EXPLORING THE PERFORMANCE OF A MINIATURE 3D WIND SENSOR UNDER EXTREME MARTIAN WINDS UP TO THE DUST DEVIL SCALE,

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Introduction: The objective of this paper is to explore the performance of a miniature 3D spherical wind sensor for Mars atmosphere, [1-3], working under extreme wind speeds, up to the Dust Devil scale.

The experimental campaign has been made for winds in the range Reynolds 1000-2000, which for typical Mars conditions and the dimensions of the sensor, represent 65-130m/s wind velocities.

The experimental results further confirm high-fidelity numerical simulations of the fluid dynamics and heat transfer from a sphere for Reynolds 1000-10^4 and Prandtl 0.7, recently published in [4], which indicate that it is possible to measure in this regime.

Sensor description: The sensor is composed of 4 equally shaped sectors, conforming a 10 mm diameter sphere, that are placed on two superimposed PCBs, which act as supporting structure and provide signal routing (see Figure 1). A customized silicon die which includes a Pt resistor is attached to each sector in order to sense temperature and provide heating power. Finally, two additional dice are placed on the supporting PCBs in order to control the temperature at the core of the sphere, on the PCBs. Mantaining the core at the same sector temperature, heat transfer between both elements is minimized.

The sensor is operated at the same constant temperature in the core and in all sectors. From the heating powers injected on the 4 resistors in the sectors and the air temperature, the thermal conductance of each sector is calculated. From these 4 signals 3D wind speed recovery can be made.

The performance of the sensor under typical Martian wind conditions (Reynolds below 200) has been previously explained [1]. The sensor presents a time response in the 1-2s range and its dynamics has been analyzed in [2-3].

Main result: The paper presents experimental results obtained under conditions representative of extreme wind velocities in Mars atmosphere. Reynolds numbers in the range 1000-2000 have been attained by controlling pressure and wind speed in a wind tunnel inside a dry-air hypobaric chamber at room temperature. These Reynolds numbers represent wind speeds of 65m/s – 130m/s for typical Mars conditions (CO_2, 210K, 630Pa), and for the sensor diameter.

Fig. 1: Photograph of the 4-sector spherical sensor (10mm diameter).

Simulation results:

The results corroborate high-fidelity simulations in [4]. Direct numerical simulations (DNS) have been made for Re1000 and large-eddy simulations (LES) for Re10^4. As an example, a snapshot of the temperature field in the wake of the sphere at Re1000 is shown in Figure 2. The scalar represented is the normalized temperature $\Phi=(T-T_{in})/(T_{sph}-T_{in})$, where T_{sph} is the temperature on the surface of the sphere and T_{in} is the temperature of the fluid at the inlet.

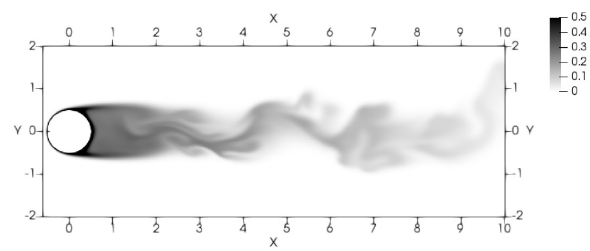

Fig. 2: Figure from [4] showing a snapshot of the temperature field in the wake of the sphere for Re1000 obtained from direct numerical simulations of the incompressible Navier-Stokes and energy equations.

Figure 3-left shows the local Nusselt number at Re1000 on the sphere. Figure 3-right shows a section of Figure 3-left corresponding to a triangular sector (a first approximation to the sectors of the sensor).
The objective is to analyze how the average Nu number on the triangular sector changes as a function of Yaw angle. This will provide information on the expected behavior at each sector of the sphere when the sensor is rotated. Figure 4 shows how the average Nu

number of this sector changes as a function of the yaw angle of the incident wind, for Re1000. Figure 5 presents the equivalent result for Re10^4.

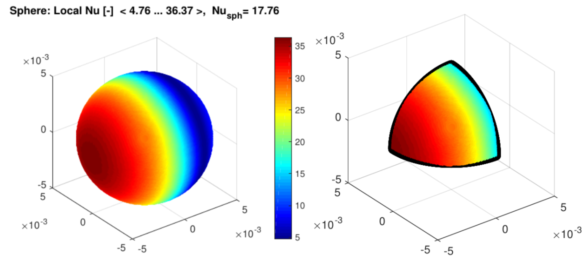

Fig. 3: (Left) Local Nusselt number on the sphere obtained from DNS simulations of Re1000. (Right) zoom corresponding to a triangular sector.

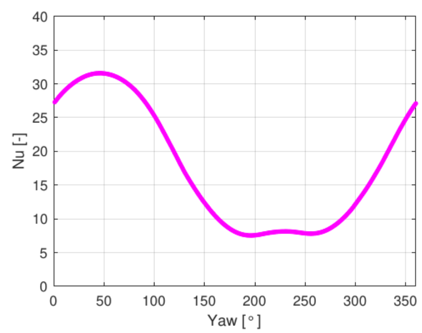

Fig. 4: Average Nu number for Re1000 on the triangle of Fig.3-right as a function of yaw angle.

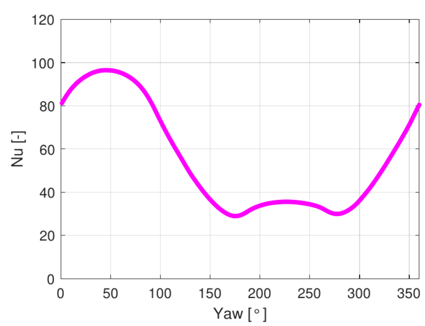

Fig. 5: Average Nu number for Re10^4 on the triangle of Fig.3-right as a function of yaw angle.

<u>Discussion</u>: The simulations indicate that the average Nusselt of the sector as a function of the incident wind yaw angle presents a minimum region which widens for increasing Re numbers. This region presents a maximum between two minima. This represents a signature of the expected behavior of the sensor.

Experimental results: Figures 6 and 7 present the experimental curves obtained with the sensor in a wind tunnel inside a vacuum chamber at room temperature:

a) **Re1000**: Equivalent $U_{Mars\text{-}flow}$ of 65m/s (under typical Mars conditions). $U_{dryair\text{-}flow}$ in the chamber 6.5-7m/s, 250mbar, T_{air}=22.9C, T_{sph}=35.6C.

b) **Re2000**: Equivalent $U_{mars\text{-}flow}$ 130m/s. $U_{dryair\text{-}flow}$ in the chamber 6.5-7m/s, 500mbar, T_{air}=23.9C, T_{sph}=34.4C.

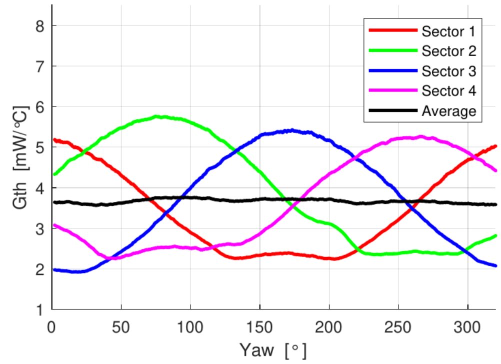

Fig. 6: Thermal conductances of each sector, and average value, as a function of Yaw angle for Re1000. Equivalent $U_{Mars\text{-}flow}$ velocity under typical Mars conditions of 65m/s.

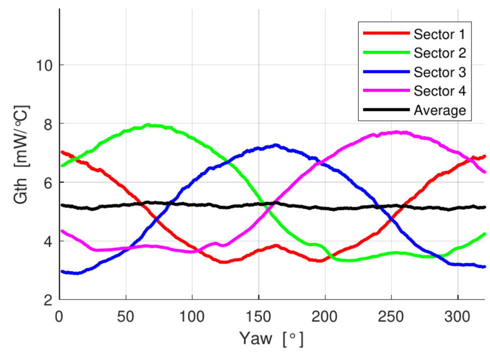

Fig. 7: Idem as Fig. 6 for Re2000 (equivalent $U_{Mars\text{-}flow}$ velocity under typical Mars conditions of 130m/s).

Conclusions: The thermal conductance of sectors follows the trend predicted by the simulations: for yaw angles leaving the sector in the wake of the sphere and for increasing Re numbers, the Gth presents widening minima and the maximum between them tends to increase.

These preliminary results indicate that 3D wind speed inference can be made in this extreme regime.

References:

[1] L. Kowalski, et al. (2016), *IEEE Sensors Journal*, *16*, 1887-1897. [2] M. T. Atienza, et al. (2017) *Sens. and Act. A*, *267*, 342-350. [3] M. Dominguez-Pumar et al. (2016), *IEEE Trans. Ind. Electr.*, 64 (1), (664-673). [4] I. Rodriguez, et al (2019), *Int. J. Heat and Fluid Flow*, 76, 141-153.