70th International Astronautical Congress
Washington D.C.

ANALYTICAL TECHNIQUES FOR ASSESSING GATEWAY AND OTHER SPACECRAFT ANTENNA LINE-OF-SIGHT

IAC-19-B2.7.4.x50328

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October 25, 2019
1. INTRODUCTION

Artemis Program
• First woman and next man on the Moon by 2024
• SLS
• Orion MPCV
• Gateway
• Human Landing System (HLS)

New Challenges for Communication in Cis-Lunar Space
• Concerns multiple central-bodies
• Competing system-level requirements
• Antennas can be frequently occulted if not placed carefully by own spacecraft geometry
  • Earth-pointing line-of-sight
  • Lunar-pointing line-of-sight
2. GATEWAY COMMUNICATION IN NRHO

2.1 Rationale for NRHO
• Earth access via Orion
• Continuously visible for communication line-of-sight
• Attractive for station-keeping
• Lunar surface access and transit time

2.2 Gateway Baseline NRHO
• 9:2 synodic resonance
• Orbit period of approximately 6.5 days
• Southern L₂ chosen for priority south-pole coverage

2.3 Attitude Constraints
• Solar Pressure Equilibrium Attitude (SPEA)
• Gateway solar arrays aligned to ecliptic poles

2.4 NRHO Ephemeris Model
• Propagation governed by Circular Restricted 3-Body Problem – high-fidelity force model
3. TRANSIENT LINE-OF-SIGHT ANALYSIS METHODOLOGY

Two Major Heuristics Considered
• Annual line-of-sight access percentage
• Maximum duration communication cut-out throughout ephemeris file year

3.1 Gateway Configuration and CAD Model
• Simplified reference model contains major elements for Artemis III mission
3. TRANSIENT LINE-OF-SIGHT ANALYSIS METHODOLOGY

3.2 Varying Antenna Positions to Understand Impact to Communication Line-of-Sight

- Demonstrate how major geometric features on the Gateway affect both Earth and lunar-pointing line-of-sight

3.3 Combining Line-of-Sight from Multiple Antennas

- Assess combined coverage of HALO lunar HGA (aft position) with PPE lunar HGA

3.4 Generating Results through Propagation

<table>
<thead>
<tr>
<th></th>
<th>X (m)</th>
<th>Y (m)</th>
<th>Z (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth HGA Base Height</td>
<td>-3.0</td>
<td>1.0</td>
<td>-3.0</td>
</tr>
<tr>
<td>Earth HGA Elevated Height</td>
<td>-3.0</td>
<td>1.0</td>
<td>-4.0</td>
</tr>
<tr>
<td>HALO Lunar HGA (Fwd)</td>
<td>6.0</td>
<td>1.0</td>
<td>-2.5</td>
</tr>
<tr>
<td>HALO Lunar HGA (Aft)</td>
<td>2.0</td>
<td>1.0</td>
<td>-2.5</td>
</tr>
<tr>
<td>PPE Lunar HGA</td>
<td>-1.0</td>
<td>-1.0</td>
<td>-2.5</td>
</tr>
</tbody>
</table>
4. COMMUNICATION COVERAGE SPHERE

4.1 Möller-Trumbore Intersection Algorithm
- Efficiently performs ray-tracing to Gateway mesh by using transformations to forego storing plane data
- 25% to 50% memory savings typically – very valuable when assessing higher-fidelity models

4.2 Coverage Sphere Mesh
- Generated omni-directional coverage shows geometric communication cut-outs relative to fixed model
5. EXAMPLE RESULTS FOR ANALYTICAL TECHNIQUES

5.1 Earth-Pointing Line-of-Sight

- Cut-outs in communication grouped together due to Earth-pointing antenna on PPE being at one end of Gateway – only experiences cutouts towards one end of vehicle
- Tracking of Earth happens in a counter-clockwise fashion from Gateway fixed frame (rotation about +Z axis) – enlarged look at transient results demonstrates this

<table>
<thead>
<tr>
<th></th>
<th>Annual Access</th>
<th>Maximum Cut-out Duration</th>
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<tbody>
<tr>
<td>Earth HGA Base</td>
<td>90.68%</td>
<td>2.17 days</td>
</tr>
<tr>
<td>Height</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Earth HGA Elevated Height</td>
<td>93.5%</td>
<td>2.12 days</td>
</tr>
</tbody>
</table>

Transient Earth-Pointing Line-of-Sight Communication Results (1 year)

Enlarged Portion of Boxed Area from 1-Year Results
5. EXAMPLE RESULTS FOR ANALYTICAL TECHNIQUES

5.1 Lunar-Pointing Line-of-Sight

<table>
<thead>
<tr>
<th>Location</th>
<th>Annual Access</th>
<th>Maximum Cut-out Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>HALO Lunar HGA (Fwd)</td>
<td>71.39%</td>
<td>2.47 days</td>
</tr>
<tr>
<td>HALO Lunar HGA (Aft)</td>
<td>88.11%</td>
<td>4.32 days</td>
</tr>
<tr>
<td>Combined Lunar PPE and HALO Aft HGAs</td>
<td>97.10%</td>
<td>0.42 days</td>
</tr>
</tbody>
</table>

- Communication line-of-sight coverage improves as HGA is moved closer to PPE solar array boom – mitigates footprint antennas sees when concerned with south-pole coverage
- Combined lunar PPE and HALO HGAs yields a communication link with a very high annual access percentage – only occulted when Gateway is over the northern hemisphere of the Moon

Combined Lunar Line-of-Sight for PPE and HALO (Aft) HGA Locations
5.3 Möller-Trumbore Communication Coverage Sphere

- Can filter out unnecessary portions of omni-directional sphere based on target locations relative to Gateway in NRHO – Gateway’s view of Earth is bounded by 16.7° above and 5.7° below the Gateway’s local XY-plane.
- Overlay latitude and longitude sphere to understand the attitude deviation costs of seeing past certain Gateway geometries if recovering line-of-sight is operationally needed when cut-outs occur during nominal flight attitude.
Possible Applications

• Earth-centric orbits like NRHO are incredibly appealing in that their entire orbit track is continuously visible from the Earth’s vantage point
• Future infrastructure will also be concerned with unique attitude constraints, and competing system-level requirements
• Very large trade space concerning optimizing systems for communication links

Conclusions

• Gateway is just one example of how even ideal orbit situations still pose communication line-of-sight challenges at an integrated-systems level
• Transient simulations of the dynamic line-of-sight behaviour can allow us to understand the performance of tested antenna locations, and combined with the Möller-Trumbore intersection algorithm for generating coverage spheres, attitude deviation costs and feasibility can be assessed