THE ORBITS OF THE MARTIAN SATELLITES

R. A. Jacobson, Jet Propulsion Laboratory/Caltech, Pasadena, CA 91109. robert.jacobson@jpl.nasa.gov

Introduction: The previous JPL ephemerides of the Martian satellites [1] were developed by fitting the extended Sinclair–Morley analytical theory [2,3,4] to the complete set of observations from 1877 to 1989. Recently we obtained Earthbased astrometry from the U. S. Naval Observatory (Pascu 2004, private comm.) and Table Mountain Observatory (Owen 2003, private comm.), and observations acquired by the MGS spacecraft with the MOLA instrument [5], by the Mars Express spacecraft with the HSRC instrument [6], and by the MRO spacecraft with the optical navigation camera (Synnott 2006, private comm.). We fit numerically integrated orbits to the observations; Lainey et al. [7] has carried out a fit of integrated orbits to all but the Table Mountain, MGS, and MRO data.

Dynamical Model: The equations of motion are expressed in Cartesian coordinates centered at the Martian system barycenter and referenced to the International Celestial Reference Frame (ICRF). The dynamics include the mutual interactions of Phobos and Deimos, the perturbations due to the Earth, Moon, Jupiter, Saturn, and the Sun, the asphericity of Mars, the tide raised on Mars by Phobos, and the Phobos figure. We ignore the tide raised by Deimos because of Deimos' smaller mass and larger distance from Mars. We do, however, account for the effect of the Phobos tide on the motion of Deimos. We assume that Phobos is in synchronous rotation with its pole normal to its orbit and its prime meridian passing through the intersection of its equator and the sub-Mars direction. The librations in latitude and longitude are ignored; they will be the subject of a future investigation. JPL planetary ephemeris DE414 [8] provides the positions and GMs of the Sun, Moon, and planets. The GMs of the satellites and the Martian gravity field and orientation are from [9]. We truncated the gravity field at degree 8 in the zonal harmonics and 5th degree and order in the tesseral harmonics. We did not directly use the Mars rotation model [9] but rather a Fourier series fit to the pole right ascension and declination and the prime meridian defined by that model.

Fit to Observations: We fit our integrated orbits, in a weighted least-squares sense, to the observational data by adjusting the epoch position and velocity of each satellite, the Phobos tidal bulge lag angle, the C_{22} of the Phobos gravity field, and the offsets of the satellites' center-of-figure from their center-of-mass in the sub-Mars direction. The quality of the data fit is as good if not better than that achieved with previous ephemerides. The fit to the MRO data is a factor of 2 better for Phobos and 50% better for Deimos than the presumed measurement accuracy. The MOLA observations, which are positions of Phobos inferred from the observed shadow of Phobos on Mars, have residuals of the order of 2 km. The fit of the Phobos orbit to the Mars Express data is consistent with the quoted 0.5–5.0 km data accuracy . On the other hand, the fit of the Deimos orbit is a factor of 5 worse than the quoted 1 km accuracy.

Comparison with Other Ephemerides: Our new Phobos orbit differs from our previous orbit primarily in the in-orbit direction due to changes in the mean motion and secular acceleration. The difference grows to 20 km by 2023. With respect to Deimos we find a significant mean motion change leading to nearly a 100 km difference in 2023. In addition there is a change in the nodal precession rate which causes an out-of-plane difference of the order of 30 km. Our orbits match those of Lainey et al. [7] at the 6 km level for Phobos and 16 km level for Deimos. Differences are most likely due to different weighting schemes and our use of the MRO data.

Concluding Remarks: Our new ephemeris is available via the JPL Horizons system. We estimate the 1 σ errors in the radial, in-orbit, and out-of-plane directions to be 2 km, 5 km, 2 km for Phobos, and 3 km, 10 km, and 3 km for Deimos.

References: [1] Jacobson, R. A. (1995) IOM 312.1-95-142 (internal document), Jet Propulsion Laboratory, Pasadena, CA. [2] Jacobson, R. A. (1996) AAS Paper 96-140, American Astronautical Society, Springfield, VA. [3] Morley, T. A. (1990) *A&AS*, 228, 260–274. [4] Sinclair, A. T. (1972) *MNRAS*, 155, 249–274. [5] Bills, B. G. et al. (2005) *JGR*, 110(E07004), 1–15. [6] Oberst, J. et al. (2006) *A&A*, 447, 1145–1151. [7] Lainey, V. et al. (2005) AGU Fall Meeting, Poster G51A-0802, San Francisco, CA. [8] Standish, E. M. (2006) IOM 343R-06-002 (internal document), Jet Propulsion Laboratory, Pasadena, CA. [9] Konopliv, A. S. et al. (2006) *Icarus*, 182, 23–50.