Abstract:
We present a novel method to quantify the heat transfer coefficient $h$ at the near environment of a spacecraft operating under Mars surface atmospheric conditions. As part of the scientific instruments of the ExoMars 2018 Surface Platform, the HABIT (Habitability Brines, Irradiance and Temperature) instrument will be operating on Mars surface in order to establish the habitability of the landing site. By resolving the energy balance equation in temperatures over the three HABIT Air Temperature Sensor (ATS), we will retrieve the fluid temperature $T_f$ and the known $m$-parameter directly related with the heat transfer coefficient and sensitive to variations in wind density and velocity field [1].

Introduction:

- Each ATS presents 3 Resistance Temperature Detectors (RTD) to measure the temperature at 3 locations along each axial direction of the rods of length L, at the base of the rod ($T_b$), an intermediate point $x = L/3$ (where $x$ is the number of rod divisions), $T_m$, and the tip ($T_t$).

- Energy Balance:

$$\frac{d}{ds} (x + \frac{1}{m} \frac{dx}{dt}) = h A \frac{dT}{dt} + \frac{c}{\rho} \frac{dx}{dt} \left( T_s - T_f \right)$$

(1)

- Heat transfer coefficient:

$$h = h_0 + h_1 = h_0 + c (T_s^2 + T_f^2) (T_s - T_f)$$

(2)

- Organizing:

$$\frac{d}{dx} \left( \frac{d\theta}{dx} \right) = \frac{\theta}{\theta_x} - \frac{\theta_0}{\theta_x}$$

(3)

$$\frac{\theta_0}{\theta_x} = \frac{x}{L} \frac{d\theta}{dx}$$

(4)

- Temperature distributions, HABIT configuration model:

$$\left( T_f - T_b \right) = \frac{\theta_0}{\theta_x} \left( T_f - T_b \right)$$

(5)

- $m$-Parameter:

$$m = L \left( \frac{1 + \cos \theta}{\sin \theta} \right)^2$$

(6)

Discussion:

- The temperature at each ATS control point is averaged over the control surfaces located over them.
- The heat transfer coefficient $h$ is calculated at each ATS in CFD computations through the local averaged heat fluxes over the control surfaces located at the three control points of the sensors. After that, the $h$ is averaged between the middle and the tip control points.
- The CFD computations show a local forced convection phenomena along the ATS which changes the heat flux distributions and thus the heat transfer coefficient locally: The averaged $h$ along each ATS changes.
- This phenomenon is less sensitive when retrieving $m$ parameter from temperature measurements at CFD and not from heat fluxes over the ATS sensors: Real case on Mars surface.
- The model gives fluid temperatures $T_f$ which agree with the CFD results.

Conclusions:

- Averaged heat transfer coefficient $h$ and $m$ parameter show a growth with the wind speed for the same near environmental conditions.
- The model presents a limitation in low velocity fluid flow conditions, when it can be assumed that there is not wind and thus not forced connection.
- The model does not describe the wind orientation over a single sensor, only through the variation of its value given this parameter is sensitive to it.
- Despite the limitations of retrieving the orientation of the wind through a single ATS sensor, their disposition over the HABIT allows a preliminary retrieval through the different temperature distributions and $m$ parameter over them. This retrieval is conditioned to an horizontal wind.
- The ATS locations are different over the HABIT and the REMS instrument, Future comparative analysis with REMS ATS data from Planetary Data System (PDS) will be influenced by this fact.
- The CFD simulation is here used to obtain a plausible thermal profile of the ATS under exposure to Mars wind conditions. The temperatures at three control points are successfully used to retrieve the temperature of the air in the vicinity of the instrument.
- The model shows a better resolution than the REMS Wind Sensors (WS) currently operating on Mars on-board Curiosity rover, it can be seen how changes in the incident wind speed are seen as real time changes of the $m$-value within 60 seconds of time span, while WS provide wind velocity averaged each 5 minutes.
- In the near future the $m$, red-long averaged, values will be retrieved from the heat flux, red-long averaged, values at each ATS and compared with the $m$-values that are retrieved from the three temperatures of the control points. This shall be done under different angles of incidence and wind speeds at stationary conditions, considering the limits of the assumptions of the retrievals.
- The future ATS Earth-scaled prototype will allow us to validate the model described for a single sensor under Earth changing conditions and within the Luleå wind tunnel facility.
- Heat fluxes under Martian conditions are very low, of the order of 100 W/m$^2$ and strongly changing in the vicinity of the spacecraft. The main limitations of this model are the problems to retrieve low wind speeds, given that heat losses due to forced convection are too small compared to radiative ones through the surface of the sensors.
- The model is applicable to stationary scenarios, while the wind characterization on Mars is foreseen to be in continuous change. It could be acceptable in case they can be considered as quasi-stationary changes.
- Assumptions and known sources of errors at this study:
  - Non-dimensional number formulation applicable to a cylinder periodically exposed and without attack angle to an external fluid flow.
  - One-dimensional model versus two-dimensional temperature $h_f$ and $h$ distributions over the ATS sensors red-shape.
  - Local force convection over the sensors not described in the mathematical model.
  - Temperature and $h_0$ values at control points from CFD studies averaged over a resolution surface of $A = 1.57 \times 10^{-6}$ m$^2$.
  - Convective heat transfer coefficients $h_f$ for each ATS averaged from averaged $h_0$ at the middle and tip control points.

References: