Aerobraking Mission Analysis Tool for Mars Exploration Missions

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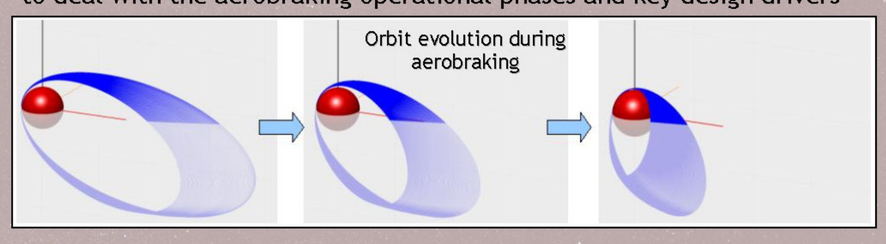
1. Introduction

What is the aerobraking strategy?

- A technique to transfer from a high-energy, highly elliptical orbit to a low-altitude, low-eccentricity science orbit, achieved by means of the drag force acting mainly on the S/C solar panels at subsequent atmospheric passes close to the pericentre
- An alternative to a fully propulsive scenario to achieve the science orbit

The aerobraking as a strategy for planetary exploration missions

- It allows for large ΔV and propellant mass savings with respect to fully propulsive insertion into a science orbit
- It has already been successfully implemented in past missions
- DEIMOS Space has developed a dedicated Aerobraking Mission Analysis Tool to deal with the aerobraking operational phases and key design drivers



2. The aerobraking phases

Walk-In Phase

- To acquire a better knowledge of the atmosphere, **S/C pericentre altitude is gradually lowered** into the atmosphere by apocentre control burns
- Last walk-in burn aims at achieving the nominal operational peak dynamic pressure at the subsequent pericentre passage

Main Phase

- It is the longest phase, which enables most of the apoapsis lowering
- It faces the most demanding orbit control issues
- Periodic **control burns at apocentre** ensure that the **peak dynamic pressure** at pericentre and the **heat load** per atmospheric pass comply with the associated constraints

Walk-Out Phase

- **Pericentre is gradually raised** out of the atmosphere to assure a minimum orbit lifetime without control and a fine tuning of the final apocentre altitude
- Last walk-out burn achieves the science orbit final pericentre

3. DEIMOS aerobraking tool functionalities

Rationale and approach for aerobraking scenario analysis

The implementation logic of each of the aerobraking phases is very close to the operational approach adopted in real past missions like Mars Global Surveyor, Mars Odyssey and Mars Reconnaissance Orbiter

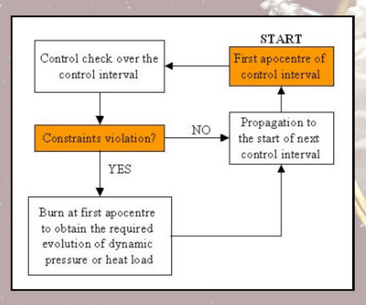
Propagation with a large set of orbit perturbations

- Non spherical gravity (up to order and degree 50)
- Third bodies gravitational effects
- Atmospheric drag (**EMCD V4.3 or MARSGRAM**)
- Solar radiation pressure

Pericentre altitude control during main phase

- Control burns are applied at apocentre
- **Peak Dynamic Pressure / Heat Flux** at pericentre, where they are highest, and integrated **Heat Load** per pericentre pass, are controlled based on orbit predictions over an input control time interval

Pericentre Control Loop



4. Aerobraking tool control strategies

Strategies for peak dynamic pressure control

- During most of the aerobraking duration, **control on the dynamic pressure** at pericentre is required. Two strategies have been implemented:
  1) Mean value over the control interval: if this gets out of a control band, control algorithm makes it attain a target value
  2) Max value over the control interval: if this gets out of a control band, control algorithm restores it to the upper boundary of the control band

Strategy for heat load control

- Heat load is the driving constraint of the main phase final part (**Endgame**)
- When the heat load constraint is no longer fulfilled, control algorithm brings the maximum heat load over the control interval to the maximum allowed value, so as to minimise the aerobraking duration

Control on aerobraking duration and number of manoeuvres

- Raising mid value of dynamic pressure control band speeds up aerobraking
- At fixed higher boundary of the dynamic pressure control band, decreasing the control bandwidth or the control interval duration increases the number of manoeuvres but speeds up the aerobraking

5. Representative aerobraking scenarios

Aerobraking scenario

Exomars-like aerobraking scenario analysed: initial 483 x 33310 km, 1-sol high-eccentricity orbit, targeting a circular science orbit at 400-km altitude

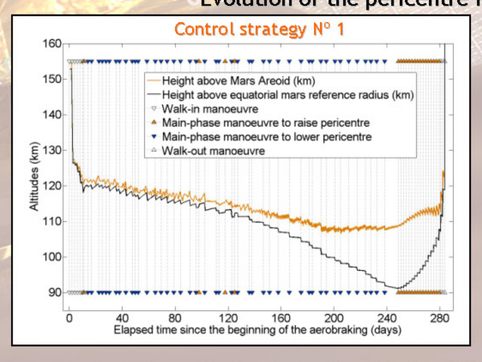
Aerobraking scenario simulations

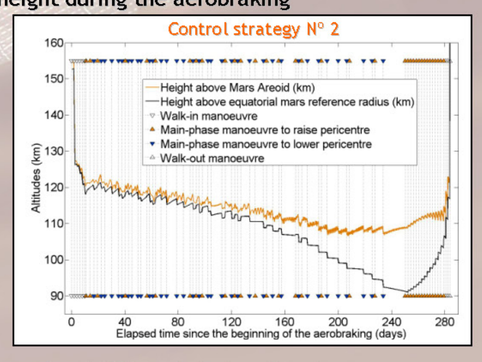
Two different control strategies applied to the same aerobraking scenario:

	Control strategy 1	Control strategy 2
Walk-in	6 burns First pericentre height: 150 km	6 burns First pericentre height: 150 km
Control interval	2 days	2 days
Main phase controlled variables	Mean peak dynamic pressure Heat load	Highest peak dynamic pressure Heat load
Controlled variables bands	Mean peak dynamic pressure: [0.25,0.30] N/m² Heat load < 0.25 MJ/m²	Highest peak dynamic pressure: [0.27,0.32] N/m² Heat load < 0.25 MJ/m²
Main phase end conditions	Lifetime < 1.5 days	Lifetime < 1.5 days
	Lifetime: remaining time before apocentre height lowers below 300 km	
Walk-out	3 burns Final pericentre height: 400 km	3 burns Final pericentre height: 400 km

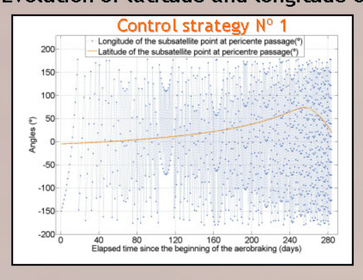
6. Simulation results (part 1)

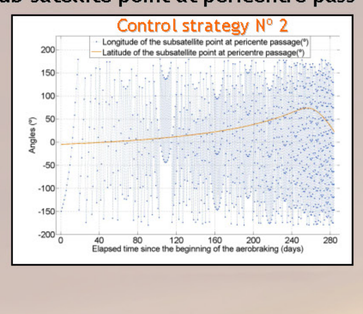
Evolution of the pericentre height during the aerobraking



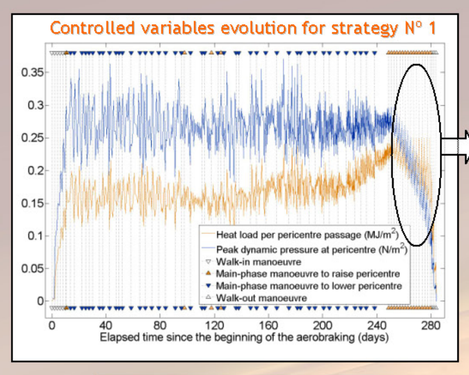


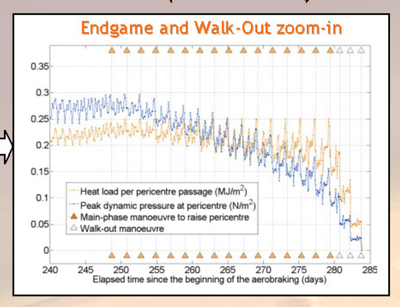
Evolution of latitude and longitude of the sub-satellite point at pericentre pass

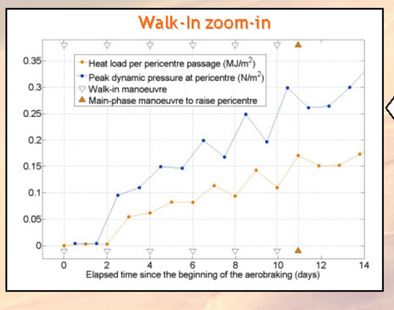


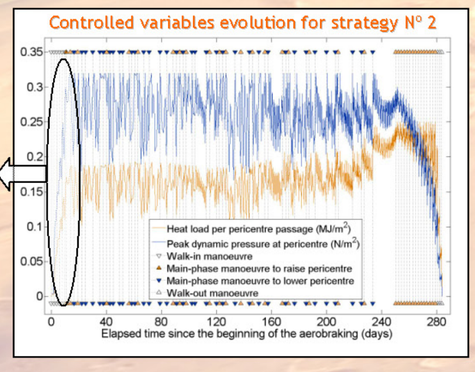


7. Simulation results (part 2)









8. Conclusions and follow-on developments

Aerobraking Tool capabilities

- Operational-like simulation of the aerobraking strategy
- Predictive control algorithm implementation
- Definition of two different control strategies for the dynamic pressure
- Automatic switch from dynamic pressure to heat load control
- Overall low control cost
- Overall low control frequency

Aerobraking Analysis Results	Strategy Nº 1	Strategy Nº 2
Aerobraking duration (days)	283.8	283.8
Nº of main phase control burns	64	71
Mean control time gap during main phase (days)	4.2	3.8
Walk-in ΔV cost (m/s)	21.1	21.1
Main phase ΔV cost (m/s)	10.0	11.4
Walk-Out ΔV cost (m/s)	67.5	68.0
Aerobraking total ΔV cost (m/s)	98.6	100.5

Follow-on developments

- Monte Carlo Analysis (random atmosphere, control burn implementation errors, etc…)
- Navigation module implementation

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Background Image Courtesy NASA