FLIGHT DYNAMICS OPERATIONS FOR VENUS EXPRESS AEROBRAKING CAMPAIGN: A SUCCESSFUL END OF LIFE EXPERIMENT

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In May and June 2014, the European Space Agency successfully performed its first aerobraking campaign with the Venus Express probe at Venus. The exercise was designed as an end of life experiment aiming at probing the upper layers of the atmosphere above the North pole, as well as providing a first experience to Europe for this kind of operations. Aerobraking operations have already been carried out at Venus and Mars by NASA. They always require significant operational efforts in order to guarantee that the spacecraft reaches unharmed the desired orbit, and they normally last for several months. The very nature of end of life experiment for Venus Express' aerobraking explains the peculiar constraints under which this exercise took place: a relatively short campaign duration, bringing the orbital period down from one day to 22 hours 24 minutes, low operating costs consisting of two commanding sessions per week only, for a spacecraft not designed to adapt its sequence of commands onboard, and no active thermal nor structural constraints.

The main concern was to ensure that the spacecraft would be in the dedicated aerobraking configuration at each pericentre passage of the commanding period. Indeed, in this configuration, the solar panels were perpendicular to the airflow in order to maximize the drag, and oriented such that the attitude was stable when subject to the aerodynamic torques. Outside the atmosphere, thrusters maintained the attitude within 15 degrees from the attitude guidance. As a side effect, in this geometry, the panels were not illuminated, limiting the duration in this mode, which should nevertheless be longer than the accumulated uncertainty on the pericentre times over the commanding period. This energy constraint, combined with the assumed then observed atmospheric density variability, drove the definition of the corridor control in terms of aerodynamic pressure, with an initial target of 0.4 Pa.

The orbit determination was based on 2way Doppler data from deep space tracking stations. During the aerobraking phase two additional inputs from spacecraft telemetry were used to model the thruster actuations and the atmospheric drag: the accelerometer data and the reconstructed attitude control thruster pulses. Three different orbit determination configurations were executed at each commanding cycle, namely to reconstruct the orbit, to estimate a scale factor for the atmospheric engineering model, and to obtain the drag ΔV at each pericentre passage. The estimated scale factors for the atmosphere densities were used to update the atmospheric model. The estimated state vector at the orbit determination data cutoff was propagated twice: one without drag to calculate the latest possible pericentre times, and another one using the refined atmospheric model to generate a prediction of the trajectory and to check the peaks of dynamic pressure per pericentre passage. Whenever the computed dynamic pressure was out of limits a manoeuvre was commanded for the first apocentre of the next commanding period to raise the pericentre height.

Venus Express orbit was such that its pericentre altitude would continuously decay under the influence of the Sun gravity, with periodic seasons of temporary stabilization. The campaign occurred around one of those pericentre altitude plateaus characterized by a Sun direction collinear with the normal to the orbital plane, a situation also thermally favourable. For the walk in, usually meant to calibrate the a priori atmospheric model, no stable pericentre altitude could be maintained, therefore a conservative atmospheric density prediction procedure was adopted. During the main phase, despite a stable pericentre altitude, the atmosphere density showed a steep decrease as the pericentre sub-satellite point passed from the day to the night side. The imparted ΔV was about 1 m/s per passage, and culminated to 1.4 m/s after the target dynamic pressure was changed to 0.6 Pa.

The walk out consisted of a series of pericentre raising manoeuvres for a total ΔV of 24 m/s, with a final altitude of 461 km and a final orbital period of 22h24min. During the campaign, all the initial goals were achieved: 3 scientific objectives, focused on measuring the variability of the density of the atmosphere, and 6 technical ones, more dedicated to assessing the efficiency of the orbital period modification and of the spacecraft robustness after the atmospheric passages. The minimum reached altitude was 129.2 km, and the maximum observed aerodynamic pressure 0.67 Pa. Two in-situ instruments requiring no custom pointing could be operated. There was no sign of damage incurred by the spacecraft over the aerobraking activities. The scientific operations were subsequently progressively resumed, until Venus Express finally ran out of propellant 6 months later, and finally reentered the atmosphere in January 2015.

This paper presents the first ever aerobraking campaign performed by the European Space Agency. First, an overview of the history and methods for aerobraking operations will be provided. This frame will be used to explain the particularities of the approach selected for Venus Express, a very special one due to the aforementioned nature of the experiment. The operational challenges and solutions will be explained for all ESOC Flight Dynamics involved disciplines: Orbit Determination, Manoeuvre optimization, Command Generation, and Attitude Monitoring. The outcome of the experiment and the lessons learned during the process will then be highlighted. Finally the applications of the obtained experience for future ESA missions will be assessed.