A LOW-DENSITY WIND TUNNEL FOR MARTIAN ENVIRONMENT SIMULATION

Chen Liu[1], Xianyu Meng[1], Yiyong Wu[1]*, Jihong Yan[1]*, Wen Zhou[2], Lifang Li[1], Chengyue Sun, Hao Wang[1], Xinbin Zhang[1], Dandan Ju[1]

1 Harbin Institute of Technology,
2 AVIC Aerodynamics Research Institute

ABSTRACT

A low-density wind tunnel has been designed and constructed at Harbin Institute of Technology for Martian environment simulation, which will be set in the context of current and future missions to the Martian surface. This work was part of the Space Environment Simulation and Research Infrastructure (SESRI), the National Major Sciences and Technology Project in China. The wind tunnel is driven by ejector and capable of providing controllable wind flow, of air or carbon dioxide, at Martian pressures (100–1500Pa), wind speeds (5–100 m/s) and dust aerosol suspension using Mars analogue materials. Crucial design features including mechanical design, ejector drive system, pressure control system, dust ejection system andbalance system will be presented. The ejector drive system succeeded in achieving the maximum flow velocity up to 100m/s at low pressure. The balance system can achieve the measurement of resistance, lift, pitch torque, roll torque and yaw torque of samples. Dust ejection into the wind flow is achieved by allowing a mixture of gas and dust to enter the chamber through a nozzle, thus forming a gas-solid two-phase flow field and transporting the dust to the test section, along with the real-time monitoring of dust concentration. The test section is cuboid, 0.2*0.2m^2 in cross section and 0.4m long. The wind speed and turbulence in the test section was calculated by computational modelling technique dust validated experimentally using a pitot probe. Particle Image Velocimetry (PIV) system has been developed to measure velocity fields of dust. Three kinds of scientific study will be presented. First, the response of materials and instruments to dust or dust exposure, such as the durability of space suit during a dust storm. Secondly,granular transport experiments using PIV, such as the wind removal of the dust layeron solar array. Finally, the low reynolds number airfoil testing can be carried out by using the balance system.

1 INTRODUCTION

The features of the Martian environment are definitely different from those of the Earth. Because of the lack of liquid water, geological activity eroded the rock on surface, and dust covered almost the entire surface of Mars[1-3]. The dust storm on Mars has many environmental effects, such as denudation, shelter, retardation, friction discharge, etc. And the dust storm also poses a great threat to the reliable operation of the probe[4,5]. Conventional atmospheric wind tunnels cannot provide experimental data due to the huge differences between the Martian atmosphere and that of Earth. Since the 1980s, the United States, Europe and Japan have built wind tunnels to study the wind environment and wind erosion in order to meet the needs of the experimental study of the wind environment and probe of Mars, as well as to verify the theoretical analysis and numerical prediction methods[6-8]. According to announced plans for the exploration of Mars, China will conduct its first Mars exploration in 2020 to develop and launch a Mars probe, and conduct orbiting and landing probes on the Mars. Therefore, it is of great significance for China to verify the impact of dust storm environment on the performance of the spacecraft through ground simulation experiments[9-12]. This paper presents the design plan and theoretical calculation results of a wind tunnel on Mars in a low pressure environment[13].

2 MECHANICAL DESIGN

The design of the wind tunnel on Mars is shown in Fig 1.

The wind tunnel is mainly composed of wind speed simulation system, dust system, sample support system, shared air source system, vacuum system, measurement and control system and chamber. The wind speed simulation system mainly includes the built-in straight flow wind tunnel and the ejector system, and is used to realize the flow field environment of 5~100m/s. Dust system is used to establish a uniform and stable dust field in the test section with a dust concentration range of 0.1~1g/m^3. The sample support system can measure the lift, resistance and pith moment of the test piece in the flow field. The vacuum system mainly conducts low-pressure simulation and maintenance work to keep the pressure of the test section constant, and simulates the low-pressure environment of 100~1500pa. The shared air source system provides carbon dioxide gas for the wind speed simulation system and the dust system.

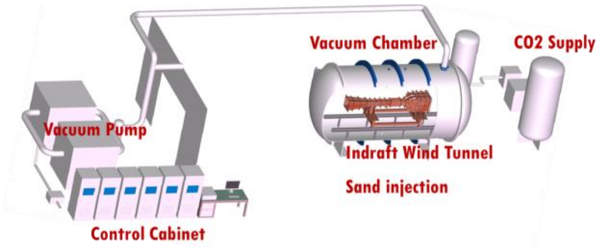


Fig. 1. Design plan of wind tunnel

2.1 Wind speed simulation system

The wind tunnel is located inside the Martian dust chamber, and on the slide rail in the chamber through the supporting legs. The wind tunnel can slide forward and backward on the slide rail, and will be locked after reaching the designated position, as shown in Fig 2. The wind tunnel body is composed of collector, stable section, contraction section, test section, straight section, dynamic section, outlet diffusion section and so on. The test section is 0.2m of width, 0.2m of height, 0.4m of length, and the length of the wind tunnel is 3.48m. The top and side of the test section are quartz glass which can be used for PIV laser testing.

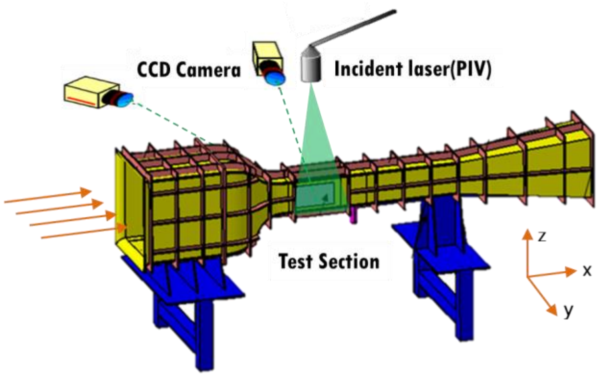
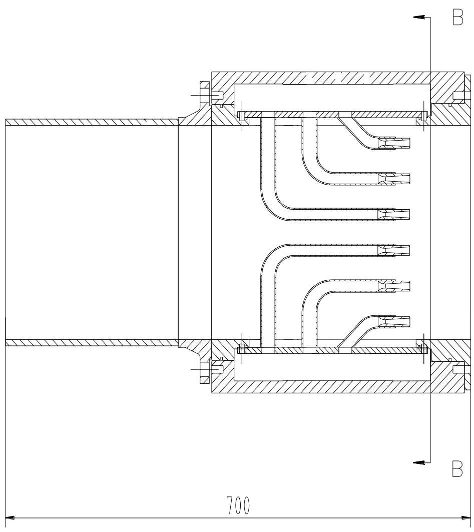


Fig. 2. Schematic figure of wind speed simulation system

The wind tunnel of Mars uses the ejector as its power system. The ejector is a mechanical device that relies on the action of one high-pressure air stream to increase the total pressure of the other air stream. The nozzle of the ejector sprays the high-speed air flow, and the mixing of the air flow at the outlet of the nozzle produces the low-pressure flow to drive the jet flow, thus producing the wind speed required by the wind tunnel test. The ejector with a diameter of 200mm×200mm contains 36 nozzles which presents a rectangular distribution of 6×6. The Ma value of nozzle is 2.435. The design figure of the ejector is shown in Fig 3.



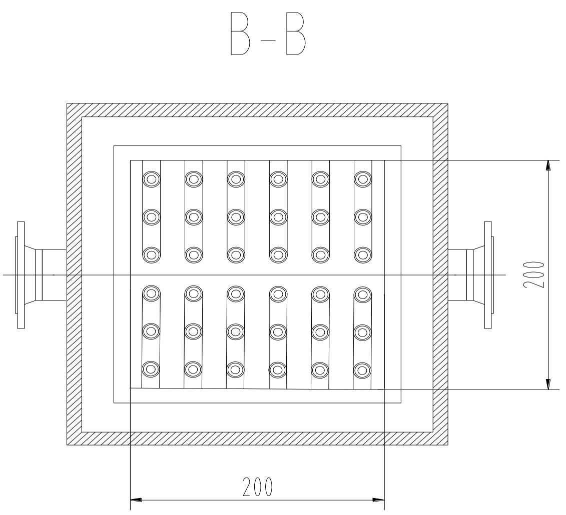


Fig. 3. Design figure of ejector

2.2 Dust ejection

The working principle of the dust system is to use the nozzle to spray the dust into the wind tunnel at a certain speed, and transport the dust to the test area through airflow wrapping to form a relatively uniform gas-solid two-phase flow field. It also uses the dust concentration meter to monitor the dust concentration in real time to ensure that the dust concentration in the test section meets the requirements. Meanwhile, filter tank is set on the exhaust pipe for dust recycling.

In this design, the gas-solid venture ejector is used to spread dust, and the shape of nozzle is laval nozzle. It uses high-pressure CO_2 gas to pump and transfer the material through the ejector to adjust the ejection speed by controlling the high-pressure gas pressure, and to control the feeding amount by controlling the rotation speed of the feeder.

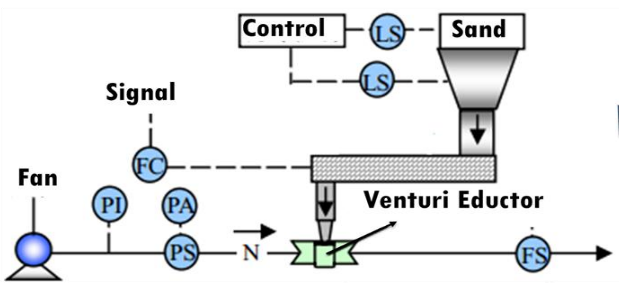


Fig. 4. Design figure of dust system

2.3 Sample support system

The support system is designed to realize the device that the object to be measured is clamped and fixed for support. Meanwhile, it can also measure the lift and resistance of the object under the action of wind, as shown in figure 5. It is composed of support frame, balance, motor support seat, and test piece, etc. Among them, the measuring range of pneumatic balance is 60N in lift direction and 10N in resistance direction.

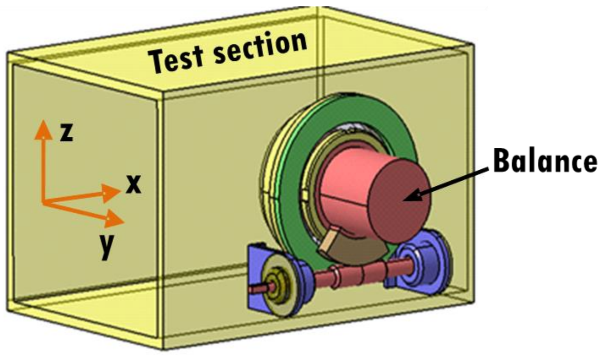


Fig. 5. Sample support system

2.4 Computational fluid dynamics modelling

Numerical simulation is used to simulate the trajectory of dust, which provides the design basis for the chamber design. A single nozzle is used for both forward and reverse ejection. The simulation conditions are as follows, 3g/cm^3 of dust density, 100um of dust particle, 0.4g/s of dust ejection amount, 100m/s of ejection speed at nozzle, 100m/s of wind speed in the test section, 100Pa of environmental pressure.

Fig 6 shows the velocity cloud map in the X direction of the flow field when the wind speed of the test section is 100m/s. It can be seen that in the working area, the velocity distribution of dust is uniform, and the flow field is of good quality. Fig 7 shows the track of dust in forward and reverse direction. It can be seen that dust will be deposited in the cave wall when blowing dust in the forward direction. At this point, it is assumed that the cave wall will release after deposition, and it will be deposited again after movement. There is almost no deposit when blowing dust in the reverse direction.

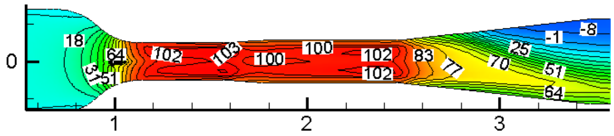


Fig. 6. Velocity map of flow field in the X direction

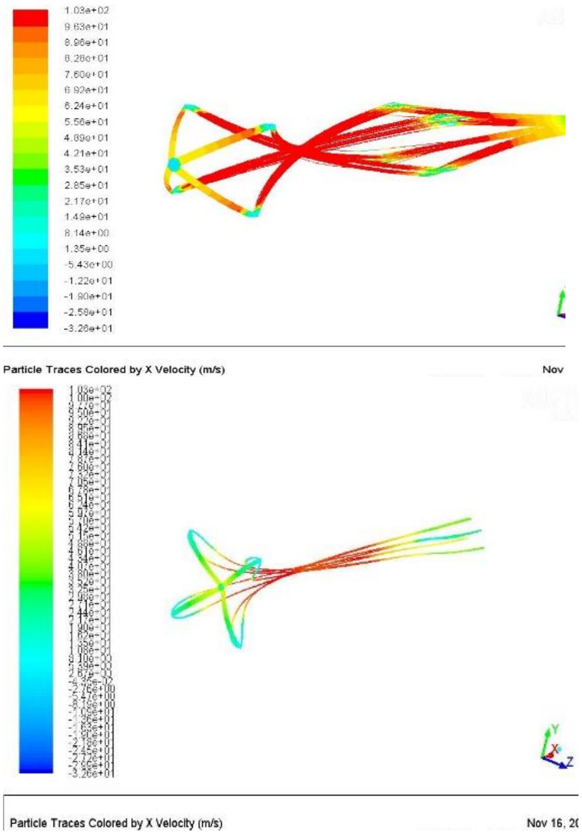


Fig. 7. Dust track of forward and reverse dusting

3 CONCLUSION

In this paper, the design of a low-density wind tunnel on Mars and the theoretical calculation results are presented. The wind tunnel of Mars is mainly composed of wind speed simulation system, dust system, sample support system, shared air source system, vacuum system, measurement and control system and chamber. The wind tunnel uses the ejector as the power source to realized such parameters as atmospheric pressure of 100~1500pa, wind speed (5~100m/s) and dust concentration (0.1-1g/m^3) under the carbon dioxide atmosphere, so as to achieve the simulation of the Martian surface environment.

REFERENCES

1. Hertzler, R. G., E. S. J. Wang, and O. J. Wilbers. "Martian sand and dust storm experimentation. ", Journal of Spacecraft & Rockets, 4.2(2015): 284-286.
2. White, Bruce, M. Benzit, and N. Bridges. "Wind-tunnel Measurements of the Coefficient of Restitution and Kinetic Energy of Quartz Sand for Mars and Earth Impacting on a Basalt Rock with Numerical Simulation.", Aiaa Aerospace Sciences Meeting and Exhibit 2013.
3. Merrison, J. P., et al. "An environmental simulation wind tunnel for studying Aeolian transport on mars.", Planetary & Space Science, 56.3-4(2008): 426-437.
4. Wilson, C. F., et al. "A wind tunnel for the calibration of Mars wind sensors.", Planetary & Space Science, 56.11(2008): 1532-1541.
5. Anyoji, Masayuki, H. Nagai, and K. Asai. "Development of Low Density Wind Tunnel to Simulate Atmospheric Flight on Mars.", Aiaa Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition 2013.
6. AIAA. "Numerical Study of Hypersonic Wind Tunnel Experiments for Mars Entry Aeroshells.", American Institute of Aeronautics & Astronautics (2009).
7. Nornberg, P, J. P. Merrison, and H. P. Gunnlaugsson. "The New Danish/ESA Mars Simulation Wind Tunnel at Aarhus University.", 41(2010).
8. Ozawa, Takashi, et al. "Modeling of Martian Dust Collection for Non-Stop Mars Sample Return Mission.", Aiaa Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition 2013.
9. Anyoji, Masayuki, et al. "Characteristics of the Mars Wind Tunnel at Tohoku University in CO2 Operation Mode.", Aiaa Aerospace Sciences Meeting Including the New Horizons Forum and

Aerospace Exposition 2013.

10. Anyoji, Masayuki, et al. "Low Reynolds Number Airfoil Testing in a Mars Wind Tunnel.", Fluid Dynamics Conference and Exhibit 2013.

11. Selig, Michael, R. Deters, and G. Wiliamson. "Wind Tunnel Testing Airfoils at Low Reynolds Numbers.", Aiaa Journal (2013).

12. Nagai, Hiroki. "Characteristics of Low-Reynolds Number Airfoils in a Mars Wind Tunnel.", 2013.

13. Numata, Daiju, T. Tsuchiya, and K. Asai. "Evaluation of free-stream turbulence intensity in the Mars Wind Tunnel under low Reynolds number conditions.", Aiaa Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition 2013.