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

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1. INTRODUCTION



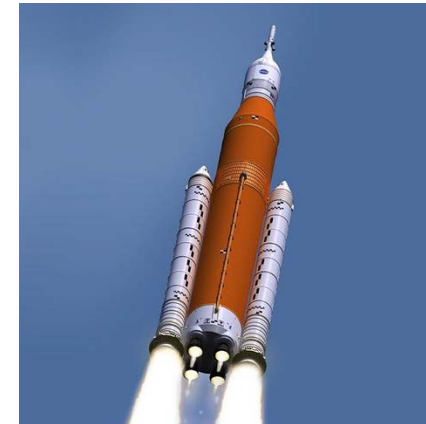
Artemis Program

- 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 occultated 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

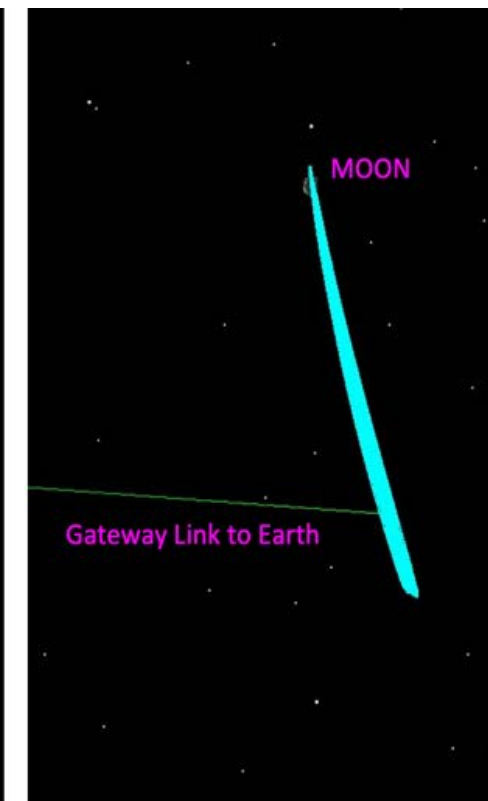
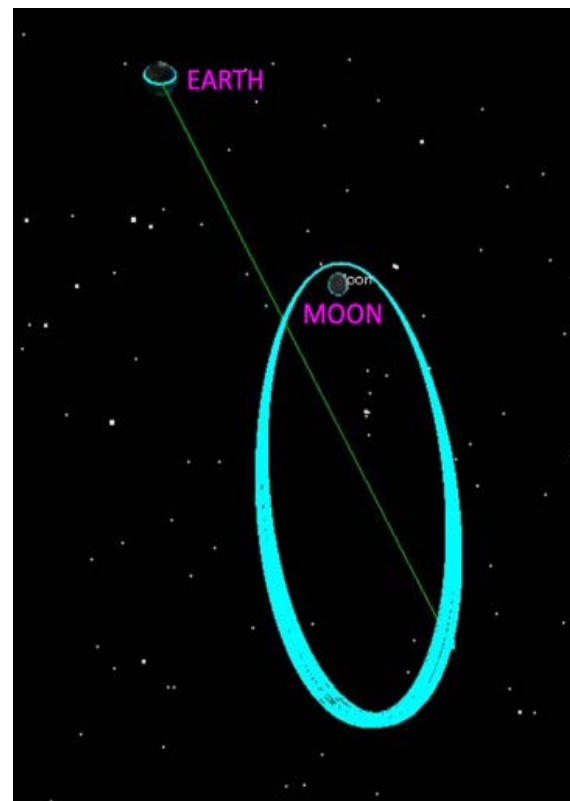
- 9:2 synodic resonance
- Orbit period of approximately 6.5 days
- Southern L_2 chosen for priority south-pole coverage

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



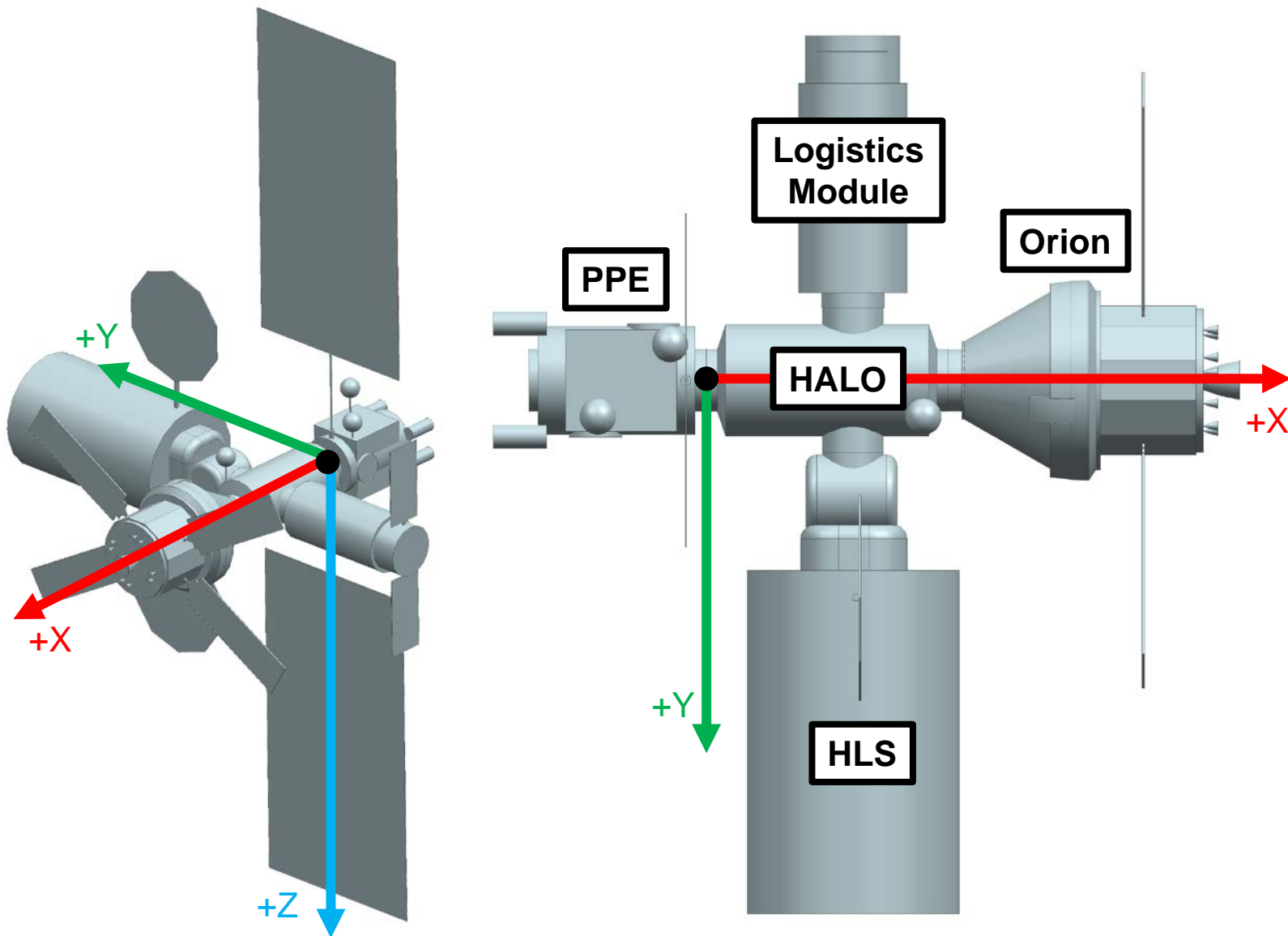
3. TRANSIENT LINE-OF-SIGHT ANALYSIS METHODOLOGY

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

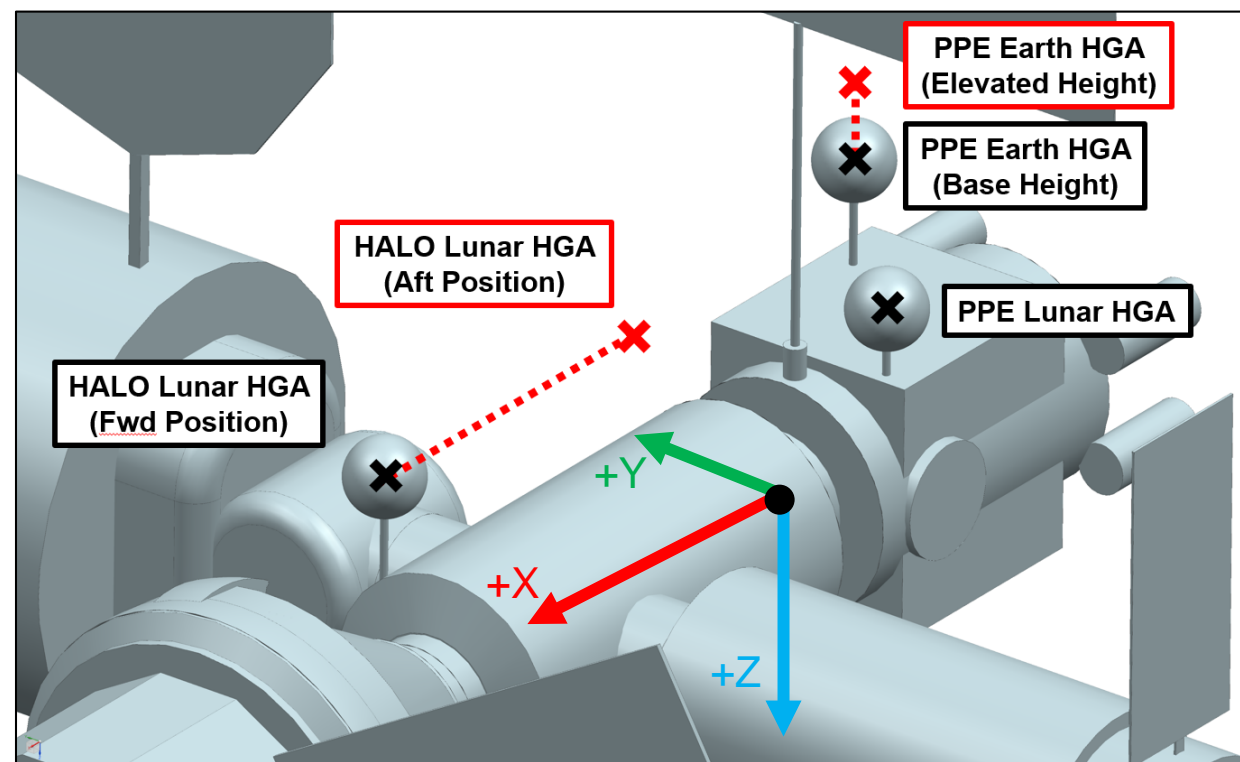
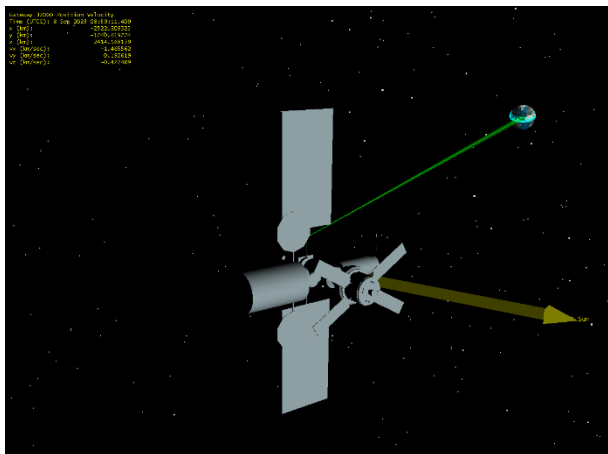
3.2 Varying Antenna Positions to Understand Impact to Communication Line-of-Sight

- 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

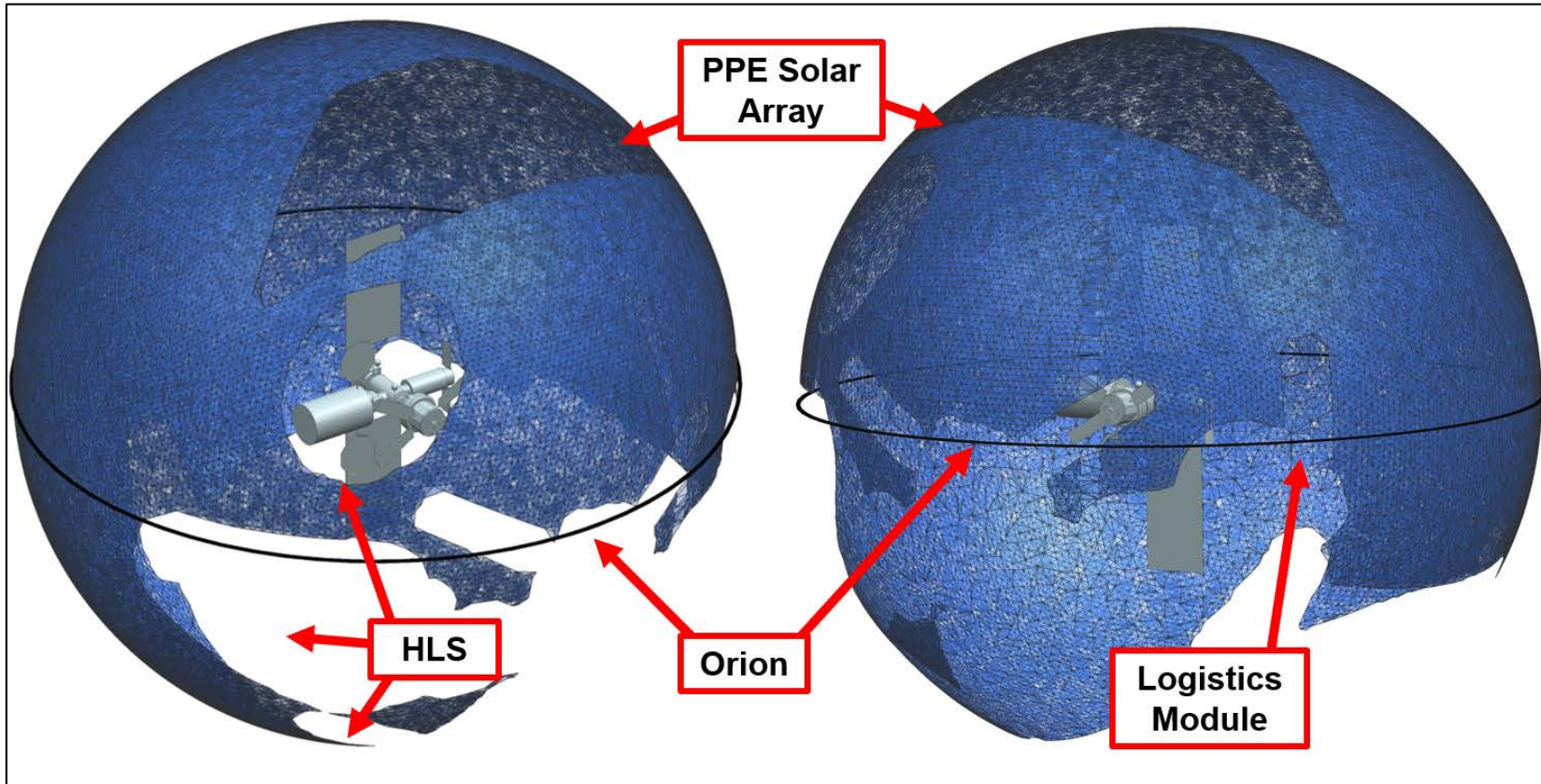
- Assess combined coverage of HALO lunar HGA (aft position) with PPE lunar HGA

3.4 Generating Results through Propagation



	X (m)	Y (m)	Z (m)
Earth HGA Base Height	-3.0	1.0	-3.0
Earth HGA Elevated Height	-3.0	1.0	-4.0
HALO Lunar HGA (Fwd)	6.0	1.0	-2.5
HALO Lunar HGA (Aft)	2.0	1.0	-2.5
PPE Lunar HGA	-1.0	-1.0	-2.5

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

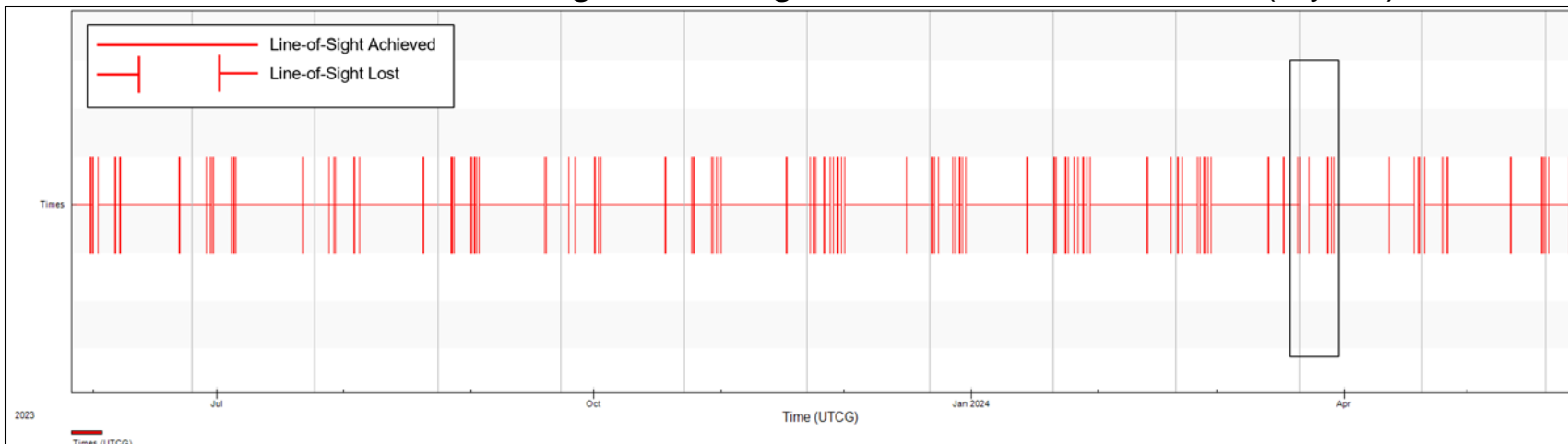
- Generated omni-directional coverage shows geometric communication cut-outs relative to fixed model



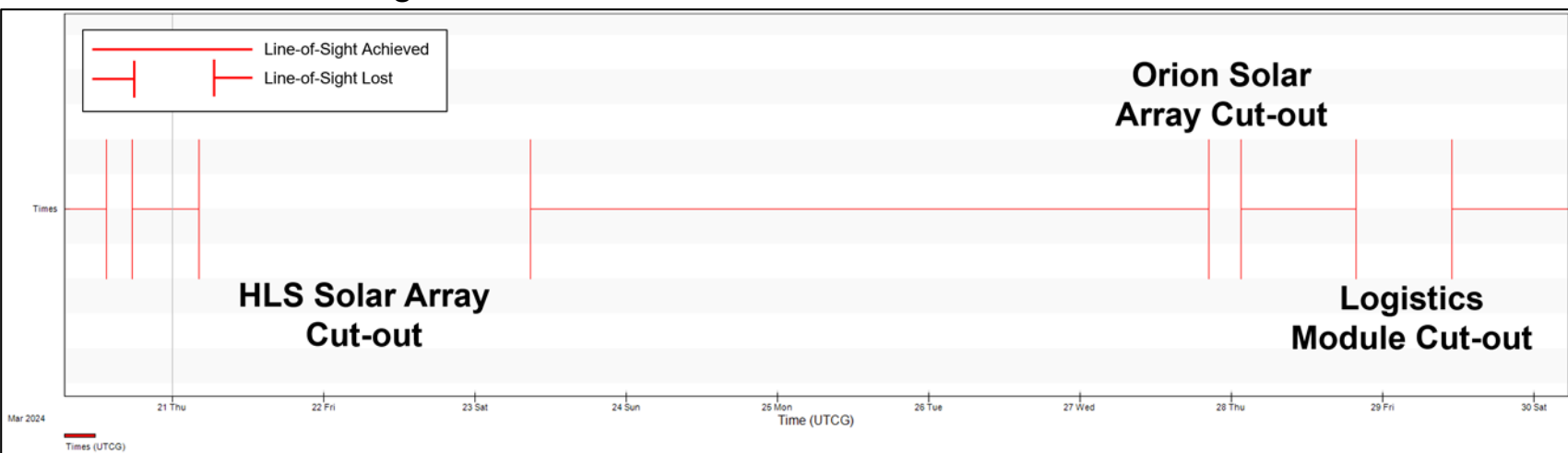
5. EXAMPLE RESULTS FOR ANALYTICAL TECHNIQUES

5.1 Earth-Pointing Line-of-Sight

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



Enlarged Portion of Boxed Area from 1-Year Results



	Annual Access	Maximum Cut-out Duration
Earth HGA Base Height	90.68%	2.17 days
Earth HGA Elevated Height	93.5%	2.12 days

- 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



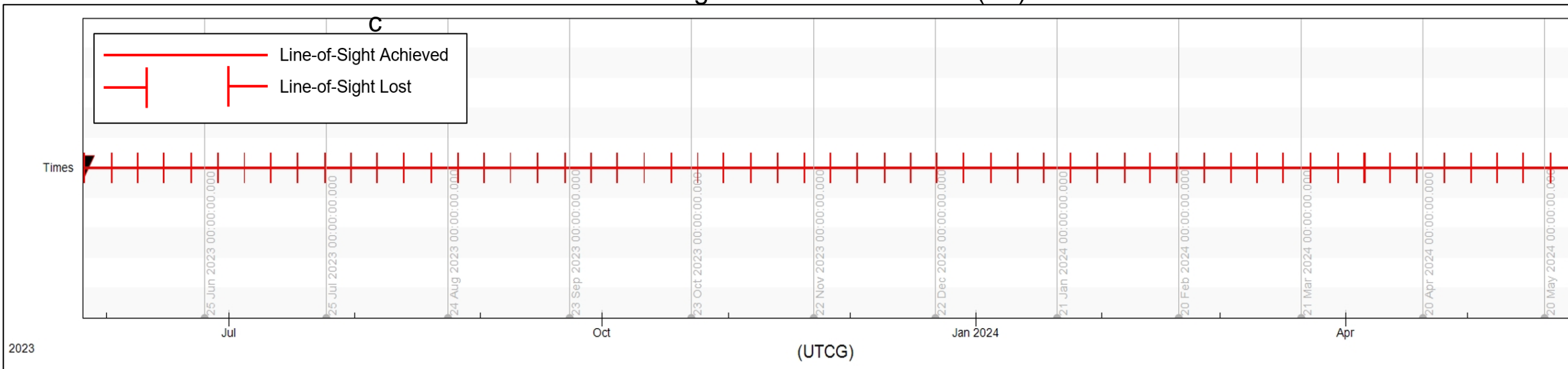
5. EXAMPLE RESULTS FOR ANALYTICAL TECHNIQUES

5.1 Lunar-Pointing Line-of-Sight

	Annual Access	Maximum Cut-out Duration
HALO Lunar HGA (Fwd)	71.39%	2.47 days
HALO Lunar HGA (Aft)	88.11%	4.32 days
Combined Lunar PPE and HALO Aft HGAs	97.10%	0.42 days

- 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 occultated when Gateway is over the northern hemisphere of the Moon

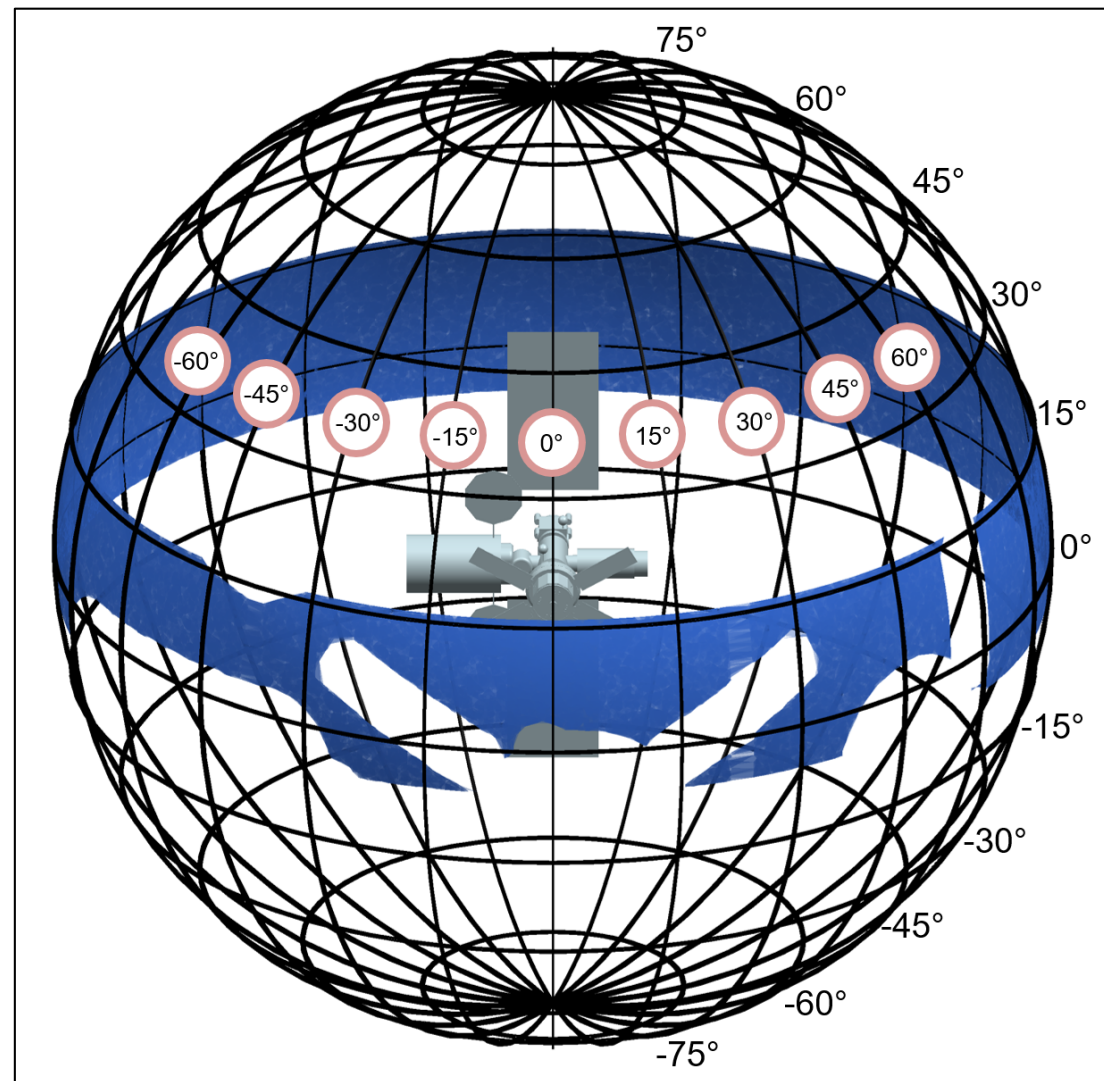
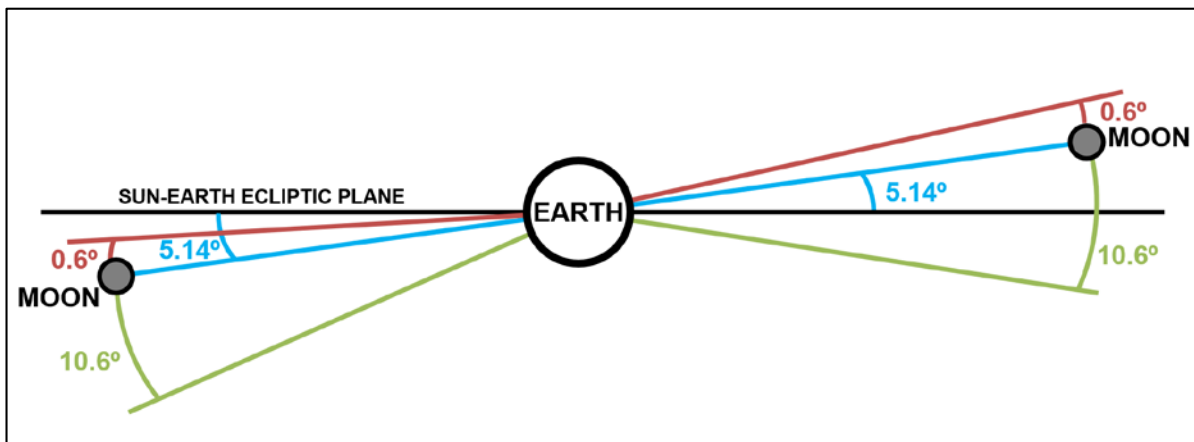
Combined Lunar Line-of-Sight for PPE and HALO (Aft) HGA Locations



5. EXAMPLE RESULTS FOR ANALYTICAL TECHNIQUES

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



6. POSSIBLE APPLICATIONS / 7. CONCLUSIONS



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

