SIMULTANEOUS SPACE DEBRIS LASER RANGING AND LIGHT CURVE MEASUREMENTS OF A LARGE RE-ENTERING UPPER STAGE

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DETAILS: RE-ENTRY OBJECT

- CZ-3B R/B, Norad ID 38253, Third stage of Long March 3B rocket
- Source: http://www.spaceflight101.net/long-march-3b.html

**Third Stage**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>CZ-3B Third Stage</td>
</tr>
<tr>
<td>Length</td>
<td>12.38m</td>
</tr>
<tr>
<td>Diameter</td>
<td>3.0m</td>
</tr>
<tr>
<td>Launch Mass</td>
<td>20,933kg</td>
</tr>
<tr>
<td>Empty Mass</td>
<td>2,740kg</td>
</tr>
<tr>
<td>Fuel</td>
<td>Liquid Hydrogen</td>
</tr>
<tr>
<td>Oxidizer</td>
<td>Liquid Oxygen</td>
</tr>
<tr>
<td>Propellant Mass</td>
<td>18,193kg</td>
</tr>
<tr>
<td>Propulsion</td>
<td>YF-76</td>
</tr>
<tr>
<td>Thrust</td>
<td>166.9kN</td>
</tr>
<tr>
<td>Specific Impulse</td>
<td>4,312Ns/kg</td>
</tr>
<tr>
<td>Chamber Pressure</td>
<td>37.6bar</td>
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<tr>
<td>Area Ratio</td>
<td>80</td>
</tr>
<tr>
<td>Restart Capability</td>
<td>Yes</td>
</tr>
<tr>
<td>Prop Utilization</td>
<td>Yes</td>
</tr>
<tr>
<td>Burn Time</td>
<td>469s</td>
</tr>
<tr>
<td>Control</td>
<td>Engine Gimbaling (Pitch &amp; Yaw)</td>
</tr>
<tr>
<td>Attitude Control Sys</td>
<td>4x70N, 8x40N (Roll, Pitch &amp; Yaw)</td>
</tr>
<tr>
<td>Prop Management</td>
<td>2x300N, 2x45N</td>
</tr>
</tbody>
</table>
ORBITAL PARAMETERS UNTIL RE-ENTRY

2017-07-01 - 2017-08-19 (reentry: 2017-08-18), TLE source: space-track.org

inclination | eccentricity | arg. of perigee
--- | --- | ---
![Graph of inclination](image1) | ![Graph of eccentricity](image2) | ![Graph of argument of perigee](image3)
Mean anom | mean motion | RAAN
![Graph of mean anom](image4) | ![Graph of mean motion](image5) | ![Graph of RAAN](image6)
Simultaneous space debris laser ranging and light curve measurements:

- **SLR:** 100 Hz, 3 ns, 20 W, 200 mJ // **LC:** wavelength ≠ 532 nm used (SPAD)
- **x-axis:** seconds of day 184 (2017-07-03)
- **y-axis:** SLR range residuals [m] (green), max. slant ranges ~3000 km
- **y-axis:** Light curve (red), scaled to fit within the SLR plot range
SPACE DEBRIS LASER RANGING / LIGHT CURVES

- Maximum SLR offset: approx. 13 meters
  - Cylinder axis roughly parallel to line of sight
- Maximum SLR residuals <-> Small light curve peaks
- Minimum SLR residuals <-> Large light curve peaks
- Large LC peaks: Sunlight reflection from cylinder jacket (SLR Minimum)
- Small LC peaks: Sunlight reflection from top/bottom surface
- Periodical offset of SLR residuals -> center of mass ≠ geometrical center?

cylinder jacket (large LC peaks, min SLR)

top / bottom surface (small LC peaks, max SLR)
Main goals of simulations

• Choose a model representing the rocket body shape
  • Cylinder with height = 12.4 m, diameter = 3.0 m

• Define parameter set for different starting positions of cylinder
  • Rotation axis orientation
  • Phase angle of rotation

• Simulate light curves and SLR residuals
• Compare simulation results to measurements
• Find a potential candidate for the rotation axis
\[ I = \frac{I_{\text{sun}} A_{\text{eff}}}{4\pi R^2 (\text{earth} - \text{object})} \]

\[ A_{\text{eff}} = \sum_{j=1}^{N} A_j a_j (\vec{n}_j \vec{i})_+ (\vec{n}_j \vec{o})_+ \]

\( a_j \) ... surface albedo
\( A_j \) ... surface area
\( \vec{n}_j \) ... surface normal vector, object
\( \vec{i} \) ... vector object - sun
\( \vec{o} \) ... vector object - observer

Reference: ANALYSIS OF OBSERVED AND SIMULATED LIGHT CURVES OF SPACE DEBRIS

Carolin Früh, Thomas Schildknecht, Astronomical Institute, University of Bern, Switzerland
**Light curves**
1) Define set of cylinder surface: Grid of normal vectors in ECI system
2) Rotate cylinder (normal vectors) to starting position / starting phase
3) Propagate & rotate normal vectors along SGP4 path
4) Set surfaces areas of normal vectors according to rocket body dimensions
5) Enter in formula (sun/satellite/observer position) -> Light curves

**SLR residuals**
1) Calculate surface vectors: Cylinder center (SGP4) - Cylinder surface
2) Rotate surface vectors to starting position / starting phase
3) Propagate & rotate surface vectors along SGP4 path
4) Calculate absolute values (distance from SGP4 path) -> SLR residuals
**Assumption:** Rotation around body fixed x-axis (no precession)

1) Cylinder initially defined along z-axis (ECI, GCRS)
2) Cylinder rotated around y-axis: initial angle: $\Theta_y$
3) Cylinder rotated around x-axis: initial angle: $\Theta_x$
4) Cylinder rotated around body fixed axis: phase angle: $\alpha$
5) Cylinder rotated around body fixed axis while SPG4 propagated along orbit

Parameter space: $\Theta_y, \Theta_y, \alpha : \ [0^\circ, 5^\circ, 10^\circ, 15^\circ, \ldots, 360^\circ]$ 
Rotation of cylinder to starting position (72*72*72 simulations, ~1200s each)
Optimization criteria: Matching peaks LC and SLR // LC and SLR residuals minimum

- Optimization: $\Theta_y_{\text{init}} = 105^\circ$, $\Theta_y_{\text{init}} = 195^\circ$, phase$_{\text{init}} = 345^\circ$
- Candidate for rotation axis = $[-0.26, -0.25, 0.93]$, dec = $69^\circ$, ra = $224^\circ$

**Optimization Results**

Light curve

SLR

green: experimental results
• SLR results height: 12.4 m, SLR results height: 18 m (estimation: nozzels)
• Better match of SLR residuals in comparison with simulation
• SLR residuals: Rotation around center of mass (not geometrical center)
• Periodic height variations in SLR residuals can be explained

\[ z_{\text{off}} = 0 \, \text{m} \]

\[ z_{\text{off}} = -1.8 \, \text{m} \]
ADVANTAGES OF SLR

- SLR residuals: Different phase angles: variation of 180°
- Due to center of mass offset -> with SLR possible to identify phase
Summary

- Simultaneous light curve and SLR measurements
- Target: large upper stage rocket body
- Comparison experiments with simulations
- Analysis based on only one set of measurements each
- Draw conclusions on rocket body orientation along path, including phase

Outlook

- Refine rocket body model
  - Simulate nozzels & top / bottom surface in greater detail (not flat)
  - Include BRDF: bidirectional reflectance distribution function

! Use the light gathered by your telescope which is not needed for SLR !

THANK YOU