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MarsTEM sensor simulations in Martian dust environment

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ABSTRACT

A wind tunnel test campaign has been conducted prior to the landing of the Exomars2016 EDM module on the Meridiani Planum on the 19th of October 2016. Test were performed in the Mars wind tunnel facility at Aahrus University (DK) under the 2015 Europlanet Call. The facility was available for a 5 days campaign where different environmental configurations were tested and both a full scale DREAMS (Dust Characterisation, Risk Assessment, and Environment Analyser on the Martian Surface) Metmast model and a Descent Module mockup were studied. In particular the MarsTEM (Mars TEMperature sensor), the temperature sensor of the DREAMS package onboard Exomars2016, was studied for different wind velocities and directions, effect of light sources and presence of dust. The test showed that the sensor response is dependent on wind direction but only slightly on wind velocities. It also seems that the presence of the dust in the wind and the consequent dust deposit on the Metmast and the sensor itself uniforms the response for different wind velocities and directions. Light is also affecting the measurements but it is still not so clear what will be the effect on Mars due to the particular light sources used for the test.

1. Introduction

The DREX esperiment (DReams EXperiment) was an experiment conducted under the 2015 Europlanet Call for testing space instrumentation in specific facilities. The goal of the experiment was the testing of the performance and functionalities of the DREAMS payload (see [1,2]) in a Martian like environment using the Planetary Environment Facilities available at Aarhus University.

The principal objectives were:

- to investigate the effects of Martian wind (velocity and direction) and dust on DREAMS sensor measurements;
- to investigate the effects of light sources on DREAMS sensors measurements;
- to investigate the influence of the EDM (Entry Descent Module) module on DREAMS measurements (in particular flow distortion and thermal effect).

In particular, for the MarsTEM sensor the first two objectives are going to be discussed in this paper. To our knowledge in the Aarhus facility only the Phoenix mission's Telltail wind sensor has been tested other than the entire DREAMS package. The DREAMS suite is therefore one of the most complex instruments that has been tested in this martian like environment. Other Mars temperature sensors have been used on other Mars missions, like NASA Vikings V1 and V2 in the '70s [3], Mars Pathfinder in the end nineties [4], the two MERs in the first 2000s [5], Phoenix in 2012 [6] and MSL since 2014 [7]. The first three missions used thermocouples while MERs measured thermal spectras with the Miniature Thermal Emission Spectrometer (Mini-TES) and Phoenix had again thermocouples measurements at three heights, 0.5 m, 1 m and 1.5 m; MSL has two thermistor (Pt1000) rods. MarsTEM sensor uses RTD thermistors, and specifically 2 custom designed Pt30 [8].

2. Facility description

A complete description of the wind tunnel facility can be found in [9,10]. The available test section is $0.9 \times 2.0 \times 2.0$ m wide; the complete DREAMS masts with the CEU (Central Electronic Unit) was fixed in the center of the test area (see Fig. 1). For our tests the wind tunnel facility was equipped, for the first time, with a new air cooling system that allowed to control directly the fluid temperature (see Fig. 2). The set-up for the monitoring of the temperatures of the DREAMS package

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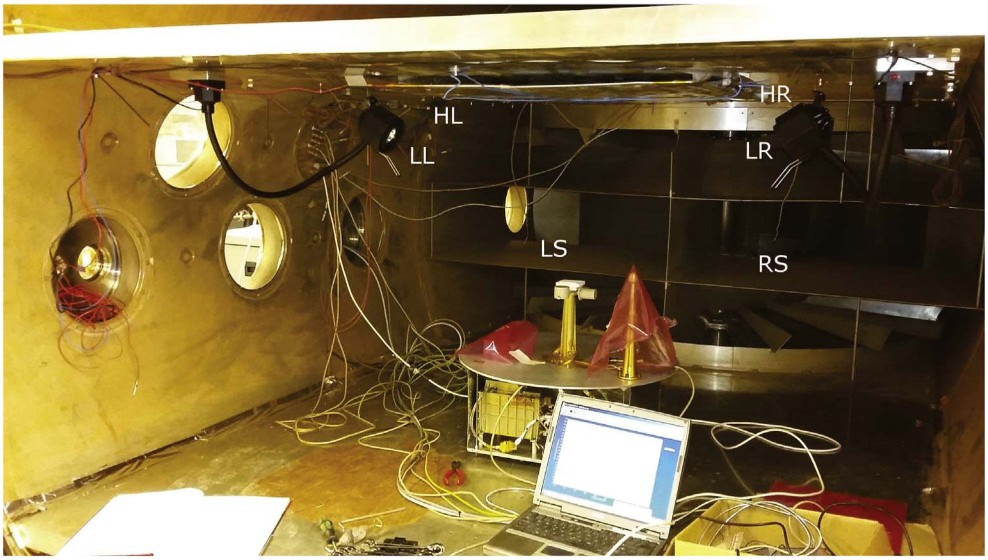

Fig. 1. Wind tunnel chamber: internal setup before starting the tests. On the back it is possible to see the fan blades: on the left and right upper sides the two pairs of halogen lamps used for the test (LL, LH, RL, RH) and the two floating sensors (LS and RS) for the fluid temperature sensing.

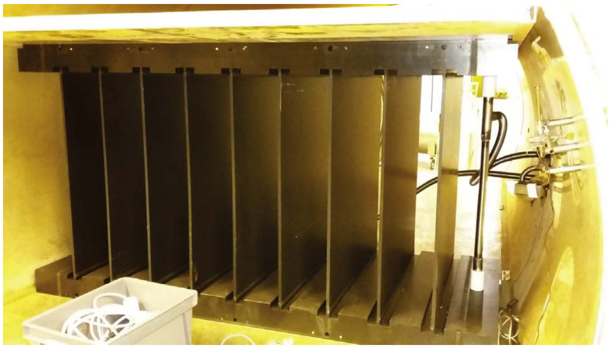

Fig. 2. The new cooling setup for controlling the fluid temperature inside the chamber.

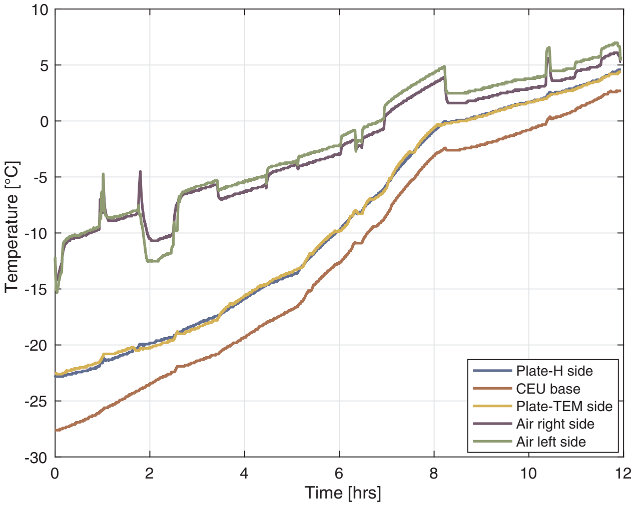

Fig. 3. Housekeeping wind tunnel temperature evolution during the wind velocity and halogen lamp tests.

considered 3 Pt100, one positioned on the base of the CEU supporting structure and the other two on the circular plate supporting the Metmast, positioned near the base of the mast itself, one facing DREAMS-H (the humidity sensor of DREAMS) sensor and the other one on the side of the MarsTEM sensor.

The fluid temperature is monitored with two floating Pt100 sensors near the Metmast and positioned downwind respect to the sensors and in the middle of the height of the test section. Thermal response of the different sensors depend on the particular environment, for this reason the chamber is filled with CO_2 maintained at a pressure of about 8 mbar. Furthermore, two pairs of halogen lamps (a low power and a high power lamp) were positioned on the sides of the chamber.

3. Test description

The tests were performed after evacuating and cooling of the wind tunnel; both the CO_2 and the mechanical interfaces were cooled. Unfortunately, once the system reached the temperature around −20 °C the liquid Nitrogen finished, the cooling stopped, and the temperature of the chamber started to constantly increase (see Fig. 3). In any case the tests were performed since the gradient was low and thermal isolation was considered sufficient to proceed.

For a good analysis of the performance all the temperature data had to be de-trended. The air temperature in Fig. 3 shows peaks and valleys that are linked to the change in pressure of the chamber, to change in the wind velocities, and the switching ON and OFF of the halogen lamps. The wind velocities were measured via an LDA (Laser Doppler Anemometry); the measuring area is located near the sensors on the Metmast. The measured velocity varied from 2.3 to 13.8 m/s. The pressure was maintained at around 8 mbar with small variations during the entire day testing. Dust was injected in the chamber via a small window in 3 different series in order to reach the total expected amount for the two martian sols of foreseen operations. The DREAMS instrument was fixed on a rotating plate that allowed the complete 360° rotation of the structure; the centre of the plate was aligned with the central vertical axis of the Metmast.

The DREAMS instrument was controlled from the outside of the chamber with the DREAMS EGSE; specific mission timelines were designed and used to test different measurements sequences.

3.1. Error sources

The housekeeping parameters were monitored by the wind tunnel system controller; in particular, the flow velocity, pressure and temperature were set by the operators. Fluid velocity standard deviation is between 6.8% and 8.2% of the measured value, i.e. 0.15 m/s to 1.5 m/s (not too much higher than the accuracy expected on Mars: ± 1.0 m/s). The incoming wind direction was externally controlled by rotating the experiment which was mounted upon a mechanical rotating platform and the angle was registered by the controlling PC; the estimated error is around ± 2° (the accuracy of the values expected on Mars from

MetWind sensor, for winds around 5 m/s is ± 10°), so during the tests we are well above the accuracy expected on Mars. The pressure in the chamber is controlled via a manual valve and measured by a set of two sensors, one for low (< 10 mbar) and one for high (> 10 mbar) pressures. The declared error at the low pressure fixed for our tests, is around ± 1 mbar. But the highest uncertainty, in the measured air temperature, comes from the class-A Pt100 RTDs sensed with a 2-wire circuit: considering the length of the cables used from the setup inside the chamber to the electronics board on the monitoring PC a probable bias on the fluid retrieved absolute temperature of 2 to 4 °C has to be considered. In any case, since we are interested in temperature differences, this aspect is not essential for the presented analysis.

3.2. Environmental test

The environmental test aims to characterise the response of the MarsTEM considering mainly two aspects:

- Temperature response to different wind velocities.
- Temperature response to different wind incoming directions.

The flow velocities were varied changing the rotation velocities of the tunnel fans: 2.3, 6.3, 9.8, 13.8 m/s. The following rotation sequence were used to measure the sensor response; for each angle the measurement was performed for at least 15 s:

(a) a rotation between −180° to + 180° at 30° steps;
(b) a rotation between + 160° to + 200° at 5° steps;
(c) a rotation between −20° to + 20° at 5° steps;

For the angle values reference frame see Fig. 4. The above sequences were selected in order to increase the measurement near the MarsTEM and Metwind sensors, sequence (b) and (c) respectively.

In order to remove the chamber temperature increase a detrend linear curve $f_T(t)$ was calculated by considering the interpolating linear curve for the temperature *T last data* of each window (black crosses in Fig. 5). The *last data*for each window (between 20 and 60 data points depending on the considered window) were used because it was observed that for all the measuring sequences this was the most stable window with respect to fluid velocity and direction.

The final temperature variations is:

$$\Delta T = T - f_T(t) \tag{1}$$

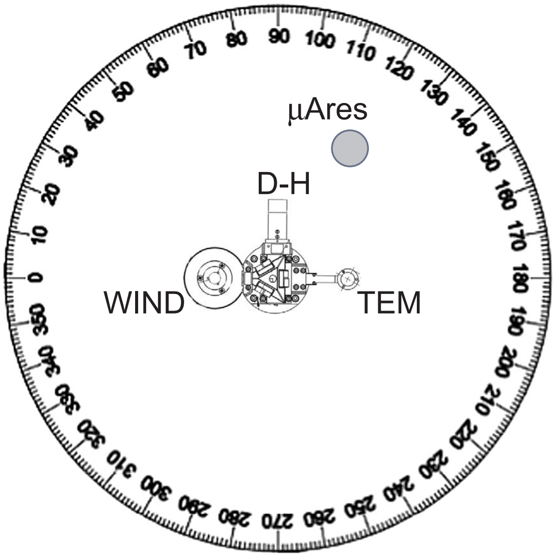

Fig. 4. MetMast reference frame.

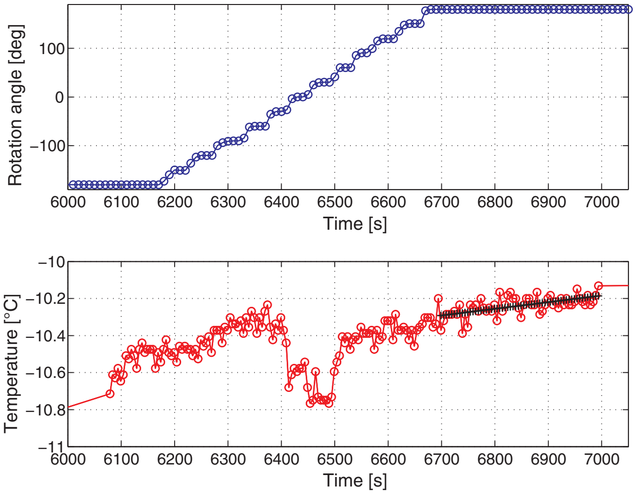

Fig. 5. Example of temperature measurements and rotation angle sequence for MarsTEM FINE sensor. Above: rotation angles; below: temperature measurements. The black cross is the detrending function used to remove the chamber increasing temperature.

As an example the detrend function $f_T(t)$ for the window of Fig. 5 is the following:

$$f_T(t) = -12.882 + 3.603\cdot 10^{-4} \times t \tag{2}$$

where t is the time of the window test (acquisition period is around 5 s).

Once all the detrend functions have been applied it can be observed that the ΔT measured temperature has a maximum $\Delta T = 0.4$ °C when the MarsTEM is downstream around 30° (see Fig. 6). In fact in this case it is shielded mainly by the MetMast itself and the DREAMS-H sensors (see Fig. 7).

It is possible to observe that the temperature variations ΔT follow the same behaviour for all the velocities tested, with very slight difference at angles lower than −30°. There is an increase in temperature from −180° to −50° and then a fast decrease until + 30°; this is probably due to the fact that the mean temperature of the Metmast is lower than the fluid temperature (see Fig. 3) and the fluid is cooling when passing near the Metmast before arriving at the MarsTEM sensor. The ΔT temperature variations seem also to be independent from the temperature difference between fluid temperature and Metmast temperature; in fact the difference is varying and linearly decreasing from 11 °C at the beginning of the tests down to 5 °C at the end of the tests while

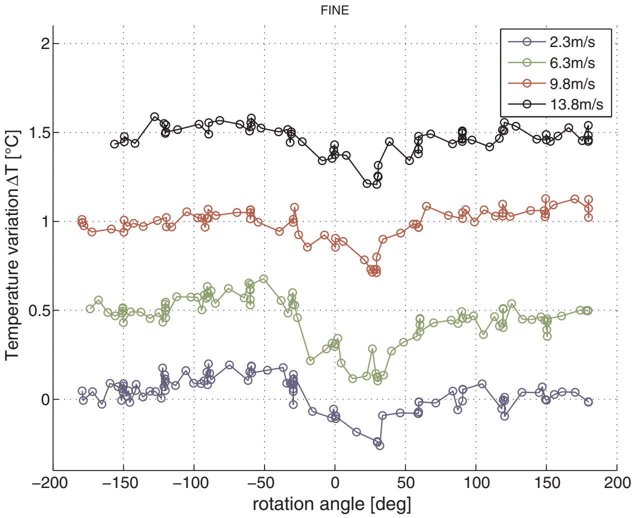

Fig. 6. Temperature variations dependence on angles. The temperature series have been shifted for presentation. The $\Delta T = 0$ value is the temperature measured by the MarsTEM sensor when facing the fluid.

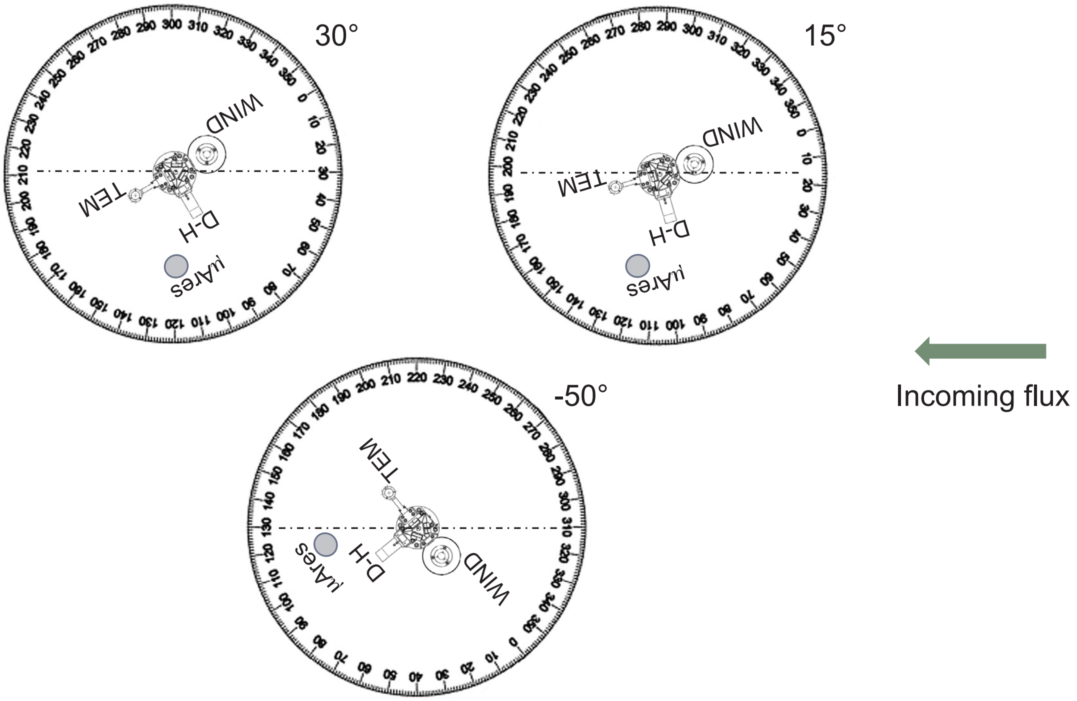

Fig. 7. MarsTEM relative angle wrt the incoming fluid.

the ΔT is similar for all the different fluid velocities (for a closer look see Fig. 13), which were performed in different moments during the day.

Furthermore, the fluid temperature experienced an increasing gradient from the left to the right part of the test section due to the lower temperature of the Nitrogen fluid when entering the fluid cooling system (mean temperature difference between the two air temperature measurements is 0.8 °C).

Another important aspect that must be underlined is the small $\Delta T = \pm 0.1$ °C that can be observed for angle values between 160° and 200° and that the behaviour for all tested velocities is similar revealing an independence of the measured temperature from that particular range of incoming directions (see Fig. 8). When the fluid is coming from the 0° ± 20° directions the variations are much more dependent on the angle; at −5° and 15° there are two directions were the variations are higher and, in particular, the latter is the highest of all the tests (Fig. 9); similarly to all the other tests the variations seem to be not dependent on fluid velocity (except for the case at 2.3 m/s where trend is similar than the other cases but absolute value is lower). It is probable that, at this low velocity, the fluid, passing nearby the Metwind sensor is heated up by its particular operating mode.

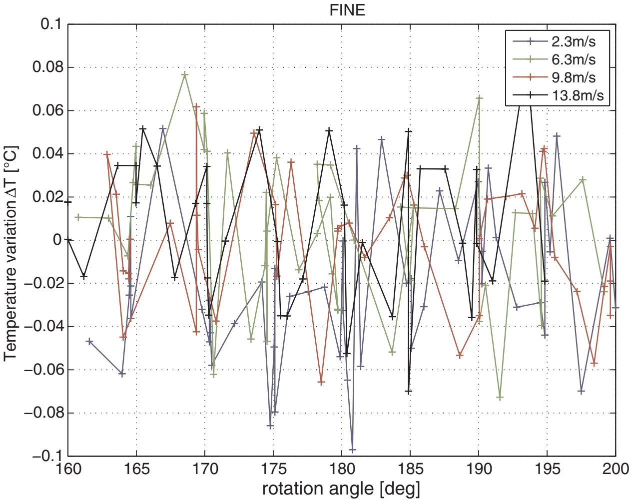

Fig. 8. Temperature variations dependence on angles; particular of the + 160°...+200 °C angle span in front of the MarsTEM. Variations are very small, in the range ± 0.1 °C. No appreciable difference is visible for different fluid velocities.

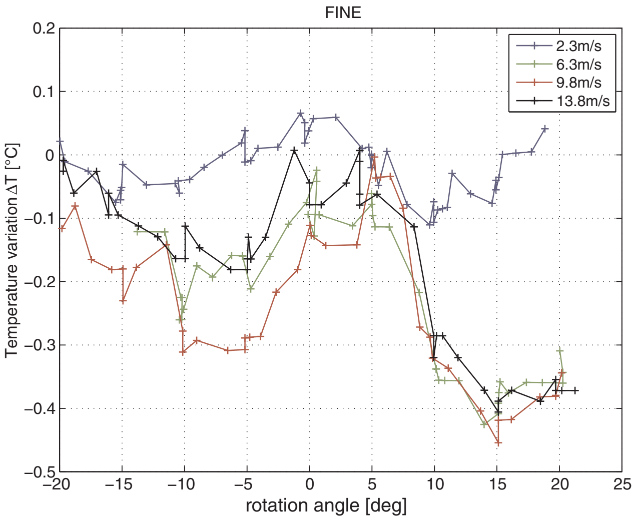

Fig. 9. Temperature variations dependence on angles; particular of the ± 20° angle span on the back of the MarsTEM (a bias of 0.15 °C has been removed from the data at 13.8 m/s). Variations are higher than the other cases; a dependence is visible on the angle, not on the velocities. Variations for low velocities are smaller but maintain the dependence on angle.

3.3. Halogen lamp test

Two pairs of halogen lamps have been fixed on the walls of the chamber and have been used as solar simulators (see Fig. 10 for the light spectrum); unfortunately the lamps spectrum is only partially similar to the one of the sun light hitting the surface of Mars (for comparison look at [11,12]).

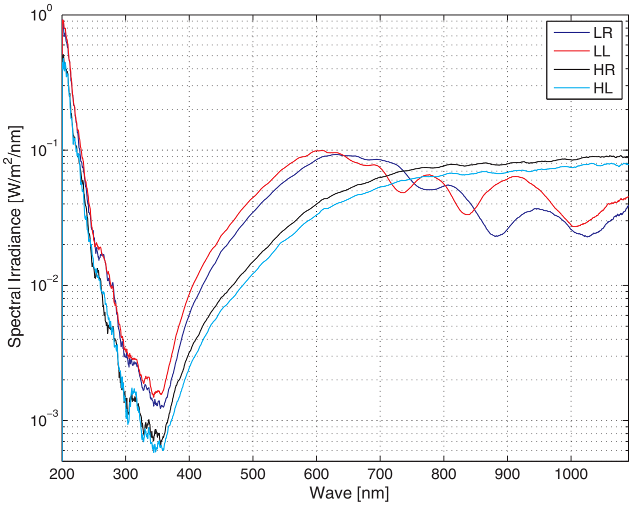

Fig. 10. Spectra of the 4 halogen lamps used for testing; LR = low power wind tunnel right side; LL = low power wind tunnel left side; HR = high power wind tunnel right side; HL = high power wind tunnel left side.

Looking at the DREAMS experiment from upwind position, we have four halogen lamps (see Fig. 1):

- LL and RL are the lower intensity left and right lamp (10×10 cm^2 spot area)
- LH and RH are the high intensity left and right lamp (2π sr diffusing area)

There is clearly an increase in the measured temperature, as expected, due to IR heating of the sensor even if, from a preliminary analysis, it is lower then the one expected on Mars (considering the much higher IR power tested in the lab wrt the total IR power expected on the surface of Mars). Specific tests are therefore going to be designed and planned, in order to better characterise the influence of IR light.

In Fig. 11 the test performed at $v_{wind} = 0$ m/s and 7 mbar pressure.

3.4. Dust test

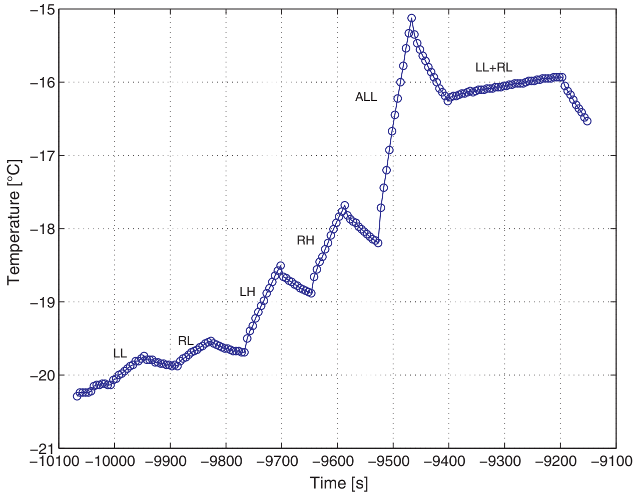

Fig. 11. Temperature variations due to Lamps switch ON and OFF.

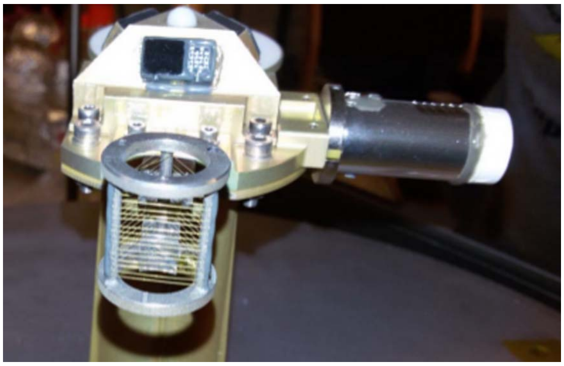

Fig. 12. Particular of the dust deposit on the MarsTEM sensor.

Table 1
Standard deviation values for Temperature difference wrt 180° angle.

Wind velocity (m/s)	Pre dust std.dev. ΔT (°C)	Post dust std.dev. ΔT (°C)
2.3	0.10	0.03
6.3	0.13	0.05
9.8	0.10	0.05
13	0.08	–

For the dust tests, ~ 0.1–2 g at a time of dry dust (JSC-1 Mars simulant crushed to an average grain size of around 2 μm) is injected using a gas dispersion system; a total of 7.5 g was injected simulating dust deposition for about 6 days on Mars (assuming a dust concentration of around 3 per cm^3 and an average wind speed of around 5 m/s). A relatively small volume at 1 bar of gas and dust is being let into the chamber dispersing the dust aggregates and suspending the dust. All the sensors, after opening the chamber show clear effect of dust deposition on their external surfaces (see Fig. 12).

As it can be observed the temperature variations after the deposition of the dust are very weak (Table 1) and result in being independent on the flow direction, except for the angles between 0° and + 50° (Fig. 13); this is still under investigation but it could be due to different factors. First the deposition of dust on the sensing wire is affecting the thermal behaviour of the wire itself, changing the response time of the sensor; second the fluid reaching the wire is not disturbed (cooled or heated) by passing in the nearby of the other sensors (i.e. Metwind and DREAMS-H) and of the Metmast structure because the dust deposit on their surfaces acts as a thermal insulator (see [13,14]) with respect to the underlying surface and not biasing the fluid temperature.

4. Conclusion

A wind tunnel test campaign has been conducted in the summer

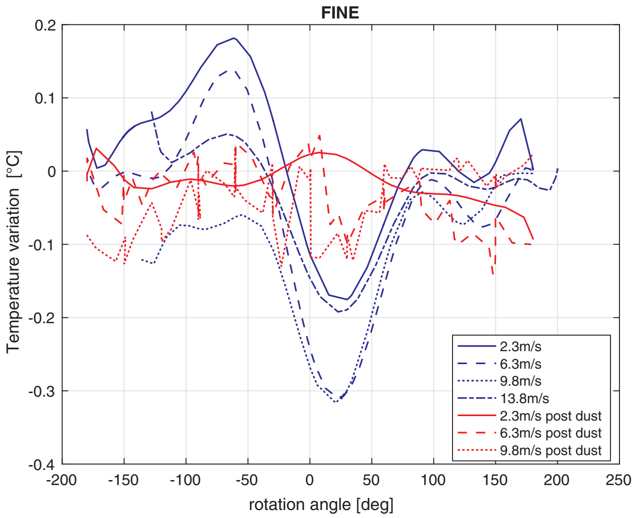

Fig. 13. Temperature variations dependence on angles and dust deposition (smoothing on data has been applied).

2016 before the landing of the Exomars2016 EDM module on Mars. Test were performed in the Mars wind tunnel facility at Aahrus University (DK) under the 2015 Europlanet Call. While the tests performed on the temperature MarsTEM sensor show a dependence of the sensed temperature on the incoming fluid directions (when no dust is deposited on the Mestmast), there is no correlation on the tested wind velocities. The tests with the halogen lamps show a correlation in the measured temperature due to IR heating, but data need to be further investigated for a deepeer understanding of the phenomenon. The deposition of the dust on the DREAMS package seems to affect the sensor response due to its thermal properties; dust smooths down the response of the sensor and in fact the variations wrt wind directions are negligible, with no dependance on the velocity. Data analysis is still going on and new outcomes are expected.

Acknowledgment

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