Mars Reconnaissance Orbiter: Aerobraking Sequencing Operations and Lessons Learned

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What is Aerobraking?

- Aerobraking is a spaceflight maneuver performed by a spacecraft near a planet with an atmosphere.
- It is used to reduce the orbital period of a spacecraft by passing it through the upper levels of the atmosphere of a planet.
- The heat generated by the friction of the spacecraft against the atmosphere dissipates the kinetic energy of the spacecraft, thus imparting a change in velocity, or delta-V.
- The spacecraft radiates this heat to space between successive passes through the atmosphere, thus reducing its specific mechanical energy.
Mars Reconnaissance Orbiter

Mars Global Surveyor

Mars 2001 Odyssey

MRO Aerobraking Operations and Lessons Learned // Roy.E.Gladden@jpl.nasa.gov

The Challenge of Aerobraking

- The density of the atmosphere at Mars is never certain.
- This makes it difficult to predict how much delta-V (and change in orbital period) would be imparted on each successive pass through the atmosphere.
- This is particularly challenging during the shorter orbits when several orbits would elapse before a new set of commands could be uploaded to the vehicles.
- The vehicles do not autonomously account for this change in velocity.
Sequence Shifting

- Odyssey included the ability to shift the commands for the next orbit based upon the detected change between the predicted periapsis for the last orbit and the periapsis it believes it experienced.
- This compensated for the previous orbit’s offset, but failed to address the effect of the delta-V on the orbital period.
- MRO augmented this sequence-shifting capability by measuring the approximate delta-V on each drag pass and predicting the time of the next periapsis passage.
The number of orbits sequenced increased monotonically.
This discontinuity reflects when we began sequencing more than one orbit at a time.
This discontinuity reflects when it was no longer possible to account for the most recent orbit’s effect on the trajectory due to time constraints. Here, we had to use trajectories that were one orbit “stale” when constructing the next command sequence.
This same discontinuity is evident for MRO, but multiple orbits were sequenced much earlier when the orbit period was closer to 28 hours (compared to 12 hours for Odyssey).
Note that the number of orbits sequenced did not increase monotonically for MRO. The drivers for sequence build frequency had changed.
MRO and Odyssey Aerobraking
Durations Between Sequence Starts

No rhyme or reason for MRO?
Plotted as “builds per day” makes the story much more clear. MRO wanted to keep the frequency of command builds to much less than once per day. The new sequence shifting algorithms made this possible.
The operational processes for both orbiters were similar, so a similar amount of time was allocated to construct each command sequence.
For MRO, this allocated time was usually more than sufficient to actually construct each sequence, something not regularly experienced on Odyssey. And we got better at it as time went on, as expected.
### Additional Comparisons

<table>
<thead>
<tr>
<th>Feature</th>
<th>Odyssey</th>
<th>MRO</th>
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<tbody>
<tr>
<td>Allocated Time to Aerobrake</td>
<td>3 months</td>
<td>6 months</td>
</tr>
<tr>
<td>Sequence Shifting Paradigm</td>
<td>Corrected for time offset from previous orbit</td>
<td>Correct for delta-V offset from previous orbit</td>
</tr>
<tr>
<td>Mechanical Design</td>
<td>Not primarily designed for aerobraking operations</td>
<td>Designed for aerobraking operations with aero-stable configuration</td>
</tr>
<tr>
<td>Inheritance</td>
<td>Inherited processes, procedures, and personnel from MGS</td>
<td>Inherited processes, procedures, and personnel from Odyssey and MGS</td>
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</tbody>
</table>

- The MRO mission design allowed for a more relaxed approach to aerobraking. Sequences were constructed during day shifts during the work-week by fewer people.
- The improved algorithms on MRO for sequence shifting were more accurate and provided a greater level of flexibility for sequencing the vehicle. Sequence builds could be delayed or moved to earlier orbits if needed.
- With higher thermal and temporal margins, operating MRO was a less tense experience, despite aerobraking for nearly twice as long.
- The depth of aerobraking experience of the operations teams made aerobraking seem routine.
Final Words

• The MRO project was able to improve aerobraking operations from the Odyssey experience in nearly every way, in itself an improvement over MGS.

• It is anticipated that these lessons will be carried forward to the next aerobraking vehicle to again simplify the process, improve the onboard software and the operational software, and to make aerobraking operations a more human-friendly experience while achieving mission objectives.
Questions?

Many thanks to all the fine people who made these numbers look so good!

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