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

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Cockpit Voice Recorder Timing and Correlation Study

DCA02MA054

Specialist's Study
by Douglass P. Brazy

A. ACCIDENT

Location:	Tallahassee, FL
Date:	July 26, 2002
Time:	0537 Eastern Daylight Time (EDT)
Aircraft:	Boeing B727-232, N497FE
Operator:	Federal Express, Flight 1478

B. GROUP

Not Applicable

C. SUMMARY

On July 26, 2002, at approximately 0537 EDT, a Boeing B-727-232, N497FE, operating as FedEx flight 1478, crashed into trees on short final approach to runway 9 at the Tallahassee Regional Airport (TLH), Tallahassee, Florida. The flight was operating under provisions of Title 14 Code of Federal Regulations Part 121, as a scheduled cargo flight from Memphis, Tennessee (MEM) to TLH. Night visual meteorological conditions prevailed at the time of the accident. The three flight

crewmembers were injured, two seriously, and the aircraft was destroyed by impact and resulting fire.

D. DETAILS OF INVESTIGATION

Overview

The times reported in the Cockpit Voice Recorder (CVR) transcript are Eastern Daylight Time[1]. However, the CVR does not record time. As a result, the comments and sounds captured by the CVR were timed using a reference clock. The CVR data were also correlated in time to the data from the Digital Flight Data (DFDR) recorder. After the correlation was established, all times associated with both recorders were converted to EDT.

CVR Elapsed Time[2]

The CVR Elapsed Time is determined for each comment or sound in the transcript. This is done using the reference clock on a digital playback unit. The time that each comment or sound *begins* is manually captured from the reference clock and stored with the associated comment in the transcript. For a majority of the comments, these times are measured and reported to the nearest whole second. However, selected comments and sounds are measured and reported to the nearest tenth (0.1) of a second. These include radio transmissions used for timing/correlation purposes and other events that must be measured more accurately in order to compare them in time with the DFDR data.

[1] Based on the clock used by the Federal Aviation Administration's Airport Surveillance Radar recorded data, and the correlation of that data with information from the Digital Flight Data Recorder.
[2] CVR Elapsed time is defined as the time that has elapsed since the beginning of the tape, as the tape is played back. For example, 00:00 (minutes:seconds) is the beginning of the CVR tape, 29:30 is 29 minutes and 30 seconds from the beginning of the tape, etc.

The CVR Elapsed Time is the fundamental basis for all timing and correlation of events recorded on the CVR.

CVR/DFDR Correlation

The CVR data were correlated in time to DFDR timing information. The DFDR time reference is separate and independent of the CVR, and is referred to as Subframe Reference Number (SRN). The SRN is defined as elapsed seconds since the beginning of a transcription of a specific segment of DFDR data.

The CVR and DFDR time references were correlated, or synchronized, by comparing the times of selected radio transmissions originating from the accident airplane. When a radio transmission is made, the keying of the microphone is recorded by the DFDR, while the audio for the transmission is captured by the CVR. A relationship between CVR Elapsed Time and DFDR Subframe Reference Number was established by associating transmissions heard on the CVR with the corresponding microphone keying captured by the DFDR.

DFDR to Eastern Daylight Time

The Aircraft Performance Group Chairman provided the correlation of DFDR time to Coordinated Universal Time (UTC)[3]:

UTC (in seconds after midnight) = DFDR (in SRN) + 27444.04

Eastern Daylight Time was calculated from UTC by subtracting four(4) hours from UTC.

[3] Coordinated Universal Time is also commonly referred to as Greenwich Mean Time (GMT).

Correlation Method

In order to correlate CVR time with the DFDR data, the variance between the CVR tape playback speed and the speed at which it was recorded must be accounted for. Despite adjustment of the playback speed using a spectrum analyzer tracking a known frequency, a small variance is unavoidable. This small variance has little effect over relatively short time periods, but can be significant over the entire duration of the recording. For example, at the adjusted playback speed, the CVR duration was about 32:19. According the correlation with the DFDR[4], the CVR duration should have been about 32:12.

This indicates that the playback speed was slightly slower than the speed at which the tape was recorded. The CVR/DFDR correlation is a mathematical conversion from CVR Elapsed time to DFDR time, which, in part, corrects the CVR elapsed timing for this difference in tape speed.

The correlation was determined by comparing the times associated with microphone clicks heard on the CVR, to the corresponding times recorded for microphone keying by the DFDR. Thirty-one radio transmissions (sixty-two microphone clicks) spanning the duration of the CVR were selected for this comparison. Data for these transmissions can be found in Table 1.

An initial correlation was established using two transmissions, one near the beginning of the CVR, and one near the end. These transmissions began at the following times:

[4] The DFDR timing data is not affected by tape speed, and is considered to be a true representation of time and duration.

Xmit	*CVR Total Time (TT)*[5]	*DFDR SRN*
1	*277.73*	*5543.034*
31	*1915.17*	*7176.034*

The correlation between the CVR and the DFDR can be described as a simple straight line, the equation for which is:

$$Y = MX + B$$

Where:

Y = Calculated DFDR time

M = slope of the line

X = length of time (CVR TT) in seconds, over which to apply the slope

B = offset in seconds

Slope (M)

The slope in the above equation compensates for the slightly slow playback speed of the CVR tape. It represents the number of "seconds per second" needed to match the duration indicated by the DFDR. The slope for the correlation equation was determined by comparing the amount of time between the two transmissions noted above. The CVR TT indicates that the time lapse between them is about 1637.44 seconds. The DFDR times indicate a lapse of about 1633 seconds, or 4.44 seconds *less* than the CVR indicates. In other words, over the 1637.44 seconds that lapse on the CVR, the CVR Elapsed time should be reduced by a total of 4.44 seconds. This equates to about 0.0027 "seconds per second".

[5] CVR Total time (TT) is synonymous with "CVR Elapsed Time". The format of Total time is the total number of seconds, while Elapsed time is minutes and seconds.

The initial slope M was determined as follows:

$$M = \frac{(CVR\ time\ lapsed) - (DFDR\ time\ lapsed)}{CVR\ time\ lapsed} = \frac{(1637.44) - (1633)}{1637.44} = 0.002712$$

Length of Time (X)

The length of time over which to apply the slope is determined by the CVR time lapse between the point of interest (the particular CVR elapsed time being converted to DFDR time)[6] and a "pinpoint". The pinpoint is a selected time, usually near the end of the CVR, where the two recorders are considered to be synchronized. The time selected was CVR TT 1915.17. The X term for the correlation equation is therefore (1915.17 - CVR TT).

Offset (B)

The offset term of the correlation equation serves two purposes. First, it adjusts the CVR time base to the DFDR time base. While the reference time for both recorders is elapsed seconds, the zero time is not the same for both recorders. Specifically, 00:00 CVR time equates to approximately 5270 DFDR Time (not including the effect of the slope adjustment).

By adding 5270 to the CVR time, the "base" becomes the same for both recorders. Second, the offset (and slope) is adjusted slightly to account for the one second sample rate of the DFDR. Because a microphone keying may actually occur between samples, the offset (and slope) is adjusted to more precisely reflect the time that the transmission is made. This adjustment was performed iteratively until of all the calculated DFDR times fell within the one second sample period of the DFDR.

[6] The correlation equation is applied to the CVR Elapsed time for each comment or sound in the transcript.

An initial offset was determined by selecting the click for one transmission (at CVR Total Time 1915.17) and equating it to the time of the corresponding microphone key recorded by the DFDR:

Microphone click at 1915.17 CVR TT = 7176.034 DFDR time or;

7176.034 – 1915.17 = 5260.864

Offset = CVR TT + 5260.864

The resulting preliminary correlation equation is therefore:

DFDR Time = 0.002712(1915.17 - CVR TT) + (CVR TT+5260.864)

Y M (X) B

This equation was used initially to calculate values for the *Calculated DFDR Time*. The results of this equation were then evaluated to determine if the calculated times fell within the one second sample period of the DFDR (defined as between the *DFDR Early* and *DFDR Late* values in **Table 1**). The offset was adjusted iteratively until virtually all of values were within the range. Decreasing the initial offset by 0.4 second, and increasing the initial slope by .0008 produced the best results. Four of the sixty-two calculated values fell outside of the one second DFDR sample period. The largest deviation outside the one second sample period was 0.3 seconds, which was the ending microphone keying for transmission number fourteen.

This correlation is dependant on two assumptions. First, the playback and record speeds of the CVR, while slightly different, remain constant throughout the recording and the playback. Second, there must be no power interruptions to either the CVR or the DFDR for the entire time frame that the correlation applies to.

The data in **Table 1** was used to determine a correlation between the CVR Elapsed Time and the Digital Flight Data Recorder (DFDR) time. Selected radio transmissions spanning the duration of the recording are listed in the rows of the table. From left to right, the columns in the table are described below:

#

Radio transmission sequential number.

CVR Elapsed Time

This is the time that each microphone "click" can be heard on the recording, in CVR Elapsed Time. The clicks indicate when the microphone is keyed or unkeyed. These times are manually noted from the reference clock on a digital playback unit. Times are to the nearest one-tenth (0.1) second. Displayed in minutes and seconds.

CVR TT

CVR "Total Time" (TT) is the CVR elapsed time displayed as total seconds, rather than minutes and seconds. e.g. 1 minute 30 seconds would be displayed as 90 seconds.

Status

Annotation indicating the beginning and end of the transmission as heard on the CVR ("on"= start of transmission, "off" = end of transmission).

DFDR SRN

The DFDR Subframe Reference Number recorded for the indication of "on and "off" for microphone keying.

CVR and DFDR Duration

The CVR data and the DFDR data indicate different values for the duration of any given radio transmission. This is due to (1) the slightly slow playback speed of the CVR tape, and (2) the DFDR samples microphone keying in 1 second intervals. The microphone *could* be keyed up to one second before the DFDR records it, and it *could* remain keyed up to one second after. The resulting DFDR minimum and maximum durations are therefore always two seconds apart.

The CVR Duration is the duration of the transmission in CVR Elapsed time. It is the difference between the two values in the CVR TT column. The DFDR Duration columns show the minimum and maximum possible duration, based on the DFDR data.

DFDR Early

This column contains the earliest possible DFDR time that the microphone could have been keyed, accounting for the one second sample rate described above. Additionally, microphone keying is recorded 0.034 second after the beginning of the subframe[7]. For example, if keying is recorded as "on" in subframe 5544, it is actually sampled 0.034 seconds later at 5544.034.

Calculated DFDR Time

This is the DFDR Subframe Reference Number *calculated* for each selected microphone "click" heard on the CVR. The equation used to calculate this value is described in the Correlation Method section of this report.

DFDR Late

This is the latest possible DFDR time that the microphone could have been keyed. It is exactly one second later than the *DFDR Early* value described above.

[7] Microphone Keying is recorded in word 3, bit 2, in the subframe. This is the 26th bit in the subframe (a total of 768 bits per subframe are recorded in series each second by the DFDR).

Calculated DFDR Duration

The duration of the transmission in seconds, based on the *Calculated DFDR Times*. This number is the difference of the 2 corresponding values in the *Calculated DFDR Time* column.

Within DFDR Limits?

This is a logical value that compares the *Calculated DFDR Time* for each “click” to the *DFDR Early* and *DFDR Late* times. If the calculated value falls within the possible range, the value of this column is TRUE. If not, the value is FALSE.

If not, how far off?

If the value of *Within DFDR Limits* is FALSE, this column indicates how far off out of range (in seconds) the calculated DFDR time is. This number is the difference between the calculated value and *DFDR Early (*or *DFDR Late*, whichever is appropriate). Value is “OK” if the calculated DFDR time is within the limits.

Direction

Left or right arrow indicating if the caculated DFDR value is to high or too low, if it falls outside the one second DFDR sample region.

Distance From DFDR Start

This column shows how far away the first click (beginning of transmission) is from the *DFDR Early* time, in seconds. It is the difference between *Calculated DFDR Time* for the first click, and corresponding *DFDR Early* value. Used For reference.

Distance From DFDR End

This column shows how far away the second click (end of transmission) is from the *DFDR Late* time, in seconds. It is the difference between *Calculated DFDR Time* for the second click, and corresponding *DFDR Late* value. Used for reference. Both this column and the *Distance From DFDR Start* column are used to determine how much the offset value in the correlation equation can be adjusted.

Radar UTC

This is the *Calculated DFDR Time* converted to Coordinated Universal Time (UTC).

Radar Local

This is the *Calculated DFDR Time* converted to local Eastern Daylight Time.

#	CVR Elapsed		CVR TT	Status	DFDR SRN	CVR	DFDR Duration		DFDR Early	calculated DFDR time	DFDR Late	Calc DFDR Duration	Within DFDR Limits?	If not, how far off	direction	distance from DFDR start	distance from DFDR end	Radar UTC	Radar Local	comment
	min	sec				Duration	min	max												
	0	2.7	2.7							5269.867								9:05:13.9	5:05:13.9	start of recording
1	4	37.7	277.7	on	5544	2.815	2	4	5543.034	5543.944	5544.034	2.805	TRUE	OK		0.910	0.090	9:09:48.0	5:09:48.0	
1	4	40.5	280.5	off	5547				5546.034	5546.749	5547.034		TRUE	OK		0.715	0.285	9:09:50.8	5:09:50.8	
2	5	4.7	304.7	on	5571	3.008	2	4	5570.034	5570.845	5571.034	2.997	TRUE	OK		0.811	0.189	9:10:14.9	5:10:14.9	
2	5	7.7	307.7	off	5574				5573.034	5573.843	5574.034		TRUE	OK		0.809	0.191	9:10:17.9	5:10:17.9	
3	5	19.4	319.4	on	5586	4.648	3	5	5585.034	5585.433	5586.034	4.632	TRUE	OK		0.399	0.601	9:10:29.5	5:10:29.5	
3	5	24.0	324.0	off	5590				5589.034	5590.064	5590.034		FALSE	0.030	>	1.030	-0.030	9:10:34.1	5:10:34.1	
4	5	40.5	340.5	on	5607	8.885	7	9	5606.034	5606.489	5607.034	8.854	TRUE	OK		0.455	0.545	9:10:50.5	5:10:50.5	
4	5	49.4	349.4	off	5615				5614.034	5615.342	5615.034		FALSE	0.308	>	1.308	-0.308	9:10:59.4	5:10:59.4	
5	5	52.9	352.9	on	5619	2.12	1	3	5618.034	5618.873	5619.034	2.113	TRUE	OK		0.839	0.161	9:11:02.9	5:11:02.9	
5	5	55.0	355.0	off	5621				5620.034	5620.985	5621.034		TRUE	OK		0.951	0.049	9:11:05.0	5:11:05.0	
6	8	8.3	488.3	on	5754	2.54	2	4	5753.034	5753.739	5754.034	2.531	TRUE	OK		0.705	0.295	9:13:17.8	5:13:17.8	
6	8	10.8	490.8	off	5757				5756.034	5756.270	5757.034		TRUE	OK		0.236	0.764	9:13:20.3	5:13:20.3	
7	8	45.5	525.5	on	5791	2.647	2	4	5790.034	5790.829	5791.034	2.638	TRUE	OK		0.795	0.205	9:13:54.9	5:13:54.9	
7	8	48.1	528.1	off	5794				5793.034	5793.467	5794.034		TRUE	OK		0.433	0.567	9:13:57.5	5:13:57.5	
8	8	55.3	535.3	on	5801	7.016	6	8	5800.034	5800.606	5801.034	6.991	TRUE	OK		0.572	0.428	9:14:04.6	5:14:04.6	
8	9	2.3	542.3	off	5808				5807.034	5807.598	5808.034		TRUE	OK		0.564	0.436	9:14:11.6	5:14:11.6	
9	9	17.2	557.2	on	5823	4.053	3	5	5822.034	5822.422	5823.034	4.039	TRUE	OK		0.388	0.612	9:14:26.5	5:14:26.5	
9	9	21.2	561.2	off	5827				5826.034	5826.460	5827.034		TRUE	OK		0.426	0.574	9:14:30.5	5:14:30.5	
10	9	32.4	572.4	on	5838	3.063	2	4	5837.034	5837.527	5838.034	3.052	TRUE	OK		0.493	0.507	9:14:41.6	5:14:41.6	
10	9	35.4	575.4	off	5841				5840.034	5840.580	5841.034		TRUE	OK		0.546	0.454	9:14:44.6	5:14:44.6	
11	9	45.6	585.6	on	5851	1.933	1	3	5850.034	5850.715	5851.034	1.926	TRUE	OK		0.681	0.319	9:14:54.8	5:14:54.8	
11	9	47.5	587.5	off	5853				5852.034	5852.641	5853.034		TRUE	OK		0.607	0.393	9:14:56.7	5:14:56.7	
12	10	27.8	627.8	on	5893	2.779	2	4	5892.034	5892.776	5893.034	2.769	TRUE	OK		0.742	0.258	9:15:36.8	5:15:36.8	
12	10	30.6	630.6	off	5896				5895.034	5895.545	5896.034		TRUE	OK		0.511	0.489	9:15:39.6	5:15:39.6	
13	10	33.2	633.2	on	5899	2.504	1	3	5898.034	5898.189	5899.034	2.495	TRUE	OK		0.155	0.845	9:15:42.2	5:15:42.2	
13	10	35.7	635.7	off	5901				5900.034	5900.684	5901.034		TRUE	OK		0.650	0.350	9:15:44.7	5:15:44.7	
14	10	43.3	643.3	on	5909	4.953	4	6	5908.034	5908.236	5909.034	4.936	TRUE	OK		0.202	0.798	9:15:52.3	5:15:52.3	
14	10	48.3	648.3	off	5914				5913.034	5913.172	5914.034		TRUE	OK		0.138	0.862	9:15:57.2	5:15:57.2	
15	10	56.0	656.0	on	5921	3.396	3	5	5920.034	5920.912	5921.034	3.384	TRUE	OK		0.878	0.122	9:16:05.0	5:16:05.0	
15	10	59.4	659.4	off	5925				5924.034	5924.296	5925.034		TRUE	OK		0.262	0.738	9:16:08.3	5:16:08.3	

Table 1. CVR/DFDR Correlation

16	13	25.8	805.8	on	6071	4.65	3	5	6070.034	6070.170	6071.034	4.634	TRUE	OK		0.136	0.864	9:18:34.2	5:18:34.2	
16	13	30.5	810.5	off	6075				6074.034	6074.803	6075.034		TRUE	OK		0.769	0.231	9:18:38.8	5:18:38.8	
17	17	43.3	1063.3	on	6327	2.351	2	4	6326.034	6326.710	6327.034	2.343	TRUE	OK		0.676	0.324	9:22:50.7	5:22:50.7	
17	17	45.6	1065.6	off	6330				6329.034	6329.052	6330.034		TRUE	OK		0.018	0.982	9:22:53.1	5:22:53.1	
18	18	31.7	1111.7	on	6376	2.162	1	3	6375.034	6374.968	6376.034	2.154	FALSE	0.066	<	-0.066	1.066	9:23:39.0	5:23:39.0	
18	18	33.8	1113.8	off	6378				6377.034	6377.123	6378.034		TRUE	OK		0.089	0.911	9:23:41.2	5:23:41.2	
19	18	41.9	1121.9	on	6386	3.336	2	4	6385.034	6385.157	6386.034	3.324	TRUE	OK		0.123	0.877	9:23:49.2	5:23:49.2	
19	18	45.2	1125.2	off	6389				6388.034	6388.481	6389.034		TRUE	OK		0.447	0.553	9:23:52.5	5:23:52.5	
20	18	52.6	1132.6	on	6396	2.156	2	4	6395.034	6395.804	6396.034	2.148	TRUE	OK		0.770	0.230	9:23:59.8	5:23:59.8	
20	18	54.8	1134.8	off	6399				6398.034	6397.952	6399.034		FALSE	0.082	<	-0.082	1.082	9:24:02.0	5:24:02.0	
21	18	59.3	1139.3	on	6403	1.2	0	2	6402.034	6402.480	6403.034	1.196	TRUE	OK		0.446	0.554	9:24:06.5	5:24:06.5	
21	19	0.5	1140.5	off	6404				6403.034	6403.675	6404.034		TRUE	OK		0.641	0.359	9:24:07.7	5:24:07.7	
22	22	33.2	1353.2	on	6616	2.129	1	3	6615.034	6615.653	6616.034	2.122	TRUE	OK		0.619	0.381	9:27:39.7	5:27:39.7	
22	22	35.3	1355.3	off	6618				6617.034	6617.775	6618.034		TRUE	OK		0.741	0.259	9:27:41.8	5:27:41.8	
23	22	40.1	1360.1	on	6623	4.6	4	6	6622.034	6622.497	6623.034	4.584	TRUE	OK		0.463	0.537	9:27:46.5	5:27:46.5	
23	22	44.7	1364.7	off	6628				6627.034	6627.081	6628.034		TRUE	OK		0.047	0.953	9:27:51.1	5:27:51.1	
24	22	59.4	1379.4	on	6642	4.033	3	5	6641.034	6641.751	6642.034	4.019	TRUE	OK		0.717	0.283	9:28:05.8	5:28:05.8	
24	23	3.4	1383.4	off	6646				6645.034	6645.770	6646.034		TRUE	OK		0.736	0.264	9:28:09.8	5:28:09.8	
25	24	53.7	1493.7	on	6756	3.181	2	4	6755.034	6755.595	6756.034	3.170	TRUE	OK		0.561	0.439	9:29:59.6	5:29:59.6	
25	24	56.8	1496.8	off	6759				6758.034	6758.765	6759.034		TRUE	OK		0.731	0.269	9:30:02.8	5:30:02.8	
26	25	7.7	1507.7	on	6770	2.783	2	4	6769.034	6769.552	6770.034	2.773	TRUE	OK		0.518	0.482	9:30:13.6	5:30:13.6	
26	25	10.4	1510.4	off	6773				6772.034	6772.325	6773.034		TRUE	OK		0.291	0.709	9:30:16.4	5:30:16.4	
27	25	18.1	1518.1	on	6780	1.997	1	3	6779.034	6779.916	6780.034	1.990	TRUE	OK		0.882	0.118	9:30:24.0	5:30:24.0	
27	25	20.1	1520.1	off	6782				6781.034	6781.906	6782.034		TRUE	OK		0.872	0.128	9:30:25.9	5:30:25.9	
28	25	33.2	1533.2	on	6795	6.27	6	8	6794.034	6795.032	6795.034	6.248	TRUE	OK		0.998	0.002	9:30:39.1	5:30:39.1	
28	25	39.5	1539.5	off	6802				6801.034	6801.280	6802.034		TRUE	OK		0.246	0.754	9:30:45.3	5:30:45.3	
29	28	49.5	1729.5	on	6991	5.092	4	6	6990.034	6990.574	6991.034	5.074	TRUE	OK		0.540	0.460	9:33:54.6	5:33:54.6	
29	28	54.6	1734.6	off	6996				6995.034	6995.648	6996.034		TRUE	OK		0.614	0.386	9:33:59.7	5:33:59.7	
30	30	37.0	1837.0	on	7098	3.917	3	5	7097.034	7097.715	7098.034	3.903	TRUE	OK		0.681	0.319	9:35:41.8	5:35:41.8	
30	30	40.9	1840.9	off	7102				7101.034	7101.618	7102.034		TRUE	OK		0.584	0.416	9:35:45.7	5:35:45.7	
31	31	55.2	1915.2	on	7176	3.406	2	4	7175.034	7175.634	7176.034	3.394	TRUE	OK		0.600	0.400	9:36:59.7	5:36:59.7	
31	31	58.6	1918.6	off	7179				7178.034	7179.028	7179.034		TRUE	OK		0.994	0.006	9:37:03.1	5:37:03.1	
	32	21.743	1941.743								7202.112							9:37:26.2	5:37:26.2	end of recording

Table 1. CVR/DFDR Correlation

Douglass P. Brazy

Mechanical Engineer (CVR)