ROVER ENVIRONMENTAL MONITORING STATION FOR MSL MISSION.

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Introduction

The Mars Science Laboratory (MSL) payload is composed of a set of instruments including the environmental monitoring station REMS (Rover Environmental Monitoring Station), which is a contribution of Spain. The Centro de Astrobiología (CAB) is leading the development of the instrument. REMS is a suite of different sensors to record pressure, humidity, air and ground temperature, UV radiation and wind speed and direction.

Viking was the first mission that recorded atmospheric data on site. The Viking Landers measured pressure, wind speed and direction, and air temperature with a small boom [1]. Mars Pathfinder with its Atmospheric Structure Investigation/Meteorology (ASI/MET) recorded a second batch of surface data (pressure, air temperature and wind direction [2]). With MSL, data will be recorded from a mobile platform. This is the first time that an exploration rover is equipped with an environmental station, which provides a big design challenge due to the fact that sensors need to measure an environment that in many cases is perturbed by the rover itself.

REMS scientific objectives are: to characterize the Martian climate and to study Mars habitability. If we understand habitability as a concept derived from local habitat, the knowledge of environmental conditions play a key role.

REMS will record atmospheric data at surface level (at aprox. 1.7 m hight) at different locations during the MSL mission. These local measurements are the combinations of many effects and many scales. Global atmospheric phenomena like Hadley cells or fronts are perturbed by large-scale orographic conditions and at the end are modified again by local orography and geology. Global circulation models and mesoscale models are the tools that the community use to simulate these effects [3][4], REMS measurements will help to validate these models, and to understand some key aspects of Mars climatology like the Martian global water cycle.

UV radiation levels have never been recorded directly at surface level. A solid understanding of the UV radiation could help to evaluate more precisely its biological damage for future manned missions as well as other important aspects: the UV radiation contribution to the geochemical processes which run at the Mars surface[5], the photochemical processes in the atmosphere [6] and, by comparison with satellite records, the study of the Mars atmospheric radiation absorption [7].

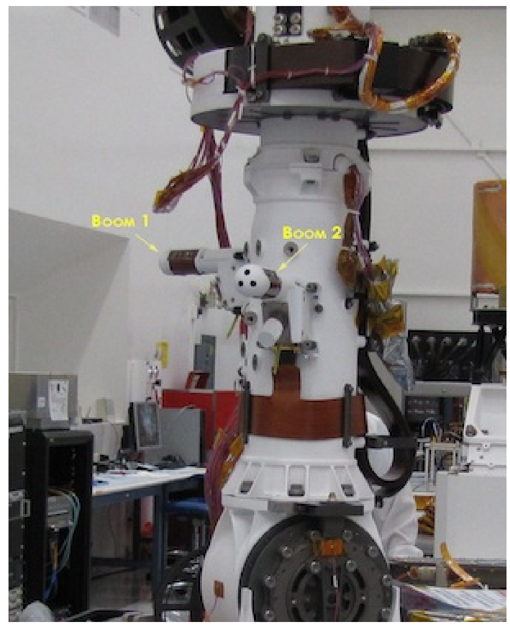

Figure 1: Remote Sensor Mast with the Boom 1 (B1) and Boom 2 (B2) installed. B2 is looking forward and B1 is pointing to the rover right side. At the beginning of the project, the minimum distance to the rover body and RSM head was estimated with the help of a quite simple CFD model. Also, the rover design has a constraint to minimize the size of any protrusion close to the booms.

To evaluate the habitability of a location it is necessary to analyze many factors together, including temperature, water conditions, minerals and morphology, radiations levels and type of microorganisms [8][9]. REMS will play an important role in this area because it will record much of the relevant data and, in collaboration with data from other MSL instruments, could give a good idea of the subsurface conditions for life development.

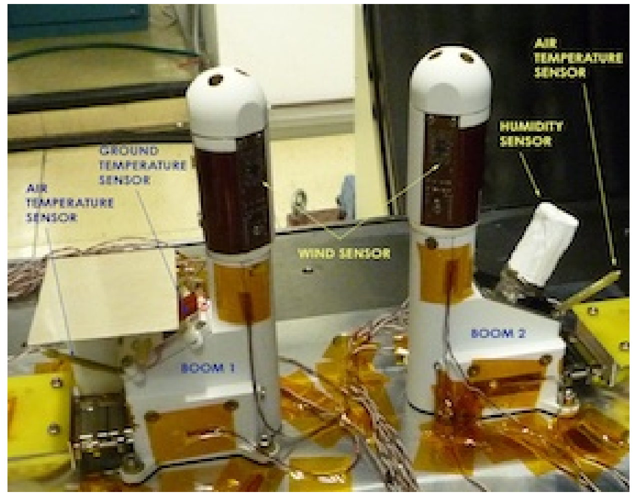

Figure 2: Boom 1 and 2 during the TVT tests. Some calibration tests have been run during TVT. One of them related with the GTS, reason by what a small plate has been place in front of the GTS in order to control the infrared radiation received by it. Regarding the WS, TVT had been used to determine its thermal conductivity losses.

Instrument

The instrument specification established the sensors requirements in the terms defined in Table 1. Besides that, the total mass was restricted to 1365 gr including all modules.

REMS instrument is composed by four modules: two booms, the ultraviolet sensor unit and the instrument control unit (ICU). Each boom has a wind sensor and an air temperature sensor, besides that the ground temperature sensor is placed in the Boom 1 and the humidity sensor in the Boom 2. The pressure sensor is included in the ICU and both are located inside the rover body. Figure 1 shows the booms installed in the Remote Sensor Mast (RSM). To understand the reason of the final configuration is important to know the design evolution. At the beginning, the instrument was a single unit located in the RSM. It was folded on the RSM body. The deployment options were the use of a small pyroshock or to control it by the RSM deployment. The instrument had a single boom with enough length to avoid rover perturbation. To minimize deployment risk, the boom should have a fixed position and therefore it should be shorter than before, to avoid interferences when the RSM was folded. A shorter boom has the disadvantage of having RSM body perturbation. With three booms at 120 degrees, the effect of the RSM wake could have been avoided, because for any wind direction at least one of them would have been out of it. At the end, two booms with a gap of 120 degrees were implemented and therefore for some wind directions, both booms will be in the RSM wake.

With the above configuration, both booms are not placed in a warm area and therefore should operate in the full range of temperatures expected (from 150 to 300 K). Each time the instrument wakes up (see Operation section) should be heated previously to get its operational temperature, i.e. 24 times each day of the martian year. To verify the design a muti-year thermal cycling test has been done.

The Ground Temperature Sensor (GTS) use a thermopile (8- 14 microns) to record the infrared radiation emitted by the 25 m^2 surface in the right rover side [10]. The frequency selected avoid the carbon dioxide absorption. A small part of the thermopile field-of-view is blocked by the calibration plate, which will be used to monitorize the thermopile degradation along the mission.

The Air Temperature Sensor (ATS) have two thermistors: one the tip of the other one in the back of a small rod located in the lower part of each boom (see Figure 2). The rod has been manufactured with a low thermal conductivity material to minimize the measurement contamination due the heat flux from the boom body. Air temperature estimations will be done based on the reading of both thermistors.

The Pressure Sensor (PS) has been developed by Finnish Meteorological Institute (FMI). As it is located in the rover body, a small opening in the rover top plate connects it with the atmosphere; the opening has a protection against dust deposition. As this component will be in contact with the atmosphere and in order to avoid any contamination of the Mars environment a HEPA filter will be placed on the opening.

The Humidity Sensor (HS) has been developed by FMI, also. The sensor is placed on the Boom 2 and protected against dust by a teflon cylinder (see Figure 2).

The UV sensor will be located on the rover deck and is composed of six photodiodes to cover the six bandwidths shown in Table 1 (the last two bands have been selected to ease comparison with Mars Reconnaissance Orbiter (MRO) data and correspond to ozone absorption bands). The sensor is placed on the rover deck without any dust protection. To mitigate dust degradation, a magnet has been placed around each photodiode with the aim to increase as much as possible their operation time. Nevertheless, to evaluate dust deposition degradation, images of the sensor will be recorded periodically to estimate photodiode degradation by comparison, of these images, with laboratory measurement.

Wind sensors will record wind speed and determines its 3D direction. These sensors are composed of three 2D wind transducers [10] on each boom, each one based on the hot film anemometry concept. Based on calibration tests, data from hot film will be translated to local wind speed and direction. Nevertheless, those data will not be enough to know actual wind information because, as

	Range	Accuracy	Resolution	Calibration results
Ground brigthness temperature	Ambient temperature (150 to 300 K)	10 K	2 K	Resolution 2K (averaging 1 minute reading), accuracy better than 10 K
Air temperature	Ambient temperature (150 to 300 K)	5 k	0.1 k	Pending of wind tunnel tests
Pressure	1 to 1150 Pa	10 Pa (20 end-of-life)	0.5 Pa	Accuracy BOL 6 Pa Resolution 0.35 Pa Accuracy EOL 14 Pa (estimated)
Relative humidity	0 to 100%		1%	Accuracy better than 3 % Resolution better than 0.5 % Not operating at temperatures below -90 C
Ultraviolet radiation	210 - 360 mm Total 215 - 277 nm (UVC) 279 - 320 nm (UVB) 315 - 370 nm (UVA) 230 - 298 nm (UVD) 311 - 343 nm (UVE)	5%	0.5%	200 - 370 mm Total 280 - 320 nm (UVB) 315 - 370 nm (UVA) 300 - 350 nm (UVE) Resolution better than 0.5% accuracy better than 5% in output current (10% in W/m^2) and a field-of-view of +/- 30
Wind speed	Horizontal 0 - 70 m/sec	1 m/sec	0.5 m/sec	Pending of wind tunnel tests (In progress)
	Horizontal angle	better 30 deg.		
	Vertical 0 to 20 m/sec	1 m/sec	0.5 m/sec	

Table 1: REMS requirements and performances

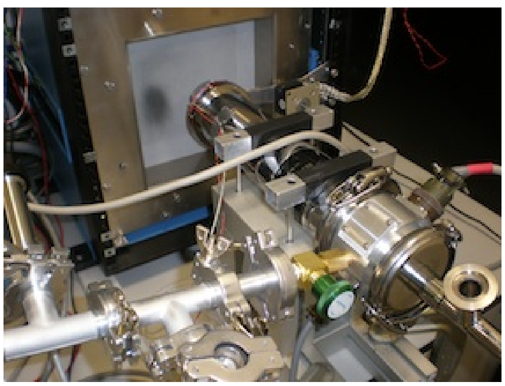

Figure 3: GTS set up for sensor calibration. The main GTS calibration has been carried with the help of a cryostat and a blackbody. Inside the cryostat were reproduced the operational conditions on Mars: low temperature, low pressure and carbon dioxide atmosphere. The black body placed in front of the sensor was the infrared radiation reference.

mentioned above, the wind sensor will record data perturbed by the rover mast and by the rover body, which means that some correction factors will be applied based on rover mast and boom tests and aerodynamic simulations.

Calibration

The REMS calibration process started at sensor level: each sensor was calibrated independently before its integration in their corresponding modules. In parallel, as the boom electronics is quite sensitive to temperature, it has been extensively tested to characterize it in a wide range of operational conditions. At the end of the integration process, a specific end-to-end test was performed to discharge any cross-interaction between sensors. Most of the tests have been performed and their results are summarized in Table 1. The Wind and Air Temperature sensor are not included because a specific boom model (fully representative of the flight unit) has been manufactured and delivered at the end of the integration phase, once all flight units were delivered.

Pressure and Humidity Sensors. Both have been calibrated at FMI premises, prior to the integration in the instrument. To evaluate the chimney (dust protection in the rover deck) effect in the pressure response, a dedicated tests, with rapid pressure change, have been carried out with the ICU+pressure sensor and a chimney dummy; the conclusion was positive with no change in the sensor response. During MSL environmental tests, a calibration check will be performed, specially during surface environmental tests; a laboratory pressure sensor will be located inside the chamber to have a good pressure reference.

Ultraviolet Sensor. FM Photodiodes have been calibrated before integration to know their spectral response at different temperatures, radiation intensity and incident angles. But once all photodiodes were integrated with the ICU, it was detected that for channels C and D the noise to signal ratios were very poor. For the other channels, the performance were the expected ones, inside the limits of its field-of-views.

Ground Temperature Sensor. As the previous sensors, FM components have been calibrated before integration with the set up shows in Figure 3. After the tests, all the parameter defined in the sensor model as well as the calibration plate performances were obtained. As with the UV sensor, the integration with the boom conditioning electronics add some constraints to the measurement: the reading should be averaged by 1 minute to reduce the signal noise and to get the accuracy required.

As it is mentioned before a dedicated calibration boom model has been manufactured for calibrating the sensor. The boom is fully representative in terms of ma-

Figure 4: Nevada desert dust devil season has been used to verify the REMS air temperature and ground temperature and UV radiation sensors response to the close dust devil passage. The results shows that UV sensor has fluctuations due to dust darkness

terials and process and the acquisition electronics has been tested at the same level that the flight units. Those tests will be performed in a chamber specially designed for the project, in which pressure and atmosphere composition are represented: both are the main parameters with influence in the sensor capabilities.

Operation

Regularity is the main driver for REMS operation. Each hour, every day, REMS will record 5 minutes of data at 1 Hz rate for all sensors. This strategy will be implemented based on a high degree of autonomy in the REMS operation. The instrument will wake up by itself each hour and after recording and storing data will go to sleep independently of the rover operation. REMS will record data during both rover operational and non-operational period, during day and night. The Rover computer will ask for data download once a day usually and send it to ground station according with rover operational strategy.

REMS operation is designed assuming three hours of operation each day, based on data volumes. In addition to the regular recording periods it is possible to increase some of the regular periods or to define new ones, in order to capture specific times with special scientific interest. Each day, REMS will received from the rover an Activity Table (AT) in which are defined all the operational periods (wake up and go to sleep) and the activities to be executed in the corresponding period.

The MSL operation will be similar to the previous NASA Mars rover missions. The Instrument data will flow to the instruments ground data system to process at the required level to prepare the next day activities, which are elaborated by the different science working groups. For REMS, it has been elaborated an user friendly software with all the calibration algorithms implemented, in such a way that sensor raw data are transformed in physical data automatically. All time series will be available to the operational and science users. The software elaborated allows to include data from other missions (like Viking) in order to compare the evolution of the atmosphere parameters.

Field tests

A number of field tests have been performed with two main goals: 1) field test of sensor engineering models to evaluate its response against natural conditions; and 2) collect environmental data similar to REMS but with a standard meteorological station in order to train the scientific operation team and prepare specific algorithms for automatic detection of atmospheric events.

The Antartic Spanish base was the first field campaign, an ultraviolet and ground temperature engineering models were used to record data in a permafrost area. Data recorded were compared with those data acquired with standard instrumentation.

In collaboration with Dr. Renno the CAB REMS Team has been involved in two campaigns along the dust devil season (see Figure 4) in the Nevada desert. The Ultraviolet Sensor, pressure oscillation and change in ground temperature have been the factors analyzed to detect the movement of a dust devil close to the station.

The Atacama desert has been used also as a place to record typical environmental data from a Mars analog. Ground temperature sensor were successfully tested to monitories ground temperature and also to detect change in the soil humidity conditions.

Another campaign it has been done in Tunez salty desert. As the the other field tests, a representative model of he GTS was used to record ground temperature evolution and an standard meteorological station to record the other environmental parameters.

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