Robust Autonomous Aerobraking Strategies

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Aerobraking is an aero-assist technique that allows significant reduction of propellant mass on missions to planets with atmospheres, typically Mars and Venus. It consists in using the braking effect of atmospheric drag over a series of periapsis passes in order to reduce the spacecraft orbit energy and therefore its orbital period and apoapsis altitude until the operational orbit is reached. The total propellant mass gain with respect to a fully propulsive planetary orbit insertion manoeuvre can be huge, typically around 300kg for Mars missions. Aerobraking has been successfully performed by Mars Global Surveyor, Mars Odyssey and Mars Reconnaissance Orbiter US missions. An aerobraking experiment is planned in 2014 for the Venus Express mission developed by Astrium, which will allow improving the operational experience in Europe, enabling the use of aerobraking on future missions to Mars.

Although very beneficial in terms of propellant mass, aerobraking is inherently a hazardous phase since it repeatedly exposes the spacecraft to atmospheric heat flux, risking over-heating of a spacecraft component (typically solar arrays which are the main drag area), or even mission loss. Aerobraking is also a long mission phase, of typically a few months, during which ground involvement is very high including mission critical activities such as orbit restitution and prediction, atmospheric conditions monitoring and prediction, manoeuvre decision-making, etc. under tightening time constraints. This heavy workload not only has a high cost that offsets the launch cost savings of aerobraking, but also increases the risk of human error. Furthermore, US experience has shown that atmospheric variability quickly turns ground-based operational sequences obsolete, imposing frequent ground updates in order to keep a correct matching between sequences and actual orbit events. Autonomy is a way to mitigate those issues and increase overall aerobraking robustness. This paper presents algorithms and methods that have been designed in order to increase the autonomy level of the aerobraking phase.

In a first autonomy level, the operational sequences that are generated by the ground and uplinked to the spacecraft are autonomously corrected by the onboard Periapsis Time Estimator (PTE). Thanks to onboard accelerometer measurements, the PTE estimates the date of last periapsis and the corresponding atmospheric drag ΔV, predicts the date of next periapsis and shifts accordingly the upcoming operational sequences. In this way the required frequency of ground updates is decreased, relaxing the pressure on ground teams. In a second autonomy level, onboard algorithms are proposed in order to perform additional activities onboard. These activities include operational sequence generation based on a simple onboard navigation approach combined with ground updates, and autonomous corridor control. The latter consists in boost manoeuvre decision-making and computation in order to control the periapsis altitude and therefore the heat flux and dynamic pressure experienced by the spacecraft. In this way, ground teams are relieved from most frequent and repetitive activities and may focus on higher-level activities such as monitoring the overall aerobraking progress, updating atmospheric and spacecraft models, atmosphere monitoring and aerobraking corridor tuning.

A last major point of interest is the management of contingencies. On-board monitoring of critical parameters (such as solar array temperatures and convective heat flux) gives the capability to autonomously command a safeguard action in case of exceeded threshold on such parameters. This is extremely valuable when the ground has not enough time to react before the next periapsis pass at the end of aerobraking, in particular in case of dust storm. Eventually, a new safe mode is proposed that copes with the specificities of the aerobraking phase, removing the need for costly pop-out maneuvers while guaranteeing spacecraft safety. This safe mode combines a low-drag configuration (with the solar arrays edge-on into the flow) with a pop-up ΔV for increased thermal protection.

A high-fidelity aerobraking simulator (HiFAS) was developed in order to implement, validate and evaluate the designed autonomous aerobraking strategies, with special features including accelerated simulations capability and high-fidelity environment modelling including Mars atmospheric models (e.g. European Mars Climate Database), as well as dedicated spacecraft aerodynamic and thermal models. This work was performed in the frame of ESA study “Robust Autonomous Aerobraking Strategies” (contract No. 4000102049).