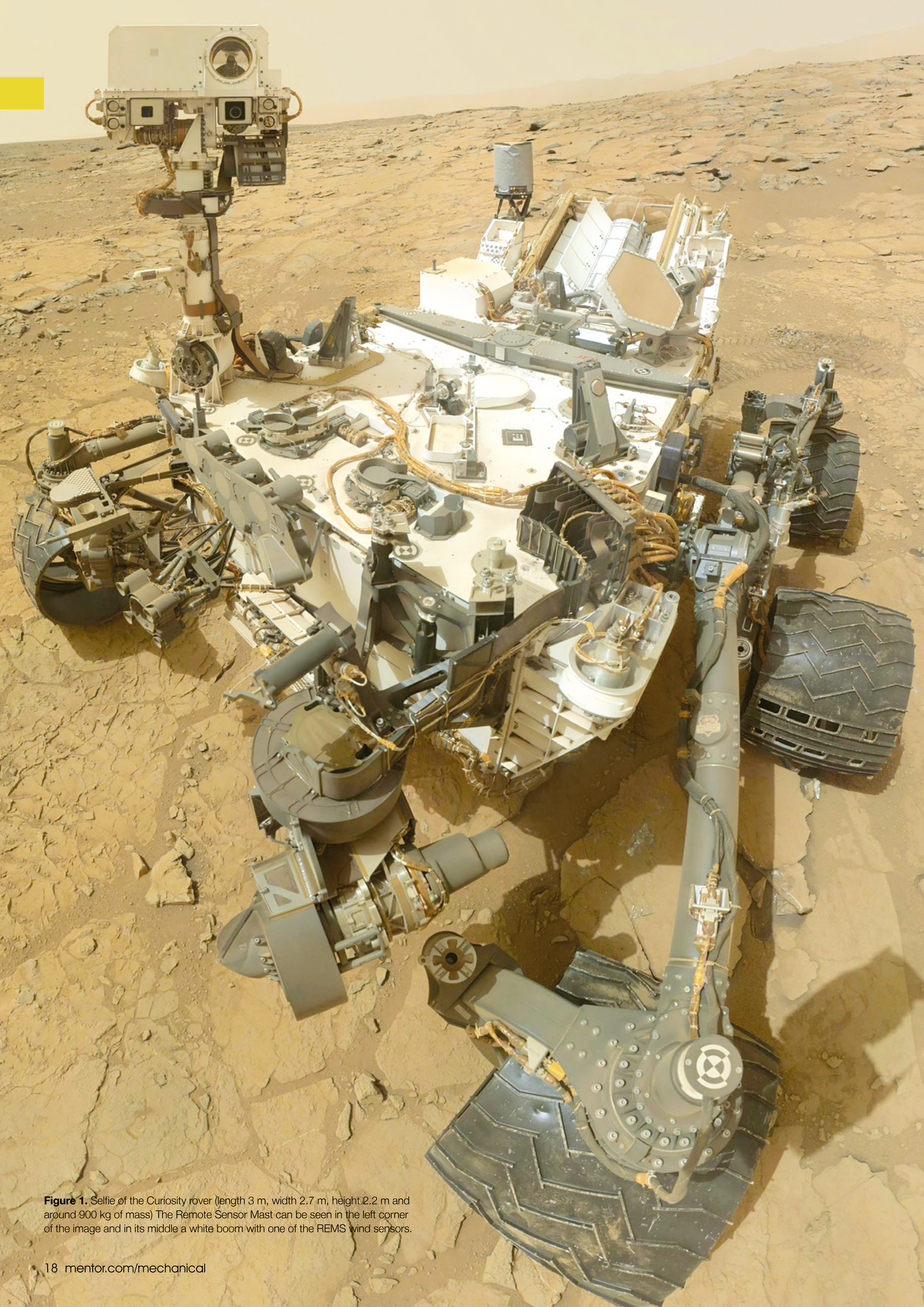

Figure 1. Selfie of the Curiosity rover (length 3 m, width 2.7 m, height 2.2 m and around 900 kg of mass) The Remote Sensor Mast can be seen in the left corner of the image and in its middle a white boom with one of the REMS wind sensors.

Curiosity: **Life on Mars**

Modeling the wind flow around the REMS instrument on board the Curiosity rover on Mars

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The Rover Environmental Monitoring Station (REMS) is part of the payload of the Mars Science Laboratory (MSL) rover, better known as the Curiosity rover, which landed on Mars in August 2012. REMS is composed of a suite of sensors, including two wind sensors. These sensors are based on hot film anemometry and are installed in two small booms which are located in the rover's Remote Sensor Mast. Measuring winds on a complex structure like a rover requires to know as best as possible the influence of the rover on the wind fluid stream.

Venus, Earth and Mars are the only inner solar planets with significant atmospheres. Venus has a hotter and denser atmosphere than Earth, whilst Mars' is colder and less dense than our planet. Pressure on Mars goes from 5 to 9 mbar, and temperatures depend on geographical location, but at the Gale crater, where the Curiosity is running, temperatures range from -80ºC to 5ºC. Nevertheless, the atmospheric phenomena on Mars are similar to that which occur on Earth. The duration of the Martian day is several minutes longer than an Earth day and the time that takes to give a complete revolution around the sun is equivalent to two Earth years. Similar to Earth, it has four seasons, and the windy period is the second half of the Martian year, when dust storms are common.

In August 2012, MSL rover reached the surface of Mars. It is the size of a small

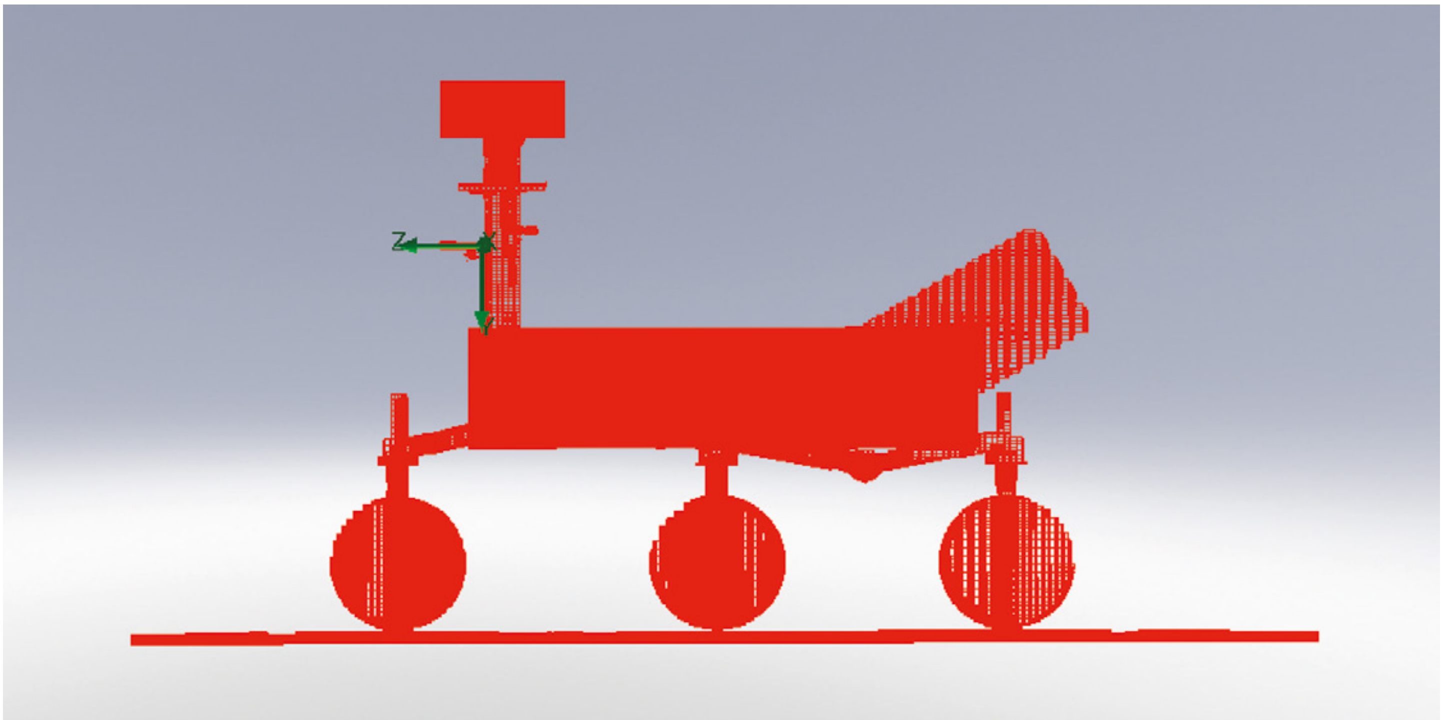

Figure 2. Rover solid cells inside FloEFD

car, and it is equipped with a payload composed of geological, geochemical and atmospheric instruments. It has a robotic arm that can dig and recover soil samples which can later be analyzed in situ. It has a number of cameras for navigation and scientific purposes. Its original mission was for one Martian year but 2017 will end its second full year on Mars. Its main goal is to determine the past habitability of the red planet, through the study of the water markers, mineral characteristics and also throughout the sediments of the Gale mount.

The MSL rover's central body contains most of the rover and instrument electronics. Its propulsion system is based on six motorized wheels and a suspension system to traverse the rough Martian terrain. It is powered by a Radioisotope Thermal Generator (RTG) and can communicate directly with one of the Deep Space Network of NASA antennas or using MRO or Mars Odyssey satellites to relay data to Earth. The Remote Sensing Mast supports some cameras for navigation and science, the ChemCam instrument and most of the REMS sensors.

Due to the general constraints of the rover design, the length of the two REMS booms are not long enough to be out of the rover fluid volume and therefore the rover can affect the fluid flow the REMS experiences. This makes it necessary to identify which

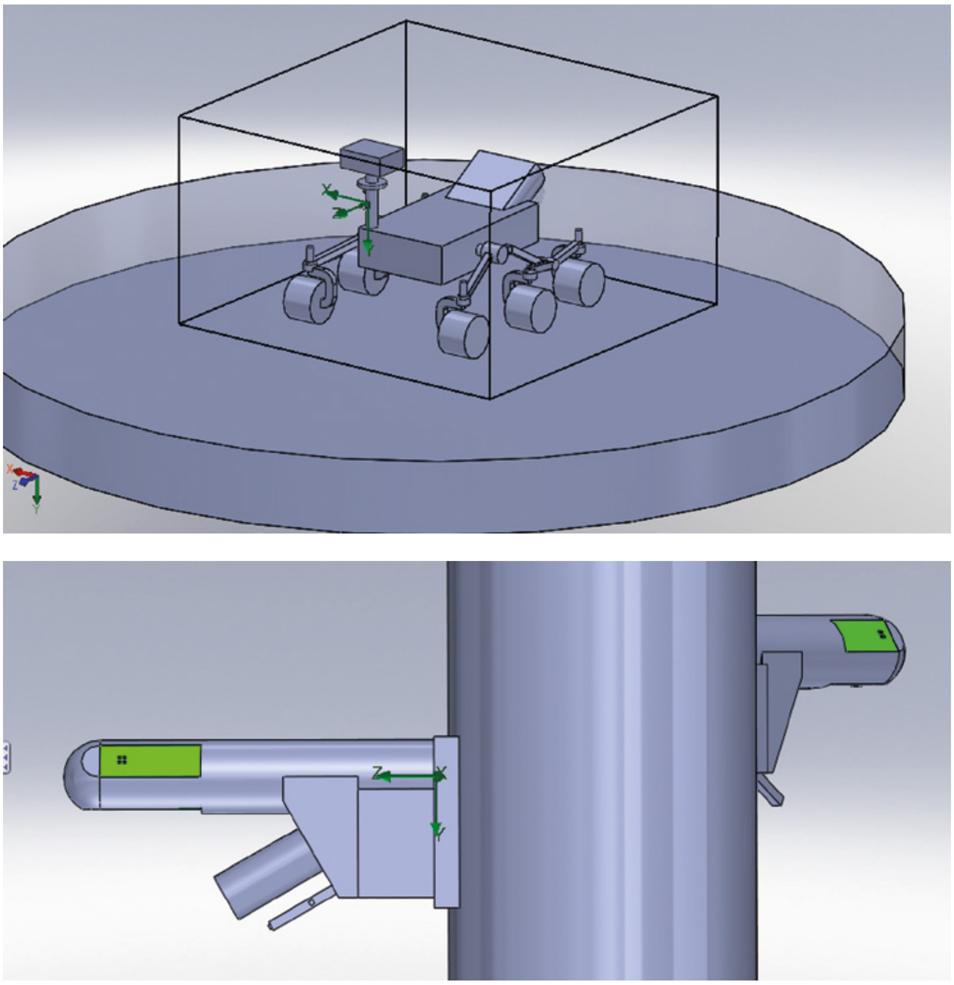

Figure 3. Top view of the Mars rover. 3D CAD model from jpl.mars.gov. Right side close up of both wind sensors on the mast, Boom 2 (left) Boom 1 (bottom)

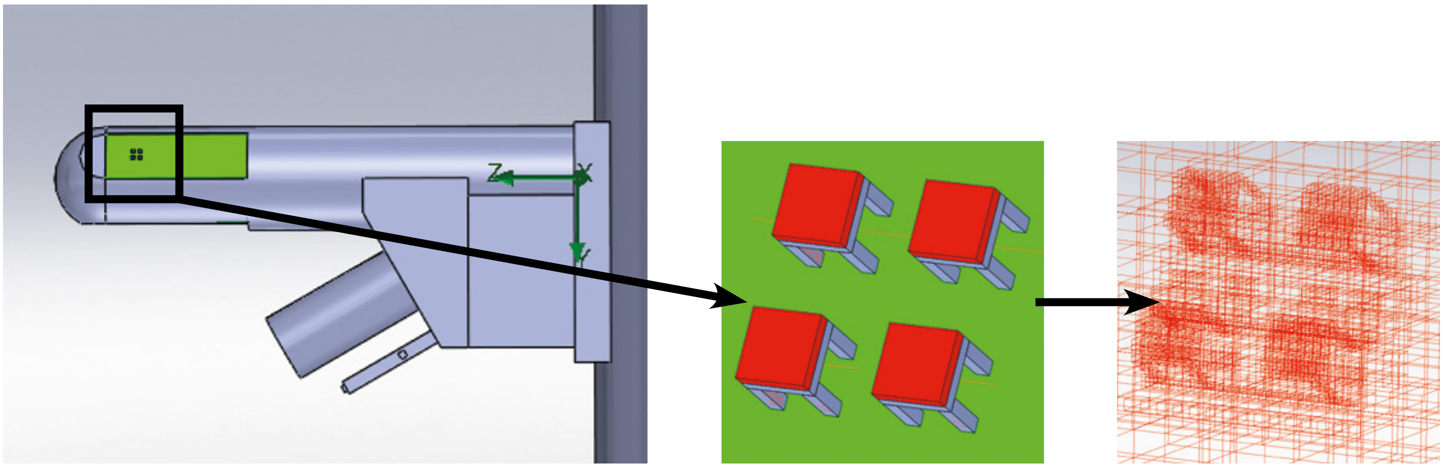

Figure 4. Detail of the wind sensor Boom 2 dice refined mesh

are the wind directions in which the impact of the rover is maximized and how it affects REMS measurement. Wind tunnel tests are not feasible due to time and facilities restrictions and therefore CFD simulation is the tool of choice. Understanding how the wind stream is perturbed by the rover, is the simulation goal for the REMS team.

The CFD simulation software used was FloEFD™ from Mentor, a Siemens Business. Utilizing FloEFD, an external boundary condition domain recreating Mars atmospheric conditions was generated with laminar and turbulent flow features activated. The simulations were also modeled with heat conduction in solids as well as free and forced convection.

The fluid computational domain size set for the simulations is 4×4×2 m. A true reproduction of the rover geometry was achieved using a fine mesh. The basic mesh dimensions Nx = 123, Ny = 123, Nz = 123 creates an initial mesh in the domain of 3cm mesh size. In addition, local meshes have been used to refine the solid cells in the rover: “wheels”, “mast and camera”, “deck”, “WS1” and “WS2”. Also a solid ground has been added to simulate the effect of the rover on the terrain.

The resulting Cartesian mesh consists of 3.2 million cells, which include 2.3 million fluid cells, 590,000 solid cells and 300,000 partial cells. Figure 2 corresponds to the rover solid cells.

The general settings for the simulations are set as follows: pressure of 713 Pa, temperature of 243 K, Fluid Air and Analysis Type “External”. Wind speed and direction are set in the velocity parameters box using the three components of wind speed Vx, Vy, and Vz.

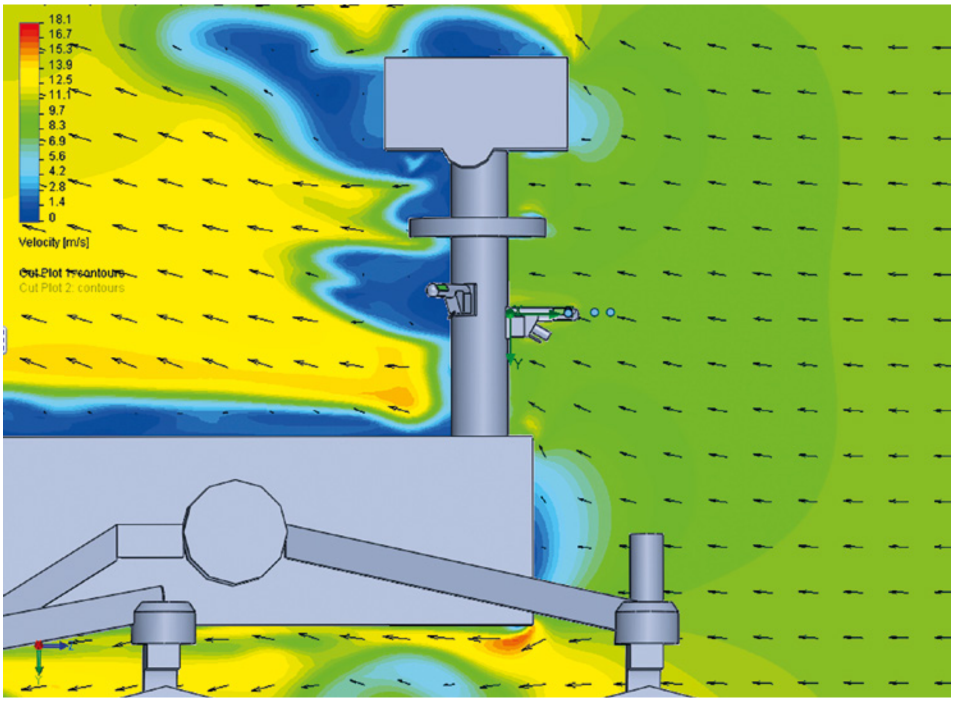

Figure 5. Detail of the point velocity around sensors

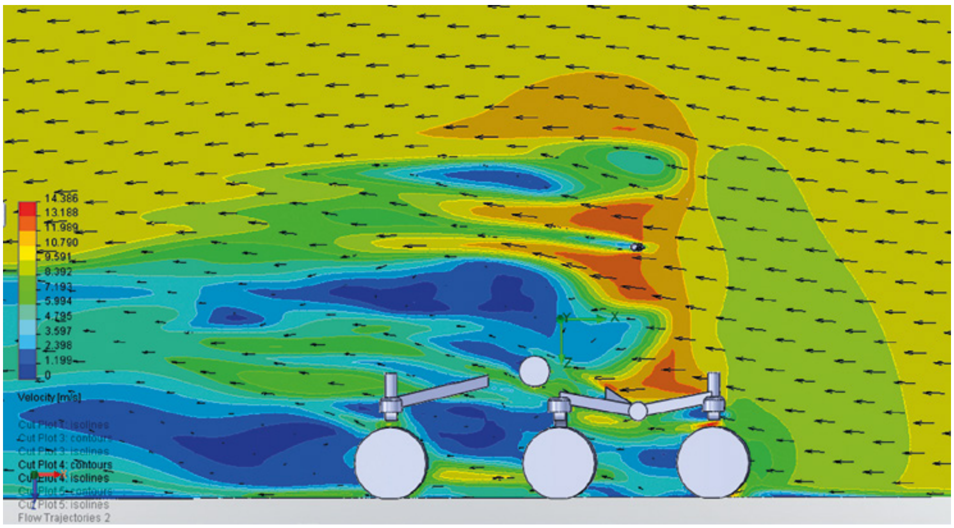

Figure 6. 10m/s Front winds (β = 0). Cut plot section at Boom 2

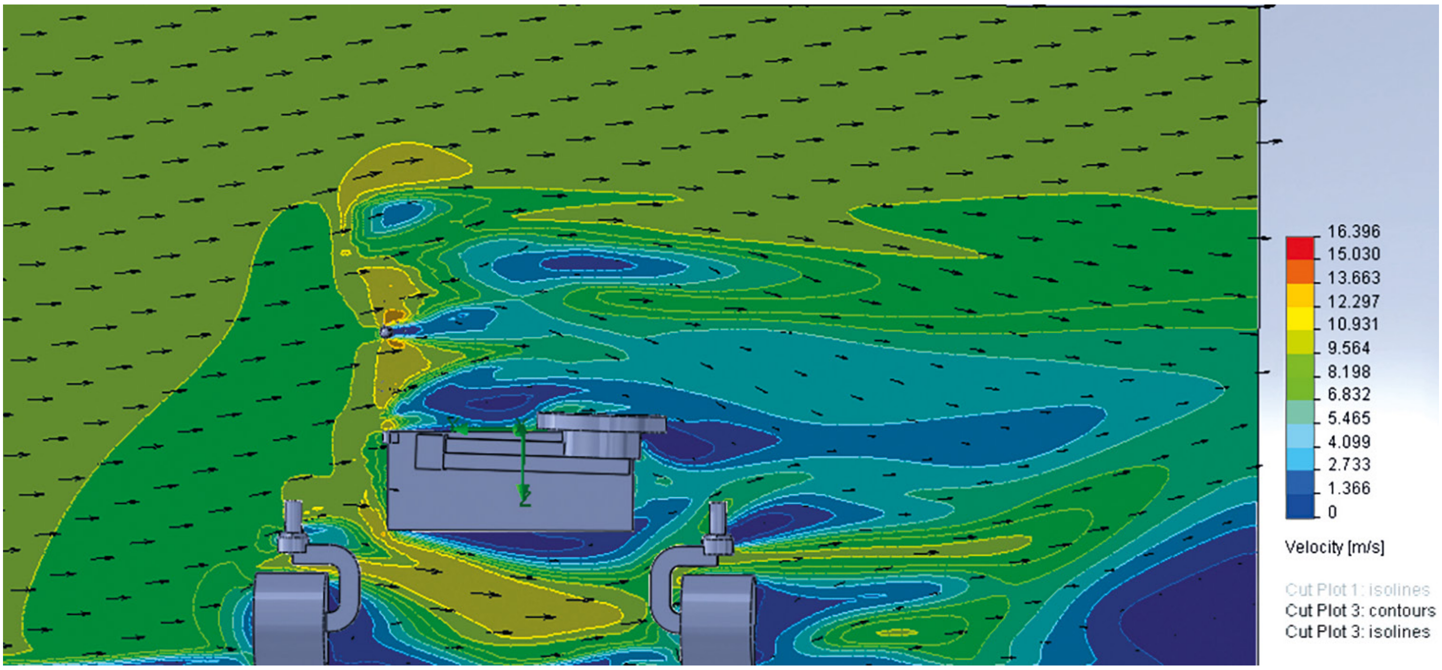

Figure 7. 10m/s side winds (β = 90). Cut plot section at Boom 1

With heat conduction in solids enabled, the team was able to simulate more realistic conditions of how the rover is heated and the interference with the atmosphere and wind stream.

CPU time of computation varies from 10 to 15 hours, depending on the wind velocity or direction chosen for the simulation in a 24 CPU machine.

The wind direction and speeds simulated have been: 5, 10 and 20 m/s of speed, yaw angles over range 0, 30…330º and pitch = 0º, 30º.

The 24 wind sensors are based on hot film anemometry, they are 1.5 mm x 1.5 mm x1.5 mm in size and are located in the front end of both Boom 1 and Boom 2. Local fine meshes have been used for each sensor to mesh the solid area correctly, an example of the detail of the refined mesh is shown in Figure 4.

From the simulation results, the perturbation of the rover on the wind sensor for different directions and speeds can be determined. For this purpose, an extended number of simulations was required but once the model was prepared, a batch run of simulations can be sent by modifying the initial parameters.

The X,Y, and Z velocity detail information can be extracted from the set point parameters. These parameters have been created near each of the wind sensors and around both of the booms.

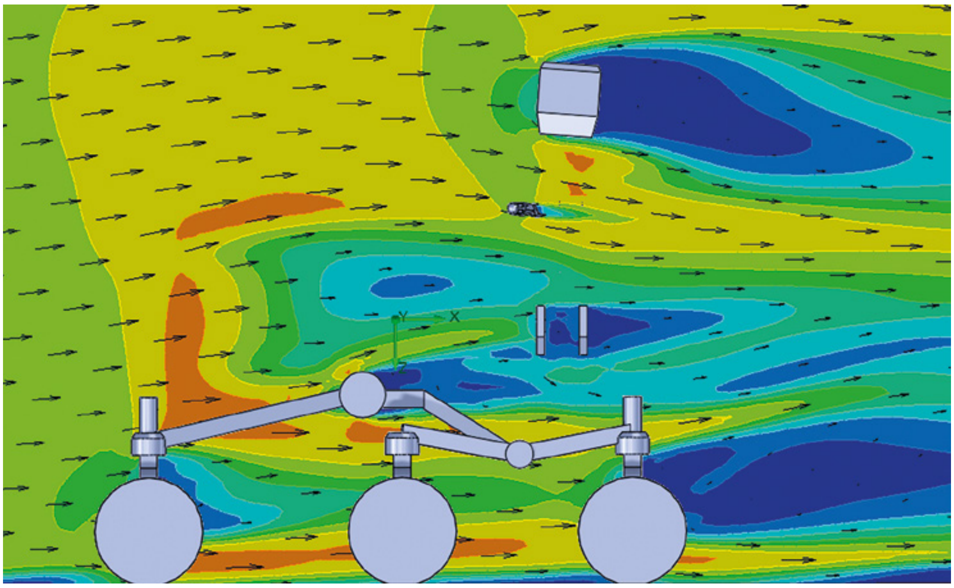

Figure 8. Rear winds (β = 180). Cut plot section Boom 2 level

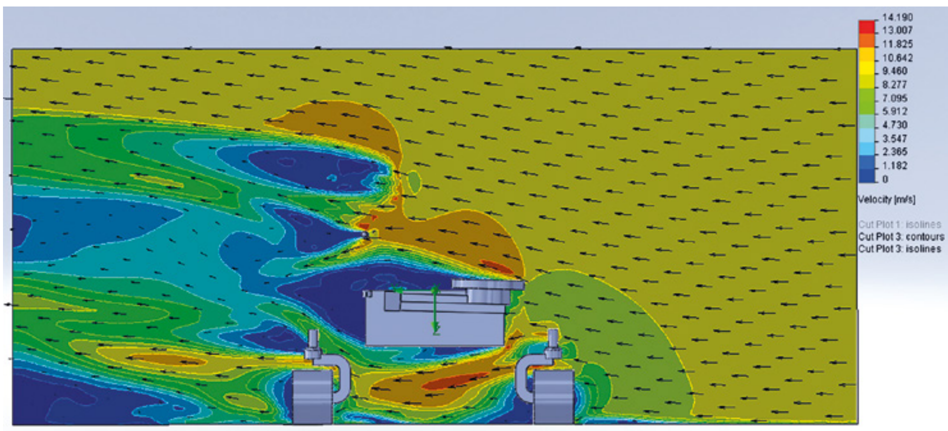

Figure 9. Front winds (β = 270). Cut plot section at Boom 1 level

> The REMS team was able to determine, through FloEFD simulations, how incident wind on the rover from different directions disturbs the reading on the wind sensors.

Figures 6, 7 and 8 detail cut plots of the perturbation of the freestream wind speed profile at 10m/s for the wind directions 0º, 90º, 180º and 270º. The perturbation that the rover creates around the wind sensor area can easily be seen.

The simulations were also modeled with conduction in solids and convection, both free and forced. This enables the simulation to heat different parts of the rover, providing a more realistic perturbation of the free stream velocity. Figure 10 shows the effect of the heat plume with no wind and with 5m/s rear wind.

The REMS team was able to determine, through FloEFD simulations, how incident wind on the rover from different directions disturbs the reading on the wind sensors. With the output of these simulations the team gained a better understanding of which wind sensor is experiencing the closest result to the freestream velocity and understand the different wind directions and speeds that could disrupt both sensors due to the geometry of the rover.

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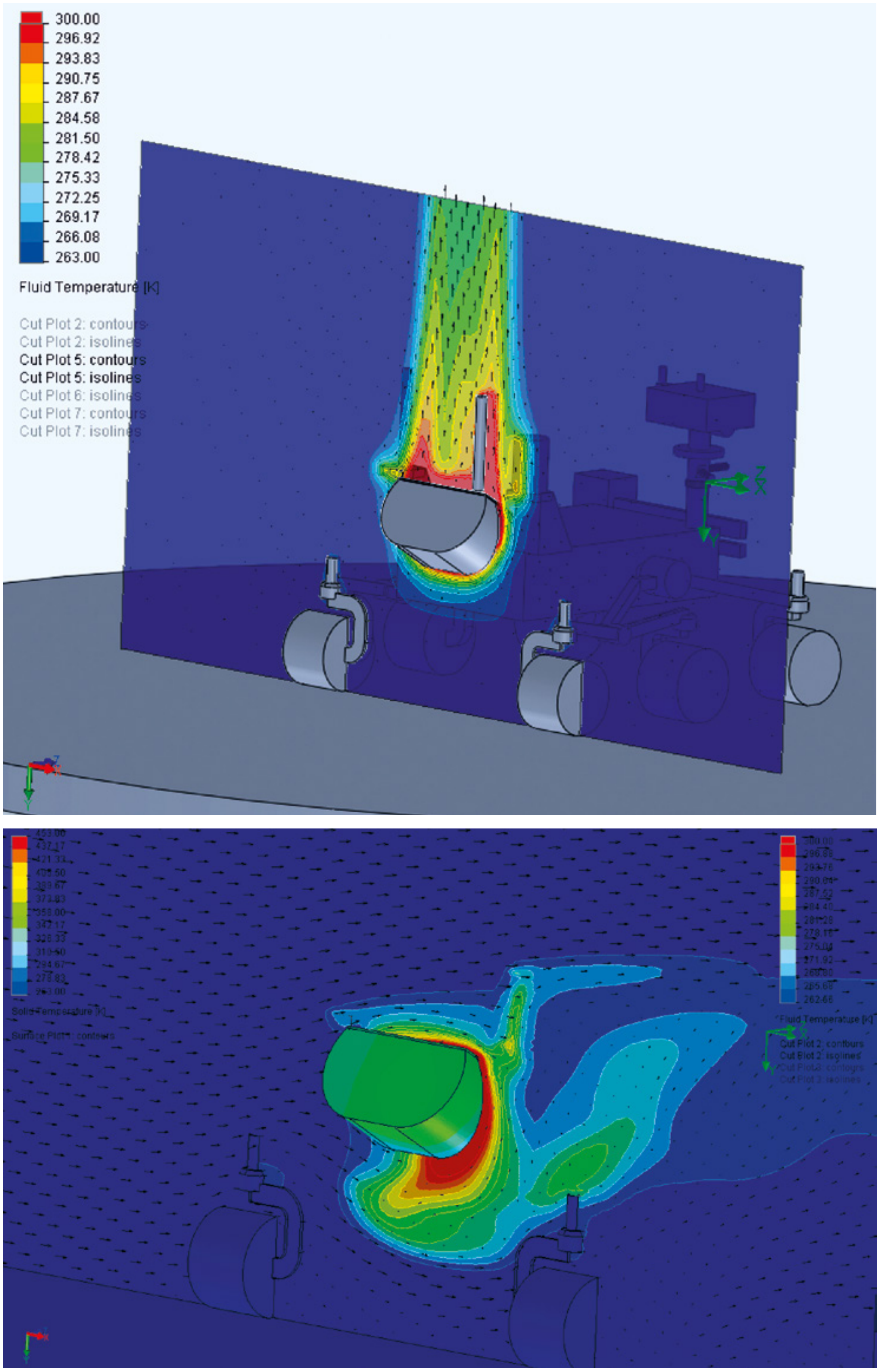

Figure 10. Rear winds (β = 180). Thermal plume of the RTG for rear winds