DAILY REPEAT-GROUNDTRACK MARS ORBITS

EXTENDED ABSTRACT

Introduction
The G. Marconi Orbiter (GMO), the first Mars orbiter optimized for relay performance rather than for science, will be placed into an orbit specifically designed to facilitate relay support to in-situ Mars probes. Relay users, such as rovers or small landers on the surface of Mars, desire relay contacts at the same times every day so that they can design their missions and their operations based on invariant communications patterns. Daily repeat-groundtrack orbits thus appear well suited to GMO.

This paper characterizes 42 Mars orbits with ground tracks that repeat every sol (Mars day). These orbits are divided into five orbit classes:

- 14 circular equatorial prograde orbits
- 14 circular equatorial retrograde orbits
- 11 circular sun synchronous orbits
- 2 eccentric equatorial orbits
- 1 eccentric critically inclined orbit

This paper compares the relay performance of some of these orbits based on coverage area, connectivity and data volume.

Orbit Identification Process
All orbits with daily repeating ground traces have the following characteristics:

1) The orbit period must be a subperiod of the planet rotation period relative to the sun.

2) If the orbit is not equatorial, the orbit plane must stay stationary with respect to the sun – i.e. the orbit must be sun synchronous.

3) If the orbit is eccentric, the line of apsides must stay stationary with respect to both the sun and to the equatorial plane of Mars.

Define $Q$, the Trace Repetition Parameter, to be the planet rotation period relative to the sun divided by the orbit period. $Q$ must be an integer for an orbit to have a daily repeating ground trace.

Circular Orbits
To identify all circular Martian orbits with daily repeating ground traces, we first find all circular Martian orbits for which $Q$ is an integer – see Table 1.
Equatorial circular orbits at Mars with the periods and altitudes shown in Table 1 will have daily repeating ground tracks. There are two possible equatorial orbits for each value of Q: one prograde (0° inclination) and one retrograde (180° inclination). The equatorial circular prograde orbit with $Q=1$ is an areostationary orbit, akin to geostationary orbits on Earth – an orbiter in this orbit will always remain over approximately the same location on the equator of Mars.

For some values of Q, there is a sun synchronous inclination, i.e. an non-equatorial inclination at which the line of nodes rotates at the same rate as Mars rotates around the sun, resulting in an unchanging orientation of the orbit with respect to the sun and hence in daily repeating ground tracks. These inclinations are shown in the fourth column of Table 1.

### Equatorial Eccentric Orbits

**Table 2. Mars Elliptical Equatorial Orbits with Daily Repeating Ground Traces**

<table>
<thead>
<tr>
<th>Orbit Period, sols</th>
<th>$\frac{1}{2}$ sol</th>
<th>$\frac{1}{2}$ sol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbit Period $P$, hours</td>
<td>12.31 hours</td>
<td>8.21 hours</td>
</tr>
<tr>
<td>Semi Major Axis $a$</td>
<td>12,682 km</td>
<td>9,657 km</td>
</tr>
<tr>
<td>Eccentricity $e$</td>
<td>0.68</td>
<td>0.366</td>
</tr>
<tr>
<td>Inclination $i$</td>
<td>0°</td>
<td>0°</td>
</tr>
<tr>
<td>Periapsis Altitude $h_{\text{min}}$</td>
<td>661 km</td>
<td>2,725 km</td>
</tr>
<tr>
<td>Apoapsis Altitude $h_{\text{max}}$</td>
<td>17,908 km</td>
<td>9,794 km</td>
</tr>
</tbody>
</table>

There are two equatorial eccentric orbits with integral values of Q in which the line of apsides rotates at the same rate as the rotation of Mars about the sun, resulting in daily repeating ground tracks. Table 2 characterizes both orbits.

### Critically Inclined Eccentric Orbit

**Table 3. Triply Synchronous Orbit Characteristics**

<table>
<thead>
<tr>
<th>Orbit period, sols</th>
<th>$\frac{1}{4}$ sol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbit period $P$, hours</td>
<td>6.16 hours</td>
</tr>
<tr>
<td>Semi Major Axis $a$</td>
<td>8,163 km</td>
</tr>
<tr>
<td>Eccentricity $e$</td>
<td>0.462</td>
</tr>
<tr>
<td>Inclination $i$</td>
<td>116.565°</td>
</tr>
<tr>
<td>Periapsis Altitude $h_{\text{min}}$</td>
<td>913</td>
</tr>
<tr>
<td>Apoapsis Altitude $h_{\text{max}}$</td>
<td>8,456 km</td>
</tr>
</tbody>
</table>

At the critical inclination, $i = 116.565°$ or $63.435°$, there is no apsidal rotation with respect to the line of nodes. It is shown that there is a single critically inclined orbit with an integral $Q$ for which the line of nodes rotates at the same rate as Mars rotates around the sun, resulting in a daily repeating ground trace. The orbit is characterized in Table 3.
Relay Performance

The paper compares the relay performance of GMO in several of the characterized orbits with the performance of relay radios on Mars science orbiters. Figure 1 compares the connectivity of various orbits:

Figure 1. Connectivity

Figure 2 shows the data volume that could be relayed from the Mars Science Laboratory (MSL) rover through various orbiters.

Figure 2. Data Volume

Figure 3 shows the amount of time in which an orbiter in the ½ sol orbit characterized in Table 2 would be in view of a lander each day.

Figure 3. Mean Pass Length of ½ Sol ACE Orbit

1 MRO: NASA 2005 Mars Reconnaissance Orbiter; PREMIER: proposed 2007 CNES Mars orbiter; ¼ sol ACCI: the triply synchronous orbit characterized in Table 3; ½ sol ACE: the ½ sol orbit characterized in Table 2.
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SHORT ABSTRACT

The G. Marconi Orbiter (GMO) will be placed into a Mars orbit designed to optimize relay support to in-situ Mars probes. Relay users, such as rovers or small landers on the surface of Mars, would like GMO to be in a daily repeat-groundtrack orbit so that they can design their missions and their operations based on invariant contact times.

This paper identifies 42 Mars orbits with ground tracks that repeat every sol and compares the relay performance of some of these orbits based on coverage area, connectivity and data volume.