CONVECTIVE HEAT TRANSFER MEASUREMENTS AT THE MARTIAN SURFACE

1st Symposium on Space Educational Activities
Student Research

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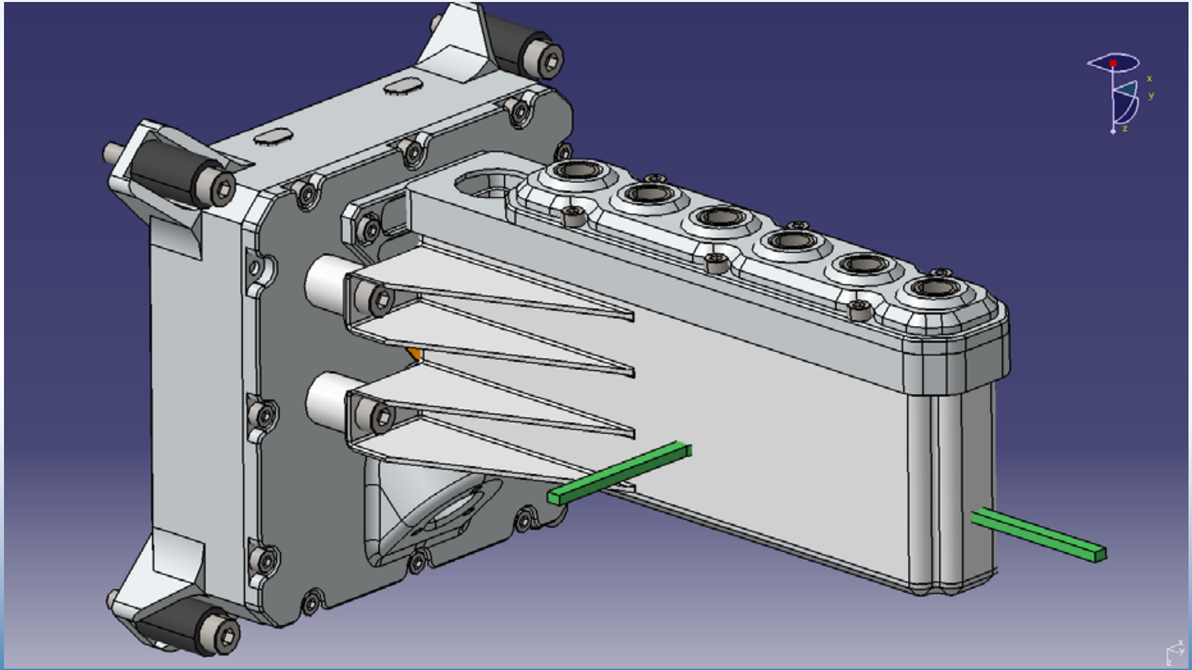
1. Introduction

- Context: HABIT (HabitAbility: Brines, Irradiation and Temperature), instrument included in ExoMars 2018 mission (http://www.esa.int/Our_Activities/Space_Science/European_payload_selected_for_ExoMars_2018_surface_platform). First Swedish instrument for the surface of Mars.
- REMS (Rover Environmental Monitoring Station) heritage.



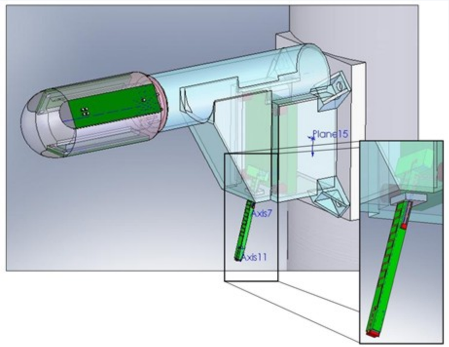
Components:

- 6 UV sensors
- 3 Air Temperature Sensors (ATS)
- 1 Ground Temperature Sensor (GTS)
- BOTTLE (Brine Observation Transition To Liquid Experiment)

1. Introduction

- Objective: Use the HABIT ATS sensors to characterize the wind on Mars surface through the convective heat transfer coefficient.

  - M-Model



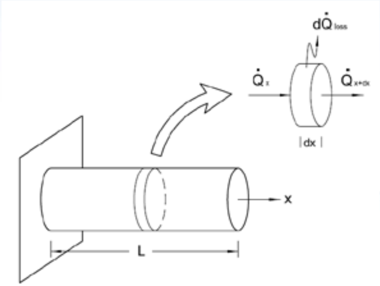
- Preliminary study:

  - Physical model for the heat transfer problem.
  - Computational fluid dynamics study.
  - Comparison between theoretical and numerical results.

2. M-model

- Energy Balance:

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



- Heat transfer coefficient:

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

- Organizing:

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

$$\theta = T_x - T_f, \chi = x/L$$

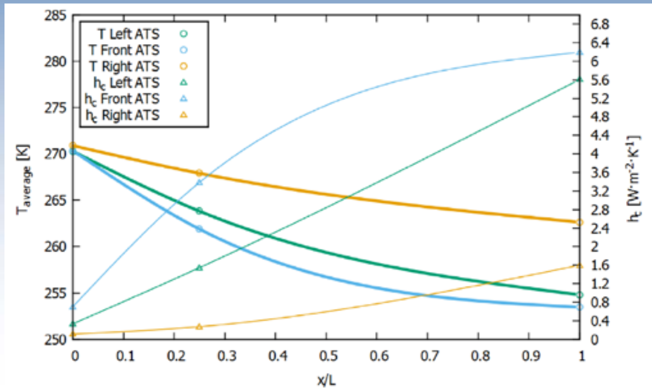
- M-Parameter:

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

2. M-model

- Non-Linear Boundary-Value Problem along ATS sensors:

$$\begin{cases} \theta|_{\chi=0} = \theta_b \\ \left.\frac{d\theta}{d\chi}\right|_{\chi=1} = 0 \end{cases} \rightarrow \quad \theta_{(\chi)} = \theta_b \frac{\cosh(m(1-m))}{\cosh(m)} \quad \rightarrow \begin{cases} (T_a - T_f) = (T_b - T_f)\frac{1}{\cosh(m)} \\ (T_{Ln} - T_f) = (T_b - T_f)\frac{\cosh(m(1-\frac{1}{n}))}{\cosh(m)} \end{cases}$$



- Analytical solution: m averaged over length of the rod.
- Retrieval Method:
  - Three simultaneous measurements
    - T_b: Temperature at the base (Platform).
    - T_{Ln}: Temperature at $x = L/n$.
    - T_a: Temperature at the tip.
  - Unknowns: m, T_f
    - T_f: Fluid temperature

Method → Variation m → Variation h → Variation h_c → Retrieval forced convection each ATS → Wind characterization

- In this preliminary study, the h_c coefficient is estimated theoretically and compared with a numerical model in order to confirm the useful of the ATS as wind sensors.

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3. Physical model

- Fluid Model:

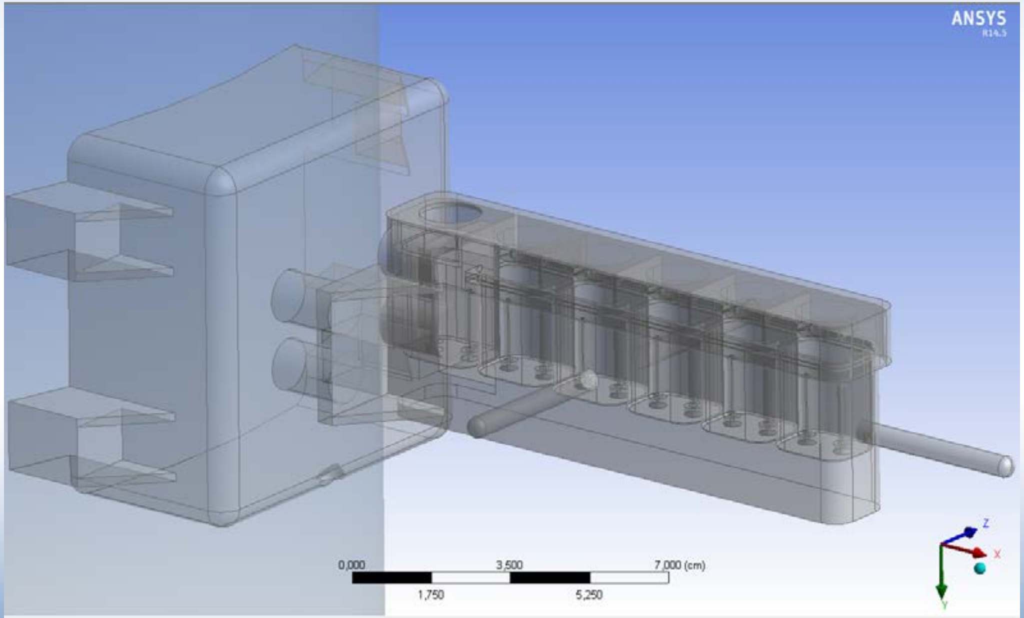
$$\mathrm{Pr} = \frac{C_p(T)\mu}{\kappa_f(T)}, Re = \frac{\rho v_{wind} L_c}{\mu}, L_c = D/\cos(\beta)$$

$$Nu = \frac{h_c L_c}{\kappa_f(T)};\ Nu = 0.3 + \frac{0.62 Re^{1/2} Pr^{1/3}}{\left[1 + \left(\frac{0.4}{Pr}\right)^{2/3}\right]^{1/4}} \left[1 + \left(\frac{Re}{28200}\right)^{5/8}\right]^{4/5}$$

- Temperature dependent polynomial models for $C_p(T)$ and $\kappa_f(T)$ in low-pressure $[1, 10^4] mbar$ and low-temperature $[200{,}1000]K$ domains.
- Chapman-Enskog's Kinetic Theory for μ (constant).
- Incompressible ideal gas CO_2 laminar flow ($M < 10^{-3}$).

4. Numerical model

- Geometrical Model



ATS sensors:

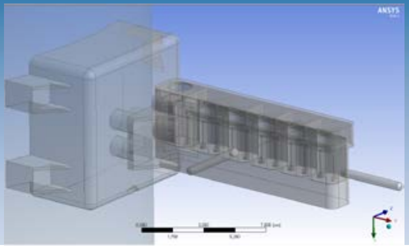
- Cylindrical rods
- $D = 5\ mm$
- $L = 42\ mm$

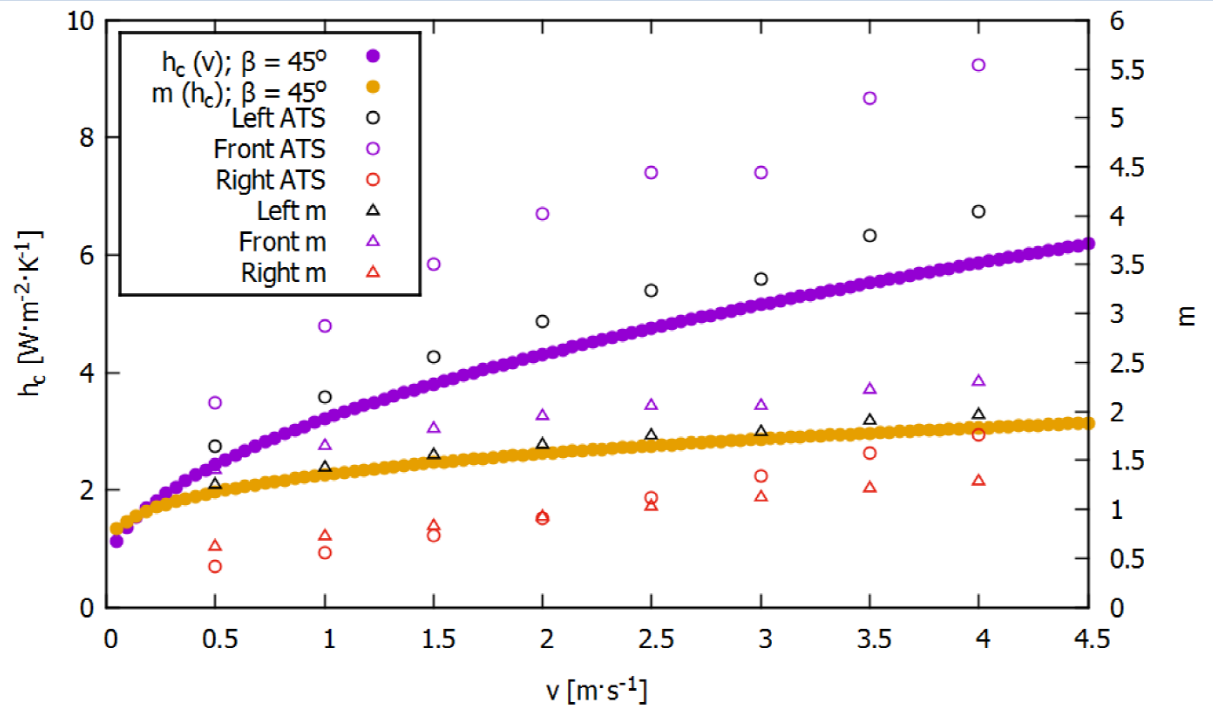
4. Numerical model

- Boundary conditions
  - Vertical pole.
  - 2 Structures: HABIT (Al) + ATS sensors (FR4).
  - Carbonate properties for Mars surface fixed at 280 K.
  - Surface Platform temperature fixed at 272.177K.
  - Radiative heat transfer considered, tacking the IR band $[0.4,0.7]\ \mu m$.
  - Solar load not included.
  - Emissivity and absorptivity (table).
- Study cases:
  - Deviation angle $\beta = 45^o$.
  - Fluid temperature $T_\infty = 250\ K$ (sol 45).
  - Velocity inlet: Range $[0.5, 4]\ ms^{-1}$ each $0.5\ ms^{-1}$.
  - Each case with and without radiative heat transfer

Surface	Emissivity ε	Absortivity α_r
Space Paint	0.88	0.2
FR4	0.9	0.3
Dolomite	0.9	0.5

5. Results





Case	$v\ [ms^{-1}]$	ATS	$h_c\ [Wm^{-2}K^{-1}]$	m
		Left	2.7375	1.2559
1	0.5	Frontal	3.4820	1.4164
		Right	0.6860	0.6287
		Left	3.5745	1.4351
2	1.0	Frontal	4.7835	1.6602
		Right	0.9335	0.7334
		Left	3.5745	1.4351
3	1.5	Frontal	4.7835	1.6602
		Right	0.9335	0.7334
		Left	3.5745	1.4351
4	2.0	Frontal	4.7835	1.6602
		Right	0.9335	0.7334
		Left	5.3980	1.7636
5	2.5	Frontal	7.4055	2.0656
		Right	1.8675	1.0370
		Left	5.5980	1.7959
6	3.0	Frontal	7.4105	2.0663
		Right	2.2410	1.1363
		Left	6.3345	1.9104
7	3.5	Frontal	8.6765	2.2359
		Right	2.6205	1.2288
		Left	6.7390	1.9705
8	4.0	Frontal	9.2360	2.3068
		Right	2.9330	1.2999

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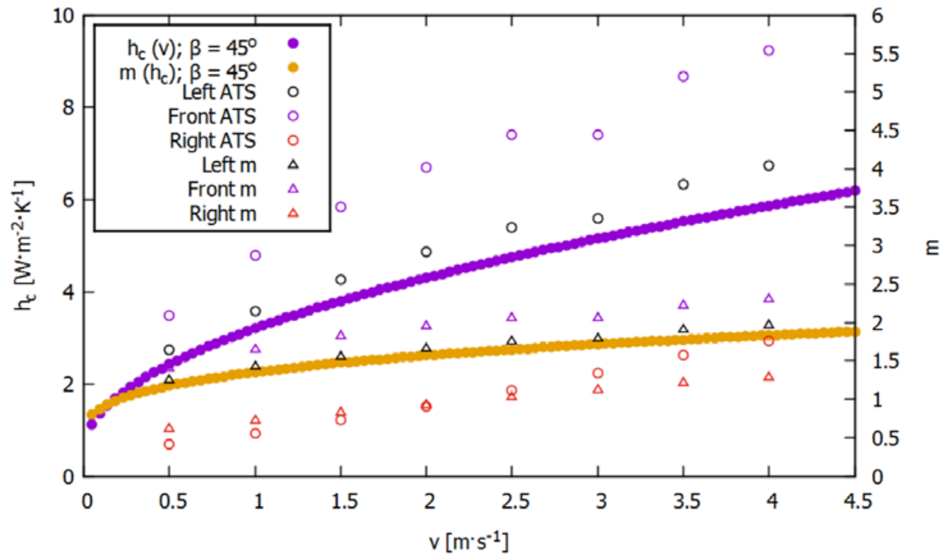
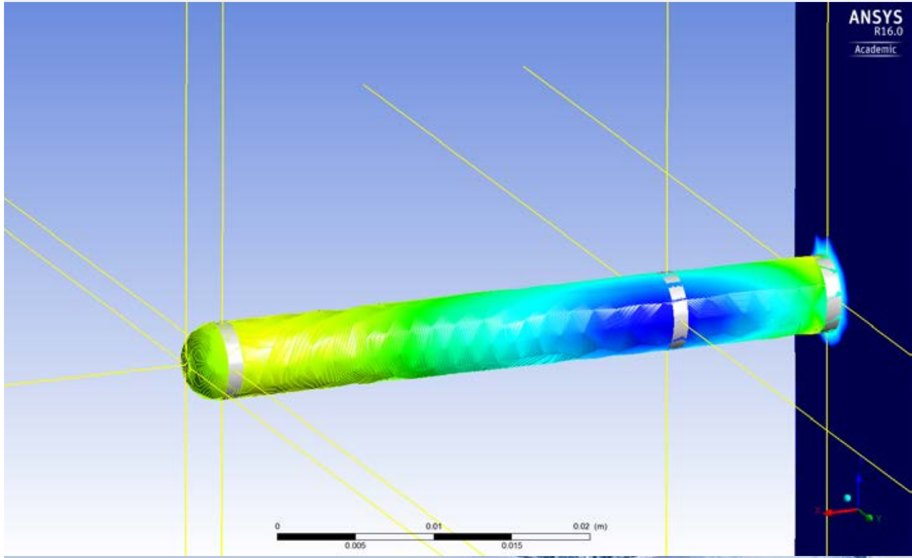
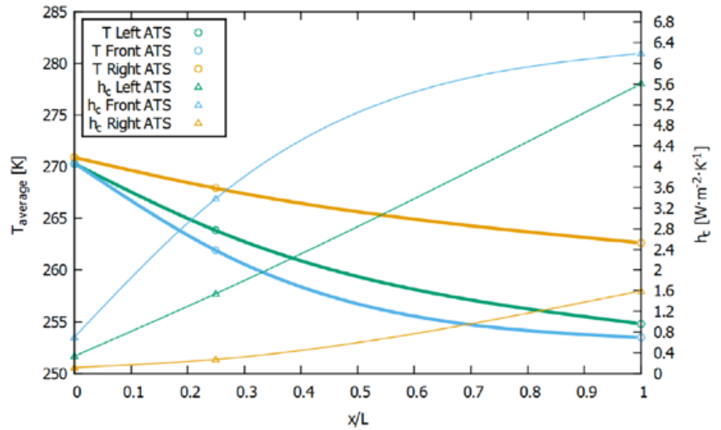
5. Results

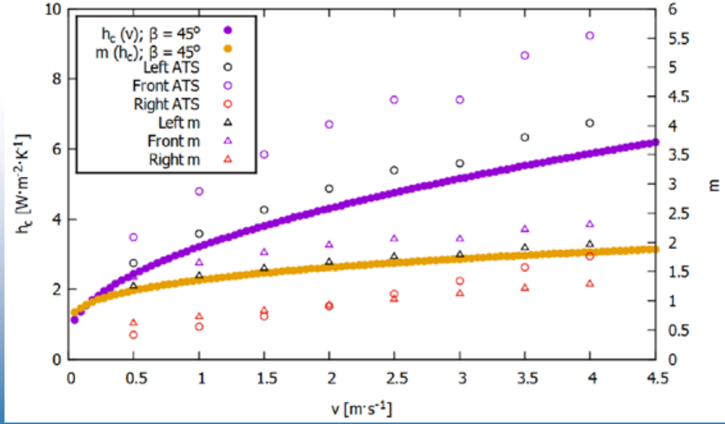
$$h_c = \frac{\dot{q}_c}{T_s - T_\infty}$$

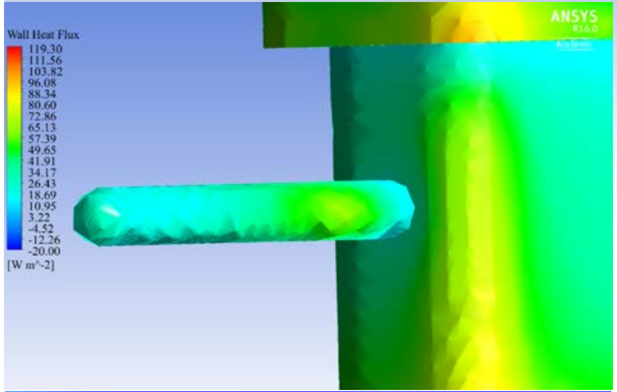


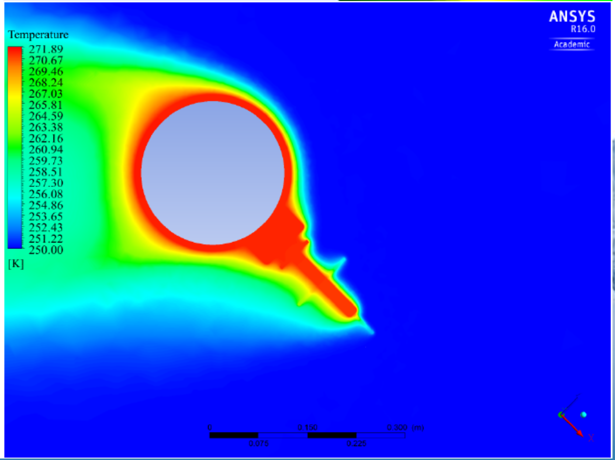


5. Results









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6. Conclusions

- ATS exposed to free flow show a h_c in agreement with the expected from the model.
- ATS not exposed to free flow, in the HABIT-Platform wake, has a lower h_c given that it is not exposed to forced convection completely.
- For the same set of atmospheric conditions, the convective term, and m value, increase with wind speed.
- The different values of the m parameter can be used as a proxy for orientation of the wind speed.
- This method is sensitive to the wind orientation and speed and can thus be used to retrieve information, in real time, about the wind activity and heat fluxes.
- Assumptions/plausible sources of errors :
  - Nu number for a cylinder normal to the fluid flow.
  - Temperature and h_c distributions along the ATS sensors no one-dimensional.
  - Local force convection along the sensors.
  - h_c calculated from two averaged values over control surfaces for a non-linear distribution.
- Future work: validation in the wind tunnel facility at LTU (Kiruna).

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Thank you for your attention

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