermal damage. The data module is shown in Figure 6.

The data was extracted by Bell's flight test data ops department, under supervision of the NTSB. The data was processed using Bell's in-house data system, known as Computer Aided Flight Test Analysis (CAFTA). Bell's standard RSM module download procedures were used to extract the data, with the exception of preparing the module for a subsequent flight. The RSM was not formatted to be used again, and all data was maintained on the drive.

Figure 8. RSM module, as-received.

4.5.2. Recording Description

The RSM recording contained approximately 1 hour and 26 minutes of data including pre-flight and flight activities. Because the flight test recording medium is erased prior to each flight, the event flight was the only flight recorded on the drive.

The telemetry system recording conformed to the IRIG-106 Chapter 10 data recording standard format[1]. The raw download contained six chapter 10 files, which when processed by the Bell CAFTA system represented the full flight.

Once processed, the data was segregated by CAFTA in to "Prime" data, which was data taken during a test point, and "Non-Prime" data, which was taken at all other times. There were 41 periods of prime data in the recording, including the period up to and including the end of the recording.

[1] The Inter-Range Instrumentation Group (IRIG) publishes standards including aeronautical flight test telemetry standards.

Over 4,100 parameters were included in the processed recording, including raw measurements and derived parameters. In an effort to reduce the number of parameters used in the analysis, a focused list of parameters of interest to the investigation was generated based on parameters that were being actively monitored for the tests in question, as well as other specific parameters needed for the investigation.

In addition to parametric data, the chapter 10 format is also capable of recording audio and video data, if available. In this case, there were no cameras connected to the system so no video data was available. Recording cockpit audio required having the pilots connect to a specific flight test audio system, which was not a requirement for the tests being conducted on the day of the crash. Therefore, no cockpit audio data was available in the RSM recorded data.

Timing of the RSM data is measured in seconds from the start of the recording of prime data, or elapsed recorder time. The start time and stop time of the total recording and each individual test point recording is synchronized to a master clock reference source recording Universal Time Code (UTC).

4.5.3. Engineering Units Conversions

The engineering units conversions used for the data contained in this report are generated inside of the CAFTA data recording system. 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=+).[2]

Table A-1 lists the parameters verified and provided in this and other NTSB group reports. Specifically, table A-1 lists the instrumentation name, parameter name, plot/table label, and unit. Additionally, table A-2 describes the unit and discrete abbreviations used in this report.

4.6. Time Correlation

Correlation of the RSM data from elapsed recorder time to the event local time, central daylight time (CDT), was established by using the recorded master clock reference source UTC time and then applying an additional -5 hours offset to change UTC to CDT.

Because each period of prime data resets the elapsed recorder time, each test point has its own time offset. Accordingly, the time offset for the event flight data from elapsed recorder time for each of the test points in CDT is provided in table 1.

[2] 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 = +, Collective Pitch Up = +, Right Tail Rotor Command = +.

Table 1. Time offset for each of the referenced test points.

Test Point	UTC Start Time	CDT Start Time	Time Offset
Total Recording	15:21:44.33	10:21:44.33	37304.33
41	16:11:38.49	11:11:38.49	40298.49
42	16:13:57.08	11:13:57.08	40437.08
43	16:16:17.88	11:16:17.88	40577.88
44	16:20:01.18	11:20:01.18	40801.18
46[3]	16:22:07.45	11:22:07.45	40927.45
47	16:25:22.11	11:25:22.11	41122.11
48	16:29:19.23	11:29:19.23	41359.23
50[4]	16:42:05.05	11:42:05.05	42125.05
51 (crash)	16:47:22.08	11:47:22.08	42442.08

$$CDT_{\text{Test Point}} = \text{Elapsed Recorder Time} + \text{Time Offset}_{\text{Test Point}}$$

For the rest of this report, times from the total recording are referenced as CDT, not elapsed recorder time. For plots and discussions of individual test points, times are presented as elapsed recorder time for consistency with other docket reports.

4.7. FDR Plots and Corresponding Tabular Data

Figures 9 to 30 contain data recorded by the telemetry system during the July 6, 2015 event flight. Specifically, figures 9 to 11 have data recorded during the full flight from engine start until the end of data, figures 12 to 22 have data recorded during test point 51, and figures 23 to 30 have data recorded on the remaining test points 50 to 41, not including cancelled test points. A list of parameters is provided in appendix A, table A-1. Some parameters are provided as tabular data for reference in attachments to this report, and are not plotted. Additionally, a number of parameter scales are redacted in the plotted data for intellectual property concerns. In table A-1 the original units are listed for all parameters, and non-dim is added for redacted parameters. In the tabular data these parameters are normalized so that the data trends are captured without revealing proprietary data.

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.

In brief, the engines were started at 10:27 and idled for about five minutes before being accelerated to 103% Np. About three and a half minutes later, engine torque output increased and the helicopter departed. Engine parameters were unremarkable during the

[3] Test Point 45 was cancelled and the flight condition was repeated in test point 46.
[4] Test Point 49 was cancelled due to the aircraft encountering turbulence during the maneuver. The test conditions were successfully repeated and completed as test point 50.

flight and the engine data showed that the engines were operating as commanded throughout the flight.

The pilots flew the aircraft through a series of pre-planned tests, culminating in a series of simulated one engine inoperative (OEI) transition points. These test points involved attaining a test-specified airspeed, entering a simulated OEI mode, and arresting rotor RPM decay by reducing the collective pitch. The test objective was to restore rotor RPM to 103% in OEI conditions. OEI conditions were simulated by proportionately reducing power on both engines such that total torque output was comparable to the torque output of a single engine at the given flight condition. The engine power reduction was controlled by a software command inputted to the engine Full Authority Digital Engine Controllers (FADECs).

A series of build-up conditions was completed (test points 41-50 shown in figures 23-30), increasing the airspeed by 10 knots in each test point, prior to what was planned to be the final condition at Vne (airframe never exceed speed), test point 51. Table 2 shows the target condition for each test point, the amount the rotor speed drooped during the condition, and the time it took to restore rotor RPM to 103%.

Table 2. Build-up test points and recovery time required for each.

Test Point	Target Airspeed	Initial Nr Droop	Time to 103% Nr
41	102 kcas (0.7 Vh)	97%	3.4 sec
42	131 kcas (0.9 Vh)	95%	14.8 sec
43	145 kcas (Vh)	86.9%	6.2 sec
44	155 ktas	94.5%	5.2 sec
46	155 ktas	93.6%	8.2 sec
47	160 ktas	89.9%	8.5 sec
48	170 ktas	89.9%	10.0 sec
50	175 ktas	90.3%	13.0 sec
51	185 ktas (Vne)	90%	Not recovered

Test point 51 began in a similar fashion to the previous build-up test points. When prime data began recording, the aircraft was about 10 degrees nose down in descending flight at 2,250 ft pressure altitude (3,700 ft density altitude) and 175 kias (185 ktas) on a northwesterly heading. Engine torque was at about 92% and main rotor speed was 100%. About 3.5 seconds in to the test point, engine power was reduced to simulate OEI conditions, stabilizing at about 60% total torque about six seconds in to the test point. Main rotor speed decreased to about 90%. This behavior was consistent with previous build-up test points.

In the build-up test points, when the main rotor speed decreased, the pilots commanded a reduction in collective stick to about 50% or less to recover the rotor RPM. However, in test point 51 the collective stick was only reduced to about 60%, and the main rotor RPM did not recover above 93% Nr.

Between five and six seconds into test point 51, there was a frequency content of around 6 Hz was observed in the tail rotor gearbox (TRGB) and tail rotor mast torque.

Between six and seven seconds into test point 51, numerous parameters began to exhibit an oscillatory beat at approximately 6 Hz. The frequency signature appeared at very low amplitudes in parameters throughout the aircraft including flight controls, airframe accelerometers, and rotor systems.

By about 10 seconds into the test point, the 6 Hz oscillatory beat had grown in amplitude and was readily identifiable in flight control and other airframe accelerometer parameters, including the collective stick, fore/aft cyclic stick, pilot seat accelerometers, and gearbox accelerometers for the main and tail rotors. As the 6-Hz amplitude grew, the main rotor exhibited large forces and displacements in the dampers and blades, as well as 6 Hz oscillatory motion in the measured lateral, longitudinal, and vertical directions of the pylon.

At about 12 seconds, and again at 17.5 seconds into the test point, the pilot seat experienced sustained vertical accelerations of greater than +/-3 g and the collective stick position increased, still with a 6 Hz oscillatory component present and +/-7% displacement in the commanded position. Engine torque and rotor mast torques experienced large fluctuations at about 6 Hz, particularly in the tail rotor mast torque. Tail rotor blade lead-lag positions and forces also became erratic at this time. With the engines still operating in simulated OEI mode, main rotor speed decreased to about 75%.

At about 20.25 seconds into the test point, the main rotor red blade string potentiometer measuring blade out-of-plane deflections reached and exceeded its upper instrumentation limit and became invalid, indicating that the blade was flapping high out of plane. Half a second and 2.5 rotor revolutions later, discontinuities and shock loads were recorded in parameters involving the horizontal stabilizer, main rotor, and tail rotor. The pilot seat lateral acceleration also spiked at this time. These readings were consistent with a high energy event such as a reaction to the main rotor red blade striking the tail boom.

Following the strike, rotor blade strain gauges became erratic until the end of the recording, about 0.2 sec later. There were no other reaction forces indicating other high energy events such as additional blade strikes. Data ended with the aircraft at about 1,100 ft above ground level and 160 knots indicated airspeed.

The corresponding tabular data used to create figures 9 to 28 are provided in electronic comma separated value (*.csv) format as attachments to this report. Due to the number of parameters and range of recording rates, parameters are grouped in to files based on their recording rate. Table A-3 describes the recording rate of each parameter. Table A-4 describes the data contained in each attachment.

Figure 9. Plot of basic parameters during entire flight.

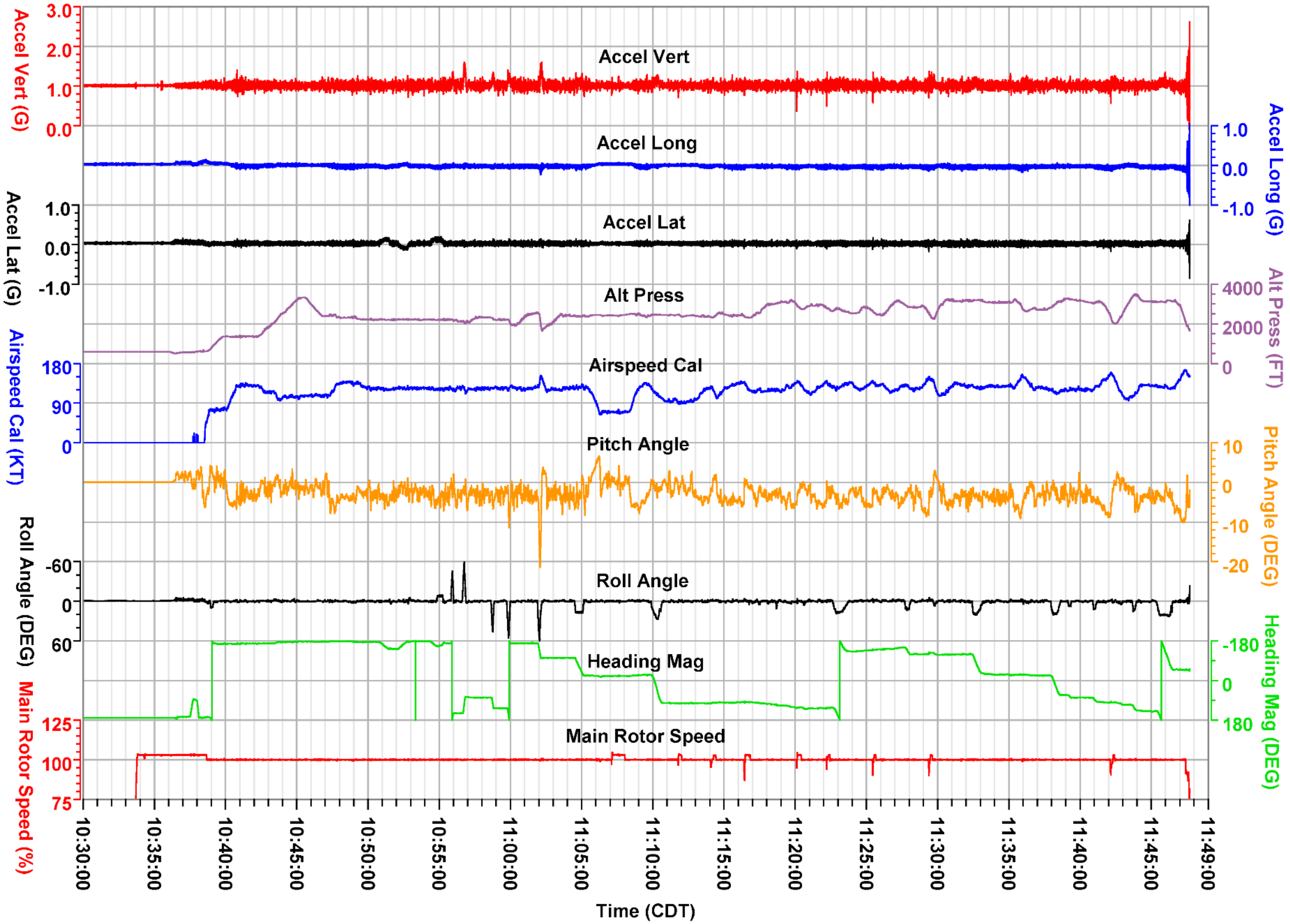


Figure 10. Plot of engine 1 parameters during entire flight.

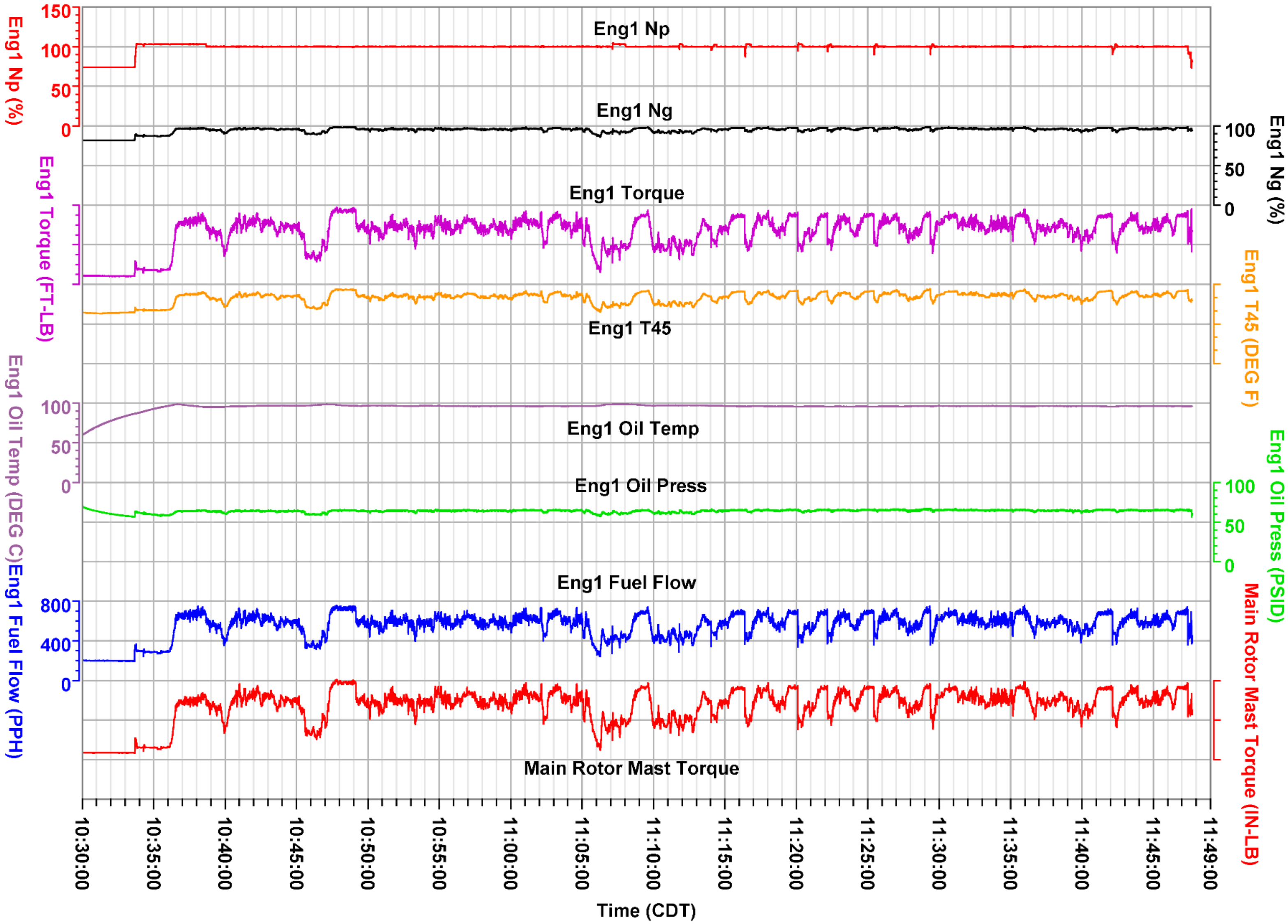


Figure 11. Plot of engine 2 parameters during entire flight.

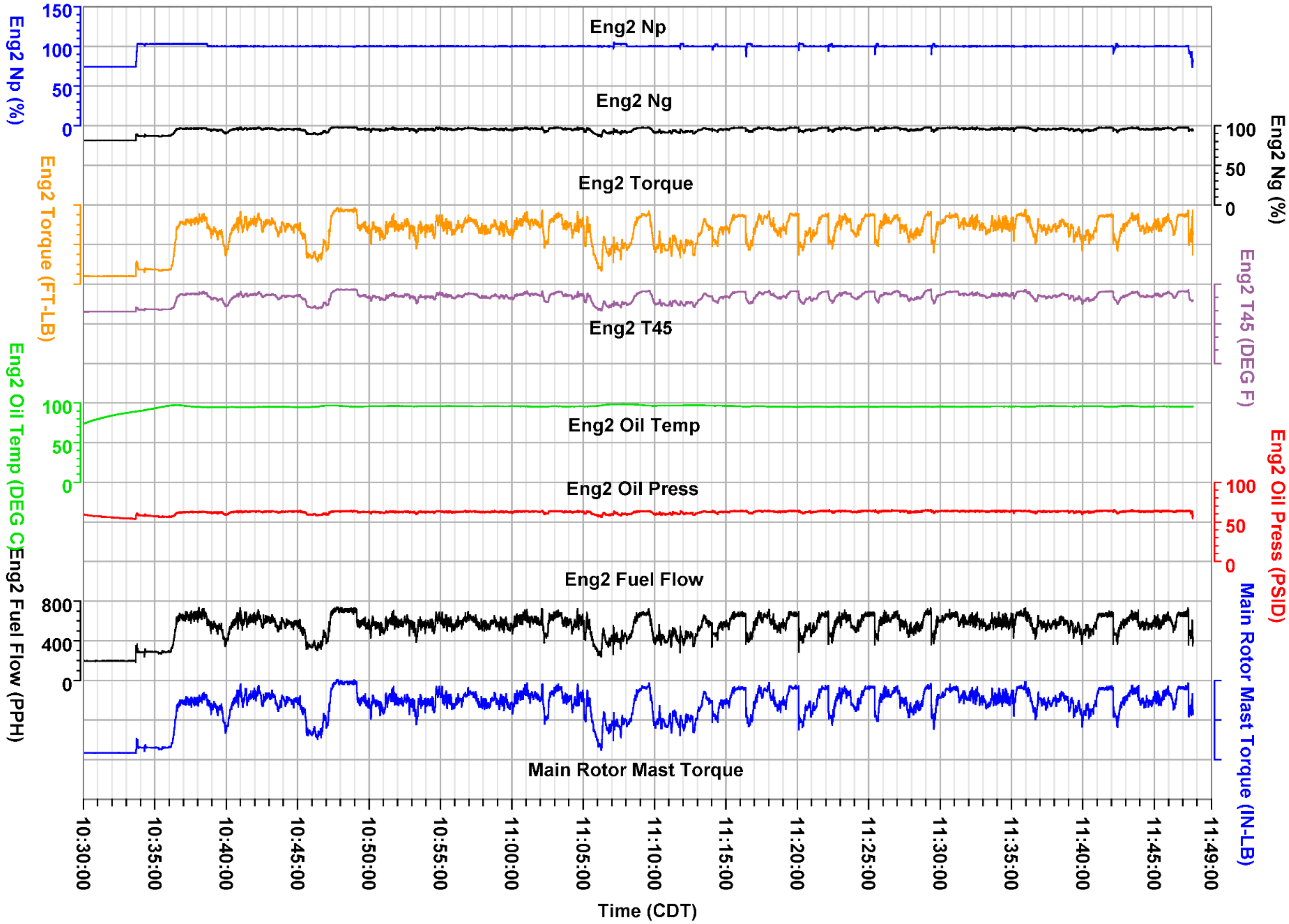


Figure 12. Map overlay of aircraft position with time and height above ground level (AGL) during test point 51.

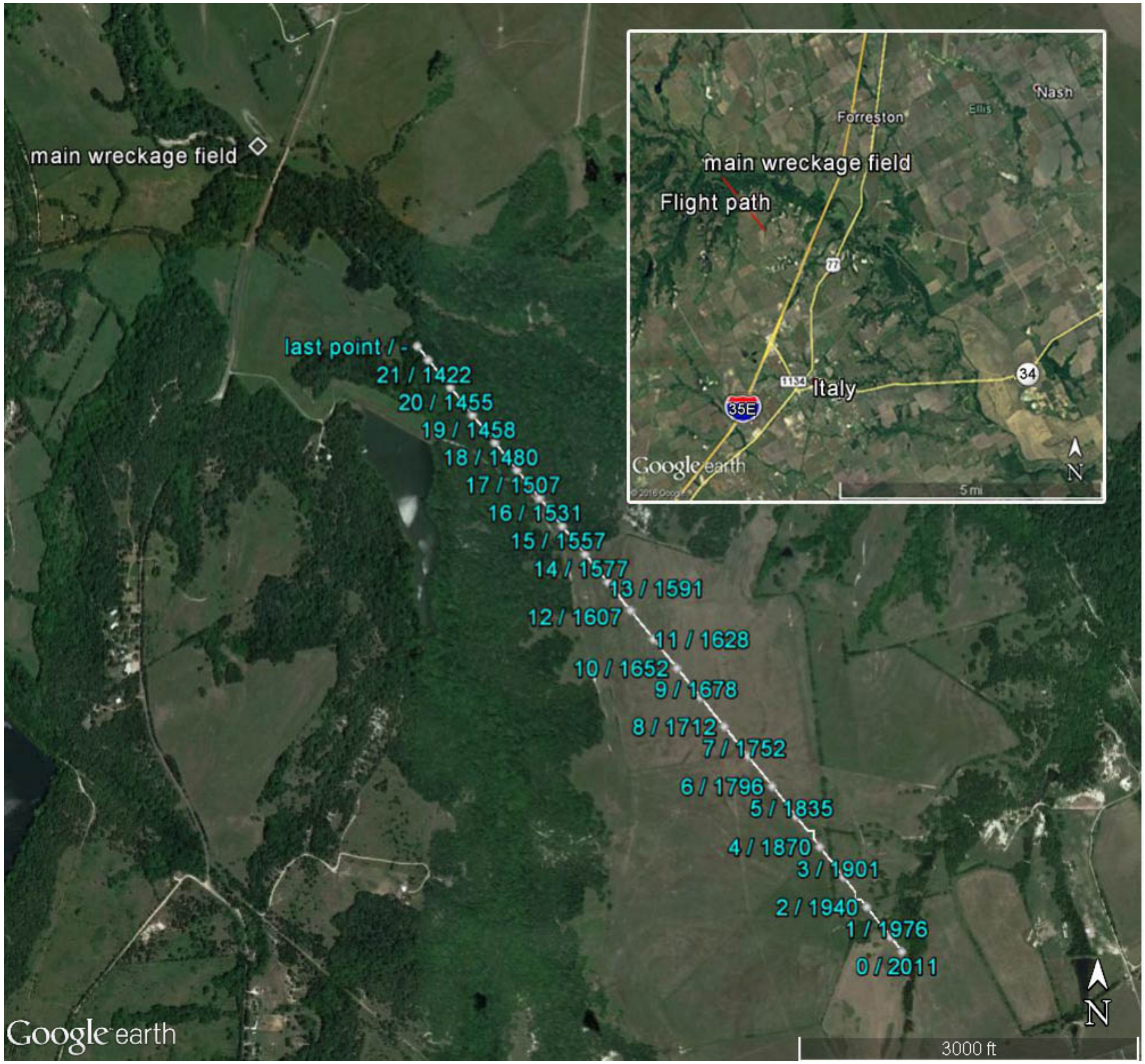


Figure 13. Plot of aircraft basic and flight control command parameters during TP 51.

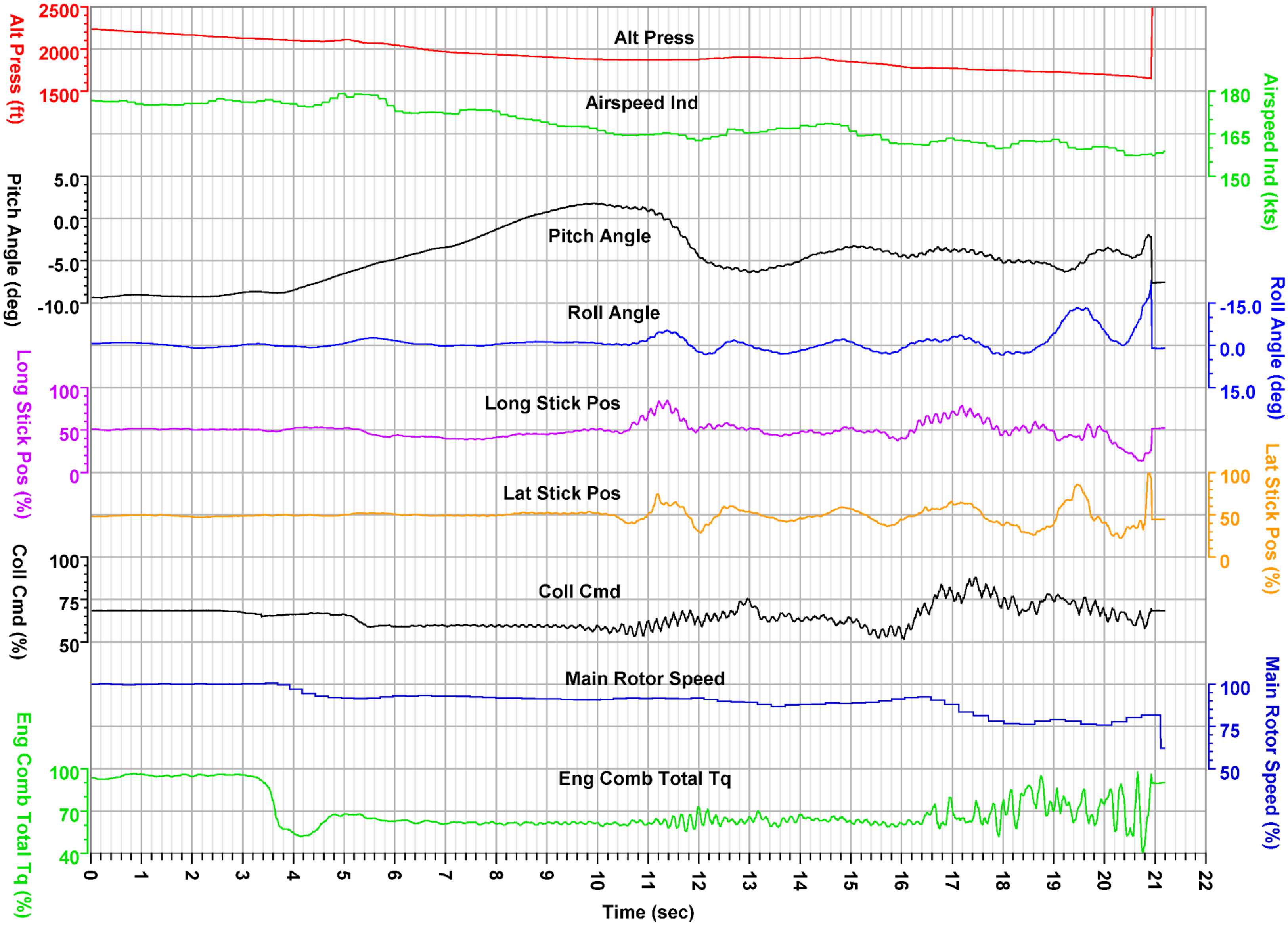


Figure 14. Engine and rotor torque, accelerometers showing vibration bloom at pilot seat during TP 51.

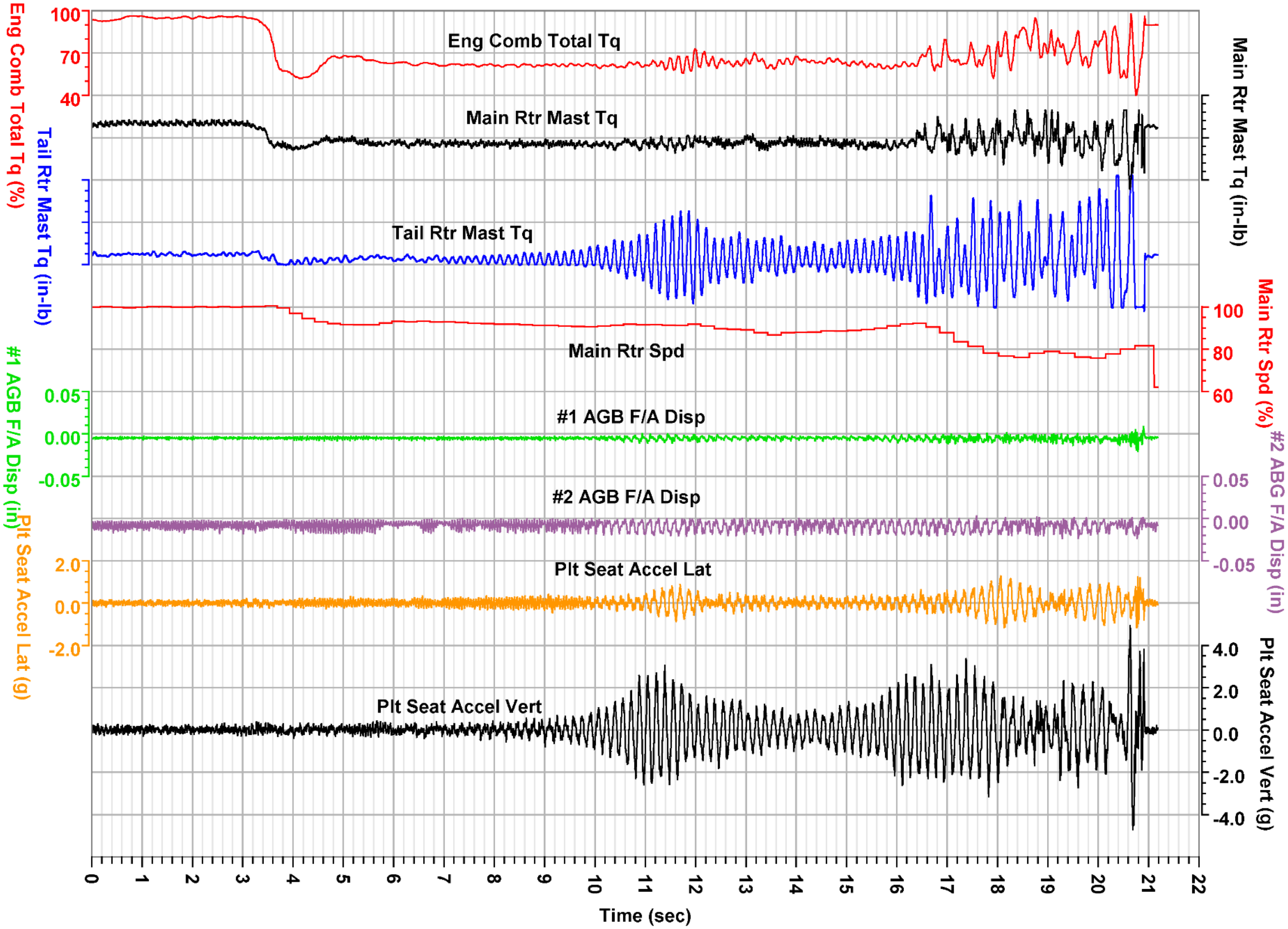


Figure 15. Pylon motion showing 6 Hz oscillations in main rotor during TP 51.

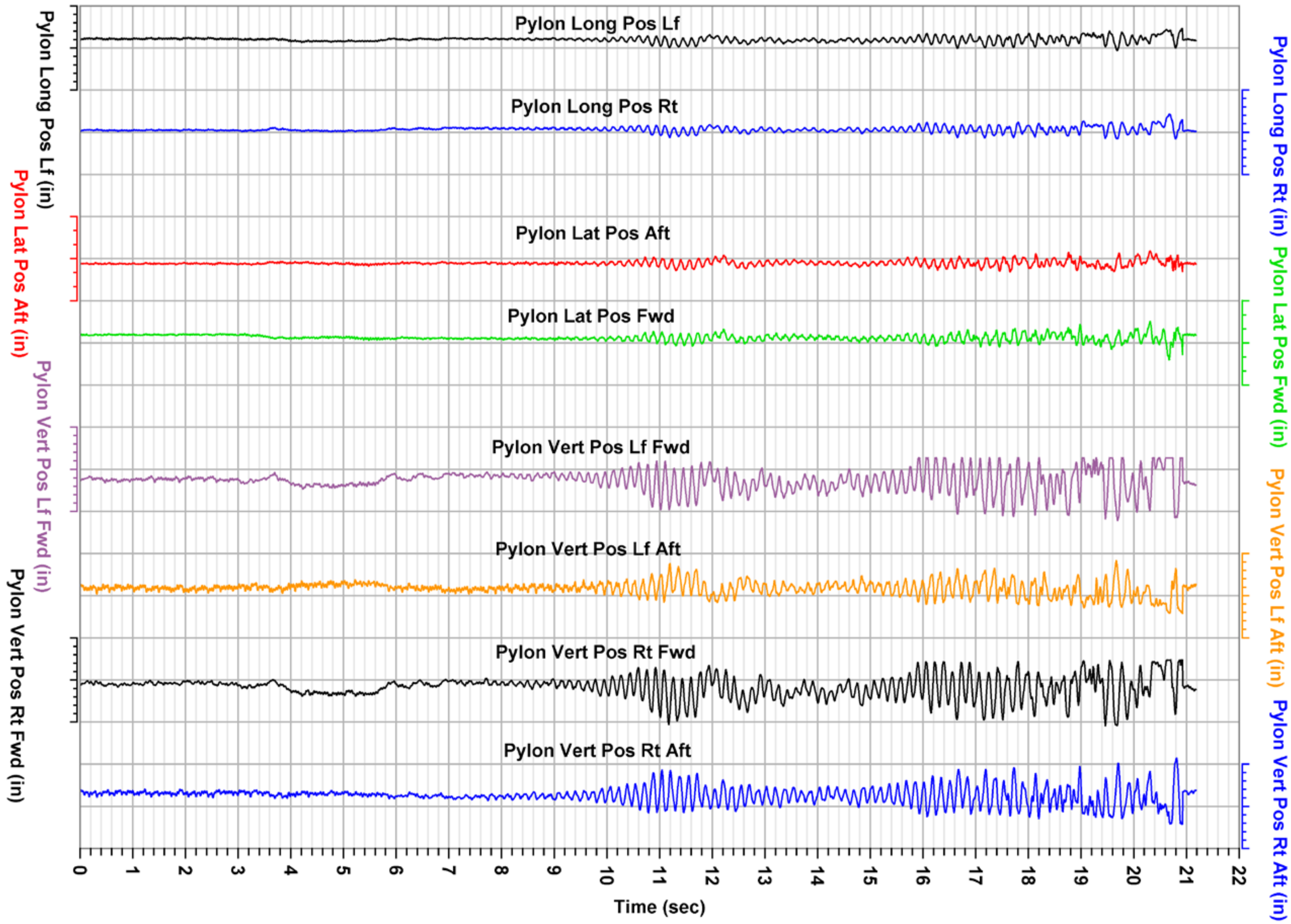


Figure 16. Additional accelerometers showing vibration bloom throughout the cabin during TP51.

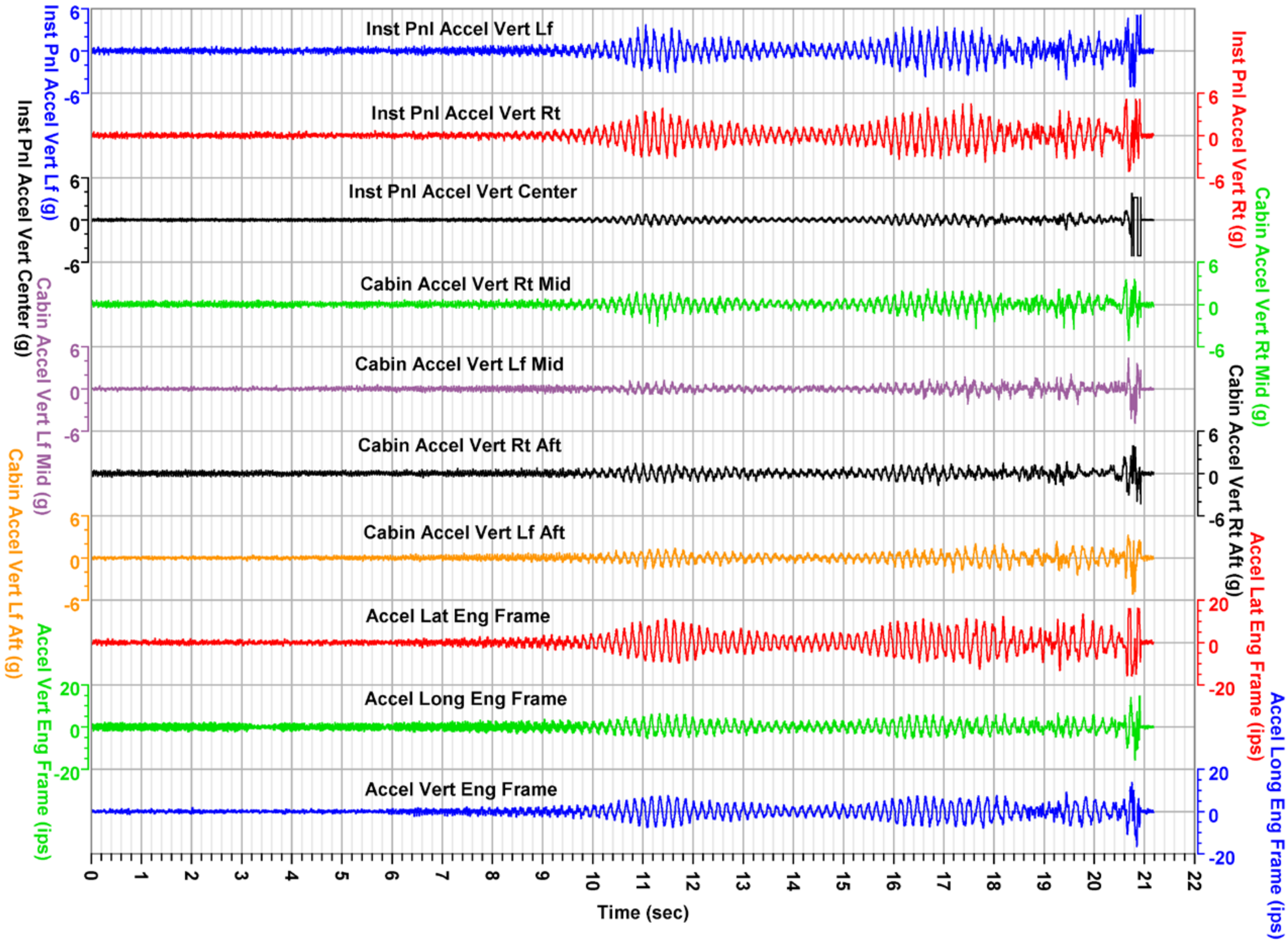


Figure 17. Swashplate, control tube, and pitch link load forces during TP51.

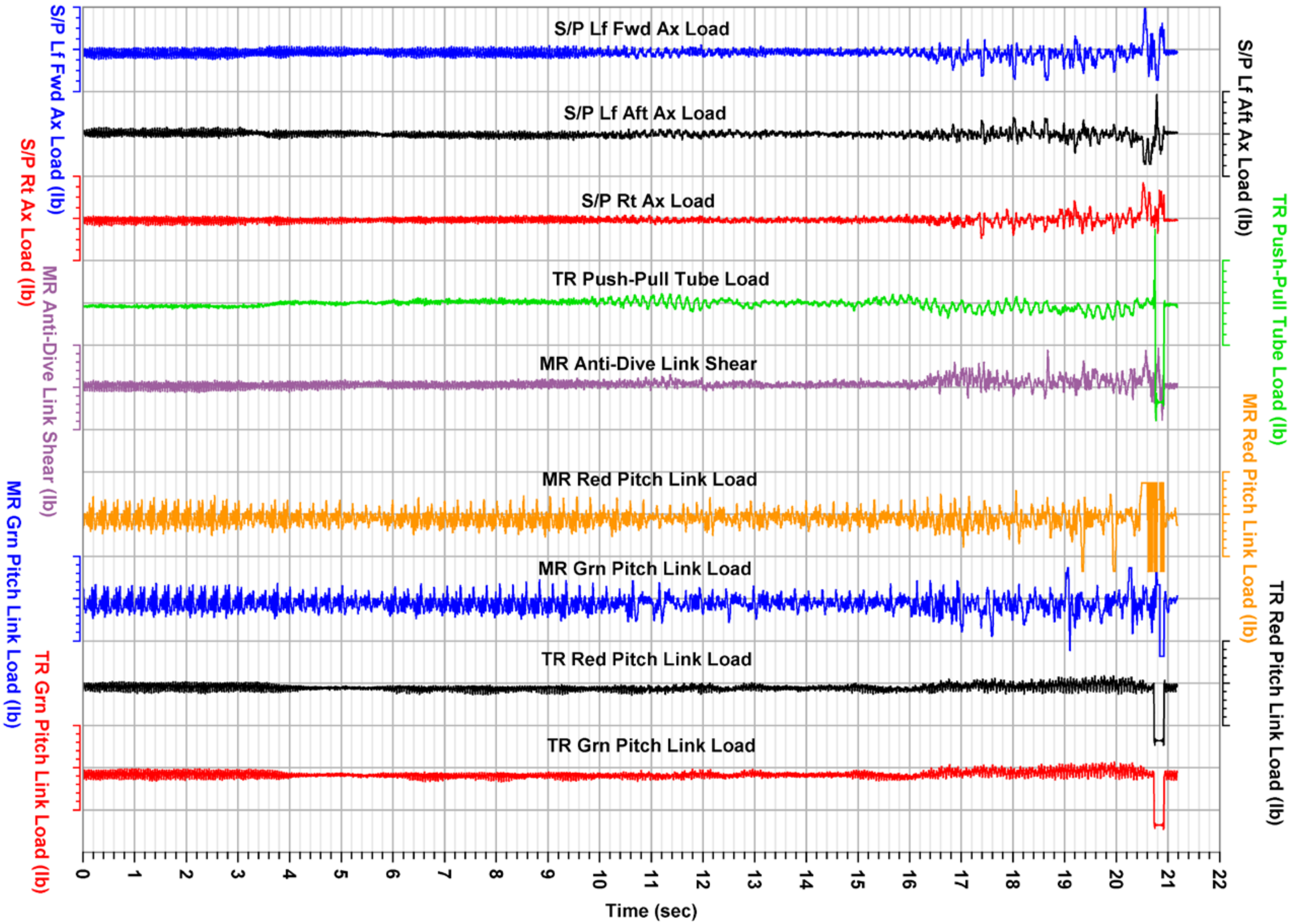


Figure 18. Main rotor red blade beam bending during TP 51.

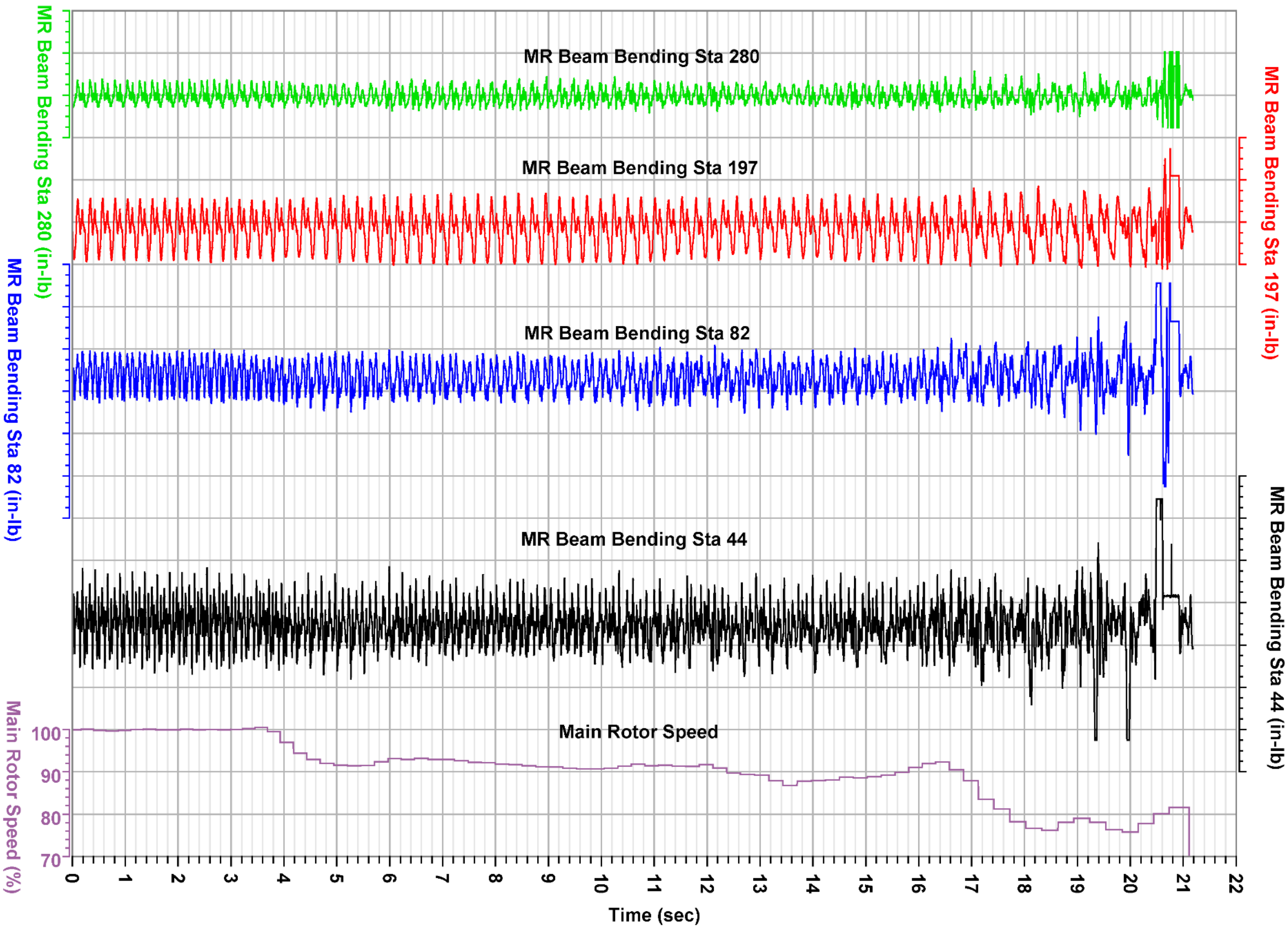


Figure 19. Main rotor damper lead-lag position and force during TP 51.

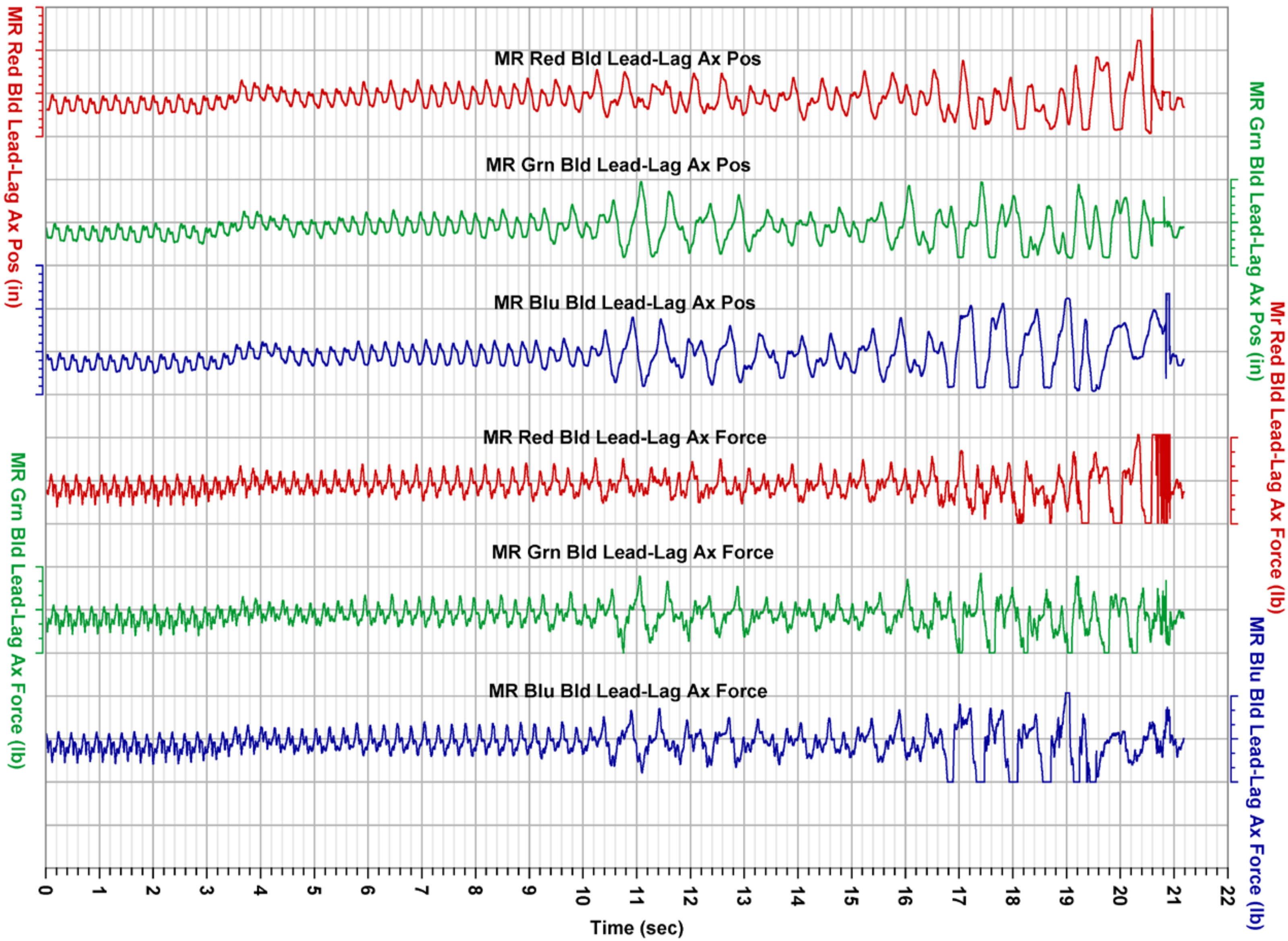


Figure 20. Tail rotor damper lead-lag position and force during TP 51.

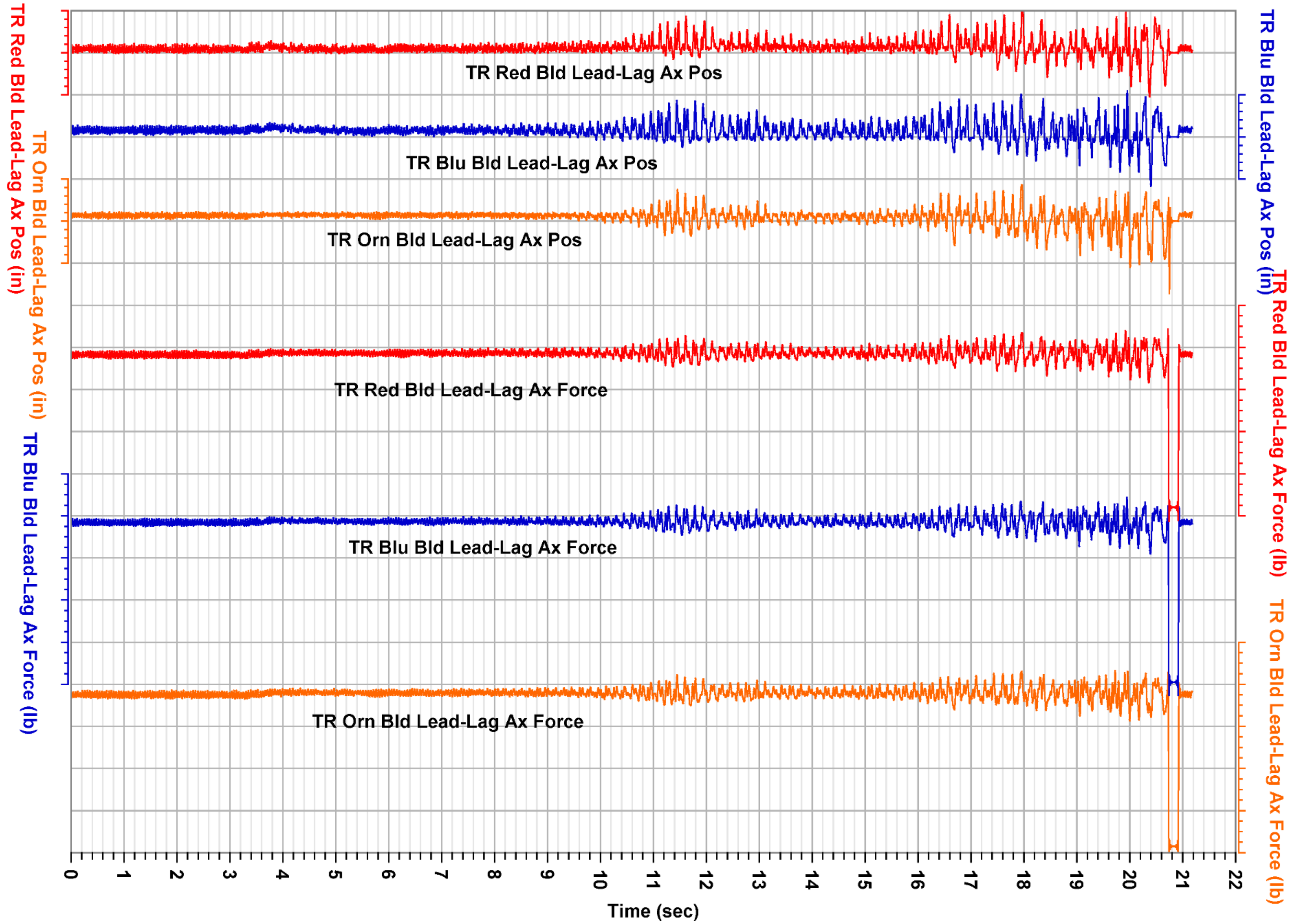


Figure 21. Parameters showing red blade impact of tail boom in TP 51.

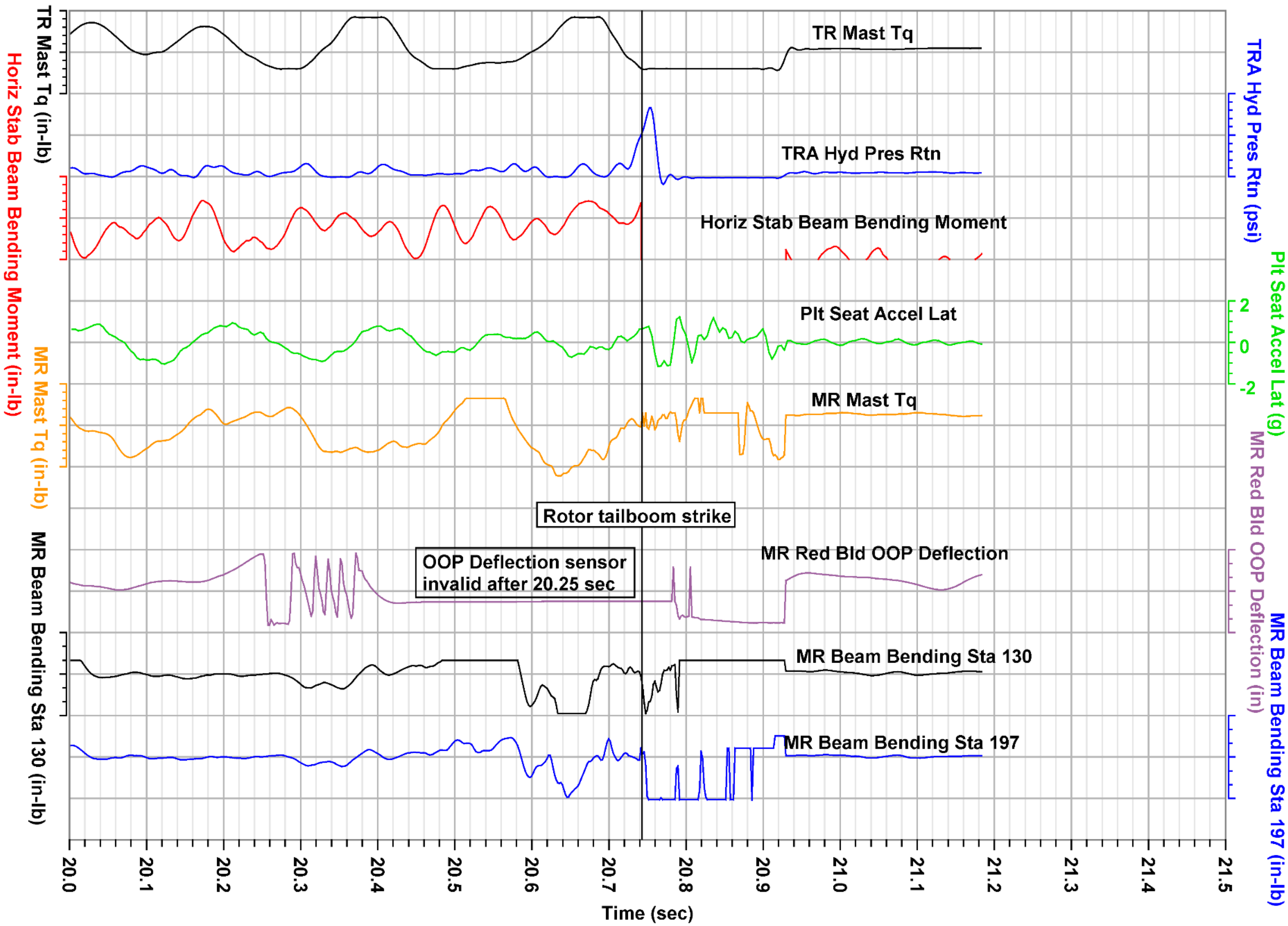


Figure 22. Additional accelerometers' response to rotor tailboom strike during TP51.

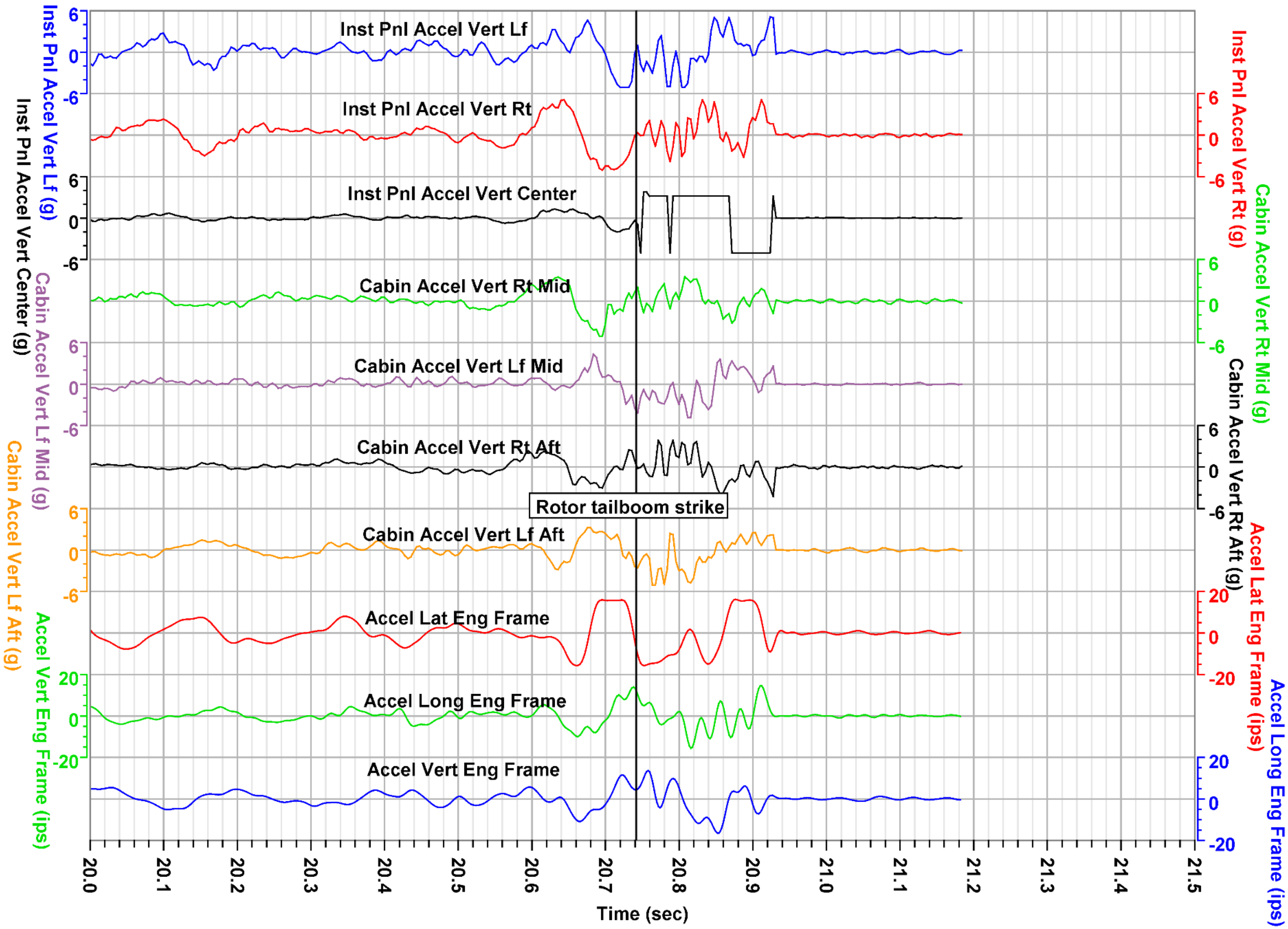


Figure 23. Plot of aircraft basic and flight control command parameters during TP 50.

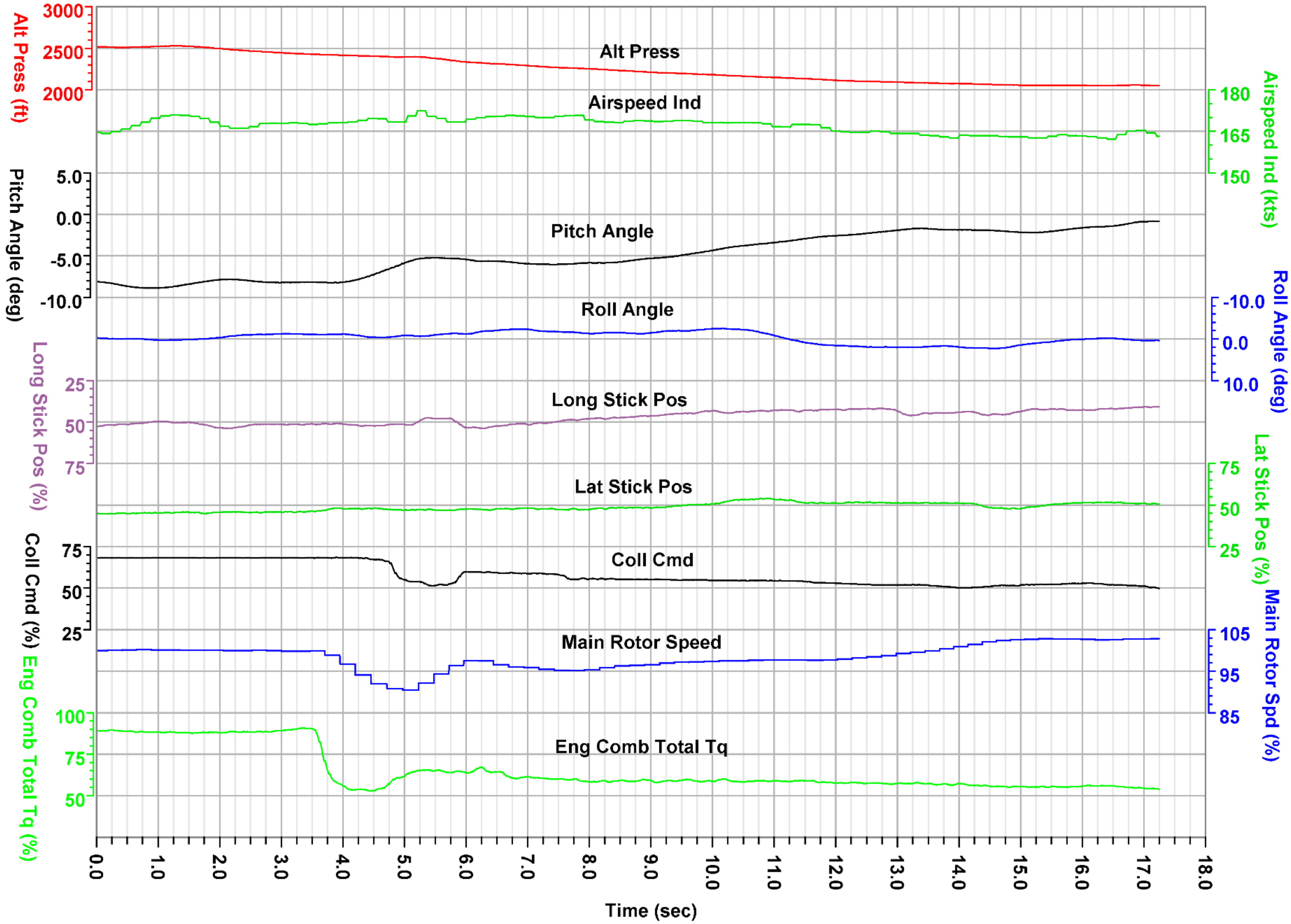


Figure 24. Plot of aircraft basic and flight control command parameters during TP 48.

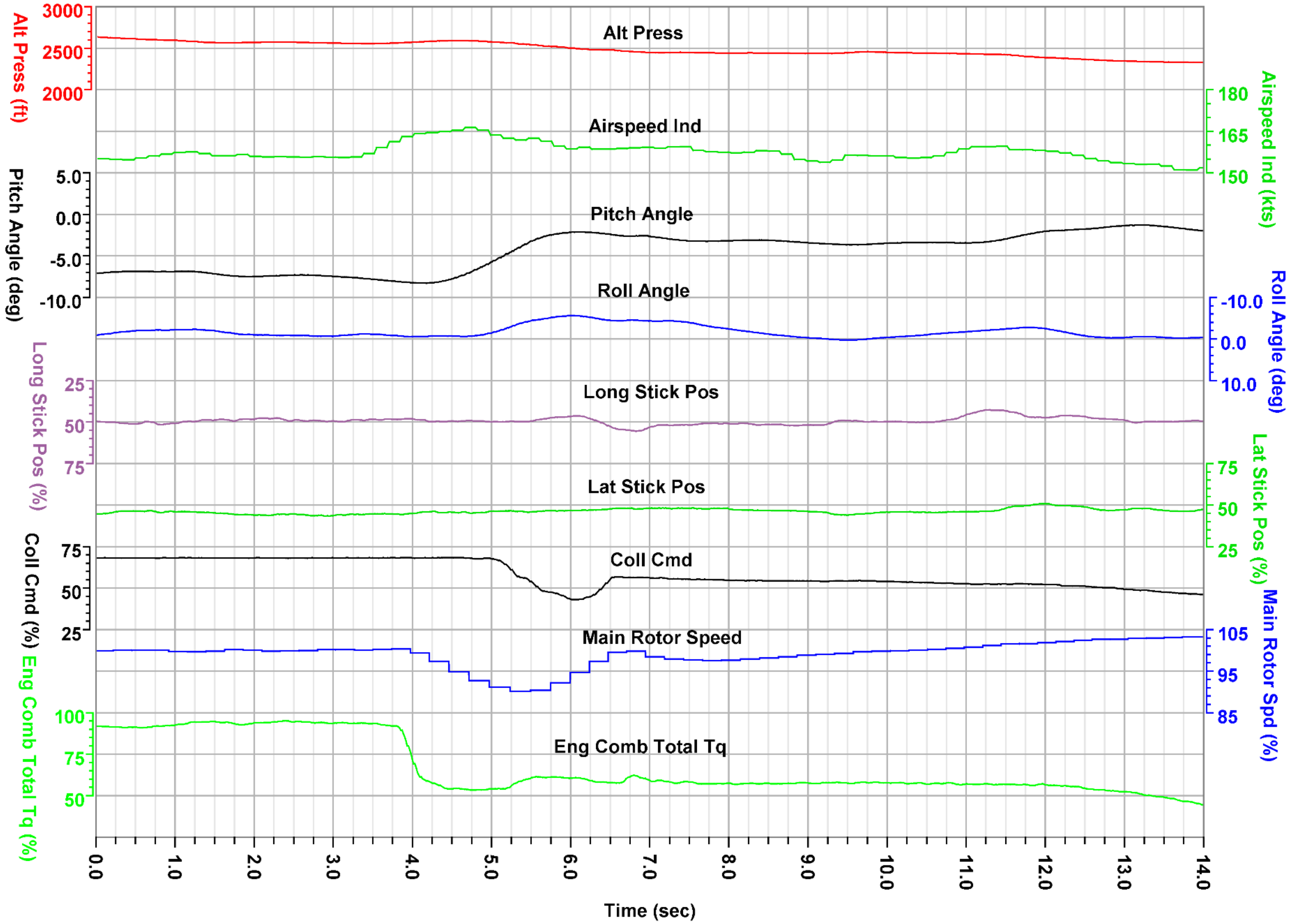


Figure 25. Plot of aircraft basic and flight control command parameters during TP 47.

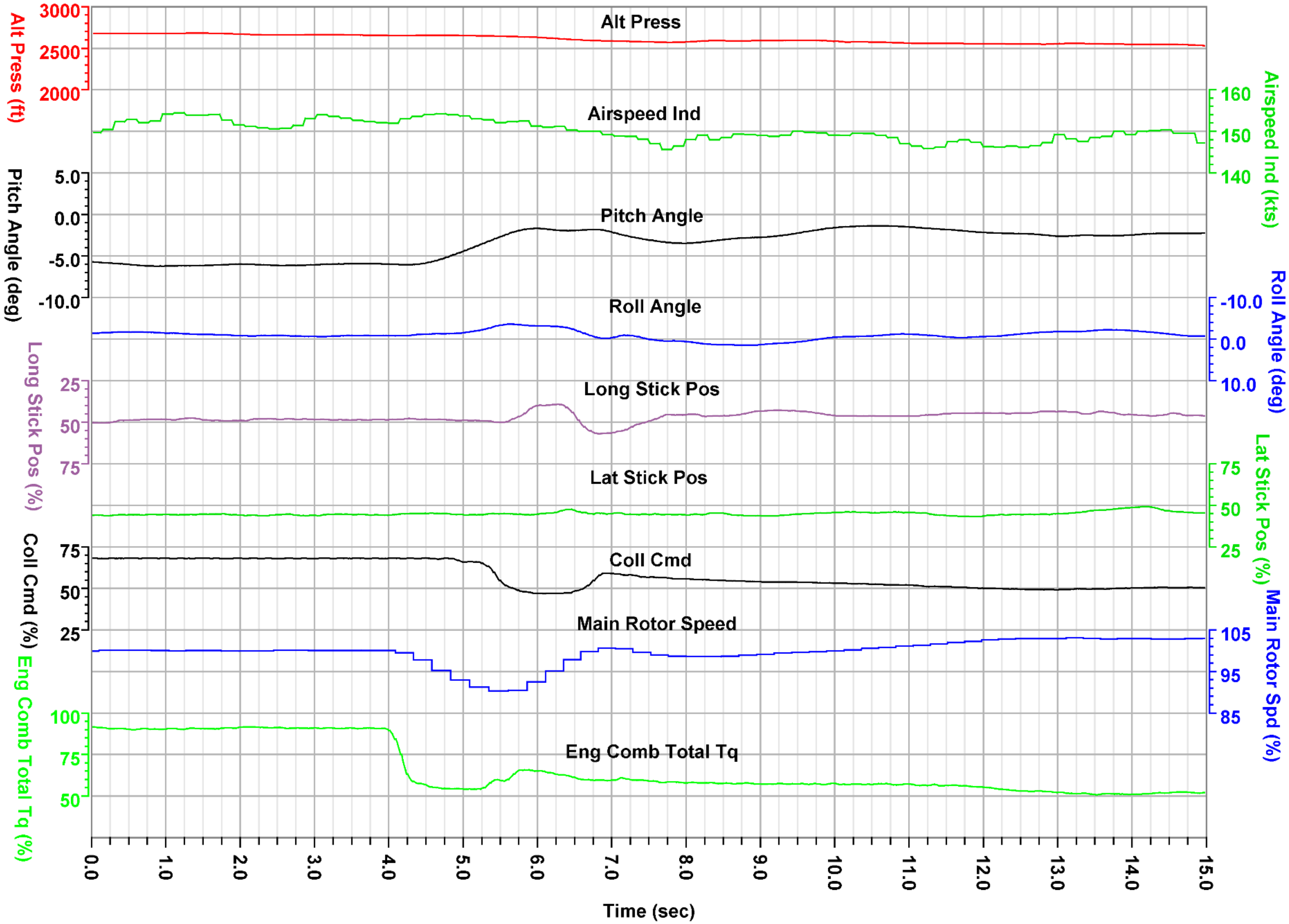


Figure 26. Plot of aircraft basic and flight control command parameters during TP 46.

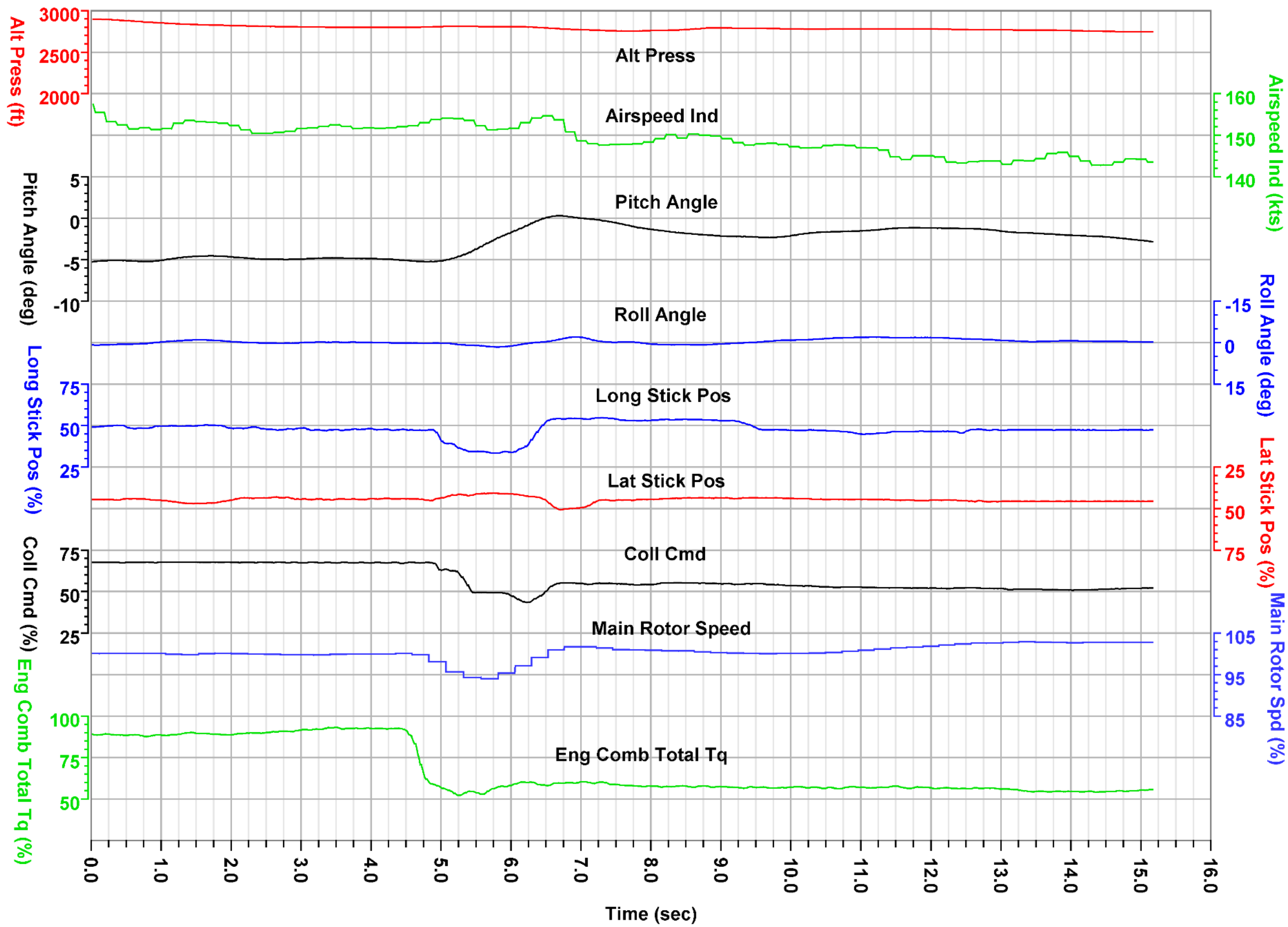


Figure 27. Plot of aircraft basic and flight control command parameters during TP 44.

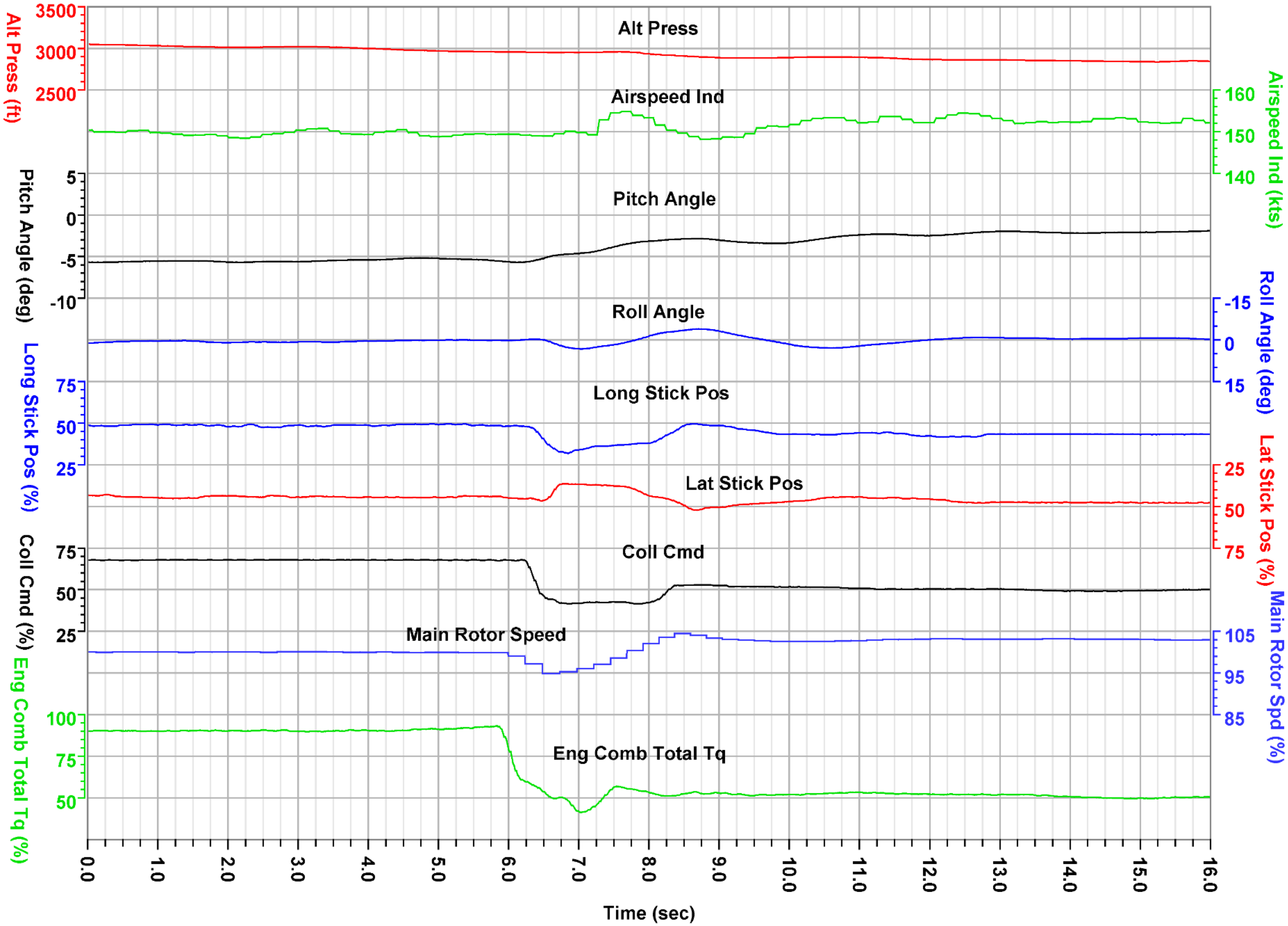


Figure 28. Plot of aircraft basic and flight control command parameters during TP 43.

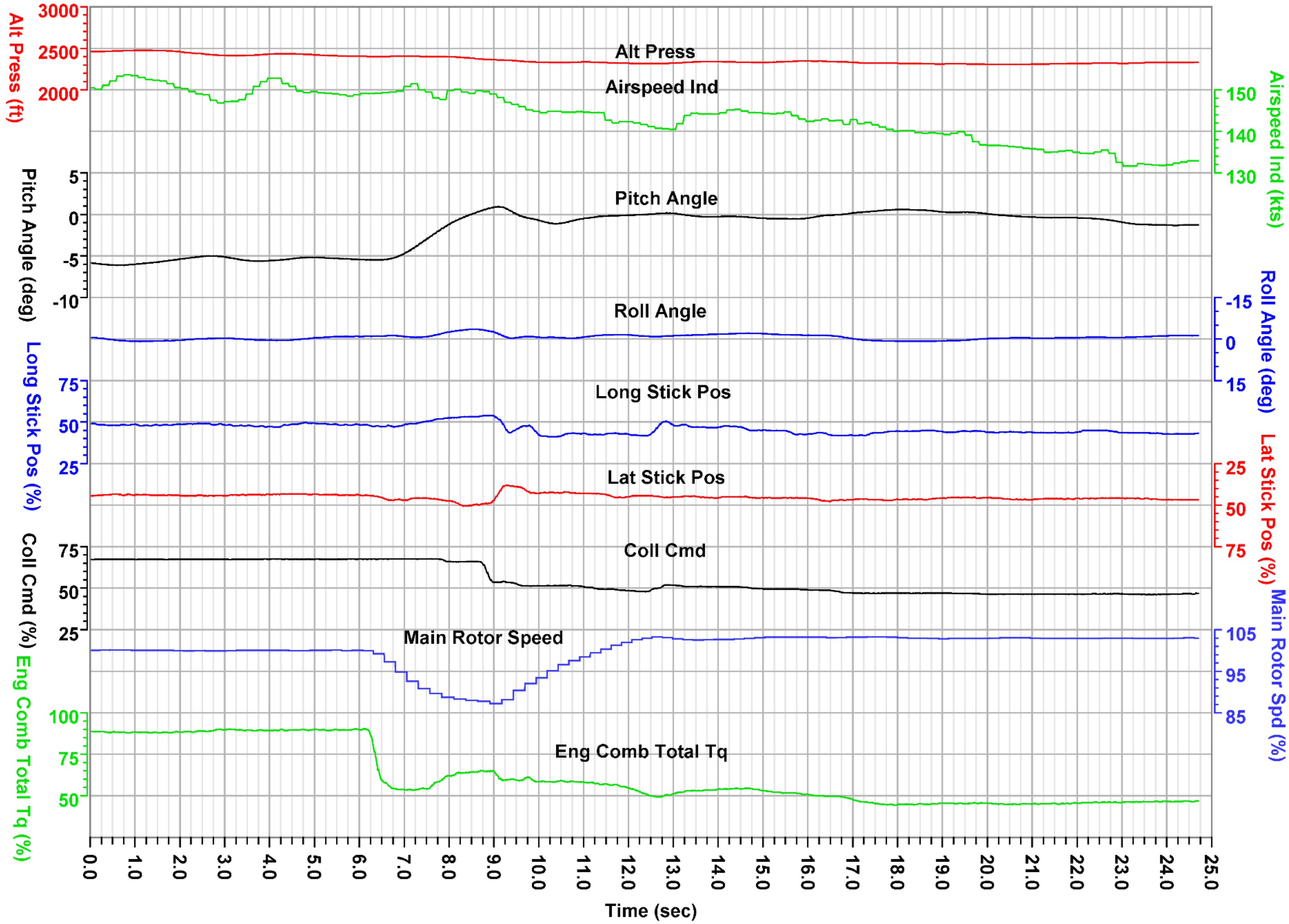


Figure 29. Plot of aircraft basic and flight control command parameters during TP 42.

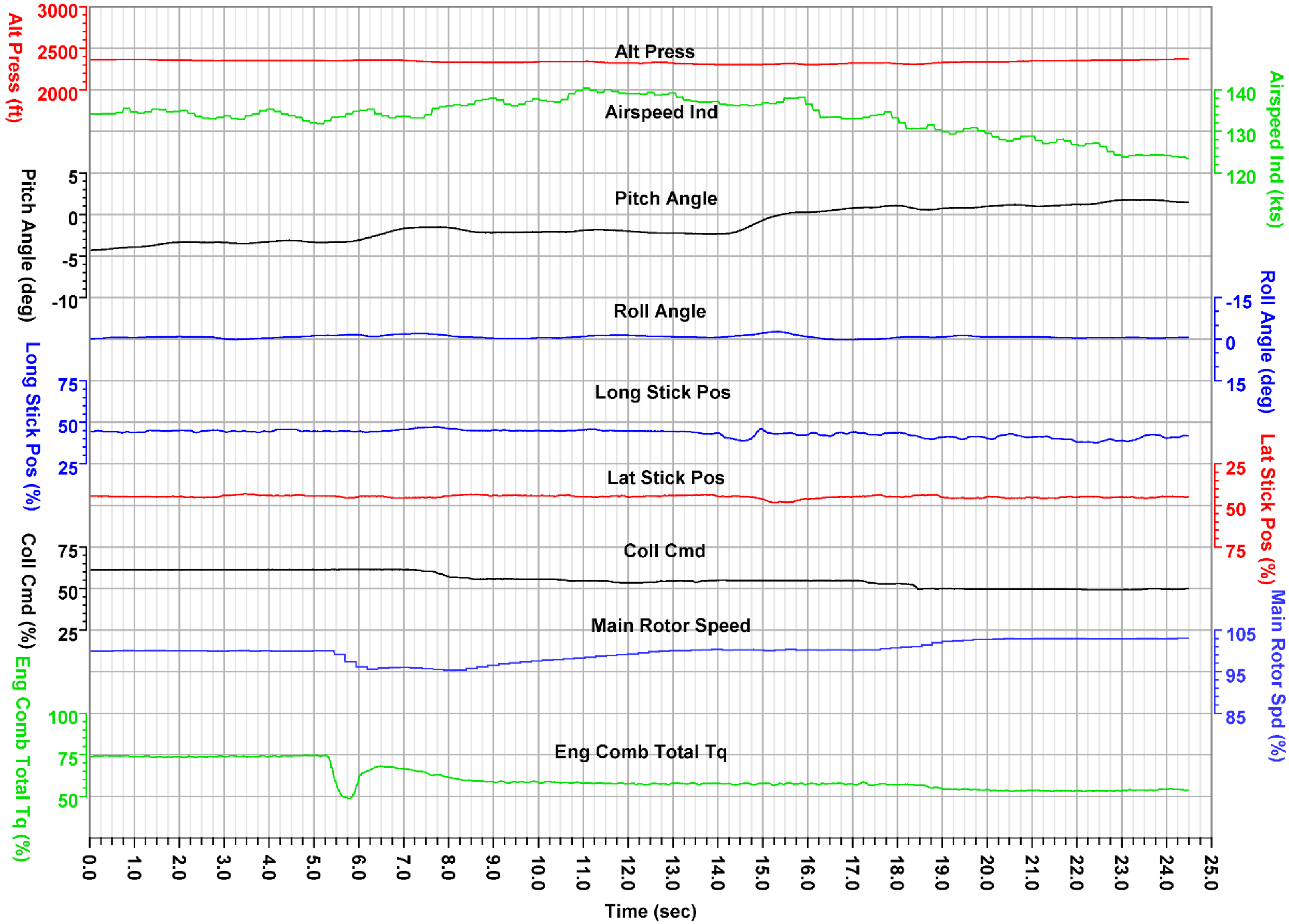
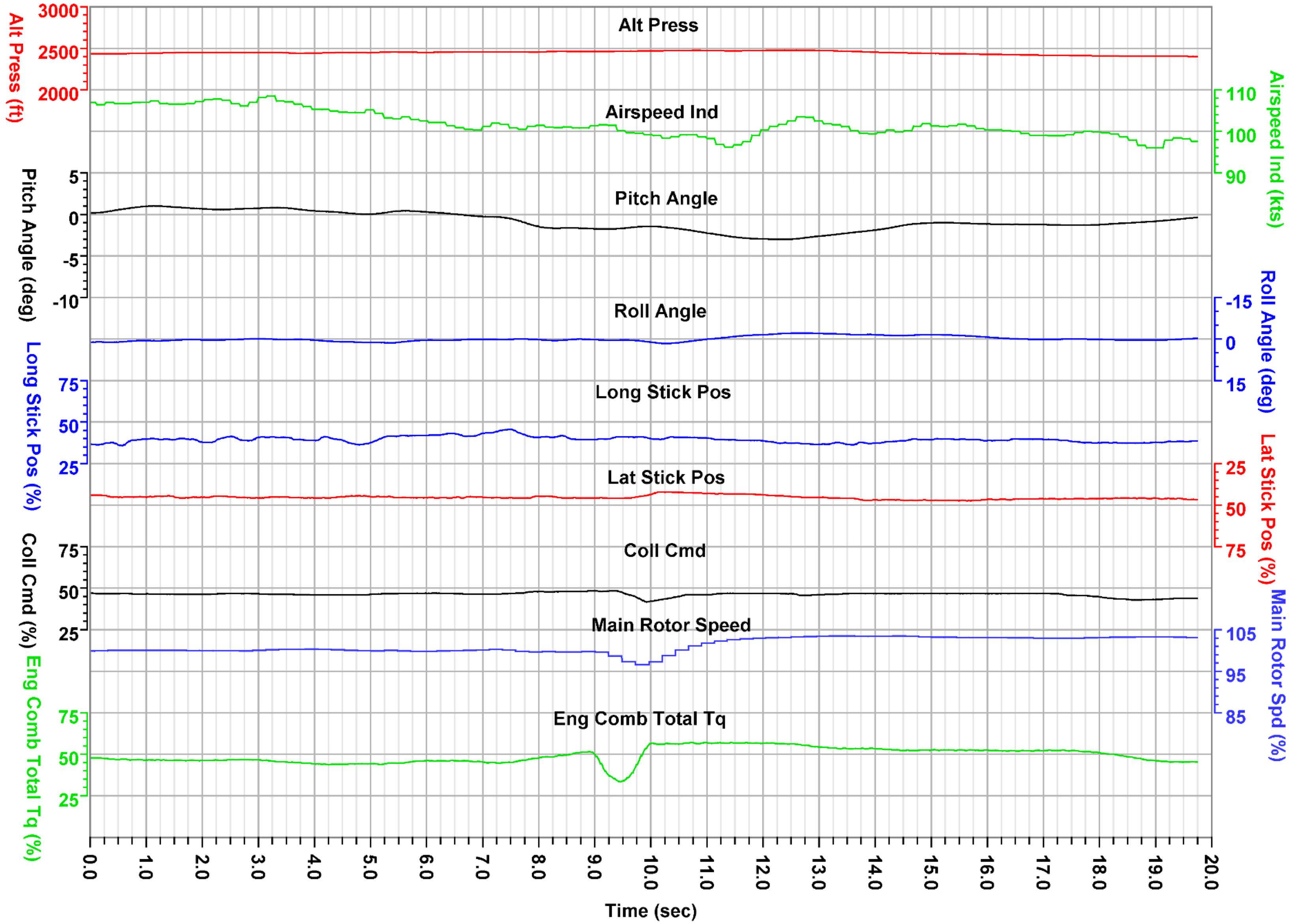


Figure 30. Plot of aircraft basic and flight control command parameters during TP 41.



APPENDIX A

This appendix describes the parameters provided and verified in this report. Table A-1 lists the parameter names, plot/table labels, and units. Additionally, table A-2 describes the unit and discrete abbreviations used in this report.

Table A-1. Instrumentation and parameter names, units, and descriptions.

Instrumentation Name	Units	Plot Label	Description
1. 20DF21	IN	#1 AGB F/A Disp	#1 AGB Longitudinal Displacement
2. 20DF22	IN	#2 AGB F/A Disp	#2 AGB Longitudinal Displacement
3. 00GL01	G	Accel Lat	Lateral Acceleration
4. 15VL55	IPS	Accel Lat Eng Frame	Left Engine Frame Lateral Acceleration
5. 00GF01	G	Accel Long	Longitudinal Acceleration
6. 15VF55	IPS	Accel Long Eng Frame	Left Engine Frame Longitudinal Acceleration
7. 00GV01	G	Accel Vert	Vertical Acceleration
8. 15VV55	IPS	Accel Vert Eng Frame	Left Engine Frame Vertical Acceleration
9. 80VF47	KT	Airspeed Ind	Indicated Airspeed FCC1
10. 80VFT1	KT	Airspeed True	True Airspeed
11. 80DV07	FT	Alt AGL	Altitude Above Ground Level
12. 80DV04	FT	Alt Density	Density Altitude
13. 80DV41	FT	Alt Press	Pressure Altitude
14. 01AVB5	G	Cabin Accel Vert Lf Aft	Cabin Left Aft Vertical Acceleration
15. 01AV73	G	Cabin Accel Vert Lf Mid	Cabin Left Mid Vertical Acceleration
16. 01AVB6	G	Cabin Accel Vert Rt Aft	Cabin Right Aft Vertical Acceleration
17. 01AV72	G	Cabin Accel Vert Rt Mid	Cabin Right Mid Vertical Acceleration
18. DP8034	%	Coll Cmd	Collective Command
19. QETOTP	%	Eng Comb Total Tq	Engine Combined Total Torque
20. 80MTL1	FT-LB (non-dim)	Eng Tq Lf	Left Engine Torque
21. 80MTR1	FT-LB (non-dim)	Eng Tq Rt	Right Engine Torque
22. 80RMJ1	%	Eng1 NG	Engine 1 Gas Generator Speed
23. 80RMR1	%	Eng1 NP	Engine 1 Power Turbine Speed
24. 80TZ64	DEG F (non-dim)	Eng1 T45	Engine 1 Interturbine Temperature
25. 80RMK1	%	Eng2 NG	Engine 2 Gas Generator Speed
26. 80RMS1	%	Eng2 NP	Engine 2 Power Turbine Speed

Instrumentation Name	Units	Plot Label	Description
27. 80TZ74	DEG F (non-dim)	Eng2 T45	Engine 2 Interturbine Temperature
28. 80QQ87	DEG	Heading Mag	Magnetic Heading
29. 02BB11	IN-LB (non-dim)	Horiz Stab Bending Moment	Left Horizontal Stabilizer Beam Bending Station 19
30. 01AV22	G	Inst Pnl Accel Vert Center	Instrument Panel Center Vertical Acceleration
31. 01AV2M	G	Inst Pnl Accel Vert Lf	Instrument Panel Left Vertical Acceleration
32. 01AV2N	G	Inst Pnl Accel Vert Rt	Instrument Panel Right Vertical Acceleration
33. DL8001	%	Lat Stick Pos	Lateral Stick Position
34. 00DLG1	DEG	Latitude	GPS Latitude
35. DF8051	%	Long Stick Pos	Longitudinal Stick Position
36. 00DFG1	DEG	Longitude	GPS Longitude
37. RM3004	RPM	Main Rotor Speed	Main Rotor Speed, see RM3040
38. RM3040	%	Main Rotor Speed	Main Rotor Speed
39. 10FS30	LB (non-dim)	MR Anti-Dive Link Shear	MR Anti-Dive Link Shear Load
40. 30BBB4	IN-LB (non-dim)	MR Beam Bending Sta 197	MR Red Blade Beam Bending Station 197
41. 30BCB4	IN-LB (non-dim)	MR Chord Bending Sta 197	MR Red Blade Chord Bending Station 197
42. 30BBB5	IN-LB (non-dim)	MR Beam Bending Sta 280	MR Red Blade Beam Bending Station 280
43. 30BBB1	IN-LB (non-dim)	MR Beam Bending Sta 44	MR Red Blade Beam Bending Station 44
44. 30BBB2	IN-LB (non-dim)	MR Beam Bending Sta 82	MR Red Blade Beam Bending Station 82
45. 30FA12	LB (non-dim)	MR Blu Bld Lead-Lag Ax Force	MR Blue Blade Damper Lead-Lag Axial Force
46. 30DA03	IN (non-dim)	MR Blu Bld Lead-Lag Ax Pos	MR Blue Blade Damper Lead-Lag Axial Position
47. 30BCB3	IN-LB (non-dim)	MR Chord Bending Sta 130	MR Red Blade Chord Bending Station 130
48. 30FA11	LB (non-dim)	MR Grn Bld Lead-Lag Ax Force	MR Green Blade Damper Lead-Lag Axial Force
49. 30DA02	IN (non-dim)	MR Grn Bld Lead-Lag Ax Pos	MR Green Blade Damper Lead-Lag Axial Position
50. 11FA61	LB (non-dim)	MR Grn Pitch Link Load	MR Green Blade Pitch Link Axial Load
51. 20MT51	IN-LB (non-dim)	MR Mast Tq	MR Mast Torque
52. 30FA10	LB (non-dim)	MR Red Bld Lead-Lag Ax Force	MR Red Blade Damper Lead-Lag Axial Force
53. 30DA01	IN (non-dim)	MR Red Bld Lead-Lag Ax Pos	MR Red Blade Damper Lead-Lag Axial Position

Instrumentation Name	Units	Plot Label	Description
54. 30DB11	IN (non-dim)	MR Red Bld OOP Deflection	MR Red Blade Out-of-plane Motion
55. 11FA41	LB (non-dim)	MR Red Pitch Link Load	MR Red Blade Pitch Link Axial Load
56. DF8054	%	Pedal Pos	Pedal Position
57. 80QP87	DEG	Pitch Angle	Pitch Angle
58. 01AL09	G	Plot Seat Accel Lat	Pilot Seat Lateral Acceleration
59. 01AV06	G	Plt Seat Accel Vert	Pilot Seat Vertical Acceleration
60. 25DL01	IN (non-dim)	Pylon Lat Pos Aft	Pylon Lateral Position Aft
61. 25DL02	IN (non-dim)	Pylon Lat Pos Fwd	Pylon Lateral Position Fwd
62. 25DF01	IN (non-dim)	Pylon Long Pos Lf	Pylon Longitudinal Position Lf
63. 25DF02	IN (non-dim)	Pylon Long Pos Rt	Pylon Longitudinal Position Rt
64. 25DV08	IN (non-dim)	Pylon Vert Pos Lf Aft	Pylon Vertical Position Lf Aft
65. 25DV07	IN (non-dim)	Pylon Vert Pos Lf Fwd	Pylon Vertical Position Lf Fwd
66. 25DV10	IN (non-dim)	Pylon Vert Pos Rt Aft	Pylon Vertical Position Rt Aft
67. 25DV09	IN (non-dim)	Pylon Vert Pos Rt Fwd	Pylon Vertical Position Rt Fwd
68. 80QR87	DEG	Roll Angle	Roll Angle
69. 10FA23	LB (non-dim)	S/P Lf Aft Ax Load	MR Swashplate Left Aft Axial Load
70. 10FA25	LB (non-dim)	S/P Lf Fwd Ax Load	MR Swashplate Left Forward Axial Load
71. 10FA27	LB (non-dim)	S/P Rt Ax Load	MR Swashplate Right Axial Load
72. RM3504	RPM	Tail Rotor Speed	Tail Rotor Speed, see RM3540
73. RM3540	%	Tail Rotor Speed	Tail Rotor Speed
74. 35FA13	LB (non-dim)	TR Blu Bld Lead-Lag Ax Force	TR Blue Blade Damper Lead-Lag Axial Force
75. 11FA62	LB (non-dim)	TR Grn Pitch Link Load	TR Green Blade Pitch Link Axial Load
76. 20MT22	IN-LB (non-dim)	TR Mast Tq	TR Mast Torque
77. 35FA14	LB (non-dim)	TR Orn Bld Lead-Lag Ax Force	TR Orange Blade Damper Lead-Lag Axial Force
78. 10FA63	LB (non-dim)	TR Push-Pull Tube Load	TR Axial Push-Pull Tube Load
79. 35FA11	LB (non-dim)	TR Red Bld Lead-Lag Ax Force	TR Red Blade Damper Lead-Lag Axial Force
80. 11FA42	LB (non-dim)	TR Red Pitch Link Load	TR Red Blade Pitch Link Axial Load

Instrumentation Name	Units	Plot Label	Description
81. 75PZ2J	PSIG (non-dim)	TRA Hyd Pres Rtn	TR Actuator Hydraulic Pressure Return
82. 00QP02	DEG		Angle of Attack from Instro Boom
83. 00QQ02	DEG		Sideslip Angle from Instro Boom
84. 00VFG1	KT		Ground Speed
85. 01AV07	G		Copilot Seat Vertical Acceleration
86. 01AV47	G		Left APU Mount Vertical Acceleration
87. 01AV48	G		Right APU Mount Vertical Acceleration
88. 01AVJ9	G		Baggage Compartment Right Vertical Acceleration
89. 01AVK9	G		Baggage Compartment Left Vertical Acceleration
90. 16VF55	IPS		Right Engine Frame Longitudinal Acceleration
91. 16VL55	IPS		Right Engine Frame Lateral Acceleration
92. 16VV55	IPS		Right Engine Frame Vertical Acceleration
93. 80VF41	KT		Select Computed Airspeed
94. 80VV41	FT/MIN		Altitude Rate
95. 86EZ11	VOLTS		#1 AC Generator Voltage
96. 86EZ12	VOLTS		#2 AC Generator Voltage
97. DV0050	FT		Pressure Altitude, from Instrumentation Boom
98. VF006A	KT		Instrument Corrected Airspeed, from Instrumentation
99. VF006B	KT		True Airspeed, from Instrumentation Boom

Table A-2. Descriptions of units and abbreviations.

Unit/Abbreviation	Description
AC	Alternating Current
AGB	Accessory Gear Box
APU	Auxiliary Power Unit
deg	degrees
deg F	degrees Fahrenheit
FCC	Flight Control Computer
ft	feet
ft-lb	foot-pounds
fwd	forward
IGB	Intermediate Gear Box
in	inches
ips	inches per second
kt	knots
lb	pounds
lf	left
MR	Main Rotor
MRGB	Main Rotor Gear Box
OOP	Out-of-plane
psi	pounds per square inch
psig	pounds per square inch, gauge
RGB	Rotor Gear Box
rpm	revolutions per minute
rt	right
TR	Tail Rotor
TRGB	Tail Rotor Gear Box
WRT	With respect to

Table A-3. Data recording rate in Hertz for all parameters.

Instrumentation Name	Plot Label	Recording Rate (Hz)	Description
1. 00DFG1	Longitude	31	GPS Longitude
2. 00DLG1	Latitude	31	GPS Latitude
3. 00GF01	Accel Long	125	Longitudinal Acceleration
4. 00GL01	Accel Lat	125	Lateral Acceleration
5. 00GV01	Accel Vert	125	Vertical Acceleration
6. 00QP02		62	Angle of Attack from Instro Boom
7. 00QQ02		62	Sideslip Angle from Instro Boom
8. 00VFG1		31	Ground Speed
9. 01AL09	Plot Seat Accel Lat	250	Pilot Seat Lateral Acceleration
10. 01AV06	Plt Seat Accel Vert	250	Pilot Seat Vertical Acceleration
11. 01AV07		250	Copilot Seat Vertical Acceleration
12. 01AV22	Inst Pnl Accel Vert Center	250	Instrument Panel Center Vertical Acceleration
13. 01AV2M	Inst Pnl Accel Vert Lf	250	Instrument Panel Left Vertical Acceleration
14. 01AV2N	Inst Pnl Accel Vert Rt	250	Instrument Panel Right Vertical Acceleration
15. 01AV47		1000	Left APU Mount Vertical Acceleration
16. 01AV48		1000	Right APU Mount Vertical Acceleration
17. 01AV72	Cabin Accel Vert Rt Mid	250	Cabin Right Mid Vertical Acceleration
18. 01AV73	Cabin Accel Vert Lf Mid	250	Cabin Left Mid Vertical Acceleration
19. 01AVB5	Cabin Accel Vert Lf Aft	250	Cabin Left Aft Vertical Acceleration
20. 01AVB6	Cabin Accel Vert Rt Aft	250	Cabin Right Aft Vertical Acceleration
21. 01AVJ9		250	Baggage Compartment Right Vertical Acceleration
22. 01AVK9		250	Baggage Compartment Left Vertical Acceleration
23. 02BB11	Horiz Stab Bending Moment	500	Left Horizontal Stabilizer Beam Bending Station 19
24. 10FA23	S/P Lf Aft Ax Load	500	MR Swashplate Left Aft Axial Load
25. 10FA25	S/P Lf Fwd Ax Load	500	MR Swashplate Left Forward Axial Load
26. 10FA27	S/P Rt Ax Load	500	MR Swashplate Right Axial Load
27. 10FA63	TR Push-Pull Tube Load	1000	TR Axial Push-Pull Tube Load
28. 10FS30	MR Anti-Dive Link Shear	500	MR Anti-Dive Link Shear Load

Instrumentation Name	Plot Label	Recording Rate (Hz)	Description
29. 11FA41	MR Red Pitch Link Load	500	MR Red Blade Pitch Link Axial Load
30. 11FA42	TR Red Pitch Link Load	1000	TR Red Blade Pitch Link Axial Load
31. 11FA61	MR Grn Pitch Link Load	500	MR Green Blade Pitch Link Axial Load
32. 11FA62	TR Grn Pitch Link Load	1000	TR Green Blade Pitch Link Axial Load
33. 15VF55	Accel Long Eng Frame	4000	Left Engine Frame Longitudinal Acceleration
34. 15VL55	Accel Lat Eng Frame	4000	Left Engine Frame Lateral Acceleration
35. 15VV55	Accel Vert Eng Frame	4000	Left Engine Frame Vertical Acceleration
36. 16VF55		4000	Right Engine Frame Longitudinal Acceleration
37. 16VL55		4000	Right Engine Frame Lateral Acceleration
38. 16VV55		4000	Right Engine Frame Vertical Acceleration
39. 20DF21	#1 AGB F/A Disp	125	#1 AGB Longitudinal Displacement
40. 20DF22	#2 AGB F/A Disp	125	#2 AGB Longitudinal Displacement
41. 20MT22	TR Mast Tq	1000	TR Mast Torque
42. 20MT51	MR Mast Tq	500	MR Mast Torque
43. 25DF01	Pylon Long Pos Lf	125	Pylon Longitudinal Position Lf
44. 25DF02	Pylon Long Pos Rt	125	Pylon Longitudinal Position Rt
45. 25DL01	Pylon Lat Pos Aft	125	Pylon Lateral Position Aft
46. 25DL02	Pylon Lat Pos Fwd	125	Pylon Lateral Position Fwd
47. 25DV07	Pylon Vert Pos Lf Fwd	125	Pylon Vertical Position Lf Fwd
48. 25DV08	Pylon Vert Pos Lf Aft	125	Pylon Vertical Position Lf Aft
49. 25DV09	Pylon Vert Pos Rt Fwd	125	Pylon Vertical Position Rt Fwd
50. 25DV10	Pylon Vert Pos Rt Aft	125	Pylon Vertical Position Rt Aft
51. 30BBB1	MR Beam Bending Sta 44	500	MR Red Blade Beam Bending Station 44
52. 30BBB2	MR Beam Bending Sta 82	500	MR Red Blade Beam Bending Station 82
53. 30BBB4	MR Beam Bending Sta 197	500	MR Red Blade Beam Bending Station 197
54. 30BBB5	MR Beam Bending Sta 280	500	MR Red Blade Beam Bending Station 280

Instrumentation Name	Plot Label	Recording Rate (Hz)	Description
55. 30BCB3	MR Chord Bending Sta 130	500	MR Red Blade Chord Bending Station 130
56. 30BCB4	MR Beam Bending Sta 197	500	MR Red Blade Chord Bending Station 197
57. 30DA01	MR Red Bld Lead-Lag Ax Pos	500	MR Red Blade Damper Lead-Lag Axial Position
58. 30DA02	MR Grn Bld Lead-Lag Ax Pos	500	MR Green Blade Damper Lead-Lag Axial Position
59. 30DA03	MR Blu Bld Lead-Lag Ax Pos	500	MR Blue Blade Damper Lead-Lag Axial Position
60. 30DB11	MR Red Bld OOP Deflection	500	MR Red Blade Out-of-plane Motion
61. 30FA10	MR Red Bld Lead-Lag Ax Force	500	MR Red Blade Damper Lead-Lag Axial Force
62. 30FA11	MR Grn Bld Lead-Lag Ax Force	500	MR Green Blade Damper Lead-Lag Axial Force
63. 30FA12	MR Blu Bld Lead-Lag Ax Force	500	MR Blue Blade Damper Lead-Lag Axial Force
64. 35FA11	TR Red Bld Lead-Lag Ax Force	1000	TR Red Blade Damper Lead-Lag Axial Force
65. 35FA13	TR Blu Bld Lead-Lag Ax Force	1000	TR Blue Blade Damper Lead-Lag Axial Force
66. 35FA14	TR Orn Bld Lead-Lag Ax Force	1000	TR Orange Blade Damper Lead-Lag Axial Force
67. 75PZ2J	TRA Hyd Pres Rtn	1000	TR Actuator Hydraulic Pressure Return
68. 80DV04	Alt Density	31	Density Altitude
69. 80DV07	Alt AGL	31	Altitude Above Ground Level
70. 80DV41	Alt Press	31	Pressure Altitude
71. 80MTL1	Eng Tq Lf	62	Left Engine Torque
72. 80MTR1	Eng Tq Rt	62	Right Engine Torque
73. 80QP87	Pitch Angle	62	Pitch Angle
74. 80QQ87	Heading Mag	62	Magnetic Heading
75. 80QR87	Roll Angle	62	Roll Angle
76. 80RMJ1	Eng1 NG	31	Engine 1 Gas Generator Speed
77. 80RMK1	Eng2 NG	31	Engine 2 Gas Generator Speed
78. 80RMR1	Eng1 NP	31	Engine 1 Power Turbine Speed
79. 80RMS1	Eng2 NP	31	Engine 2 Power Turbine Speed
80. 80TZ64	Eng1 T45	31	Engine 1 Interturbine Temperature

Instrumentation Name	Plot Label	Recording Rate (Hz)	Description
81. 80TZ74	Eng2 T45	31	Engine 2 Interturbine Temperature
82. 80VF41		31	Select Computed Airspeed
83. 80VF47	Airspeed Ind	31	Indicated Airspeed FCC1
84. 80VFT1	Airspeed True	31	True Airspeed
85. 80VV41		31	Altitude Rate
86. 86EZ11		31	#1 AC Generator Voltage
87. 86EZ12		31	#2 AC Generator Voltage
88. DF8051	Long Stick Pos	62	Longitudinal Stick Position
89. DF8054	Pedal Pos	62	Pedal Position
90. DL8001	Lat Stick Pos	62	Lateral Stick Position
91. DP8034	Coll Cmd	62	Collective Command
92. DV0050		31	Pressure Altitude, from Instrumentation Boom
93. QETOTP	Eng Comb Total Tq	62	Engine Combined Total Torque
94. RM3004	Main Rotor Speed	500	Main Rotor Speed
95. RM3040	Main Rotor Speed	500	Main Rotor Speed
96. RM3504	Tail Rotor Speed	2000	Tail Rotor Speed
97. RM3540	Tail Rotor Speed	2000	Tail Rotor Speed
98. VF006A		31	Instrument Corrected Airspeed, from Instrumentation
99. VF006B		31	True Airspeed, from Instrumentation Boom

Table A-4. Description of attachment contents.

Attachment Number	Contents	Figure(s)
1a	31 Hz parameters from entire flight	9-11
1b	62 Hz parameters from entire flight	9-11
1c	125 Hz parameters from entire flight	9-11
2a	31 Hz parameters from TP51	12-22
2b	62 Hz parameters from TP51	12-22
2c	125 Hz parameters from TP51	12-22
2d	250 Hz parameters from TP51	12-22
2e	500 Hz parameters from TP51	12-22
2f	1000 Hz parameters from TP51	12-22
2g	2000 Hz parameters from TP51	12-22
2h	4000 Hz parameters from TP51	12-22
3a	31 Hz parameters from TP50	23
3b	62 Hz parameters from TP50	23
3c	500 Hz parameters from TP50	23
4a	31 Hz parameters from TP48	24
4b	62 Hz parameters from TP48	24
4c	500 Hz parameters from TP48	24
5a	31 Hz parameters from TP47	25
5b	62 Hz parameters from TP47	25
5c	500 Hz parameters from TP47	25
6a	31 Hz parameters from TP46	26
6b	62 Hz parameters from TP46	26
6c	500 Hz parameters from TP46	26
7a	31 Hz parameters from TP44	27
7b	62 Hz parameters from TP44	27
7c	500 Hz parameters from TP44	27
8a	31 Hz parameters from TP43	28
8b	62 Hz parameters from TP43	28
8c	500 Hz parameters from TP43	28
9a	31 Hz parameters from TP42	29
9b	62 Hz parameters from TP42	29
9c	500 Hz parameters from TP42	29

Attachment Number	Contents	Figure(s)
10a	31 Hz parameters from TP41	30
10b	62 Hz parameters from TP41	30
10c	500 Hz parameters from TP41	30