Title

VENUS EXPRESS AEROBRAKING
Executive summary

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REFERENCES

[RD1] Statement of work: preparing an aerobraking phase at Venus with Venus Express , ESA, SRE-RSSD-SOW-01/2009, issue 1.1, February 26th, 2009

[RD2] Astrium Proposal for an aero-braking phase preparation around Venus, SOE.VEX.PP.02465.ASTR, issue 2.1, 09/06/2010

[RD3] Venus Express Aerobraking. Synthesis document. SOE.VEX.TCN.03045.ASTR, 1.0, 29/06/2011

[RD4] Venus Express Aerobraking. AOCS analyses, SOE.VEX.TCN.03077.ASTR, Issue 1.1, 29/06/2011

[RD5] Venus Express Aerobraking. Thermal analyses, SOE.VEX.TCN.03078.ASTR, Issue 2.0, 28/06/2011

ACRONYMS

AOCS	Attitude and Orbit Control System
FDIR	Failure Detection Isolation and Recovery
HGA	High Gain Antenna
MLI	Multi Layer Insulation
SA	Solar Array
S/C	Spacecraft
VEX	Venus Express

1 STUDY CONTEXT

Venus Express is an ESA research satellite developed by Astrium. Venus Express was launched on November 9th 2005 by a Soyuz-Fregat launcher from Baikonour and reached Venus on April 11th 2006.

The original purpose of aerobraking was to enable the spacecraft to reach the operational orbit acquisition in case of a failure of the main engine after the Venus orbit insertion operation or to save propellant if deemed necessary. But this feature was not actually used.

The Venus Express project requested to analyse the use of aerobraking to reduce the 24h current orbit period down to 18 hours or even 12 hours. Such a modified orbit will enable new improved and more frequent opportunities for scientific return observations. It will also provide a more stable orbit that needs less frequent control manoeuvres and thereby it will extend the mission. Finally, unique information on the atmosphere will be collected during the aerobraking itself.

The purpose of Astrium study was to assess the actual feasibility of aerobraking on VENUS EXPRESS and determine under which conditions the aerobraking operations can be performed.

The analyses focused on three main domains:

- thermal analyses,
- AOCS and dynamic analyses
- operations

The analyses have covered all the points identified in [RD2], but during the study other points have been identified and have led to further investigations.

A significant emphasis has been put on the operational aspects and some algorithms have been introduced although this was not the original goal of the study.

2 PRODUCED DOCUMENTATION

The thermal analyses are detailed in [RD5].

The AOCS analyses are detailed in [RD4].

A synthesis document summarising the results of the analyses and describing the operations has been issued ([RD3]).

3 CONCLUSIONS, OPEN ISSUES AND LIMITS TO THE ANALYSES

The analyses have proved that aerobraking on Venus Express is feasible with some limitations:

- The aerobraking shall be performed ideally during the so-called plateaus when the sun is at 90° from Venus Express orbit plane (see figure 1),
- Aerobraking aggressiveness (maximum aerodynamic pressure) is determined by thermal constraints: maximum acceptable peak aerothermal flux lies between 3000 and 4000 W/m² depending on the sun aspect angle during the plateaus (see figure 2)

- Some degradation of MLI scotch tape and lacing tape has to be accepted (but it is not considered critical)

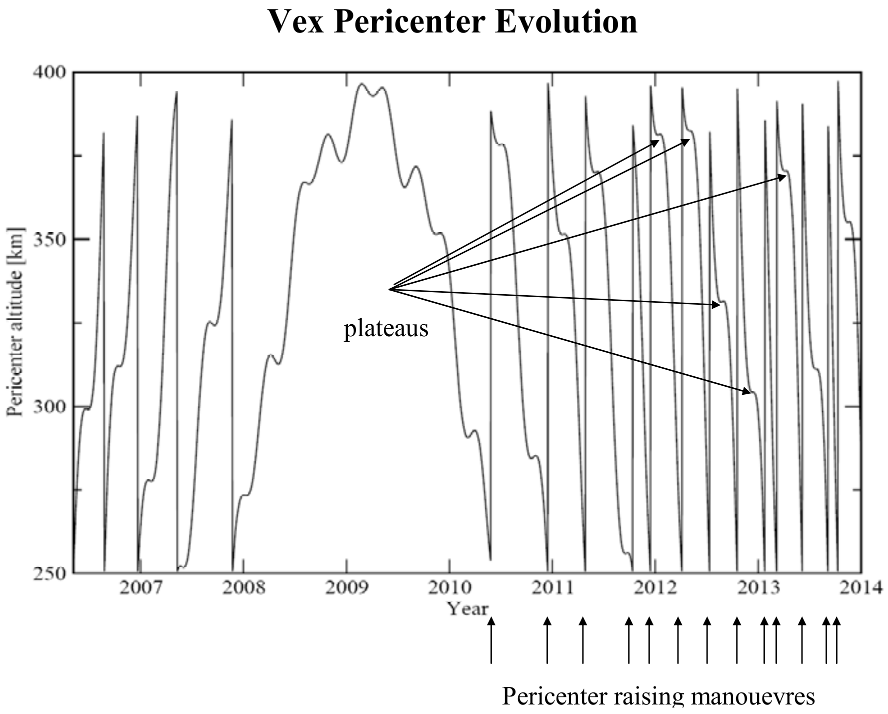
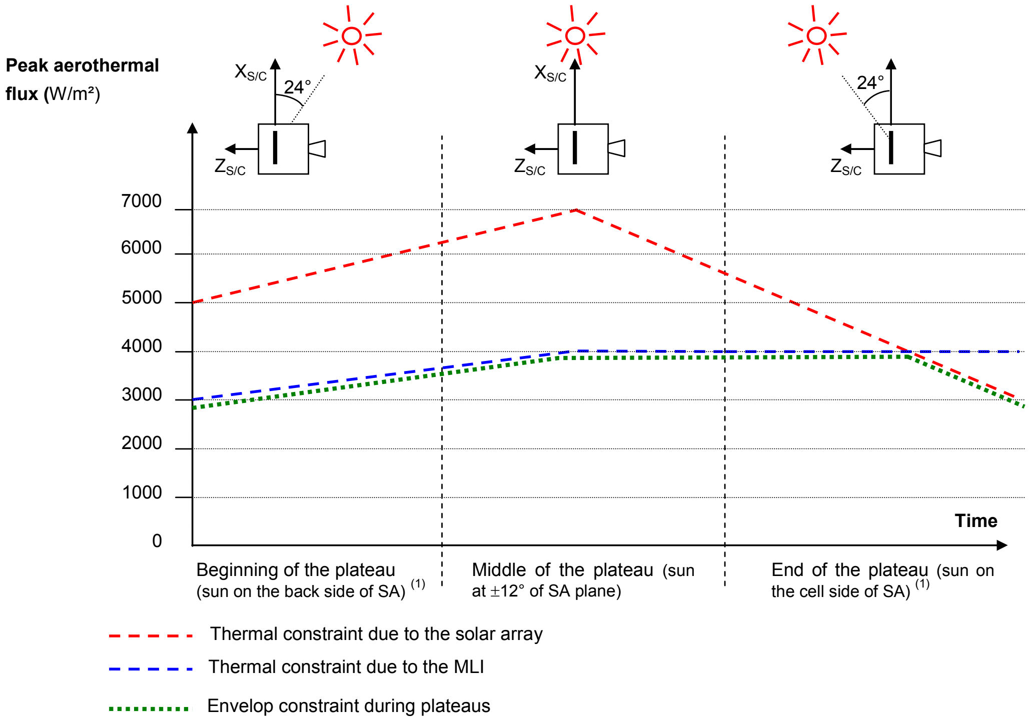


Figure 1: Orbital decay and plateaus



Note (1) : Depending on the plateau the sun will be illuminating the back side of the SA either at the beginning or at the end of the plateau

Figure 2: Thermal constraints due to SA and MLI during the plateaus

At the end of the VEX Aerobraking analyses, some points are open because the information is not yet available for operational reasons but these points will be defined just before or during the aerobraking operations:

- actual behaviour of SA (impact of SA cooling before the atmosphere crossing, response to the aerothermal flux) and $-\ Z_{S/C}$ MLI (response to the aerothermal flux). Note that in the case of the MLI we have no direct observable on board,
- knowledge of atmosphere variability at low altitudes (130-140 km): this information is necessary to tune the aerobraking corridor ; it will be available after the 1st aerobraking plateau.

In addition to the above points, the study provides a feasibility status for the aerobraking based on a certain amount of elements. Some subjects have not been (or only partially) addressed:

- the potential material erosion during atmosphere crossing was not addressed by these VEX aerobraking studies,
- the Safe Mode capacity to withstand atmosphere crossing in any attitude has not been addressed: it would have required the analysis of a large amount of different satellite attitudes, which was not compatible with the scope of the studies. However the analyses have made it possible to identify some actions or operations aiming at preventing unwanted Safe Mode triggerings or aiming at reducing the risks induced by such a triggering,
- the S/C FDIR has not been reviewed but there are some recommendations aiming at preventing the triggering of some monitorings,
- there has been no formal risk analysis associated to the aerobraking operations (during the analyses we have only examined at a high level the risks associated to an unwanted Safe Mode triggering).

On the other hand there are some potential margins linked to the way of calculating the aerothermal flux:

- we have assumed the S/C was under a free molecular regime (which is a pessimistic assumption at low altitudes),
- all particle reflections have been considered inelastic which is a worst case: according to the ADE (Air Drag Experiment) campaigns only 90% of the particles interact inelastically with the solar array surface

4 LESSONS LEARNT FOR FUTURE MISSIONS USING AEROBRAKING

This paragraph presents the lessons learnt from the Venus Express experience and which can be useful for future missions using aerobraking:

- Need to select adapted materials on exposed faces
    - MLI scotch tape and HGA1 lacing tape are not able to withstand the envisaged aerothermal fluxes (3000 W/m²)

  - Currently solar array and, most of all, MLI qualification temperatures are a limiting factor to the aerobraking efficiency (aerobraking is ideally limited to the plateaus and the aerodynamic pressure will presumably be lower than 0.4 N/m²)
- Need to include on board the S/C some critical observables
  - Need of thermistors on the S/C faces exposed to the aerothermal flux to assess the MLI thermal behaviour, including potential hot spots.
  - Need of additional thermistors on the Solar Array (back and cells side) in order to monitor hot spots
- Interest to manage on-board some operations in order to simplify ground operations (increased S/C autonomy). Note that in the case of VEX we only consider long period orbits, so the situation is less critical
  - Determination of pericentre crossing time to reduce timing errors and schedule several pericentre crossings ahead of time
- Need to design a Safe Mode able to withstand atmosphere crossings and which does not generate orbit disturbances (e.g. using a “pure-torque” thrusters configuration)