Acta Astronautica 98 (2014) 163–168

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

Influence of seasonal cycles in Martian atmosphere on entry, descent and landing sequence

Dušan Marčeta [a,*], Stevo Šegan [a], Boško Rašuo [b]

[a] University of Belgrade, Faculty of Mathematics, Studentski trg 16, Belgrade, Serbia
[b] University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, Belgrade, Serbia

ARTICLE INFO

Article history:
Received 17 July 2013
Received in revised form
28 January 2014
Accepted 5 February 2014
Available online 13 February 2014

Keywords:
Mars
Atmosphere
Entry
Descent
Landing

ABSTRACT

The phenomena like high eccentricity of Martian orbit, obliquity of the orbital plane and close alignment of the winter solstice and the orbital perihelion, separately or together can significantly alter not only the level of some Martian atmospheric parameters but also the characteristics of its diurnal and seasonal cycle. Considering that entry, descent and landing (EDL) sequence is mainly driven by the density profile of the atmosphere and aerodynamic characteristic of the entry vehicle. We have performed the analysis of the influence of the seasonal cycles of the atmospheric parameters on EDL profiles by using Mars Global Reference Atmospheric Model (Mars-GRAM). Since the height of the deployment of the parachute and the time passed from the deployment to propulsion firing (descent time) are of crucial importance for safe landing and the achievable landing site elevation we paid special attention to the influence of the areocentric longitude of the Sun (Ls) on these variables. We have found that these variables have periodic variability with respect to Ls and can be very well approximated with a sine wave function whose mean value depends only on the landing site elevation while the amplitudes and phases depend only on the landing site latitude. The amplitudes exhibit behavior which is symmetric with respect to the latitude but the symmetry is shifted from the equator to the northern mid-tropics. We have also noticed that the strong temperature inversions which are usual for middle and higher northern latitudes while Mars is around its orbital perihelion significantly alter the descent time without influencing the height of the parachute deployment. At last, we applied our model to determine the dependence of the accessible landing region on Ls and found that this region reaches maximum when Mars is around the orbital perihelion and can vary 50° in latitude throughout the Martian year.

1. Introduction

More than 35 years after the first fully successful landing on the surface of Mars performed by Viking 1, landing on Mars is still very challenging and risky task. The hardware and EDL scenarios of previous missions and future concepts are described in detail in the literature [1–5]. The difficulty of landing on the surface of Mars is best illustrated by surface elevations of the landing sites of the previous successful landings. Due to the so-called dichotomy of Martian surface, average difference in elevation between Northern Lowlands and Southern Highlands is only about 4 km relative to reference MOLA areoid [6]. As a consequence, an entry vehicle trying to land on the southern hemisphere would encounter just slightly smaller portion of the atmosphere and hence has less possibility to decelerate through the interaction with the

* Corresponding author.
E-mail addresses: dmarceta@matf.bg.ac.rs (D. Marčeta), ssegan@matf.bg.ac.rs (S. Šegan), brasuo@mas.bg.ac.rs (B. Rašuo).

http://dx.doi.org/10.1016/j.actaastro.2014.02.001

atmosphere and less time to perform all necessary EDL events. Because of this small difference in elevations there was no full successful landing on the Southern Highlands up to date, comparing to 7 full successful landings in the lower areas of the northern hemisphere and equatorial region. This means that due to the characteristics of the atmosphere, technology imposed limitations and dichotomy of Mars, surface explorations have been limited to the lower regions which date mainly from Amazonian (1.8 Ga–present) and Hesperian (3.5–1.8 Ga) eon. On the other side, the ancient terrain in the southern hemisphere, which dates all the way back to the Noachian eon (4.6–3.5 Ga) of planetary evolution has left outside the reach of the landers up to date.

In accordance with the above statements the aim of this paper is to present the qualitative and quantitative analyses of the influence of seasonal variations of the Martian atmosphere on the EDL sequence and to emphasize relations between these variations and achievable landing site elevation.

2. Variability of the atmosphere

Extremely thin atmosphere of Mars has low heat capacity and physical inertia and therefore it is very sensitive on the amount of energy received from the Sun. Because of this, seasonal and diurnal cycles are very strong. Seasonal cycle is further emphasized by very eccentric orbit of Mars ($e = 0.0935$) which causes the incoming solar flux at the top of the atmosphere about 45% larger at the perihelion than at the aphelion. Beside its strength, seasonal cycle also exhibits non-symmetric behavior because of the close alignment of the orbital perihelion ($Ls = 251^\circ$) and winter solstice ($Ls = 270^\circ$).

In our analysis we have used the environmental statistics summarized in the Mars Global Reference Atmospheric Model (Mars-GRAM) [7,8] which is based on the NASA/Ames Mars Global Circulation Model (GCM) the development of which started in 1969 [9] and have continued up to date. Another very useful statistics are summarized in Mars Climate Database [10] which is based on two GCMs developed by Laboratoire de Météorologie Dynamique du Centre National de la Recherche Scientifique (LMD) and the University of Oxford.

In Fig. 1 are shown seasonal and latitudinal daily average atmospheric density variations at 50 km height relative to MOLA areoid, which we generated using Mars-GRAM atmospheric model, all divided by minimum annual value.

In this figure one can see that at an altitude of 50 km, where significant deceleration of the entry vehicle starts to occur, we can expect seasonal variation of atmospheric density by factor of 15. At lower altitudes, these variations are relatively smaller (factor of 1.5 at 10 km altitude), but these variations are still extremely large in absolute values. It is evident that the local extremes occur in the vicinity of the solstices and orbital perihelion ($Ls = 251^\circ$). These large variations of the atmospheric parameters clearly illustrate that the Martian atmosphere is the most hostile environment in the Solar system to perform EDL [11] and emphasizes the importance of analyzing their influence on EDL sequence.

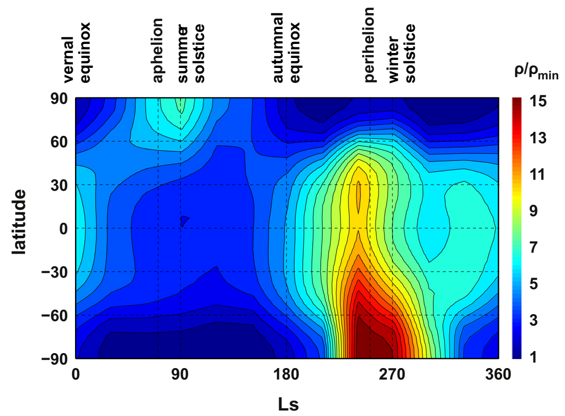

Fig. 1. Seasonal and latitudinal variations of atmospheric density and temperature.

3. Methodology

To analyze the influence of the seasonal variations of atmospheric parameters, we simulated almost 2000 trajectories for landing on 52 landing sites along 0°, 90°E, 180° and 270°E longitude meridians and for latitudes from 60°S to 60°N with a step of 10°. These meridians were chosen because they uniformly cover the planet and because they have very different elevation profiles. While the elevation profiles of 0° and 180° longitude meridians are relatively smooth, the meridians with longitudes of 90°E and 270°E which pass across some large topographical entities such as Thaumasia Montes, Solis Planum, Hellas Planitia and Isidis Planitia. have vary uneven elevation profiles. The analysis was performed for the Mars Exploration Rover (MER) entry vehicle (diameter of the capsule 2.6 m, diameter of the parachute 14 m, entry mass 832 kg), with the initial flight path angle of -11.47° as it was for the entry of MER-B (Opportunity). The integration was performed for entire Martian year with a step of 10° in Ls, starting from 1 August 2013 which corresponds to the vernal equinox ($Ls = 0^\circ$).

An independently developed MATLAB-based trajectory simulation routine integrated 3-degree-of-freedom trajectories using kinematic and dynamic governing equations for translation within the atmosphere, relative to the rotating planet [12]. To account for the effects of gravity, we have used a gravity model that includes the first zonal harmonic coefficient $J2 = 1960.454E-06$ [13]. Higher order harmonics are of much smaller magnitude and can be neglected over the short time interval of EDL.

For obtaining atmospheric profiles we have used Mars-GRAM 2010 model [7,8] which was integrated in our trajectory integration routine. To account only for the influence of seasonal variations of the atmospheric parameters, we used daily average values of the atmospheric parameters. All Martian ephemeris necessary for obtaining the atmospheric parameters from the Mars-GRAM model were calculated according to [14].

The analysis has been done under assumption that the vehicle flies under zero angle of attack (AoA) so the only aerodynamic force that acts on the vehicle is aerodynamic