# Wind Noise and Sound Propagation Experiments in the Aarhus Mars Atmosphere Simulation Chamber

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**Introduction:** Here we explore the potential for a simple microphone to estimate wind speed on Mars via the amplitude of turbulent pressure fluctuations

**Background:** There is recurring public interest in recording sounds on Mars : as one of our primary senses, audio signals provide information on the environment, and wind noise is very familiar.

Active acoustic instrumentation (a speed of sound sensor and a sonar) was carried on the Huygens probe : echoes from the surface just prior to landing on Titan indicated surface roughness (Towner et al., 2006) and a curious suppression of ultrasound signals some time after touchdown suggests the evolution of heavy organic gasses with strong acoustic absorption (Lorenz et al., 2014). The aeroacoustic noise of descent was also detectable on a passive microphone.

It is possible that a microphone may be an effective and low-resource quantitative windspeed sensor. While an amplitude-based acoustic measurement of wind direction has not been developed for planetary application, an amplitude-based measurement of wind speed was reported on Venus by Ksanfomality et al. (1983) using the Groza instrument designed to detect thunder. The signal voltage was related to windspeed on the Venera 13 and 14 landers by assuming the amplitude scaled with dynamic pressure, and thus the square of windspeed.

On Mars, with an atmospheric pressure 200 times lower than Earth (and 10,000 times lower than Venus) the effectiveness of such a technique is not obvious. However, we show here that indeed the fluctuating signal on a microphone can robustly indicate windspeed at Mars conditions. A microphone was developed for the Mars Polar Lander (e.g. Delory, 1998), which was lost, and that on the Phoenix lander was not activated. A recent proposal (Maurice et al., 2016) aims to fly a microphone to support the Supercam investigation on the Mars 2020 rover.

In addition to being diagnostic of purely meteorological conditions, a microphone can shed insight into other aspects of geophysical processes, such as detecting saltation (which tends to have an audible hiss on Earth), sounds from booming dunes, or volcanic processes (e.g. Lorenz, 2016). In fact, terrestrial field experiments with a microphone showed promise as a wind measurement technique, and encouraged the laboratory experiments reported here.

**Field Experiments:** An off-the shelf Micro ElectroMechanical System (MEMS) microphone (Analog Devices ADMP401) on a small breakout board (BOB-09868, www.sparkfun.com) with a built-in x67 OPA344 preamplifier was deployed with a small long-duration pressure logger in the field at La Jornada Experimental Range in New Mexico. Dust devil encounters were identified via the well-known pressure drop associated with vortical flow. It is seen that the microphone generates appreciable signals associated with the vortex passage. Note, however, that the sample rate afforded by the field logger (1 Hz) is (far) too low to characterize the sound, and the microphone is not sensitive to infrasound (3dB points are 60Hz and 15 kHz) thus the microphone data give only a statistical indication of wind fluctuations. However, this field experience motivated a more controlled investigation.

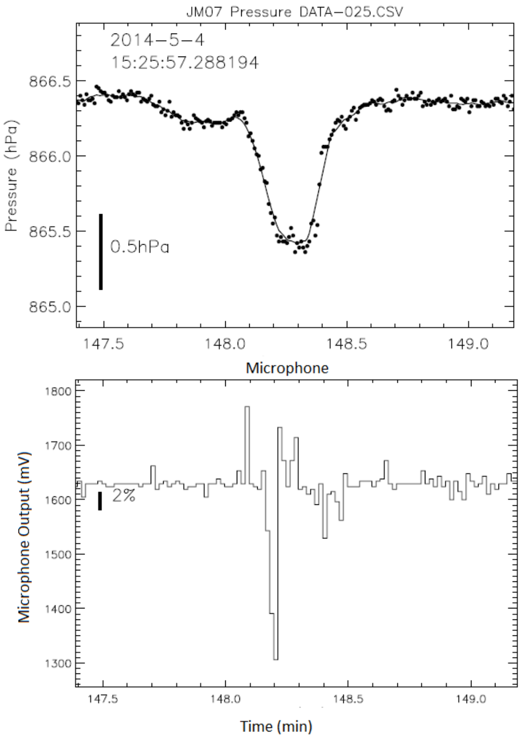


Figure 1. The characteristic pressure dip (top, e.g. Lorenz, 2012) of a dust devil vortex compared with the simultaneously-recorded voltage on a microphone, sampled only at 1Hz during an encounter in May 2014 at La Jornada.

**Wind Tunnel Experiments:** The same microphone device was installed on a 5cm standoff from the floor of the Aarhus Wind Tunnel Simulator II (AWTSII). This is a 50m$^3$ chamber (Figure 2) able to generate wind and dust in a simulated Mars atmosphere (6mb CO2) – e.g. Holstein-Rathlou et al. (2014).

The goal of the installation (Figures 3,4) was not to obtain flow out of the boundary layer so much as to simulate a likely low-impact accommodation on a small lander or rover.

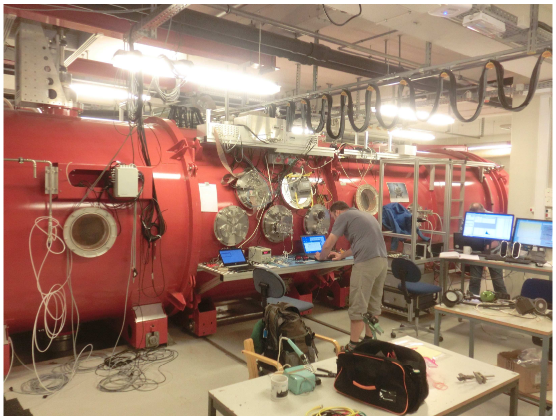


Figure 2. The Aarhus Chamber. As well as rapid (<1 hr) pump down to Mars pressure, the facility has many windows and feedthroughs to monitor conditions insider and permits rapid experiment reconfiguration.

Figure 3. Installing microphones on the floor of the tunnel working section, near a pitot tube to independently measure pressure fluctuations. A telltale wind indicator hangs from the tunnel ceiling, and the fans that drive the wind are visible at the back.

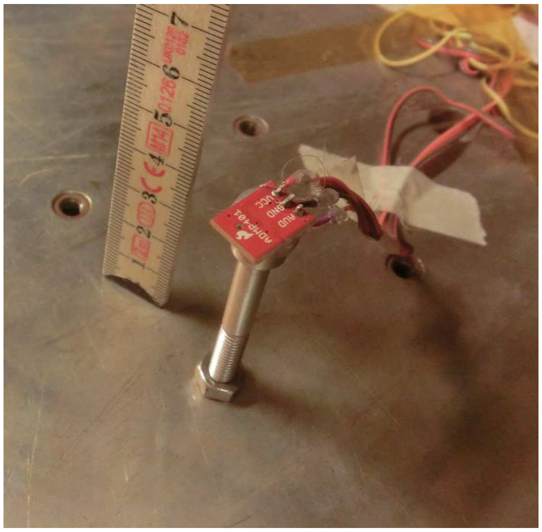


Figure 4. Microphone mounted ~5cm above the tunnel floor, on an M6 bolt. The hole in the circuit board exposing the microphone aperture is exposed, pointing upwards. This crude installation is analogous to a non-intrusive accommodation on a lander or rover.

The tunnel was operated at a range of pressures and speeds : data were acquired at 100 Hz by a PACE Scientific 12-bit XR-440M datalogger, and at 44 kHz by a TEAC VR-10 portable digital audio recorder used by us in field experiments at a volcano in Vanuatu (Lorenz et al., 2016)

The tunnel's operation by large fans does lead to significant ambient turbulence (e.g. Holsten-Rathlou et al., 2014) of typically 15%, but for low pressure flows at least, the turbulence falls to just a few per cent upon installation of a double mesh grid in the upstream part of the tunnel.

**Results:** Prominent signals (figures 5 and 6) were observed that correlate well with wind speed. We believe we can exclude mechanical coupling of e.g. fan vibration as a major contributor to the signal. First, a geophone was installed on the tunnel floor to detect structural oscillations – in general no movement was noticed except during speed changes (when the fan drive clutch occasionally slipped) or at very high speeds (>150 rpm at 1 bar; > 700 rpm at 6 mbar). Second, at a given fan speed (and thus, approximately, air speed), the fluctuations were roughly proportional to pressure, as would be expected. (Since the tunnel temperature is constant, pressure and density are directly proportional for a given gas composition, and dynamic pressure fluctuations should be proportional to density.)

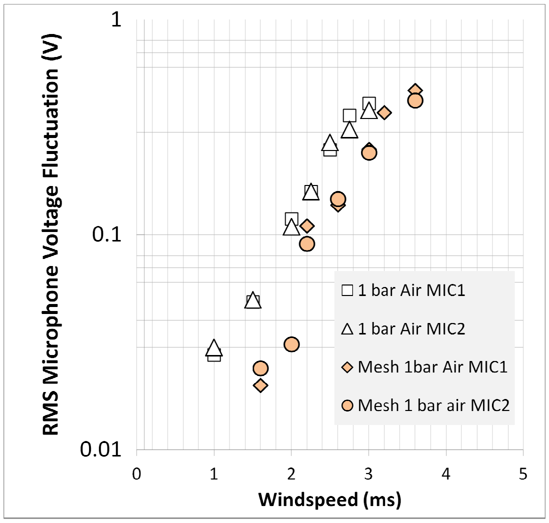


Figure 5. Microphone output in 1 bar air (rms voltage fluctuation calculated on 5s of samples at 100 Hz). It is seen that the signal varies monotonically with wind speed (estimated from fan motor rpm – future work will independently estimate wind speed and turbulent fluctuation from a laser doppler anemometer). It is further seen that the signal, which responds to turbulent fluctuations, is lower by a factor of ~2 for a given speed when the turbulence-suppressing mesh is installed.

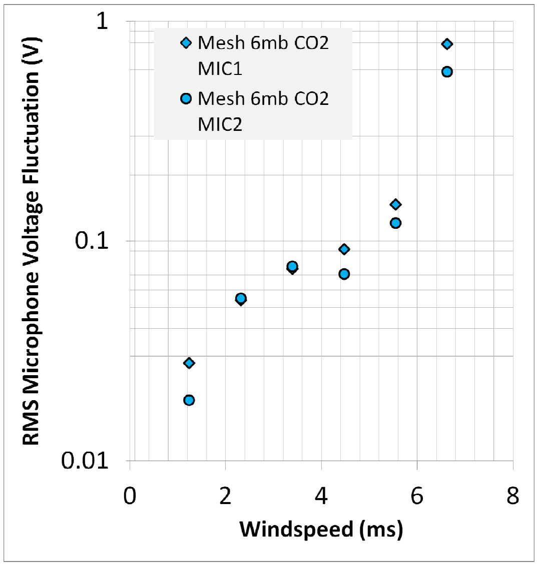


Figure 6. RMS microphone output (from 500 voltage samples acquired at 100 Hz) as a function of windspeed with a 6mbar CO2 atmosphere. While rather lower than the 1 bar values at a given speed, the signal is still easily measured. A double turbulence suppression mesh was installed upstream in the tunnel. Even at Mars atmosphere conditions, a strong signal is detected that shows a usefully monotonic variation with windspeed. The jump at 7 m/s is a vibration artifact as the tunnel fan system becomes stressed at its maximum operating speed.

**Sound Propagation Experiments:** In addition to measuring the aeroacoustic noise developed by the flow, we also inserted acoustic signals into the chamber with a conventional moving-coil loudspeaker and a piezoelectric buzzer.

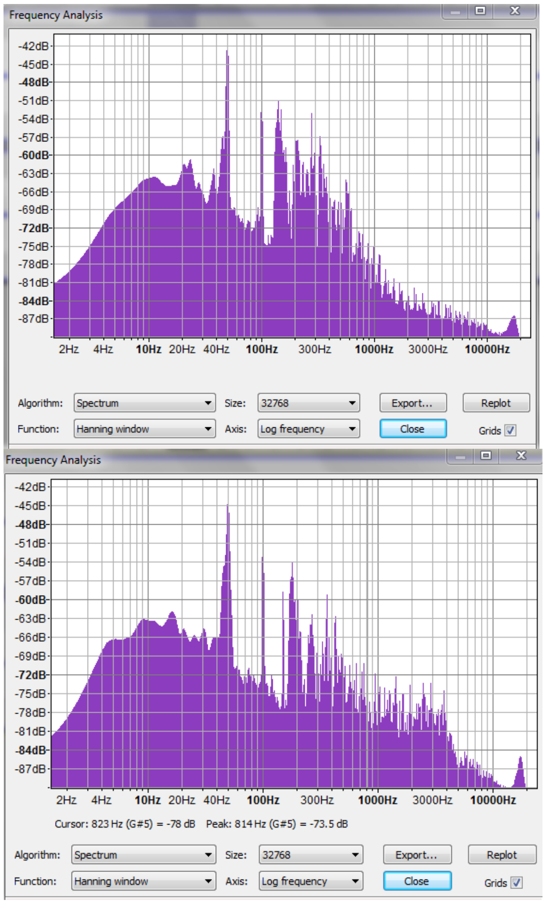
The tunnel floor and ceiling are flat and made of solid aluminium, and thus are near-perfect acoustic reflectors. Thus accurate acoustic measurements are challenged by multipath propagation effects, reverberation etc. and so we have not yet attempted experimental quantification of the predicted acoustic attenuation in low-pressure carbon dioxide atmospheres (e.g. Williams, 2001; Petculescu and Lueptow, 2007). However, over distances of ~4m, it was possible to detect and identify sounds (e.g. Movement II of Oxygene by Jean-Michel Jarre – see http://www.lpl.arizona.edu/~rlorenz/oxygene_on_Mars.mp3)

More quantitatively, white noise, logarithmic frequency sweeps (chirps) and DIN dual-tone test signals were generated with a Macintosh utility and transmitted from the upstream end of the tunnel from a conventional PC amplified speaker, set on a compliant isolation mount about 20cm above the tunnel floor. The received microphone signals were recorded at two locations, separated by 30cm, the closer one being 4.2m from the speaker. It was noted that the overall signal amplitudes were similar for random signals (like the white noise, and the log sweep on average) but for individual tones (such as the DIN signal, with 250 and 8000 Hz components) the signal amplitudes could be quite different, suggesting that some significant effects relating to propagation in the chamber are occurring. Future quantitative studies should install anechoic material on the tunnel walls to inhibit reflection.

Nonetheless, it was very straightforward to see that the RMS microphone voltage from the same (electrical) test signal declined by about 2 orders of magnitude between tests in 1 bar air and tests in 6 mbar of CO2. For eample, the microphone voltage on a -12 dB white noise signal at 1 bar was 0.25V whereas at 6 mbar it was 0.002 V (for both 6 mbar air and 6 mbar CO2).

Despite the nonideal propagation, and the presence of much electrical noise, There is some evidence (figure 7) that some attenuation is seen at kHz frequencies in CO2 at 6mbar that is not seen in air at a similar pressure.

Even a modest wind at 6mbar CO2 (can generate microphone signals (figure 8) which are an order of magnitude stronger than sounds transmitted from a few meters away. Nonetheless, if the characteristic of the known sound (the crack from a laser shot, for example) is known and has broad frequency content, careful signal processing may be able to extract it. Dedicated experiments for this application are recommended.



Algorithm: Spectrum Size: 32768
Function: Hanning window Axis: Log frequency
Grids ☑

Cursor: 823 Hz (G#5) = -78 dB Peak: 814 Hz (G#5) = -73.5 dB

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Figure 7. Spectrum of the microphone signal when a white noise (-12dB) signal was sent from the speakers. There are prominent lines at 50Hz and other frequencies from the electrically-noisy facility. Upper curve in 6 mbar CO2, lower curve in 4 mbar air. Note the drop in signal level, presumably due to acoustic absorption, between about 1kHz and 5kHz.

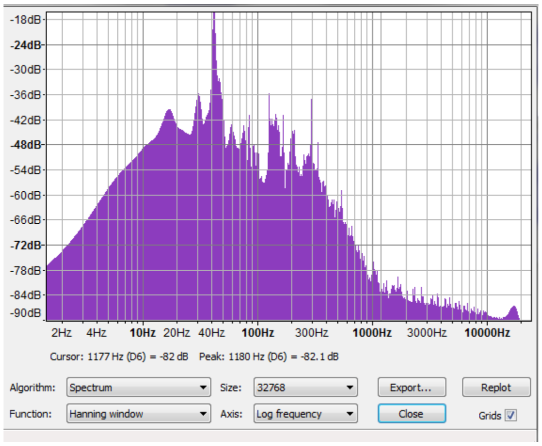

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Figure 8. Wind noise spectrum with 6mbar CO2 at ~2m/s. Note that the low-frequency signal power is much stronger with wind noise (e.g. -50dB at 10Hz, compared with -66dB with the white noise source above).

**Conclusions:** While only partly quantitative, these experiments show considerable promise that a microphone such as that proposed by Maurice et al. (2016) may (1) record sounds e.g. generated by the lander or laser operations (2) may record wind noise and (3) the wind noise may be interpretable as a measure of wind speed. It is seen that wind noise is most significant at lower frequencies, and so laser-related applications may wish to focus on as high frequencies as the propagation through CO2 will permit.

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**References:**

Williams, J. P. (2001). Acoustic environment of the Martian surface. Journal of Geophysical Research: Planets (1991–2012), 106(E3), 5033-5041

Delory, G. T., et al. (2007). Development of the first audio microphone for use on the surface of Mars. J. Acous. Soc. of Am., 121(5), 3116-3116

Holstein-Rathlou, C., Merrison, J., Iversen, J.J., Jakobsen, A.B., Nicolajsen, R., Nørnberg, P., Rasmussen, K., Merlone, A., Lopardo, G., Hudson, T. and Banfield, D., 2014. An environmental wind tunnel facility for testing meteorological sensor systems. Journal of Atmospheric and Oceanic Technology, 31(2), pp.447-457

Ksanfomality, L., Goroschkova, N., Khondryev, V., 1983. Wind velocity near the surface of Venus from acoustic measurements. Cosm. Res. 21, 161–167.

Lorenz, R. D., E. P. Turtle, R. Howell, J. Radebaugh, R. Lopes, The Roar of Yasur : Handheld Audio Recorder Monitoring of Vanuatu Volcanic Vent Activity, Journal of Volcanology and Geothermal Research, in press

Lorenz, R. D., M. R. Leese, J. C. Zarnecki, A. Hagermann, P. Rosenberg, M. Towner, J. Garry and H. Svedhem, Silence on Shangri-La : Detection of Titan Surface Volatiles by Acoustic Absorption, Planetary and Space Science, 90, 72–80, 2014

Maurice, S., R. C. Wiens, W. Rapin, D. Mimoun, X. Jacob, B. Betts, J.F. Bell III, G. Delory, S. M. Clegg, A. Cousin, O. Forni, O. Gasnault, J. Lasue, P.-Y. Meslin (2016) A Microphone Supporting LIBS Investigations at Mars,#3044, 47th Lunar and Planetary Science Conference, Houston, TX.

Petculescu, A., Lueptow, R. M. (2007). Atmospheric acoustics of titan, mars, venus, and earth. Icarus, 186(2), 413-419

Towner, M. C., J.R.C. Garry, R.D. Lorenz, B. Hathi, A. Hagermann, H. Svedhem, B.C. Clark, M.R. Leese, J.C.