OPTIMAL ORBITS FOR MARS ATMOSPHERE REMOTE SENSING.

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Introduction

The two last spacecrafts successfully in orbit around Mars, Mars Global Surveyor and Mars Odyssey, are operating in circular Sun-synchronous orbit. This orbit presents numerous well-known advantages. But one of these benefits – the satellite overpasses a given location at the same local time, and then observes the scene with roughly the same conditions of solar illumination – leads to a very poor sampling in terms of local solar time. For instance, this is problematic when studying the diurnal cycle of the hazes and clouds, or to study of the dynamics of the thermal tides which are of key importance for the martian atmosphere circulation. The observation of such atmospheric phenomena implies to obtain a local time sampling over 24 hours (a complete sol). Yet, it is also necessary to observe all latitudes up to the polar regions, since these regions are of key importance to study the water cycle (northern polar cap source), the CO2 cycle (polar caps) the dust cycle (cap edge dust storms) and the atmospheric dynamic (high latitude baroclinic waves, polar warming, etc.).

In this paper, we present the method to obtain the characteristics of an orbit allowing a complete diurnal sampling (over one sol), in a short period compare to the seasonal evolution (less than 50 sols), and permitting the observation of the polar regions. The result is a compromise solution between polar orbit, for pole viewing, and low inclination orbit, for short precession period.

Firstly, we study the viewing geometry and its constraint. Secondly, we compute the nodal precession velocity, giving the precession cycle. We conclude with examples of sampling, illustrating the choice of the orbit.

Viewing geometry

The satellite S, altitude h, observes the point P, on the surface of the planet. We consider an accross-track swath. Let us note O the center of the planet (considered as spherical, radius R), with N the North Pole, and S_o the subsatellite point. We note the distances: $h = SS_o$, $a = R + h = OS$, and $\eta = a/R$, the relative distance.

The viewing angles (see Fig. 1) are f (half-swath angle), ζ (viewing zenith angle) and α (angle at the centre). For a satellite on circular orbit with inclination i, the maximal latitude observed by an instrument (half-swath f) is:

$$\phi = i + \alpha \quad (1)$$

(ϕ is the absolute value of the latitude).

By geometric considerations (Capderou, 2002), we obtain the value of α, as function of ζ and η uniquely : $\alpha = \zeta - \arcsin[(1/\eta)\sin\zeta]$. Then, for a defined mission (extreme latitude ϕ and viewing zenith angle ζ, both fixed), we obtain a relation between the inclination i of the orbit and its altitude h:

$$i = \phi - \zeta + \arcsin\left(\frac{R}{R+h}\sin\zeta\right) \quad (2)$$

A nadir viewing (only the subsatellite point S_o is seen by the satellite S) corresponds to $\zeta = 0^o$. For a limb viewing, the viewing zenith angle, for the target P, is $\zeta = 90^o$.

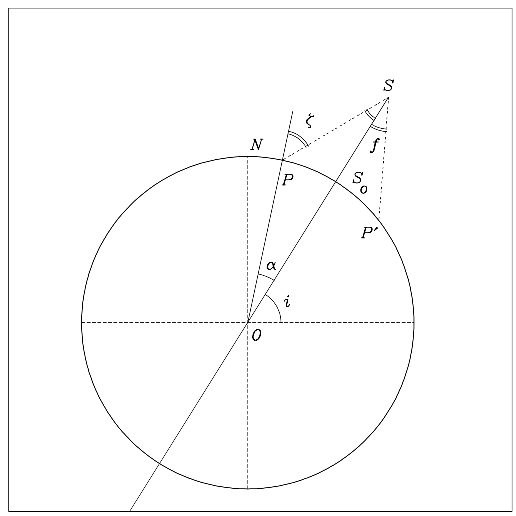
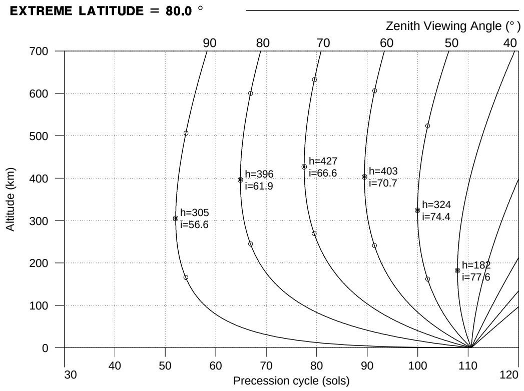
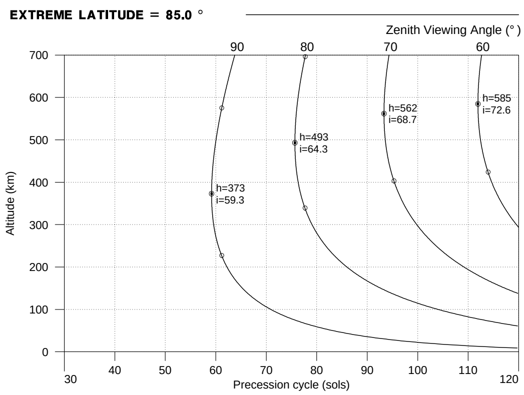


FIGURE 1: *Viewing geometry, satellite S observing point P by accross-track swath.*

Nodal precession velocity

The intersection of the orbit with the equatorial plane of the planet defines two particular points, the nodes (ascending and descending) of the orbit. The perturbation theory, initialised by Lagrange, shows that the orbital plane (defined by longitude Ω of the ascending node, in a galilean referential) is submitted to a motion, with pole axis as rotation axis. This motion, said *precession motion*, is secular (*i. e.* proportional to time). It is due to the non-sphericity of the planet and to the action of other celestial badies. However, the principal cause of this





FIGURES 2 (a) and (b): *Precession cycle as function of altitude, for different zenith viewing angles. (a): extreme latitude observed 80°; (b): extreme latitude observed 85°.*

movement is the oblatness of the planet, characterised by the J_2 term of the geopotential. Considering only this term, the velocity $\dot{\Omega}$ of the nodal precession is given by:

$$\dot{\Omega} = -K_0 \left(\frac{R}{R+h}\right)^{\frac{7}{2}} \cos i \qquad (3)$$

The coefficient, here noted K_0, is only function of J_2, mass and radius R of the planet (Capderou, 2002). For Mars:

$$K_0 = 3.074\ 84\ 10^{-6}\ \text{rad.s}^{-1}$$

corresponding to $K_0 = 15.640$ degrees/sol = 29.047 rounds/(martian year).

Then, for each orbit, defined by i and h – but i and h linked by eqn.(2) –, we obtain, with, eqn.(3), the nodal precession velocity, $\dot{\Omega}(i,h)$. The longitude Ω is a mesurement of the *Hour Angle*, and $\Omega(t) = \Omega(t_0) + \dot{\Omega}\ (t - t_0)$ gives directly the *Local Solar Time* (LST) of the ascending node, and consequently the local time of each location overpassed (varying with latitude).

Specif.		Optimal orbit			h limits	
ϕ	ζ	h	i	$C/2$	h_i	h_s
90.0	90	455	61.9	34	304	656
87.5	90	412	60.6	32	264	614
85.0	90	373	59.3	30	227	575
80.0	60	403	70.7	45	241	606

TABLE 1: *Characteristics (h, i) of optimal orbit for each specifications, giving (C/2). Variation domain (h_i to h_s) allowing half-cycle between (C/2) and (C/2) + 1. Angles (ϕ, ζ, i) in degrees, altitudes (h, h_i, h_s) in km, half-cycle (C/2) in sols.*

Precession cycle

The Precession cycle is another way, more vivid, to illustrate nodal precession velocity: that represents the time interval necessary to obtain the same relative configuration orbit/planet/Sun. The Precession cycle C is given by:

$$C = \frac{Y}{\dot{\Omega}_y - 1} \qquad (4)$$

with Y, length of the year, and $\dot{\Omega}_y$, precession velocity expressed in round by martian year (with $\dot{\Omega}_y = 1$, in the case of Sun-synchronous orbit, providing infinity for C). C and Y have the same unit. We choice here: sol.

In this paper, as usually, we consider the absolute value of C (for inclination inferior to Sun-synchronous inclination, cycle C, by eqn.(4), is negative). The shortest possible cycle is 22 sols, for $i = 0$ and $h = 0$.

Important remark. In practice, nodes (ascending or descending) are undifferentiated for observation acquiring data, and a half-cycle of precession is sufficient to obtain the required sampling.

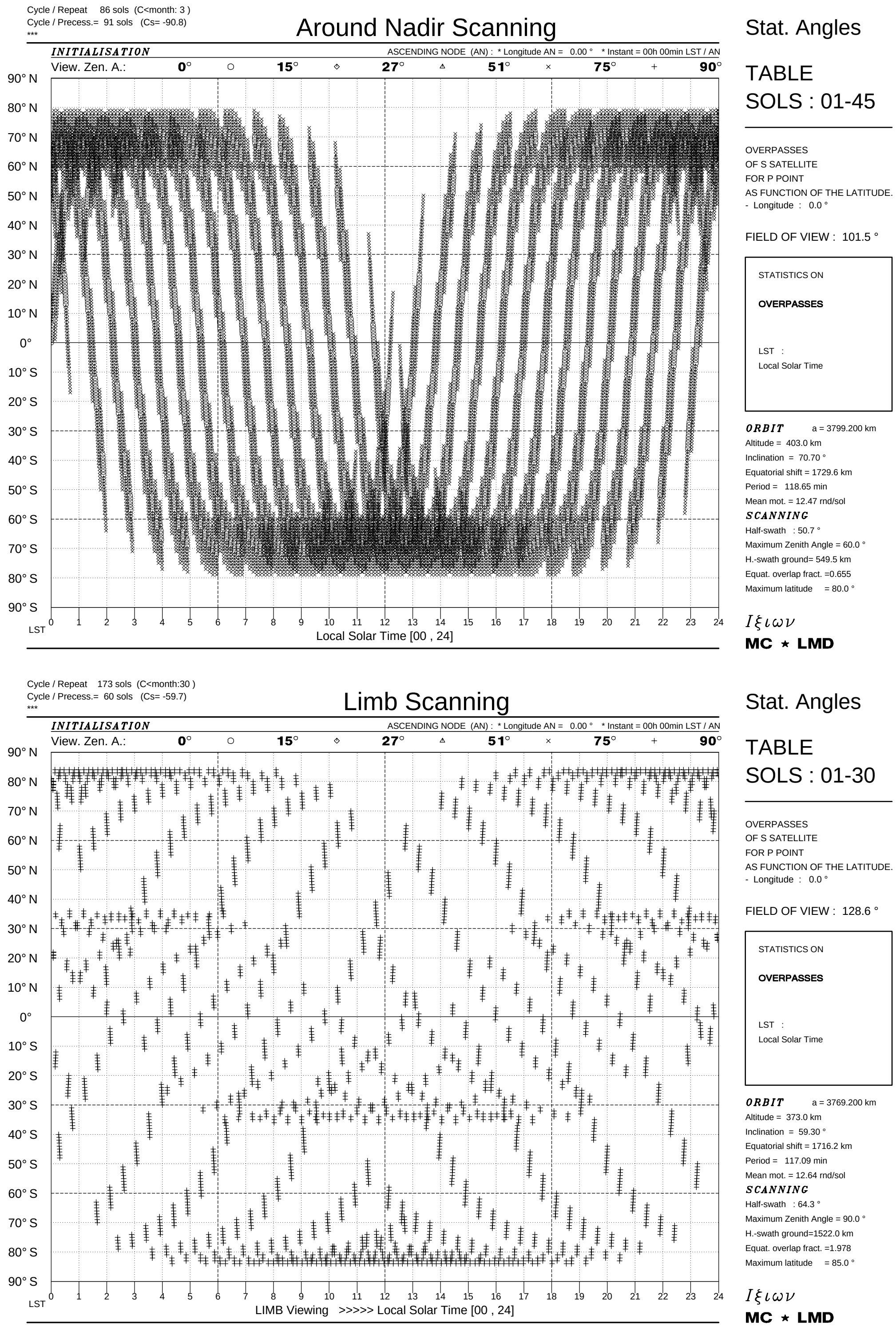
Results: orbits, viewing angles and sampling

In the following study, each case is defined by ϕ, extreme latitude, corresponding to the maximum latitude we want reach with accross-track swath. For each case, we plot, for each viewing zenith angle ζ, the precession cycle C related to orbit altitude h. In the realistic cases ($\phi > 70^o$, $\zeta > 50^o$), function $C(h)$ presents a minimum, denoting the *best* orbit, according our criteria. For this minimum cycle (shortest period to obtain general sampling), altitude h and inclination i of the orbit are defined, assuring the required conditions of view.

It is significant to note that curve minimum is flat: for a large variation around the central altitude, the value of the cycle remains quite the same. We emphasize these notions with two examples.

- **Around nadir scanning instrument.**

Mission constraints for this instrument: viewing zenith angle ζ = 60° and latitude observed up to ϕ = 80°. The variation $C(h)$ for different values of ζ is represented on



FIGURES 3 (a) and (b): *Temporal sampling as function of latitude (from North Pole to South Pole), for different instruments and satellites, during a half-cycle of precession. (a): around nadir scanning instrument (viewing zenith angle ζ = 60°), extreme latitude observed 80°; (b): limb scanning instrument (ζ = 90°), extreme latitude observed 85°.*

Fig. 2(a). For $\zeta = 60^o$ as required, the characteristics of the optimal orbit are h = 403 km, i = 70.7, giving a half-cycle of 45 sols – see Tab. 1.

Fig. 3(a) represents spatial and temporal sampling for the optimal orbit described above. For a given meridian, for all the latitudes, we note each overpass (with zenith viewing angle of the swath lower than 60^o). We see that, in a 45-sol period, all the latitudes are scanned, between 80^{o}N and 80^{o}S, with homogeneous repartition in space and in local time.

The little lacks of sampling, seen in this figure, would be filled if we consider a complete precession cycle (here, 90 sols).

- **Limb scanning instrument**

Mission constraints for this instrument (like Mambo instrument on board Premier Mission 07): limb scanning and polar ice cap viewing. These specifications imply: ζ = 90^o and $\phi > 85^o$. The computation gives the following results, noted in Tab. 1.

For example, for ϕ =85^o and ζ = 90^o, the optimal orbit is h = 373 km (i = 59^o) provinding a half-cycle of 30 sols. For a half-cycle of one sol more, orbit may vary between 656 km (i = 57^o) and 304 km (i =67^o), allowing a complete sampling in a time interval of 31 sols – see Fig. 2(b).

Fig. 3(b) represents spatial and temporal sampling for the optimal orbit described above. Like on Fig. 3(a), we note each overpass (only limb scanning here), for a given meridian, for all the latitudes. We see that, in a 30-sol period, all the latitudes are scanned, between 85^{o}N and 85^{o}S, with homogeneous repartition in space and in local time, and with the same remark, seen above, about half-cycle and complet cycle.

Conclusion

For missions requesting complete temporal sampling in local solar time (00 to 24) in a relatively short period (less than 50 sols) and a quasi-complete spatial sampling in latitudes, it is possible to select suitable circular orbits using judicious choices of the orbital parameters.

References

[1] Capderou, M. *Satellites - Orbits and missions*. [Chapter 10 : Satellite of Mars] (*in french*). 504 pages, Springer-Verlag, Berlin, Paris, 2002.

[2] Forget, F. et al., “MAMBO, The Mars Atmosphere Microwave Brightness Observer”, this issue.