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NATIONAL TRANSPORTATION SAFETY BOARD

Washington, D. C.

Group Chairman's Sound Spectrum Study
Cockpit Voice Recorder

NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Vehicle Recorders Division
Washington, D.C. 20594

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Cockpit Voice Recorder - 12

Group Chairman's Sound Spectrum Study

By Anna W. Cushman

A. ACCIDENT

Location:	Rancho Cordova, California
Date:	February 16, 2000
Time:	1951 pacific standard time (PST)
Aircraft:	DC8-71F, N8079U
Operator:	Emery Worldwide Airlines, Flight 17
NTSB Number:	DCA00MA026

B. GROUP

Chairman:	Anna W. Cushman Aerospace Engineer (CVR) National Transportation Safety Board
Member:	Jerry Buffington Check Airman/Instructor Emery Worldwide Airlines
Member:	Michael Huhn Accident Investigations Engineer Air Line Pilots Association
Member:	Donald Boston Associate Technical Fellow Boeing Company
Member:	T. R. Proven Air Safety Investigator Federal Aviation Administration

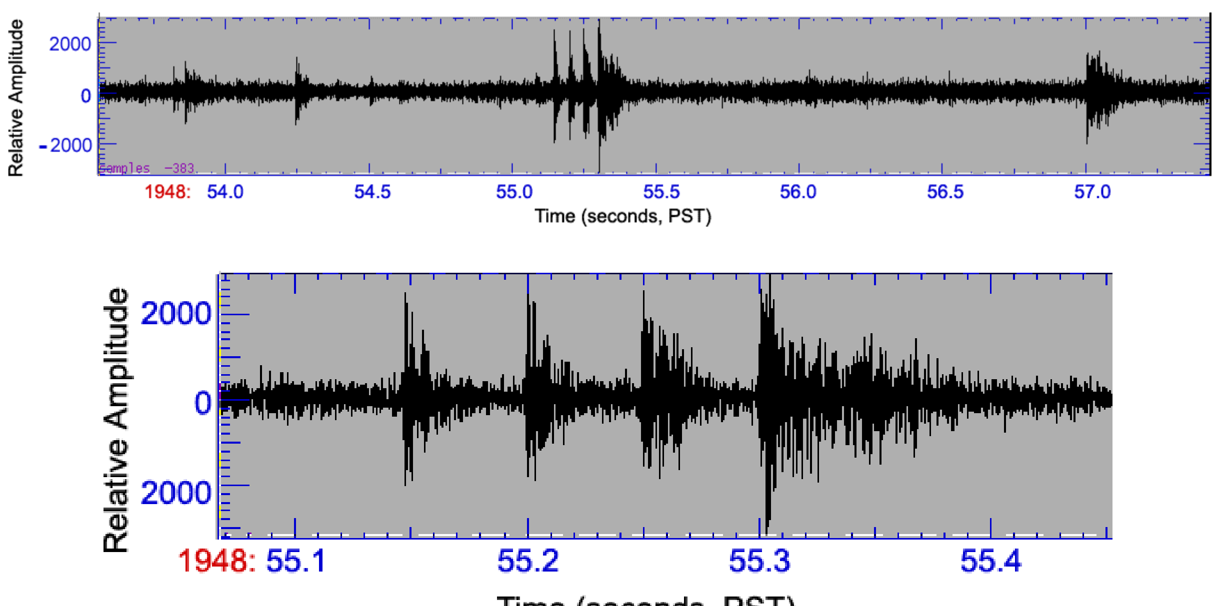
C. SUMMARY

At about 1951 PST[1] on February 16, 2000 Emery Worldwide Airlines Flight 17, a DC8-71F aircraft registered as N8079U, crashed after takeoff from runway 22L at Mather Field in Ranch Cordova, California. A Sundstrand AV557 tape cockpit voice recorder (CVR)[2] was recovered from the wreckage and sent to the audio laboratory of the National Transportation Safety Board. The CVR group convened and prepared a transcript of the 33-minute 24-second recording (reference the Group Chairman's CVR Factual Report, with attached transcript). As shown in the CVR transcript, the CVR group members could not clarify or identify a ratcheting noise that was recorded on the cockpit area microphone (CAM) channel immediately prior to rotation. A sound spectrum group was formed to further investigate the origin of the noise.

D. DETAILS OF STUDY

After the crew called "eighty knots" and "elevator check" at 1948:50, an unidentified ratchet noise was recorded on the CAM channel at 1948:55.15. At 1949:02 the Captain called "V one" and then "rotate." The ratcheting noise recorded on the CAM channel is distinctive with particular characteristics, as shown in its waveform in Figure 1a and 1b. From the waveform, it appears that the noise is cyclic with a frequency of 18.8 Hz. Also, each ratchet is an impulse, with a sharp rise in amplitude—almost 400% higher than the background noise level at the peaks.

a)



b)

Figure 1: a) Waveform of ratchet noise from accident recording and b) zoom view.

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[1] All times are expressed in pacific standard time (PST), unless otherwise noted.
[2] A serial number for the CVR was not identified.

The spectrogram[3] of the ratchet noise is shown in Figure 2. The noise appears to be broadband in frequency, with medium to high intensity. Because of its cyclic nature, short rise time and broadband frequency range, the noise can generally be characterized as a cyclic impulse produced relatively close to the recording source. Historically CVR recordings of cyclic impulse noises are generally produced by an on board aircraft system or a repeatable external factor, such as runway seams.

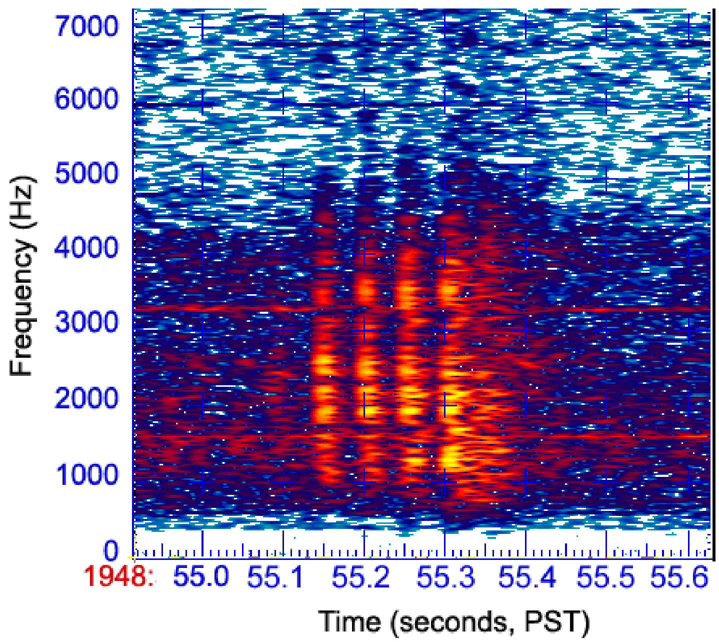


Figure 2: Spectrogram of ratchet noise.

To document the on board systems of the DC8, two audio tests were arranged on different days aboard two DC8-71F aircraft similar to N8079U. The tests were conducted on the airport ramp with the aircraft's engine-generated power. Electrical system audible alerts and switch/handle movement were captured within the cockpit. Additionally, crew seats were moved on their tracks, and cargo pans and ULDs (uniform loading device) were rolled on the rollers in the cargo area. The following table summarizes the audio captured during the static ground tests aboard the DC8-71F aircraft:

[3] Color on the spectrogram (also referred to as a voiceprint plot) represents a relative magnitude of frequency strength – specifically, from low strength to high strength: white, blue, red, orange, yellow and teal.

Aircraft System Aural Advisories/Warnings	Handle/Switch/Button Movement	Other Control/Equipment Motion
Overspeed Aural Alert	Brake Release	Flight Control Columns
Stall Warning – Stick Shaker	Gust Lock	Crew Seat Adjustments
GPWS Aural Advisories	Flaps/Slot	Crew Seat Arm Rest
Pitch Trim Compensator	Anticollision Light	Crew Shoulder Harness
Stabilizer Trim wheel-in-motion	Anti-ice	Cockpit Door open/close
Altitude Alert	Landing Light	Cockpit Window open/close
Gear Warning Horn	No Smoking/Fasten Seat	Rudder Pedal Adjustment
Gear Configuration	Intrph to VHF2 switch	ULD movement on rollers (empty palette) in Cargo Area
	Alt. Longitudinal Trim	Pan movement on rollers (empty palette) in Cargo Area
	Radio Frequency Dial	ULD movement on rollers (weighted ~3000 lbs) in Cargo Area
	Fuel Lever	Pan movement on rollers (weighted ~2500 lbs) in Cargo Area
	Autopilot On/Release	

Table 1: Summary of audio captured during static ground tests aboard DC8-71F aircraft.

Upon reviewing the audio data, the following sources had characteristics similar to the unidentified ratchet:

1. ULD/Pan movement in cargo area
2. Crew seat motion in seat track
3. Rudder pedal adjustment
4. Stall Warning – stick shaker

ULD/Pan Movement in Cargo Area

To capture audio of the ULD and pan rolling over the rollers in the cargo area, several samples in various configurations were required. Load movement was constrained to the cargo hold positions that were closest to the cockpit—between positions 1 and 4. The loads were moved manually the length of the cargo position to an abrupt stop, slamming into the position locks. There were two sets of cargo load weight configurations: 1) empty ULD and pan, and 2) a ULD with 3000 lbs and a pan with 2500 lbs. For each of the scenarios, audio was captured via the CAM and recorded to the CVR, with both the cockpit door open and closed.

The results from the audio tests revealed that the movement of the ULD and pan in the cargo positions closest to the front of the aircraft—with the cockpit door open or closed—was not significantly pronounced from the background noise. That is, on the CAM channel CVR recordings, the amplitude of the noise of the cargo load rolling over the rollers and slamming into the position locks was imbedded within the amplitude of the background noise. The waveform of a weighted ULD rolling into position 4, recorded with the cockpit door open, is shown in Figure 3, and a weighted pan, recorded with the cockpit door open, is shown in Figure 4.

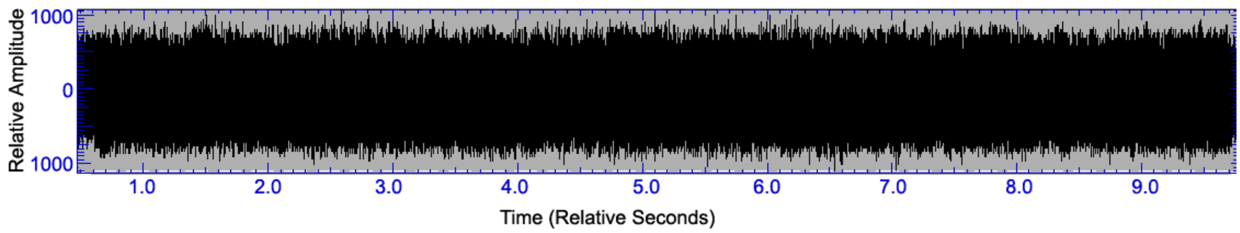


Figure 3: ULD rolling from cargo hold position 3 to 4. The beginning of the roll occurs at 1.6 seconds and ends with a slam into the position locks at 6.6 seconds. Recorded with the cockpit door open.

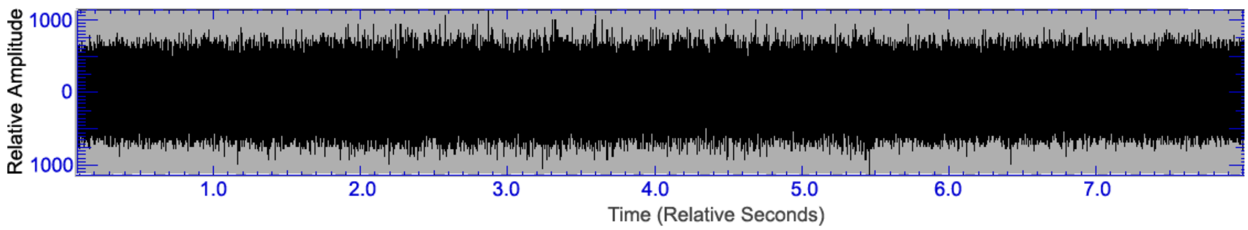


Figure 4: Pan rolling from cargo hold position 1 to 2. The beginning of the roll is at 0.5 seconds and ends with a slam into the position locks at 5.5 seconds. Recorded with the cockpit door open.

Figures 3 and 4 are indicative of the amplitude shown throughout the test data of load movement within the cargo hold, as recorded on the CAM channel—regardless of the specific test scenario. Although the rolling noise has a similar cyclic, ratchet-type effect while rolling over the rollers to the accident's ratchet noise, the amplitude of the signal is not greater than the overall background noise level, as recorded by the CVR via the CAM. The unidentified ratchet recorded by the accident CVR was impulsive with a distinct rise in amplitude above the background noise. Based on the recorded audio test data, cargo load movement is not acoustically similar to the unidentified ratchet noise recorded on N8079U's CVR.

Crew Seat Motion in Seat Track

During the audio tests it was evident that the seat moving in the seat track could produce a ratchet-type noise. The mechanism of the seat is such that in order to move the seat, a spring-loaded pin must be disengaged from a positioning slot along the seat track, the seat is moved along the track to the desired location, and then the pin is released into the new positioning slot. If the seat track positioning slots are worn, the spring in the pin is old, or if the pin is not firmly positioned within the slot, it is possible for the seat to move along the track without the pin engaging into a positioning slot. Specifically, the pin will hit the edge of each slot as it moves along the track—creating a ratcheting noise—until the spring-loaded pin catches and the seat stops moving.

There are several variables that were encountered with testing the seat motion, including: seat track wear, pin spring resilience, type of crew seat, and speed (or force) that the seat was moved along the track. The two separate audio tests yielded inconclusive results. Although impulse-type noises could be recreated, the seats in the test aircraft could not be moved at a constant rate to yield a cyclic result. Because the seat track slots are spaced at a constant distance, it is theoretically possible that a seat moving along the track could move at a speed that would result in a cycle similar to the accident ratchet noise cycle. Regardless, a cyclic ratcheting noise could not be demonstrated through crew seat motion during the two audio tests.

Rudder Pedal Adjustment

Because the rudder pedals are spring-loaded, it is possible to produce a ratcheting noise when adjusting the rudder pedal setting. During the audio tests, a ratchet noise was created once, but could not be executed again. In subsequent trials it was possible to produce an impulse noise, but not in a series resembling the cyclic nature of the unidentified noise in the accident recording. Moreover, the single occurrence of the ratchet-type noise from the audio test was not truly cyclic, in that the period of the impulses varied, as shown in Figure 5.

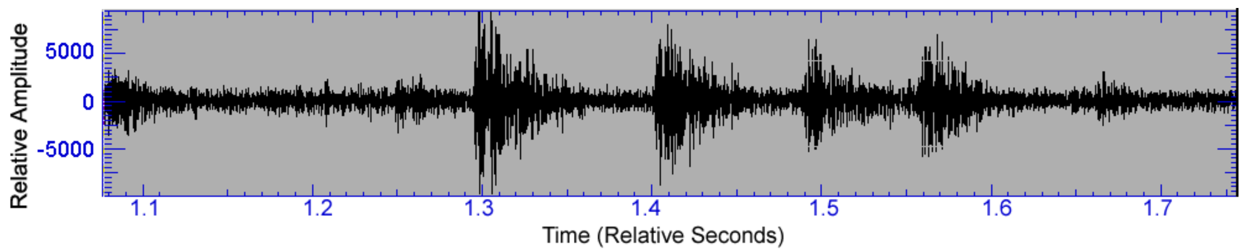
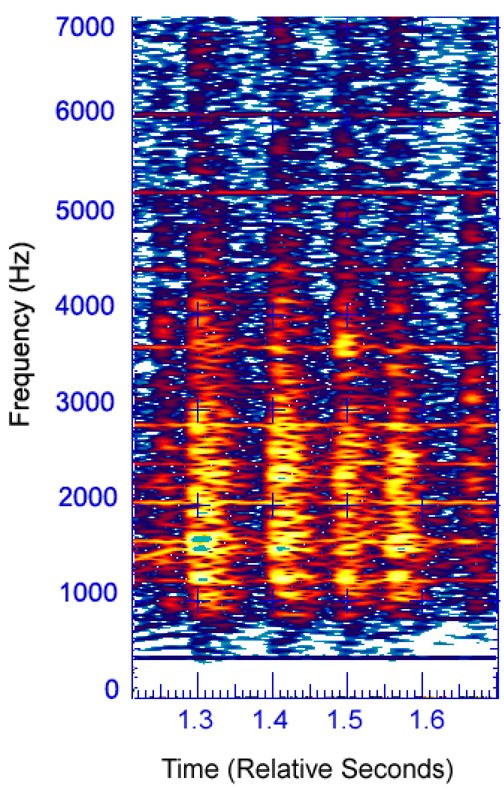


Figure 5: Waveform of rudder pedal adjustment from audio test.



The spectrogram (Figure 6) of the rudder pedal adjustment shows a broadband impulse noise with a high intensity of signal strength. Although similar to the unidentified ratchet noise from the accident, there is a higher concentration of frequency strength between 1000 and 2000 Hz in the test recording. The accident ratchet's intensity level is relatively even throughout the bandwidth, with a slightly higher concentration in the 2000 to 3000 Hz range. Although the audio test resulted in capturing a series of impulse noises during rudder pedal adjustment, the acoustic data was insufficient to make a determination as to the likelihood that the rudder pedal adjustment was the source of the accident ratcheting noise.

Figure 6: Spectrogram of rudder pedal adjustment impulses.

Stall Warning – Stick Shaker

The CVR group was able to identify the stick shaker within the accident recording. The accident aircraft's stick shaker recording shows a cycle of 18.7 Hz, as shown in Figure 7. The stick shaker's cycle falls within the operating range of the stick shaker motor, which is specified to run between 800 and 1200 RPM (or 13.3 Hz to 20.0 Hz). From the waveform it is evident that the stick shaker noise is impulsive with a relatively sharp rise in amplitude that has peaks close to 250% of the level of the background noise—slightly lower than the peaks shown in the waveform of the ratcheting noise.

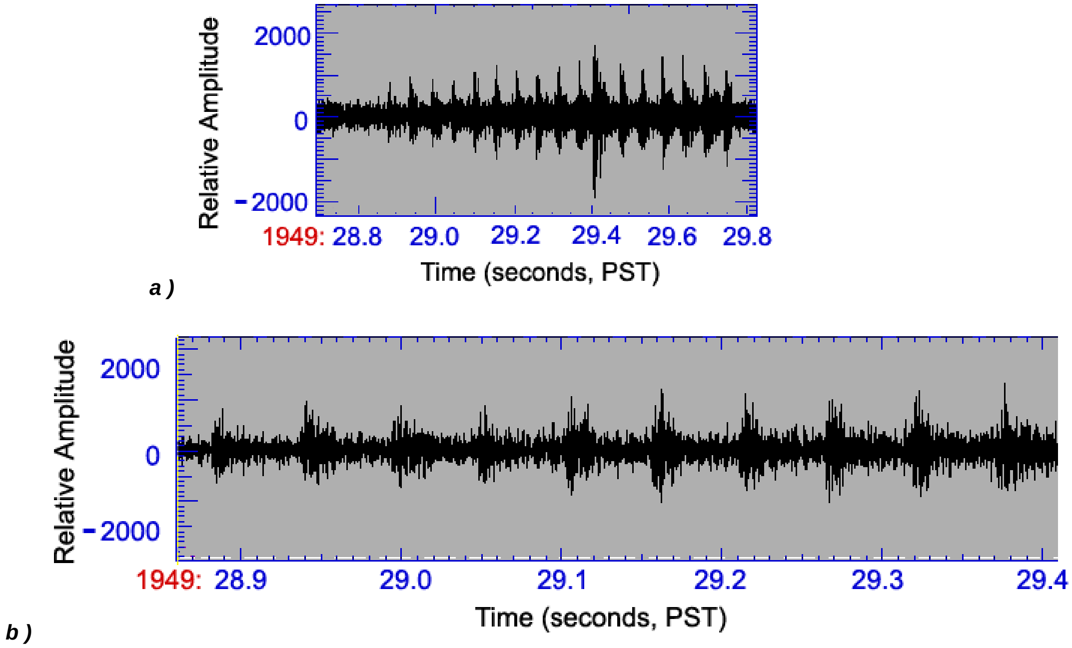
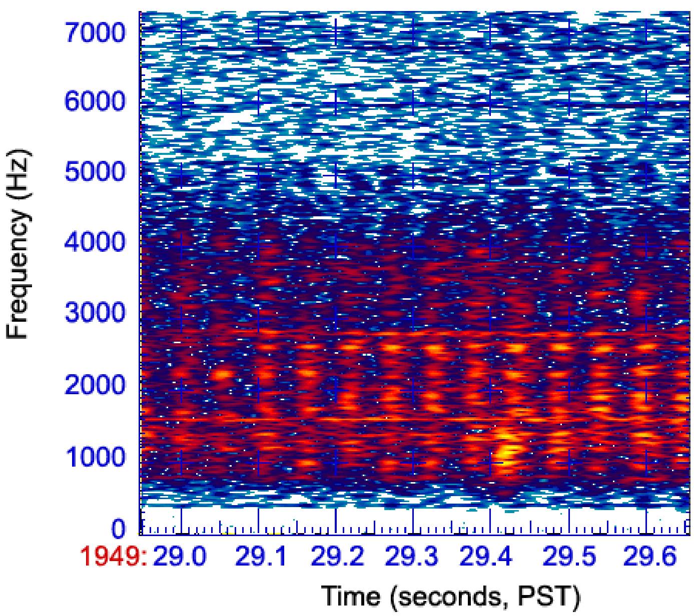


Figure 7: a) Waveform of the stick shaker recorded on the accident aircraft's CVR and b) the zoomed view.



The spectrogram of the stick shaker, Figure 8, reveals a broadband noise of medium intensity. The intensity distribution of the impulse differs slightly from the ratcheting noise in that the strength appears to drop off after about 2750 Hz. Regardless it is notable that the stick shaker cycle is 18.7 Hz, whereas the ratcheting noise has a cycle of 18.8 Hz.

Figure 8: Spectrogram of stick shaker from accident recording.

E. STUDY SUMMARY

Notably, although the audio tests concentrated on noise sources within the aircraft, an exterior source was considered. Specifically, in order to produce a cyclic noise recorded via the CAM, the nose gear of an aircraft would generally have to run over a series of seams or objects spaced together within a short distance from each other across the runway. An inspection of runway 22L at Mather field did not reveal any seams or objects along the pavement that N8079U's nose gear could have rolled over, producing a ratcheting noise. There was only one noticeable seam at about 2500 feet from the end of the runway 22L at a transition point between concrete and asphalt.

There are three sources identified from the test and accident recordings that could have produced the ratcheting noise recorded on the CAM channel during the accident aircraft's takeoff roll: crew seat motion, rudder pedal adjustment and the stick shaker. The stick shaker shows several characteristics that are similar to the ratcheting noise—in particular, its cycle. Regardless because the ratcheting noise, which lasts less than 0.3 seconds, is impulsive and does not have a single frequency source, it is not possible to definitively determine its cause. Also, there are several parameters inherent to crew seat motion, rudder adjustments and the stick shaker operation that decrease the chances of repeatability during an audio test. Nevertheless, the acoustic evidence from the two audio tests reveals that the source of the ratchet noise is not likely to be a cargo load rolling on the rollers within the cargo area of the aircraft.

Anna W. Cushman
CVR/Sound Spectrum Group Chairman