SPEED OF SOUND MEASUREMENT ON MARS AND ITS IMPLICATIONS. Baptiste Chide[1,2], Sylvestre Maurice[2], David Mimoun[1], Naomi Murdoch[1], Ralph D. Lorenz[3] and Roger C. Wiens[4], [1]Institut Supérieur de l'Aéronautque et de l'Espace (ISAE-SUPAERO), Toulouse, France, [2]Institut de Recherche en Astrophysique et Planétologie (IRAP), [3]Applied Physics Laboratory (APL), [4]Los Alamos National Laboratory (LANL) Baptiste.Chide@isae-supaero.fr

Introduction. Despite strong attenuation due to CO2, sounds do propagate on Mars at speeds close to that on Earth [1]. For a perfect gas, the speed of sound c only depends on temperature and atmosphere composition, and is given by:

$$c = \sqrt{\frac{\gamma RT}{M}}$$

where T is the air temperature, γ the ratio of specific heats, M the mean molar weight of the atmosphere (annual mean of $43.48\,\mathrm{g\,mol^{-1}}$ determined in [2]) and R the perfect gas constant. On Mars, air temperature ranges from $180\,\mathrm{K}$ at night ($c = 216\,\mathrm{m\,s^{-1}}$) up to $280\,\mathrm{K}$ during the day ($c = 270\,\mathrm{m\,s^{-1}}$) [3]. The Planetary Boundary Layer (PBL), which represents the lower part of the atmosphere interacting with the surface, is a highly dynamical layer that follows an important diurnal cycle. It is strongly turbulent during the daytime due to convectives plumes induced by the warm surface whereas at night, the atmosphere is more stable and stratified [4]. In-situ measurements provided by Pathfinder [5] and by the Mars Explorations Rovers [6] showed that there is a vertical thermal gradient between the surface and 1 meter of height on the order of $-20\,\mathrm{K\,m^{-1}}$ during daytime leading to a speed of sound variation of 10% from the surface to an height of 2 meters. The layer also shows a maximum instability during the afternoon with temperature fluctuations up to $8\,\mathrm{K}$ over time scales shorter than $30\,\mathrm{s}$ [7]. At night, the thermal gradient reverses and reaches +$4\,\mathrm{K\,m^{-1}}$. Consequently, measurement of the speed of sound on Mars gives us a direct measurement of the temperature and thus of the properties of the atmosphere close to the surface.

Speed of Sound Measurements. As an add-on to the SuperCam instrument suite, the Mars Microphone will record laser-induced sparks on rocks, and associated shock wave, to support Laser-Induced Breakdown Spectroscopy (LIBS) investigations [8]. One of its operating modes is a $60\,\mathrm{ms}$ wide recording window around the laser pulse, in order to precisely measure the propagation time that it takes for the acoustic wave to travel from the target to the microphone. The $100\,\mathrm{kHz}$ sampling frequency gives an uncertainty on the spark arrival time of $10\,\mathrm{\mu s}$. The detection threshold of the acoustic peak, depending on the signal-to-noise ratio of the recording, also adds an absolute uncertainty of $\sim 5\,\mathrm{\mu s}$. The distance from the target to the microphone is known via the autofocus capability of SuperCam. Currently at Gale crater, the ChemCam LIBS instrument estimates the target distance with an relative uncertainty of $\pm 0.5\%$ [9]. However, in the case of calibration target located on the deck of the rover [10], the distance is more precisely known by design even though the thermal expansion of the aluminum that composes the structure of the rover ($23\,\mathrm{\mu m\,K^{-1}\,m^{-1}}$) leads to a distance uncertainty of a few millimeters (less than 0.28%).

Validation during rover thermal tests. Mars 2020 rover flight model end-to-end tests were performed in October 2019 at JPL. The SuperCam microphone recorded LIBS shock-waves from the titanium and ferrosilite calibration targets [11]. Fig. 1 shows the detection of the waveform recorded on the ferrosilite target. The thermal chamber was filled with 7 mbar of N_2 and tests were conducted at $-55\,^{\circ}\mathrm{C}$ and $-80\,^{\circ}\mathrm{C}$ respectively. Estimations of the nitrogen speed of sound at these two temperatures are synthesized in Table 1. These tests show that it is possible to retrieve the speed of sound with the Mars Microphone

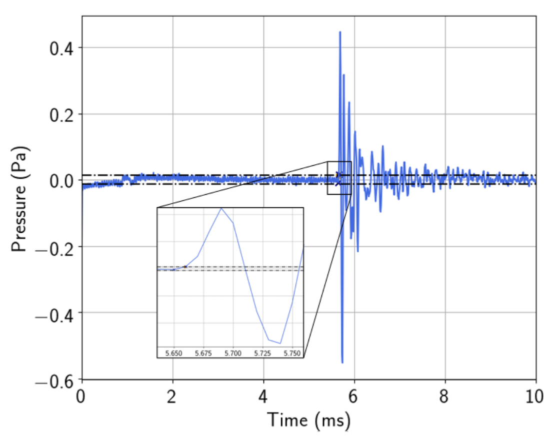

Figure 1: LIBS spark recorded on the SuperCam titanium calibration target during Mars2020 System Thermal tests. Black dashed lines are the detection threshold at $\pm 2\sigma$. The arrival time is set when the signal crosses this detection threshold.

Target	Shroud Temp (°C)	Microphone-to-Target Distance (mm)	Propagation Time (ms)	Measured Sound Speed (m/s)	Theoretical Sound Speed (m/s)
Titanium	-55	1493.5 ± 7.5	5.159 ± 0.015	289.5 ± 2.0	301.1
Ferrosilite	-80	1492.7 ± 7.5	5.280 ± 0.015	282.7 ± 1.9	283.3

Table 1: Summary of parameters and results acquired during SuperCam Microphone end-to-end tests on calibration targets used to estimate the sound speed in nitrogen. Theoretical speed is given considering a ration of specific heats of 1.4 for N_2 and an atmosphere temperature given by the temperature of the chamber. Microphone to-target distance was computed taking into account the thermal contraction at colder temperatures. Uncertainty for this distance is considered to be $\sim$0.5%.

with a precision better than 1%. For the first case, the measured speed differs by more than the stated uncertainty suggesting a slightly colder environment than expected. In the second case the measured speed of sound is consistent with the theoretical value. These preliminary results show the robustness of the method. This measurement sequence should be similar and applied the same way on Mars.

Tracking the Boundary Layer Gradient. For a target located around the rover at a distance D from the microphone, the propagation time measurement integrates the variation of the speed of sound from the surface up to an height H of the microphone due to a thermal gradient ΔT close to the surface. All the introduced notations are referenced in Fig. 2. Assuming a linear thermal gradient, the propagation time can be expressed as follows:

$$\delta t = \sqrt{\frac{M}{R\gamma}} \times \int_0^D \frac{1}{\sqrt{T_0 + z\Delta T}}\,\mathrm{d}r$$

with T_0 being the surface temperature, and z the height from relative to the surface. Expanding this relationship gives the expression of the vertical thermal gradient:

$$\Delta T = \frac{4T_0}{H}\left(1 - \frac{c_0 \delta t}{D}\right)$$

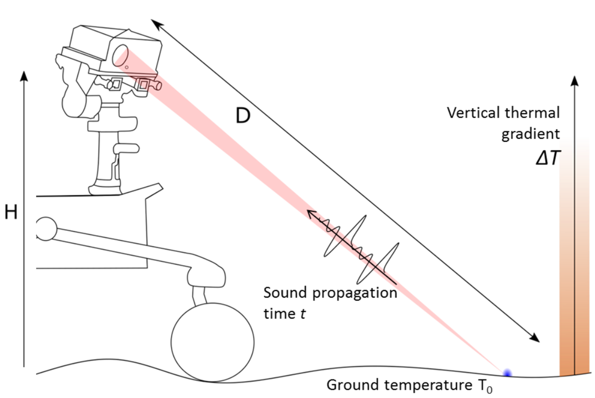

Figure 2: Thermal gradient estimation by analysis of the sound speed by the SuperCam Microphone.

where c_0 is the sound speed at the surface of temperature T_0. The surface temperature will be provided by the Mars Environmental Dynamics Analyzer (MEDA) of Mars2020 that relies on the heritage of REMS onboard Curiosity to measure the ground temperature via infrared brightness with an accuracy of $\pm 5\,\mathrm{K}$ and a precision of $0.1\,\mathrm{K}$ [12]. Considering uncertainty of the surface temperature, the propagation time and the distance, the uncertainty of the temperature gradient from the microphone is expected to be given with a precision of 35% from a single measurement. Special care should be taken in the case of winds coming from the rear of the rover, yielding thermal contamination by the RTG [13].

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