Orbit determination and prediction accuracy of TOPEX with a priori solar radiation force derived from photometrics and laser ranging data

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Revisiting the Topex/Poseidon (T/P) Mission

- T/P was a joint mission between NASA and CNES to map ocean surface topography
- Launched in 1992, T/P was one of the first oceanographic satellites which revolutionized oceanography
- A malfunctioning pitch momentum wheel lead to its mission ending in 2006
Revisiting the Topex/Poseidon (T/P) Mission

- From 1336 km above Earth T/P measured ocean height to 4-5 centimetres
- Achieved through subtracting Radar Altimeter ranging with T/P altitude determined via POD
- Primary tracking system consisted of 10-20 SLR stations and DORIS tracking data using 50 ground-based beacons measuring Doppler shift
- NASA (experimental) GPS receiver also provided continuous tracking

SLR and Light Curve measurements of Defunct T/P

• SLR tracking of defunct T/P was reinitiated in 2014 by the Graz SLR station (Austria)

• Followed by the (ILRS) Space Debris Study Group in 2015 (data is publically available on the Graz Space Debris Server ftp://sddis.oeaw.ac.at)

• The Odessa photometric system has acquired light curves of T/P since it was decommissioned

• The Odessa system measures the intensity of the reflected sunlight from the satellite surfaces towards the ground station

Spin-Up of T/P

• During its mission, T/P was Nadir stabilized

• However, by combining SLR ranging and photometric data collected by the Odessa system, D. Kucharski et al., determined that T/P is gaining rotational energy

KUCHARSKI ET AL., SPIN-UP OF TOPEX, AGU 2017
What is driving the spin-up of T/P?

- The mechanism driving the spin-up was demonstrated to be due to torques arising from solar flux interacting with the surfaces of T/P.
- The BDRF model used to calculate the solar radiation force and hence the torque was that of Milani et al. (1987):

\[
\frac{d\vec{F}}{dt} = -\frac{\Phi}{c} \left[ (1 - \rho)\hat{\mathbf{R}} + 2\left(\frac{\delta}{3} + \rho \cos \beta\right)\hat{\mathbf{n}}\right] dS |\cos \beta|
\]

- Light blue - direct solar radiation pressure – total force varies between 65 – 228 \( \mu \)N
- Dark blue and orange are the earth albedo and irradiation forces, respectively.
**Orbit Determination Settings and Forces**

**OD/OP spans:**
- 10 days OD, 7 days OP (between 02 Nov - 07 Dec 2015)

**Integrator**
- 11th order Störmer-Cowell predictor-corrector
- Step-Size: 30 Seconds

**Forces**
- Earth Gravity (70×70 EGM 96)
- Earth Tides
- Lunisolar & planetary gravity (JPL Planetary Ephemeris DE200)
- General relativity
- Drag Density Model (NRLMSIS-00)

Apply atmospheric drag (cannon-ball model):

\[
\mathbf{a}_{\text{drag}} = -\frac{1}{2} C_D \frac{A_D}{m} \rho v_{\text{rel}}^2 \frac{v_{\text{rel}}}{|v_{\text{rel}}|}
\]

Apply cannon-ball solar radiation pressure model - as benchmark:

\[
\mathbf{a}_{\text{SRP}}^{(\text{sph})} = -v C_R \frac{A_\odot}{m} \rho_{\text{srp}} \frac{\mathbf{r}_{\odot\odot}}{|\mathbf{r}_{\odot\odot}|}
\]

Apply 3-constant solar radiation pressure model:

\[
\mathbf{a}_{\text{SRP}}^{(3-C)} = -v \frac{\rho_{\text{SRP}}}{m} [A_1 \mathbf{U} + A_2 \mathbf{V} + A_3 \mathbf{W}]
\]

where
\[
\mathbf{U} = -\frac{r_\odot}{|r_\odot|}, \quad \mathbf{W} = \cos \phi \mathbf{\hat{Z}} - \sin \phi \mathbf{\hat{Z}} \times \mathbf{U}, \quad \mathbf{V} = \mathbf{W} \times \mathbf{U}
\]

and
\[
A_1 = \mathbf{a}_{\text{srp}}^{(\text{spin})} \cdot \mathbf{U}, \quad A_2 = \mathbf{a}_{\text{srp}}^{(\text{spin})} \cdot \mathbf{V}, \quad A_3 = \mathbf{a}_{\text{srp}}^{(\text{spin})} \cdot \mathbf{W}
\]

J. W. McMahon & D. J. Scheeres, JGCD. 38-8, 2015
Orbit Determination Results – Cannon Ball Model

![Graphs showing orbit determination results with data points and distributions for different dates and models.](image-url)
Orbit Prediction Accuracy – Cannon Ball Model

Position Difference Projected in RSW (m)

Days from OD Start Date

Along

Cross

Range

Days from OD Start Date
Orbit Determination Results – 3-Constant Model
Orbit Prediction Accuracy – 3-Constant Model

Position Difference Projected in RSW (m)

- Along
- Cross
- Range

Days from OD Start Date
SRP Force projected in the UVW directions

Cannon - Ball

Projected Acceleration in UVW (m/s²)

Date

Projected Acceleration in UVW (m/s²)

Date

Projected Acceleration in UVW (m/s²)

Date

Projected Acceleration in UVW (m/s²)

Date

Projected Acceleration in UVW (m/s²)

Date
• Proposed a 3-Constant Model to represent the averaged A priori SRP force derived from combining light curve and SLR data
• Surprisingly, the 3-Constant Model approach yielded worse results than the cannon-ball approach
• However, the magnitude of acceleration from the 3-Constant is smaller than that of the cannon-ball model, which requires further investigation
Thank You

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