Wind Retrieval Measurements for the Mars Surface Exploration

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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 as 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 Thermo-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 $x = L/n$ (where n is the number of rod divisions), T_{Ln}, and the tip (T_a).
- Energy Balance:

$$\frac{d}{dx}\left(\kappa A_c \frac{dT}{dx}\right) = h_c \frac{dA_s}{dx}(T - T_\infty) + \varepsilon\sigma \frac{dA_s}{dx}\left(T^4 - {T_\infty}^4\right) \quad (1)$$

- Heat transfer coefficient:

$$h = h_c + h_r = h_c + \varepsilon\sigma\left(T^2 + {T_\infty}^2\right)(T + T_\infty) \quad (2)$$

- Organizing:

$$\frac{d^2\theta}{d\chi^2} - {m_\chi}^2(\chi, \theta, T_f, \beta)\theta = 0 \quad (3)$$

$$\begin{cases} \theta|_{\chi=0} = \theta_b \\ \left.\frac{d\theta}{d\chi}\right|_{\chi=1} = 0 \end{cases} \quad (4)$$

$$\theta = T_x - T_f, \qquad \chi = \frac{x}{L} \quad (5)$$

$$\theta_{(\chi)} = \theta_b \frac{\cosh(m(1-m))}{\cosh(m)} \quad (6)$$

$$\begin{cases} (T_a - T_f) = (T_b - T_f)\frac{1}{\cosh(m)} \\ (T_{Ln} - T_f) = (T_b - T_f)\frac{\cosh\left(m\left(1-\frac{1}{n}\right)\right)}{\cosh(m)} \end{cases} \quad (7)$$

- M-Parameter:

$$m_\chi = L\sqrt{\frac{\left[3(1+\cos(\beta)) - \sqrt{(3+\cos(\beta))(1+3\cos(\beta))}\right]h}{D\kappa}} \quad (8)$$

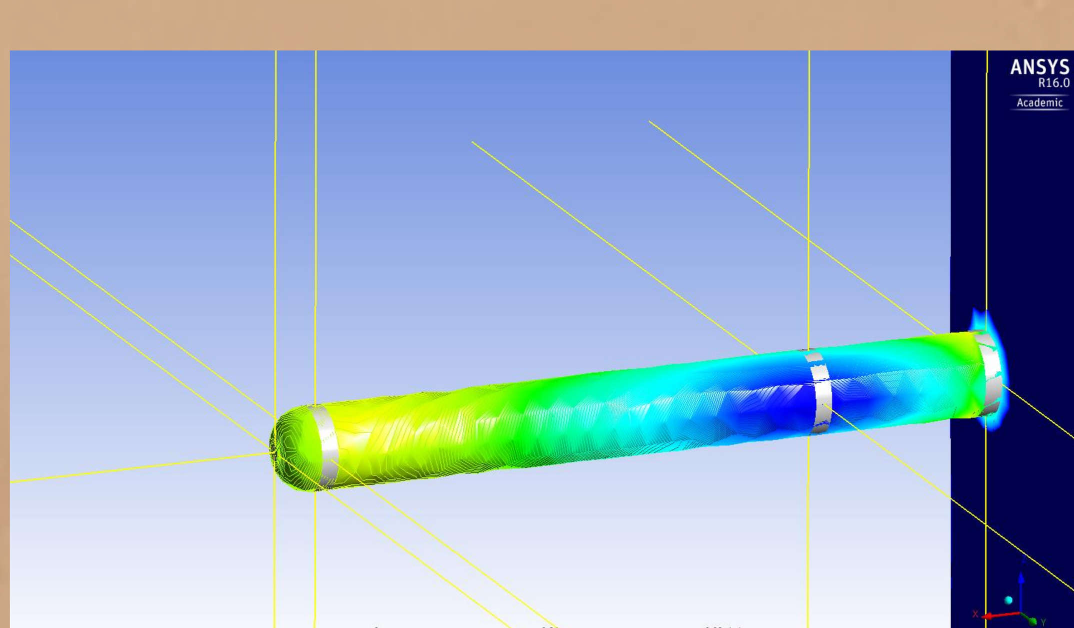

Figure 1.- Air Temperature Sensor 3D model for CFD studies.

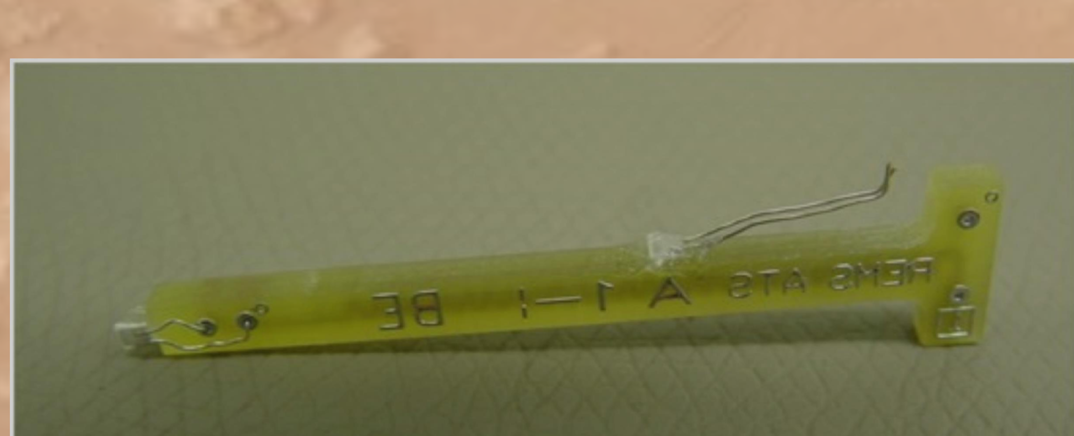

Figure 2.- Air Temperature Sensor.

Validation m-model

- CFD Studies
  - Temperature distributions, HABIT configuration model
- Experimental Setup
- PDS REMS
  - Temperature distributions, REMS on Mars surface

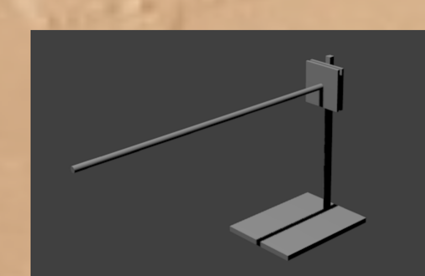

Figure 3.- Earth-scaled ATS prototype.

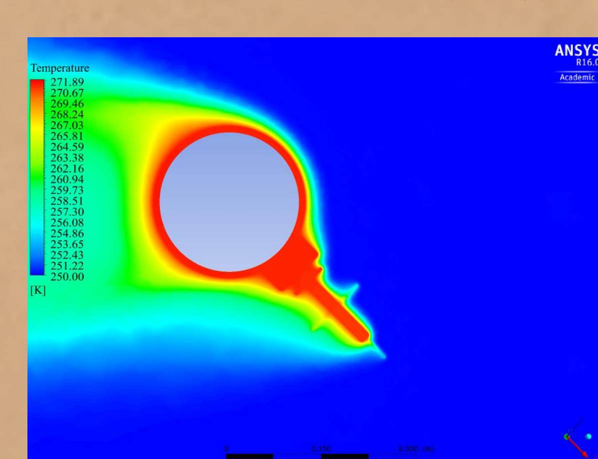

Figure 4.- Horizontal section for the thermal wake at a case of a fluid flow of $v = 1\ m/s$ at $T_f = 250\ K$.

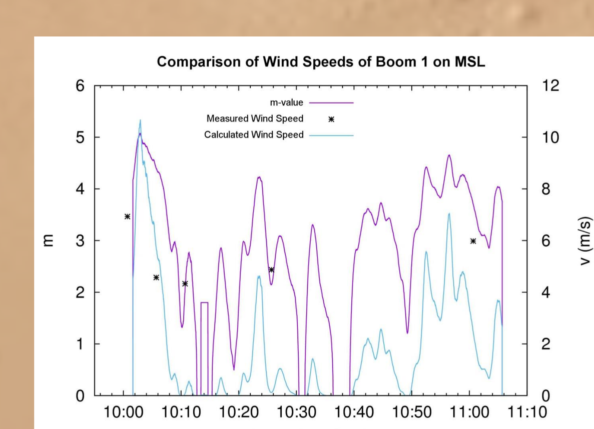

Figure 5.- Model approximation to wind speed measurements of MSL mission sol 547.

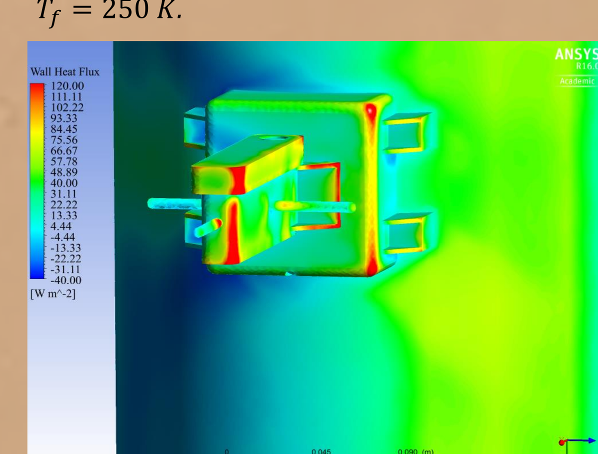

Figure 6.- Convective heat flux distribution over the HABIT-Pole structural model.

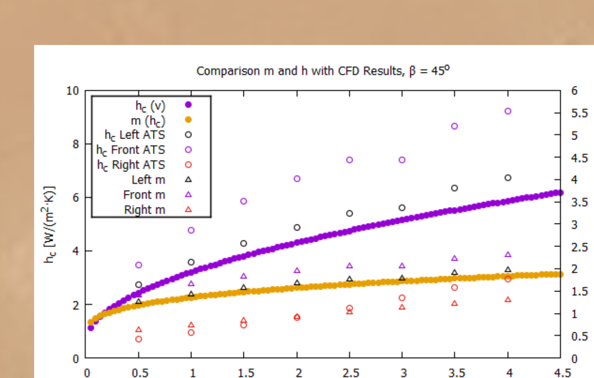

Figure 7.-Results for the m parameter and h coefficient at a case of a fluid flow of $v = 1\ m/s$ and an attack angle of $\beta = 45^\circ$.

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.

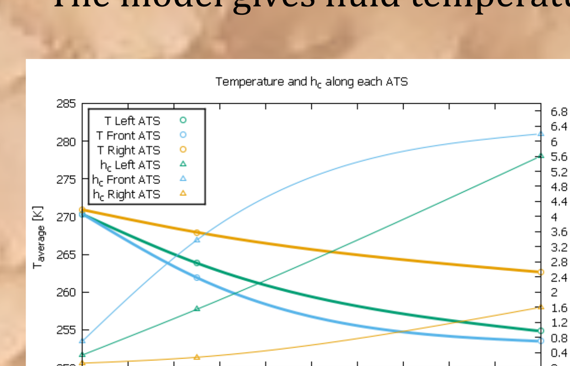

Figure 8.- Temperature and h_c distributions.

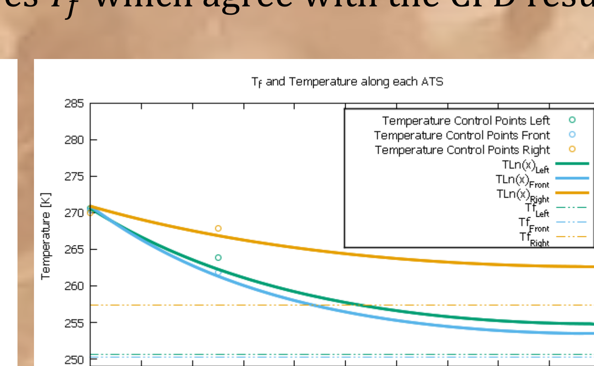

Figure 9.- Temperature distribution and T_f .

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 convection.
- 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, rod-long averaged, values will be retrieved from the heat flux, rod-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 outdoors 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:
  - Nusselt number formulation applicable to a cylinder perpendicularly exposed and without attack angle to an external fluid flow.
  - One-dimensional model versus two-dimensional temperature and h_c distributions over the ATS sensors rod-shape.
  - Local force convection over the sensors not described in the mathematical model.
  - Temperature and h_c values at control points from CFD studies averaged over a revolution surface of $A \approx 1.57 \cdot 10^{-5} m^2$.
  - Convective heat transfer coefficients h_c for each ATS averaged from averaged h_c at the middle and tip control points.

References

[1]. D. W. Mueller Jr. & H. I. Abu-Mulaweh, *Prediction of the temperature in a fin cooled by natural convection and radiation*, J. Applied Thermal Engineering 26 (2006) 1662–1668.

[2]. Casey A. Moore, et al., *A Full Martian Year of Line-of-Sight Extinction within Gale Crater, Mars as Acquired by the MSL Navcam through sol 900*, Icarus (in print 2015).

[3]. ANSYS FLUENT Theory Guide. ANSYS Inc., October 2012. Release 14.5.

[4]. Gómez-Elvira, J., et al., *REMS: The environmental sensor suite for the Mars Science Laboratory rover*, Space Sci. Rev., 170, 583–640, doi: 10.1007/s11214-012-9921-1, 2012.

[5]. Washington University in St. Louis; National Aeronautics and Administration; *PDS: The planetary atmospheres data node*, http://atmos.pds.nasa.gov. Last visit: February 2016.

[6]. Division of Fluid and Experimental Mechanics, *Experimental Determination of the Lift and Drag Coefficients of an Airfoil and a Blade*, Luleå University of Technology, May 2015.

Method → Variation m → 3 Temperatures: T_b, T_n, T_a → Variation m → Variation h → Variation h_c → Retrieval of forced convection at each ATS → Wind characterization

HABIT

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