THE REMOVAL OF PERIODIC GRAVITATIONAL PERTURBATIONS FROM MARS GLOBAL SURVEYOR'S SCIENCE PHASING ORBITS APPLIED TO THE STUDY OF THE MARTIAN EXOSPHERE. P. W. Tracadas[1], M. T. Zuber[1,2], F. G. Lemoine[2], and D. E. Smith[2], [1]Massachusetts Institute of Technology (Rm. 54-521, 77 Mass. Ave., Cambridge, MA. 02139, tracadas@mit.edu), [2]NASA/GSFC (Greenbelt, MD. 20771).

Introduction: The martian exosphere and upper atmosphere exert measurable drag on the Mars Global Surveyor (MGS) spacecraft [1, 2, 3]. Using the Goddard Space Flight Center's GEODYN orbit determination software [4], the science phasing orbits (SPO) were analyzed to determine the atmospheric drag and hence, measure the average density near the orbits' perifocus (170-180 km altitude above high northern latitudes). Future work will include the gravity calibration and mapping periods as well.

Previous Work: The Martian atmosphere was first probed by radio occultation [5] and spacecraft landers [6] to an altitude of 200 km between 1965 and 1976. In 1997, Pathfinder made additional in situ measurements [7]. MGS has been in orbit around Mars since September 1997 and nearly one hundred radio occultations have been collected [8] as well as thermal IR spectra of the lower atmosphere [9]. Wave 1, 2 and 3 density structures have been detected from density measurements made below 170 km by the on-board accelerometers during aerobraking orbits [1, 2]. The martian atmosphere is too tenuous above 200 km to be measured by remote sensing or by accelerometers. But MGS stayed in a 170 – 180 km perifocus (~0.7 eccentricity) orbit for 290 orbits during SPO with little orbital maneuvering and will spend significant time in the circular ~400 km orbit (the mapping orbit). Numerical analysis of these many MGS orbits at various altitudes can separate the non-conservative air drag and radiation pressure forces from the Keplerian motion. The goal of this study is to understand the drag force on the spacecraft after aspherical gravitational perturbations have been removed.

Orbit Analysis: GEODYN is currently being employed to provide 30 meter orbits for areocentric positioning of the Mars Orbiter Laser Altimeter [10. 11]. The atmospheric drag on MGS was a significant part of the mission's method for orbit insertion (so-called aerobraking), but the atmospheric drag effects on the higher altitude mapping orbit have been given little consideration in the mission's science plan. Where the accelerometers are insensitive to the small instantaneous drag imparted by the very tenuous atmosphere at altitudes above 170 km, the average air drag acceleration for an entire orbit revolution can be measured using doppler radio tracking and orbit integration.

For the SPO and “hiatus” portions of the mission, when little spacecraft thrust maneuvering is occurring, the air drag is measurable near the orbit's relatively high altitude perifocus due to the large area to mass ratio of MGS. A macro-model of the spacecraft has been designed for GEODYN that includes fourteen panels in a fixed, nadir-mapping configuration [10] (a moveable solar panel model is in the works). For this work, a 70 degree and order gravity field derived from tracking data of all martian orbiters, including data from the gravity calibration mission, was used along with an a priori atmospheric density model by Culp and Stewart [12] (the Culp and Stewart model yields $5x10^{-11}$ kg/m^3 for an average density measure at 170-180 km altitude). Solar radiation and the martian reradiation fluxes are both computed for accelerations on the spacecraft (no self shadowing of the macro-model is included). From the analysis of 330 orbits over four months, the decrease in orbital semi-major axis is apparent (figure 1) and indicative of atmospheric drag; likewise, the eccentricity of these orbits shows a similar decrease.

The large (~20 km) oscillating variation in the osculating semi-major axis is mainly due to the aspherical gravity perturbations of Mars. We compute the spectrum of the linear perturbations (e.g. [13]) to each of the Keplerian orbital elements of the spacecraft and sum over all perturbation frequencies to degree and order 20x20 (for computational quickness; besides, the major effects are from J_2 and J_2^2). The resulting mean semi-major element is over-plotted in figure 1 and shows more clearly the decay of the orbit.

The two-sloped character of the long wavelength trend of the osculating (and mean) elements is consistent with the long wavelength rise and fall of the orbit's perifocus. The perifocus begins at 170 km altitude at the beginning of the SPO period, rises to 180 km by mid-SPO, and the lowers to 170 km by the end. With an estimated scale height of about 10 km for Mars in this region, the drag force variation is consistent with the density variation.

Future Work: The gravity mapping mission, performed by MGS during February 1999 at an altitude of 400 km, planned from the beginning to use analyses of the MGS orbits to measure the likewise small acceleration effects of surface and subsurface gravity anomalies on the spacecraft. Our atmospheric study is complementary to that study since the longitude of the ascending node and the argument of perigee are mainly perturbed by gravity anomalies while atmospheric drag effects are second order. Thus, a better drag model will help in resolving fine scale gravity anomalies.

In addition, we hope to find evidence of density changes in the exosphere on both short and long timescales during the mapping mission. Solar storms heat the upper atmosphere with their plasma discharges causing density changes on timescales of weeks, whereas dust storms heat the lower atmosphere and cause changes on timescales of months.

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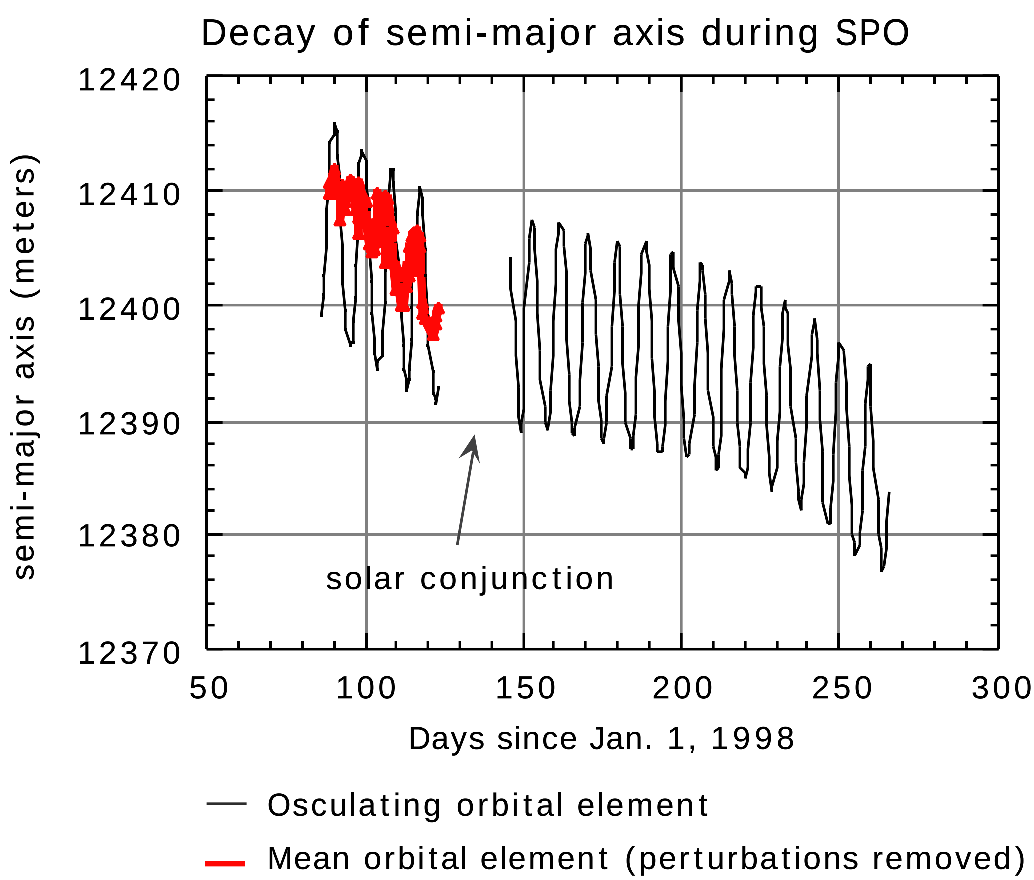

Figure 1. The decrease in the semi-major axis length of the MGS orbit over the five month SPO period. Each point is the osculating semi-major axis at apoapsis and the publicly available MGS navigation team elements have been included for orbits not yet analyzed by us (where our solutions overlap there are differences of up to 60 m, although occasionally there are kilometer discrepancies). The high frequency oscillation is due to aspherical gravity (i.e. J_2 mainly) and can be removed by linear orbit perturbation theory to yield mean elements. The mean elements confirm the decay trend and give a better estimate of the orbital decay rate.