Aerobraking at Venus and Mars:
A Comparison of the Magellan and Mars Global Surveyor Aerobraking Phases

by

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Abstract:

On February 4, 1999 the Mars Global Surveyor spacecraft became the second spacecraft to successfully aerobrake into a nearly circular orbit about another planet. This paper will highlight some of the similarities and differences between the aerobraking phases of this mission and the first mission to use aerobraking, the Magellan mission to Venus.

Although the Mars Global Surveyor (MGS) spacecraft was designed for aerobraking and the Magellan spacecraft was not, aerobraking MGS was a much more challenging task than aerobraking Magellan, primarily because the spacecraft was damaged during the initial deployment of the solar panels. The MGS aerobraking phase had to be completely redesigned to minimize the bending moment acting on a broken yoke connecting one of the solar panels to the spacecraft.

Even if the MGS spacecraft was undamaged, aerobraking at Mars was more challenging than aerobraking at Venus for several reasons. First, Mars is subject to dust storms, which can significantly change the temperature of the atmosphere due to increased solar heating in the low and middle altitudes (below 50 km), which in turn can significantly increase the density at the aerobraking altitudes (above 100 km). During the first part of the MGS aerobraking phase, a regional dust storm was observed to have a significant and very rapid effect on the entire atmosphere of Mars. Computer simulations of global dust storms on Mars indicate that even larger density increases are possible than those observed during the MGS aerobraking phases. For many aerobraking missions, the duration of the aerobraking phase must be kept as short as possible to minimize the total mission cost. For Mars missions, a short aerobraking phase means that there will be less margin to accommodate atmospheric variability, so the operations team must be ready to propulsively raise periapsis by tens of kilometers on very short notice. This issue was less of a concern on Venus, where the thick lower atmosphere and the slow planet rotation resulted in more predictable atmospheric densities from one orbit to the next.

Although atmospheric drag was used to remove about 1200 m/s from the orbits of both MGS and Magellan, the smaller gravity field of Mars resulted in an orbital period change that was much larger for MGS than it was for Magellan. The MGS orbit period was reduced from the capture orbit period of 45 hours to 1.89 hours at the end of aerobraking. The Magellan orbit period was reduced from 3.26 hours to 1.5 hours. The large range of orbit periods for Mars aerobraking missions led to several distinctly different operational modes, while the smaller change in periods for Magellan was handled by a single operational mode.

Although the MGS spacecraft hardware was designed with aerobraking in mind, while the Magellan spacecraft hardware was not, the flight software for MGS was inherited from the Mars Observer program, while the Magellan flight software was rewritten during the mission to accommodate the repetetive activities associated with aerobraking. Adapting the Mars Observer software led the MGS mission to build and uplink the complete sequence of commands for every orbit, while the Magellan spacecraft commands were generated on-board by an "infinite loop". Only a few parameters were updated each day to keep the on-board sequence aligned with reality. The Magellan approach would be more easily adapted to autonomous aerobraking operations on future missions which would compute the parameter updates based on the observed time of maximum drag and the measured integrated deceleration.

The atmospheric density is an important measurement during aerobraking, not only because the key engineering parameters, drag and aerodynamic heating, are directly proportional to the density, but also for the scientific value. The Magellan spacecraft did not carry an accelerometer, since an accelerometer was not required to fly the primary mission. When aerobraking was attempted during the extended mission, atmospheric densities at Venus had to be inferred from the integrated effects of the drag on the orbit by assuming a value for the scale height of the atmosphere. Although the MGS spacecraft was designed for aerobraking, it was developed with a very limited budget. Since there was no requirement to fly an accelerometer as a science instrument, no money was spent to include a high quality accelerometer package as part of the mission. Fortunately, the spare Inertial Measurement Units (IMUs) that were inherited from Mars Observer and flown on MGS already included accelerometers which were used to measure the density profiles during each drag pass. The data from the accelerometers showed unusual wave pattens in the atmospheric density which made it possible to explain the relationship between the maximum drag force and the integrated drag effects. The accelerometer data also showed that there is a very repeatable and as yet unexplained atmospheric density profile that is tied to the planet. The data from the MGS mission provides a solid base for updating the atmospheric models for use by the numerous missions that are planned for studying Mars.

The discussion of these and other topics will be framed in the context of what might be done to reduce the risk associated with aerobraking future missions to Venus and Mars. Another Mars mission which depends on aerobraking, the Mars Climate Orbiter, is already on the the way to Mars. Numerous mission proposals to Venus and Mars have included the aerobraking option as a way to maximize the science payload and minimize the mission cost. The lessons learned from these first aerobraking missions at Venus and Mars will help to make aerobraking a more robust technique for these future missions.