National Transportation Safety Board
Office of Research and Engineering
Washington, DC 20594

DCA22WA102

COCKPIT VOICE AND FLIGHT DATA RECORDER

Combined Download Report
July 1, 2022

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A. ACCIDENT

Location: Wuzhou, China
Date: March 21, 2022
Time: 0630 UTC
Airplane: Boeing 737-800, China Eastern Airlines, Registration B-1791

B. COCKPIT VOICE AND FLIGHT DATA RECORDER DATA RECOVERY GROUP

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C. DETAILS OF THE INVESTIGATION

A data recovery group was convened on March 28, 2022, consisting of representatives from the Civil Aviation Administration of China (CAAC) and the National Transportation Safety Board (NTSB). The NTSB Vehicle Recorder Division received the memory modules from a Cockpit Voice Recorder (CVR) and a Flight Data Recorder (FDR). Work on the memory devices was performed by NTSB personnel and overseen and recorded by CAAC personnel. Memory modules from the following recorders were provided to the NTSB:

Recorder Manufacturer/Model:	Honeywell HFR5-V CVR
Part Number:	980-6032-001
Recorder Serial Number:	CVR-04014

Recorder Manufacturer/Model:	Honeywell HFR5-D FDR
Part Number:	980-4750-009
Recorder Serial Number:	FDR-02952

D. DATA RECOVERY

Data recovery from damaged flight data recorders is a methodical process of evaluation, repair, and readout. The highest priority is placed on recovering stored data in a method is the least likely to result in lost or corrupted data. Extensively damaged hardware is a particular challenge due to the possibility of shorted or otherwise damaged board components leading to data loss when power is applied. Careful handling and thorough inspections of components prior to readout attempts can find and catalog damage so that a methodical repair and recovery plan can be pursued. The use of tools specifically designed for recovery of damaged hardware is essential to preserving the integrity of the recorded data. This includes hardware such as cables and readout chassis as well as recovery software packages.

1.0 HFR5-V CVR Description

The Honeywell HFR5-V Cockpit Voice Recorder records four channels of high-quality audio information from the Captain's audio panel, the First Officer's audio panel, the Cockpit Observer's audio panel, and the Cockpit Area Microphone (CAM). The digital recording is stored on a solid-state memory module. The channels sourced from the audio panels record for two hours, and the CAM channel records for three hours. The HFR5-V is designed to meet the crash-survivability requirements laid out in EUROCAE standard ED-112A.

1.1 HFR5-V CVR Damage

The CVR Crash Survivable Memory Unit (CSMU) was reported to have been recovered from the aircraft wreckage on March 23, 2022. The recorder was heavily damaged by impact forces. The CSMU was opened and the memory module was removed at the CAAC's facilities in Beijing. The red Room Temperature Vulcanizing (RTV) sealant protecting the memory board Circuit Card Assembly (CCA) was removed and several attempts to download the memory contents of the device were made by the CAAC using a surrogate recorder chassis. It was reported that the software annunciated numerous errors during the decompression process, and none of the attempts resulted in intelligible .wav audio files.

1.2 HFR5-V CVR Recovery

On March 28, 2022, the NTSB was given a CVR download file in .dlu format from one of the download attempts of the CVR prior to arrival at the NTSB. The file was decompressed in the NTSB CVR lab using Honeywell's recorder recovery software Playback32. Numerous errors were presented during the decompression process. At the end of the decompression, four .wav audio files were generated. The lengths and sample rates of the four files was as expected, however when played back the files were unintelligible, with stuttering and echoing artifacts and digital noise throughout, and the audio data were unusable.

The CVR memory module was presented to the NTSB for microscopic inspection. Figure 1 shows the connector side of the board and Figure 2 shows the opposite side. Both sides have FLASH memory chips containing data. Preliminary findings showed the board to have substantial damage to the connector area of the device. Numerous solder pads attaching the connector to the board and providing the electrical signal path to the data chips were found bent or completely dislodged from the board. (See Attachment 1, CMM Recovery Report, for additional details and specifics of connector damage). The damaged pins corresponded to chip data lines and address lines. This damage would be significant to the download and is consistent with the audio artifacts present in the data. Damage to chip data lines would manifest as quantization error-type digital noise and damage to chip address lines would manifest as stuttering, echoing, and repeating-type noises.

Further inspections also revealed that the plastic portion of the connector itself was deformed subtly out of its normal state. The long edge along the board end was

Figure 1. CVR memory module board, connector side.

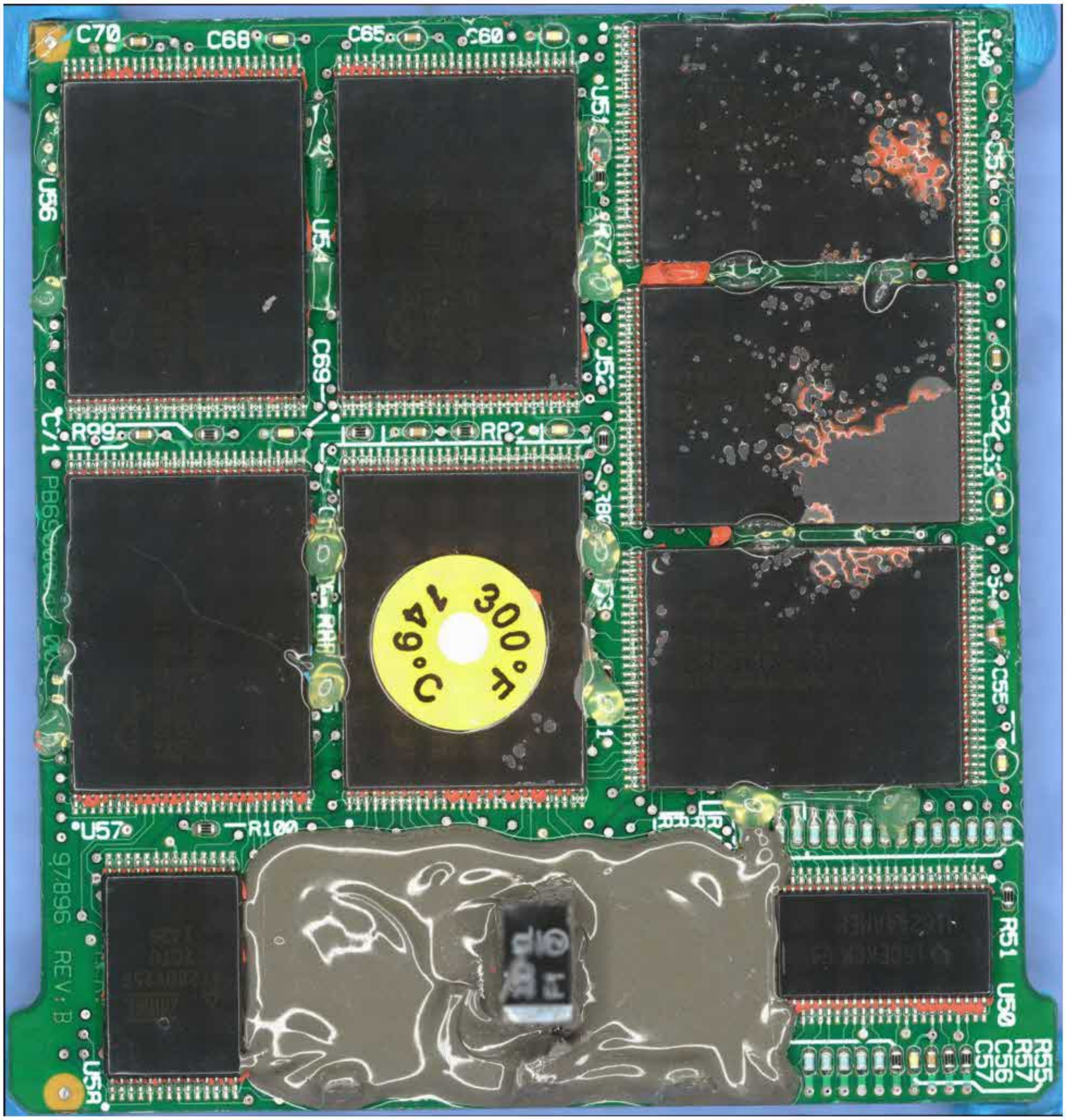

Figure 2. CVR memory board, side opposite connector.

raised above its normal position, and the pins along that edge were recessed inside the connector housing. In this state it would have been difficult for the male pins on the recovery cable to make a reliable connection with the board. The long edge facing the memory chips was crushed down below its normal position with the pins projecting out notably from the connector housing. It was also found that the ground plane between the two sides of the connector was damaged underneath the connector housing. Several sections of the ground plane were severed or lifted from the board. Figure 3 shows the connector, as received.

Figure 3. Detail of CVR memory module connector, as received.

There was one additional anomaly noted that was determined to have been present at the time of manufacture of the board. A capacitor was lifted from the board and not in contact with the board pads, and it had been sealed over with conformal coating in this fashion. This means that the capacitor had never been a part of the circuit it was designed to be in. Review of board schematics showed that this was a power conditioning capacitor, serving to filter frequency fluctuations that may be caused by a dirty power supply. Because it had not been detected in board pass-off testing or continued airworthiness checks of the CVR system performed by the airline, it is unlikely that it impacted the performance of the CVR.

To finalize the preliminary inspections of the board, the remaining RTV sealant on the board was carefully removed from the connector area. All the pins from the connector that were accessible for inspection were physically tested for integrity. (Some pins were not accessible because they were routed under the board.) Numerous loose or separated pins were catalogued. Figure 4 shows the connector prepped for inspection with remaining RTV sealant removed.

A damage recovery work plan was developed to attempt to repair the damage discovered during preliminary inspections as safely as possible before powering the board and attempting another download of the memory. The circuit board Gerber files were reviewed to determine the location and routing of all the significant vias and memory traces. A continuity test was developed to check for hidden electrical damage between the connector pins and the flash memory chips. The test was confirmed using a known good surrogate memory module.

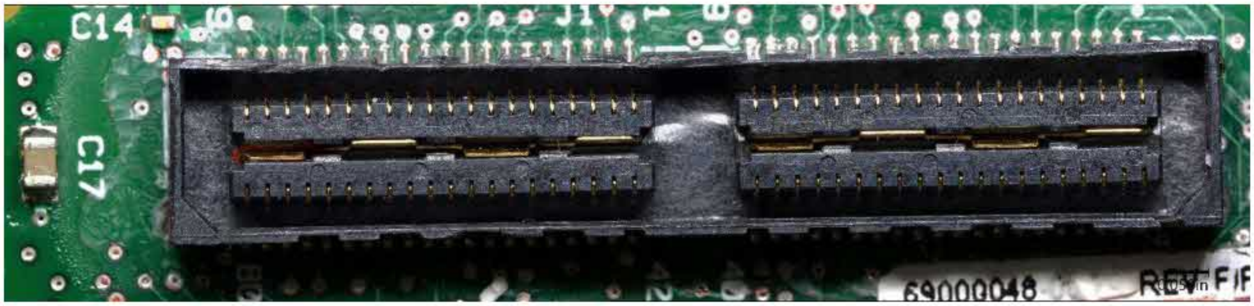

Figure 4. Connector detail with RTV sealant removed.

The loose and separated pins found in the inspections were repaired using a microscope and a special cyanoacrylate glue. To help make the best connection possible with the damaged board connector, an HFR-5 recovery flex cable was modified to aid in positive connections between the cable and the board. Many of the pins on the cable were bent slightly away from the plastic of the connector, causing them to interface better with the pins that were recessed into the damaged board connector.

With these repairs complete, the accident CPM was interfaced with the modified recovery flex cable and installed in the NTSB's HFR5-V golden chassis. A download was attempted using Honeywell Playback32 software, which failed to generate a usable .dlu file.

A subsequent download was performed without unplugging or reseating the connector from the golden chassis using an engineering tool called DLDR. DLDR provides a direct read of the flash memory chip contents and writes each chip image into binary chip image files. The chip images can then be recombined in the proper sequence into the full memory contents and written into a .dlu file using another engineering tool called CHIPS. This download generated 14 chip image files (one for each flash memory chip on the board, as expected) which were combined into a .dlu file. Playback32 was able to generate 4 .wav files from the images, however it generated a large volume of errors during the decompression process. A second DLDR download was completed to check for consistency between the two downloads. The downloads had minor single byte differences spaced throughout the file which were never explained.

The .wav files included three audio panel channels sampled at 8k Hz of two hours in length each and one CAM channel sampled at 16k Hz of three hours in length. The files were loaded into a CVR listening room for audition. Because of the method of recombining chip image files, the .wav files were not in sequential order (i.e. with the oldest data at the beginning running sequentially through the most recent data at the end). Instead, the data was in the order in which it was written across the chips, and the most recent data (the accident sequence) was near the middle of the files, followed by the oldest data.

The audition showed that all four channels contained intelligible audio. The audio panel channels were of Fair quality on the NTSB quality rating scale[1], and the CAM channel was of Poor quality. There was digital noise and distortion present on all channels, and there were portions of repeated audio noted during the accident sequence. The digital artifacts in the audio data were consistent with damage between the recovery cable and the NVM chip data lines, and the repeated audio was consistent with similar damage to the chip address lines.

The download results provided additional evidence of damage to the connector area of the board, so further inspections were developed to identify the issues with the pin connections. These included both 2-D and 3-D X-ray imaging to determine if any non-visible damage had occurred to the memory module and additional microscopic inspections.

X-ray inspections showed several instances where the pins of the connector had minimal clearance between either board traces or vias, however the clearance indicated it was unlikely to lead to shorts or other problems with the signal path of the chip data and address lines. No other damage was seen in the additional microscopic inspections.

The modified recovery ribbon cable was adjusted again with the help of the X-ray images in an attempt to make better connections with the damaged connector. A comprehensive pin check was undertaken to ensure that the pins with minimal clearance were not causing issues with the electrical signal path. Another series of downloads was attempted, with similar results to the previous downloads.

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[1] Appendix A comprises the CVR Quality Rating Scale.

With the downloads only providing poor to fair results and the audio being consistent with damage to chip data and address lines even after attempts to correct the issue, the team determined that the damaged board connector should be removed and possibly replaced. An NTSB surrogate board was identified to be used as a test article to determine the safest process to remove the plastic housing of the connector shell while leaving the pins soldered in place on the board.

The CVR connector housing was fully removed, which revealed additional damage to the pins that was hidden underneath the plastic. Pins were found pushed down underneath the plastic and numerous additional pads and traces were found to be loose or completely removed from the board. It is likely that the only reason some pins were making contact was that they were pinned down to the board by the connector housing itself. The central ground planes were found to be loose at every attachment point except for one. The memory module with the connector shell removed is shown in Figure 5. Some of the deformations to the pins is shown in Figure 6.

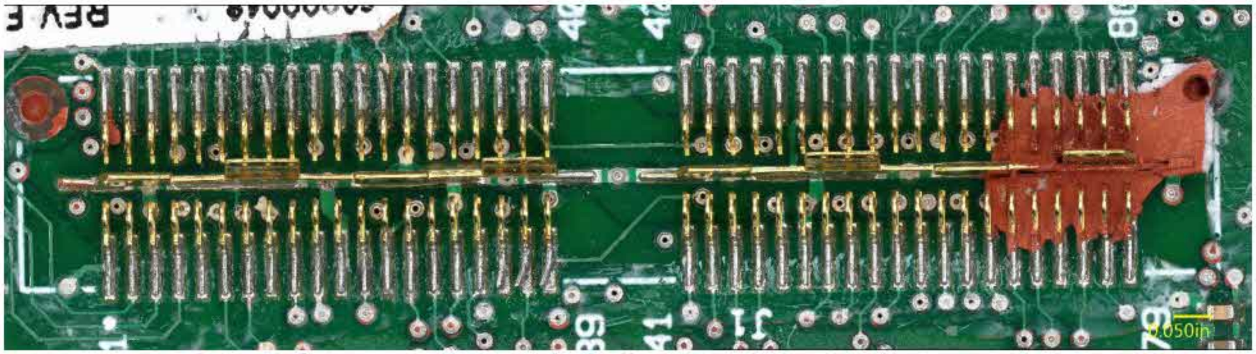

Figure 5. Detail view of connector pins with shell removed.

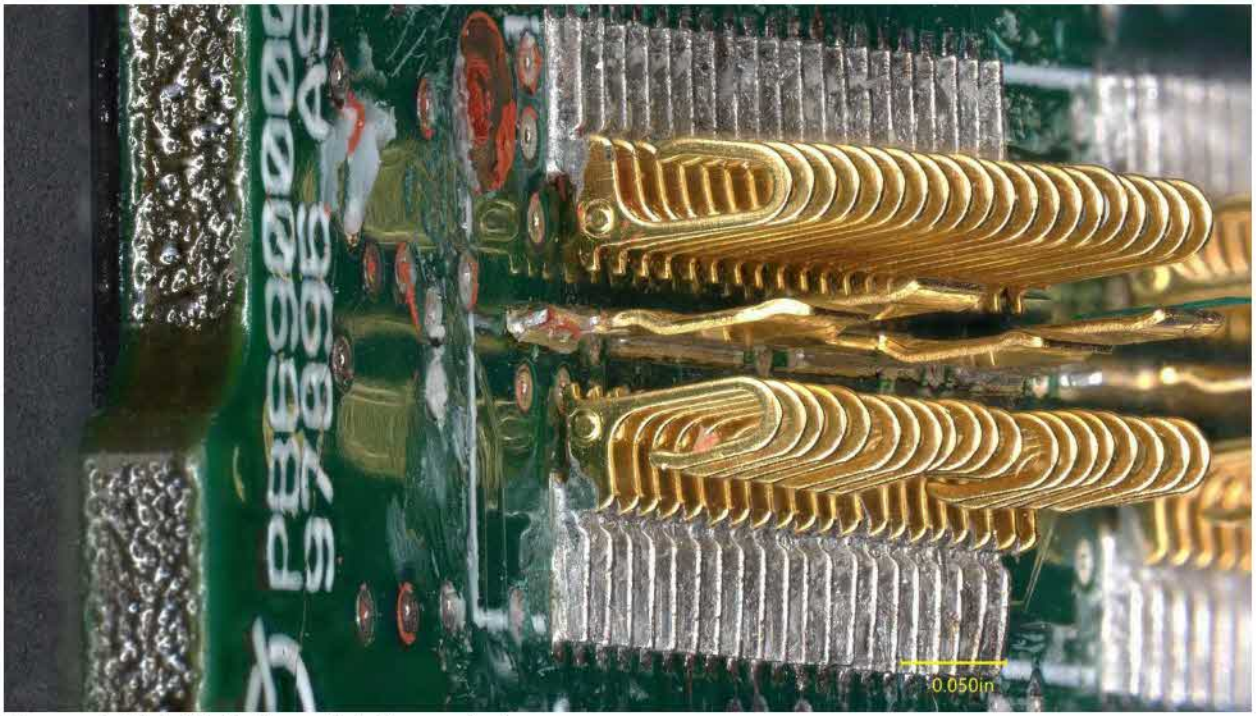

Figure 6. Detailed view of deformed pins.

The pins, now without the plastic connector shell, were again stabilized and loose areas were reworked with cyanoacrylate glue and allowed to cure. With the pins completely stabilized work was undertaken to carefully re-shape them into their proper positions. The pins on the surrogate board were used as a template for this activity. Re-shaping the pins into the best approximation of their original shapes provided the best chance of securely mating to the recovery cable once the plastic housing was replaced. With the pins re-shaped it also became clear that the odd-numbered pins were critically close to many of the uninsulated vias and traces, which was previously hidden by the connector shell. To solve this issue a thin insulation strip was fabricated out of Kapton tape and placed between the pins and the board.

A new connector shell was carefully installed over the reworked pins. This work was performed under the microscope due to the delicate nature of the pins and the need to have them align with the individual grooves in the connector. The modified flex cable was mated to the board and secured with ESD tape. The board and flex cable assembly was then attached to the NTSB HFR5-V golden chassis and downloaded using both Playback32 and DLDR.

The Playback32 download proceeded normally with none of the errors seen in previous download attempts. Likewise, the decompression process went smoothly with a small number of errors during the decompression of the wideband (CAM) channel, but none in the narrowband channels, or in the sheer quantity that was seen in previous downloads. Playback32 generated 4 .wav files the bit depth and sampling rate characteristics equivalent to previous downloads, as expected.

The .wav files were loaded into a CVR listening room for audition. The files were in sequential order from the oldest data to the most recent (accident) data. The accident was captured, and audio quality was Excellent per the NTSB audio quality rating standards on all channels.

Further analysis of the individual tracks revealed that there was a time drift between the wideband CAM channel and the narrowband crew audio channels. The drift was not linear, and the CAM and crew channels drifted from each other throughout the full two hours of the crew channel recordings. When a common audio anchor point was used to synchronize the CAM and crew channels it could be determined that the crew channels were occasionally missing small portions of data, likely corresponding with individual packets of digital audio data being dropped in the recovery.

The DLDR download was also decompressed and .wav files were generated with the files from the DLDR generated chip images. The .wav files were directly compared with the .wav files generated from the Playback32 download. It was determined that the Playback32 files provided the most accurate time history for the event. The narrowband channels exhibited minor data loss for very short durations occurring at random intervals throughout the recording. These artifacts may have been related to the as-manufactured bypass capacitor damage identified on the CVR board during initial microscopic inspection, but this could not be confirmed because there was no exemplar download from before the accident for comparison.

With excellent quality recordings and an accurate time history on the CAM channel it was determined that an acceptable download was recovered, and no additional download attempts or more invasive recovery techniques were required.

1.3 Audio Recording Description

Each channel's audio quality and duration from the final download files is indicated in Table 1.

Table 1: Audio Quality

Channel Number	Content/Source	Quality	Duration
1	Cockpit Observer Audio Panel	Excellent	~120 min
2	First Officer Audio Panel	Excellent	~120 min
3	Captain Audio Panel	Excellent	~120 min
4	Cockpit Area Microphone (CAM)	Excellent	~180 min

1.4 CVR Data Provided to CAAC

CVR data provided to the CAAC delegation included the following:

- Raw download files from all download attempts made, both with Playback32 and DLDR
- Raw chip image files from all DLDR download attempts
- All .dlu files generated from both Playback32 and DLDR/CHIPS, including those that did not generate valid .wav files
- All .wav files generated from the downloads.
- All .wav files that were timeline-corrected and all crew audio channels that were upsampled from their default 8k Hz sample rate to match the CAM channel sample rate at 16k Hz.
- All session files generated by the NTSB's audio analysis tool, known as RAPT-R .mdf files.
- .wav files that included noise filtering and audio enhancements to help bring out crucial portions of the audio.
- Time stretched .wav files to match the timing of the crew channels and the CAM channel as best as possible given the packet dropouts discussed in the text above.
- All photographs, scans, and microscopic images taken of the CVR memory boards throughout the recovery process.

The NTSB did not retain any of the above files provided to the CAAC delegation other than the photographs, scans, and microscopic images. No CVR audio files or other raw or intermediate download files that could be used to generate audio files were maintained by the NTSB.

2.0 HFR5-D FDR Description

The Honeywell HFR5-D Flight Data Recorder records airplane flight information in a digital format using solid-state flash memory as the recording medium. The HFR5-D can receive data in the ARINC 573/717/747 configurations and can record a minimum of 25 hours of flight data. It is configured to record 512 12-bit words of digital information every second. Each grouping of 512 words (each second) is called a subframe. Each subframe has a unique 12-bit synchronization (sync) word identifying it as either subframe 1, 2, 3, or 4. The sync word is the first word in each subframe. The data stream is "in sync" when successive sync words appear at proper 512-word intervals. Each data parameter (e.g. altitude, heading, airspeed) has a specifically assigned word number within the subframe. The HFR5-D is designed to meet the crash-survivability requirements of EUROCAE standard ED-112A.

2.1 HFR5-D FDR Damage

The FDR crash survivable memory unit (CSMU) was reported to have been recovered from the aircraft wreckage on March 27, 2022. The recorder was heavily damaged by impact forces. The CSMU was opened and the memory module was removed at the CAAC's facilities in Beijing. It was reported that one attempt to download the memory contents was made by the CAAC using a surrogate FDR chassis, which was unsuccessful.

2.2 HFR5-D FDR Recovery

The FDR CCA was presented to the NTSB on April 4, 2022. The red RTV sealant protecting the memory board CCA was left intact, with only the FLASH memory temperature dot exposed for inspection. The temperature dot indicated no significant heat exposure to the board and none of the damage present on the CVR board was noted on the FDR.

The NTSB golden chassis was reconfigured to be a proper FDR surrogate and the accident memory was connected. A download attempt using Playback32 was attempted, which failed. Several downloads were performed of the individual FLASH memory devices using the DLDR tool. The results varied slightly from one download attempt to the next, however generally resulted in files of all 0's for each FLASH chip image.

The red RTV was removed from the FDR memory board to allow for an initial visual inspection of the entire module. Figures 7 and 8 show the connector side and opposite side, respectively, of the FDR memory module. The module was inspected under high-power microscopy, revealing that FLASH module number U2 had a crack extending from the top edge of the memory packaging into the center of the chip. The crack penetrated to the surface of the conformal coating over the device. Many of the epoxy balls bonding the chip to the board also showed evidence of cracking and/or separation from the FLASH devices to which they were originally adhered.

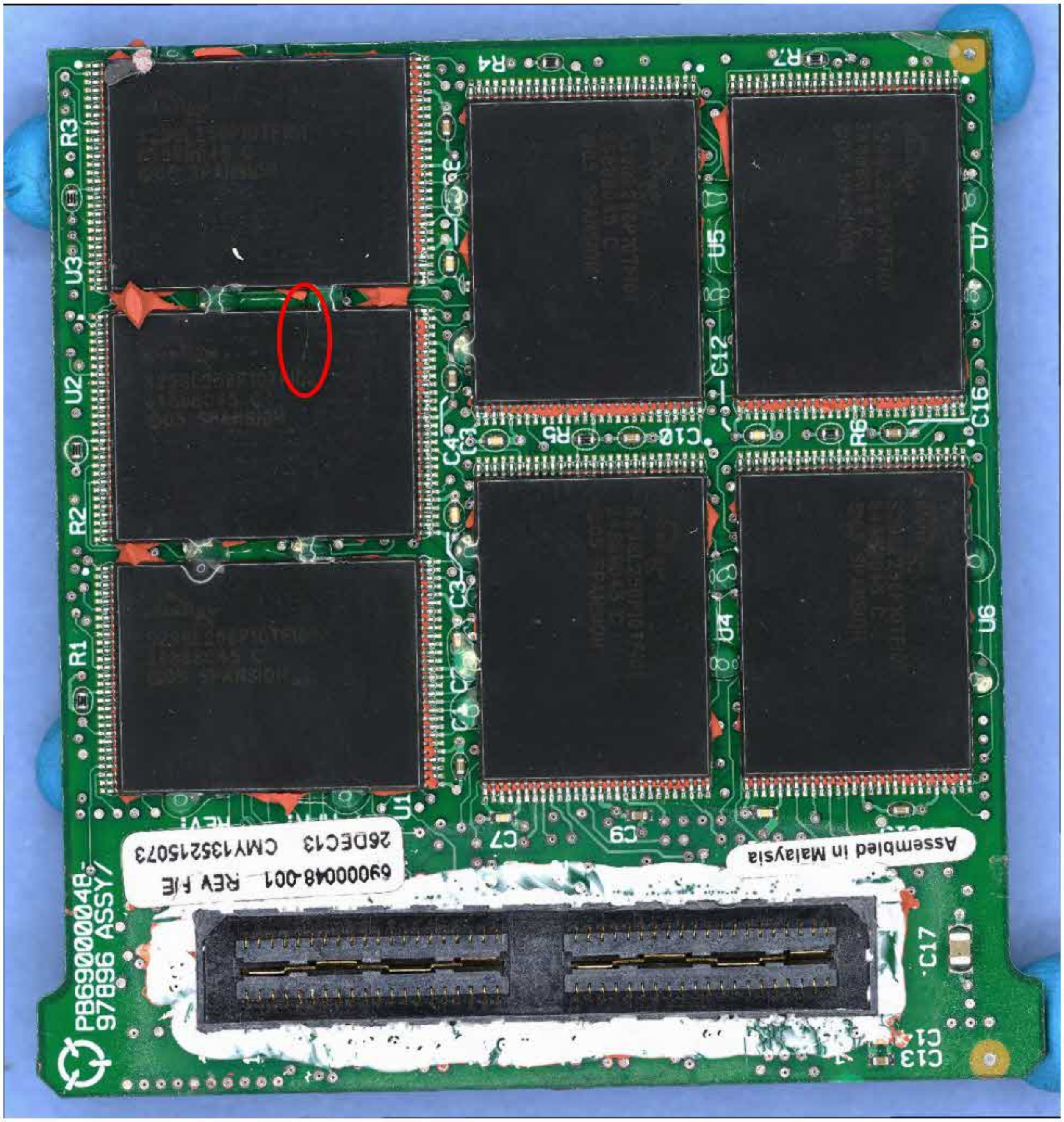

Figure 7. Connector side of FDR memory module with crack faintly visible in chip U2, marked with a red circle in the photograph.

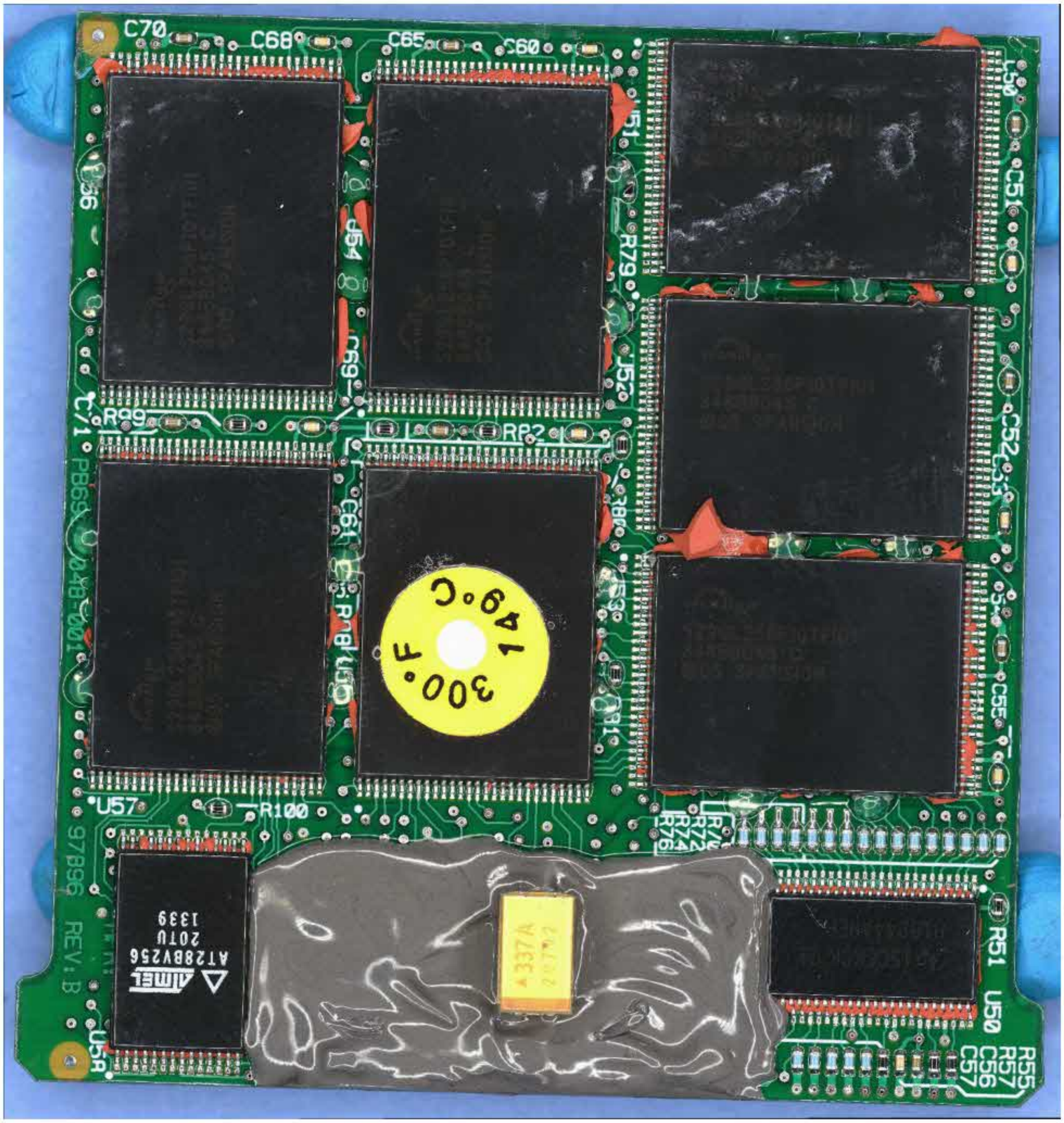

Figure 8. FDR memory module side opposite connector.

Additional minor cracking was found in the chip packaging areas of many of the epoxy bonds between FLASH modules. This included minor cracking in FLASH module numbers U1 & U2, U5 & U7, and U51 & U52. The majority of the epoxy bonds on both sides of the memory module showed evidence of fractures. Figure 9 shows an example of the cracking seen in the epoxy bond between chips U1 and U2.

Figure 9. Example of cracks seen in epoxy bond between chips U1 and U2.

X-ray inspection of the FDR module was undertaken to evaluate any damage not detectable via optical examination. This damage could include broken bond wires within the device packaging, damage to the frame of the chip, or damage to the chip silicon die. No additional damage was discovered during this inspection.

Following the discovery of chip-level cracking and the behavior of the downloads using the DLDR chip-level recovery tool, there was concern for the integrity of the data using additional standard download methods. Following discussions among staff, the conclusion was reached that the safest method for recovery of any surviving data would be to remove the individual FLASH memory devices (chips) containing flight data and read the data directly using a FLASH memory chip reader.

Removal of FLASH memory devices from a circuit board assembly is a technically challenging and somewhat risky procedure. It is possible to damage the chips both physically and electrically during the removal and readout process. As a risk-reduction exercise the NTSB decided to use a known good surrogate memory module as a test article to develop the safest procedure for removal and readout of the individual FLASH memory modules.

A suitable NTSB surrogate test article was identified, and the memory was first downloaded using the DLDR tool. This would permit direct comparison of the chip images prior to removal from the board with the images generated with a FLASH memory reader/programmer. If any differences existed, it would be possible to characterize and remediate differences between the two chip readout methods.

NTSB electronics specialists removed all of the conformal coating from the FLASH memory pins of the test article in preparation of de-soldering the chips from the PCB. Then, all the epoxy bonds were manually removed from each of the chips. A first pass at solder removal was made by hand, prior to using an automated tool. This was done to reduce the stress of removal of the chips. It was expected that there would still be residual RTV, conformal coating, and epoxy trapped underneath the chip where it was placed on the PCB.

Finally, a recipe was developed for the Finetech FinePlacer microelectronics workstation for chip removal. The recipe consisted of the following:

1. Heating of the entire board to an equilibrium temperature somewhat below the solder melt temperature for the solder used by the manufacturer.
2. Application of heat to the pins of the memory chip through a chip-specific nozzle that ramped the temperature at a safe rate to reach solder-melt temperatures.
3. Application of suction to lift the chip free of the PCB once the solder was fully melted.

On the HFR5 memory board there are a total of 14 FLASH memory chips, 7 on each side of the board. However, in the FDR application (HFR5-D) only 6 of the chips (chips defined as U1, U2, U3, U4, U5, and U6) are used to store flight data. For the first test of removal from the test article chip U7 was removed. The first try of the Finetech removal recipe worked well and the chip was removed without difficulty.

Following the success of the removal of chip U7, each of the six chips from the test article containing flight data was removed individually in-turn with the same recipe. In some cases, additional force was needed to remove the chips from the board because of residual sealant trapped underneath. As each chip was removed it was cleaned and any remaining residual solder was removed. The chip was then placed into the proper socket for a Xeltek SP-6100 FLASH memory reader/programmer for download via computer.

The chip images generated by the chip reader were compared to the original chip images generated by the DLDR tool and found to be byte-swapped identical copies of each other. This is because the DLDR tool was designed to create binary chip images in the Big Endian (Intel) format and the chip reader generated images in the Little Endian (Motorola) format. This was not an issue because the Honeywell CHIPS utility is able to read chip images in either format, as selected by the user.

As a final test, DLU files were generated using both the DLDR chip images and the memory reader/programmer chip images. The two DLU files were found to be functionally identical, thus validating the full process for chip-off downloads and data recovery to be used on the accident memory board.

Permission was granted by the CAAC to begin recovery of data from the accident module using the same process developed with the test article. The same process of conformal coating stripping and epoxy removal was used to prepare the chips for removal from the board. Excess solder was again removed by hand before being placed in the FinePlacer tool. The chip removal process with the Finetech FinePlacer went smoothly for all six of the chips of interest.

An inspection of chip U2 (the chip with the visible crack in the packaging) identified a network of cracks on the bottom of the chip in addition to the previously observed crack. The other chips did not reveal additional damage when they were removed from the board. Figure 10 shows the bottom of chip U2 following removal from the board.

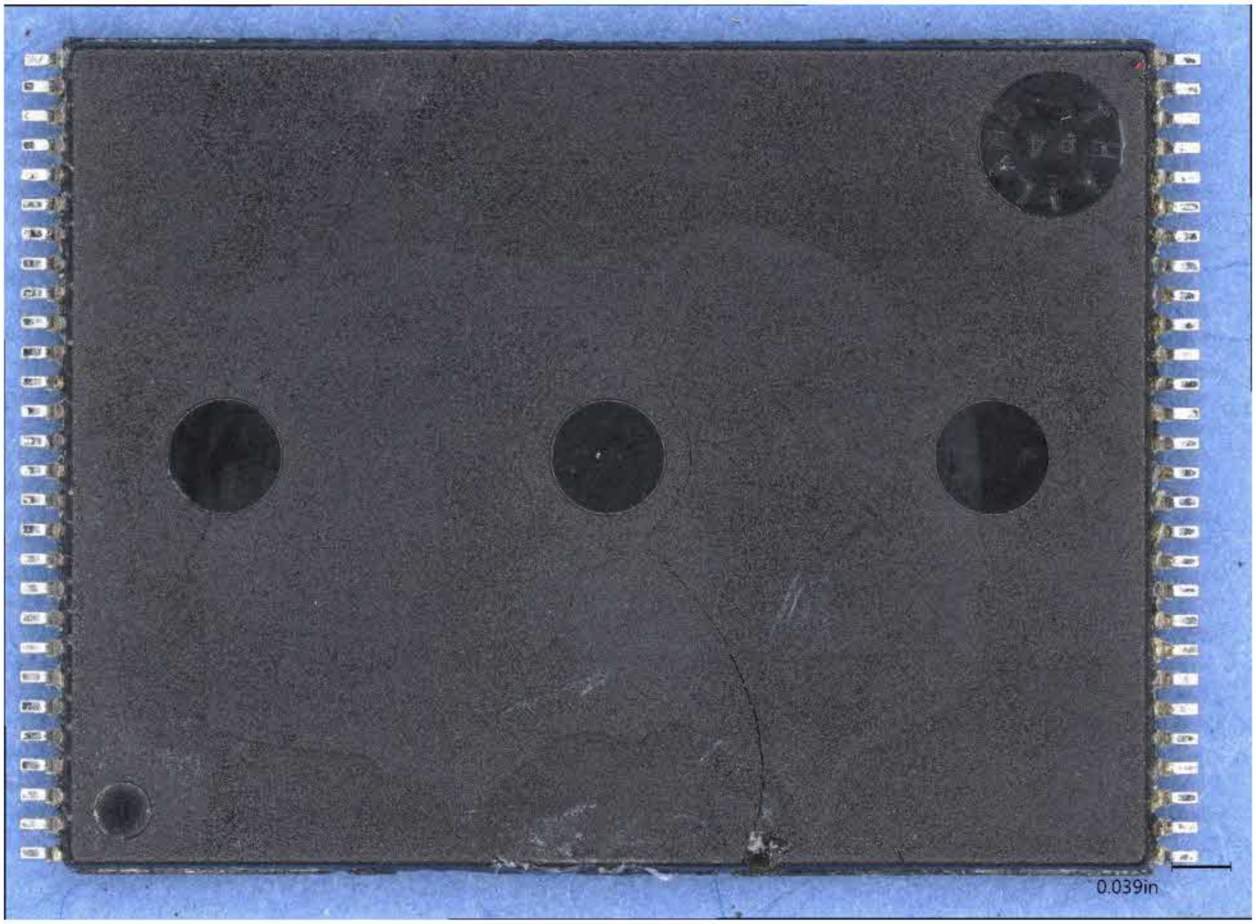

Figure 10. Bottom side of chip U2 showing cracks throughout chip packaging.

The chips were read in the Xeltec memory reader and the resulting binary images for chips U1, U3, U4, U5, and U6 were found to contain data. Chip U2 could not be read and the Xeltec reported numerous pin-check errors and messages indicating that many of the pins were shorted. This was a sign of significant internal damage to the silicon die within the chip itself.

Chip U2 was X-rayed and CT scanned, and chip U4 was also X-rayed as an exemplar. The results of the CT scan were noisy and revealed no new information. Some of the cracks identified visually on the bottom side of the packaging were apparent in the 2-D X-ray images. These cracks passed through the region of the chip housing the silicon die containing all the internal circuitry. Several other of the undersurface cracks were not visible in the X-ray because they appeared to follow the outline of the X-shaped copper die pad upon which the silicon die was bonded during manufacture of the chip. This extreme damage rendered any data from U2 unrecoverable.

A dummy file of all hexadecimal 'FF' (binary '1') was created and used in place of the image from U2 in the Honeywell CHIPS utility to create a FDR DLU file. The resultant DLU file was then imported into the NTSB CIDER data analysis application. The data was framed out with information provided by the aircraft manufacturer.

When framed out, the accident was found in the middle of the data stream, because the pointer information was lost when the DLU was created in CHIPS without chip U2. The converted data was manually re-ordered to place the accident flight at the end of the recording.

Because of the missing chip image there were regular data dropouts throughout the duration of the data file. This was expected due to the way the HFR5-D writes flight data across the six chips. The stream of flight data is striped progressively across each chip. In this case, at 512 data words per second, each chip write consisted of about 1.3 seconds of data. Therefore, the final reconstructed data stream missing chip U2 should appear as chunks of about 6.5 seconds of valid data followed by a 1.3 second gap of missing data from chip U2.

When initially reconstructed in the analysis software, the data exhibited much larger gaps than the expected 1.3 seconds, on the order of about 4 seconds. This faulty timing invalidated the time history of the data and made it impossible to align it with CVR events.

It was found that because the missing data broke across subframe boundaries, the analysis software, expecting to see consecutive subframe sync word markers, padded the data with erroneous extra subframes. These disruptions were caused by the loss of sync whenever the dummy data that replaced chip U2 was processed. The sync loss caused the analysis software to pad 4 full subframes about every 8 subframes (seconds).

Correcting the condition of the superfluous subframes was a highly labor-intensive process. To accurately align the data required manually inspecting every gap and subframe boundary in the data stream and hand marking each time the chip U2 expected dropout began and ended and adding in the missing subframe sync word boundary. This allowed the replay software to keep the data stream in sync and display the correct timing for the data.

Due to the amount of time it took to correct the timing of the data stream, only the final 12 minutes of the recorded data from the accident flight were corrected to be time accurate. Additionally portions of the previous landing and taxi were corrected to aid in the validation of the individual parameters.

Parameter validation is the process of evaluating individual parameters to determine whether the parameter was being recorded correctly and accurately by the data system, and check that the scaling and offset of the engineering units are correct. Of the more than 1,000 parameters recorded in this Boeing dataframe, approximately 150 were positively validated. Validation focused on parameters that captured the aircraft's, accelerations, position, altitude, attitude, and speed (basic parameters), parameters related to flight controls, surfaces, and flight control forces, and parameters related to the operation of the aircraft's engines. A table of the validated parameters can be found in Appendix B.

The FDR data ended with the aircraft still in flight. The data stopped with the aircraft in a descent at approximately 26,000 ft. It did not capture the remainder of the descent and final accident sequence. Investigating the reason for the premature end of the flight data it was found that while at cruise at 29,000 ft, both engine N2 values decreased rapidly below the point at which the generators drop offline. The FDR does not have a battery backup, so without power from the aircraft generators it will power down. This is different from the CVR, which does have a battery backup and can continue recording for at least 10 minutes after the loss of the aircraft generators. Looking for the reason that the engine N2 dropped below the generator cutoff speed, it was found that while cruising at 29,000 ft, the fuel switches on both engines moved from the run position to the cutoff position. Engine speeds decreased after the fuel switch movement.

2.3 FDR Data Provided to CAAC

Data provided to the CAAC delegation included the following:

- All raw chip download image files, including the dummy U2 file used to generate the FDR .dlu files.
- All FDR .dlu files generated by the Honeywell CHIPS utility, both directing the utility to skip the erased blocks found in memory and maintain the erased blocks found in memory.
    - Both methods generated functionally identical files. The skip erased blocks files were used in the NTSB's data analysis tools, as this method most closely models the behavior of the Playback32 utility when creating a .dlu file.
- All FDR unpacked binary files generated by the NTSB's CIDER FDR analysis software.
- Manually corrected unpacked binary files that correctly time-aligned the final 12 minutes of recorded data.
- Plots of validated data, including plots of aircraft basic parameters, flight controls, control forces, and engine parameters.
    - Plots were generated for time spans of the final 10 minutes of recorded data and the final 100 seconds of recorded data.
- Tabular data of all validated parameters in both exact sample timing and timed to the closest 1/16th of a second.

- All files necessary for generation of the dataframe in the CAAC's FDR software analysis tools.
- All images, scans, and microscopic photographs taken of the FDR board taken during the data recovery process.

The NTSB maintained copies of these FDR files to maintain the ability to assist the CAAC in the development of the flight history and sequence of events for the final report.

Submitted by:

Charles Cates
Mechanical Engineer/Recorder Specialist

2.3.1 FDR Plots

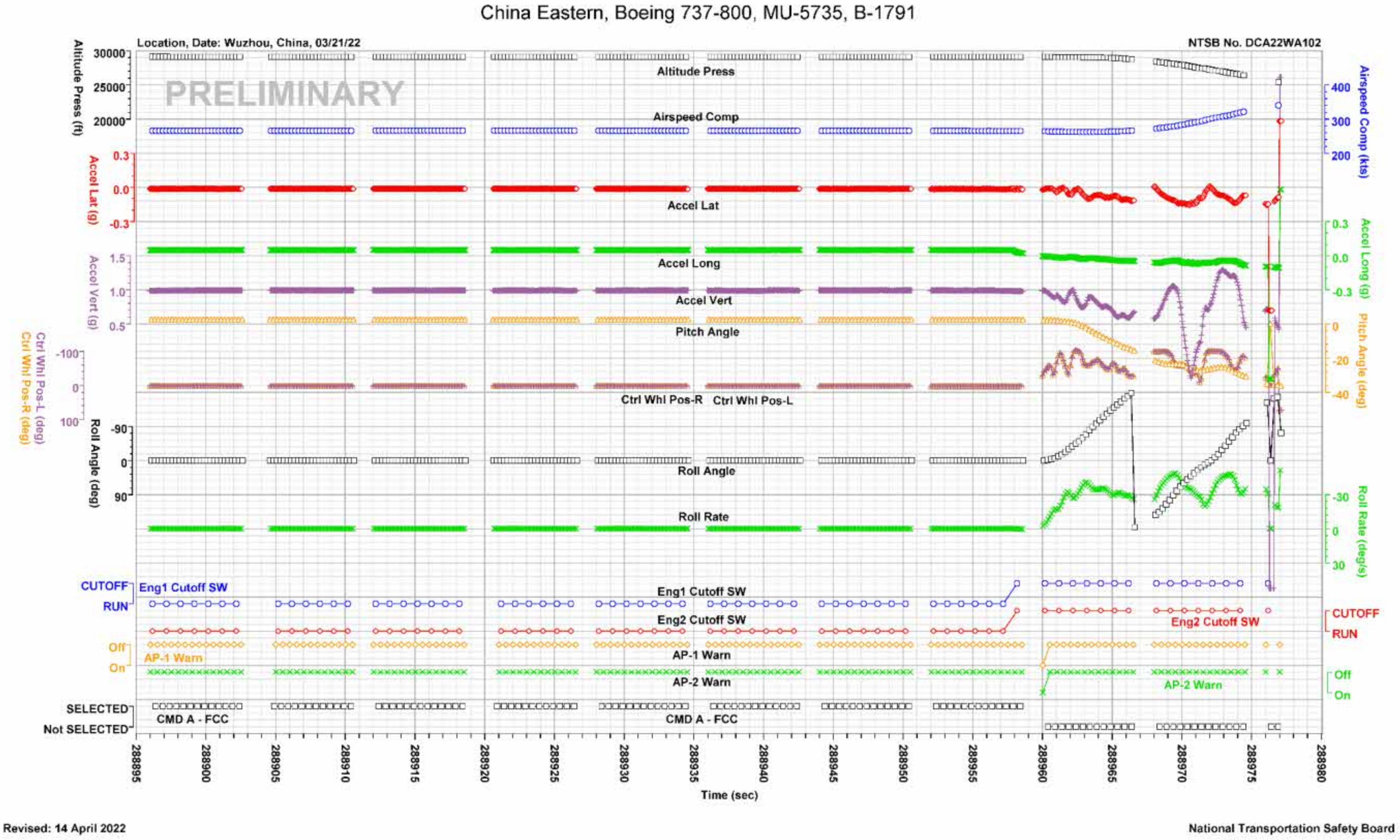

Figure 11. Basic aircraft parameters from final 90 seconds of recording.

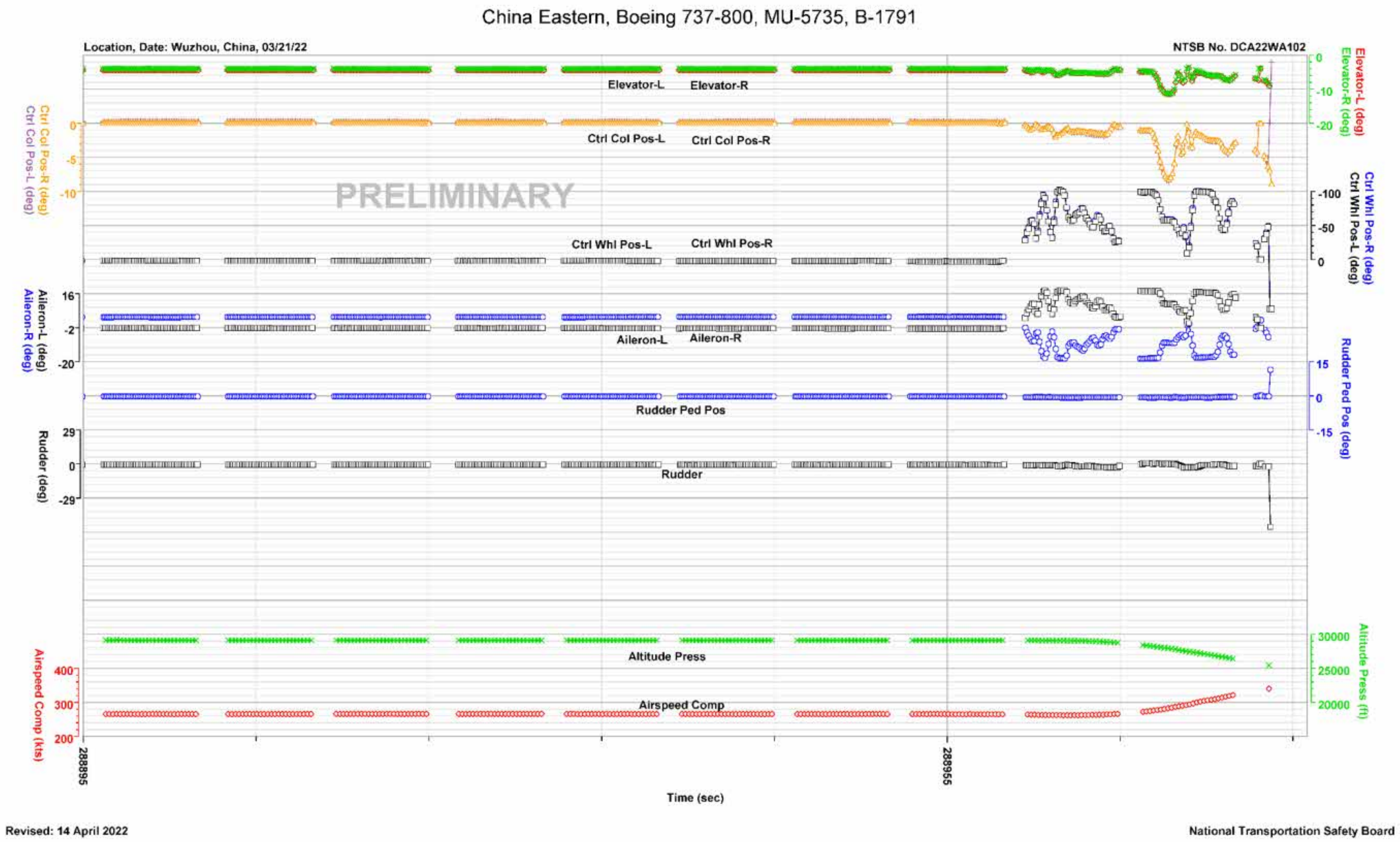

Figure 12. Flight control and input positions for final 90 seconds of recording.

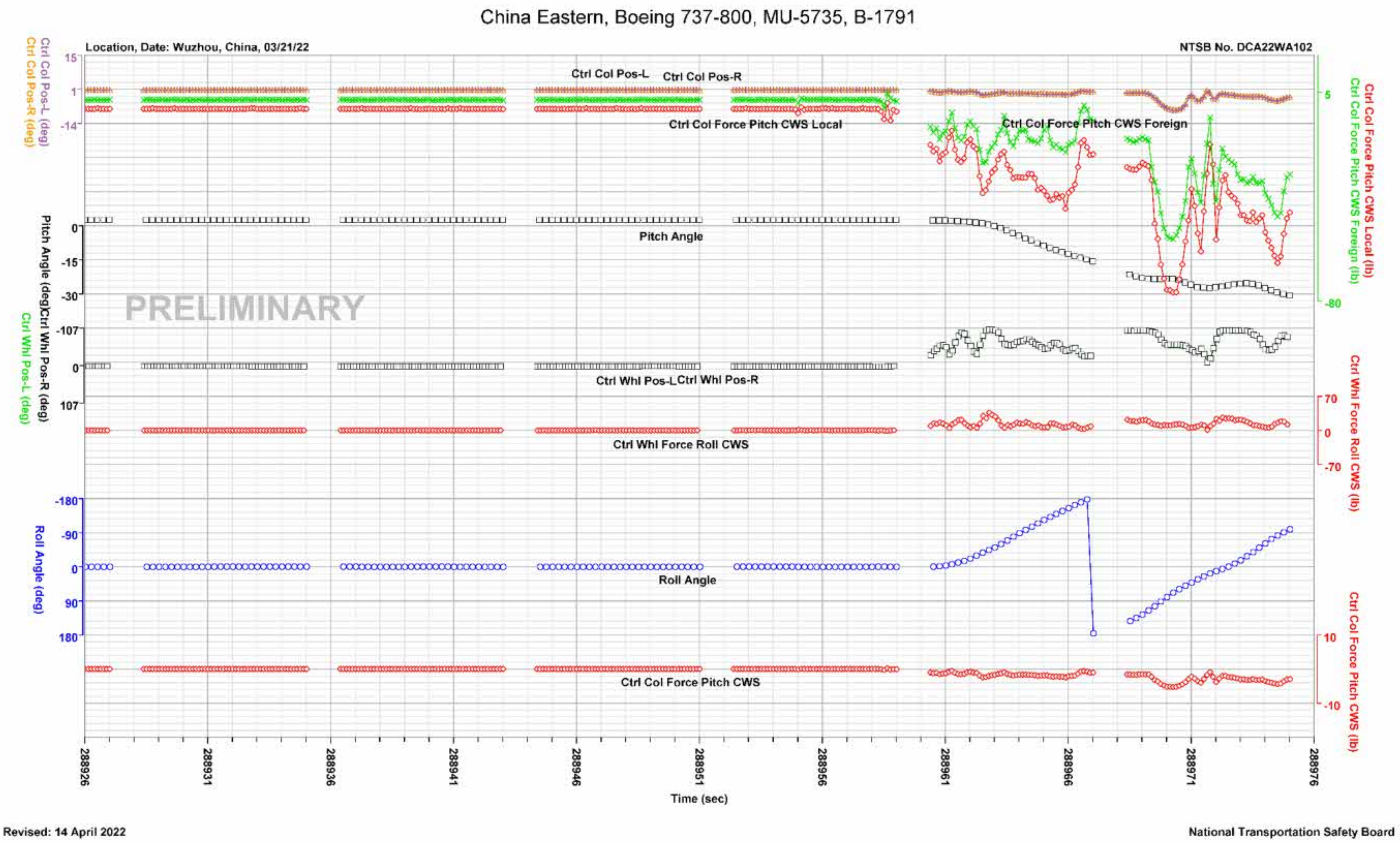

Figure 13. Control forces recorded during upset event through end of recording.

APPENDIX A. CVR QUALITY RATING SCALE

The levels of recording quality are characterized by the following traits of the cockpit voice recorder information:

Excellent Quality	Virtually all of the crew conversations could be accurately and easily understood. The transcript that was developed may indicate only one or two words that were not intelligible. Any loss in the transcript is usually attributed to simultaneous cockpit/radio transmissions that obscure each other.
Good Quality	Most of the crew conversations could be accurately and easily understood. The transcript that was developed may indicate several words or phrases that were not intelligible. Any loss in the transcript can be attributed to minor technical deficiencies or momentary dropouts in the recording system or to a large number of simultaneous cockpit/radio transmissions that obscure each other.
Fair Quality	The majority of the crew conversations were intelligible. The transcript that was developed may indicate passages where conversations were unintelligible or fragmented. This type of recording is usually caused by cockpit noise that obscures portions of the voice signals or by a minor electrical or mechanical failure of the CVR system that distorts or obscures the audio information.
Poor Quality	Extraordinary means had to be used to make some of the crew conversations intelligible. The transcript that was developed may indicate fragmented phrases and conversations and may indicate extensive passages where conversations were missing or unintelligible. This type of recording is usually caused by a combination of a high cockpit noise level with a low voice signal (poor signal-to-noise ratio) or by a mechanical or electrical failure of the CVR system that severely distorts or obscures the audio information.
Unusable	Crew conversations may be discerned, but neither ordinary nor extraordinary means made it possible to develop a meaningful transcript of the conversations. This type of recording is usually caused by an almost total mechanical or electrical failure of the CVR system.

APPENDIX B. VALIDATED PARAMETERS

This appendix describes the parameters validated and provided to the CAAC. Table B-1 lists the parameter names, units, and a description of each parameter. Additionally, Table 2 describes the units and abbreviations used in this report.

Table B-1. Validated and provided FDR parameters

Validated Parameter Name		Units	Description
1.	Absolute Roll Rate	deg/s	Aircraft Roll Rate
2.	Accel Lat	g	Lateral Acceleration
3.	Accel Long	g	Longitudinal Acceleration
4.	Accel Vert	g	Vertical Acceleration
5.	Active Altitude Ref - FCC		FCC Altitude Reference
6.	Aileron Actuator Pos-L	deg	Left Aileron Actuator Position
7.	Aileron Quadrant Pos	deg	Aileron Control Quadrant Position
8.	Aileron Roll Cmd-L	deg	Left FCC Aileron Roll Command
9.	Aileron-L	deg	Left Aileron Position
10.	Aileron-R	deg	Right Aileron Position
11.	Air Gnd On Gnd		Air Ground Sensor on Ground
12.	AIR GROUND - SMYDC-1		SMYDC 1 On Ground
13.	AIR GROUND - SMYDC-2		SMYDC 2 On Ground
14.	Air-Ground		Air/Ground
15.	Airspeed Comp	kts	Computed Airspeed
16.	Airspeed Max Allowable	kts	FCC Max Allowable Airspeed
17.	Airspeed Target FCC	kts	FCC Computed Airspeed Target
18.	Alt 1 Baro Corr	ft	Barometric Corrected Altitude 1
19.	Alt 2 Baro Corr	ft	Barometric Corrected Altitude 2
20.	Alt 3 Baro Corr	ft	Barometric Corrected Altitude 3
21.	Alt 4 Baro Corr	ft	Barometric Corrected Altitude 4
22.	ALT ACQ Engaged - FCC		Altitude Acquire Autopilot Mode Engaged
23.	Alt Baro Corr Combine	ft	Combined Barometric Corrected Altitude
24.	ALT HOLD Engaged - FCC		Altitude Hold Autopilot Mode Engaged
25.	Altitude Press	ft	Pressure Altitude
26.	Altitude Radio DEU	ft	Displayed Radio Altitude
27.	Altitude Radio-1	ft	Radio Altimeter 1
28.	Altitude Radio-2	ft	Radio Altimeter 2
29.	AP Off - FCC		Autopilot Off
30.	AP-1 Warn		Autopilot Warning 1
31.	AP-2 Warn		Autopilot Warning 2
32.	APU N1	%RPM	APU Shaft Speed
33.	APU On		APU Running
34.	APU Ready To Load		APU Ready for Load
35.	AT FMC SPD Engaged		Autothrottle Speed Mode Engaged
36.	CMD A - FCC		FCC A In Command
37.	CMD A Light - FCC		FCC A Light Active
38.	CMD B Light - FCC		FCC B Light Active
39.	Ctrl Col Force Pitch CWS	lb	Combined Control Column Force

Validated Parameter Name		Units	Description
40.	Ctrl Col Force Pitch CWS Foreign	lb	Control Column Force Opposite FCC
41.	Ctrl Col Force Pitch CWS Local	lb	Control Column Force Commanding FCC
42.	Ctrl Col Pos-L	deg	Left Control Column Position
43.	Ctrl Col Pos-R	deg	Right Control Column Position
44.	Ctrl Whl Force Roll CWS	lb	Control Wheel Force
45.	Ctrl Whl Pos-L	deg	Left Control Wheel Position
46.	Ctrl Whl Pos-R	deg	Right Control Wheel Position
47.	Drift Angle -FMC	deg	Computed Drift Angle
48.	Elevator Actuator Pos-L	deg	Left Elevator Actuator Position
49.	Elevator Pitch Cmd-L	deg	Left FCC Elevator Pitch Command
50.	Elevator-L	deg	Left Elevator Position
51.	Elevator-R	deg	Right Elevator Position
52.	Eng1 Cutoff SW		Left Engine Cutoff Switch
53.	Eng1 EGT	degC	Left Engine Exhaust Gas Temperature
54.	Eng1 Fire		Left Engine Fire Detected
55.	Eng1 FMC N1 Bug Drive	%RPM	Left Engine N1 Bug Drive
56.	Eng1 FMC N1 Target	%RPM	Left Engine N1 Target
57.	Eng1 FMV Pos	%	Left Engine Fuel Metering Valve Position
58.	Eng1 Fuel Flow	pph	Left Engine Fuel Flow
59.	Eng1 N1	%RPM	Left Engine Fan Speed
60.	Eng1 N1 Cmd	%RPM	Left Engine Fan Speed Commnad
61.	Eng1 N1 Ref	%RPM	Left Engine Reference Fan Speed
62.	Eng1 N1 Tach	%RPM	Left Engine Fan Speed Tach
63.	Eng1 N2 Actual	%RPM	Left Engine Core Speed
64.	Eng1 N2 Tach	%RPM	Left Engine Core Speed Tach
65.	Eng1 Oil Press	psi	Left Engine Oil Pressure
66.	Eng1 Oil Qty	qt	Left Engine Oil Quantity
67.	Eng1 Oil Temp	degC	Left Engine Oil Temperature
68.	Eng1 TRA	deg	Left Engine Throttle Resolver Angle
69.	Eng2 Cutoff SW		Right Engine Cutoff Switch
70.	Eng2 EGT	degC	Right Engine Exhaust Gas Temperature
71.	Eng2 Fire		Right Engine Fire Detected
72.	Eng2 FMC N1 Bug Drive	%RPM	Right Engine N1 Bug Drive
73.	Eng2 FMC N1 Target	%RPM	Right Engine N1 Target
74.	Eng2 FMV Pos	%	Right Engine Fuel Metering Valve Position
75.	Eng2 Fuel Flow	pph	Right Engine Fuel Flow
76.	Eng2 N1	%RPM	Right Engine Fan Speed
77.	Eng2 N1 Cmd	%RPM	Right Engine Fan Speed Command
78.	Eng2 N1 Ref	%RPM	Right Engine Reference Fan Speed
79.	Eng2 N1 Tach	%RPM	Right Engine Fan Speed Tach
80.	Eng2 N2 Actual	%RPM	Right Engine Core Speed
81.	Eng2 N2 Tach	%RPM	Right Engine Core Speed Tach
82.	Eng2 Oil Press	psi	Right Engine Oil Pressure
83.	Eng2 Oil Qty	qt	Right Engine Oil Quantity
84.	Eng2 Oil Temp	degC	Right Engine Oil Temperature
85.	Eng2 TRA	deg	Right Engine Throttle Resolver Angle
86.	FAC Engage - FCC		Final Approach Course AP Mode Engaged

Validated Parameter Name		Units	Description
87.	FCC In Command of MACH Trim - R		Right FCC Commanding Mach Trim
88.	FCC-L In Command of MACH Trim		Left FCC Commanding Mach Trim
89.	FD-A Switch - FCC		Flight Director A Switch
90.	FD-B Switch - FCC		Flight Director B Switch
91.	Flap Handle Pos	deg	Flap Handle Position
92.	Flap-L	deg	Left Flap Position
93.	Flap-R	deg	Right Flap Position
94.	FMC Selected Airspeed	kts	Selected Airspeed - FMC
95.	FMC Selected Altitude	ft	Selected Altitude - FMC
96.	FMC Selected Mach	mach	Selected Mach Number - FMC
97.	FMC Valid		FMC Valid
98.	G/S Dev Warn - FCC		Glideslope Deviation Warning
99.	GP Engage - FCC		Glidepath AP Mode Engaged
100.	Ground Spd	kts	Ground Speed
101.	Groundspeed FMC	kts	Ground Speed Calculated by FMC
102.	Groundspeed Disp -L	kts	Ground Speed Displayed on Left PFD
103.	GS Engaged - FCC		Glideslope AP Mode Engaged
104.	HDG SEL Light - FCC		Heading Select Light Active
105.	HDG SELECT - FCC		Heading Select AP Mode Engaged
106.	Heading	deg	Magnetic Heading
107.	Heading Selected FCC	deg	FCC Heading Selected
108.	High Speed Buffet Speed	kts	High Speed Buffet Speed
109.	Hyd Oil Press - A	psi	Hydraulic Pressure System A
110.	Hyd Oil Press - B	psi	Hydraulic Pressure System B
111.	Hyd Oil Qty - A	%	Hydraulic Oil Quantity System A
112.	Hyd Oil Qty - B	%	Hydraulic Oil Quantity System B
113.	Hydraulic Oil Pressure Standby	psi	Standby Hydraulic Pressure
114.	Hydraulic System A ELEC		Hydraulic A Electric Pump
115.	Hydraulic System A Eng 1		Hydraulic A Engine Pump
116.	Hydraulic System B ELEC		Hydraulic B Electric Pump
117.	Hydraulic System B Eng 2		Hydraulic B Engine Pump
118.	Hydraulic System Standby		Hydraulic Standby System Engaged
119.	IAS Display - FCC		Indicated Airspeed Displayed
120.	LNAV Engaged - FCC		LNAV AP Mode Engaged
121.	LNAV Light - FCC		LNAV Light Active
122.	LOC Engaged - FCC		Localizer AP Mode Engaged
123.	LOCAL LIMITED MASTER FCC-L		FCC Left Master
124.	LOCAL LIMITED MASTER FCC-R		FCC Right Master
125.	LVL Change Light - FCC		Flight Level Change AP Mode Active
126.	MACH Trim Servo Brake Status - FCC-L		Mach Trim Servo Status
127.	N1 Light - FCC		N1 Light Active
128.	N1 Limit Mode Cmd - FCC		N1 Limit AT Mode Engaged
129.	Pitch Angle	deg	Aircraft Pitch Angle
130.	Roll Angle	deg	Aircraft Roll Angle
131.	Roll Rate	deg/s	Aircraft Roll Rate
132.	Rudder	deg	Rudder Position
133.	Rudder Ped Pos	deg	Rudder Pedal Position

Validated Parameter Name		Units	Description
134.	Rudder Pos- LVDT DEMOD-STBY PCU	deg	Rudder Standby PCU LVDT Position
135.	Rudder Servo Cmd-STBY PCU	deg	Rudder Standby PCU Servo Command
136.	Selected Airspeed FCC	kts	Selected Airspeed - FCC
137.	Selected Altitude FCC	ft	Selected Altitude - FCC
138.	Selected Course Foreign FCC	deg	Selected Course Foreign FCC
139.	Selected Course Local FCC	deg	Selected Course Local FCC
140.	Selected Mach FCC	mach	Selected Mach Number - FCC
141.	Selected Vertical Speed FCC	fpm	Selected Vertical Speed - FCC
142.	Single Channel - FCC		AP on Single Channel
143.	SPD Light On - FCC		SPD Light Active
144.	SPEED INTERVENTION ACTIVE - FCC		Speed Intervention Active
145.	TOGA Engaged - FCC		AT TOGA Mode Engaged
146.	Track Angle True FMC	deg	True Track Angle
147.	VISUAL ALTITUDE ALERT - FCC		Visual Altitude Alert Active
148.	VNAV Light On - FCC		VNAV Light Active
149.	VNAV PATH Engaged - FCC		VNAV Path AP Mode Engaged
150.	VNAV SPD Engaged - FCC		VNAV Spd AP Mode Engaged
151.	Wind Direction True -FMC	deg	Wind Direction
152.	Wind Speed -FMC	kts	Wind Speed
153.	Yaw Rate	deg/s	Aircraft Yaw Rate

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 tabular data has not been corrected for the local altimeter setting at the time of the event.

Note: Parameters with a blank unit description in table B-1 are discretes. 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.

Table B-2. Units and abbreviations

Unit/Abbreviation	Description
Alt	Altitude
AP	Autopilot
APU	Auxiliary Power Unit
AT	Autothrottle
Baro	Barometric
CWS	Control Wheel Steering
deg	degrees
degC	degrees Celsius
FCC	Flight Control Computer
FMC	Flight Management Computer
fpm	feet per minute
ft	feet
kts	knots
lb	pounds
LVDT	Linear Variable Differential Transformer
MCP	Mode Control Panel
PCU	Power Control Unit
PFD	Primary Flight Display
pph	pounds per hour
psi	pounds per square inch
qt	quart
RPM	revolutions per minute
s	second
SMYDC	Stall Management and Yaw Damper Computer