# EXPERIMENTS OF SPEED OF SOUND IN THE LOW PRESSURE ATMOSPHERE OF MARS

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Future Mars Landers might include kinds of acoustic sensors to detect obstacles, to listen for sounds, or to measure the wind speed, etc. The atmosphere on Mars is much different from that on earth, that the pressure is very low (i.e. 600-1000 Pa) and the dominant constituent is $CO_2$. The speed of sound in the tenuous Martian atmosphere had been theoretically predicted by assuming that the idea gas law applies to this very low-pressure case. In this paper, we present the experimental results of the measurements of the speed of sound in a cylindrical vacuum chamber by using the ultrasound technique. The chamber is filled with air or pure $CO_2$, respectively. The pressure in the chamber is adjusting from $10^5$ Pa to 600 Pa with different pressure intervals. And the pitch-catch technique has been applied to measure the sound speed at different pressures. The experimental results show that the speed of sound barely varies with the pressure in the range from $10^5$ Pa to 600 Pa, while it depends on the composition of the gas and the temperature.
Keywords: sound speed, Mars atmosphere, low pressure, ultrasound

## 1. Introduction

Future missions to the planet Mars might include several acoustic probes to record ambient sounds [1], to measure the wind speed [2,3], and to assist the safety of future Landers. Acoustic waves can detect planetary environments, since they are being directly coupled to the medium. The investigation of properties of acoustic waves, such as the sound speed, in Martian atmosphere is vital for applications of all the acoustic probes which need to be specially designed for the extraterrestrial Mars environment.

In literatures, gas in the Martian atmosphere is considered as following the ideal gas law, and the sound wave is assumed to be an adiabatic disturbance [4-6]. However, very little work has been done to quantify the speed of acoustic wave in Martian atmosphere based on experiments. In this paper, we carried out experiments to measure the speed of sound in a test chamber which can be filled with $CO_2$ at Beijing Institute of Spacecraft Environment Engineering.

## 2. Experiment setup

The experiment setup is illustrated in Fig.1. The vacuum chamber is 1.6 m long and its radius is 0.4 m. It is filled with air or pure $CO_2$, respectively. The pressure in the test chamber can be down to $10^{-3}$ Pa, which is much lower than the pressure of the Martian surface (600-1000 Pa). The pressure is controlled to be $10^5$, $10^4$, 5000, 1000, 800, and 600 Pa, respectively, in order to measure the sound speed at different pressures.

Two opposing transducers, one emitter and one receiver, are installed on a remote controlled linear stage. Pulses are emitted by one transducer and received by the other. The time of flight, *t*, is recorded, and the distance between two transducers, *l*, is known, so that the speed of sound can be calculated from $c = l/t$. Four pairs of piezo-transducers of central frequencies being to 21, 25, 34, and 40 kHz were tested in the chamber.

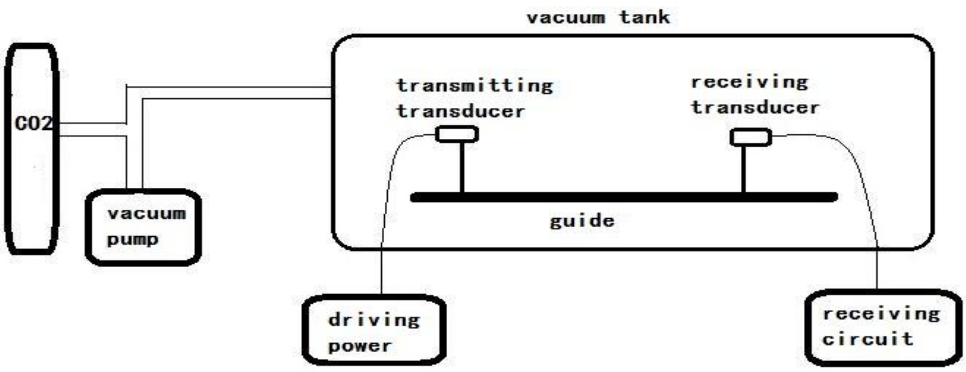


Figure 1: The sketch of our experiment setup.

## 3. Experimental results and analyses

### 3.1 The speed of sound in low-pressure air

The sound speeds in air at different pressures from $10^5$ to 600 Pa were measured in the test chamber. Typical results of 21 kHz emitted and received pulses are given in the left and right axes of Fig.2, respectively. The received pulse consists of the direct echo of the arrived time $t_1$ and the second echo of the arrived time $t_2$. In order to avoid the error from the electro-acoustic conversion time of the ultrasound probe, $t'$, the sound speed can be calculated from

$$\begin{cases} L = v(t_1 - 2t'), \\ 3L = v(t_2 - 2t'), \end{cases} \tag{1}$$

that is, the sound speed is $v = \frac{2L}{t_2 - t_1}$, and the conversion time is $2t' = t_1 - \frac{L}{v}$.

The experimental results of sound speeds of 21 kHz acoustic waves in air of pressures $10^5$, $10^4$, 5000, 1000, 800, and 600 Pa are 341.6, 341.2, 337.8, 337.1, 338.4, and 337.5m/s, respectively. It seems that the speed of 21 kHz acoustic pulse in air is not sensitive to the reducing pressure. Similar experimental results exist for the cases of 25, 34, and 40 kHz acoustic waves. And the average speed of sound in air is about 340.2 m/s.

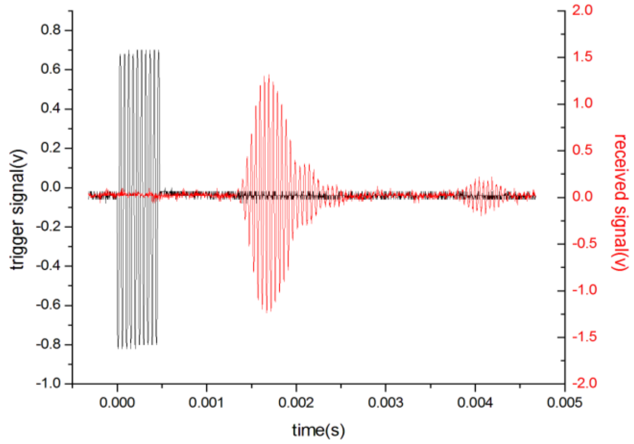


Figure 2: Experimental data of 21 kHz emitted (the black line in the left axis) and received acoustic signals (the red line in the right axis) at 5000 Pa of air. The path length is about *l* = 0.4 m. The amplification factor of the received pulse is 80.

## 3.2 The speed of sound in low-pressure $CO_2$

The velocities of 21, 25, 34, and 40 kHz acoustic waves in pure $CO_2$ were measured in the chamber. Typical results of 40 kHz emitted and received pulses were recorded in Fig. 3. The sound absorption is much stronger in $CO_2$ than that in air, as the amplitude of the second echo of the received signal is too small to be seen in Fig. 3. In this case, the speed of sound in $CO_2$ is calculated from

$$v = \frac{L}{t_1 - 2t'}. \tag{2}$$

where the average electro-acoustic conversion time of the transducer is $2t' = 114\mu s.$ From experimental results, the speed of sound in pure $CO_2$ is barely changed with the pressure in the chamber, and the average value is 269.1 m/s.

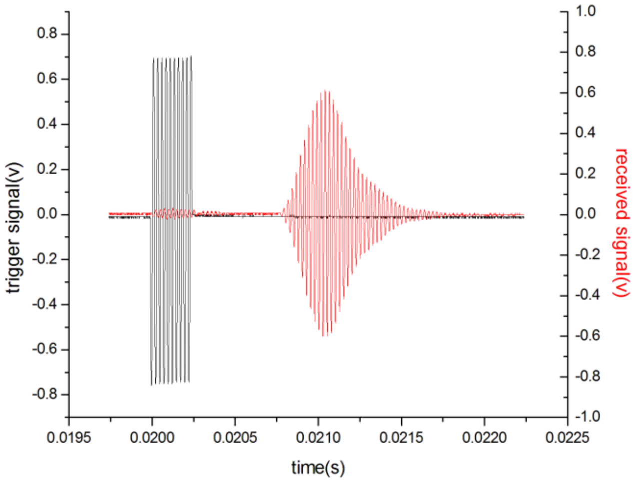


Figure 3: Experimental data of 40 kHz emitted (the black line in the left axis) and received acoustic signals (the red line in the right axis) at 5000 Pa of pure $CO_2$. The path length is about *l* = 0.2 m. The amplification factor of the received pulse is 20.

### 3.3 Theoretical sound speed

At low pressure(600-1000 Pa), by assuming the $CO_2$ gas follows the ideal gas law and the sound wave is longitudinal wave, the sound speed, *v*, can be given by

$$v = \sqrt{\gamma \frac{RT}{M}}, \quad (3)$$

where $R$ = 8.314 $jmol^{-1}K^{-1}$ is the universal gas constant, $M$ = 0.044 kg/mol is the molecular weight of $CO_2$, $T$ is the Kelvin temperature of the gas, and $\gamma$ is the ratio of the specific heat of the gas at constant volume which is related to the temperature[7]. For a $CO_2$ atmosphere at 288 K, $\gamma \approx$ 1.304.[7] Hence, the sound speed in $CO_2$ at 288 K (15℃) is expected to be 268.3m/s , which is close to our experimental result, 269.1 m/s.

## 4. Conclusions

From experimental results, the average speeds of ultrasonic waves of frequencies 21, 25, 34, and 40 kHz in air and pure $CO_2$ are 340.2 m/s and 269.1 m/s, respectively. The pressure in the vacuum chamber drops from $10^5$ to 600 Pa, and the temperature is around 288 K. The errors might come from four reasons. Firstly, the temperature of the gas is varying with the varying pressure in the chamber, and it should be recorded simultaneously. Secondly, the signal to noise ratio of ultrasound in 600-1000 Pa $CO_2$ gas is quite small which causes an inaccurate travel time, *t*. Thirdly, the remote controlled linear stage may bring in an error of the travel distance, *l*, within ±1 mm. Fourthly, the humidity of the gas in the chamber affects the sound speed.

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