National Aeronautics and Space Administration

Trajectory Design for the Transiting Exoplanet Survey Satellite (TESS)

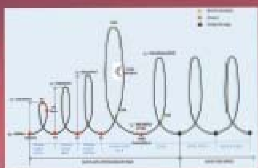
Donald Dichmann • Joel Parker • Trevor Williams • Chad Mendelsohn
Navigation and Mission Design Branch, NASA Goddard Space Flight Center
donald.j.dichmann@nasa.gov • (301) 286-6621

Mission Overview

- TESS, an Explorer-class mission, will perform an all-sky survey over 2 years
- Science orbit is highly eccentric, highly inclined, in 2:1 resonance with the Moon
  - Choice inspired by analysis of KRONOS (2:1) and IBEX (3:1) mission orbits
- Lunar gravity assist to achieve Science orbit
- 3.5 Phasing loops

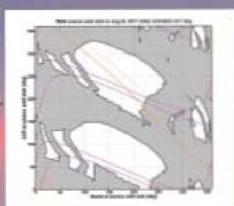
Requirements

- Lunar Resonant Phasing condition for Operational orbit stability; need Moon-Earth-Spacecraft angle at apogee of 90 ± 30 deg
- Short, infrequent eclipses: Need initial ecliptic AOP between 35 and 40 deg
- Perigee between 7 and 22 Earth Radii for duration of mission



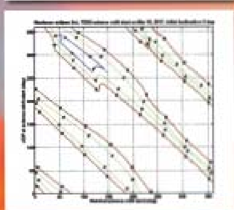
SWM/TESS: VoP Analysis

- Schematic Window Methodology (SWM)
- Uses Variation of Parameters (VoP) equations and geometric proxies of constraints
- Developed for Magnetospheric Multiscale (MMS) mission, also using highly eccentric, highly inclined orbit
- Allows fast assessment of constraints
- Used to identify launch opportunity RAAN and AOP
- Led to 1st guesses for GMAT trajectories



Eclipse Tolerance

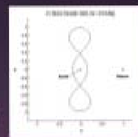
- A critical decision was the number of batteries needed to survive eclipses
- Initial plan called for 2-hour maximum eclipses
- SWM analysis showed that 2-hour maximum eclipse restricted launch opportunities too much
- Led to decision to allow at least 4-hour eclipses
  - Later raised to allow a 6-hour eclipse



Dynamical Systems

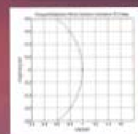
Circular Restricted 3-Body Problem (CR3BP)

- Assess long-term behavior: stability, variability
- Continuation method used to find three families of resonant periodic orbits (planar, mirror, axial) analogous to Libration Point Orbits
- Floquet analysis of mirror solution showed it is neutrally stable with medium-term (9 month) and long-term (12 year) oscillations
- Analysis was extended to include Sun in Bi-Circular Restricted 4-Body Problem



Lidov-Kozai Mechanism: averaging removes short-term variations

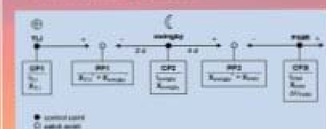
- For highly eccentric, highly inclined orbits
  - Semi-major axis is nearly constant
  - Perigee radius and inclination to Moon orbit plane oscillate in unison, with period near 12 years for TESS
  - For higher inclinations, AOP librates around 90 deg: helps avoid eclipses



High-fidelity orbit propagation, including Moon & Sun, exhibits Kozai mechanism

GMAT: High-fidelity Design and Optimization

- High-fidelity, open-source mission analysis and design tool
- Strengths include flexible mission scripting, optimization, wide applicability
- Fully tested, production quality, operationally certified with ACE mission

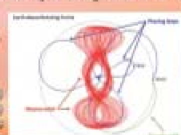


1st guess at segments

Converged continuous trajectory

Two-stage multiple-shooting optimization strategy

- Stage 1: trajectory from Trans-Lunar Injection (TLI) through flyby to Science Orbit
  - 1st guess based on algorithm by J. Gangestad et al. at The Aerospace Corporation
- Stage 2: prepend phasing loops to solve continuously, injection through science orbit



Earth-Moon Rotating (left) and Inertial frame (right) each provide insights to dynamics

http://gmatcentral.org