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

June 18, 2009

Sound Spectrum Study Cockpit Voice - 12

Group Chairman's Report
By Joseph A. Gregor

A. EVENT

Location:	Columbia, SC
Date:	September 19, 2008, 23:53 EDT
Aircraft:	LearJet 60, N999LJ
Operator:	Global
NTSB Number:	DCA08MA098

B. GROUP

A sound spectrum group was formed.

Chairman:	Joseph A. Gregor National Transportation Safety Board
Member:	Anna Cushman Air Safety Investigator Federal Aviation Administration
Member:	Ed Grabman Engineering Test Pilot Bombardier
Member:	Sid-Ali Meslioui Air Safety Investigator Pratt & Whitney Canada

C. SUMMARY

On September 19, 2008, a LearJet 60, registration N999LJ operated by Global, overran the runway while aborting a takeoff in Columbia, SC. A solid state cockpit voice recorder (CVR) was sent to the National Transportation Safety Board's Audio Laboratory for readout. The sound spectrum group was formed to examine the engine and tire sounds found on the aircraft's CVR recording.

D. DETAILS OF INVESTIGATION

On September 20, 2008, the NTSB Vehicle Recorder Division's Audio Laboratory received the following CVR:

Recorder Manufacturer/Model:	Universal 1603-02-12 (CVR-120)
Recorder Serial Number:	1629

A 50-second portion at the end of the 2-hour recording was examined to document sounds related to engine operation and aircraft movement during takeoff roll and the subsequent abort. In order to document engine operation, the highest relative-amplitude narrow-band audio sound corresponding to the engine compressor blade-passage was examined. In order to document aircraft acceleration on takeoff roll, the narrow-band sound produced by the tires rolling over the grooved runway was examined.

The audio sounds recorded on the cockpit area microphone (CAM) channel of the CVR recording were digitized and examined using FASA, a software-based frequency analysis program used to document and analyze sounds from audio frequency recordings. Figures 1 and 2 show the spectra from a 16 kSa/s[1] audio extract illustrating relative signal energy as a function of time and frequency for the last 50-seconds of the CAM recording. The FFT was performed using a block size of 1024, an overlap of 512, and a Hamming window. The y-axis in each figure depicts frequency in Hz. The x-axis depicts elapsed time (in milliseconds) into the audio extracted, relative to the beginning of the file. Time zero in these figures corresponds to approximately 2354:32.2 EDT. Relative signal energy is depicted by color as described in the figure captions. To aid in the visual identification of features in the spectra, figure 2 repeats the data shown in figure 1 using a slightly different color map.

Audio data corresponding to engine operation can be seen as a series of narrow-band energy lines which peak in frequency at approximately 10 s elapsed time, and remain constant for the next 20 s prior to the onset of a high amplitude wide-band frequency noise burst. This noise bursts occurs at approximately 29.83 s into the audio extract, which coincides with a loud rumbling sound which begins on the CVR recording at 2355:12 EDT. The most prominent line corresponding to engine sounds was assumed to be the primary blade passage frequency for the N_1 compressor. For the times between t = 0 and 5 s, a 3rd harmonic of the primary line, which can be seen in the figures, was used for the N_1 calculation.

Audio data corresponding to aircraft acceleration down the runway can be seen as a single narrow-band energy line which increases in frequency approximately linearly in time prior to the onset of the high amplitude wide-band noise burst at 29.83 s into the audio extract. This line was assumed to correspond with sound produced as the aircraft tires rolled over the grooved runway. For the times between t = 0 and 8 s, a 7th

[1] KSa/s: kilo-Samples per second. Indicates the sample rate in units of thousands of samples per second.

harmonic of the primary line, which can be seen in the figures, was used for the calculation.

Sound signatures corresponding to rotation frequency for the aircraft engine N_1 compressor were composed of numerous harmonics and sub-harmonics indicating a complex, non-sinusoidal, waveform. It was assumed that the strongest signal – peaking at approximately 3900 Hz in Chart 1 – corresponded to the primary blade passage frequency. A presumed 3rd harmonic of this line can be observed early in time, when the background noise was low. The following conversion, obtained from the engine manufacturer,[2] was used to obtain N_1 from this primary blade passage frequency signal:

$$N_1 = \left(2.357 \times 10^{-2}\right) \cdot f \ , \qquad [1]$$

where f is the primary audio frequency corresponding to fan blade passage in Hz and N_1 is in $\%N_1$. Equation one applies to an engine with a 24 bladed fan and with 100% engine N1 occurring at 10,608 rpm.

Sound signatures corresponding to tire travel over a grooved runway were composed of a single, prominent narrow-band line and a 7th harmonic line occurring early in time when the background noise was low. Aircraft groundspeed would have been too low for the CVR to capture the primary frequency. This is indicative of a rounded square-wave type waveform. The runway grooves were measured to be approximately 0.5 inches wide, with centroid spaced approximately $\Delta x = 1.5$ inches apart. This indicates that an 8 Hz sound would correspond to travel at a 1 ft / minute rate. Aircraft ground speed may be obtained from the frequency of tire sounds produced by travel on a runway with this groove spacing using the following formula:

$$v = \Delta x \cdot f \cong \left(7.406 \times 10^{-2}\right) \cdot f \ , \qquad [2]$$

where f is the primary audio frequency corresponding to tire passage on the grooved runway in Hz, and v is the calculated aircraft groundspeed in knots.

[2] Private communication, Pratt & Whitney Canada.

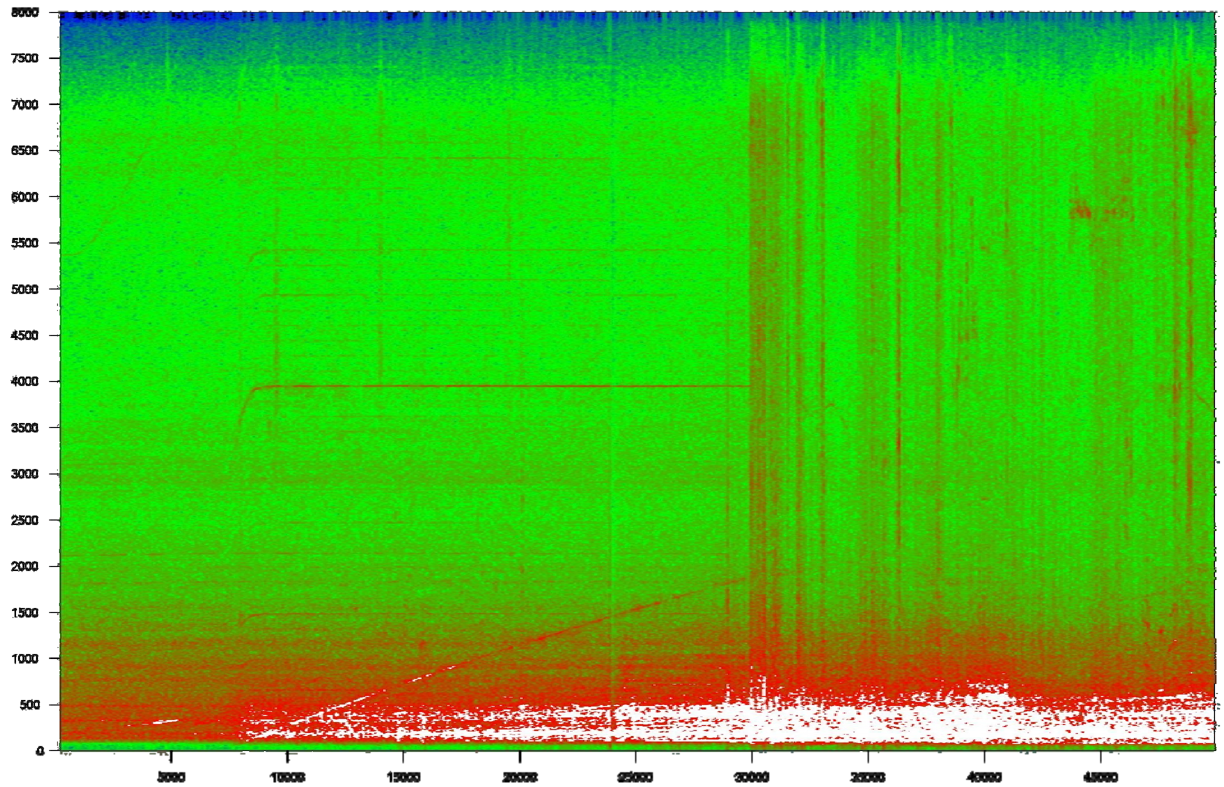

Figure 1. Frequency domain view (Spectrum) of audio corresponding to the last approximately 50-seconds of the cockpit area microphone (CAM) channel from the Universal 1603-02-12 (s/n 1629). The x-axis represents elapsed time in milliseconds from zero to 50 seconds. The y-axis represents frequency in Hz from zero to 8 kHz. The z-axis is represented by color, with white indicating the highest signal level, and blue the lowest signal level in the spectrum.

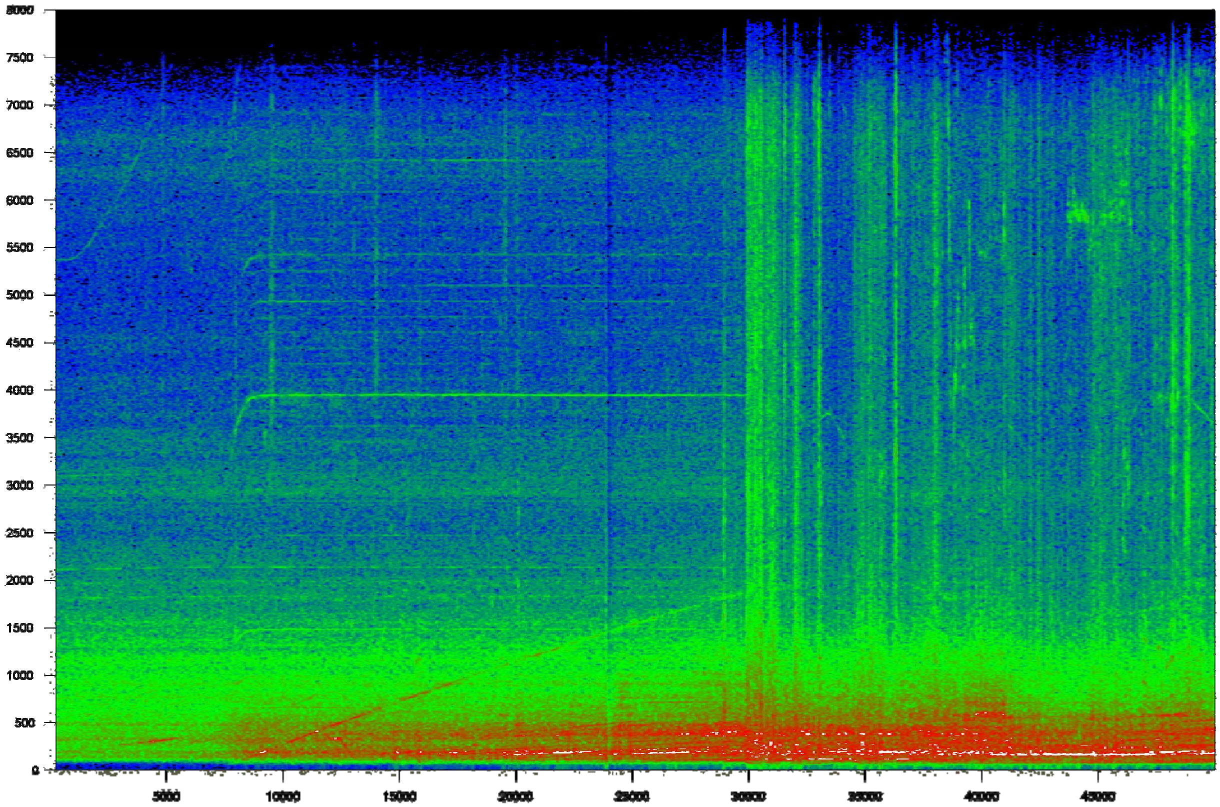

Figure 2. Frequency domain view (Spectrum) of audio corresponding to the last approximately 50-seconds of the cockpit area microphone (CAM) channel from the Universal 1603-02-12 (s/n 1629). The x-axis represents elapsed time in milliseconds from zero to 50 seconds. The y-axis represents frequency in Hz from zero to 8 kHz. The z-axis is represented by color, with red indicating the highest signal level, and black the lowest signal level in the spectrum.

Eq. (1) together with the audio data described above was used to obtain a curve of aircraft N_1 as a function of time. This curve is shown in figures 3 and 4. Breaks in the curve indicate those times during which there was no discernable narrow-band line corresponding to engine operation. The temporary absence of engine sounds is most likely due to swamping of the narrow-band signal in the presence of other broadband, high-amplitude sounds.

Eq. (2) together with the audio data described above was used to obtain aircraft ground speed as a function of time. This curve is shown in figure 5. Breaks in the curve indicate those times during which there was no discernable narrow-band line corresponding to tire rolling sounds. The temporary absence of tire sounds is likely the result of swamping of the signal due to the presence other broadband, high-amplitude sounds.

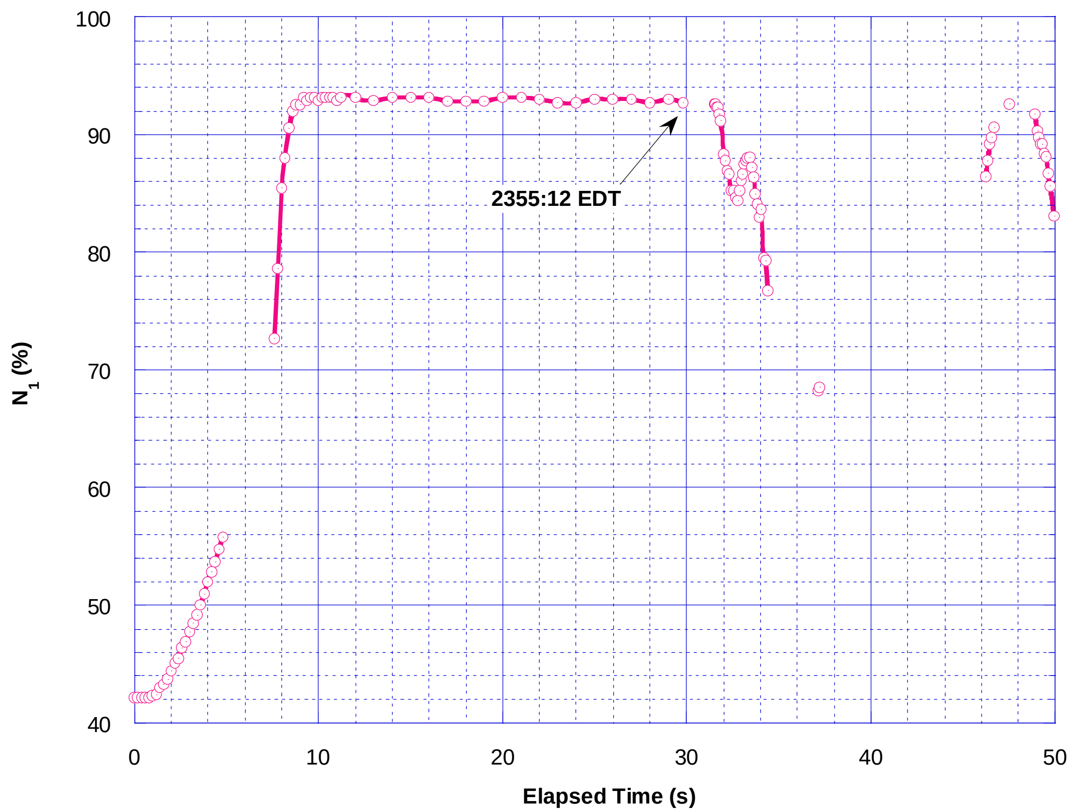

Figure 3. Calculated engine N_1 as a function of elapsed time into the extracted audio spectrum file. The time corresponding to a high amplitude wide-band noise signature recorded on the CAM channel of the CVR is depicted on the graph.

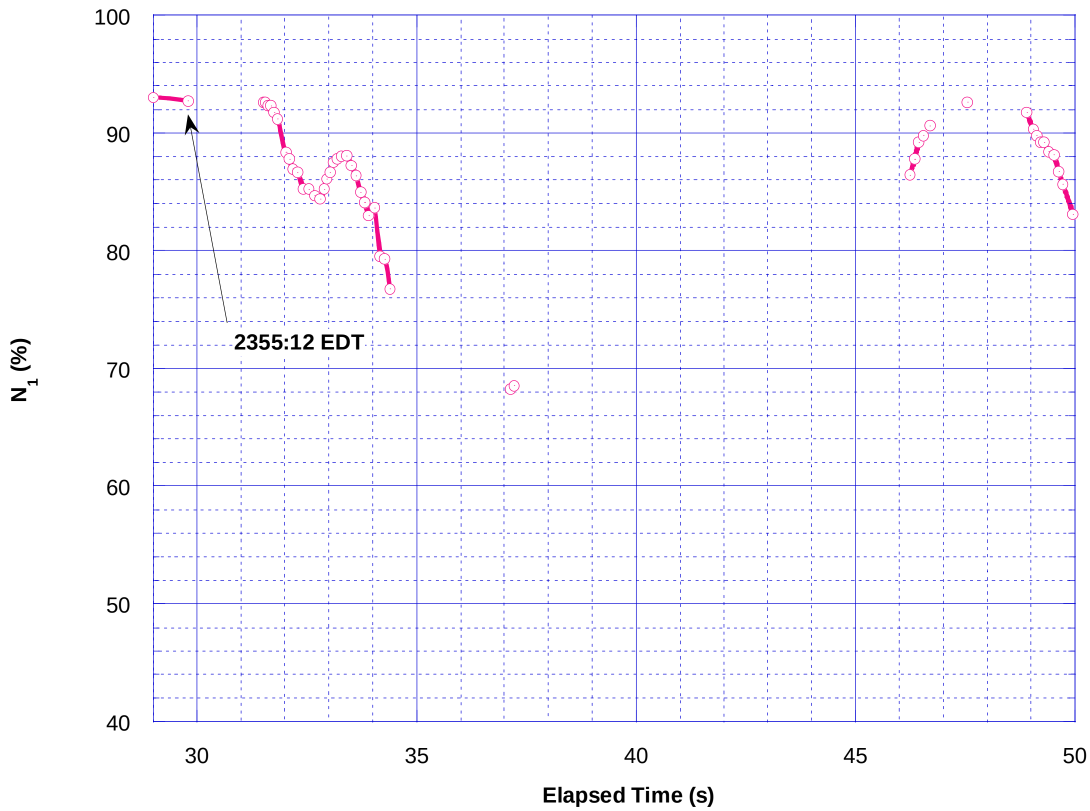

Figure 4. Expanded view of calculated engine N_1 as a function of elapsed time into the extracted audio spectrum file. The time corresponding to a high amplitude wide-band noise signature recorded on the CAM channel of the CVR is depicted on the graph.

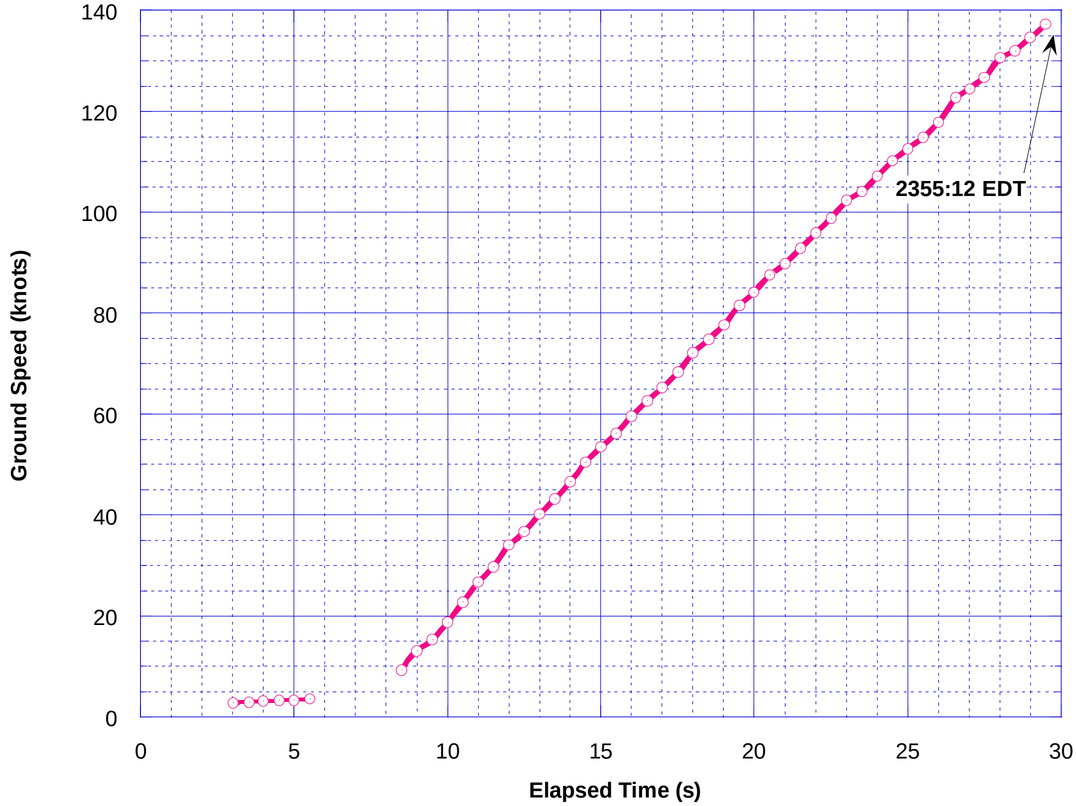

Figure 5. Calculated aircraft groundspeed as a function of elapsed time into the extracted audio spectrum file. The time corresponding to a high amplitude wide-band noise signature recorded on the CAM channel of the CVR is depicted on the graph.

Joseph A. Gregor
Electronic Engineer

APPENDIX A

Tabular data corresponding to figures 4 – 6 giving measured frequency for the peak of each peak narrow-band energy line used to calculate aircraft ground speed and engine rotation speed, together with the calculated parameters.

LEGEND

Time	Elapsed time in seconds into the audio extract
f_{meas}	Frequency of most prominent narrow band (NB) energy 'line' associated with the parameter being measured
f_{pri}	Frequency of most prominent narrow band (NB) energy 'line' associated with the parameter being measured, scaled to the frequency of the 'primary' line
N_1	Calculated engine N_1 based on the measured/scaled primary frequency

Data measured and used for calculating engine N_1:

Time [s]	f_{meas} [Hz]	f_{pri} [Hz]	N_1 [rpm]	N_1 [%]
0.0	5362.0	1787.3	4468.3	42.1
0.2	5362.0	1787.3	4468.3	42.1
0.4	5362.0	1787.3	4468.3	42.1
0.6	5362.0	1787.3	4468.3	42.1
0.8	5362.0	1787.3	4468.3	42.1
1.0	5386.0	1795.3	4488.3	42.3
1.2	5398.0	1799.3	4498.3	42.4
1.4	5471.0	1823.7	4559.2	43.0
1.6	5507.0	1835.7	4589.2	43.3
1.8	5567.0	1855.7	4639.2	43.7
2.0	5652.0	1884.0	4710.0	44.4
2.2	5737.0	1912.3	4780.8	45.1
2.4	5785.0	1928.3	4820.8	45.4
2.6	5906.0	1968.7	4921.7	46.4
2.8	5967.0	1989.0	4972.5	46.9
3.0	6076.0	2025.3	5063.3	47.7
3.2	6172.0	2057.3	5143.3	48.5
3.4	6257.0	2085.7	5214.2	49.2
3.6	6366.0	2122.0	5305.0	50.0
3.8	6487.0	2162.3	5405.8	51.0
4.0	6620.0	2206.7	5516.7	52.0
4.2	6729.0	2243.0	5607.5	52.9
4.4	6838.0	2279.3	5698.3	53.7
4.6	6971.0	2323.7	5809.2	54.8
4.8	7104.0	2368.0	5920.0	55.8
7.6	3082.0	3082.0	7705.0	72.6
7.8	3335.0	3335.0	8337.0	78.6
8.0	3626.0	3626.0	9065.0	85.5
8.2	3734.0	3734.0	9335.0	88.0
8.4	3843.0	3843.0	9607.0	90.6
8.6	3903.0	3903.0	9757.0	92.0

Line measured on the spectrum assumed to be 3rd harmonic of the primary frequency. (rows 0.0 – 4.8)

8.8	3927.0	3927.0	9817.0	92.5
9.0	3927.0	3927.0	9817.0	92.5
9.2	3952.0	3952.0	9880.0	93.1
9.4	3940.0	3940.0	9850.0	92.9
9.6	3952.0	3952.0	9880.0	93.1
9.8	3952.0	3952.0	9880.0	93.1
10.0	3940.0	3940.0	9850.0	92.9
10.2	3952.0	3952.0	9880.0	93.1
10.4	3952.0	3952.0	9880.0	93.1
10.6	3952.0	3952.0	9880.0	93.1
10.8	3952.0	3952.0	9880.0	93.1
11.0	3940.0	3940.0	9850.0	92.9
11.2	3952.0	3952.0	9880.0	93.1
12.0	3952.0	3952.0	9880.0	93.1
13.0	3940.0	3940.0	9850.0	92.9
14.0	3952.0	3952.0	9880.0	93.1
15.0	3952.0	3952.0	9880.0	93.1
16.0	3952.0	3952.0	9880.0	93.1
17.0	3939.0	3939.0	9847.0	92.8
18.0	3939.0	3939.0	9847.0	92.8
19.0	3939.0	3939.0	9847.0	92.8
20.0	3952.0	3952.0	9880.0	93.1
21.0	3952.0	3952.0	9880.0	93.1
22.0	3946.0	3946.0	9865.0	93.0
23.0	3934.0	3934.0	9835.0	92.7
24.0	3934.0	3934.0	9835.0	92.7
25.0	3946.0	3946.0	9865.0	93.0
26.0	3946.0	3946.0	9865.0	93.0
27.0	3946.0	3946.0	9865.0	93.0
28.0	3934.0	3934.0	9835.0	92.7
29.0	3946.0	3946.0	9865.0	93.0
29.8	3934.0	3934.0	9835.0	92.7
31.5	3928.0	3928.0	9820.0	92.6
31.6	3928.0	3928.0	9820.0	92.6
31.6	3916.0	3916.0	9790.0	92.3
31.7	3916.0	3916.0	9790.0	92.3
31.8	3892.0	3892.0	9730.0	91.7
31.8	3868.0	3868.0	9670.0	91.2
32.0	3748.0	3748.0	9370.0	88.3
32.1	3724.0	3724.0	9310.0	87.8
32.2	3688.0	3688.0	9220.0	86.9
32.3	3676.0	3676.0	9190.0	86.6
32.4	3616.0	3616.0	9040.0	85.2
32.5	3616.0	3616.0	9040.0	85.2
32.7	3592.0	3592.0	8980.0	84.7
32.8	3580.0	3580.0	8950.0	84.4
32.9	3616.0	3616.0	9040.0	85.2
33.0	3652.0	3652.0	9130.0	86.1
33.0	3676.0	3676.0	9190.0	86.6
33.1	3712.0	3712.0	9280.0	87.5
33.2	3724.0	3724.0	9310.0	87.8
33.3	3734.0	3734.0	9335.0	88.0
33.4	3736.0	3736.0	9340.0	88.0
33.5	3700.0	3700.0	9250.0	87.2
33.6	3664.0	3664.0	9160.0	86.3
33.7	3604.0	3604.0	9010.0	84.9
33.8	3568.0	3568.0	8920.0	84.1
33.9	3520.0	3520.0	8800.0	83.0
34.0	3549.0	3549.0	8872.0	83.6
34.2	3375.0	3375.0	8437.0	79.5
34.3	3363.0	3363.0	8407.0	79.3
34.4	3255.0	3255.0	8137.0	76.7
37.2	2895.0	2895.0	7237.5	68.2

37.2	2907.0	2907.0	7267.5	68.5
46.2	3666.0	3666.0	9165.0	86.4
46.3	3725.0	3725.0	9312.5	87.8
46.4	3785.0	3785.0	9462.5	89.2
46.6	3809.0	3809.0	9522.5	89.8
46.7	3845.0	3845.0	9612.5	90.6
47.5	3928.0	3928.0	9820.0	92.6
48.9	3893.0	3893.0	9732.5	91.7
49.0	3833.0	3833.0	9582.5	90.3
49.1	3809.0	3809.0	9522.5	89.8
49.2	3785.0	3785.0	9462.5	89.2
49.3	3785.0	3785.0	9462.5	89.2
49.4	3751.0	3751.0	9377.5	88.4
49.5	3739.0	3739.0	9347.5	88.1
49.6	3680.0	3680.0	9200.0	86.7
49.7	3632.0	3632.0	9080.0	85.6
50.0	3525.0	3525.0	8812.5	83.1

Data measured and used for calculating aircraft ground speed:

Time [s]	f_{meas} [Hz]	f_{pri} [Hz]	V [knots]
3.0	261.6	37.4	2.8
3.5	279.1	39.9	3.0
4.0	290.7	41.5	3.1
4.5	302.3	43.2	3.2
5.0	314.0	44.9	3.3
5.5	331.4	47.3	3.5
8.5	123.7	123.7	9.2
9.0	176.7	176.7	13.1
9.5	206.2	206.2	15.3
10.0	253.3	253.3	18.8
10.5	306.3	306.3	22.7
11.0	359.4	359.4	26.6
11.5	400.6	400.6	29.7
12.0	459.5	459.5	34.0
12.5	494.9	494.9	36.7
13.0	542.0	542.0	40.1
13.5	583.1	583.1	43.2
14.0	629.7	629.7	46.6
14.5	682.2	682.2	50.5
15.0	723.0	723.0	53.5
15.5	758.0	758.0	56.1
16.0	804.7	804.7	59.6
16.5	845.5	845.5	62.6
17.0	880.5	880.5	65.2
17.5	921.3	921.3	68.2
18.0	973.8	973.8	72.1
18.5	1008.8	1008.8	74.7
19.0	1049.6	1049.6	77.7
19.5	1101.0	1101.0	81.5
20.0	1136.2	1136.2	84.1
20.5	1183.0	1183.0	87.6
21.0	1212.3	1212.3	89.8
21.5	1253.3	1253.3	92.8
22.0	1294.3	1294.3	95.9
22.5	1335.3	1335.3	98.9
23.0	1382.1	1382.1	102.4
23.5	1405.6	1405.6	104.1
24.0	1446.6	1446.6	107.1
24.5	1487.6	1487.6	110.2
25.0	1520.1	1520.1	112.6
25.5	1549.9	1549.9	114.8
26.0	1591.7	1591.7	117.9
26.6	1657.2	1657.2	122.7
27.0	1681.1	1681.1	124.5
27.5	1710.9	1710.9	126.7
28.0	1764.5	1764.5	130.7
28.5	1782.4	1782.4	132.0
29.0	1818.2	1818.2	134.7
29.5	1854.0	1854.0	137.3

Line measured on the spectrum assumed to be 7th harmonic of the primary frequency. (applies to rows 3.0–5.5 s)