NATIONAL TRANSPORTATION SAFETY BOARD
OFFICE OF AVIATION SAFETY (AS-50)
Washington, D.C. 20594

May 5, 1997

SPEECH EXAMINATION FACTUAL REPORT

A. ACCIDENT: DCA-94-MA-076

Location: Aliquippa, Pennsylvania
Date: September 8, 1994
Time: 1904 Eastern Daylight Time
Airplane: Boeing 737-300, N513AU

B. SPEECH EXAMINATION GROUP

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C. SUMMARY

On September 8, 1994, at 1904 Eastern Daylight time USAir flight 427, a Boeing 737-300, N513AU, crashed while maneuvering to land at Pittsburgh International Airport, Pittsburgh, Pennsylvania. The airplane was being operated on an instrument flight rules (IFR) flight plan under the provisions of Title 14, Code of Federal Regulation (CFR), Part 121, on a regularly scheduled flight from Chicago-O'Hare International Airport, Chicago, Illinois, to Pittsburgh. The airplane was destroyed by impact forces and fire near Aliquippa, Pennsylvania. All 132 persons on board the airplane were fatally injured.

D. DETAILS OF INVESTIGATION

Following a request from the Human Performance Group, the Speech Examination Group studied speech analysis as an investigative tool. The investigators conducted a detailed examination of the cockpit voice recorder (CVR) audio recording to obtain scientific evidence relevant to the actions and psychological stress of the pilots during the final upset sequence.

This report summarizes the results of this effort. The report consists of: a summary of speech analysis work from previous accident investigations; a summary of laboratory measurements completed by the NTSB Audio Laboratory; and a summary of opinions by three outside experts.

1. Examples of speech analysis in previous accident investigations.

Safety Board staff reviewed previous accident reports and spoke with senior investigators at foreign investigative agencies to determine whether speech analysis was used in previous accident investigations in ways that would serve as a precedent and guideline for the present effort. Speech analysis is a relatively new investigative tool, but staff identified several previous examples of its use. Reprints of these works are attached to this report.

Japanese authorities used speech analysis in the investigation of a 1985 accident involving a Boeing 747 aircraft in Gunman Prefecture, Japan, that resulted in 520 fatalities. Speech analysis was employed to address issues of psychological stress and possible hypoxia in the flight crew. Attachment 1 is a reprint from the accident report that describes this work [as translated into English by the Japanese authorities].

Australian authorities used speech analysis in the investigation of a 1988 mid-air collision near Tweed Heads, New South Wales, that resulted in four fatalities. Speech analysis was employed to address issues of workload and performance by the air traffic controller. Attachment 2 is a reprint from the accident report.

The Safety Board used speech analysis in its investigation of the 1989 catastropic oil spill involving the U.S. tankship Exxon Valdez near Valdez, Alaska. Speech analysis was employed to address issues of possible alcohol impairment of the master. Attachment 3 is a scientific article describing this work. The Safety Board used speech analysis in its investigation of two general aviation accidents, which occurred in 1991, at Midland, Texas, and in 1995, at Swan Lake, Montana. In both accidents, the Safety Board determined that "pilot incapacitation" was the probable cause of the accident. Attachments 4 and 5 are reprints describing the speech analysis work.

Authorities in the former Soviet Union used speech analysis extensively in accident investigations. This work continues in the Commonwealth of Independent States (CIS), according to information obtained by the Safety Board investigators through a scientific exchange program between the NTSB and the Interstate Aviation Committee (MAK) of the Commonwealth of Independent States (CIS). Attachment 6 is a reprint of a scientific paper [in English] by Dr. Belan, chief of the acoustics laboratory of MAK, while Attachment 7 is a reprint of two scientific papers describing aspects of the Russian work. Attachments 6-7 were published

by the Office of Aviation Medicine of the Federal Aviation Administration. in a 1995 technical publication.

2. Laboratory measurement by the NTSB Audio Laboratory

The NTSB Audio Laboratory measured three aspects of speech in the individual statements made by the captain during the routine and emergency portions of the flight. The three aspects were fundamental frequency ("pitch"), amplitude ("loudness"), and speaking rate. It was hoped that these measures would provide quantitative information useful for estimating the psychological stress of the captain during the emergency segment of the flight.

Scientific literature indicates that all three measures, especially fundamental frequency, tend to increase in response to the psychological stress experienced by the speaker (References 1 to 4). All three measures have been employed in previous accident investigations.

Description of the speech samples

The captain made numerous statements and radio calls during the routine portion of the flight, and, during the emergency period (approximately 1902:55 until 1903:23), made 12 statements noted on the CVR transcript and a radio call. He spoke the phrase "four twenty seven" during both routine and emergency radio calls, providing a basis for a direct comparison using the same words. Laboratory measurements was attempted on all statements by the captain.

No laboratory speech analysis was attempted for the first officer because of insufficient speech during the emergency period to provide meaningful analysis.

Extraction of the speech measures

Investigators attempted to derive high quality laboratory measures through the use of automated scoring techniques and conservative data strategies that would minimize contamination by artifacts. Fundamental frequency and amplitude were scored directly by computer, and speaking rate was determined with computer assistance.

The cockpit voice recorder (CVR) provided an audio record of the last 30.9 minutes of the flight as recorded at a rate of 1 7/8 inches per second on a Fairchild Model A-100 analog tape recorder located in the tail of the airplane. Speech for the captain, obtained from the captain's hot microphone channel ("HOT-1"), was captured through the boom microphone attached to the captain's headset and positioned directly in front of the mouth. The audio quality of the recording was excellent.

The CVR tape was digitized at a rate of 20 KHz., and the digital version was analyzed through the Entropic Signal Processing System for computer analysis (Entropic Research Laboratory, Inc., Washington, D.C.). The program estimated the probability of voicing at regular points within the waveform, and, for voiced samples, selected fundamental frequency estimates from candidates proposed by solving for the roots of the linear predictor polynomial computed periodically for the waveform. Amplitude was the estimate of the energy of the fundamental frequency. Speech samples and analysis parameters were portrayed on a Waves digital video

display contained in the system. It plotted the speech wave form over time and, on a separate display, estimated fundamental frequency, probability of voicing, and amplitude, all plotted over time. Speech duration was read directly from the wave form by the computer when the operator, having listened to a played sample, marked the start and end points of the desired speech sample.

Table 1 lists every statement made by the captain and the resulting laboratory measurements. The statements listed in Table 1 are identical to those in the CVR transcript except that some CVR statements were broken into several segments to correspond to the way the captain spoke. A pause in speech of 300 msec. or greater was used to define individual speech segments.

Table 1 shows a "dot" to indicate missing data. For example, there were missing data on all laboratory measurements for statements spoken between 1857:45 and 1858:20. These statements were nearly inaudible on the Hot-1 channel, although statements before and after this period were recorded with excellent fidelity. It is believed that the captain moved the boom microphone away from his mouth during this period to drink a refreshment, and repositioned the microphone at 1858:36 to speak with air traffic control. Table 1 also shows missing data on all laboratory measures for several other statements. This was due to significant background noise, either audible background speech by the air traffic controller or other loud noise in the cockpit, that made computer analysis impractical. Finally, Table 1 shows missing data for some individual measures. This is due to the requirements of the individual measures, as described below.

1) Fundamental Frequency

Extraction of fundamental frequency scores was complicated by the presence of a steady tone, about 400 Hz., produced by the airplane electrical system and recorded on the CVR tape. The recording was filtered to remove signals between 380 to 420 hz. and a scoring of all samples was completed. Those speech samples that received high scores (above 190 Hz.) were processed a second time with the filter removed and with careful visually monitoring of the program's extraction profile to prevent artifact introduction of high frequency estimates due to this tone. There was no missing data due to this procedure.

2) Amplitude

Amplitude measurements were not made on air-to-ground transmissions because these transmissions are processed through the aircraft electrical system and amplitude is subject to the arbitrary setting of listening comfort adjustments which can change during the flight. Amplitude measurements were made on statements recorded after 1859:06. Amplitude measurement required that the microphone be kept a constant distance from the speaker's mouth, and it was believed that the captain repositioned his microphone at this time following his drinking a refreshment.

3) Speaking rate.

Samples were examined using the Waves video display of the waveform with aural presentation to listen to the section being displayed. When the exact start and stop times of a desired statement were captured, these times were recorded and provided a precise measurement

of segment duration. Syllables in the statement were counted, as summarized in Table 1, and speaking rate was calculated in syllables per second. Speaking rate measures were computed only when the statement contained more than three syllables.

Results

Figures 1 and 2 plot the fundamental frequency and amplitude data obtained for the captain's speech before and during the emergency period. Because of missing data, no similar plot could be made for speaking rate.

Table 2 plots a separate set of measurements made on the phrase "four twenty seven" spoken by the captain under routine and emergency conditions. Because of missing data, no similar measurement could be reported for amplitude.

These laboratory results were made available to the three outside experts, as noted below.

3. Opinions by outside experts

The Safety Board identified and brought into the speech investigation experts in three specialties: breathing physiology, communication, and general speech analysis. All experts were approved by the Human Performance Group. Each expert visited Washington, D.C., studied the transcript and CVR tape, discussed his/her observations with the Human Performance Group, and prepared a final report. Experts had access to NTSB Audio Laboratory speech measures and any materials in the public docket on this accident that the specialist deemed relevant.

Scott Meyer, Ph.D., was an exercise physiologist at the Naval Aerospace Medical Research Laboratory, who focussed on breathing information. Attachment 9 is a copy of his final report.

Barbara Kanki, Ph.D., was a Human Performance Researcher at the NASA-Ames Research Center, who focussed on communication information. Attachment 10 is a copy of her report.

Alfred Belan, M.D., was Chief of the Acoustical Laboratory of the Interstate Aviation Committee, of the Commonwealth of Independent States. He participated in the investigation twice, first as an expert on issues of acoustic analysis and second as an expert on speech analysis, focussing on issues of psychological stress and physical effort. Dr. Belan's native language was Russian, and he conducted his work and his meeting with the Human Performance Group with the assistance of a translator. Attachment 11 is a copy of his original report in Russian followed by a certified English translation.

[redacted]
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Senior Human Performance Investigator

BSL 5/9/97

REFERENCES

1. Brenner, M., Doherty, E. T., & Shipp, T. Speech measures indicating workload demand. Aviation, Space, & Environmental Medicine, 1994; 65:21-6.

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3. Johnson, K., Pisoni, D. B., & Bernacki, R. H. Do voice recordings reveal whether a person is intoxicated? A case study. Phonetica, 1990; 47:215-37.

4. Ruiz, R., Legros, C., & Guell, A, Voice analysis to predict the psychological or physical state of a speaker. Aviation, Space, and Environmental Medicine, 1990; 61:266-71.

LIST OF TABLES

TABLE 1

Summary of the speech measures obtained on whole statements by the captain (5 pages).

Time	Source	Statement	F_o	Amp	Syl	Dur	Rate
1832:33	R	twenty six ninety seven, USAir four twenty seven, good day.	147	.	17	2.70	6.30
1833:08	R	center USAir four twenty seven at two nine oh.	152	.	14	2.17	6.45
1833:37	R	direct Akron, best forward, you got it, four twenty seven USAir.	154	.	18	2.98	6.04
1838:00	R	blocked.	133	.	1	0.39	.
1840:43	R	nineteen eighty seven, USAir four twenty seven, good day.	152	.	16	2.63	6.08
1840:50	R	Cleveland, USAir four twenty seven at two niner zero.	150	.	16	2.51	6.37
1840:57	R	uh, we're indicating uh, 'bout uh, three hundred uh, assigned.	156	.	15	3.22	4.66
1843:32	H	had a four and a seven in it.	175	.	9	1.16	7.76
1843:37	H	do you wanta let 'em up for a while?	.	.	.	.	.
1845:35	R	out of two nine oh for two four oh, USAir four twenty seven.	146	.	17	2.85	5.96
1845:56	H	what?	.	.	.	.	.
1847:27	R	twenty eight fifteen, USAir four twenty seven. good day.	158	.	15	2.32	6.47
1847:35	R	center, USAir four twenty seven descending two four oh.	154	.	16	2.61	6.13
1851:01	R	CUTTA at ten, thirty eleven, USAir four twenty seven.	147	.	17	3.01	5.65

Source: H = hot microphone, R = radio. F_o = fundamental frequency in Hertz. Amp = Amplitude in volts (not valid for radio transmissions or statements prior to 1859:06). Syl = number of syllables. Dur = Duration in seconds. Rate = syllables per second (calculated for statements of more than 3 syllables).

Time	Source	Statement	F_o	Amp	Syl	Dur	Rate
1851:11	H	it's true.	173	.	2	0.47	.
1851:18	H	I'm off.	179	.	2	0.47	.
1851:54	H	three two and two eight right.	.	.	.	.	.
1851:58	H	yep.	.	.	.	.	.
1853:29	H	not yet.	156	.	2	0.41	.
1853:31	H	no.	147	.	1	0.24	.
1853:34	H	pretzels.	145	.	2	1.06	.
1853:38	H	uh, I could use a glass of somethin',	175	.	9	1.92	4.69
1853:38	H	whatever's open. water uh,	162	.	8	1.46	5.48
1853:38	H	water,a juice..	147	.	4	1.06	3.77
1853:56	H	how fruity is it?	155	.	5	0.96	5.21
1854:30	R	ten two fifty over CUTTA, USAir four twenty seven.	150	.	16	2.55	6.27
1854:42	H	thirty eleven.	184	.	5	0.63	7.94
1854:44	H	you can't make it?	186	.	4	0.60	6.67
1856:22	R	OK speed back to two ten USAir four twenty seven. uh,	145	.	16	3.10	5.16
1856:22	R	we'll do our best to make the restriction.	145	.	10	1.33	7.52
1856:31	R	you got it.	145	.	3	.32	.
1856:36	R	twenty one twenty five, USAir four twenty seven, good day.	160	.	16	2.30	6.96

Source: H = hot microphone, R = radio. F_o = fundamental frequency in Hertz. Amp = Amplitude in volts (not valid for radio transmissions or statements prior to 1859:06). Syl = number of syllables. Dur = Duration in seconds. Rate = syllables per second (calculated for statements of more than 3 syllables).

Time	Source	Statement	F_o	Amp	Syl	Dur	Rate
1856:43	H	two ten, he said.	.	.	.	.	.
1856:49	H	I may have misunderstood him.	155	.	8	1.18	6.78
1856:52	R	approach, USAir four twenty seven is descending to ten.	169	.	16	2.66	6.02
1857:09	H	alright.	.	.	.	.	.
1857:14	H	that's good	.	.	.	.	.
1857:29	R	we're, comin' back to two ten and uh, one sixty heading down to ten, USAir four twenty seven,	149	.	25	4.92	5.08
1857:29	R	and uh, we have Yankee.	125	.	6	0.78	7.69
1857:40	H	what runway did he say?	194	.	6	0.89	6.74
1857:40	H	OK.	137	.	2	0.21	.
1857:45	H	it tastes like a **	.	.	.	.	.
1857:47	H	there's little grapefruit in it.	.	.	.	.	.
1858:02	C	how else is in it?	.	.	.	.	.
1858:10	C	yeah, there's more?	.	.	.	.	.
1858:20	C	I always mix the cranberry and the grapefruit, I like that.	.	.	.	.	.
1858:36	R	cleared to six, USAir four twenty seven.	135	.	11	1.61	6.83
1858:56	H	cranberry orange and sprite.	.	.	.	.	.
1859:06	H	altimeters and flight instruments thirty eleven?	160	719	14	1.94	7.22
1859:11	H	aah, where are we .... landing data is ...	.	.	.	.	.

Source: H = hot microphone, R = radio. F_o = fundamental frequency in Hertz. Amp = Amplitude in volts (not valid for radio transmissions or statements prior to 1859:06). Syl = number of syllables. Dur = Duration in seconds. Rate = syllables per second (calculated for statements of more than 3 syllables).

Time	Source	Statement	F_o	Amp	Syl	Dur	Rate
1859:16	H	thirty three, forty three an two hundred.	.	.	.	.	.
1859:22	H	shoulder harness?	.	.	.	.	.
1859:28	H	approach brief?	142	465	3	0.56	.
1859:54	H	ah, don't do this to me.	148	357	6	1.56	3.85
1900:12	H	I hate it when you don't hear the other transmissions.	.	.	.	.	.
1900:20	R	OK, one	145	.	3	0.50	.
1900:20	R	four zero heading and one ninety on the speed, USAir four twenty seven.	141	.	20	3.47	5.76
1900:34	H	seventy five.	.	.	.	.	.
1901:04	R	did you say two eight left for USAir four twenty seven?	147	.	15	2.01	7.46
1901:08	R	two eight right, thank you.	123	.	5	0.63	7.94
1901:10	H	two eight right.	143	520	3	0.58	.
1901:35	H	I can't ***.	.	.	.	.	.
1901:56	H	seven for six.	129	242	4	0.78	5.13
1902:06	H	boy, they always slow you up so bad here.	127	237	10	2.08	4.81
1902:24	H	[sound of chuckle] OK.	.	.	.	.	.
1902:32.0	R	we're looking for the traffic, turning to one zero zero, USAir four twenty seven.	130	.	23	3.21	7.17
1902:57.5	H	sheeez.	210	904	1	0.79	.

Source: H = hot microphone, R = radio. F_o = fundamental frequency in Hertz. Amp = Amplitude in volts (not valid for radio transmissions or statements prior to 1859:06). Syl = number of syllables. Dur = Duration in seconds. Rate = syllables per second (calculated for statements of more than 3 syllables).

Time	Source	Statement	F_o	Amp	Syl	Dur	Rate
1902:59.4	H	whoa.	175	599	1	0.44	.
1903:01.1	H	hang on.	191	653	2	0.33	.
1903:02.0	H	hang on.	188	588	2	0.34	.
1903:03.6	H	hang on.	216	793	2	0.41	.
1903:05.2	H	hang on.	215	879	2	0.52	.
1903:08.0	H	what the hell is this?	202	1091	5	1.12	4.46
1903:09.6	H	what the ...	.	.	.	.	.
1903:10.6	H	oh God..	214	2164	2	0.68	.
1903:10.6	H	oh God.	282	2324	2	0.63	.
1903:15.0	R	four twenty seven emergency.	219	500	9	1.65	5.45
1903:18.1	H	pull	286	2865	1	0.20	.
1903:19.1	H	pull	370	2761	1	0.20	.
1903:19.7	H	(pull)	.	.	.	.	.
1903:21.1	H	[sound of screaming]	.	.	.	.	.

Source: H = hot microphone, R = radio. F_o = fundamental frequency in Hertz. Amp = Amplitude in volts (not valid for radio transmissions or statements prior to 1859:06). Syl = number of syllables. Dur = Duration in seconds. Rate = syllables per second (calculated for statements of more than 3 syllables).

TABLE 2

Measurements obtained on the call sign "four twenty seven" spoken by the captain in radio transmissions under routine and emergency conditions
(1 page)

Table 2. Measurements obtained on the call sign "four twenty seven" spoken by the captain in radio transmissions under routine and emergency conditions.

ROUTINE PERIOD:

Time	Fundamental frequency (Hz.)	Duration (sec.)
1832:33	140	.73
1833:08	156	.79
1833:37	149	.67
1840:43	148	.80
1840:50	157	.74
1845:35	136	.79
1847:27	147	.71
1847:35	163	.76
1851:01	141	.76
1854:30	142	.80
1856:22	142	.79
1856:36	145	.66
1856:52	176	.78
1857:29	127	.70
1858:36	---	---
1900:20	123	.53
1901.04	138	.61
1902:32.0	128	.68
Average:	144.6	.725

EMERGENCY PERIOD:

Time	Fundamental frequency (Hz.)	Duration (sec.)
1903:15.0	214	.84

LIST OF FIGURES

FIGURE 1

Graph of the fundamental frequency measures for the captain's statements before and during the emergency

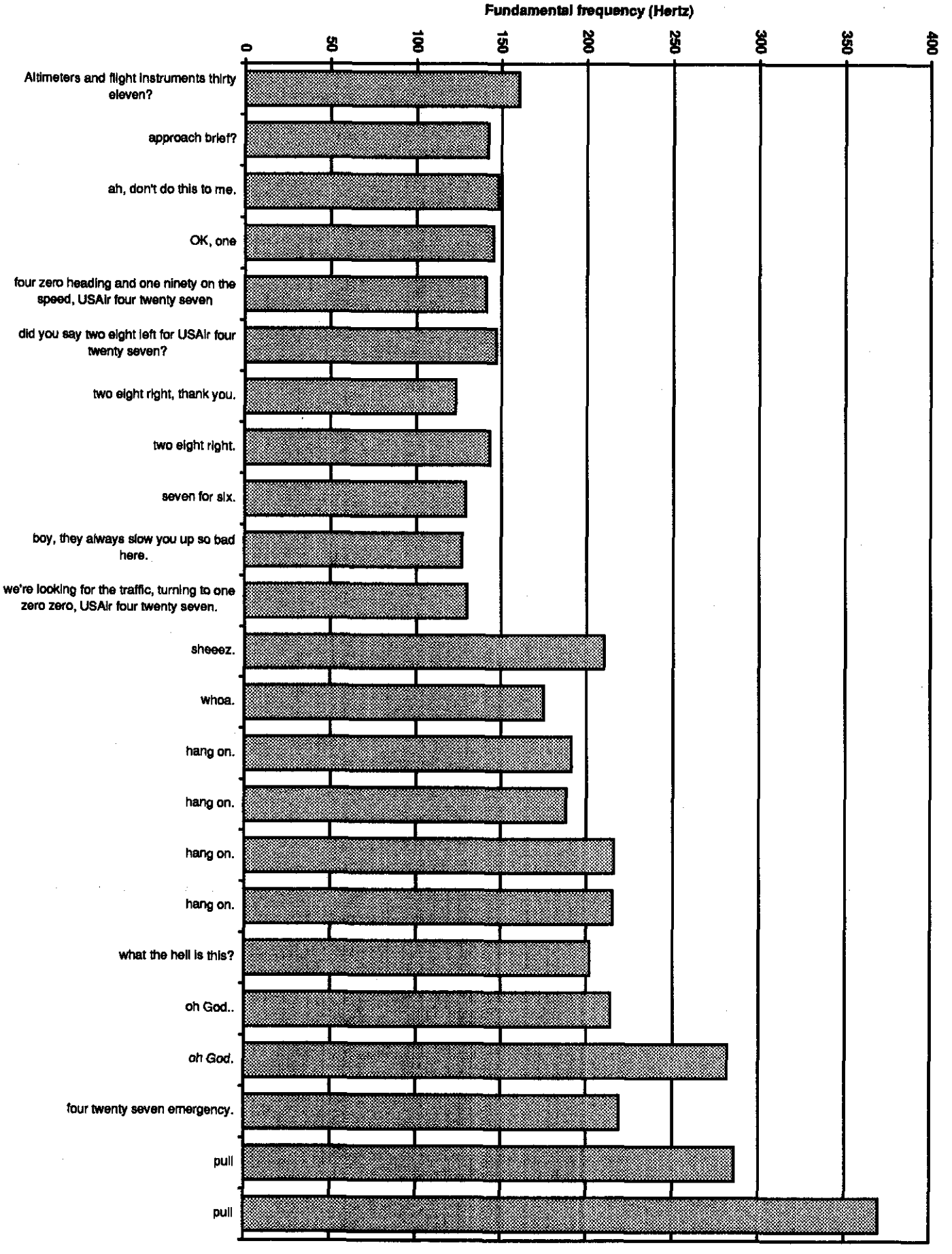
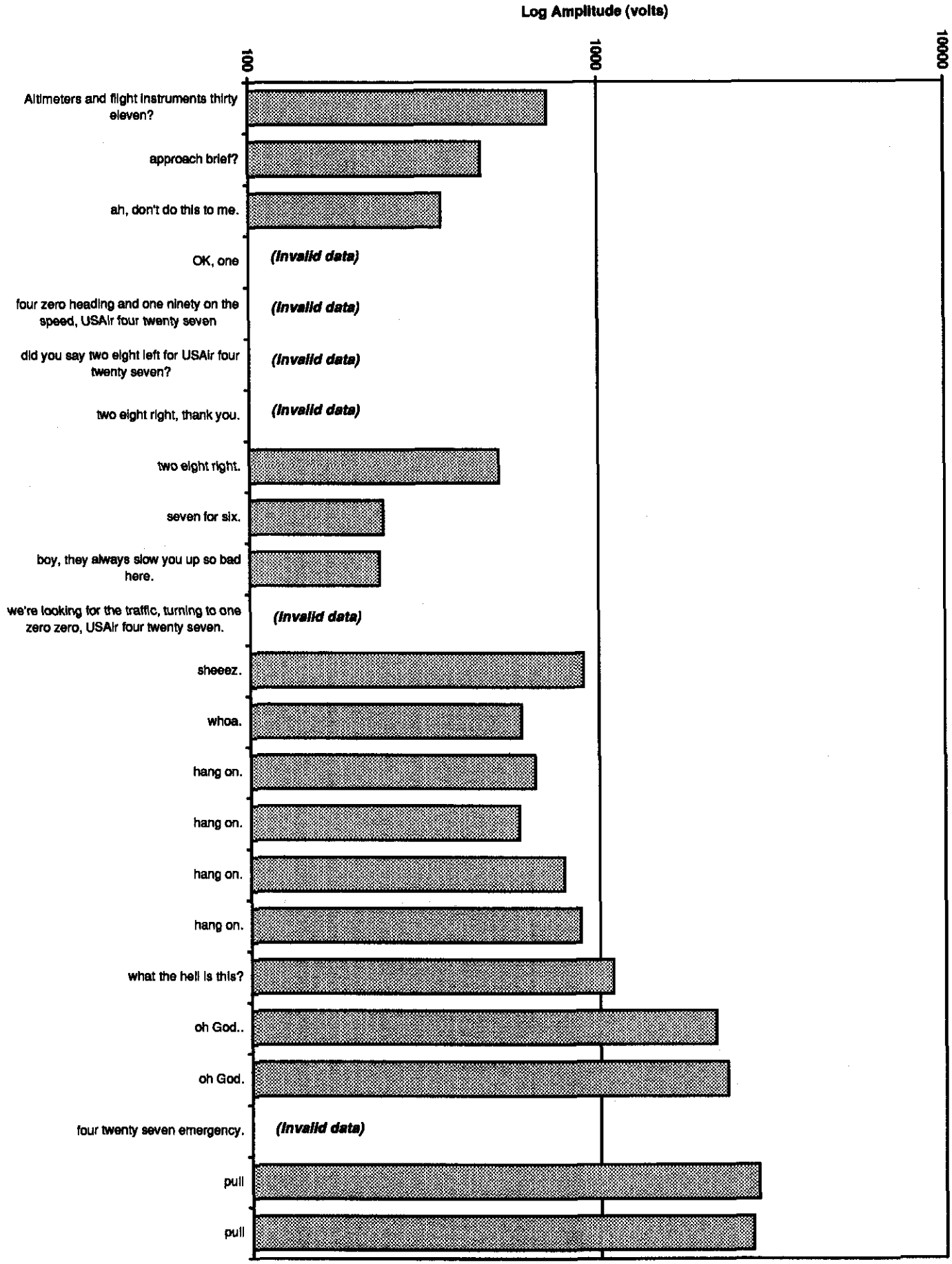

Fundamental frequency (Hertz)
0
50
100
150
200
250
300
350
400
Altimeters and flight instruments thirty eleven?
approach brief?
ah, don't do this to me.
OK, one
four zero heading and one ninety on the speed, USAir four twenty seven
did you say two eight left for USAir four twenty seven?
two eight right, thank you.
two eight right.
seven for six.
boy, they always slow you up so bad here.
we're looking for the traffic, turning to one zero zero, USAir four twenty seven.
sheeez.
whoa.
hang on.
hang on.
hang on.
hang on.
what the hell is this?
oh God..
oh God.
four twenty seven emergency.
pull
pull

FIGURE 2

Graph of the amplitude measures for the captain's statements before and during the emergency


Log Amplitude (volts)
100
1000
10000
Altimeters and flight instruments thirty eleven?
approach brief?
ah, don't do this to me.
OK, one
(Invalid data)
four zero heading and one ninety on the speed, USAir four twenty seven
(Invalid data)
did you say two eight left for USAir four twenty seven?
(Invalid data)
two eight right, thank you.
(Invalid data)
two eight right.
seven for six.
boy, they always slow you up so bad here.
we're looking for the traffic, turning to one zero zero, USAir four twenty seven.
(Invalid data)
sheeez.
whoa.
hang on.
hang on.
hang on.
hang on.
what the hell is this?
oh God..
oh God.
four twenty seven emergency.
(Invalid data)
pull
pull

LIST OF ATTACHMENTS

1. Reprint from a Japanese accident report concerning speech analysis.

2. Reprint from an Australian accident report concerning speech analysis.

3. Reprint of a scientific article on speech analysis in an American accident investigation.

4. Reprint from an American accident report concerning speech analysis in the investigation of a 1991 general aviation accident.

5. Reprint from an American accident report concerning speech analysis in the investigation of a 1995 general aviation accident.

6. Reprint of a scientific article on speech analysis by Dr. Alfred Belan.

7. Reprints of two scientific articles addressing aspects of speech analysis in the Commonwealth of Independent States.

8. Report prepared for this investigation by Dr. Scott Meyer.

9. Report prepared for this investigation by Dr. Barbara Kanki.

10. Report prepared for this investigation by Dr. Alfred Belan [in Russian], followed by an English translation.