MARS GLOBAL REFERENCE ATMOSPHERIC MODEL (MARS-GRAM) AND DATABASE FOR MISSION DESIGN

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Introduction:
Mars Global Reference Atmospheric Model (Mars-GRAM 2001) is an engineering-level Mars atmosphere model widely used for many Mars mission applications (Justus and Johnson, 2001; Justus et al., 2002a). From 0-80 km, it is based on NASA Ames Mars General Circulation Model (MGCM; Haberle et al., 1993), while above 80 km it is based on Mars Thermospheric General Circulation Model (Bougher et al., 1990). Mars-GRAM 2001 and MGCM use surface topography from Mars Global Surveyor Mars Orbiting Laser Altimeter (MOLA; Smith and Zuber, 1998).

Validation with TES and Radio Science Data:
Validation studies (Justus et al., 2002b,c) are described comparing Mars-GRAM with Mars Global Surveyor Radio Science (RS; Hinson et al., 1999) and Thermal Emission Spectrometer (TES; Smith et al., 2001) data. RS data from 2480 profiles were used, covering latitudes 75° S to 72° N, surface to ~40 km, for seasons ranging from areocentric longitude of Sun (Ls) = 70-160° and 265-310°. RS data spanned a range of local times, mostly 0-9 hours and 18-24 hours. For interests in aerocapture and precision landing, comparisons concentrated on atmospheric density. Figure 1 shows that, at a fixed height of 20 km, RS density varied by about a factor of 2.5 over ranges of latitudes and Ls values observed. Evaluated at matching positions and times, average RS/Mars-GRAM density ratios, shown in Figure 2, were generally 1±0.05, except at heights above ~25 km and latitudes above ~50° N. Average standard deviation of RS/Mars-GRAM density ratio was 6%.

TES data were used covering surface to ~40 km, over more than a full Mars year (February, 1999 – June, 2001, just before start of a Mars global dust storm). Depending on season, TES data covered latitudes 85° S to 85° N. Most TES data were concentrated near local times 2 hours and 14 hours. Observed average TES/Mars-GRAM density ratios were generally 1±0.05, except at high altitudes (15-30 km, depending on season) and high latitudes (>45° N), or at most altitudes in the southern hemisphere at Ls ~ 90 and 180°. Compared to TES averages for a given latitude and season, Figures 3-5 show that TES data had average density standard deviation about the mean of ~2.5% for all data, or ~1-4%, depending on time of day and dust optical depth. Average standard deviation of TES/Mars-GRAM density ratio was 8.9% for local time 2 hours and 7.1% for local time 14 hours. Thus standard deviation of observed TES/Mars-GRAM density ratio, evaluated at matching positions and times, is about three times the standard deviation of TES data about the TES mean value at a given position and season.

Validation with Accelerometer Data:
Mars-GRAM has been used for operational support of aerobraking for both Mars Global Surveyor (Keating et al., 1998) and Mars Odyssey (Tolson et al., 2002). Figures 6-8 show some results of comparisons between Mars-GRAM and periapsis density and scale height from these two aerobraking opera-
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![Graph](image_url)  
**Figure 3.** Standard deviation of TES temperature or density versus pressure level.

![Graph](image_url)  
**Figure 4.** Standard deviation of TES/Mars-GRAM density ratio.

![Graph](image_url)  
**Figure 5.** Standard deviation of density ratio (RS/Mars-GRAM; circles) versus height. Standard deviations of TES/Mars-GRAM ratio (triangles and squares) and of TES data (RMS over all TES data bins; diamonds) are also shown for comparison.

New Near-Surface Mars-GRAM Features:
A new feature in Mars-GRAM 2001 allows quantitative evaluation of dust physical and optical properties, and details of near-ground-surface conditions (including surface albedo) so that estimates can be made for upwelling and downwelling components.
Figure 8 - Density scale height at periapsis from Mars Odyssey accelerometer during aerobraking and simulated by Mars-GRAM using various seasonal height offsets and dust optical depths.

Table 1 – Height offset used, and statistical results from Odyssey Accelerometer/Mars-GRAM density comparison, shown in Figure 7.

<table>
<thead>
<tr>
<th>Optical Depth</th>
<th>Height Offset (km)</th>
<th>Average Acc/Mars-GRAM</th>
<th>Std. Dev. (1-Orbit Value)</th>
<th>Std. Dev. (20-Orbit Mean)</th>
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</thead>
<tbody>
<tr>
<td>0.5</td>
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<td>32.6</td>
<td>14.8</td>
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<td>2.0</td>
<td>-2.8</td>
<td>0.999</td>
<td>33.5</td>
<td>15.8</td>
</tr>
</tbody>
</table>

Figure 9. Latitude-longitude cross section of downwelling longwave irradiance at the surface, expressed as sky temperature, at Ls = 270 degrees, dust optical depth 1.0. Local time is plotted across the top of the figure.

Figure 10. Latitude-longitude cross section of downwelling shortwave (solar) irradiance at the surface, at Ls = 270 degrees, dust optical depth 1.0. Local time is plotted across the top of the figure.

Other new Mars-GRAM 2001 features (Justus and Johnson, 2001) related to near-surface environments include realistic boundary layer representation of temperature gradients and winds and wind shears.

Conclusions:
As demonstrated by the validation studies here, Mars-GRAM 2001 is an engineering-level Mars atmospheric model suitable for a wide range of mission design, systems analysis, and operations tasks.

For orbiter missions, Mars-GRAM applications include analysis for aerocapture or aerobraking operations, analysis of station-keeping issues for science orbits, analysis of orbital lifetimes for end-of-mission planetary protection orbits, and atmospheric entry issues for accidental break-up and burn-up scenarios.

For lander missions, applications include analysis for entry, descent and landing (EDL), guidance and control analysis for precision landing, and (with the new near-surface environment features) systems design, thermal loads analysis, and solar power system performance analysis for lander operations.

With its realistic wind fields (not discussed here), Mars-GRAM is also well suited for studies of systems to operate within the atmosphere of Mars, such as airplanes or balloons used as mobile remote sensing platforms.

Using Mars-GRAM’s perturbation model (not discussed here) in Monte-Carlo mode makes Mars-
GRAM especially suited for design and testing of guidance and control algorithms and for heat loads analysis of thermal protection systems.

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References:


