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NOV 15 '95 11:37AM PROSPERITY MORTGAGE P.1/12

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DOCKET NO. SA-510
EXHIBIT NO.

NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C.

ACOUSTICS PRESENTATION
JAMES R. CASH

Good morning ladies and gentleman, I would like to start my presentation this morning by describing how a cockpit voice recorder works and how sounds get to the microphones to be recorded on the CVR.

The CVR receives it electrical power from the aircraft and operates any time there is electrical power on the aircraft. The unit is an endless loop recorder, constantly erasing the older information and recording new information. When electrical power is removed from the unit or after an aircraft crashes, the recorder contains information from this point back 30 minutes.

The recording consists of 4 channels of audio information. **(show slide 1)** One of the channels contains audio information from the Captains audio selector panel. This channel records the same audio information that the crew member was listening to in his headset. Another channel contains similar audio information but from the CO-pilots audio selector panel. The third channel (which usually contains audio information from the 2nd officers audio selector in a three crew member aircraft) but in a two crewman aircraft like the Boeing 737 it is usually wired to the observers or jump seat audio selector panel. The forth CVR channel contains audio information from the cockpit area microphone This open microphone is mounted in the overhead instrument panel between the two crew members and is our primary microphone for picking up cockpit sounds or noises. On this aircraft the two crew members were wearing individual headset microphones which were wired hot to the CVR recorder. This means that what ever sounds were picked up by the crews headset microphones was recorded on their individual audio tracks of the CVR. In addition to the normal area microphone, and the two crew members headset microphones, the microphone selector switch on the jump seat audio selector panel was inadvertently left in the oxygen mask position. This enabled the microphone that is installed in the emergency oxygen mask to be "hot" similar to the captains and the CO-pilots headset microphones. For the investigation of this accident we had a total of 4 microphones that were picking up audio information and recording it on the CVR.

Sound information arrives at the various microphones via several methods. The first and most prominent method is by airborne sound waves, in which the sound energy is transmitted via the air to the microphones in the cockpit. This is the main transmission mode for the sounds recorded on the CVR. The second mode of sound transmission is structure borne sounds. These are sounds that are transmitted through the metal structure of aircraft. These sounds normally are of very low frequency as compared to the airborne sounds. The cockpit area microphone and to a lesser extent the jump seat oxygen mask are the only microphones capable or picking up these structure borne sound The sounds recorder by the CVR may be composed of either of the two sounds or maybe a combination of the two sounds. One characteristic of structure borne sounds is that they normally travel about 8 or 9 time faster through the metal structure than they do through the air. By knowing the speed that sound travels through the air, approximately a foot every hundredth of a second, and by measuring the time difference between the arrival of the structure sound and the arrival of the air sound we are able to calculate the approximate distance the source of the sound was from the microphone. Later in my presentation I have a slide that depicts this event.

(show slide 2) This slide shows the sounds that we found on the various channels of the CVR from the accident aircraft. This slide starts just prior to the initial upset and continues for about ten seconds. From this slide you can see a picture of the various audio sounds found on the individual channels. The top trace is the information found on the Captains channel. The second trace is the audio information found on the CO-Pilots CVR channel, The third channel is the open area microphone channel and the remaining forth channel is the audio information that was found on the jump seat/ observers channel of the CVR. Because of the nature of the area microphone the same speech found on the crew channels usually appears on the area mike and to a lesser extent on the jump seat microphone channels of the CVR

(Show slide 3) This next slide is from area microphone channel at approximately the same time slice as the preceding slide. Instead of showing the simple wave form it shows the same information in frequency in what is commonly called a spectrogram or a voice print format. When you look at a the frequency plot, several additional pieces of information becomes apparent. This constant frequency trace shown in red is the sound signature made by the aircraft's engines. This sound is produced by the rotation of the first stage fan in the engine. It is very similar to the noise that a household fan would make. The frequency of the sound is dependent on how fast the fan is turning in the air. It is not apparent on this slide but if I increased the scale, two separate traces could be observed. The two traces are due to the fact that the two engines were operating at speeds a few tenths of a percent different from each other. You can see from this presentation that the engine sounds change intensity. This change is depicted by the change in the red redness just after the initial upset. We identified this abnormality early in the investigation but had no explanation why the engine sounds got louder just after the event. Please remember this event because I will be coming back to it in a minute. Several other events are depicted on this frequency slide. Just after the 1st officer finishes saying "JET STREAM" three what we call thumps are recorded on the CVR. These thumps are found on both the area microphone and the jump seat channels of the CVR. These sounds are very low in frequency and are relatively low in intensity as compared to the other events on the CVR. Several other sounds are also depicted on the frequency plot. There are additional "THUMP" sounds very similar in characteristics to the first series shown here. The voice prints of the two crew members speech is also shown on the plots.

To further investigate the "THUMPS" found on the accident CVR recording we conducted several tests on identically configured Boeing 737 aircraft. One test was conducted on the ground. In this tests we struck various places on the aircraft with a rubber mallet while recording the sounds. The resulting data allowed us to validated our assumptions as to how the various sounds reach the CVR's microphones. **(Show slide 4)** In this slide you can see the various wave form recorded on the area and jump seat microphones. This sound was made by striking the aircraft structure in the forward cargo compartment. In this data we were able to see both the arrival of the structure wave , followed several hundredth of a second later by the arrival of the air wave. This test also gave us some indication of the frequency make up of sounds. As a result of the test we were able to verify both the direction that the sounds came from as well as the approximated distance the source was from the microphone. By using this same technique we were able to determine the approximate distance and the direction that the "THUMPS" on the accident CVR were coming from. **(Show slide 5)** As you can see the arrival times of the various waves on the accident recording is not as easily identified as on the ground test recording. The "THUMP" sounds on the accident recording are not very loud and with the addition of the normal background noise the onset of the thump sounds tended to masked. To aid us in determining when the thump sound started we used a signal processing function that calculates the total sound energy contained in the signal. **(show slide 5a)** With this plot it becomes easier to determine when the two components of the sound arrived at the microphone. We calculated the source of the "THUMP" sounds to be approximately 20 feet toward the rear of the aircraft from the area microphone. This places the sound source approximately in vicinity of first class rows 1 or 2 of the aircraft. The frequency composition of the "THUMP" sounds was similar to the ground test rubber mallet strikes. This is not totally unexpected because the frequency composition of the recorded sounds have more to do with the sound transmission characteristics of the aircraft than they do with the initiating event. Even though these test did tell us some properties of the sounds, they didn't help us determine what was the source of the "THUMPS" on the accident aircraft's CVR .

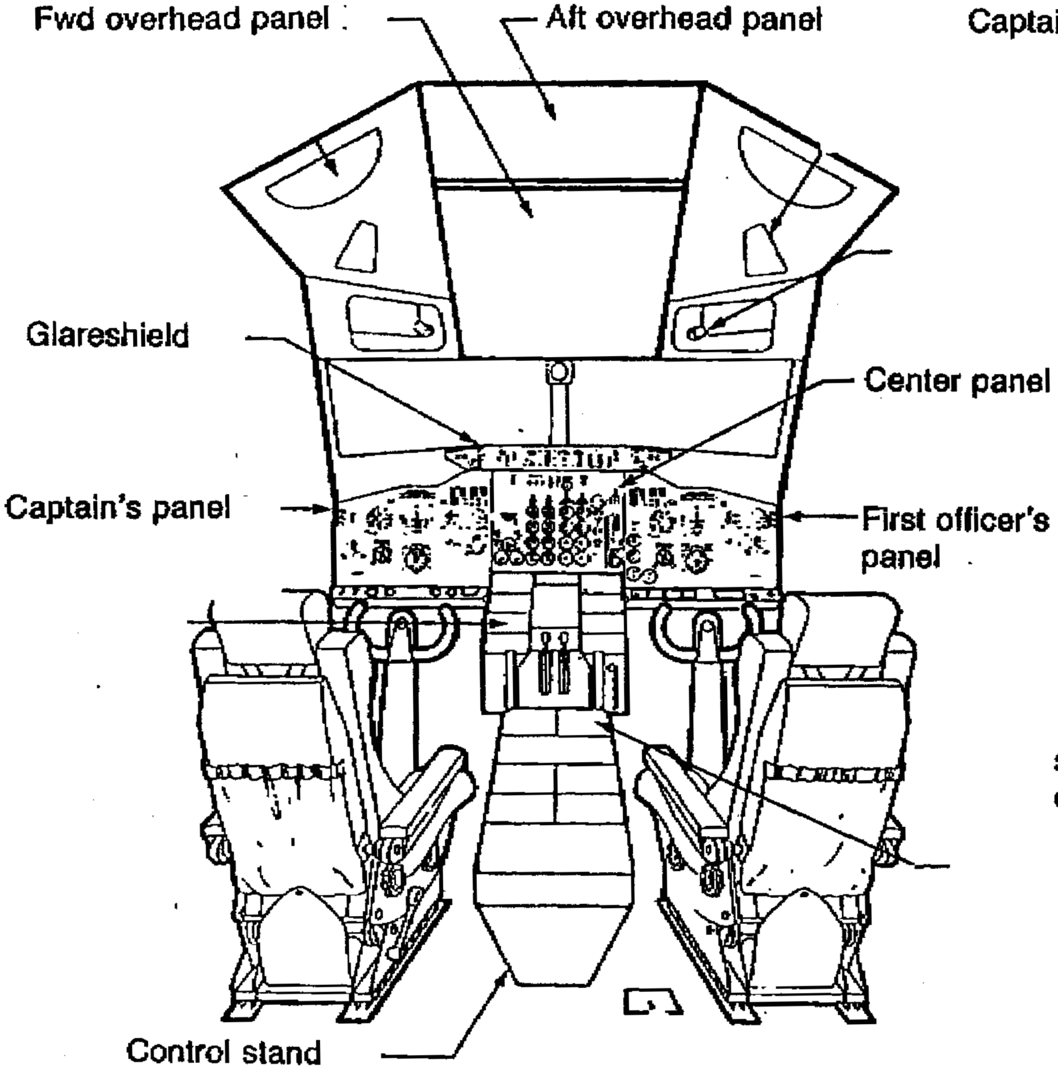
In the Fall of this year we conducted a controlled flight demonstration that involved flying a similar Boeing 737 aircraft in the wake turbulence of a Boeing 727 aircraft. This test was conducted to determine the characteristics and severity of the wake at various distances behind the 727 aircraft. There will be more testimony in this hearing explaining the wake test in greater detail so I won't take time to describing the details of the tests. During the flight demonstration cockpit sounds were recorded when the aircraft encountered the wake. **(show video tape of the wake)** The pilots reported on the first day that some of the wake encounters did make a distinct sound in the cockpit of the test aircraft. The sounds that they heard were reported as not being identical to those on the accident recording. When the cockpit recordings were heard after the flight, the wake encounter sounds sounded identical to the ones that were found on the accident aircraft. **(Show slide 6)**

This is due to the structure sounds being added to the air sounds that the crew heard , the CVR is recording both. We were able to calculate the approximate distance and direction of the wake encounter thumps. Most of the thumps documented to date originated 20 to 26 feet back from the area microphone. Again the frequency composition of the wake encounter sounds was very similar to the "THUMP" sounds heard on the accident CVR. The consensus by the spectrum committee was that the source of the

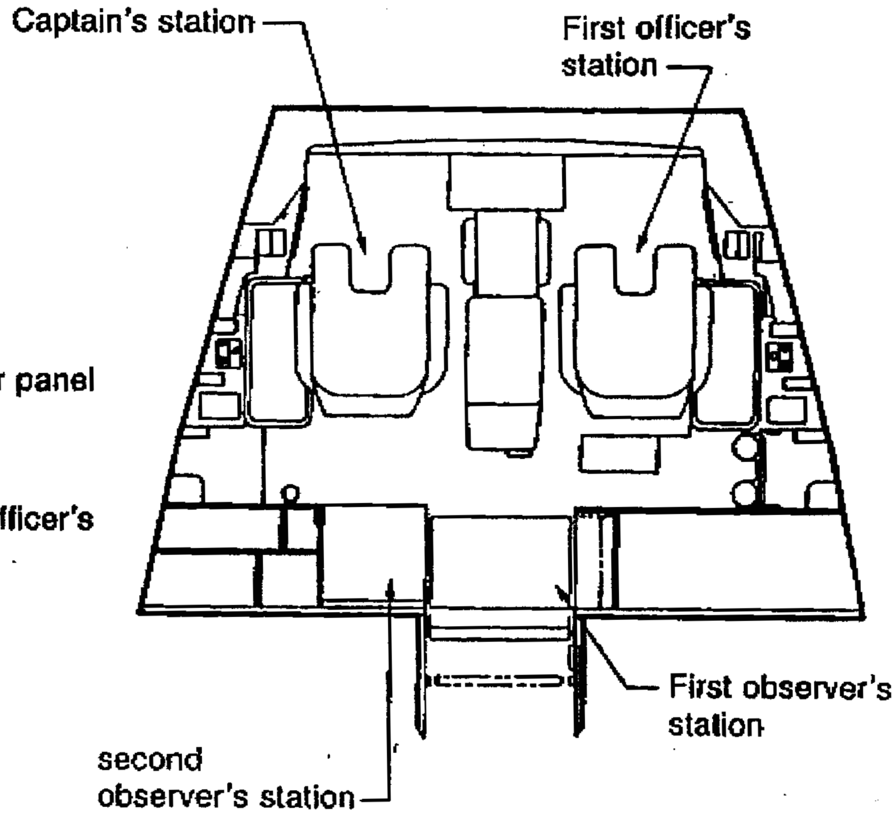
"THUMPS" on the accident aircraft's recording was most probably an encounter with the wake turbulence of the preceding 727 aircraft.

As I mentioned before we observed an unexplained increase in the amplitude of the noise that the engines were making on the accident aircraft. (Show slide 3) During our review of the audio data accumulated during the six days of the wake turbulence testing we noticed a similar change of the amplitude of the engine sounds during some of the test maneuvers. Some of these maneuvers were unrelated to the 727 wake turbulence encounters but were conducted to validate some of the flight characteristics of the Boeing 737 aircraft. Again the specifics of these maneuvers will be the subject of much discussion in the following days of this hearing. One of these maneuvers was called the steady heading slide slip test. This controlled test was accomplished by slowly inputting rudder while opposing the resulting yaw with opposite aileron to maintain a constant heading and level flight. These test were all conducted at a similar altitude, speed and configuration as the accident aircraft. During these tests using both left and right rudder, the engine sounds were noted as getting louder when a rudder input in the 7 to 14 degree range was made. This level of increase was very similar to the increase noted on the accident aircraft. (Show slide 7) I have plotted the corresponding increases in the amplitude of just the engine sounds over time. While the exact reason why the engine sounds increase as result of aircraft yaw is not fully understood the spectrum group did conclude that the sound signatures on the accident aircraft matched the engine sound signatures identified on the test aircraft with a rudder input of between 7 and 14 degrees.

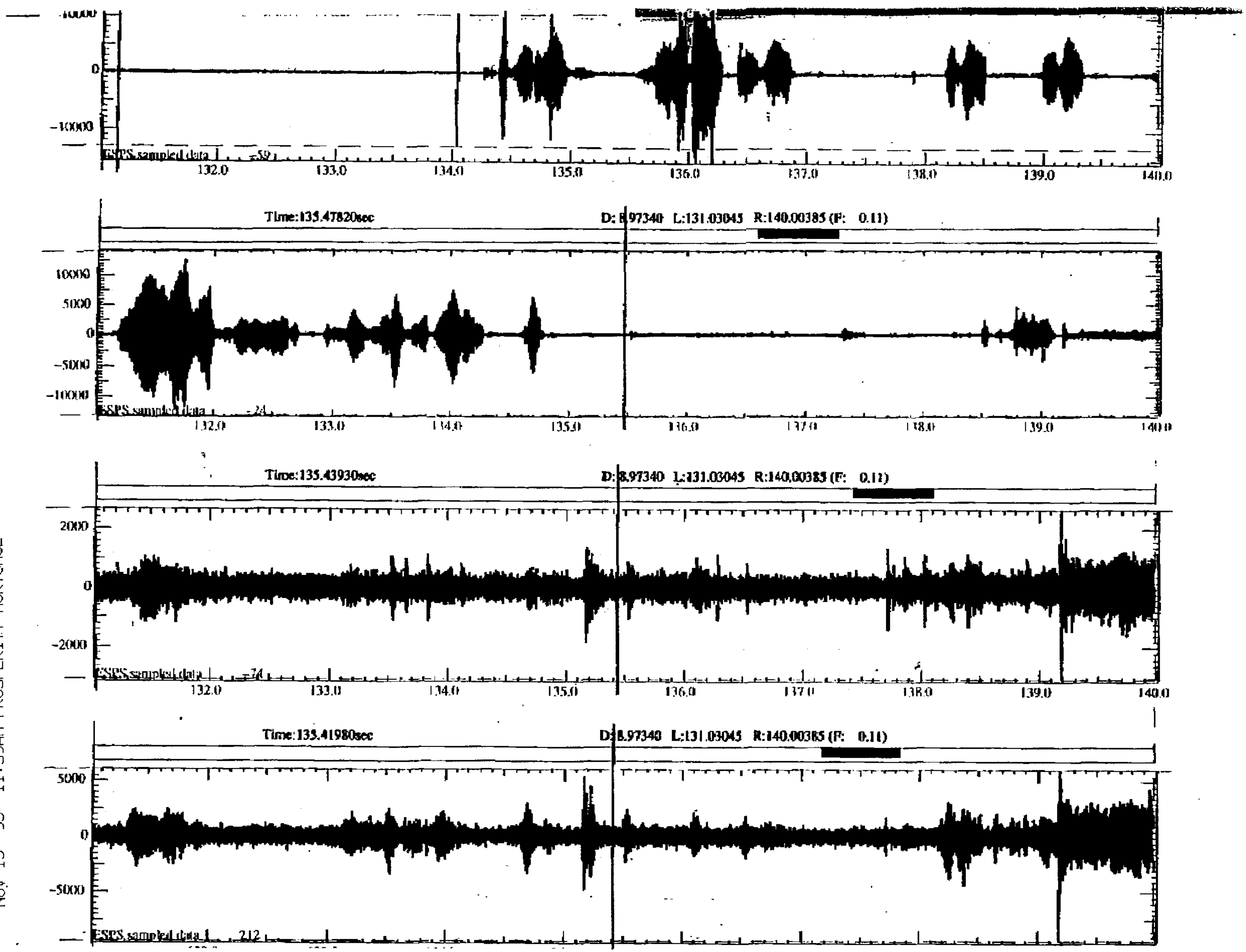
This concludes my presentation. While we have made some headway in finding out the origins of several of the unknown events on the CVR. Our work is not done, we still have further tests scheduled in conjunction with the other investigative groups to try to identify all of our unknown sounds on the accident recording CVR.



Looking Forward



Plan View



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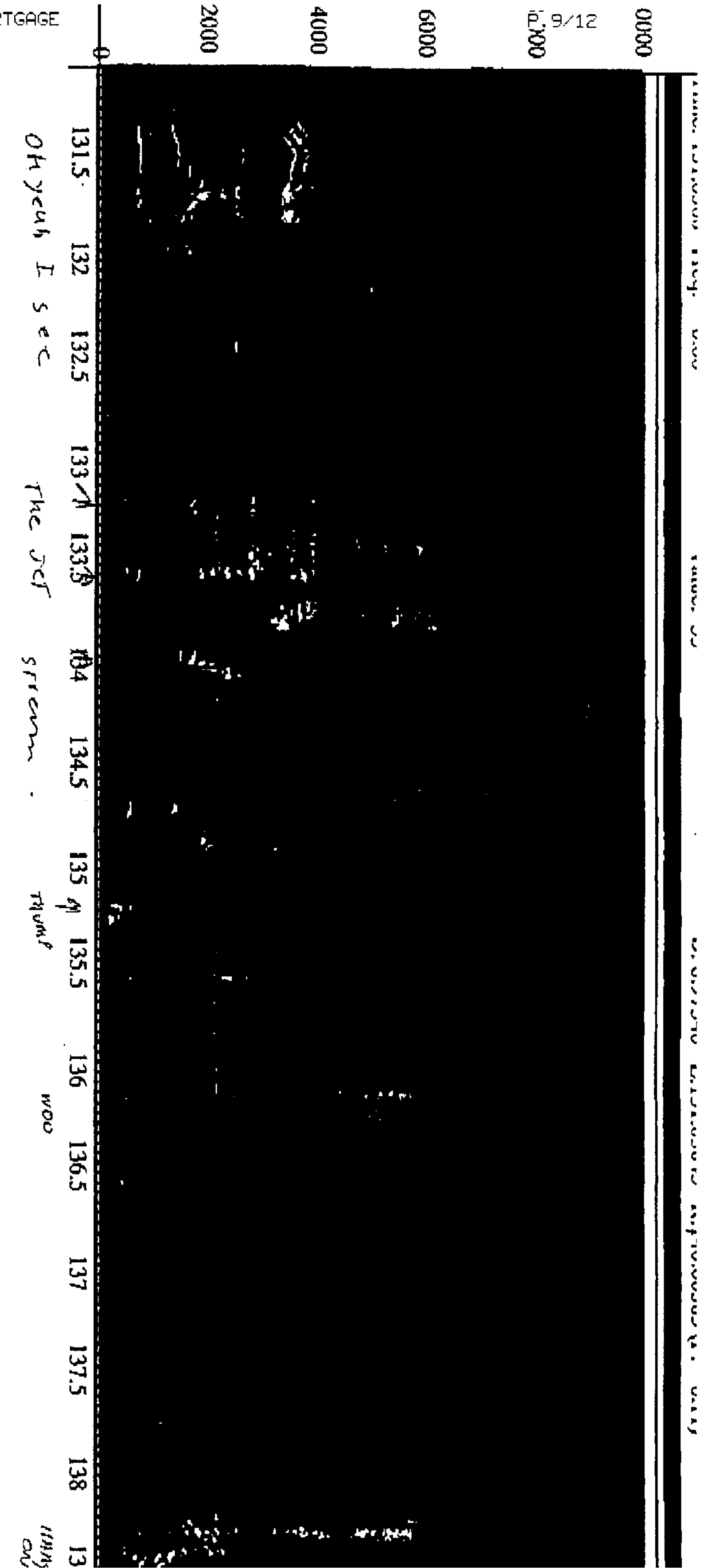
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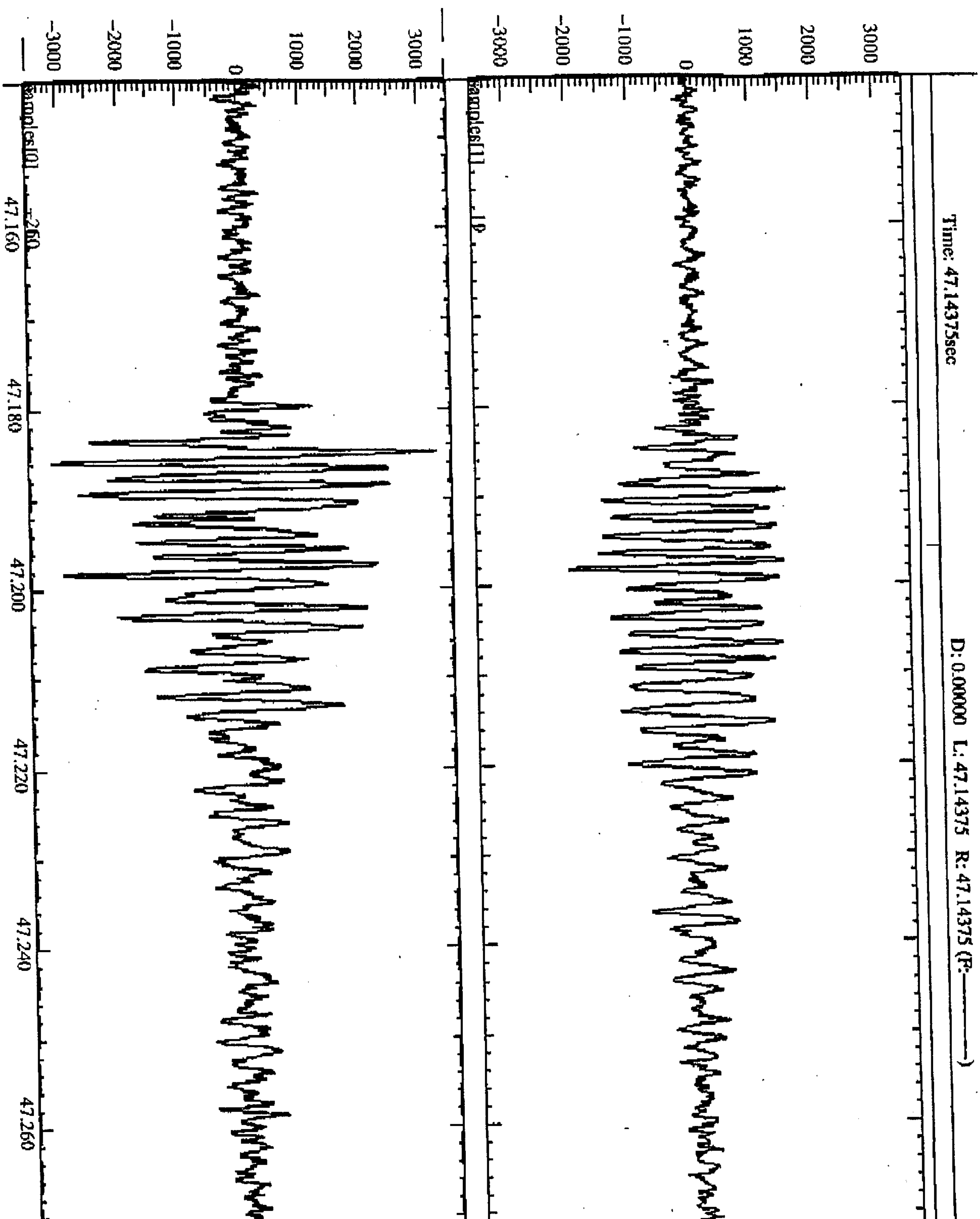
6000
131.5
132
132.5
133
133.5
134
134.5
135
135.5
136
136.5
137
137.5
138
Oh yeah I see
The JCT scream
thump
woo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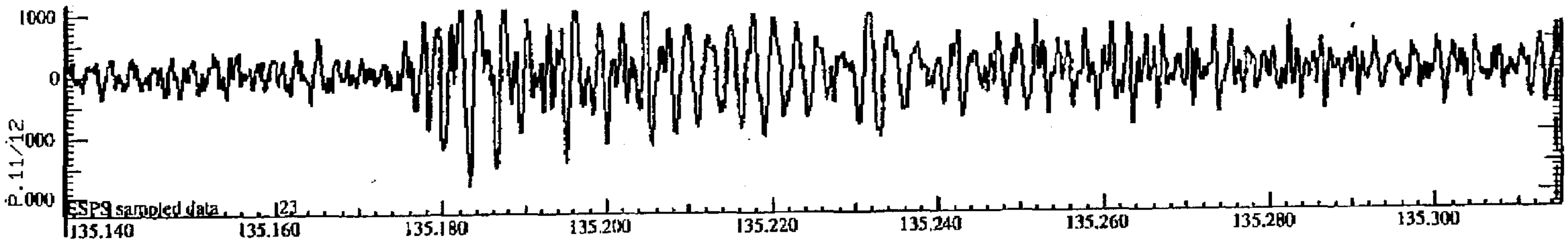
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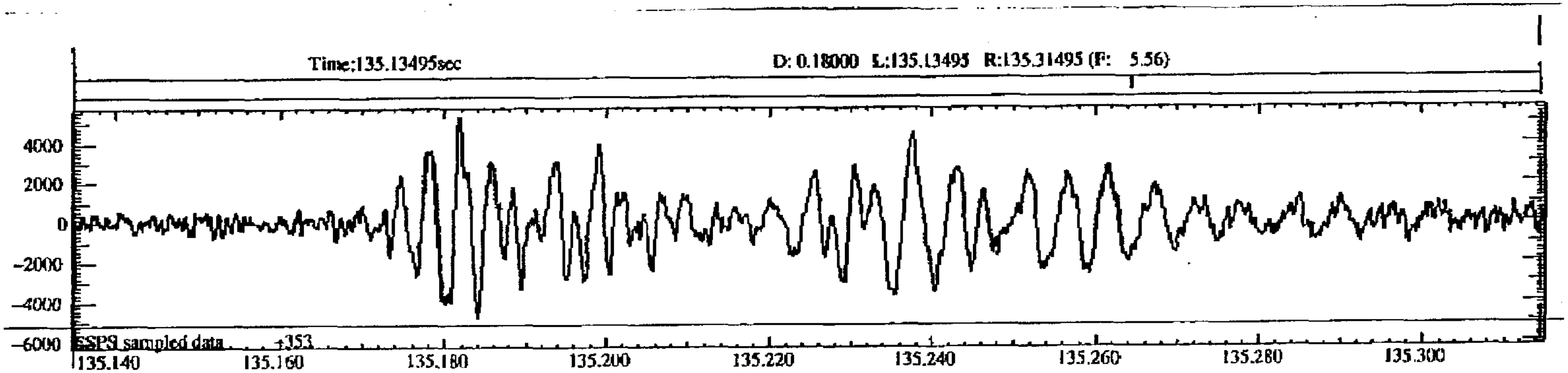
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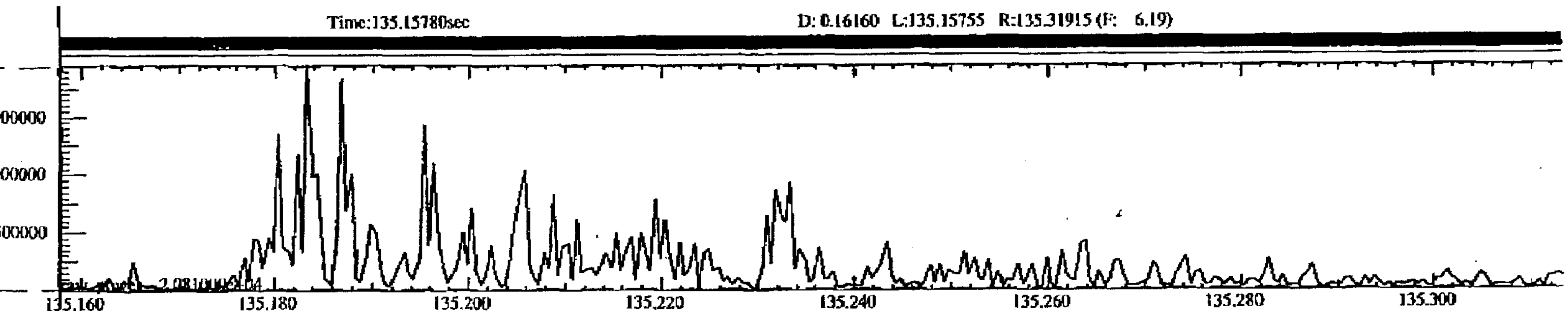
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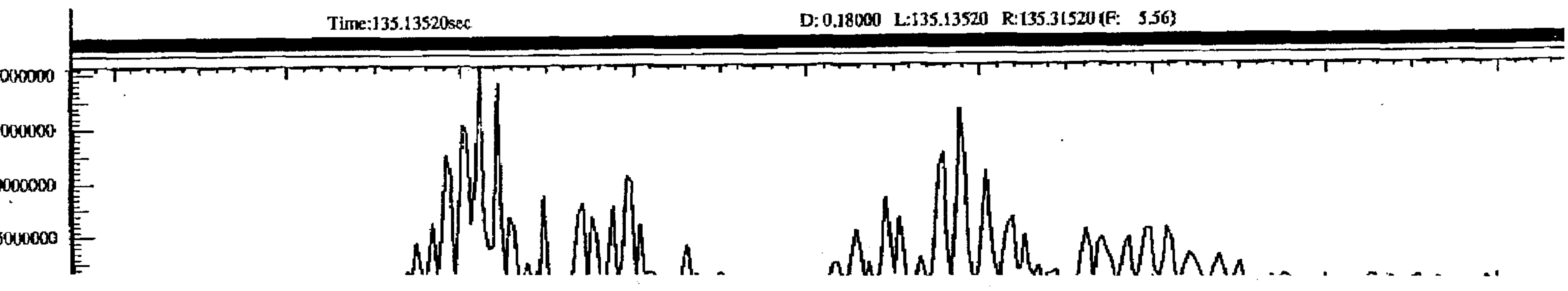
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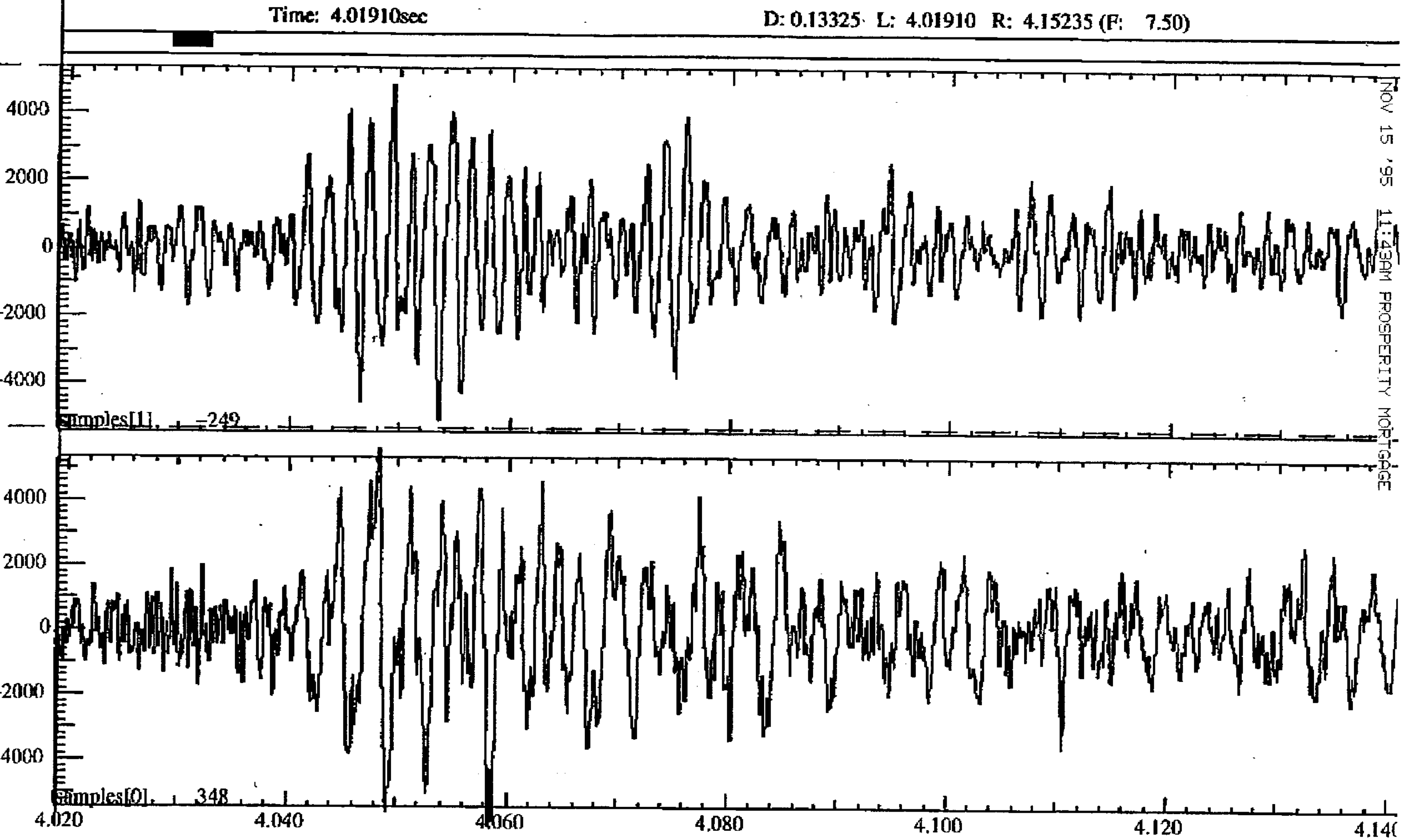
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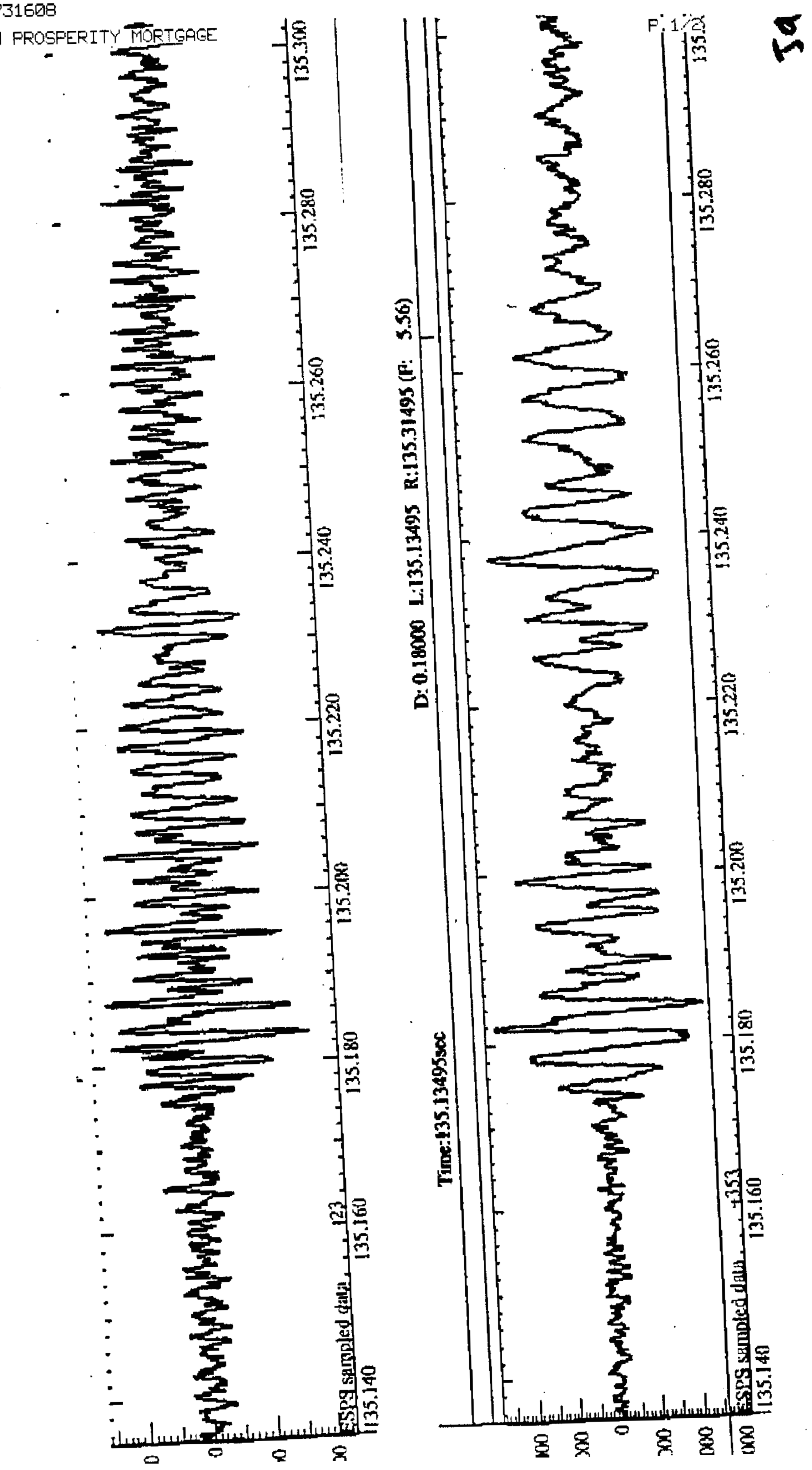
6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135.300
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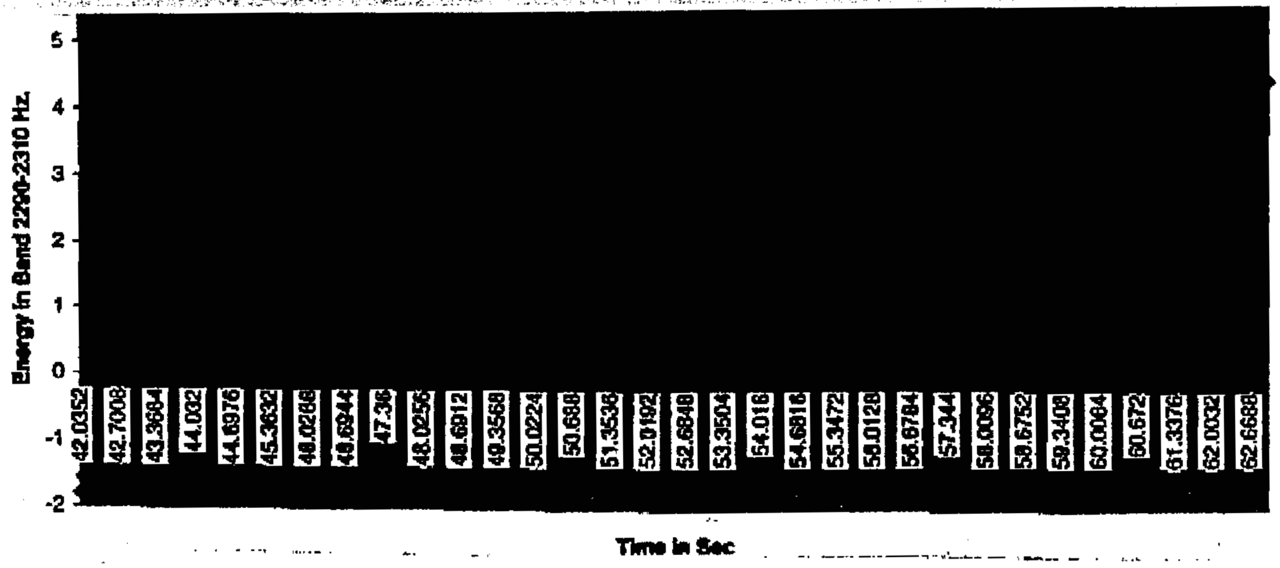
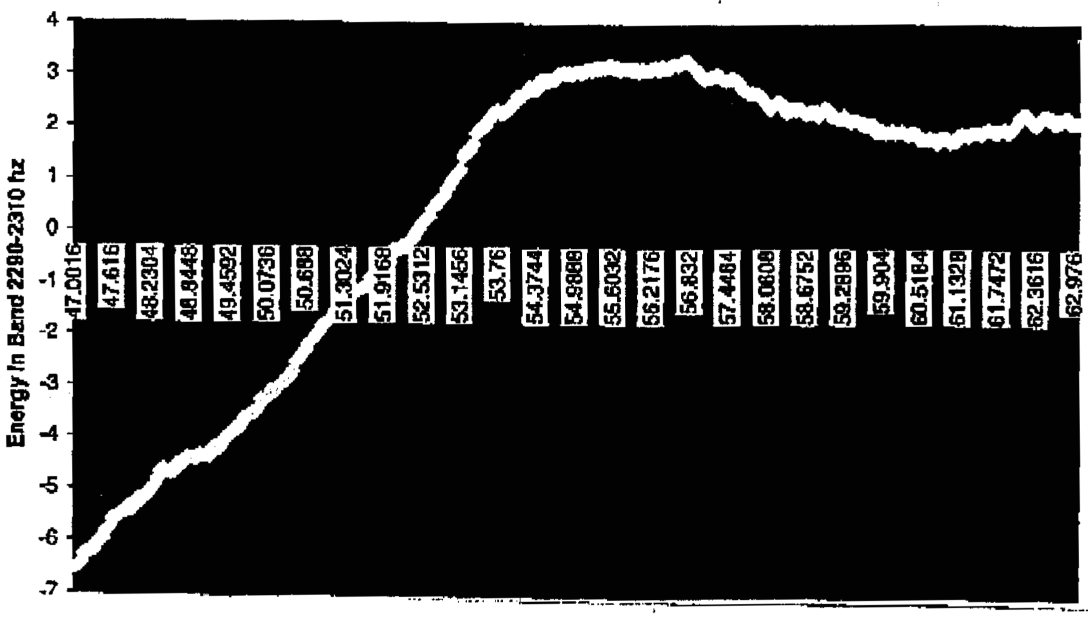
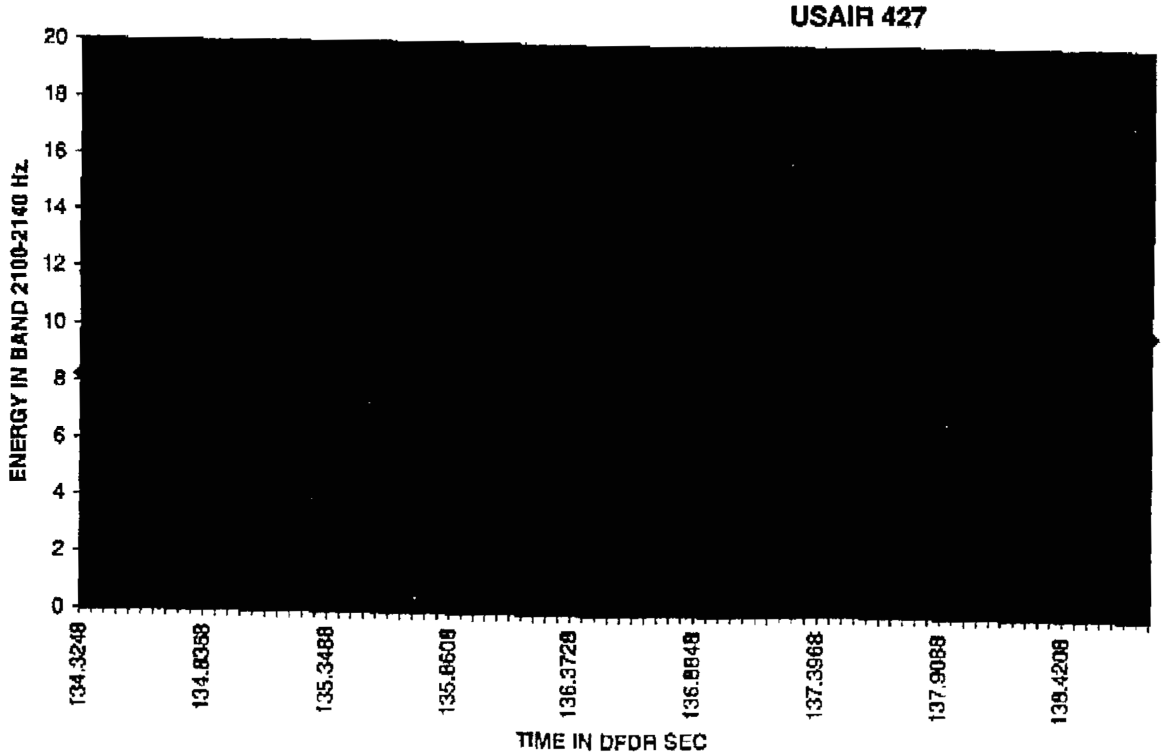
153
Ja



Condition 13.1



USAIR 427



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22. Autopilot engagement status**
23. Automatic Flight Control System (AFCS) modes and engagement status**
24. Outside or total air temperature**

(*) Indicates a new or changed parameter relative to the current 11-parameter requirement. (**) Indicates a new or changed parameter relative to the current 17-parameter requirement.

Notes:

1. Data shall be recorded within the range, resolution, accuracy and sampling intervals specified in EUROCAE Document ED-55, Chapter 3 and Annex 1, unless otherwise noted.

2. Each airplane type will need to be assessed to identify any novel or unique design or operational characteristics. It will then be necessary to ensure that sufficient dedicated parameters, appropriate to these characteristics, are recorded in addition to or in place of other parameters.

3. The flight recorder shall use a digital method of recording and storing the data and a method of readily retrieving those data from the storage medium. The data shall be obtained from sources within the aircraft that enable accurate correlation with data displayed to the flight crew, except when the flight deck displays are filtered or manipulated so as to produce values that do not meet the resolution and accuracy requirements for all phases of flight (for example, some EICAS flight control position display data).

National Transportation Safety Board
February 1995

Attachment B

Proposed FDR Enhancements for Newly Manufactured Airplanes

Acceleration Parameters:
Vertical
Lateral
Longitudinal

Airplane Performance/Position Parameters:
Altitude
Airspeed
Air/ground sensor (primary airplane systems reference, nose or main gear)
Brake pressure and pedal position
Drift angle (when an information source is installed)
Ground speed (when an information source is installed)
Wind speed and direction (when an information source is installed)
Outside air temperature or total air temperature
Radio altitude (when an information source is installed)
Latitude and longitude (when an information source is installed)

Airplane Attitude Parameters:
Angle of attack left and right (when an information source is installed)
Pitch
Roll
Magnetic heading
True heading (when an information source is installed, sampled 1 per 4 seconds)
Yaw or sideslip angle (when an information source is installed)*

Flight Controls Position and Input Parameters:
All control surface positions--primary controls (pitch, roll, and yaw)
All cockpit flight control input positions and forces (control wheel, control column, rudder pedal) (sidestick controllers on fly-by-wire systems)
All trim surface positions--primary controls** (pitch, roll, and yaw)

All cockpit trim control input positions--primary controls**
(pitch, roll, and yaw)
Thrust/power--primary flightcrew reference
(may require multiple parameters for all phases of flight)
Throttle/power lever position
Thrust reverser status (i.e., stow, transit, deployed, reverse pitch.)
Thrust command (when an information source is installed)
Thrust target (when an information source is installed)
Engine bleed valve position (when an information source is installed)

Airplane Configuration Parameters:
Flap position (trailing and leading edge)
Spoiler position (ground and speed brake)
Spoiler/speed brake cockpit selection/status (armed—ground spoiler)
Flap cockpit control selection
Landing gear position
Landing gear cockpit control selection
De-icing or anti-icing system selection
(when an information source is installed, sampled 1 per 4 seconds)
Fuel quantity in CG trim tank (when an information source is installed)
Computed center of gravity (when an information source is installed)
AC electrical bus status
DC electrical bus status
APU bleed valve position
Hydraulic pressure (all systems)

Navigation Aids:
Localizer deviation
Glideslope deviation
DME 1 and 2 distances
NAV 1 and 2 selected frequency
GPS position data (when an information source is installed)
Marker beacon passage

Autopilot Parameters:
Engagement status (all systems)
AFCS modes and engagement status

Timing:

Radio transmitter keying
UCT (when an information source is installed)
Recorder elapsed time (frame counter, 0 to 4095)
CVR/DFDR synchronization reference
(when an information source is installed)
Event marker

Warning Parameters:

GPWS
Hydraulic pressure low (each system)
Master warning
Loss of cabin pressure
TCAS--TA, RA, and sensitivity (as selected by crew)
Icing (when an information source is installed)
Engine warnings each engine--
Vibration (when an information source is installed)
Over temp. (when an information source is installed)
Oil pressure low (when an information source is installed)
Over speed (when an information source is installed)
Windshear (when an information source is installed)
Computer failure
Stick shacker/pusher (when an information source is installed)

Manual/Automatic Selected Parameters:

Selected barometric setting
Selected speed
Selected vertical speed
Selected heading
Selected flight path
Selected decision height
EFIS display format
Head-up display (when an information source is installed)
Para-visual display (when an information source is installed)
Multi-function/engine/alerts display format

(*) Range, as installed; accuracy, as installed; resolution, 0.3% of full range; sampling, 1 per second. (**) Range, full travel; accuracy, ± 3% unless higher accuracy uniquely required; resolution, 0.3% of full range; sampling, 1 per second.

)

Notes:

1. Data shall be recorded within the range, resolution, accuracy and sampling intervals specified in EUROCAE Document ED-55, Chapter 3 and Annex 1, unless otherwise noted.

2. Each airplane type will need to be assessed to identify any novel or unique design or operational characteristics. It will then be necessary to ensure that sufficient dedicated parameters, appropriate to these characteristics, are recorded in addition to or in place of other parameters.

3. The flight recorder shall use a digital method of recording and storing the data and a method of readily retrieving those data from the storage medium. The data shall be obtained from sources within the aircraft that enable accurate correlation with data displayed to the flightcrew, except when the flight deck displays are filtered or manipulated so as to produce values that do not meet the resolution and accuracy requirements for all phases of flight (for example, some EICAS flight control position display data).

National Transportation Safety Board
February 1995

2. Safety Recommendation A-95-28

National Transportation Safety Board
Washington, D.C. 20594

Safety Recommendation

Date: March 9, 1995
In reply refer to: A-95-28

To the operators of air carrier service under 14 CFR Part 121 and commuter air carrier service under 14 CFR Part 135 (see attached mailing list)

On September 8, 1994, a USAir Boeing 737-300, flight 427, was on a scheduled passenger flight from Chicago, Illinois, to Pittsburgh, Pennsylvania. During the approach to landing, the airplane suddenly rolled to the left and pitched nose down until it reached a nearly vertical attitude and struck the ground near Aliquippa, Pennsylvania. The airplane was destroyed; the 5 crewmembers and 127 passengers were fatally injured. The Safety Board's investigation of this accident is continuing, and the probable causes have not been determined.

On March 3, 1991, a United Airlines Boeing 737-291, flight 585, was on a scheduled passenger flight from Denver to Colorado Springs, Colorado. As the airplane was completing the turn to final approach, it rolled rapidly to the right and pitched nose down, reaching a nearly vertical attitude before it struck the ground. The airplane was destroyed; the five crewmembers and 20 passengers were fatally injured. In its report on this accident, the National Transportation Safety Board did not reach a determination of the probable cause.[1]

Both airplanes were equipped with a flight data recorder (FDR). In each case, however, the FDR did not provide needed information about airplane motion and flight control surface positions during the accident sequence.

[1] National Transportation Safety Board. 1992. United Airlines flight 585, Boeing 737-291, N999UA, Uncontrolled collision with terrain for undetermined reasons 4 miles south of Colorado Springs, Colorado, March 3, 1991. Aircraft Accident Report NTSB/AAR-92/06. Washington, DC.

In the Colorado Springs accident, five parameters--altitude, airspeed, heading, vertical acceleration, and microphone keying--were recorded by the FDR. Currently, regulations contained in Title 14 of the Code of Federal Regulations (14 CFR) Part 121.343 require these five parameters to be recorded by FDRs on airplanes that, like the airplane involved in the Colorado Springs accident, were type certificated prior to October 1, 1969, and were manufactured (received an individual certificate of airworthiness) prior to May 26, 1989.[2] The FDR of the airplane involved in the Colorado Springs accident did not record (nor was it required to record) other parameters critical to this accident investigation: airplane pitch and roll attitude; engine thrust values; lateral and longitudinal acceleration; control wheel position; rudder pedal position; and control surface positions, such as rudder, aileron, and spoiler.

In the Aliquippa accident, the accident airplane was the same type, a Boeing 737, but the airplane's FDR system had been retrofitted with six additional parameters, in anticipation of the 1995 deadline for these enhancements. However, the additional parameters did not include information on cockpit flight control inputs, flight control surface positions, lateral acceleration, or autopilot status, which has hampered the Board's continuing accident investigation. In a public hearing on the accident, conducted by the Safety Board in Pittsburgh, Pennsylvania, on January 23-27, 1995, witnesses from the FAA, aircraft manufacturers, and airlines agreed that additional FDR parameters would have assisted the Board in determining the probable cause of this accident.

Had the airplanes involved in the Colorado Springs and Aliquippa accidents been equipped with enhanced FDRs, information from the additional parameters would have allowed the Safety Board to quickly identify any abnormal control surface movements, configuration changes, or autopilot status changes that may have been involved in the loss of airplane control. Just as important, information from the additional parameters would have allowed the Board to rule out certain factors, if warranted, and to focus its investigations on other areas.

Information from FDRs with additional parameters substantially aided the Safety Board's investigations of two regional airline accidents that occurred during 1994. The first accident occurred on October 31, 1994, while an American Eagle ATR-72-210, flight 4184, was on a scheduled flight from Indianapolis, Indiana, to

[2] Part 121.343 requires that by May 26, 1995, large airplanes type certificated prior to October 1, 1969 (which would have included the airplanes involved in the Colorado Springs and Aliquippa accidents) must be equipped with FDRs that record 11 parameters. The additional parameters are longitudinal acceleration, pitch attitude, roll attitude, control column or pitch control surface position, and thrust of each engine (two thrust values for the Boeing 737). Part 121.343 also requires that airplanes type certificated after October 1, 1969 (regardless of the date of manufacture) and airplanes manufactured after May 26, 1989 (regardless of the date of type certification) must be equipped with FDRs that record 17 parameters. Airplanes manufactured after October 11, 1991 (regardless of the date of type certification) must be equipped with FDRs that record 31 parameters.

Chicago, Illinois. The flight had been placed in a holding pattern over Roselawn, Indiana, because of weather delays at O'Hare Airport. The flight was cleared to remain in the holding pattern and to descend from 10,000 to 8,000 feet. The airplane rolled to the right, entered a steep descent, and struck the ground; all 64 passengers and 4 crewmembers were fatally injured. The Safety Board's continuing investigation has not yet determined the probable cause of the accident; however, information from the enhanced FDR enabled the Safety Board to identify, within hours after receiving the recorder in its laboratories, the key events leading to the airplane's departure from controlled flight and the events during its final descent.

The ATR-72 was equipped with an FDR that recorded 98 parameters, including vane angle of attack (VAOA), aileron bellcrank position, flap position, aileron trim position, and autopilot engagement status. The FDR data showed that as the airplane was descending through 9,400 feet, the wing flaps began to retract and the airplane's VAOA increased. As the VAOA reached 5 degrees the autopilot disengaged, and within 1/4 second the ailerons deflected to near maximum travel in the right-wing-down direction. The FDR data also showed that the rolling moment was reversed when the VAOA was reduced to below 5 degrees, and the ailerons deflected in the left-wing-down direction. The right rolling moment recurred as the VAOA again increased to 5 degrees, and the ailerons deflected in the right-wing-down direction. Control of the airplane was not restored in time to prevent impact with the ground.

The data available from the ATR-72 FDR indicated to investigators that the airplane rolled as expected in response to aileron control surface movements, and that the aileron movements were correlated with increases in the airplane's angle of attack. As a result, the Safety Board was able to focus its efforts on possible explanations for the aileron control surface movements and, within days of the accident, the Board issued urgent safety recommendations to minimize the likelihood of similar occurrences in the future. As part of its continuing investigation, the Safety Board is also examining readouts from FDRs with expanded parameters from seven other ATR airplanes that have reportedly encountered flight control anomalies, three of which have shown important similarities to the accident flight.

The second accident involving an FDR with expanded parameters was one in which FDR data quickly moved the focus of the investigation from airplane systems to operations and human performance. On February 1, 1994, an American Eagle Saab 340B, flight 3641, was approaching Baton Rouge, Louisiana, on a scheduled passenger flight from Dallas/Fort Worth, Texas. As the airplane descended through 9,000 feet, both engines failed. The flightcrew executed a forced landing at False River Air Park in New Roads, Louisiana, during which the airplane sustained substantial damage. The flight attendant received minor injuries during the emergency evacuation. The 2 pilots and 23 passengers aboard were not injured.

The FDR installed on the Saab 340B recorded 128 parameters. FDR data showed that as the airplane descended through 9,040 feet, there was a rapid rise of both propellers' rotational speed well above the maximum allowable revolutions per minute. Because the FDR also was equipped to capture the positions of the engine power levers, the Safety Board was able to determine that at the same time the propeller speed increased, the power levers moved from the flight idle gate position to aft of the ground idle detents. The airplane's approved flight manual prohibits such power lever movements while in flight. This flightcrew action explained the propeller overspeed, which resulted in dual engine failure. With the expanded FDR data, the Safety Board was able to rule out alternative explanations for the propeller overspeed, including propeller systems failures that previously had affected similar propellers installed in another turboprop regional airliner.[3]

The importance of FDR data is not limited to investigations of catastrophic accidents. FDR data from incidents, which are less serious but occur more often, can provide to investigators and the aviation community critical information to help prevent accidents involving similar circumstances. Following the Colorado Springs and Aliquippa accidents, the Safety Board investigated 12 Boeing 737 incidents involving anomalous rudder activity or uncommanded roll oscillations. The FDRs aboard the incident airplanes, however, were not equipped to record flight control surface positions, flight control inputs, or lateral acceleration. Like 79 percent of all U.S.-registered Boeing 737s, the airplanes involved in the incidents were manufactured prior to May 26, 1989; consequently, they were required by current regulations to record only the five basic FDR parameters. As a result, critical, objective data were not available from the FDRs, and investigators had little more than the flightcrews' subjective recollections of these dynamic events.

In contrast to the investigations of these 12 Boeing 737 incidents, for which important FDR data were not available, investigations of other incidents have been greatly aided by the availability of enhanced recorded information. These incidents involved airplanes equipped with a digital data bus that transmits information from many sensors to the onboard recording devices.

On October 7, 1993, a British Airways Boeing 747-436 experienced a nose-down pitching moment immediately after departure from London Heathrow Airport. The captain avoided ground contact by exerting substantial back pressure on his control column. The incident was investigated by the United Kingdom's Air Accidents Investigation Branch (AAIB). Of the many parameters that were available on the airplane's digital data bus, recorded by a Quick Access Recorder (QAR)[4] and available to the FDR, several were useful in the AAIB's investigation. These parameters included the position of each of the four elevator control surfaces, control column

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[3] National Transportation Safety Board. 1992. Atlantic Southeast Airlines, Inc., flight 2311, Uncontrolled collision with terrain, an Embraer EMB-120, N270AS, Brunswick, Georgia, April 5, 1991. Aircraft Accident Report NTSB/AAR/92/03. Washington, DC.

[4] QARs and FDRs have similar data storage capabilities, but QARs, primarily intended for air carrier maintenance fault analysis, are not hardened to survive crash impact and fire conditions.

position, radar altitude, landing gear position, and hydraulic system pressure. By analyzing the information from the QAR, the AAIB established that "the upset was caused by the uncommanded pitch-down movement of both right-side elevators, coincident with landing gear retraction."[5] As a result of its investigation, the AAIB recommended that the FAA require modifications of Boeing 747 hydraulic systems and elevator power control units.

Between June and August 1993, Air France Boeing 737-300 airplanes experienced three rudder deflection anomalies. For each incident, about 206 flight data parameters were available to the French accident investigation authority, Bureau Enquetes Accidents (BEA). The data were recorded on QARs, and available parameters included control surface positions, flight path data, acceleration in three axes, yaw damper, and autopilot modes. The Safety Board is evaluating the data from these incidents for possible applicability to the Aliquippa or Colorado Springs accidents.

The data required to be recorded on FDRs have been based on the Safety Board's accident investigation experience and the capacity of the recording devices. Over the course of decades, many accidents investigated by the Board focused on wind shear, takeoff overruns, and instances of controlled flight into terrain; fewer accidents involved the inflight loss of lateral or directional control. In response, FDR parameter requirements focused on airplane performance (such as airspeed, altitude, and longitudinal acceleration) rather than on flight control (such as rudder position and trim settings). However, the recent accidents and incidents, discussed above, have demonstrated that more information about flight control parameters should be recorded by FDRs.

Among the additional flight control parameters that are needed are parameters that pertain to the positions of flight control inputs and flight control surfaces. Under current rules, airplanes fitted with conventional flight controls are permitted to record either the cockpit control input (such as control wheel position) or the control surface (such as the direction and amount of aileron deflection), if one can be derived from the other. But in its investigations of the recent Boeing 737 accidents, the Safety Board found that in some failure modes, flight control surface positions could move independently of cockpit flight control inputs. Also, under some conditions, additional information is needed by investigators to determine whether the controls on the flight deck caused the control surfaces to move, or vice versa. Consequently, FDRs should record both the flight control inputs and flight control surface positions.

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[5] U.K. Department of Transport, Air Accidents Investigation Branch. 1995. Report on the incident to Boeing 747-436, G-BNLY at London Heathrow Airport on 7 October 1993. Aircraft Accident Report 1/95. London, England.

Flight control trim information, including the positions of trim controls for roll and yaw, also has been essential during recent accident investigations. For example, the aileron and rudder trim parameters provided answers to critical questions early in the investigation of the Roselawn accident. The airplane involved had previously experienced trim anomalies; the FDR revealed none on the accident flight.

Recent technological changes have made feasible the acquisition and storage of large amounts of data on FDRs. Today, even for older airplanes, many FDR systems can record additional parameters because of unused capacity in the flight recording system. In terms of flight recording systems, there are two general categories of airplanes in the current air carrier fleet: analog airplanes, and airplanes equipped with a digital data bus.

On an analog airplane, information from remotely located data sensors (for example, a rudder position sensor located in the tail section) is transmitted to the FDR via dedicated wires in an analog format. The information is then converted to digital format in the FDR or the flight data acquisition unit (FDAU).

On an airplane equipped with a digital data bus, information is transmitted in digital format from a multitude of sensors, along a single, high capacity communications pathway (data bus). Information transmitted on the bus is provided to a number of systems, including flight management computers, cockpit displays, QARs, and FDRs. Additional data can readily be fed from the bus to the FDR, based on information that is already on the bus for other purposes or added to the bus by new sensors.

Upgrading FDRs with additional parameters would result in improved aviation safety. The Safety Board acknowledges, however, that retrofitting airplanes that are currently operating in air carrier service would necessitate a significant monetary investment, especially for analog airplanes.

The Safety Board obtained information about the cost of upgrading FDRs on analog airplanes from an air carrier trade group and an FDR equipment manufacturer. In a petition submitted to the FAA, the Air Transport Association (ATA) reported that to upgrade an FDR with six additional parameters would require a one-time expenditure of about $250,000 per airplane type for engineering specifications and the development of retrofit kits.[6] These one-time costs would be spread over all of the individual airplanes of each type that are retrofitted; that is, if there are 500 airplanes in service, the cost for basic engineering would be $500 per airplane. Additional expenditures would be required for labor and equipment to upgrade each individual airplane; an ATA member survey stated that the installed

[6] Letter of June 5, 1992, to the FAA Office of General Counsel Rules Docket, from Joseph D. Vreeman, Vice President of Engineering, Maintenance, and Materiel, Air Transport Association.

equipment cost for a six-parameter upgrade would total between $20,000 and $40,000 per individual airplane.[7]

The Safety Board also obtained estimates of installed equipment cost to upgrade an FDR to record the parameters listed in "Proposed Minimum FDR Parameter Requirements for Airplanes in Service" (attachment A to this letter). The information was provided by an FDAU manufacturer and an FDR manufacturer.

The FDAU manufacturer estimates that retrofitting an analog airplane could cost about $20,000 to $30,000. This estimate includes about $1,000 per additional parameter ($200 to $400 of which is for sensors; the remainder is for associated wiring and labor). The FDR manufacturer estimates that to record the parameters listed in attachment A, many airplanes may require the use of an FDAU, which could cost an additional $15,000 to $20,000 for each airplane not already so equipped. Based on the various estimates, it appears that retrofitting an analog airplane to record the parameters listed in attachment A could cost between $25,000 and $70,000.

Retrofitting an airplane equipped with an ARINC 429 digital data bus or equivalent (such as the Boeing 757 and 767) to record, as a minimum, the parameters listed in attachment A would be less expensive. Most wiring changes would be confined to the electronic equipment compartment, and some reprogramming of the digital FDAU would be required. All of the airplanes would require the addition of flight control surface position sensors. Some airplanes that were manufactured on or before October 11, 1991, may also require additional sensors.

During the public hearing on the Aliquippa accident, a major U.S. air carrier expressed concern about the costs of upgrading FDRs on the carrier's fleet. The Safety Board recognizes that enhanced FDR capability needs to be weighed against the costs. However, the Board also believes that the costs should be balanced against the remaining useful life and revenue-earning potential of an airplane. Using an upper-bound retrofit cost of $70,000 per airplane and reasonable assumptions about airplane utilization,[8] the Safety Board estimates the cost of retrofitting an airplane in current service with an enhanced FDR to be less than 7¢ per passenger.

The Safety Board believes that public safety outweighs the 7¢-per-passenger cost of equipping older airplanes to record more FDR parameters, especially if the retrofit program is limited to airplane types that remain in production (including

[7] Summarized by the FAA in its Notice of Proposed Rulemaking on extension of the compliance date for installation of digital FDRs on Stage 2 airplanes, Federal Register (Vol. 59, No. 36), p. 8573.

[8] Assumptions are as follows: average seating capacity of 150 passengers, 3 departures per day, a 65-percent passenger load factor, and a useful life of 10 years.

derivative models[9]). According to information provided by the FAA to the Safety Board,[10] the U.S. register currently lists about 2,000 transport category airplanes (such as DC-9s, B-737s, and F-28s) that were type certificated before October 1, 1969. These types are still in production (including derivatives, such as MD-80s, B-737-400s, and F-100s), and most of these airplanes use the analog method of data acquisition and transmission.

The Safety Board believes that transport category airplanes of a type that is still in production and operated under 14 CFR Parts 121, 125, or 135 should be retrofitted with the sensors and FDAU needed to record, as a minimum, the parameters listed in attachment A. Further, these airplanes should continue to record the FDR parameters required by current regulations applicable to each airplane (based on its dates of certification and manufacture). Although Boeing 727 and Lockheed L-1011 airplanes are not currently in production, nearly 800 airplanes of these types are expected to remain in the U.S. airline fleet by the end of the 1990s.[11] Accordingly, the Safety Board believes that these airplanes should also be retrofitted to record on FDRs, as a minimum, the parameters listed in attachment A.

To ensure that individual airplanes have a substantial useful life over which to recoup the cost of FDR enhancement, the Safety Board believes that the retrofit should apply only to airplanes (except for Boeing 737s, which are addressed later in this letter) that comply with Stage 3 noise requirements,[12] or that remain in service after December 31, 1999, by receiving a waiver or exemption from Stage 3 noise requirements. This criterion would apply the FDR enhancements only to individual airplanes that have the opportunity to operate well into the next decade.

The Safety Board believes that the FAA should complete its rulemaking on FDR enhancements by December 31, 1995. Further, the FAA should require all operators of transport category airplanes under 14 CFR Parts 121, 125, or 135 to complete the FDR enhancements by January 1, 1998. Airplanes that do not currently comply with Stage 3 noise requirements should be retrofitted with these FDR enhancements by January 1, 1998, or by the later date when they meet Stage 3 noise requirements but, regardless of Stage 3 compliance status, no later than December 31, 1999.

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[9] Derivative models are updated versions of older airplane types that continue to use the original FAA aircraft type certificate. Examples include the McDonnell Douglas MD-80 series, based on the DC-9, and the Fokker F-100, based on the F-28.

[10] Letter of December 14, 1994, from FAA Administrator David R. Hinson to Safety Board Chairman Jim Hall.

[11] Derived from information in the letter of December 14, 1994, from FAA Administrator Hinson.

[12] According to 14 CFR 91.853, all airplanes will be required to meet Stage 3 noise requirements by December 31, 1999.

With regard to Boeing 737 airplanes, which account for about 23 percent of the U.S. air carrier fleet, the Safety Board believes that FDR enhancement is needed sooner. Data from enhanced FDRs play a vital role in helping to prevent accidents through information they provide about incidents.[13] During the public hearing on the Aliquippa accident, the Boeing Commercial Airplane Group indicated that it had records of 187 flight control incidents involving Boeing 737s that occurred between 1970 and 1994. Of the 187 incidents, 35 occurred in 1993 and 1994. Because the Boeing 737 will be used for years to come, it is essential that the airplanes involved in future incidents be equipped with enhanced FDRs. Consequently, the Safety Board believes that the FAA should require that all Boeing 737 airplanes operated under 14 CFR Parts 121 and 125, regardless of Stage 3 compliance status, be equipped, by December 31, 1995, with FDRs that record, as a minimum, the parameters required by current regulations plus the following parameters (recorded at the sampling rates specified in attachment A): lateral acceleration; flight control inputs for pitch, roll, and yaw; and primary flight control surface positions for pitch, roll, and yaw.

According to information provided to the Safety Board by the FAA,[14] as many as 1,000 Boeing 737 airplanes would be affected by the retrofit. The additional parameters could, in most cases, be accommodated by the currently installed FDR and FDAU systems. As a result, the Safety Board estimates that the cost to add these parameters would total between $10,000 and $20,000 per airplane.

In the ATR-72 and Saab-340B accidents, the traveling public benefited from earlier corporate decisions by Avions de Transport Regional (ATR), Saab Aircraft AB, and AMR Corporation/American Eagle to equip the airplanes with FDRs that record more parameters than are currently required by the Federal Aviation Regulations. American Eagle also has taken the initiative to retrofit its 19-seat, British Aerospace Jetstream airplanes with enhanced FDRs. In the Safety Board's opinion, the leadership role taken by these companies should be followed by others in the aircraft manufacturing and air carrier industries. Because the Board recognizes that regulatory change is not accomplished as quickly as action taken by individual companies, the Safety Board believes that the operators of transport category airplanes currently in service under 14 CFR Parts 121 and 135 should voluntarily modify FDRs installed on their airplanes to record, as a minimum, the parameters listed in attachment A plus the parameters that are currently required by the regulations applicable to each airplane.

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[13] In addition to the role that enhanced FDR data can play in accident and incident investigations, the data will be of great assistance to air carriers' Flight Operations Quality Assurance (FOQA) programs. FOQA is a proactive, accident prevention program that involves the analysis of data collected during normal flights, for the purpose of enhancing the safety of flight operations. The Safety Board joins the FAA, the Department of Transportation, and many industry representatives in supporting the development of FOQA programs.

[14] Letter of December 14, 1994, from FAA Administrator Hinson.

Most newly manufactured airplanes used in air carrier service are routinely equipped with digital data buses that carry information on hundreds of parameters. Also, the current state of the art in solid-state memory devices has lifted the previous constraints on the number of parameters that FDRs can record. Consequently, the cost of adding FDR parameters usually will be minimal if the parameters are specified before the airplane is built.

The Safety Board's accident investigation experience in recent years indicates that the FDR parameter requirements for newly manufactured airplanes need to be expanded further. The Board believes that the required FDR parameters for newly manufactured airplanes should include those proposed in EUROCAE Document ED-55[15] plus additional parameters such as flight control input and surface positions. Accordingly, the Safety Board believes that the FAA should require that all airplanes operated under 14 CFR Parts 121, 125, or 135 (10 seats or larger) for which an original airworthiness certificate is issued after December 31, 1996, be equipped with FDRs that record the parameters listed in "Proposed FDR Enhancements for Newly Manufactured Airplanes" (attachment B to this letter). Also, the Safety Board believes that because available technology now permits all FDRs to record at least 25 hours of data, all FDRs installed on these newly manufactured airplanes should have this recording capacity after December 31, 1996.

Because aircraft manufacturers can react more quickly than regulatory requirements can be changed, the Safety Board also believes that the manufacturers should establish, for all newly manufactured airplanes that will be operated under 14 CFR Parts 121, 125, or 135 (10 seats or larger), a minimum standard for recording FDR parameters in accordance with attachment B.

Air travelers and the air carrier industry cannot afford additional unresolved accidents. The Safety Board will continue its efforts to identify the probable cause of the accidents at Colorado Springs and Aliquippa, but enhanced FDR data are essential to help prevent future accidents.

Therefore, the National Transportation Safety Board recommends that the operators of air carrier service under 14 CFR Part 121 and commuter air carrier service under 14 CFR Part 135:

> Ensure that the flight data recorders installed on transport category airplanes used in air carrier and commuter air carrier service record, as a minimum, the parameters listed in "Proposed Minimum FDR Parameter Requirements for Airplanes in Service" plus other parameters required by current regulations applicable to each airplane. (Class II, Priority Action) (A-95-28)

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[15] European Organisation For Civil Aviation Equipment [EUROCAE]. May 1990. Minimum Operational Performance Specification For Flight Data Recorder Systems (ED-55). Paris, France.

Recommendations were also issued to the Federal Aviation Administration and to the manufacturers of airplanes operated under Parts 121, 125, or 135.

The National Transportation Safety Board is an independent Federal agency with the statutory responsibility "...to promote transportation safety by conducting independent accident investigations and by formulating safety improvement recommendations" (Public Law 93-633). The Safety Board is vitally interested in any actions taken as a result of its safety recommendations and would appreciate a response from you regarding action taken or contemplated with respect to the recommendation in this letter. Please refer to Safety Recommendation A-95-28 in your reply.

Chairman HALL, Vice Chairman FRANCIS, and Member HAMMERSCHMIDT concurred in this recommendation.

By: Jim Hall
Chairman

Enclosures

Attachment A

Proposed Minimum FDR Parameter Requirements for Airplanes in Service

Proposed Minimum Parameters:

1. Altitude
2. Airspeed
3. Vertical acceleration
4. Heading
5. Time of each radio transmission to air traffic control
6. Pitch attitude
7. Roll attitude
8. Longitudinal acceleration
9. Pitch trim position*
10. Yaw trim position**
11. Roll trim position**
12. Control column and pitch control surface position**
13. Control wheel and lateral control surface position**
14. Rudder pedal and yaw control surface position**
15. Thrust of each engine
16. Position of each thrust reverser (or equivalent for propeller airplane)*
17. Trailing edge flap or cockpit flap control position*
18. Leading edge flap or cockpit flap control position*
19. Ground spoiler position/speed brake selection**
20. Angle of attack (when information source is available)**
21. Lateral acceleration**

22. Autopilot engagement status**

23. Automatic Flight Control System (AFCS) modes and engagement status**

24. Outside or total air temperature**

(*) Indicates a new or changed parameter relative to the current 11-parameter requirement. (**) Indicates a new or changed parameter relative to the current 17-parameter requirement.

Notes:

1. Data shall be recorded within the range, resolution, accuracy and sampling intervals specified in EUROCAE Document ED-55, Chapter 3 and Annex 1, unless otherwise noted.

2. Each airplane type will need to be assessed to identify any novel or unique design or operational characteristics. It will then be necessary to ensure that sufficient dedicated parameters, appropriate to these characteristics, are recorded in addition to or in place of other parameters.

3. The flight recorder shall use a digital method of recording and storing the data and a method of readily retrieving those data from the storage medium. The data shall be obtained from sources within the aircraft that enable accurate correlation with data displayed to the flight crew, except when the flight deck displays are filtered or manipulated so as to produce values that do not meet the resolution and accuracy requirements for all phases of flight (for example, some EICAS flight control position display data).

National Transportation Safety Board
February 1995

Attachment B

Proposed FDR Enhancements for Newly Manufactured Airplanes

Acceleration Parameters:
- Vertical
- Lateral
- Longitudinal

Airplane Performance/Position Parameters:
- Altitude
- Airspeed
- Air/ground sensor (primary airplane systems reference, nose or main gear)
- Brake pressure and pedal position
- Drift angle (when an information source is installed)
- Ground speed (when an information source is installed)
- Wind speed and direction (when an information source is installed)
- Outside air temperature or total air temperature
- Radio altitude (when an information source is installed)
- Latitude and longitude (when an information source is installed)

Airplane Attitude Parameters:
- Angle of attack left and right (when an information source is installed)
- Pitch
- Roll
- Magnetic heading
- True heading (when an information source is installed, sampled 1 per 4 seconds)
- Yaw or sideslip angle (when an information source is installed)*

Flight Controls Position and Input Parameters:
- All control surface positions--primary controls (pitch, roll, and yaw)
- All cockpit flight control input positions and forces (control wheel, control column, rudder pedal) (sidestick controllers on fly-by-wire systems)
- All trim surface positions--primary controls** (pitch, roll, and yaw)

All cockpit trim control input positions--primary controls**
(pitch, roll, and yaw)
Thrust/power--primary flightcrew reference
(may require multiple parameters for all phases of flight)
Throttle/power lever position
Thrust reverser status (i.e., stow, transit, deployed, reverse pitch.)
Thrust command (when an information source is installed)
Thrust target (when an information source is installed)
Engine bleed valve position (when an information source is installed)

Airplane Configuration Parameters:
Flap position (trailing and leading edge)
Spoiler position (ground and speed brake)
Spoiler/speed brake cockpit selection/status (armed--ground spoiler)
Flap cockpit control selection
Landing gear position
Landing gear cockpit control selection
De-icing or anti-icing system selection
(when an information source is installed, sampled 1 per 4 seconds)
Fuel quantity in CG trim tank (when an information source is installed)
Computed center of gravity (when an information source is installed)
AC electrical bus status
DC electrical bus status
APU bleed valve position
Hydraulic pressure (all systems)

Navigation Aids:
Localizer deviation
Glideslope deviation
DME 1 and 2 distances
NAV 1 and 2 selected frequency
GPS position data (when an information source is installed)
Marker beacon passage

Autopilot Parameters:
Engagement status (all systems)
AFCS modes and engagement status

Timing:

Radio transmitter keying
UCT (when an information source is installed)
Recorder elapsed time (frame counter, 0 to 4095)
CVR/DFDR synchronization reference
(when an information source is installed)
Event marker

Warning Parameters:

GPWS
Hydraulic pressure low (each system)
Master warning
Loss of cabin pressure
TCAS--TA, RA, and sensitivity (as selected by crew)
Icing (when an information source is installed)
Engine warnings each engine--
Vibration (when an information source is installed)
Over temp. (when an information source is installed)
Oil pressure low (when an information source is installed)
Over speed (when an information source is installed)
Windshear (when an information source is installed)
Computer failure
Stick shacker/pusher (when an information source is installed)

Manual/Automatic Selected Parameters:

Selected barometric setting
Selected speed
Selected vertical speed
Selected heading
Selected flight path
Selected decision height
EFIS display format
Head-up display (when an information source is installed)
Para-visual display (when an information source is installed)
Multi-function/engine/alerts display format

(*) Range, as installed; accuracy, as installed; resolution, 0.3% of full range; sampling, 1 per second. (**) Range, full travel; accuracy, ± 3% unless higher accuracy uniquely required; resolution, 0.3% of full range; sampling, 1 per second.

Notes:

1. Data shall be recorded within the range, resolution, accuracy and sampling intervals specified in EUROCAE Document ED-55, Chapter 3 and Annex 1, unless otherwise noted.

2. Each airplane type will need to be assessed to identify any novel or unique design or operational characteristics. It will then be necessary to ensure that sufficient dedicated parameters, appropriate to these characteristics, are recorded in addition to or in place of other parameters.

3. The flight recorder shall use a digital method of recording and storing the data and a method of readily retrieving those data from the storage medium. The data shall be obtained from sources within the aircraft that enable accurate correlation with data displayed to the flightcrew, except when the flight deck displays are filtered or manipulated so as to produce values that do not meet the resolution and accuracy requirements for all phases of flight (for example, some EICAS flight control position display data).

National Transportation Safety Board
February 1995

3. Safety Recommendation A-95-29

National Transportation Safety Board
Washington, D.C. 20594

Safety Recommendation

Date: March 9, 1995
In reply refer to: A-95-29

To the manufacturers of airplanes
operated under 14 CFR Parts 121, 125, or 135
(see attached mailing list)

On September 8, 1994, a USAir Boeing 737-300, flight 427, was on a scheduled passenger flight from Chicago, Illinois, to Pittsburgh, Pennsylvania. During the approach to landing, the airplane suddenly rolled to the left and pitched nose down until it reached a nearly vertical attitude and struck the ground near Aliquippa, Pennsylvania. The airplane was destroyed; the 5 crewmembers and 127 passengers were fatally injured. The Safety Board's investigation of this accident is continuing, and the probable causes have not been determined.

On March 3, 1991, a United Airlines Boeing 737-291, flight 585, was on a scheduled passenger flight from Denver to Colorado Springs, Colorado. As the airplane was completing the turn to final approach, it rolled rapidly to the right and pitched nose down, reaching a nearly vertical attitude before it struck the ground. The airplane was destroyed; the five crewmembers and 20 passengers were fatally injured. In its report on this accident, the National Transportation Safety Board did not reach a determination of the probable cause.[1]

Both airplanes were equipped with a flight data recorder (FDR). In each case, however, the FDR did not provide needed information about airplane motion and flight control surface positions during the accident sequence.

[1] National Transportation Safety Board. 1992. United Airlines flight 585, Boeing 737-291, N999UA, *Uncontrolled collision with terrain for undetermined reasons 4 miles south of Colorado Springs, Colorado, March 3, 1991.* Aircraft Accident Report NTSB/AAR-92/06. Washington, DC.

In the Colorado Springs accident, five parameters--altitude, airspeed, heading, vertical acceleration, and microphone keying--were recorded by the FDR. Currently, regulations contained in Title 14 of the Code of Federal Regulations (14 CFR) Part 121.343 require these five parameters to be recorded by FDRs on airplanes that, like the airplane involved in the Colorado Springs accident, were type certificated prior to October 1, 1969, and were manufactured (received an individual certificate of airworthiness) prior to May 26, 1989.[2] The FDR of the airplane involved in the Colorado Springs accident did not record (nor was it required to record) other parameters critical to this accident investigation: airplane pitch and roll attitude; engine thrust values; lateral and longitudinal acceleration; control wheel position; rudder pedal position; and control surface positions, such as rudder, aileron, and spoiler.

In the Aliquippa accident, the accident airplane was the same type, a Boeing 737, but the airplane's FDR system had been retrofitted with six additional parameters, in anticipation of the 1995 deadline for these enhancements. However, the additional parameters did not include information on cockpit flight control inputs, flight control surface positions, lateral acceleration, or autopilot status, which has hampered the Board's continuing accident investigation. In a public hearing on the accident, conducted by the Safety Board in Pittsburgh, Pennsylvania, on January 23-27, 1995, witnesses from the FAA, aircraft manufacturers, and airlines agreed that additional FDR parameters would have assisted the Board in determining the probable cause of this accident.

Had the airplanes involved in the Colorado Springs and Aliquippa accidents been equipped with enhanced FDRs, information from the additional parameters would have allowed the Safety Board to quickly identify any abnormal control surface movements, configuration changes, or autopilot status changes that may have been involved in the loss of airplane control. Just as important, information from the additional parameters would have allowed the Board to rule out certain factors, if warranted, and to focus its investigations on other areas.

Information from FDRs with additional parameters substantially aided the Safety Board's investigations of two regional airline accidents that occurred during 1994. The first accident occurred on October 31, 1994, while an American Eagle ATR-72-210, flight 4184, was on a scheduled flight from Indianapolis, Indiana, to

[2] Part 121.343 requires that by May 26, 1995, large airplanes type certificated prior to October 1, 1969 (which would have included the airplanes involved in the Colorado Springs and Aliquippa accidents) must be equipped with FDRs that record 11 parameters. The additional parameters are longitudinal acceleration, pitch attitude, roll attitude, control column or pitch control surface position, and thrust of each engine (two thrust values for the Boeing 737). Part 121.343 also requires that airplanes type certificated after October 1, 1969 (regardless of the date of manufacture) and airplanes manufactured after May 26, 1989 (regardless of the date of type certification) must be equipped with FDRs that record 17 parameters. Airplanes manufactured after October 11, 1991 (regardless of the date of type certification) must be equipped with FDRs that record 31 parameters.

Chicago, Illinois. The flight had been placed in a holding pattern over Roselawn, Indiana, because of weather delays at O'Hare Airport. The flight was cleared to remain in the holding pattern and to descend from 10,000 to 8,000 feet. The airplane rolled to the right, entered a steep descent, and struck the ground; all 64 passengers and 4 crewmembers were fatally injured. The Safety Board's continuing investigation has not yet determined the probable cause of the accident; however, information from the enhanced FDR enabled the Safety Board to identify, within hours after receiving the recorder in its laboratories, the key events leading to the airplane's departure from controlled flight and the events during its final descent.

The ATR-72 was equipped with an FDR that recorded 98 parameters, including vane angle of attack (VAOA), aileron bellcrank position, flap position, aileron trim position, and autopilot engagement status. The FDR data showed that as the airplane was descending through 9,400 feet, the wing flaps began to retract and the airplane's VAOA increased. As the VAOA reached 5 degrees the autopilot disengaged, and within 1/4 second the ailerons deflected to near maximum travel in the right-wing-down direction. The FDR data also showed that the rolling moment was reversed when the VAOA was reduced to below 5 degrees, and the ailerons deflected in the left-wing-down direction. The right rolling moment recurred as the VAOA again increased to 5 degrees, and the ailerons deflected in the right-wing-down direction. Control of the airplane was not restored in time to prevent impact with the ground.

The data available from the ATR-72 FDR indicated to investigators that the airplane rolled as expected in response to aileron control surface movements, and that the aileron movements were correlated with increases in the airplane's angle of attack. As a result, the Safety Board was able to focus its efforts on possible explanations for the aileron control surface movements and, within days of the accident, the Board issued urgent safety recommendations to minimize the likelihood of similar occurrences in the future. As part of its continuing investigation, the Safety Board is also examining readouts from FDRs with expanded parameters from seven other ATR airplanes that have reportedly encountered flight control anomalies, three of which have shown important similarities to the accident flight.

The second accident involving an FDR with expanded parameters was one in which FDR data quickly moved the focus of the investigation from airplane systems to operations and human performance. On February 1, 1994, an American Eagle Saab 340B, flight 3641, was approaching Baton Rouge, Louisiana, on a scheduled passenger flight from Dallas/Fort Worth, Texas. As the airplane descended through 9,000 feet, both engines failed. The flightcrew executed a forced landing at False River Air Park in New Roads, Louisiana, during which the airplane sustained substantial damage. The flight attendant received minor injuries during the emergency evacuation. The 2 pilots and 23 passengers aboard were not injured.

The FDR installed on the Saab 340B recorded 128 parameters. FDR data showed that as the airplane descended through 9,040 feet, there was a rapid rise of both propellers' rotational speed well above the maximum allowable revolutions per minute. Because the FDR also was equipped to capture the positions of the engine power levers, the Safety Board was able to determine that at the same time the propeller speed increased, the power levers moved from the flight idle gate position to aft of the ground idle detents. The airplane's approved flight manual prohibits such power lever movements while in flight. This flightcrew action explained the propeller overspeed, which resulted in dual engine failure. With the expanded FDR data, the Safety Board was able to rule out alternative explanations for the propeller overspeed, including propeller systems failures that previously had affected similar propellers installed in another turboprop regional airliner.[3]

The importance of FDR data is not limited to investigations of catastrophic accidents. FDR data from incidents, which are less serious but occur more often, can provide to investigators and the aviation community critical information to help prevent accidents involving similar circumstances. Following the Colorado Springs and Aliquippa accidents, the Safety Board investigated 12 Boeing 737 incidents involving anomalous rudder activity or uncommanded roll oscillations. The FDRs aboard the incident airplanes, however, were not equipped to record flight control surface positions, flight control inputs, or lateral acceleration. Like 79 percent of all U.S.-registered Boeing 737s, the airplanes involved in the incidents were manufactured prior to May 26, 1989; consequently, they were required by current regulations to record only the five basic FDR parameters. As a result, critical, objective data were not available from the FDRs, and investigators had little more than the flightcrews' subjective recollections of these dynamic events.

In contrast to the investigations of these 12 Boeing 737 incidents, for which important FDR data were not available, investigations of other incidents have been greatly aided by the availability of enhanced recorded information. These incidents involved airplanes equipped with a digital data bus that transmits information from many sensors to the onboard recording devices.

On October 7, 1993, a British Airways Boeing 747-436 experienced a nose-down pitching moment immediately after departure from London Heathrow Airport. The captain avoided ground contact by exerting substantial back pressure on his control column. The incident was investigated by the United Kingdom's Air Accidents Investigation Branch (AAIB). Of the many parameters that were available on the airplane's digital data bus, recorded by a Quick Access Recorder (QAR)[4] and available to the FDR, several were useful in the AAIB's investigation. These parameters included the position of each of the four elevator control surfaces, control column

[3] National Transportation Safety Board. 1992. Atlantic Southeast Airlines, Inc., flight 2311, Uncontrolled collision with terrain, an Embraer EMB-120, N270AS, Brunswick, Georgia, April 5, 1991. Aircraft Accident Report NTSB/AAR/92/03. Washington, DC.

[4] QARs and FDRs have similar data storage capabilities, but QARs, primarily intended for air carrier maintenance fault analysis, are not hardened to survive crash impact and fire conditions.

position, radar altitude, landing gear position, and hydraulic system pressure. By analyzing the information from the QAR, the AAIB established that "the upset was caused by the uncommanded pitch-down movement of both right-side elevators, coincident with landing gear retraction."[5] As a result of its investigation, the AAIB recommended that the FAA require modifications of Boeing 747 hydraulic systems and elevator power control units.

Between June and August 1993, Air France Boeing 737-300 airplanes experienced three rudder deflection anomalies. For each incident, about 206 flight data parameters were available to the French accident investigation authority, Bureau Enquetes Accidents (BEA). The data were recorded on QARs, and available parameters included control surface positions, flight path data, acceleration in three axes, yaw damper, and autopilot modes. The Safety Board is evaluating the data from these incidents for possible applicability to the Aliquippa or Colorado Springs accidents.

The data required to be recorded on FDRs have been based on the Safety Board's accident investigation experience and the capacity of the recording devices. Over the course of decades, many accidents investigated by the Board focused on wind shear, takeoff overruns, and instances of controlled flight into terrain; fewer accidents involved the inflight loss of lateral or directional control. In response, FDR parameter requirements focused on airplane performance (such as airspeed, altitude, and longitudinal acceleration) rather than on flight control (such as rudder position and trim settings). However, the recent accidents and incidents, discussed above, have demonstrated that more information about flight control parameters should be recorded by FDRs.

Among the additional flight control parameters that are needed are parameters that pertain to the positions of flight control inputs and flight control surfaces. Under current rules, airplanes fitted with conventional flight controls are permitted to record either the cockpit control input (such as control wheel position) or the control surface (such as the direction and amount of aileron deflection), if one can be derived from the other. But in its investigations of the recent Boeing 737 accidents, the Safety Board found that in some failure modes, flight control surface positions could move independently of cockpit flight control inputs. Also, under some conditions, additional information is needed by investigators to determine whether the controls on the flight deck caused the control surfaces to move, or vice versa. Consequently, FDRs should record both the flight control inputs and flight control surface positions.

[5] U.K. Department of Transport, Air Accidents Investigation Branch. 1995. Report on the incident to Boeing 747-436, G-BNLY at London Heathrow Airport on 7 October 1993. Aircraft Accident Report 1/95. London, England.

Flight control trim information, including the positions of trim controls for roll and yaw, also has been essential during recent accident investigations. For example, the aileron and rudder trim parameters provided answers to critical questions early in the investigation of the Roselawn accident. The airplane involved had previously experienced trim anomalies; the FDR revealed none on the accident flight.

Recent technological changes have made feasible the acquisition and storage of large amounts of data on FDRs. Today, even for older airplanes, many FDR systems can record additional parameters because of unused capacity in the flight recording system. In terms of flight recording systems, there are two general categories of airplanes in the current air carrier fleet: analog airplanes, and airplanes equipped with a digital data bus.

On an analog airplane, information from remotely located data sensors (for example, a rudder position sensor located in the tail section) is transmitted to the FDR via dedicated wires in an analog format. The information is then converted to digital format in the FDR or the flight data acquisition unit (FDAU).

On an airplane equipped with a digital data bus, information is transmitted in digital format from a multitude of sensors, along a single, high capacity communications pathway (data bus). Information transmitted on the bus is provided to a number of systems, including flight management computers, cockpit displays, QARs, and FDRs. Additional data can readily be fed from the bus to the FDR, based on information that is already on the bus for other purposes or added to the bus by new sensors.

Upgrading FDRs with additional parameters would result in improved aviation safety. The Safety Board acknowledges, however, that retrofitting airplanes that are currently operating in air carrier service would necessitate a significant monetary investment, especially for analog airplanes.

The Safety Board obtained information about the cost of upgrading FDRs on analog airplanes from an air carrier trade group and an FDR equipment manufacturer. In a petition submitted to the FAA, the Air Transport Association (ATA) reported that to upgrade an FDR with six additional parameters would require a one-time expenditure of about $250,000 per airplane type for engineering specifications and the development of retrofit kits.[6] These one-time costs would be spread over all of the individual airplanes of each type that are retrofitted; that is, if there are 500 airplanes in service, the cost for basic engineering would be $500 per airplane. Additional expenditures would be required for labor and equipment to upgrade each individual airplane; an ATA member survey stated that the installed

[6] Letter of June 5, 1992, to the FAA Office of General Counsel Rules Docket, from Joseph D. Vreeman, Vice President of Engineering, Maintenance, and Materiel, Air Transport Association.

equipment cost for a six-parameter upgrade would total between $20,000 and $40,000 per individual airplane.[7]

The Safety Board also obtained estimates of installed equipment cost to upgrade an FDR to record the parameters listed in "Proposed Minimum FDR Parameter Requirements for Airplanes in Service" (attachment A to this letter). The information was provided by an FDAU manufacturer and an FDR manufacturer.

The FDAU manufacturer estimates that retrofitting an analog airplane could cost about $20,000 to $30,000. This estimate includes about $1,000 per additional parameter ($200 to $400 of which is for sensors; the remainder is for associated wiring and labor). The FDR manufacturer estimates that to record the parameters listed in attachment A, many airplanes may require the use of an FDAU, which could cost an additional $15,000 to $20,000 for each airplane not already so equipped. Based on the various estimates, it appears that retrofitting an analog airplane to record the parameters listed in attachment A could cost between $25,000 and $70,000.

Retrofitting an airplane equipped with an ARINC 429 digital data bus or equivalent (such as the Boeing 757 and 767) to record, as a minimum, the parameters listed in attachment A would be less expensive. Most wiring changes would be confined to the electronic equipment compartment, and some reprogramming of the digital FDAU would be required. All of the airplanes would require the addition of flight control surface position sensors. Some airplanes that were manufactured on or before October 11, 1991, may also require additional sensors.

During the public hearing on the Aliquippa accident, a major U.S. air carrier expressed concern about the costs of upgrading FDRs on the carrier's fleet. The Safety Board recognizes that enhanced FDR capability needs to be weighed against the costs. However, the Board also believes that the costs should be balanced against the remaining useful life and revenue-earning potential of an airplane. Using an upper-bound retrofit cost of $70,000 per airplane and reasonable assumptions about airplane utilization,[8] the Safety Board estimates the cost of retrofitting an airplane in current service with an enhanced FDR to be less than 7¢ per passenger.

The Safety Board believes that public safety outweighs the 7¢-per-passenger cost of equipping older airplanes to record more FDR parameters, especially if the retrofit program is limited to airplane types that remain in production (including

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[7] Summarized by the FAA in its Notice of Proposed Rulemaking on extension of the compliance date for installation of digital FDRs on Stage 2 airplanes, Federal Register (Vol. 59, No. 36), p. 8573.

[8] Assumptions are as follows: average seating capacity of 150 passengers, 3 departures per day, a 65-percent passenger load factor, and a useful life of 10 years.

derivative models[9]). According to information provided by the FAA to the Safety Board,[10] the U.S. register currently lists about 2,000 transport category airplanes (such as DC-9s, B-737s, and F-28s) that were type certificated before October 1, 1969. These types are still in production (including derivatives, such as MD-80s, B-737-400s, and F-100s), and most of these airplanes use the analog method of data acquisition and transmission.

The Safety Board believes that transport category airplanes of a type that is still in production and operated under 14 CFR Parts 121, 125, or 135 should be retrofitted with the sensors and FDAU needed to record, as a minimum, the parameters listed in attachment A. Further, these airplanes should continue to record the FDR parameters required by current regulations applicable to each airplane (based on its dates of certification and manufacture). Although Boeing 727 and Lockheed L-1011 airplanes are not currently in production, nearly 800 airplanes of these types are expected to remain in the U.S. airline fleet by the end of the 1990s.[11] Accordingly, the Safety Board believes that these airplanes should also be retrofitted to record on FDRs, as a minimum, the parameters listed in attachment A.

To ensure that individual airplanes have a substantial useful life over which to recoup the cost of FDR enhancement, the Safety Board believes that the retrofit should apply only to airplanes (except for Boeing 737s, which are addressed later in this letter) that comply with Stage 3 noise requirements,[12] or that remain in service after December 31, 1999, by receiving a waiver or exemption from Stage 3 noise requirements. This criterion would apply the FDR enhancements only to individual airplanes that have the opportunity to operate well into the next decade.

The Safety Board believes that the FAA should complete its rulemaking on FDR enhancements by December 31, 1995. Further, the FAA should require all operators of transport category airplanes under 14 CFR Parts 121, 125, or 135 to complete the FDR enhancements by January 1, 1998. Airplanes that do not currently comply with Stage 3 noise requirements should be retrofitted with these FDR enhancements by January 1, 1998, or by the later date when they meet Stage 3 noise requirements but, regardless of Stage 3 compliance status, no later than December 31, 1999.

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[9] Derivative models are updated versions of older airplane types that continue to use the original FAA aircraft type certificate. Examples include the McDonnell Douglas MD-80 series, based on the DC-9, and the Fokker F-100, based on the F-28.

[10] Letter of December 14, 1994, from FAA Administrator David R. Hinson to Safety Board Chairman Jim Hall.

[11] Derived from information in the letter of December 14, 1994, from FAA Administrator Hinson.

[12] According to 14 CFR 91.853, all airplanes will be required to meet Stage 3 noise requirements by December 31, 1999.

With regard to Boeing 737 airplanes, which account for about 23 percent of the U.S. air carrier fleet, the Safety Board believes that FDR enhancement is needed sooner. Data from enhanced FDRs play a vital role in helping to prevent accidents through information they provide about incidents.[13] During the public hearing on the Aliquippa accident, the Boeing Commercial Airplane Group indicated that it had records of 187 flight control incidents involving Boeing 737s that occurred between 1970 and 1994. Of the 187 incidents, 35 occurred in 1993 and 1994. Because the Boeing 737 will be used for years to come, it is essential that the airplanes involved in future incidents be equipped with enhanced FDRs. Consequently, the Safety Board believes that the FAA should require that all Boeing 737 airplanes operated under 14 CFR Parts 121 and 125, regardless of Stage 3 compliance status, be equipped, by December 31, 1995, with FDRs that record, as a minimum, the parameters required by current regulations plus the following parameters (recorded at the sampling rates specified in attachment A): lateral acceleration; flight control inputs for pitch, roll, and yaw; and primary flight control surface positions for pitch, roll, and yaw.

According to information provided to the Safety Board by the FAA,[14] as many as 1,000 Boeing 737 airplanes would be affected by the retrofit. The additional parameters could, in most cases, be accommodated by the currently installed FDR and FDAU systems. As a result, the Safety Board estimates that the cost to add these parameters would total between $10,000 and $20,000 per airplane.

In the ATR-72 and Saab-340B accidents, the traveling public benefited from earlier corporate decisions by Avions de Transport Regional (ATR), Saab Aircraft AB, and AMR Corporation/American Eagle to equip the airplanes with FDRs that record more parameters than are currently required by the Federal Aviation Regulations. American Eagle also has taken the initiative to retrofit its 19-seat, British Aerospace Jetstream airplanes with enhanced FDRs. In the Safety Board's opinion, the leadership role taken by these companies should be followed by others in the aircraft manufacturing and air carrier industries. Because the Board recognizes that regulatory change is not accomplished as quickly as action taken by individual companies, the Safety Board believes that the operators of transport category airplanes currently in service under 14 CFR Parts 121 and 135 should voluntarily modify FDRs installed on their airplanes to record, as a minimum, the parameters listed in attachment A plus the parameters that are currently required by the regulations applicable to each airplane.

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[13] In addition to the role that enhanced FDR data can play in accident and incident investigations, the data will be of great assistance to air carriers' Flight Operations Quality Assurance (FOQA) programs. FOQA is a proactive, accident prevention program that involves the analysis of data collected during normal flights, for the purpose of enhancing the safety of flight operations. The Safety Board joins the FAA, the Department of Transportation, and many industry representatives in supporting the development of FOQA programs.

[14] Letter of December 14, 1994, from FAA Administrator Hinson.

Most newly manufactured airplanes used in air carrier service are routinely equipped with digital data buses that carry information on hundreds of parameters. Also, the current state of the art in solid-state memory devices has lifted the previous constraints on the number of parameters that FDRs can record. Consequently, the cost of adding FDR parameters usually will be minimal if the parameters are specified before the airplane is built.

The Safety Board's accident investigation experience in recent years indicates that the FDR parameter requirements for newly manufactured airplanes need to be expanded further. The Board believes that the required FDR parameters for newly manufactured airplanes should include those proposed in EUROCAE Document ED-55[15] plus additional parameters such as flight control input and surface positions. Accordingly, the Safety Board believes that the FAA should require that all airplanes operated under 14 CFR Parts 121, 125, or 135 (10 seats or larger) for which an original airworthiness certificate is issued after December 31, 1996, be equipped with FDRs that record the parameters listed in "Proposed FDR Enhancements for Newly Manufactured Airplanes" (attachment B to this letter). Also, the Safety Board believes that because available technology now permits all FDRs to record at least 25 hours of data, all FDRs installed on these newly manufactured airplanes should have this recording capacity after December 31, 1996.

Because aircraft manufacturers can react more quickly than regulatory requirements can be changed, the Safety Board also believes that the manufacturers should establish, for all newly manufactured airplanes that will be operated under 14 CFR Parts 121, 125, or 135 (10 seats or larger), a minimum standard for recording FDR parameters in accordance with attachment B.

Air travelers and the air carrier industry cannot afford additional unresolved accidents. The Safety Board will continue its efforts to identify the probable cause of the accidents at Colorado Springs and Aliquippa, but enhanced FDR data are essential to help prevent future accidents.

Therefore, the National Transportation Safety Board recommends that the manufacturers of airplanes operated under Parts 121, 125, or 135:

> Establish, for all newly manufactured airplanes that will be operated under 14 CFR Parts 121, 125, or 135 (10 seats or larger), a minimum standard for recording flight data recorder parameters in accordance with "Proposed FDR Enhancements for Newly Manufactured Airplanes." (Class II, Priority Action) (A-95-29)

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[15] European Organisation For Civil Aviation Equipment [EUROCAE]. May 1990. Minimum Operational Performance Specification For Flight Data Recorder Systems (ED-55). Paris, France.

Recommendations were also issued to the Federal Aviation Administration and to the operators of air carrier service under 14 CFR Part 121 and commuter air carrier service under 14 CFR Part 135.

The National Transportation Safety Board is an independent Federal agency with the statutory responsibility "...to promote transportation safety by conducting independent accident investigations and by formulating safety improvement recommendations" (Public Law 93-633). The Safety Board is vitally interested in any actions taken as a result of its safety recommendations and would appreciate a response from you regarding action taken or contemplated with respect to the recommendation in this letter. Please refer to Safety Recommendation A-95-29 in your reply.

Chairman HALL, Vice Chairman FRANCIS, and Member HAMMERSCHMIDT concurred in this recommendation.

By: Jim Hall
Chairman

Enclosures

Attachment A

Proposed Minimum FDR Parameter Requirements for Airplanes in Service

Proposed Minimum Parameters:

1. Altitude
2. Airspeed
3. Vertical acceleration
4. Heading
5. Time of each radio transmission to air traffic control
6. Pitch attitude
7. Roll attitude
8. Longitudinal acceleration
9. Pitch trim position*
10. Yaw trim position**
11. Roll trim position**
12. Control column and pitch control surface position**
13. Control wheel and lateral control surface position**
14. Rudder pedal and yaw control surface position**
15. Thrust of each engine
16. Position of each thrust reverser (or equivalent for propeller airplane)*
17. Trailing edge flap or cockpit flap control position*
18. Leading edge flap or cockpit flap control position*
19. Ground spoiler position/speed brake selection**
20. Angle of attack (when information source is available)**
21. Lateral acceleration**

22. Autopilot engagement status**

23. Automatic Flight Control System (AFCS) modes and engagement status**

24. Outside or total air temperature**

(*) Indicates a new or changed parameter relative to the current 11-parameter requirement. (**) Indicates a new or changed parameter relative to the current 17-parameter requirement.

Notes:

1. Data shall be recorded within the range, resolution, accuracy and sampling intervals specified in EUROCAE Document ED-55, Chapter 3 and Annex 1, unless otherwise noted.

2. Each airplane type will need to be assessed to identify any novel or unique design or operational characteristics. It will then be necessary to ensure that sufficient dedicated parameters, appropriate to these characteristics, are recorded in addition to or in place of other parameters.

3. The flight recorder shall use a digital method of recording and storing the data and a method of readily retrieving those data from the storage medium. The data shall be obtained from sources within the aircraft that enable accurate correlation with data displayed to the flight crew, except when the flight deck displays are filtered or manipulated so as to produce values that do not meet the resolution and accuracy requirements for all phases of flight (for example, some EICAS flight control position display data).

National Transportation Safety Board
February 1995

Attachment B

Proposed FDR Enhancements for Newly Manufactured Airplanes

Acceleration Parameters:
- Vertical
- Lateral
- Longitudinal

Airplane Performance/Position Parameters:
- Altitude
- Airspeed
- Air/ground sensor (primary airplane systems reference, nose or main gear)
- Brake pressure and pedal position
- Drift angle (when an information source is installed)
- Ground speed (when an information source is installed)
- Wind speed and direction (when an information source is installed)
- Outside air temperature or total air temperature
- Radio altitude (when an information source is installed)
- Latitude and longitude (when an information source is installed)

Airplane Attitude Parameters:
- Angle of attack left and right (when an information source is installed)
- Pitch
- Roll
- Magnetic heading
- True heading (when an information source is installed, sampled 1 per 4 seconds)
- Yaw or sideslip angle (when an information source is installed)*

Flight Controls Position and Input Parameters:
- All control surface positions--primary controls (pitch, roll, and yaw)
- All cockpit flight control input positions and forces (control wheel, control column, rudder pedal) (sidestick controllers on fly-by-wire systems)
- All trim surface positions--primary controls** (pitch, roll, and yaw)

All cockpit trim control input positions--primary controls**
(pitch, roll, and yaw)
Thrust/power--primary flightcrew reference
(may require multiple parameters for all phases of flight)
Throttle/power lever position
Thrust reverser status (i.e., stow, transit, deployed, reverse pitch.)
Thrust command (when an information source is installed)
Thrust target (when an information source is installed)
Engine bleed valve position (when an information source is installed)

Airplane Configuration Parameters:

Flap position (trailing and leading edge)
Spoiler position (ground and speed brake)
Spoiler/speed brake cockpit selection/status (armed--ground spoiler)
Flap cockpit control selection
Landing gear position
Landing gear cockpit control selection
De-icing or anti-icing system selection
(when an information source is installed, sampled 1 per 4 seconds)
Fuel quantity in CG trim tank (when an information source is installed)
Computed center of gravity (when an information source is installed)
AC electrical bus status
DC electrical bus status
APU bleed valve position
Hydraulic pressure (all systems)

Navigation Aids:

Localizer deviation
Glideslope deviation
DME 1 and 2 distances
NAV 1 and 2 selected frequency
GPS position data (when an information source is installed)
Marker beacon passage

Autopilot Parameters:

Engagement status (all systems)
AFCS modes and engagement status

Timing:

Radio transmitter keying
UCT (when an information source is installed)
Recorder elapsed time (frame counter, 0 to 4095)
CVR/DFDR synchronization reference
(when an information source is installed)
Event marker

Warning Parameters:

GPWS
Hydraulic pressure low (each system)
Master warning
Loss of cabin pressure
TCAS--TA, RA, and sensitivity (as selected by crew)
Icing (when an information source is installed)
Engine warnings each engine--
Vibration (when an information source is installed)
Over temp. (when an information source is installed)
Oil pressure low (when an information source is installed)
Over speed (when an information source is installed)
Windshear (when an information source is installed)
Computer failure
Stick shacker/pusher (when an information source is installed)

Manual/Automatic Selected Parameters:

Selected barometric setting
Selected speed
Selected vertical speed
Selected heading
Selected flight path
Selected decision height
EFIS display format
Head-up display (when an information source is installed)
Para-visual display (when an information source is installed)
Multi-function/engine/alerts display format

(*) Range, as installed; accuracy, as installed; resolution, 0.3% of full range; sampling, 1 per second. (**) Range, full travel; accuracy, ± 3% unless higher accuracy uniquely required; resolution, 0.3% of full range; sampling, 1 per second.

Notes:

1. Data shall be recorded within the range, resolution, accuracy and sampling intervals specified in EUROCAE Document ED-55, Chapter 3 and Annex 1, unless otherwise noted.

2. Each airplane type will need to be assessed to identify any novel or unique design or operational characteristics. It will then be necessary to ensure that sufficient dedicated parameters, appropriate to these characteristics, are recorded in addition to or in place of other parameters.

3. The flight recorder shall use a digital method of recording and storing the data and a method of readily retrieving those data from the storage medium. The data shall be obtained from sources within the aircraft that enable accurate correlation with data displayed to the flightcrew, except when the flight deck displays are filtered or manipulated so as to produce values that do not meet the resolution and accuracy requirements for all phases of flight (for example, some EICAS flight control position display data).

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