Testing campaign of a martian spherical wind sensor at the AWTSII Wind Tunnel Facility

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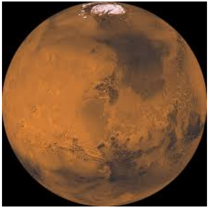
Overview

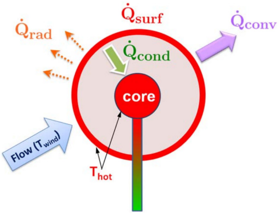
Challenge: 3D wind sensing for Mars



- Shallow atmosphere (6-12 mbar), wide temp. range (150-300K).
- Necessity of a fast, robust & simple sensor.
- 3D wind component recovery must be possible and simple !
- Design for reliability and durability.

In this paper: Experimental results obtained at the Aarhus Wind Tunnel Simulator II (AWTSII) with a spherical wind sensor.

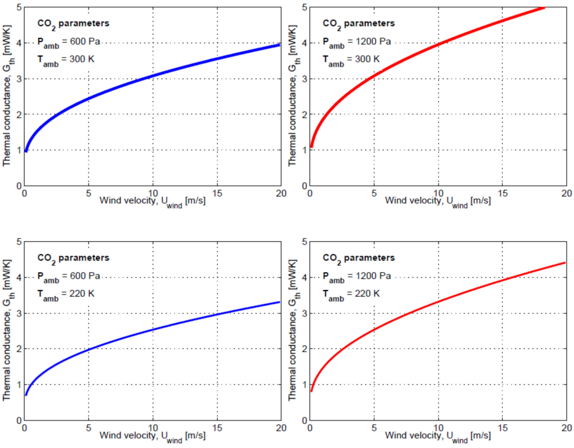
Spherical sensor: a *miniature* sensor



- Constant temperature operation.
- Heat transfer from the sphere: $\dot{Q}_{\mathrm{surf}} = \dot{Q}_{\mathrm{conv}} + \dot{Q}_{\mathrm{rad}} + \dot{Q}_{\mathrm{cond}}$.
- $\dot{Q}_{\mathrm{cond}}$ is eliminated by enforcing $T_{\mathrm{core}} = T_{\mathrm{surf}}$.
- $\dot{Q}_{\mathrm{rad}}$ is reduced by gold plating the sphere.

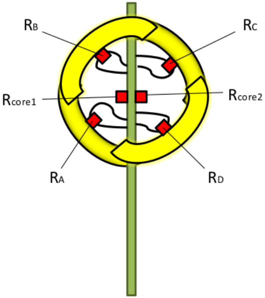
> - Spherical geometry simplifies 3D wind data reconstruction.
> - **Wind speed**: heat transfer with the whole sphere.
> - **Angle information**: heat transfer of 4 *sectors* of the sphere.

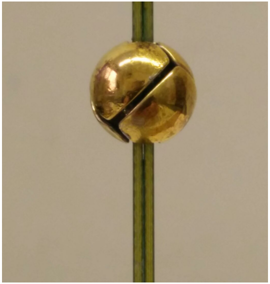
Sensor modeling: laminar flow regime



Thermal conductance of a sphere **perfectly known** for relevant values of temperature and pressure.

Spherical sensor: 4 sectors

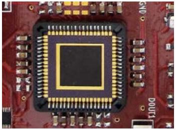




- 4 gold plated silver tetrahedral sectors (Ø = 10mm)[1].
- 2 'back-to-back' PCBs provide mechanical and electrical support.
- R_A, R_B, R_C, R_D: Pt resistors for heating and sensing sectors.
- R_{core1}, R_{core2}: Resistors to enforce $T_{\mathrm{core}} = T_{\mathrm{surf}}$.

[1] L. Kowalski et al, "Spherical wind sensor for the atmosphere of Mars ", IEEE Sensors Journal 16 (7), 1887-1897, 2016

Size, weight and power



Unit	Mass	Size
Sensor head	3g	10mm in diameter
2 x half PCB	12g (2 × 6g each)	230 × 35 mm
PCB connector	7g	55 × 25 × 8 mm

- Power consumption (**sphere** 6 resistors) < 300mW (generally dependent on overheat, ΔT.
- Typical ASIC power < 200mW

Experimental results at the AWTSII Wind Tunnel Facility

- Constant temperature in all sectors and core resistors $T_{\mathrm{surf}} = T_{\mathrm{core}}$.
- Air temperature monitored: T_{air}.
- Inference of wind speed from global thermal conductance:

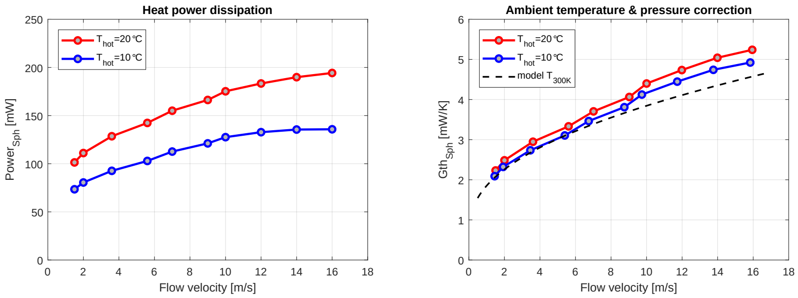
$$G_{th} = \frac{P_A + P_B + P_C + P_D}{T_{\mathrm{surf}} - T_{\mathrm{air}}}$$

  where P_i is power injected in sector i.
- Angle information retrieved from normalized sector powers:

$$\overline{P}_i = \frac{P_i}{P_A + P_B + P_C + P_D}$$

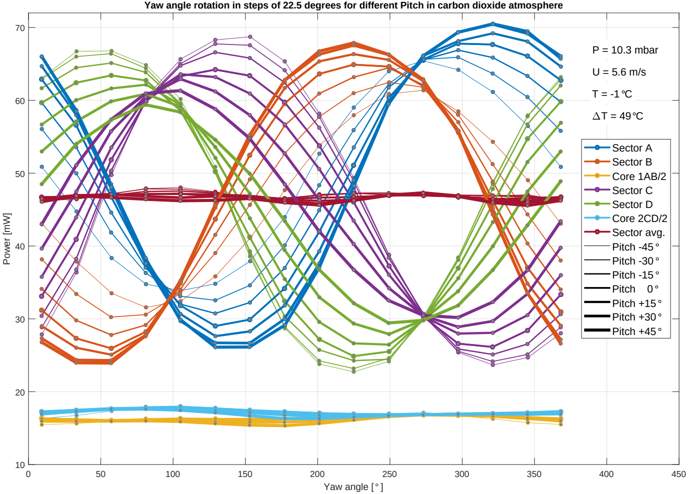
G_{th} inference for wind velocity estimation

CO_2 atmosphere 7.6mbar Ambient temp. -21.5°C.



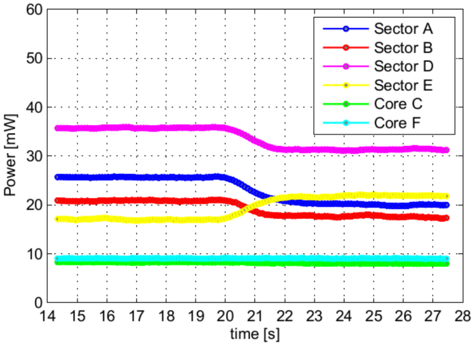
- Two different setting points for T_{surf}: 20°C and 10°C.
- Good agreement between the obtained G_{th} and literature models.

Pitch and Yaw sweep



- Almost constant value of $\sum P_i$. Easy solid angle recovery.

Sensor dynamics



- Sudden angle change at t=20s. Time response 1-2s.
- Fast sensor response under constant temperature operation [2].

[2] M. Dominguez-Pumar et al, "Heat flow dynamics in thermal systems described by Diffusive Representation ", IEEE Transactions on Industrial Electronics 64 (1), 664-673, 2017

Conclusions

- A *miniature* 3D wind sensor for Mars atmosphere.
- Low power, low mass, realiable structure.
- Performance of current prototypes
  - Time response: 1-2s.
  - Wind speed resolution: 0.5 m/s
  - Angle resolution: 5^{o}.
- Extremely easy and reliable solid angle recovery.