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

国家运输安全委员会研究与工程办公室
华盛顿特区 20594

DCA22WA102

驾驶舱语音及飞行数据记录仪

2022年7月1日综合下载报告

TABLE OF CONTENTS

目录

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

Report Author	Charles Cates Mechanical Engineer/Recorder Specialist National Transportation Safety Board(NTSB)
Group Member	Xiangdong Wan Team Leader,Chief Pilot of CAAC Civil Aviation Administration of China(CAAC)
Group Member	Hang Lin Investigator In Charge(IIC) CAAC
Group Member	Yu Zhang Investigator CAAC
Group Member	Liling Yu Lab Engineer CAAC
Group Member	Xin Miao Lab Engineer CAAC
Group Member	Chun Wang Lab Engineer CAAC
Subject Matter Expert	Joseph Gregor,Ph.D. Electrical Engineer/Recorder Specialist NTSB

A. 事故

地点：中国吴州
日期：2022年3月21日
时间：0630 UTC
飞机：波音737-800型，中国东方航空公司，注册号B-1791

B. 驾驶舱语音及飞行数据记录仪数据恢复组

报告	作者	查尔斯·凯茨 机械工程师/记录员专家 国家运输安全委员会（NTSB）
组	成员	王相东 团队负责人、中国民用航空局首席飞行员 中国民用航空局（CAAC）
组	成员	杭林 负责调查员（IIC） 中国民航
组	成员	张瑜 研究者 CAAC
组	成员	莉玲· Yu 实验室工程师 中国民航
组	成员	Xin 苗 实验室工程师 中国民航
组	成员	王春 实验室工程师 中国民航

主题专家约瑟夫·格雷戈尔博士

电气工程师/记录员专家（NTSB）

Subject Matter Expert	R.Greg Smith Branch Chief,Vehicle Recorders Division(Blue) NTSB
Specialist	W.Deven Chen Electrical Engineer/Recorder Specialist NTSB

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:	HoneywellHFR5-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 wellas 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

案件主题专家 R. 格雷格·史密斯
车辆记录器部门（蓝色）主管
全国运输安全委员会

专家 W.陈德文
电气工程师/记录专家
全国运输安全委员会

C. 调查详情

2022年3月28日，成立了一个数据恢复小组，成员包括中国民用航空局（CAAC）和美国国家运输安全委员会（NTSB）的代表。NTSB车辆记录器部门接收了来自驾驶舱语音记录器（CVR）和飞行数据记录器（FDR）的存储模块。NTSB人员负责对这些存储设备进行处理，而中国民用航空局的人员则负责监督并记录整个过程。以下记录器的存储模块已提供给NTSB：

记录仪制造商/型号：霍尼韦尔 HFR5-V CVR	
零件编号:	980-6032-001
记录器序列号:	CVR-04014
制造商/型号：:	HoneywellHFR5-D FDR
零件编号:	980-4750-009
记录器序列号:	FDR-02952

D. 数据恢复

从受损的飞行数据记录仪中恢复数据是一个包含评估、修复和读取步骤的系统化流程。首要任务是采用最不可能导致数据丢失或损坏的方法来恢复存储数据。对于严重受损的硬件设备而言尤为棘手，因为电路板组件可能发生短路或其他损伤，在通电时可能导致数据丢失。在尝试读取数据前，必须对组件进行仔细处理和全面检查，以便发现并记录损坏情况，从而制定系统的修复与恢复方案。使用专为受损硬件恢复设计的工具对于保障记录数据的完整性至关重要，这包括电缆、读取机箱等硬件设备以及专用恢复软件包。

1.0 HFR5-V CVR 描述

霍尼韦尔HFR5-V驾驶舱语音记录仪可从机长音频面板及副驾驶音频面板采集四个高质量音频通道信息。

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

该设备配备音频面板、驾驶舱观察员专用音频面板以及驾驶舱区域麦克风（CAM）。数字录音数据存储于固态存储模块中：来自音频面板的通道可录制两小时，CAM通道则可录制三小时。HFR5-V的设计符合欧洲航空安全局标准 ED -112A规定的坠机生存要求。

1.1 HFR5-V CVR 损伤

据报道， CVR 坠机幸存者存储单元（CSMU）已于2022年3月23日从飞机残骸中被打捞出来。该记录仪因撞击力受到严重损坏。 CSMU 在民航总局北京基地被拆解，其存储模块也被取出。保护存储板电路板组件（CCA）的红色室温硫化（RTV）密封胶已被移除；民航总局曾多次尝试使用替代记录仪外壳来下载设备存储内容，但均未成功生成可播放的.wav音频文件。据报告，在数据解压过程中软件报出了大量错误。

1.2 HFR5-V CVR 恢复情况

2022年3月28日，美国国家运输安全委员会（NTSB）从 CVR 系统在抵达NTSB前的下载尝试中，收到了一个以.dlu格式的 CVR 下载文件。该文件在NTSB的 CVR 实验室中，使用霍尼韦尔的记录器恢复软件“Playback32”进行了解压缩。解压缩过程中出现了大量错误。解压缩完成后，生成了四个.wav音频文件。这四个文件的长度和采样率均符合预期，但当播放这些文件时，音频内容无法理解，存在卡顿、回声伪影及数字噪声等问题，导致音频数据无法使用。

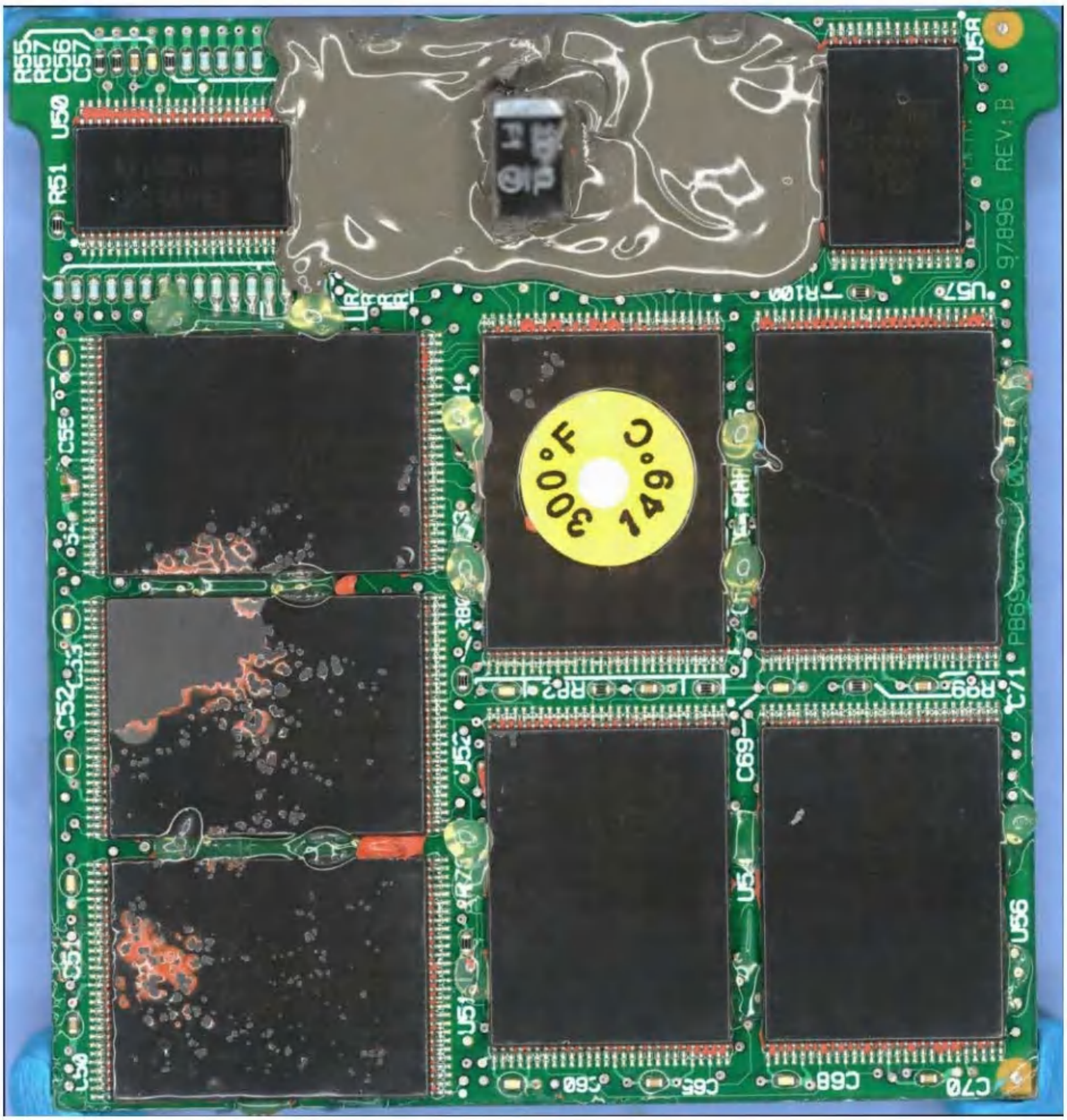
该 CVR 存储模块已提交至美国国家运输安全委员会（NTSB）进行显微镜检测。图1展示了电路板的连接器侧，图2则展示其背面结构；两面均设有存储数据的闪存芯片。初步检测结果显示，该电路板的连接器区域存在严重损坏：连接器与电路板之间的多个焊盘（这些焊盘负责将电信号传输至数据芯片）出现弯曲或完全脱落现象（有关连接器损伤的具体细节，请参见附件1《 CMM 恢复报告》）。受损引脚均对应芯片的数据线和地址线。此类损伤将严重影响数据下载过程，并与数据中出现的音频异常现象一致：芯片数据线的损坏会表现为量化误差型数字噪声；而芯片地址线的损坏则会引发断续、回声及重复型噪声。

进一步检查还发现，连接器自身的塑料部分已轻微偏离其正常状态发生变形。沿电路板末端的长边亦存在类似情况。

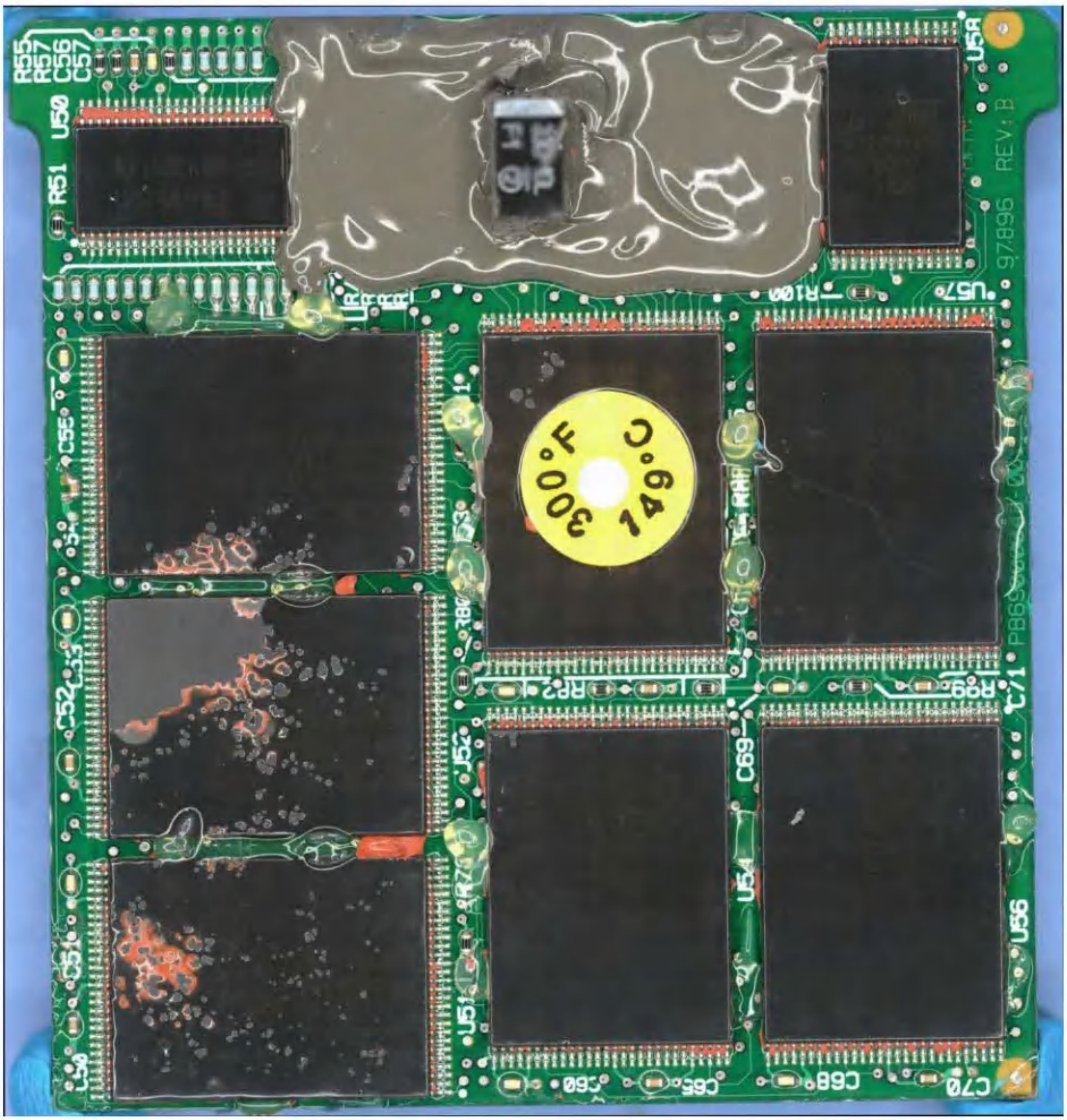
Figure 1.CVR memory module board,connector side.

图1. CVR 内存模块板，连接器侧。

JO1əuuo a!soddo ap!s'pJeoq luouəu AADzəun6!



JO1əuuo a¡ soddo ap¡ s 'pJeoq luouəu AADzəun6¡



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.

该连接器被抬高至超出正常位置，其边缘上的引脚均凹陷在连接器外壳内部。在这种状态下，恢复电缆上的公接头难以与电路板建立稳定连接。面向内存芯片的长边被压低至低于正常位置，引脚明显突出于连接器外壳之外。同时发现连接器两侧之间的接地平面在壳体下方遭到损坏，多个接地平面区域已从电路板上断裂或脱落。图3展示了该连接器的实际状态。

图3. CVR 存储模块连接器的细节（如收到时所示）。

还发现了一个额外异常情况，经确认该问题在电路板制造时即已存在：一个电容器被从电路板上取下后未与焊盘接触，并采用共形涂层进行密封处理。这意味着该电容器从未成为其设计所属电路的组成部分。查阅电路板原理图可知，这是一个电源调理电容器，用于滤除由污染电源可能引起的频率波动。由于该元件既未在电路板出厂检测中被发现，也未出现在航空公司对 CVR 系统进行的持续适航性检查中，因此极不可能影响 CVR 系统的性能。

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.

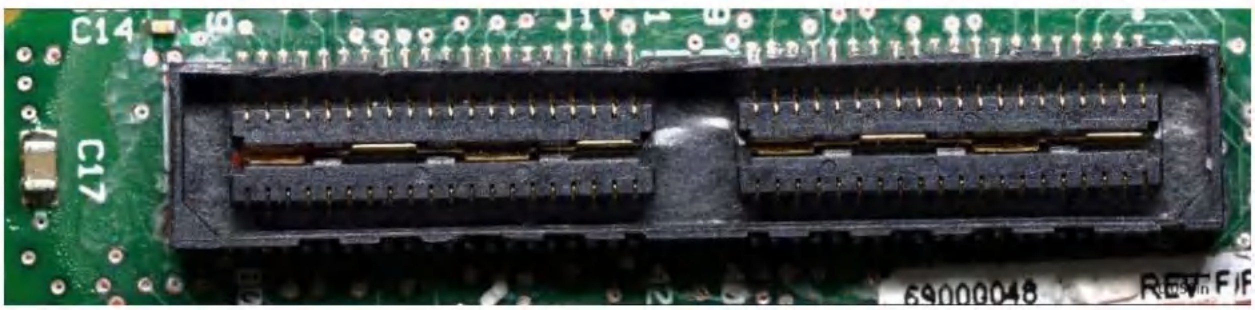


Figure 4.Connector detail with RTV sealant removed.

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

为完成对电路板的初步检测，我们仔细清除了连接器区域残留的RTV密封胶。对所有可接触以进行检查的连接器引脚均进行了物理完整性测试（部分引脚因位于电路板下方而无法触及）。同时记录了大量松动或分离的引脚情况。图4展示了清除残留RTV密封胶后、准备进行检测的连接器状态。

我们制定了损坏修复工作计划，旨在尽可能安全地修复初步检查中发现的故障，之后再为电路板通电并尝试重新加载内存数据。通过查阅Gerber公司的电路板文件，确定了所有关键过孔及内存线路的具体位置与布线路径。同时开发了连续性测试方案，用于检测连接器引脚与闪存芯片之间是否存在潜在电气损伤；该测试结果已通过使用已知可靠的替代存储模块进行验证。

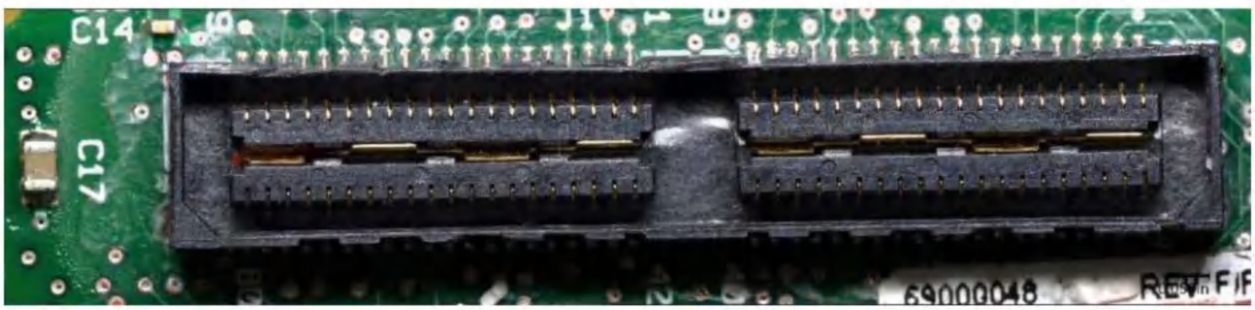


图4. 去除RTV密封剂后的连接器细节图。

检查中发现的松动或分离的引脚均使用显微镜和专用氰基丙烯酸酯胶进行了修复。为确保与受损电路板连接器实现最佳接合，对 HFR -5型恢复用柔性电缆进行了改造，以促进电缆与电路板之间的可靠连接。电缆上的许多引脚略微向远离连接器塑料外壳的方向弯曲，从而能更紧密地与嵌入受损电路板连接器内的引脚对接。

完成上述维修后，事故CPM与经改装的恢复柔性电缆进行接口连接，并安装于NTSB的HFR5-V金质机箱内。尝试使用Honeywell Playback32软件进行数据下载，但未能生成可用的.dlu文件。

随后使用名为 DLDR 的工程工具，在未拔出或重新安装连接器的情况下完成了后续下载操作。 DLDR 可直接读取闪存芯片的内容，并将每个芯片图像写入二进制文件中。这些芯片图像随后可按正确顺序重组为完整的存储内容，并通过另一款名为chips的工程工具写入.a.dlu文件。此次下载共生成了14个芯片图像文件（与预期一致，每个板载闪存芯片对应一个

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 allfour 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-DX-ray imaging to determine if any non-visible damage had occurred to the memory module and additional microscopicinspections.

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.

1Appendix A comprises the CVR Quality Rating Scale.

文件），最终合并为.a.dlu文件。Playback32软件虽能根据这些图像生成4个.wav文件，但在解压缩过程中出现了大量错误。为验证两次下载结果的一致性，我们进行了第二次 DLDR 下载测试：文件中存在零星的单字节差异，但始终未能找到明确原因。

这些.WAV文件包含三个音频面板通道（每个通道采样频率为8 kHz，时长均为两小时）以及一个CAM通道（采样频率为16 kHz，时长为三小时）。文件被导入 CVR 监听室进行试听。由于芯片图像文件的重组方式，WAV文件并非按顺序排列（即从最旧数据到最新数据依次排列），而是按照数据写入芯片的顺序组织：最新数据（事故序列）位于文件中部附近，随后是最早的数据。

试听测试表明，所有四个通道均包含可辨识的音频信号：音频面板通道在NTSB质量评级量表上评定为“Fair”[1]，而CAM通道则为“Poor”质量；所有通道均存在数字噪声与失真现象，在事故序列过程中还观察到部分重复音频片段；音频数据中的数字伪影与恢复电缆与NVM芯片数据线之间的损伤相符，而重复音频则与芯片地址线的类似损伤相符。

下载结果进一步证实了电路板连接器区域存在损坏，因此我们开展了进一步检测以排查引脚连接问题。检测手段包括二维及三维X射线成像技术，用于判断内存模块是否存在不可见损伤，并辅以额外的显微镜检查。

X射线检测结果显示，有数例情况中，连接器的插针与电路板焊盘或通孔之间的间隙极小；但根据该间隙数据判断，这种情况不太可能导致芯片的数据及地址信号路径发生短路或其他问题。在额外的显微镜下检测中，未发现其他损伤。

借助X射线图像，对改良后的恢复型带状电缆进行了再次调整，以期与受损连接器建立更稳定的连接。同时开展了全面的引脚检查，确保间隙过小的引脚不会影响电信号传输路径。另尝试了多次下载操作，结果与之前的尝试一致。

附录A包含 CVR 质量评级量表。

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.

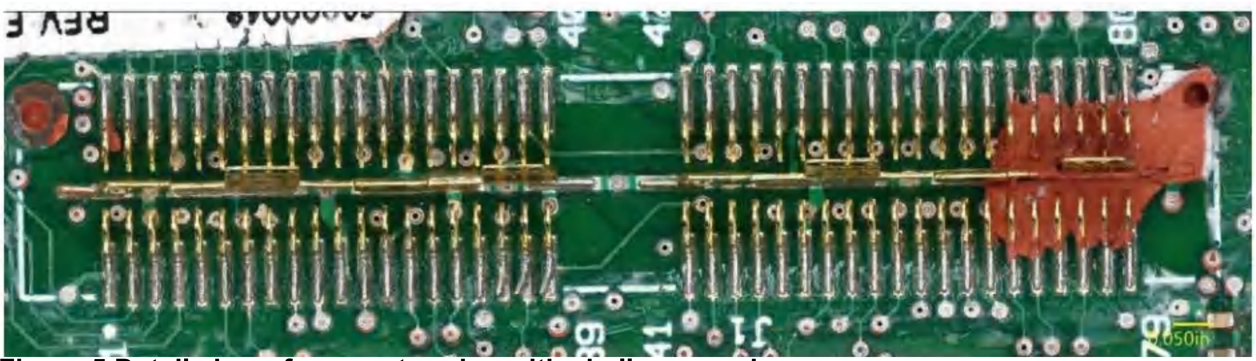


Figure 5.Detail view of connector pins with shell removed.

由于下载测试结果仅显示较差至一般水平，且即使尝试修复问题后音频信号仍存在芯片数据与地址线路损坏现象，团队最终认定该连接器板体连接器应被拆除并可能更换。为此，他们选用了一块NTSB替代板作为测试样本，旨在确定在保持连接器壳体引脚焊接状态下最安全的塑料外壳拆卸方法。

CVR 连接器外壳已被完全拆卸，从而揭示出塑料层下引脚存在额外损伤：部分引脚被压入塑料下方，大量其他焊盘及线路痕迹均出现松动或完全脱落现象。某些引脚仍能导通电流的原因很可能在于它们被连接器外壳本身固定在电路板上。除一处外，所有连接点处的中心接地平面均处于松动状态。移除连接器外壳后的内存模块如图5所示；引脚的部分形变情况见图6。

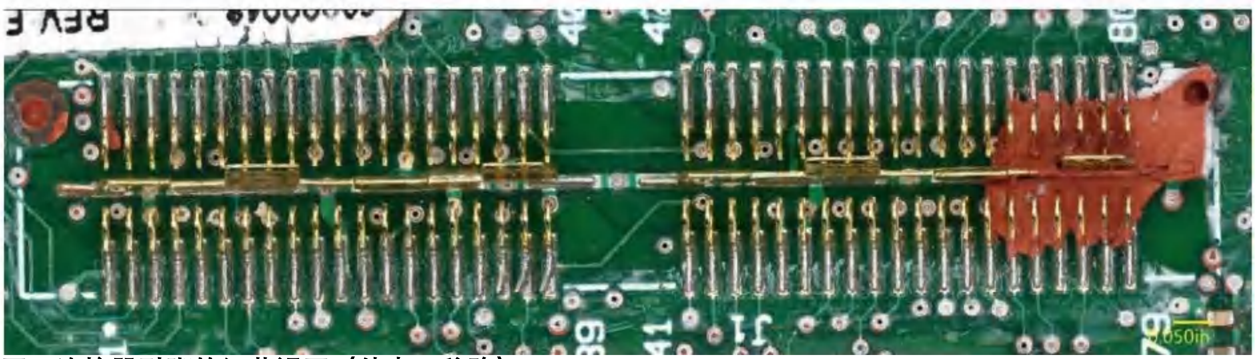


图5. 连接器引脚的细节视图（外壳已移除）。

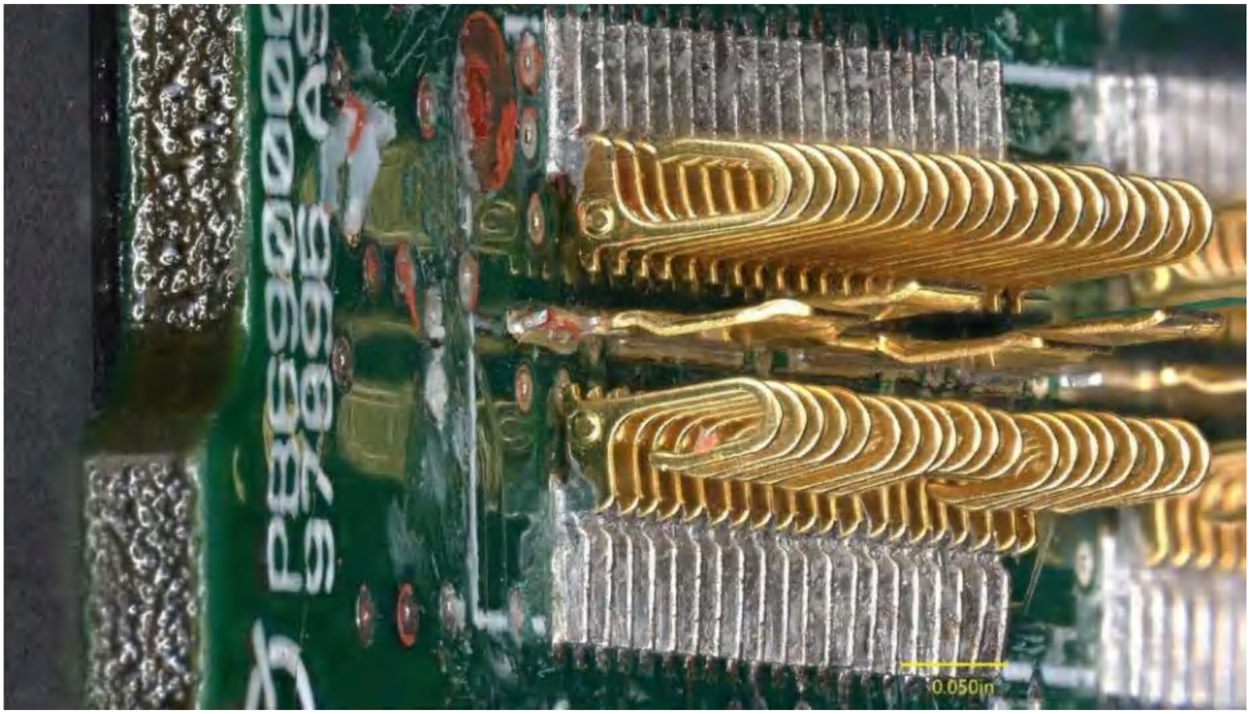


Figure 6.Detailed view of deformed pins.

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.

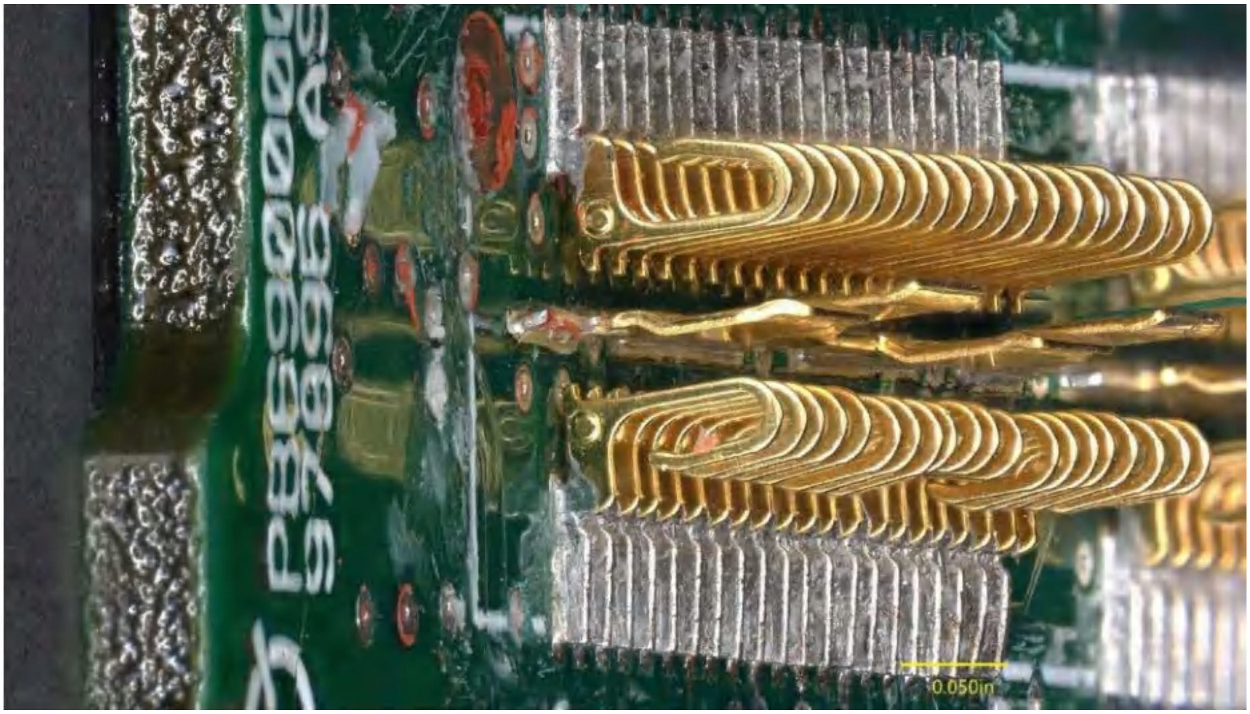


图 6. 变形销钉的详细视图。

这些销钉现已去除塑料连接外壳，再次进行固定处理：松动部位用氰基丙烯酸酯胶重新粘合并静置固化。待销钉完全稳固后，便着手将其精确复位至正确位置。实验中以替代电路板上的销钉作为参照模板——将销钉重塑至最接近原始形状的状态，才能在更换塑料外壳后确保其与回收电缆实现可靠对接。通过重新定位发现，奇数编号的销钉与许多未绝缘的通孔及线路路径位置极为接近（此前因连接外壳遮挡而难以察觉）。为解决此问题，我们使用聚酰亚胺胶带制作了薄层绝缘条，并将其置于销钉与电路板之间。

新的连接器外壳被仔细安装在重新加工的引脚上。由于引脚结构精密且需与连接器上的各个凹槽精确对齐，整个操作均在显微镜下完成。改装后的柔性电缆与电路板对接后用ESD防静电胶带固定；随后将电路板与柔性电缆组件安装到NTSB HFR5-V金色机箱上，并通过Playback32和 DLDR 软件完成下载。

Playback32的下载过程运行正常，未出现此前下载尝试中所见的任何错误；同样，解压缩过程也进展顺利——在宽带（CAM）信道的解压缩过程中出现了少量错误，但在窄带信道中则未出现任何错误，亦未出现此前下载时常见的大量错误。Playback32成功生成了4.wav文件，其位深度和采样率特性与此前的下载结果完全一致，符合预期。

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 allchannels.

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:

这些.wav文件被导入 CVR 试听室进行试听。文件按数据时间顺序排列，从最早期的数据到最新事故数据。事故过程已被完整记录，且根据美国国家运输安全委员会（NTSB）的音频质量评级标准，所有声道的音质均达到“优秀”级别。

对各音频轨道的进一步分析表明，宽带CAM信道与窄带机组音频信道之间存在时间漂移现象。这种漂移并非线性关系，在整个两小时的机组音频录制过程中，CAM信道与机组信道始终存在同步偏差。当使用共同音频基准点对两者进行同步时，可发现机组信道偶尔会缺失部分数据片段，这很可能与数字音频数据包在恢复过程中被丢弃有关。

DLDR 下载文件亦经解压缩处理，并利用 DLDR 生成的芯片图像文件生成了.wav格式文件。这些 WAV 文件与Playback32下载包生成的 WAV 文件进行了直接比对，结果表明Playback 32文件能提供该事件最精确的时间序列数据。窄带通道在记录过程中随机出现极短时间内的轻微数据丢失现象；这些伪影可能与初始显微镜检查时在 CVR 板上发现的出厂旁路电容器损坏有关，但由于缺乏事故前的原始下载样本作为对比，此结论尚未得到证实。

通过CAM通道获取的高质量录音数据及精确的时间记录表明，已成功恢复可接受的下载内容，无需进行额外下载尝试或采用更侵入性的恢复技术。

1.3 音频录制描述

各频道的音频质量及最终下载文件中的时长详见表1。

表1：音频质量

通道数量	内容/来源	质量	时长
1	驾驶舱观察员音频面板	出色	~120 min
2	副驾驶音频控制面板	出色	~120 min
3	船长音频面板	出色	~120 min
4	驾驶舱区域麦克风（CAM）	出色	~180 min

1.4 提供给中国民用航空局的 CVR 数据

CVR 提供给中国民航局代表团的数据包括以下内容:

- 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 51212-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

- 从所有下载尝试中获取的原始文件（包括使用Playback32和 DLDR 两种方式下载的结果）
- 所有 DLDR 下载尝试生成的原始芯片图像文件

·所有由Playback32和 DLDR / chips生成的dlu文件（包括未生成有效.wav文件的文件）

- 所有从下载内容生成的 .wav 文件。
- 所有经过时间轴校正的.wav文件，以及所有从默认8 kHz采样率提升至与CAM通道16 kHz采样率匹配的 Crew音频通道。
- 由美国国家运输安全委员会（NTSB）的音频分析工具RAPT-R生成的所有会话文件 .MDF文件。
- 这些.wav文件经过噪声过滤和音频增强处理，旨在突出音频中的关键部分。

- 鉴于上文所述的数据包丢失问题，对.wav文件进行时间拉伸处理，以尽可能匹配机组频道与CAM频道的时序。

·在整个恢复过程中，对 CVR 内存板拍摄的所有照片、扫描图及显微图像。

美国国家运输安全委员会（NTSB）未保留向中国民用航空局代表团提供的上述任何文件，仅保留了照片、扫描件及显微镜图像；此外，NTSB亦未保存任何 CVR 音频文件或可用于生成音频文件的其他原始或中间下载文件。

2.0 HFR5.D 的错误发现率（FDR）描述

霍尼韦尔HFR5-D飞行数据记录仪采用固态闪存作为存储介质，以数字格式记录飞机飞行信息。该设备支持 ARINC 573/717/747配置标准的数据接收功能，可记录至少25小时的飞行数据，每秒可记录51212位数字信息。每组512个字（即每秒数据量）称为一个子帧，每个子帧均包含独特的12位同步字（用于标识其为第1、2、3或4子帧），该同步字位于子帧起始位置。当连续同步字按精确的512字间隔出现时，数据流即处于“同步”状态。各数据参数（如高度、航向、空速）在子帧内均具有专属的字号标识。HFR5-D的设计符合欧空局 ED -112A标准规定的坠机生存要求。

2.1 HFR5.D FDR损伤

据报道，FDR坠机可生存存储单元（CSMU）已于2022年3月27日从飞机残骸中成功回收。该记录仪因撞击力受到严重损坏。技术人员打开 CSMU 后，取出了存储模块。

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 forinspection.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 O'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 8show 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.

设备已从中国民用航空局（CAAC）位于北京的设施中移除。据报道，CAAC曾尝试使用替代FDR测试机下载内存内容，但未成功。

2.2 HFR5-D的FDR恢复过程

故障报告记录证书（FDR）中的电路板组件（CCA）已于2022年4月4日提交至美国国家运输安全委员会（NTSB）。保护内存板CCA的红色RTV密封胶保持完好，仅闪存温度标记点暴露以供检查。该温度标记表明电路板未受到显著热影响，且 CVR 板上的所有损坏均未在FDR中记录。

NTSB金质底盘经过重新配置，成为合适的FDR替代器，并连接了事故记忆模块。尝试使用Playback32进行下载时，未能成功。随后，使用 DLDR 工具对各个闪存设备进行了多次下载操作。每次下载的结果略有差异，但总体上，每个闪存芯片的镜像文件中均显示全部为“O”字符。

将红色RTV胶从FDR存储器板上移除，以便对整个模块进行初步目视检查。图7和图8分别展示了FDR存储器模块的连接器侧及相对侧。在高倍显微镜下对该模块进行检查后，发现闪存模块编号U2的存储器封装顶部边缘处存在一条裂纹，该裂纹延伸至芯片中心；该裂纹还穿透至器件上方的共形涂层表面。此外，许多将芯片与电路板键合的环氧树脂球也显示出裂纹或与原附着闪存器件发生分离的迹象。

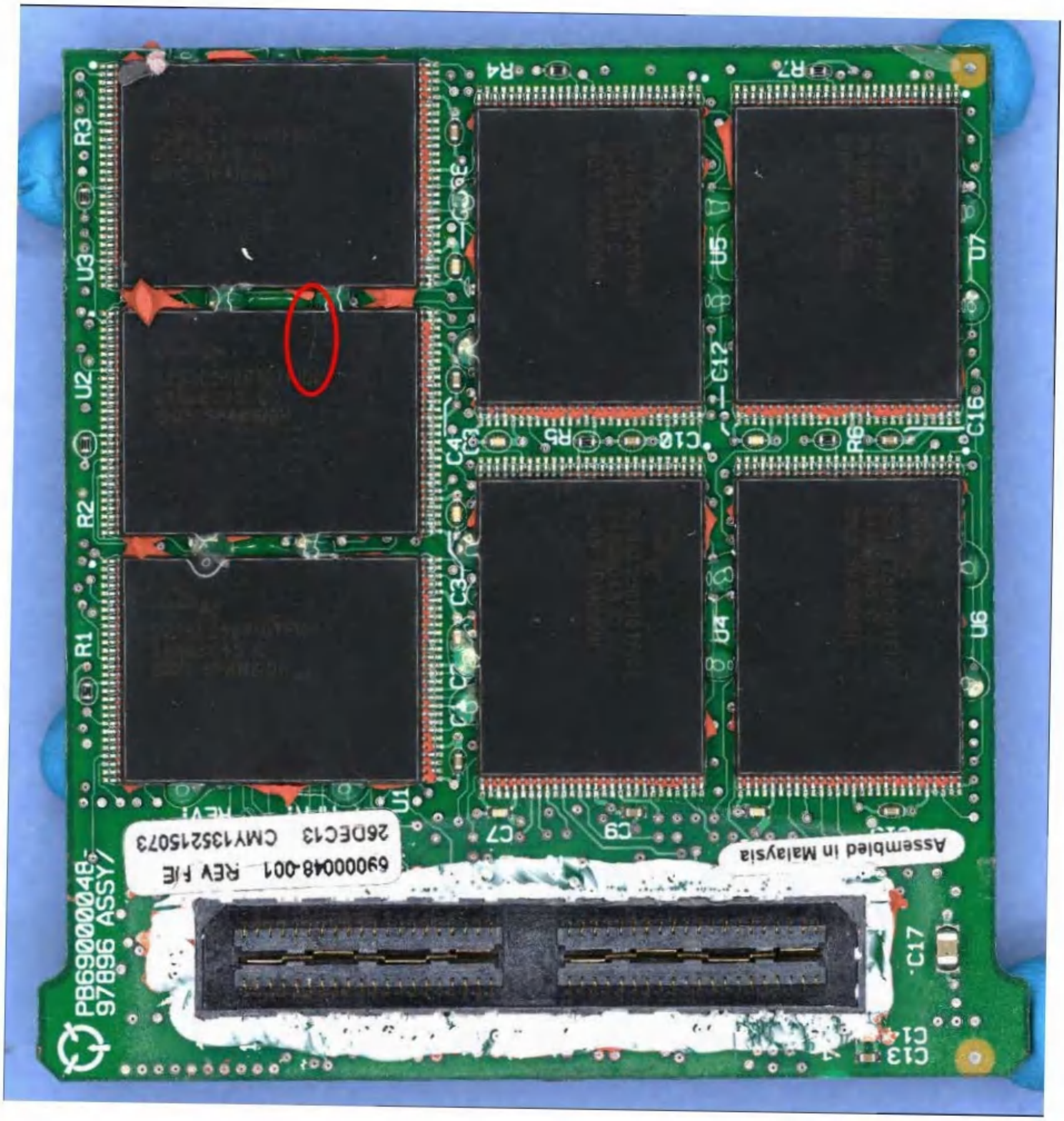


Figure 7.Connector side of FDR memory module with crack faintly visible in chip U2.marked with a red circle in the photograph.

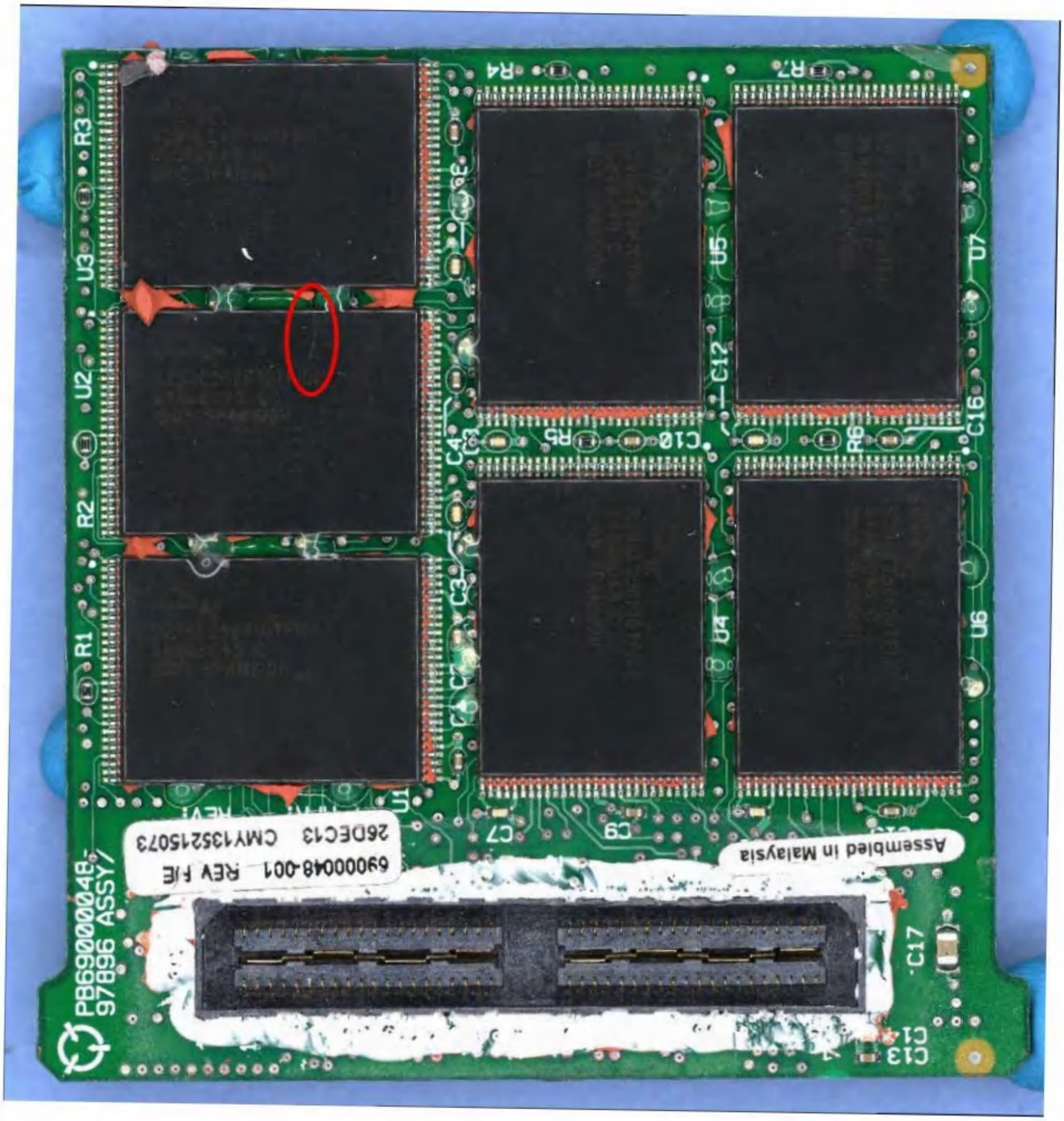


图7：FDR内存模块的连接器侧，芯片U2上可见微弱裂纹（在照片中用红圈标出）。

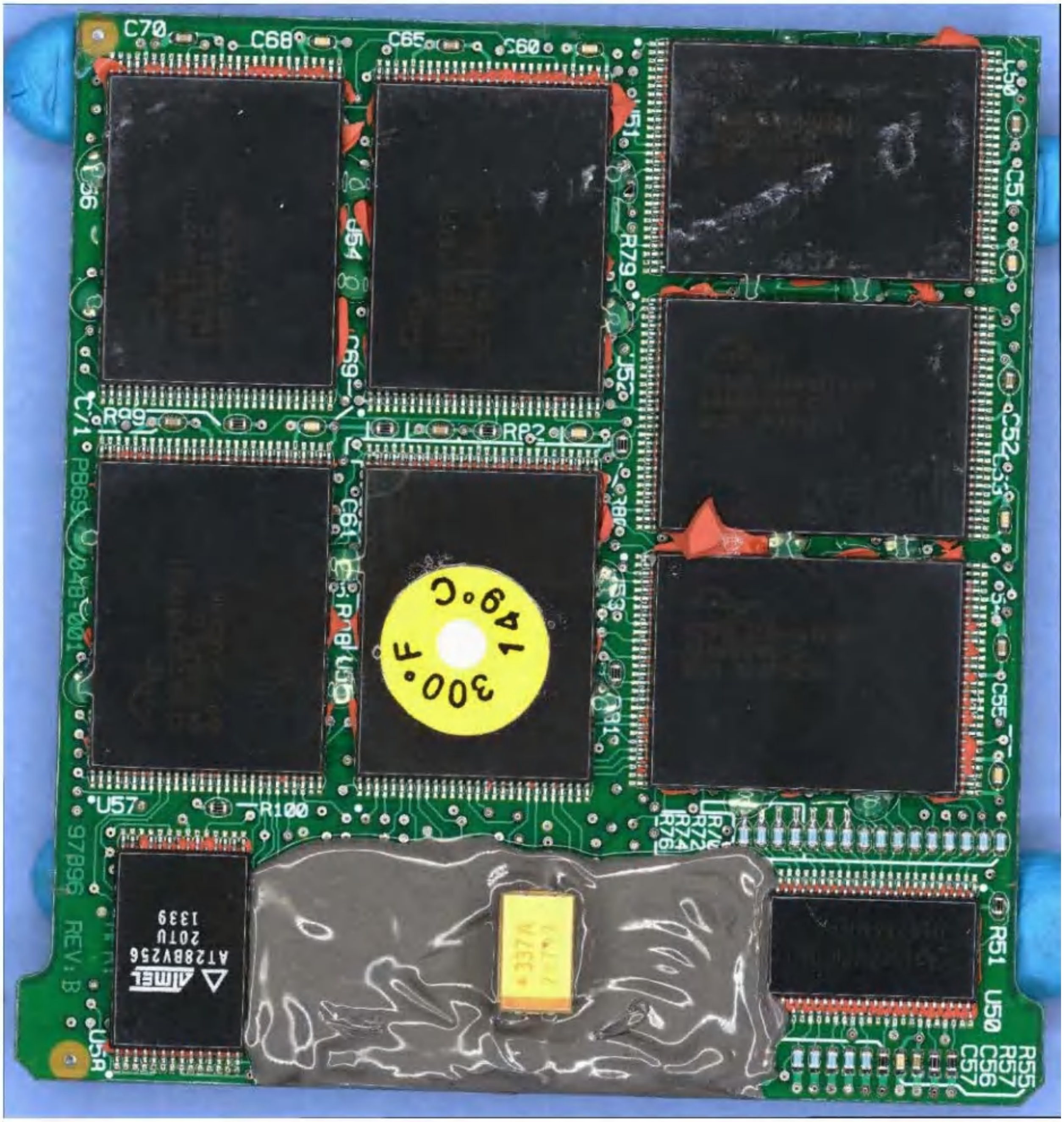


Figure 8.FDR memory module side opposite connector.

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.

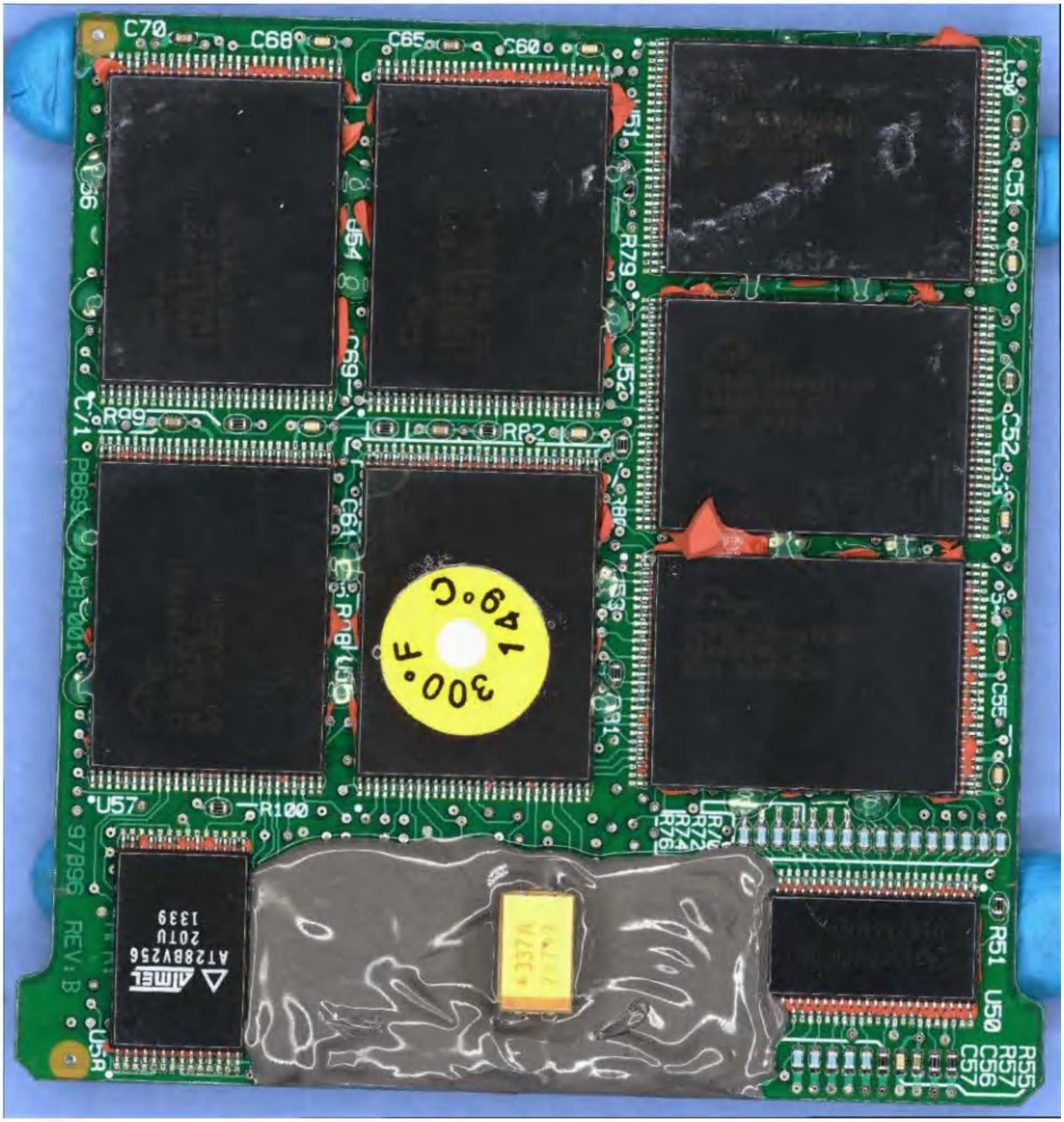


图8. FDR存储模块相对侧连接器。

在多个闪存模块之间的环氧树脂粘接层芯片封装区域均发现轻微裂纹，其中闪存模块U1与U2、U5与U7以及U51与U52处尤为明显。内存模块两侧的大部分环氧树脂粘接层均出现断裂迹象。图9展示了芯片U1与U2之间环氧树脂粘接层的典型裂纹示例。

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

图9. 芯片U1与U2之间环氧粘接处可见裂纹示例。

对FDR模块进行了X射线检测，以评估光学检查无法发现的任何损伤。此类损伤可能包括器件封装内的键合线断裂、芯片框架损坏或芯片硅片损坏。本次检测未发现其他额外损伤。

在发现芯片级数据损坏现象，并利用 DLDR 芯片级恢复工具分析下载行为后，人们开始担忧采用其他标准下载方法对数据完整性的影响。经内部讨论，最终达成共识：恢复所有存留数据最安全的方法是移除存储飞行数据的单个闪存芯片，并使用专用闪存读取器直接读取数据。

从电路板组件中拆卸闪存设备是一项技术难度高且存在一定风险的操作。在拆卸和读取过程中，芯片可能遭受物理损伤或电学损坏。为降低风险，美国国家运输安全委员会（NTSB）决定采用一种已知性能可靠的替代存储模块作为测试样本，以制定出最安全的单

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

个闪存模块拆卸与读取操作流程。

我们确定了合适的NTSB替代测试样品，并首先使用 DLDR 工具下载了存储数据。此举可使芯片从电路板上取下前的图像与闪存读写器/编程器生成的图像进行直接比对；若存在差异，则可对两种芯片读取方法间的差异进行分析并予以修正。

美国国家运输安全委员会（NTSB）的电子专家首先清除了测试样品闪存引脚上的所有保形涂层，为后续从印刷电路板（PCB）上拆卸芯片做好准备。随后，他们手动移除了每个芯片表面的所有环氧树脂粘接层。在使用自动化工具前，先采用人工方式完成首次焊料清除操作，此举旨在降低芯片拆卸过程中的应力负荷。预计在芯片安装于PCB基板下方的位置，仍可能存在残留的RTV胶、保形涂层及环氧树脂。

最终，我们为Finetech FinePlacer微电子工作站开发了一套用于芯片移除的专用操作流程。该流程包含以下步骤：

1. 将整个电路板加热至略低于制造商所用焊料熔点的平衡温度。

2. 通过专用芯片喷嘴对存储芯片引脚施加热量，使温度以安全速率逐步升高至焊料熔化温度。

3. 待焊料完全熔化后，应用吸力将芯片从PCB上分离。

HFR5存储板共配备14块闪存芯片，每侧各7块。但在FDR应用（HFR5-D）中，仅使用其中6块芯片（定义为U1、U2、U3、U4、U5和U6）用于存储飞行数据。在首次从测试样品中取出芯片的实验中，移除了U7芯片。采用Finetech公司的专用取出方案后首次尝试即成功完成操作，芯片无任何困难地被取出。

在成功移除U7芯片后，研究人员采用相同的操作流程，依次单独移除了测试样品中所有六个包含飞行数据的芯片。部分情况下，由于芯片下方残留密封剂，需要施加额外压力才能将其从电路板上取下。每次移除芯片后均对其进行清洁，并清除残留的焊料。
安装至Xeltek SP-6100闪存读写器/编程器的专用插槽中，以便通过计算机
下载。

将芯片读取器生成的芯片图像与 DLDR 工具生成的原始芯片图像进行比对后，发现二者均为字节顺序互换后的完全相同副本。这是因为 DLDR 工具专为生成大端序（英特尔）格

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.

式的二进制芯片图像而设计，而芯片读取器则生成小端序（摩托罗拉）格式的图像。这并非问题所在，因为霍尼韦尔芯片工具能够根据用户选择读取任意格式的芯片图像。

作为最终测试，我们分别使用 DLDR 芯片图像和存储器读写器/编程器芯片图像生成了 DLU 文件。结果表明这两个 DLU 文件功能完全一致，从而验证了适用于事故存储板的芯片解封下载与数据恢复完整流程的有效性。

中国民用航空局（CAAC）已批准采用与测试样品相同的工艺流程，开始从故障模块中提取数据。为将芯片从电路板上移除，采用了相同的共形涂层剥离及环氧树脂去除工艺；在将芯片置于FinePlacer设备中之前，再次通过手工方式清除多余的焊料。使用Finetech FinePlacer进行的芯片移除过程，在涉及的所有6枚目标芯片上均顺利完成。

对芯片U2（封装中可见裂纹的芯片）进行检查后，除先前观察到的裂纹外，还发现其底部存在一个裂纹网络。其他芯片从电路板上取下后均未出现额外损伤。图10展示了芯片U2从电路板上取下后的底部状态。

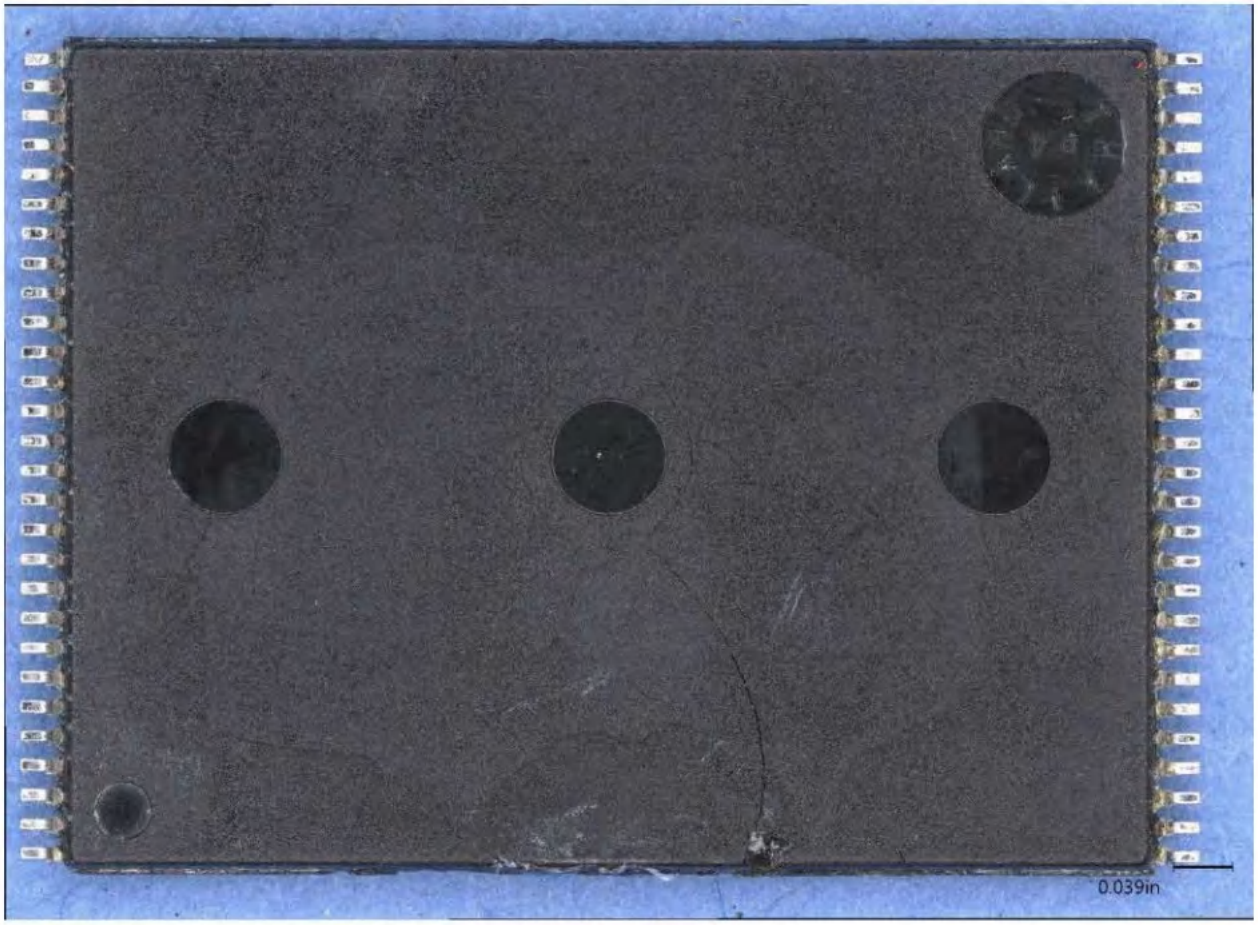


Figure 10.Bottom side of chip U2 showing cracks throughout chip packaging.

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-DX-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.

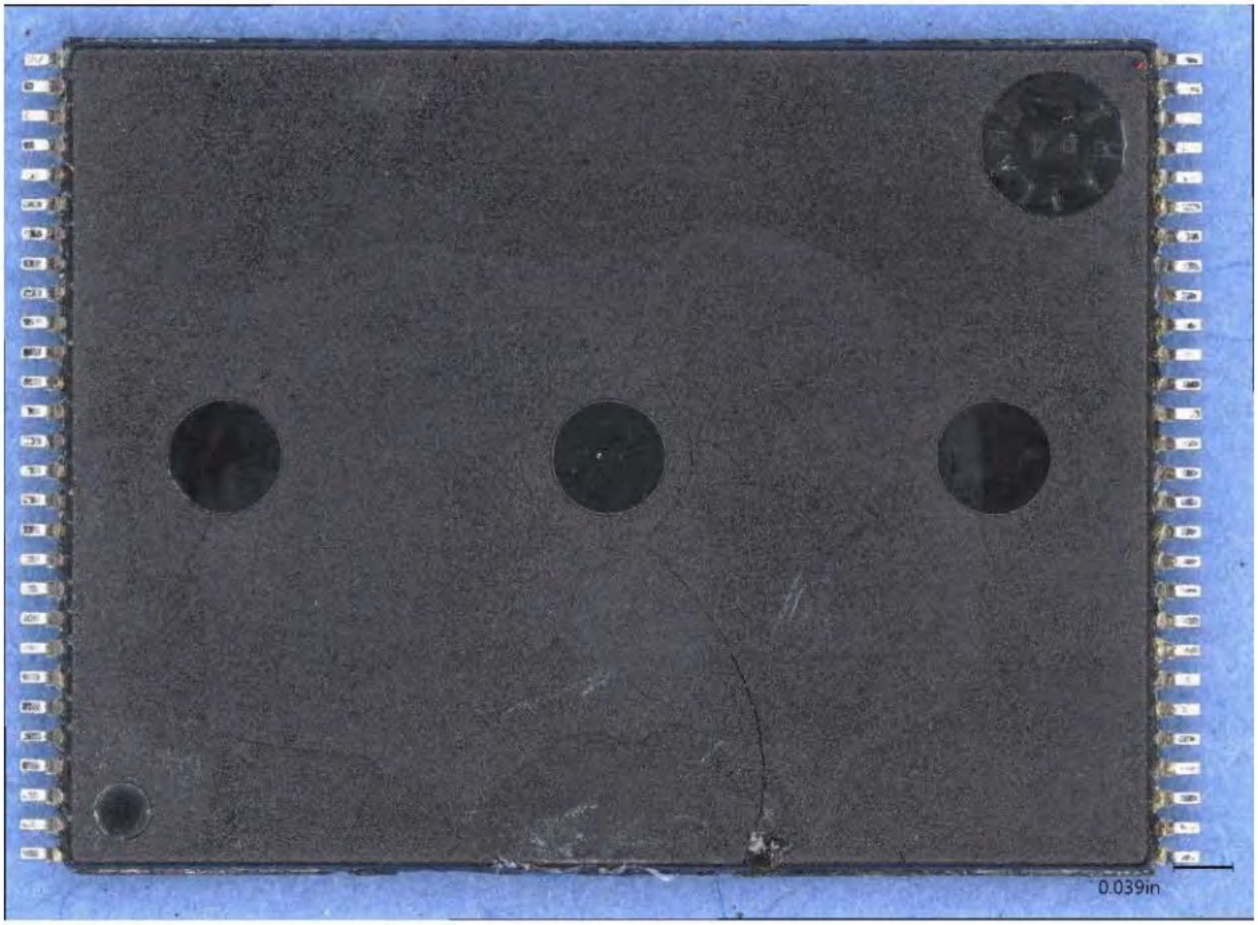


图10. 芯片U2底部侧面显示芯片封装体表面存在多处裂纹。

使用Xeltec内存读取器对芯片进行读取，结果发现U1、U3、U4、U5和U6芯片生成的二进制图像中均包含有效数据；而U2芯片无法被读取，且Xeltec读取器报告了大量引脚校验错误及提示多数引脚存在短路的报错信息——这表明芯片内部的硅晶圆已遭受严重的内部损伤。

芯片U2接受了X射线检测和CT扫描，芯片U4也作为样本进行了X射线检测。CT扫描结果存在噪声干扰且未提供新的信息。包装底部肉眼可见的一些裂纹在二维X射线图像中同样清晰可见；这些裂纹贯穿了封装芯片内部含全部电路的硅片区域。另有数条底面裂纹在X射线图像中不可见，因为它们似乎沿着制造过程中用于固定硅片的X形铜焊盘轮廓延伸。这种严重损坏导致U2芯片的所有数据均无法恢复。

A dummy file of all hexadecimal 'FF'(binary'1')was created and used in place of the image from U2 in the HoneywellCHIPS 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 fullsubframes 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

在HoneywellCHIPS工具中，创建了一个包含所有十六进制值“FF”（二进制值“1”）的虚拟文件，并用其替代U2图像数据以生成FDR DLU 文件。随后将生成的 DLU 文件导入NTSB cider数据分析应用程序，并结合飞机制造商提供的信息对数据进行格式化处理。

在框架化处理过程中，事故数据出现在数据流的中间位置，这是因为当在未配备U2芯片的芯片上创建 DLU 时，指针信息丢失了。随后，对转换后的数据进行了手动重新排序，将出故障的飞行数据置于记录的末尾。

由于缺少芯片数据图像，整个数据文件的传输过程中均存在规律性的数据丢失现象。这种情况完全符合HFR5-D系统将飞行数据写入六个芯片的工作原理：飞行数据流会按条带状方式依次分配到每个芯片上。在每秒512个数据字的传输速率下，每次芯片写入操作对应约1.3秒的数据量。因此，最终重建的缺失芯片U2数据流应呈现为：先连续出现约6.5秒的有效数据块，随后接续1.3秒来自芯片U2的缺失数据段。

在分析软件中进行初步重建时，数据所显示的时隙比预期的1.3秒大得多，约为4秒量级。这种错误的时间定位导致数据的时间历程无效，使得无法将数据与CVR 事件对齐。

研究发现，由于缺失数据跨越了子帧边界，分析软件在预期看到连续的子帧同步字标记时，会通过填充错误的额外子帧来补全数据。这些干扰现象源于：每当处理替换芯片U2的虚拟数据时，都会导致同步信号丢失；而同步信号的丢失则致使分析软件每约8个子帧（秒）就会填充4个完整的子帧。

修正冗余子帧的状态是一项极其耗时的工作流程：为实现数据的精确对齐，需手动检查数据流中的每个间隙及子帧边界，逐个标注芯片U2预期丢包起始与结束位置，并补充缺失的子帧同步字边界。此举可确保重放软件保持数据流同步，并准确显示数据的时间信息。

由于校正数据流时间戳所需时间较长，仅对事故航班记录数据的最后12分钟进行了时间精度校正；同时对先前着陆及滑行阶段的部分数据也进行了校正，以辅助验证各项参数。

参数验证是指评估各个参数的过程，以确定数据系统是否正确且准确地记录了这些参数，并检查工程单位的缩放与偏移是否正确。在波音公司该数据框中记录的逾1,000

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.

个参数中，约有150个通过了正向验证。验证工作重点针对以下参数：反映飞机状态的参数（如加速度、位置、高度、姿态及速度——即基础参数）、与飞行控制装置、机翼表面及飞行控制力相关的参数，以及与飞机发动机运行相关的参数。已验证参数的列表可参见附录B。

飞行数据记录器的数据采集在飞机仍处于飞行状态时结束；数据停止时，飞机正以约26,000英尺的高度进行下降。该记录未能捕捉到下降过程及最终事故序列的剩余部分。对飞行数据提前终止原因的调查发现：当飞机在29,000英尺高度巡航时，两台发动机的N2转速值均迅速下降至发电机断电点以下。FDR未配备电池备份电源，因此在失去飞机发电机供电的情况下，将自动关机。这与 CVR 系统不同——后者配备电池备份电源，在飞机发电机失效后仍可继续记录至少10分钟。针对发动机N2转速降至发电机切断速度以下的原因进行排查，发现：当飞机在29,000英尺高度巡航时，两台发动机的燃油开关从运行位置切换至切断位置。燃油开关切换后，发动机转速随之下降。

2.3 FDR数据已提供给中国民用航空局

提供给中国民用航空局代表团的数据包括以下内容：

·所有原始芯片下载图像文件，包括用于生成FDR.dlu文件的虚拟U2文件。

- 由Honeywell芯片工具生成的所有FDR.dlu文件均包含两种设置选项：一种指示工具跳过内存中已擦除的数据块，另一种则要求保留内存中的已擦除数据块。

  - 两种方法生成的功能完全相同的文件。经过跳过擦除块处理的文件被用于美国国家运输安全委员会（NTSB）的数据分析工具中，因为该方法最能准确模拟Playback32实用程序创建.a.dlu文件时的行为。

·所有由NTSB的Cider FDR分析软件生成的FDR解包二进制文件。

- 经手动校正的未打包二进制文件，可正确实现最终数据的时间对齐。

  12分钟的记录数据。

- 经验证的数据图，包括飞机基本参数、飞行控制参数、控制力参数及发动机参数的图表。

  - 分别针对记录数据的最后10分钟和最后100秒的时间段生成了图表。

·涵盖精确采样时序及最接近1/16秒精度下的所有经验证参数的表格数据。

- ·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

·生成中国民用航空局（CAAC）FDR软件分析工具所需数据框的所有必要文件。
·所有图像、扫描图及显微照片均是在数据恢复过程中拍摄的FDR板图像。

美国国家运输安全委员会（NTSB）保存了这些飞行数据报告（FDR）文件的副本，以便为民航局（CAAC）编制最终报告中的飞行历史记录及事件序列提供支持。

已提交 通过:

查尔斯·凯茨
机械工程师/录音师

2.3.1 FDR Plots

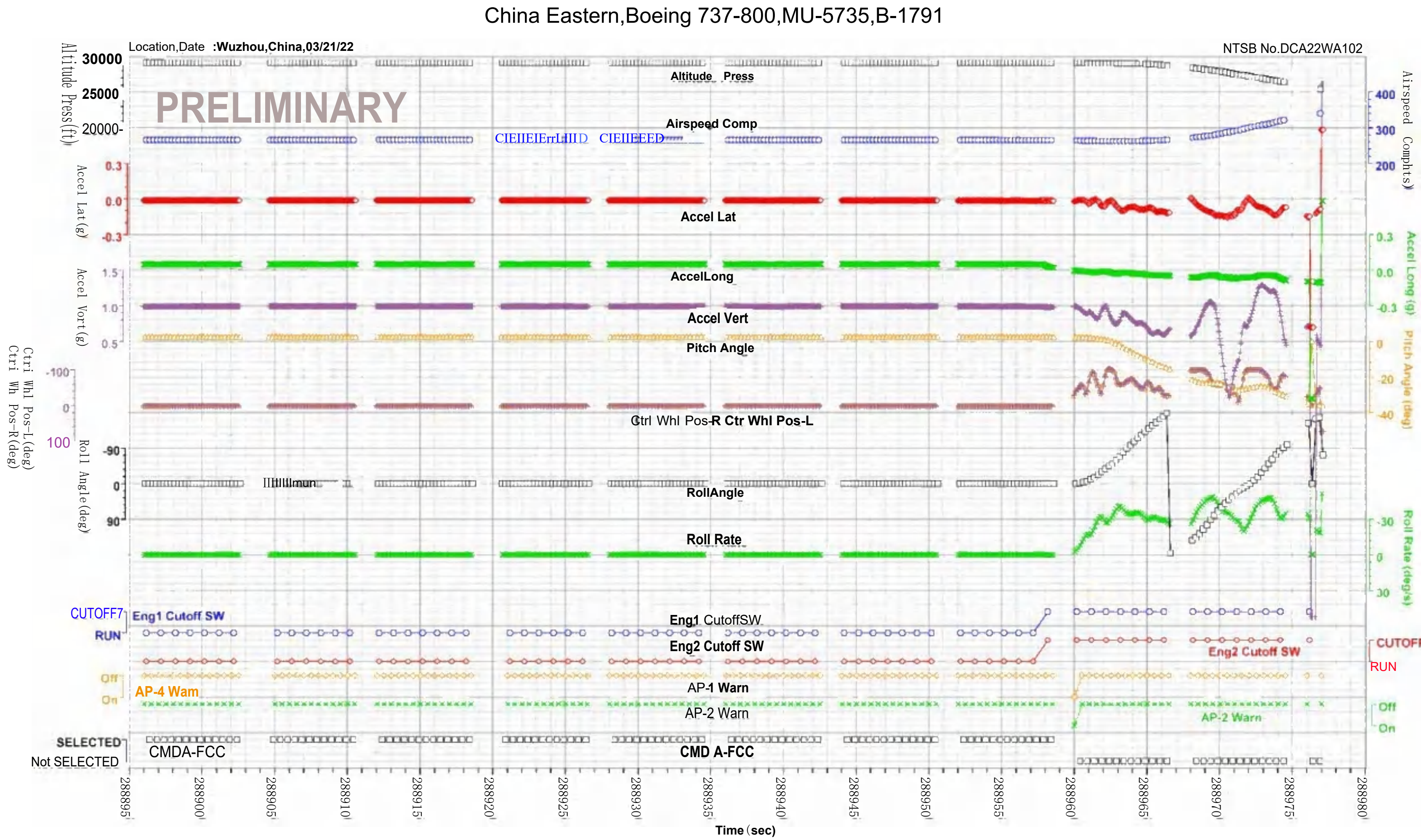
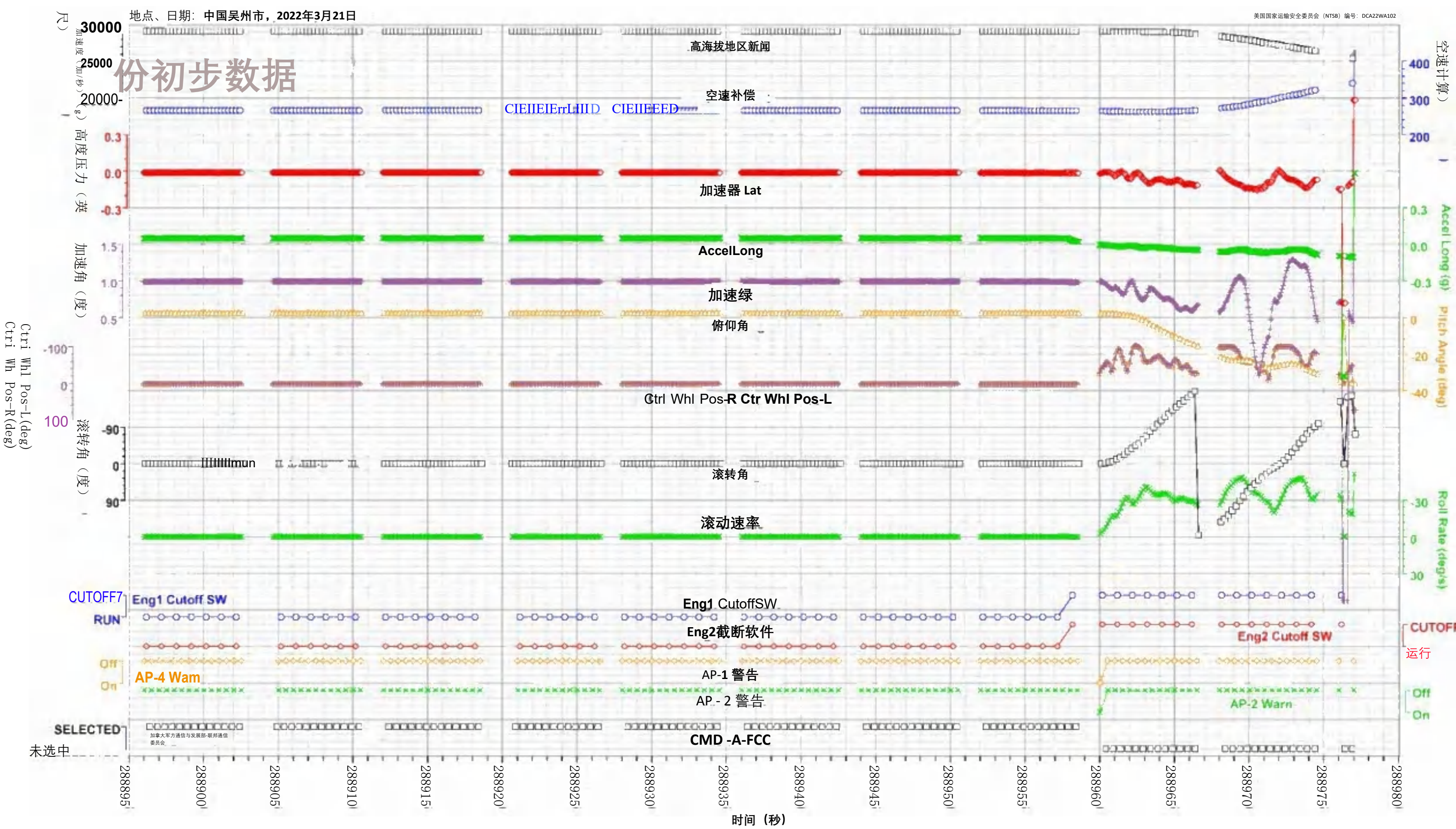


Figure 11.Basic aircraft parameters from final 90 seconds of recording.

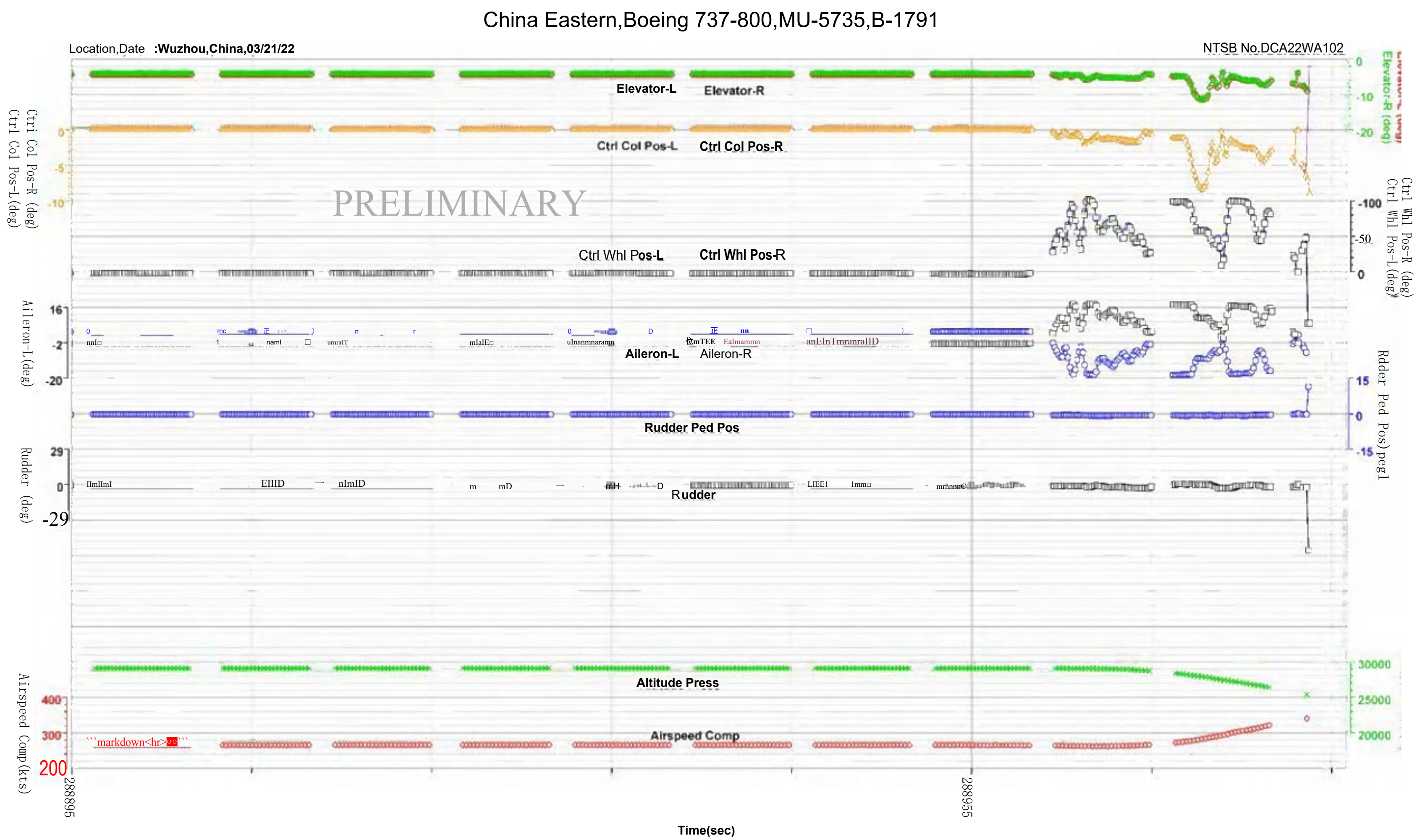
2.3.1 FDR 图表

中国东方航空，波音737-800型飞机，MU-5735号机，B-1791号机



修订日期：2022年4月14日 美国国家运输安全委员会

图11：基于录音最后90秒数据获取的飞机基本参数。



Revised:14 April 2022

National Transportation Safety Board

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

中国东方航空，波音737-800型飞机，MU-5735号机，B-1791号机

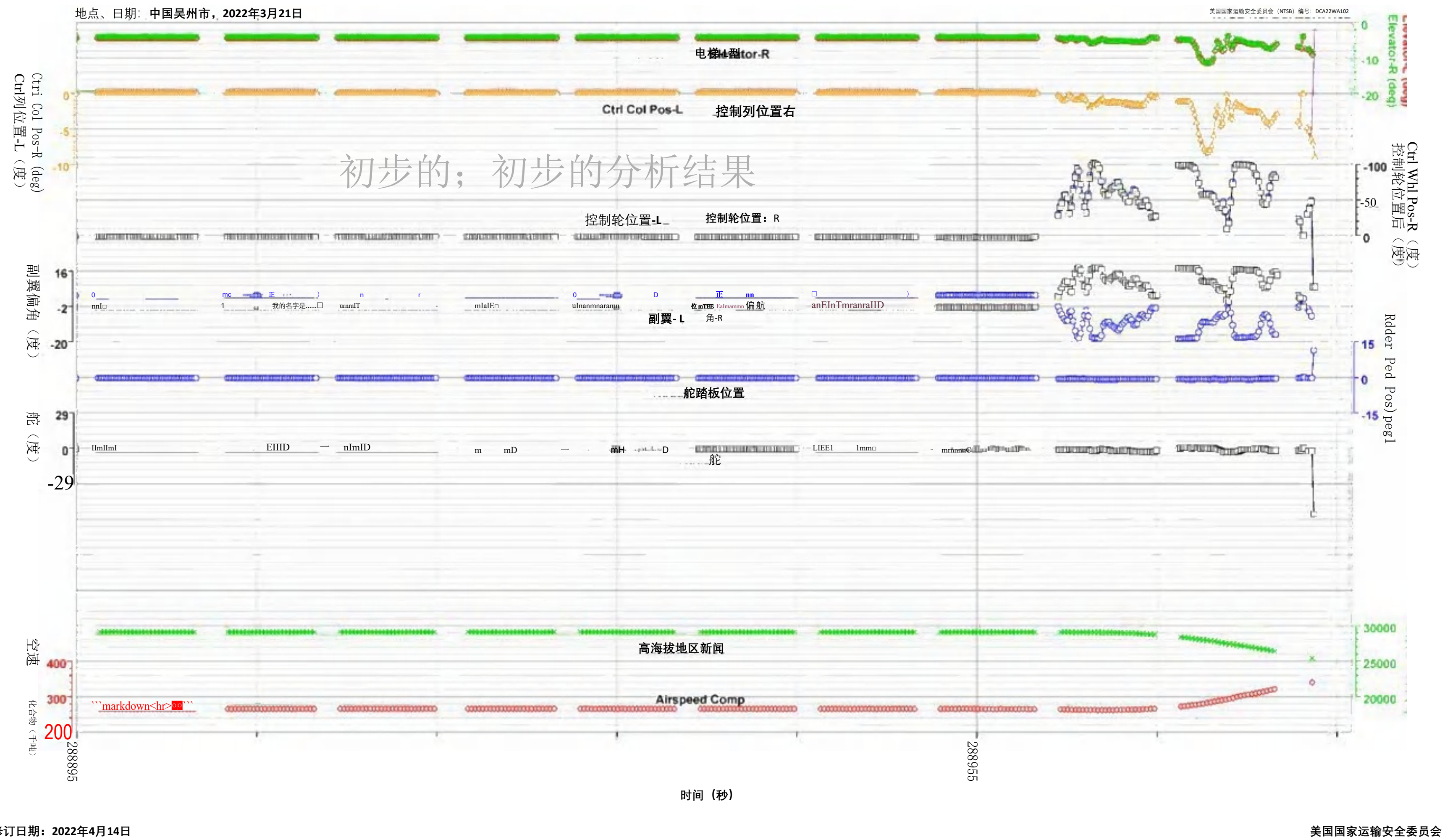


图12. 飞行控制与输入 录音最后90秒内的播放位置。

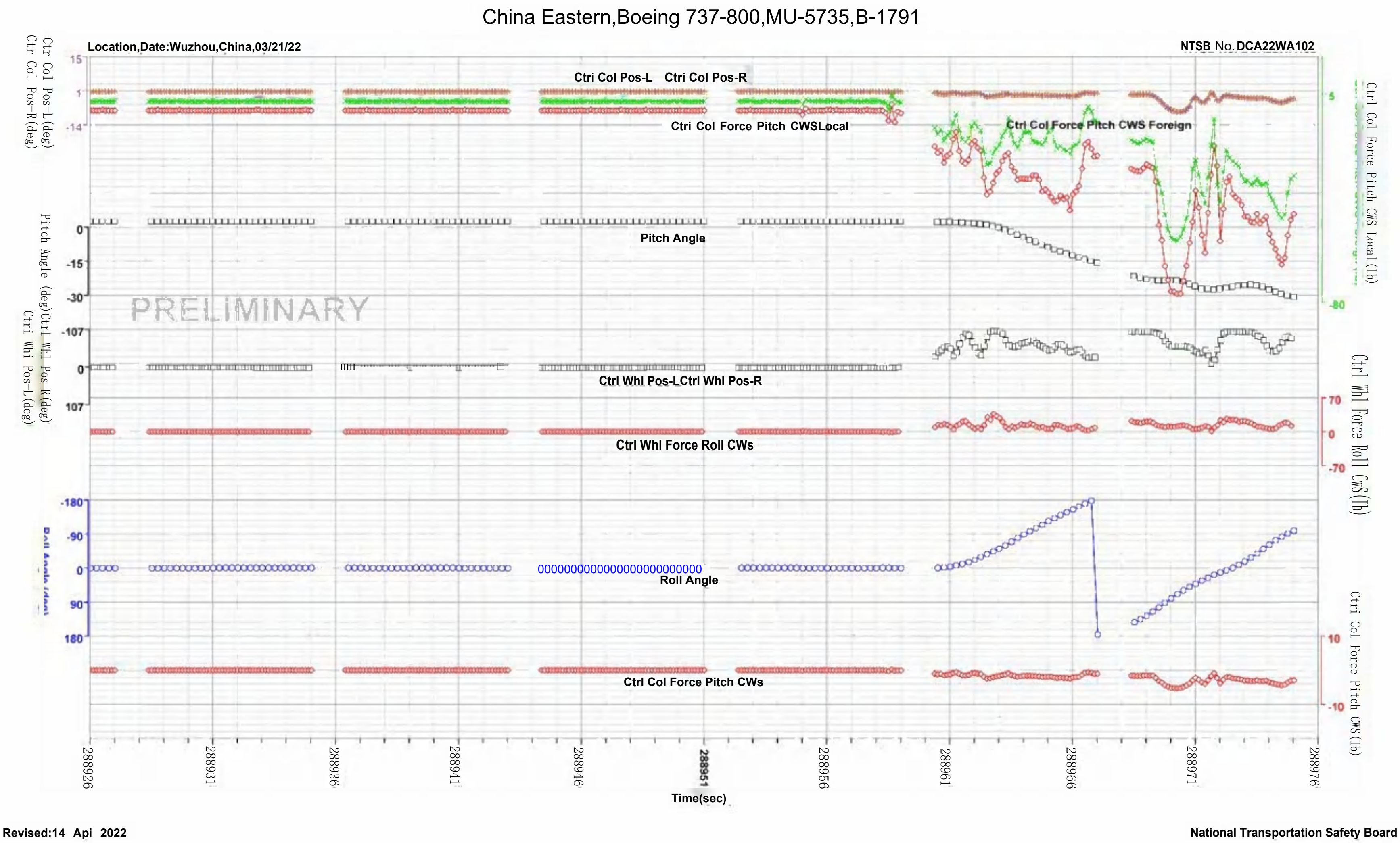


Figure 13.Control forces recorded during upset event through end of recording.

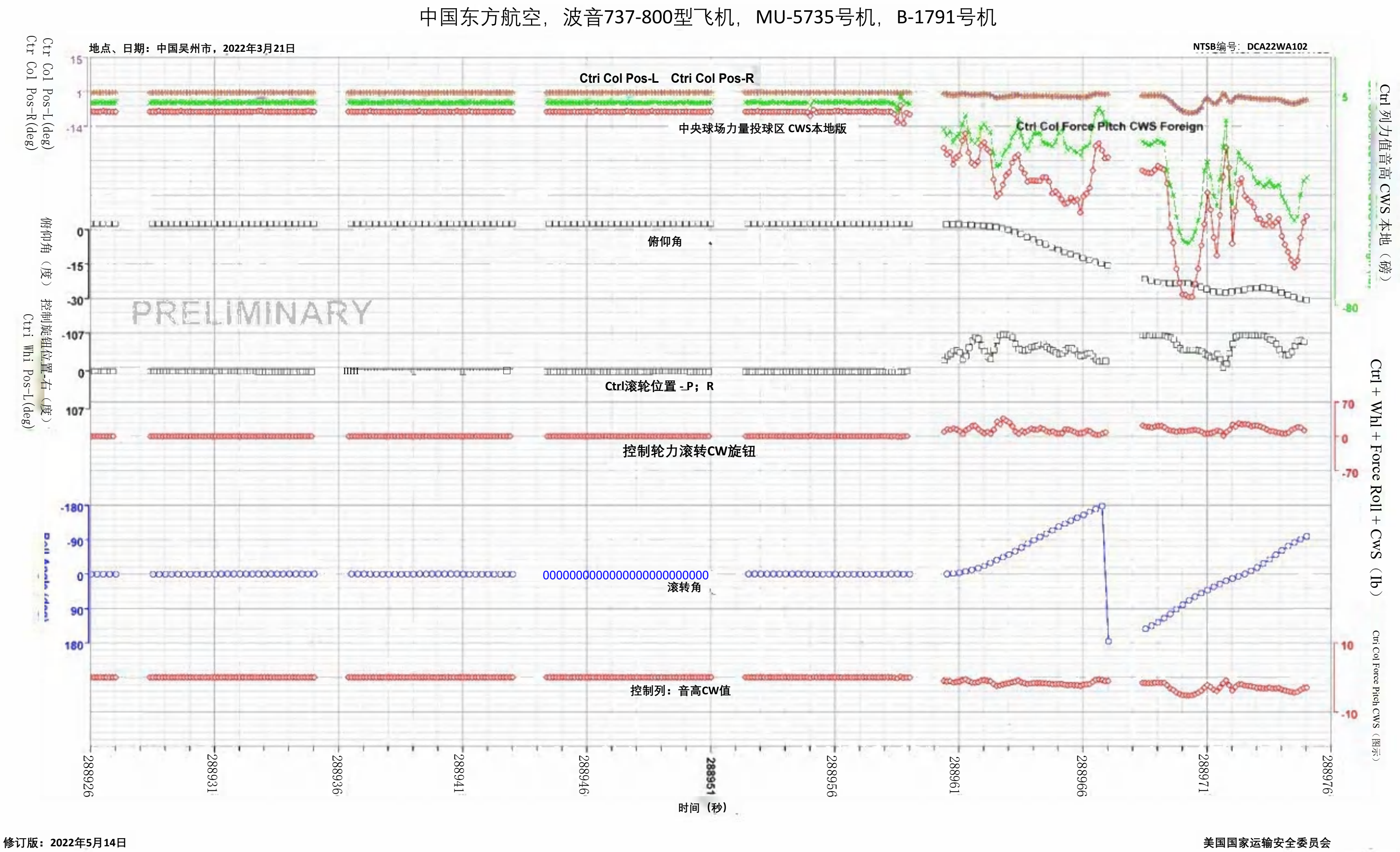


图13. 在失稳事件发生期间至记录结束时记录的控制力。

APPENDIXA.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.

附录： CVR 质量评级量表

录音质量水平可通过驾驶舱语音记录仪信息的以下特征来表征：

卓越品质几乎所有机组人员的对话都能被准确记录。
易于理解。所生成的转录文本可能仅显示一两个无法辨识的词语。转录文本中的任何缺失通常归因于同步录音过程中的干扰。
驾驶舱/无线电传输信号相互干扰。

优质 机组人员的大部分对话都能被准确且轻松地理解。所生成的录音文字记录中可能包含若干难以辨识的词语或短语。录音内容的缺失通常可归因于轻微的技术缺陷、录音系统出现短暂故障，或是驾驶舱与无线电设备同时进行的大量传输信号相互干扰所致。

公平质量 机组人员的大部分对话内容均可清晰辨识。所生成的录音记录可能显示存在对话不清或片段化的情况。此类录音问题通常由驾驶舱噪音导致语音信号部分被掩盖，或由 CVR 系统出现轻微电气或机械故障致使音频信息失真或模糊所致。

质量差 必须采用特殊手段才能使部分机组人员的对话内容清晰可辨。最终生成的录音记录可能包含零散的短语和对话片段，甚至存在大量对话内容缺失或难以辨识的情况。此类录音问题通常由两种因素共同导致：一是驾驶舱内噪音水平过高而语音信号微弱（信噪比极低）；二是 CVR 系统出现机械或电气故障，导致音频信息严重失真或模糊不清。

无法使用 虽可辨识船员间的对话内容，但无论是常规手段还是特殊手段均未能实现有意义的记录。
对话记录文本。此类录音通常由 CVR 系统几乎完全的机械或电气故障引起。

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.	ALTACQ 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 Altimeter2
29.	AP Off-FCC		Autopilot Off
30.	AP-1 Warn		Autopilot Warning 1
31.	AP-2 Warn		Autopilot Warning 2
32.	APUN1	%RPM	APU Shaft Speed
33.	APU On		APU Running
34.	APU Ready To Load		APU Ready for Load
35.	AT FMC SPDEngaged		Autothrottle Speed Mode Engaged
36.	CMDA-FCC		FCCA In Command
37.	CMD A Light-FCC		FCCA Light Active
38.	CMD B Light-FCC		FCCB Light Active
39.	Ctrl Col Force Pitch CWS	Ib	Combined Control Column Force

附录B. 验证参数

本附录阐述了已验证并提交至中国民用航空局（CAAC）的各项参数。表B-1列出了各参数的名称、单位及描述；此外，表2详细说明了本报告中使用的计量单位及缩写符号。

表 B-1. 已验证并提供的 FDR 参数

已验证的参数名称		单位	描述
1.	绝对旋转速率	deg/s	飞机滚动速率
2.	加速器 Lat	g	侧向加速度
3.	加速长线	g	纵向加速度
4.	加速绿	g	垂直加速度
5.	活动高度参考值（FCC标准）		面心立方高度参考
6.	副翼执行器安装位置	deg	左副翼作动器位置
7.	副翼象限位置	deg	副翼控制象限位置
8.	副翼滚转指令-L	deg	左面心立方翼型滚转指令
9.	副翼- L	deg	左副翼位置
10.	副翼- R	deg	右副翼位置
11.	接地空气；接地状态		地面空地传感器
12.	空气　　地面-SMYDC-1		SMYDC 1 地面情况
13.	空气　　地面-SMYDC-2		SMYDC 2：地面情况
14.	空中-地面		空地
15.	空速补偿	kts	计算空速
16.	允许的最大空速	kts	面心立方最大允许空速
17.	空速目标面心立方	kts	面心立方计算空速目标
18.	阿尔特1号巴罗·科尔	ft	气压校正海拔高度1
19.	阿尔特2号巴罗科里	ft	经气压校正后的海拔高度：2
20.	阿尔特3号巴罗科里	ft	经气压校正后的海拔高度：3
21.	阿尔特4号巴罗科里	ft	经气压校正后的海拔高度：4
22.	ALTACQ　　参与式联邦通信委员会		高程获取自动驾驶模式已启用
23.	阿尔特巴罗联合训练营	ft	综合气压修正高度
24.	ALT保持激活状态-FCC		高度保持自动驾驶模式已启用
25.	高海拔地区新闻	ft	压力高度
26.	Altitude Radio DEU	ft	显示的无线电高度
27.	高海拔广播电台-1	ft	无线电高度计1
28.	高海拔广播二台	ft	高度计2型无线电设备
29.	AP（非 FCC 认证版本）		自动驾驶功能已关闭
30.	AP 1 警告		自动驾驶仪警告 1
31.	AP - 2 警告		自动驾驶仪警告 2
32.	APUN1	%RPM	APU 轴转速
33.	APU 开启		APU 运行
34.	APU 准备加载		APU 已就绪加载
35.	AT FMC SPDE 已启用		自动油门速度模式已启用
36.	加拿大军方通信与发展部-联邦通信委员会		FCCA 掌控全局
37.	命令：轻型 FCC		FCCA 主动发光
38.	CMD B 轻型-FCC		FCCB 亮激活
39.	控制键列音高 CWS	Ib	组合控制列力

	Validated Parameter Name	Units	Description
40.	Ctrl Col Force Pitch CWS Foreign	Ib	Control Column Force Opposite FCC
41.	Ctrl Col Force Pitch CWS Local	Ib	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	Ib	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 FMCN1 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 FMCN1 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

	已验证的参数名称	单位	描述
40.	Ctrl 键列音高 CWS 外部	Ib	控制柱力与面心立方方向相反
41.	Ctrl 键列音高 CWS 本地	Ib	控制列力指令面心立方
42.	控制列位置：左	deg	左侧控制列位置
43.	控制列位置右	deg	右侧控制柱位置
44.	Ctrl Whl 力度滚动 CWS	Ib	控制轮力
45.	Ctrl Whl Pos-L	deg	左侧控制轮位置
46.	Ctrl Whl Pos-R	deg	右侧转向盘位置
47.	漂移角度-FMC	deg	计算得出的漂移角度
48.	电梯执行器后端	deg	左侧电梯执行器位置
49.	电梯式推介语（Cmd-L）	deg	左面心立方电梯间距指令
50.	电梯-L型	deg	左侧电梯位置
51.	电梯-R型	deg	右升降舵位置
52.	Eng1截断软件		左发动机切断开关
53.	Eng1 EGT	degC	左发动机排气温度
54.	Eng1 火灾		检测到左发动机起火
55.	Eng1 FMC N1 Bug Drive	%转速	左发动机N1故障驱动装置
56.	Eng1：FMCN1的靶标	%转速	左发动机N1目标
57.	Eng1 FMV Pos	%	左发动机燃油计量阀位置
58.	Eng1燃料流量	pph	左发动机燃油流量
59.	Eng1 N1	%RPM	左侧发动机风扇转速
60.	Eng1 N1 Cmd	%转速	左发动机风扇转速指令
61.	Eng1 N1 Ref	%转速	左发动机参考风扇转速
62.	Eng1 N1 Tach	%转速	左侧发动机风扇转速表
63.	Eng1 N2 实际值	%转速	左发动机核心转速
64.	Eng1 N2 Tach	%RPM	左侧发动机核心转速表
65.	Eng1型油压机	psi	发动机左侧油压
66.	Eng1 油量	qt	左发动机机油量
67.	Eng1油温	degC	左发动机机油温度
68.	Eng1 TRA	deg	左发动机节气门调节角度
69.	Eng2截断软件		右发动机切断开关
70.	Eng2 EGT	degC	右发动机排气温度
71.	Eng2 火灾		检测到发动机右侧起火
72.	Eng2 FMCN1缺陷驱动	%转速	右引擎N1故障驱动程序
73.	Eng2 FMC N1 目标	%转速	Right Engine N1目标
74.	Eng2 FMV Pos	%	右发动机燃油计量阀位置
75.	Eng2燃油流量	pph	右发动机燃油流量
76.	Eng2 N1	%转速	右发动机风扇转速
77.	Eng2 N1 Cmd	%RPM	右发动机风扇转速指令
78.	Eng2 N1 Ref	%RPM	右发动机参考风扇转速
79.	Eng2 N1 Tach	%RPM	右发动机风扇转速计
80.	Eng2 N2 实际值	%RPM	右引擎核心转速
81.	Eng2 N2 Tach	%RPM	右引擎核心转速表
82.	Eng2石油出版社	psi	发动机右侧油压
83.	Eng2 油量	qt	发动机机油正确用量
84.	Eng2油温	degC	右侧机油温度
85.	Eng2 TRA	deg	右发动机节气门调节角度
86.	FAC Engage-面心立方		进近最终航路AP模式已启用

	Validated Parameter Name	Units	Description
87.	FCCIn Command of MACH Trim-R		Right FCC Commanding Mach Trim
88.	FCC-LIn 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 BEng 2		Hydraulic B Engine Pump
118.	Hydraulic System Standby		Hydraulic Standby System Engaged
119.	IAS Display-FCC		Indicated Airspeed Displayed
120.	LNAV Engaged-FCC		LNAVAP 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

已验证的参数名称		单位	描述
87.	面心立方结构的MACH Trim-R指令		右侧面心立方指令调节机械间隙左侧
88.	MACH 的面心立方指令 修剪		面心立方 指挥；率领 调整边距
89.	FD-A 交换机 - 面心立方		飞行总监：A开关
90.	FD-B Switch –面心立方		飞行控制台B开关襟翼手柄
91.	翻盖把手位置	deg	
92.	Flap-L–	deg	位置；左侧襟翼位置
93.	瓣片 R	deg	右皮瓣 选择的空速-
94.	FMC选定空速	KTS	FMC位置
95.	FMC选定高度	FT	选定高度-FMC
96.	FMC选定的马赫数	Mach	选定的马赫数——FMC验证：
97.	FMC 有效		FMC有效
98.	G/S开发警告——面心立方		滑行道偏差警告；滑行路径AP
99.	GP Engage-面心立方		
100.	地面速度	kts	模式已启用；地面速度
101.	Groundspeed FMC	kts	地面速度由FMC计算；地面速度显示
102.	Groundspeed Disp -L	kts	在左侧PFD上；已启用下滑道AP模
103.	GS Engaged-FCC		式；航向选择灯已激活。
104.	HDG SEL-Light-FCC		
105.	HDG 选择面心立方		标题 选择AP模式磁航 已婚
106.	标题	deg	向
107.	标题：选定的面心立方	deg	面心立方方向已选
108.	高速自助式油压机	kts	高速自助餐服务：速度与压力的完
109.	Hyd	psi	液压 美结合 体系 A
110.	Hyd Oil Press-B型	psi	
	油压机-油A		液压系统B油 A
111.	Hyd Qty 型	%	液压 计量系统
		%psi	液压油量系统 B 备用液压压力 液压
112.	液压油数量-B		
113.	液压油压备用装置		A 电动泵
115.	液压系统工程		液压 发动机水泵
114.	液压系统 A ELEC A 1		液压B型电动泵
116.	液压系统 B ELEC 2		
117.	液压系统工程学士学位		液压 B 发动机水泵
118.	液压系统备用模式		液压备用系统已启动，显示空速；
119.	IAS显示屏-FCC认证		
120.	LNAV Engaged-		LNAVAP 模式已启用
121.	FCCLNAV 灯 -面心立方		LNAV 灯 活跃的
122.	LOC 已启用 - FCC		定位器AP模式已启用
123.	本地的 有限 主面心立方–L		面心立方左主晶胞
124.	本地受限的最高频率（FCC-R标准）		面心立方右主晶型
125.	LVL 变化光线 - 面心立方		飞行高度变化 AP模式激活 马赫数调节
126.	MACH 调节伺服制动器状态-FCC-L N		
127.	1 灯 -面心立方		伺服状态 N1 灯 活跃的
128.	N1 限值模式 命令-FCC		N1极限AT模式下的飞机俯仰
129.	俯仰角	deg	角
130.	滚转角	deg	飞机滚转角
131.	滚动速率	deg/s	飞机滚转速率与方向
132.	舵	deg	舵位置
133.	舵踏板位置	deg	舵踏板位置

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		APon 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.

已验证的参数名称		单位	描述
134.	舵位置 - LVDT DEMOD - STBY PCU	deg	舵备用 PCU LVDT 位置
135.	舵机伺服命令 STBY PCU	deg	舵备用 PCU 伺服控制指令
136.	选定空速面心立方	kts	选定空速-面心立方
137.	选定高度的面心立方	ft	选定高度-FCC
138.	选修课程：面心立方结构	deg	选修课程：面心立方结构
139.	精选课程：局部面心立方	deg	精选课程：局部面心立方
140.	选定的马赫面心立方	机器；设备	选定的马赫数 - FCC
141.	选定的垂直速度面心立方	fpm	选定垂直速度-面心立方
142.	单通道-FCC		基于单通道的AP
143.	SPD Light（符合 FCC 标准）		SPD轻量级主动模式
144.	SPEED INTERVENTION ACTIVE-FCC		速度干预已激活
145.	TOGA已与美国联邦通信委员会（FCC）达成合作		AT TOGA模式已启用
146.	轨道轨迹真实FMC值	deg	真实轨迹角度
147.	视觉高度警报——联邦通信委员会		视觉高度警报已激活
148.	VNAV FCC认证的照明产品		VNAV 主动发光
149.	VNAV PATH Engaged-FCC		VNAV 路径AP模式已启用
150.	VNAV SPD 参与了 FCC 的工作		VNAV Spd AP模式已启用
151.	风向真值 - FMC	deg	风向
152.	风速 – FMC	kts	风速
153.	Yaw 利率	deg/s	飞机横滚角速率

注：该FDR记录的是压力高度，该数值基于29.92英寸汞柱（in Hg）的标准气压表设定值。FDR图表及表格数据中所呈现的压力高度信息，并未根据事件发生时当地的气压表设定值进行修正。

注：表B-1中单位描述为空的参数均为离散参数。离散参数通常是指1位参数，其取值为0状态或1状态，且每个参数的各状态均具有唯一定义。

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
Ib	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

表 B-2. 单位与缩写

单位/缩写	描述
Alt	海拔
AP	自动驾驶模式
APU	辅助动力单元
阿特；AT	自动油门
巴罗	气压计的
CWS	控制轮转向
deg	程度
degC	摄氏度
面心立方	飞行控制计算机
FMC	飞行管理计算机
fpm	每分钟英尺
ft	脚
kts	结
Ib	英镑
LVDT	线性可变差动变压器
MCP	模式控制面板
PCU	电源控制单元
PFD	主飞行显示
pph	磅/小时
psi	每平方英寸的磅数
qt	夸脱
转速（RPM）	转/分
S	第二
SMYDC	停车管理与偏航阻尼器计算机