MONITORING OF AERODYNAMIC PRESSURES FOR VENUS EXPRESS IN THE UPPER ATMOSPHERE DURING DRAG EXPERIMENTS BASED ON TELEMETRY

Sylvain Damiani[1,2], Mathias Lauer[1], and Michael Müller[1]

[1] *ESA/ESOC, Robert-Bosch-Str. 5, 64293 Darmstadt, Germany, +49 6151900, first.last@esa.int*

[2] *GMV GmbH, Robert-Bosch-Str. 7, 64293 Darmstadt, Germany, +49 61513972970, sylvain.damiani@gmv.com*

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ABSTRACT

The European Space Agency's Venus Express spacecraft has been orbiting around Venus since 2006, and its mission has now been extended until 2015. During the extended mission, it has already successfully accomplished 7 Aerodynamic Drag Experiment campaigns until May 2012. Each campaign aims at probing the planet’s atmospheric density at high altitude and next to the South pole by lowering the orbit pericenter (down to 165 km of altitude), and observing its perturbations on both the orbit and the attitude of the probe. An overview of the operational process as well as first results have already been published (see [1] and [2]). While [2] uses tracking data to determine density estimates from the relative deceleration of the spacecraft as it crosses the atmosphere, [1] obtains the same information from the reaction wheels additional momentum load. Both rely on a model of the evolution of the atmospheric density with respect to the altitude. The purpose of this paper is to describe and discuss the method used to timely reduce the spacecraft’s attitude dynamics over the crossing of the atmosphere, in order to extract the aerodynamic torque. The operationally relevant characterization of the atmosphere, namely the dynamic pressure, is further obtained by comparing the measurements to predictions based on an enhanced spacecraft geometric model. While more sensitive to data noise and to attitude disturbances, this method can be applied even when the spacecraft is not in inertial attitude, and allows a sampling of the dynamic pressure variation over the few minutes of atmospheric crossing. It reveals surprising fluctuations on short timescales, such as asymmetries between day and night sides, which can then be taken into account daily to decide on the continuation of the experiments.

Venus Express orbit pericenter constantly decays under the influence of the Sun's gravity field, but the decay rate evolves as Venus orbits the Sun. For regularly occurring short periods lasting about one month, the decay rate is close to null, which reduces the risk of lowering the pericenter into the atmosphere. Atmospheric drag campaigns are implemented during such periods, by lowering the pericenter enough to sense the atmosphere without endangering the spacecraft, while leaving some margin in case of safe mode to raise it again. Some pericenter passages are then dedicated to aerodynamic experiments during which the attitude is inertially fixed and the solar panels commanded to a fixed position. High frequency housekeeping telemetry, including spacecraft rotation rates, reaction wheels angular momentum, and attitude controller commanded torque, is available around pericenter. For safety reasons, the maximum reaction wheel torque allocated to the counteraction of the aerodynamic drag has been set to one tenth of the maximum operational torque per wheel, that is to 4 mNm. Therefore, a method has been implemented to derive the evolution of the aerodynamic torque along the atmosphere crossing, in order to check

a posteriori that the aforementioned constraint is satisfied. This method consists of modeling the complete attitude dynamics with the relevant perturbations, namely: the solar radiation pressure, the gravity gradient, the spacecraft and reaction wheel gyroscopic torques, and the reaction wheel produced torque. After filtering and summing up all modeled torques, the remainder is attributed to the atmospheric perturbation. Typically, with an inertially fixed attitude, its maximum, tuned to be around 1 mNm, is several times smaller than the gravity gradient torque, and one order of magnitude or more bigger than the other torques. The paper will show plots of the different contributions, and will pinpoint the difficulties encountered for the reduction.

From the aerodynamic torque, the atmosphere density can be extracted by dividing it by a reference torque expected from the wind direction in spacecraft frame and the spacecraft geometry. The main contribution is caused by the solar panels (see [1]). However, by considering all the main spacecraft parts (that is, the solar panels, the body and the high gain antenna) together with the shadowing that they cast on each other, the accuracy of the reference torque is improved. This approach is a direct adaptation of the spacecraft model and software routinely used to compute the solar radiation pressure. In the model, the spacecraft is represented by several units, one for each main part. Each unit consists of several polygons with associated surface properties. For each polygon, the subpart directly exposed to the wind is computed (we present two different algorithms to do so), considering its normal direction and the other polygons possibly hiding it, generating a center of pressure position and an exposed area. The surface properties (possibly parameterized) are then used to determine the force then the torque around the spacecraft center of mass produced by every piece. The parameters are fitted such that the measured and modeled torque direction match, and the atmosphere density obtained by dividing their norm, knowing the atmospheric molecules velocities and assuming a hyper-thermal free-molecular flow. The density estimate, the modeled evolution of the density with the altitude, and the commanded spacecraft geometry are finally used to verify whether the operational constraints (see [1] for a complete list) will be satisfied for the next air drag experiment. If the predicted aerodynamic torque is too high on at least one wheel, then the commanded solar panel angles to the wind are accordingly adapted or, in the worst case, a pericenter raising maneuver is executed.

[1] Venus Express Solar Arrays Rotation Experiments To Measure Atmospheric Density
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L. Arona, M. Müller, G. Huguet, I. Tanco, N. Keil

[2] First ever in situ observations of Venus' polar upper atmosphere density using the tracking data of the Venus Express Atmospheric Drag Experiment (VExADE)
Icarus Volume 217, Issue 2, February 2012, Pages 831–838M.
P. Rosenblatt, S.L. Bruinsma,.C.F. Müller-Wodarg, B. Häusler, H. Svedhem, J.C. Marty