A SIMPLE ANALYTICAL EQUATION TO ACCURATELY CALCULATE THE ATMOSPHERIC DRAG DURING AEROBRAKING CAMPAIGNS. VALIDATION IN THE MARTIAN CASE. .

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Introduction

Planetary orbital missions are often designed to fly through atmospheric layers dense enough to significantly alter the spacecraft velocity during a single orbit pass. On the one hand, such a maneuver can be used to circularize the orbit and lower the periapsis using much less fuel than what would have been necessary directly using a rocket engine (aerobraking). On the other hand, lowering the orbit periapsis of a scientific probe can be useful to perform in-situ observations in the lower thermosphere and mesosphere, increase the precision of the gravity field measurements, or improve the mapping of surface properties like the crustal magnetic field (e.g. the MAVEN mission to Mars, to be launched in 2013).

To accurately compute the orbital perturbation due to the atmosphere, engineers must usually couple numerical simulators of the spacecraft navigation with atmospheric model of the density and the winds in order to integrate the action of the atmospheric friction timestep after timestep. We have developped such a tool by combining the state of the art satellite orbitography model *Ixion* with the LMD Mars General Circulation Model throught the Mars Climate Database (see Millour et al., this issue)

However, on the basis of theoretical considerations and thorough validation, we have discovered that the orbital perturbation due to the atmosphere can be calculated with very high accuracy using a simple analytical equation combining the orbit parameters and the atmospheric density and scale height at a single point: periapsis. The equation is derived from the complete equations of atmospheric motion around a planet and through the atmosphere, and take advantage of the fact that if the orbit is non circular (an eccentricity larger than 0.03 is sufficient), the time spent in the dragging atmosphere is short and the spacecraft velocity relatively constant while in the atmosphere.

The main uncertainty lies in the assumed atmospheric winds. If the actual value of the velocity v'_0 relative to the atmosphere at perihelion (i.e. v'_0 computed with respect to planetary rotation and atmosphere) is known, the expression of the atmospheric drag over one period is simply:

$$\Delta v = k \; \rho_0 \; {v'}_0^2 \; r_p \sqrt{\frac{2\,\pi}{\mu}} \; \frac{1}{\sqrt{e}} \; \sqrt{H} \qquad (1)$$

with ρ_0 and v_0 the atmospheric density and velocity at periapsis, r_p the distance between periapsis and the center of the planet, $\mu = \mathcal{G}M$ is the central attractive constant (for Mars $\mu = 4.282\ 837\ 10^{13}\ \mathrm{m^3\ s^{-2}}$), e the eccentricity, and H the scale height of the atmosphere at periapsis. $k = B/2$ with $B = C_d S/m$ the so-called ballistic coefficient derived from the probe aerodynamical data and surface.

In practice, the atmospheric circulation is not easy to estimate. It typically requires a general circulation model. An approximation is to the neglect the atmospheric winds and assumes that the satellite velocity relative to the atmosphere is the velocity in the galilean frame.

This is especially valid for polar orbits.In that case, the atmospheric drag over one period simply becomes:

$$\Delta v = k \; \rho_0 \; \sqrt{2\,\pi\,\mu} \; \frac{1+e}{\sqrt{e}} \; \sqrt{H} \qquad (2)$$

Such an equation can be useful to design future missions. For instance, future aerobraking or scientific "deep dip" campaign can be optimized by choosing the best combination of season, local time, latitude or longitude for the periapsis as well as orbit inclination, excentricity, etc. To our knowledge, such equations have not been described elsewhere. Analytical development can be found in King-Hele [1964]. In this fundamental book the author studied contraction of orbits under the influence of drag, in a spherically symmetrical atmosphere then in an oblate atmosphere. He gets very complex equations, always presented in analytical form, taking into account the variation of the orbital parameters orbit after orbit. Here we just compute Δv for each individual orbit.

We will present detailed validation studies performed by comparing Δv calculations from a state of the art complete model with our simple equations in a wide variety of cases, and show that the results are always extremely accurate.