TRAJECTORY DESIGN FOR THE TRANSITING EXOPLANET SURVEY SATELLITE (TESS)

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ABSTRACT

The Transiting Exoplanet Survey Satellite (TESS), launching in 2017, is a National Aeronautics and Space Administration (NASA) Explorer-class mission that will perform a survey of the entire sky over its nominal two-year mission. TESS will travel in a highly eccentric orbit around Earth, with initial perigee radius near 17 Earth radii (Re) and apogee radius near 59 Re. The high apogee allows observations far from Earth for extended intervals. The orbit period is near 2:1 resonance with the Moon, with each apogee nearly 90 degrees out-of-phase with the Moon, in a configuration that has been shown to be stable. TESS will execute three phasing orbits followed by a lunar flyby to align the line of apsides and to achieve desired inclination to the ecliptic plane. A final maneuver is performed at perigee to achieve 2:1 resonance with the Moon. For such a highly eccentric orbit it is known that eccentricity and inclination oscillate, as described by the Kozai mechanism. The mission orbit must keep perigee below 22 Re to maintain communications and above 7 Re to reduce risk of collision within the geosynchronous belt.

The goals to achieve a resonant orbit with long-term orbit stability, short eclipses and limited oscillations of perigee, together with the need for a lunar flyby, present significant challenges to the trajectory design. To rapidly assess launch opportunities, we adapted the SWM76 launch window tool, developed originally for the Magnetospheric Multi-Scale mission. Computational speed in SWM76 is achieved by making use of the orbital Variation of Parameter equations, together with "geometry proxies" for the constraints. The geometry proxies were derived for three TESS orbital constraints: that eclipses be limited in duration, that the science orbit be reachable via a lunar gravity-assist, and that TESS reach each apogee nearly 90 degrees out-of-phase with the Moon.

The stability of such a resonant orbit is a critical feature for mission design. We have used dynamical systems techniques to examine the long-term dynamics in the Earth-Moon system using a Circular Restricted 3-Body model. Because the Sun's gravitation has a significant effect on the dynamics, we extended the analysis to a Bi-circular Restricted 4-Body model. For more precise trajectory analysis we use a high-fidelity ephemeris model in the General Mission Analysis Tool (GMAT). With GMAT we employed multiple shooting to optimize the maneuver delta-V while assuring that mission constraints are met. This analysis builds upon work performed by Gangestad and Henning of The Aerospace Corporation.

Finally, we describe how the flight dynamics analysis techniques we have developed for TESS can be applied to science missions with similar requirements.