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A Proposed Mission to Very Low Mars Orbit – Supported by an Electric Propulsion System

Kai Wickhusen (1), Jürgen Oberst (1,2), and Friedrich Damme (2)
(1) German Aerospace Center (DLR), Berlin, Germany, (kai.wickhusen@dlr.de),
(2) Technical University of Berlin, Germany

Abstract

We investigate possible missions in Low Mars Orbit (LMO) (< 200 km), where the thin but significant Martian atmosphere causes a strong drag force and typically limits the lifetime of orbiting satellites. To prolong satellite operation, we investigate possibilities to compensate atmospheric drag with an electric propulsion system. As a reference we used a spacecraft system similar to the DAWN mission with electric thrusters of 90 mN. The results showed that a compensation of the drag force with these thrusters could be possible for a long-lasting mission at altitudes above 150 km. The mission opens opportunities for novel remote sensing approaches of Mars.

1. Introduction

Due to the atmospheric drag, spacecraft in circular orbits about the planet (e.g., MRO or the ExoMars Trace Gas Orbiter), typically travel in heights above 250-400 km. In our study we focus on the idea of placing an orbiter at closer distances (approx. 150 km) to the surface.

Remote sensing can benefit from such an orbital mission in terms of better data resolution, while sounding instruments may profit from high signal strength. We anticipate high-resolution imaging (not requiring excessive telescope equipment), as well as radar sounding and Laser altimetry (not requiring excessive power). Magnetic field mapping will enjoy high signal strength and high spatial resolution of data.

The thin atmosphere of Mars and the resulting drag reduces the altitude of a spacecraft. In order to avoid a de-orbiting of the spacecraft we plan to use an electric propulsion system which compensates the drag force continuously. In this study we investigate at which altitude a propulsion system would be capable to compensate this drag.

2. Method

First, we consider a simple density scale height model, which yields Mars' atmospheric density for given spacecraft height h. in our numerical simulation of the type:

$$\rho(h) = \rho_0 * e^{-h/H} \qquad (1)$$

with ρ_0 being the reference density at the reference surface and H is the atmospheric scale height of 11.1 km.

We used two different reference densities to best fit the data from the MCD. The first is the high density state with $\rho_0 = 0.001\ \mathrm{kg/m^3}$ and a low density with $\rho_0 = 0.0001\ \mathrm{kg/m^3}$.

We also considered the existing models of the Martian atmosphere, which is known to vary with latitude, with time of day and season. The Mars Climate Database (MCD v 5.3) [1][2] was used as a baseline.

To determine the drag force, which acts on the S/C, the following equation was used:

$$F(h) = {}^{1}\!/_{2}\, \rho(h)\, v(h)^2\, C_D\, A \qquad (2)$$

where A= 40.8 m² is spacecraft cross section (2.8 m² S/C + 38 m² solar panel), v(h) is spacecraft circular velocity at a given altitude and C_D = 2.0 is the drag coefficient. Typical spacecraft speeds in LMO are in the range of 3.45-3.55 km/s.

We adopt a spacecraft model to determine the resulting drag force. Mass and cross section of the

DAWN mission are used a reference to calculate the resulting drag force on the spacecraft.

DAWN is equipped with an electric propulsion system, with engines have a specific impulse of 3100s and a thrust of 90mN [4]. We determined at which distance the electrical propulsion system would be capable to compensate the atmospheric drag.

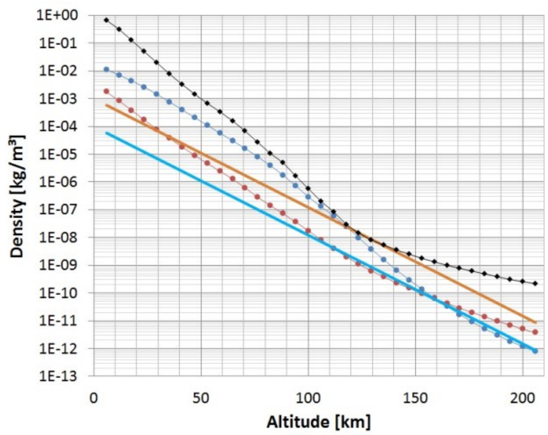

Figure 1: Martian atmospheric density over height, used in the study. Blue dots: MCD values for Lat 0N, Long 0E; red dots: MCD values for Lat 90N, Long 0E; solid orange: high density ($\boldsymbol{\rho_0 = 0.001\ kg/m^3}$); solid blue: low density ($\boldsymbol{\rho_0 = 0.0001\ kg/m^3}$); black dots: Earth atmosphere, for reference [3]

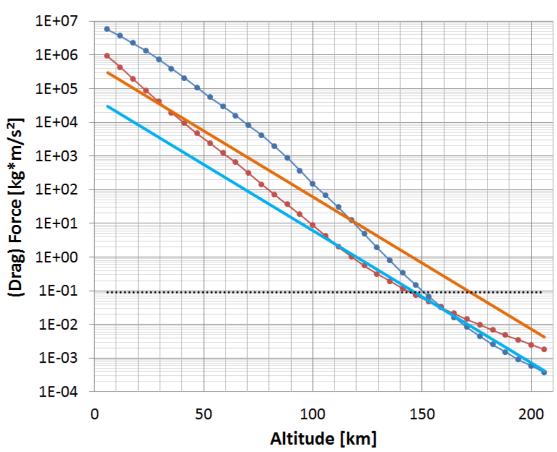

Figure 2: The figure shows the Martian atmospheric drag force over height used in the study, adopting the drag equation and parameters as described in the text. The black dots show the output of the 90 mN DAWNs ion thrusters (other color codes as in Fig. 1)

3. Results, Summary and Conclusions

The results show that the atmospheric drag is in the range of approximately 100 mN at a height of 150 km above the Mars surface. Using numerical integration, we find that the lifetime of a typical free-flying spacecraft would be in the range of 1 day up to two weeks. However, a spacecraft system similar to DAWN would generally be capable to compensate the atmospheric drag in a circular orbit by continuously using its ion thrusters. If we consider an eccentric orbit, a spacecraft may achieve temporarily lower altitudes. (Note that Mars Express, e.g., travels in a highly eccentric orbit of 258 x 11560 km).

Any such spacecraft mission must deal with the complex structure of the Martian atmosphere, varying regionally and over time. Also, the solar power requirements for the electric propulsion (and limited Sun viewing when in low Mars orbit) must be carefully studied.

With the given orbital mission, we anticipate new opportunities for spacecraft instrumentation and science. The mission would also allow for mapping of the density structure of the Martian atmosphere and its variations in space and time.

At approximately 150 - 170 km the density above the North Pole and above the equator are of the same order of magnitude. Consequently it could be possible to place a spacecraft in a polar orbit.

References

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