Lunar Polesitter

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Presentation Agenda

- The Lunar and Mars Communications Challenges
- The Polesitter Advantages
- The Polesitter Concept
  - Mission and Operations Description
  - Relay Satellite
- Notional Schedule
- Opportunities for International Cooperation
- Summary
- Acknowledgements

The Lunar and Mars Communications Challenges

- Provide basic navigation and communication mission support for the initial US/NASA-developed launch vehicle and lunar lander capabilities for the human exploration of the Moon:
  - Launch vehicle architecture: Crew Exploration Vehicle (CEV). Not to include the Ares launch vehicles and Earth Departure Stage.
  - Lunar lander: Ascent vehicle, descent vehicle, basic habitation at or near the lunar south pole.
- Satisfy the following key requirements in support of the initial capabilities:
  - 10 Gb/day from the lunar surface.
  - 8 kbps relay-to-CEV; 28 kbps CEV-to-relay.
- Provide for easy augmentation of communications services at the Moon.
  - Higher bandwidth.
  - Extension of services beyond the initial south pole station to include human and robotic exploration 100 km to 200 km beyond the initial site and ultimate extension to complete coverage of the lunar far side in support of desired science community objectives.
- Provide for potential international cooperation in meeting the communication and navigation objectives.
- Provide for portability of the communications architecture to Mars.

The Polesitter Advantages

- **Continuous Coverage:** Relay satellite is in continuous view of lunar surface assets and the Earth, enabling continuous coverage from the Earth. Alternatives have dark periods.

- **Lower Resource Demand on Lunar Surface Assets:** No requirement for surface asset acquisition and tracking systems and mechanisms. Simpler, lower-cost, lower-mass, surface assets.

- **Lower Cost:** Polesitter relay concept requires only one satellite for continuous coverage of the lunar south pole, two for north and south pole coverage. Alternatives require up to six satellites for continuous coverage. Low launch mass of 235 kg to 255 kg may permit piggyback launch, launch on a smaller, lower-cost launch vehicle than the alternatives.

- **Easily Satisfies the Key Requirements in Support of the Initial Capabilities:**
  - 13 Gb/day capability from the lunar surface vs. 10 Gb/day requirement.
  - 8 kbps relay-to-CEV and 28 kbps CEV-to-relay capabilities, matching the requirements.

- **Greater Operational Simplicity:** Surface assets point continuously at a fixed point in space. Alternatives require surface assets to continuously acquire, track, and re-acquire relay satellites.

- **Lifetime Not Propellant Limited:** Polesitter requires no propellant. Alternatives require propellant.

- **More Attractive for International Participation**

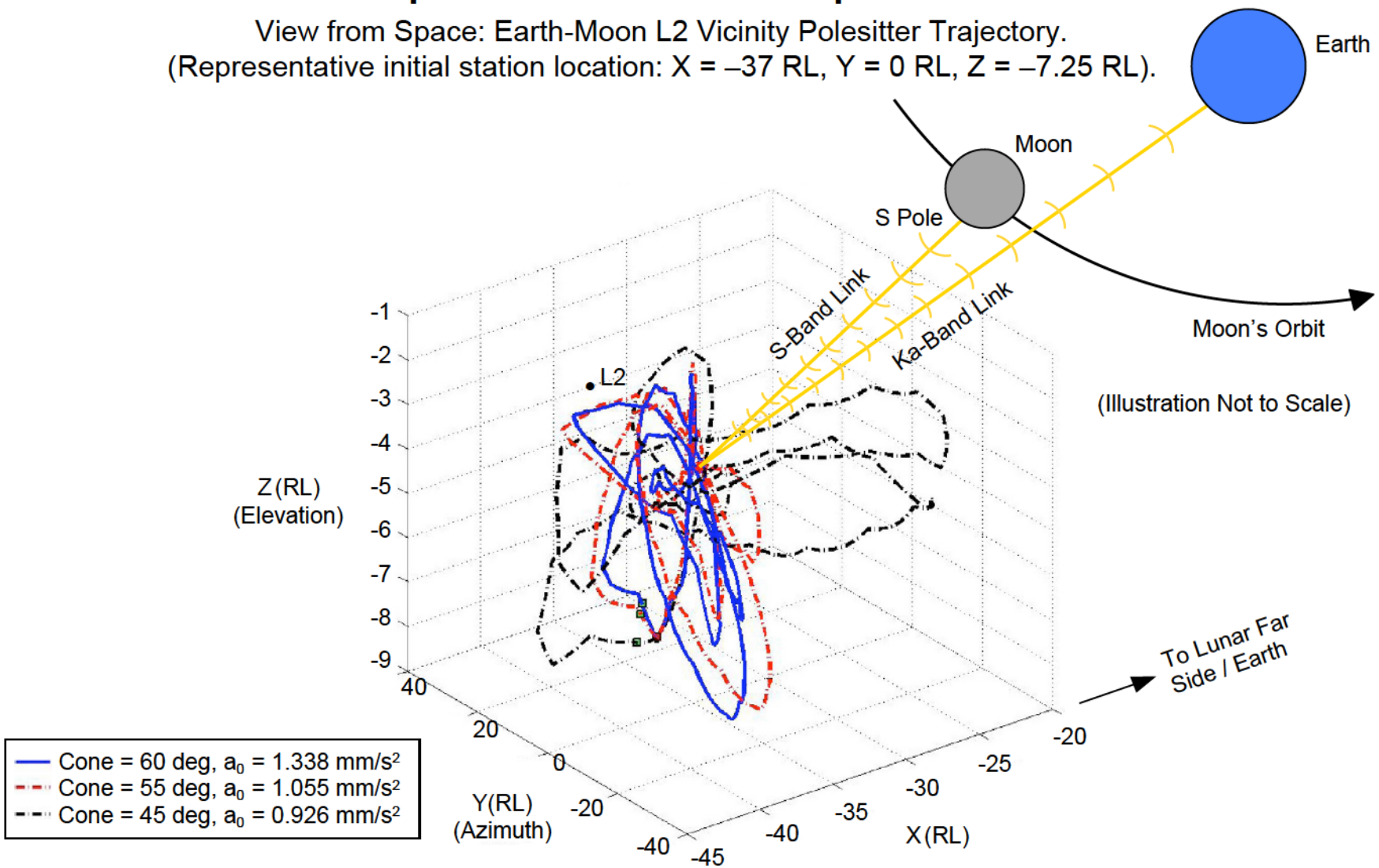
The Polesitter Concept - Mission and Operations Description

- **Launch:** Small-to-medium size expendable launch vehicle.
- **Earth-Moon Transfer:** Conventional ballistic.
- **Orbit Insertion at the Desired Lunar Operational Station Location:** Conventional chemical propulsion. Sail deploys after orbit insertion.
- **Operational Station Location and Maintenance**
  - Earth-Moon L2 vicinity: Far side of the Moon and slightly displaced southward from the Earth-Moon plane (Initial location: X = - 44 lunar radii (RL), Y = 0 RL, Z = - 7 RL). In continuous view of manned and robotic assets at or near the lunar south pole and the Earth for the relay-to-Earth link.
  - Location maintained by solar sail propulsion. Control of location requires no sailcraft maneuvering. Sailcraft maintained at a fixed cone angle (angle between the sailcraft-Sun line & sail plane normal) of 55 deg for the mission duration. Required characteristic acceleration (a0): 1.055 mm/s2 vs. sailcraft capability of 1.2 mm/s2. Active location control using sailcraft control vanes available to enable re-positioning of the satellite, if desired.
  - Second optional Polesitter near the lunar north pole for complete lunar far side coverage, redundancy for south pole Polesitter, continuous Earth-to-lunar-polar-orbiting CEV coverage.
- **On-Station Operations**
  - Communications links (S-band lunar-surface-to-relay; Ka-band relay-to-Earth) maintained by continuous gimbaled antenna tracking of the Moon and Earth, respectively. Link maintenance requires twice per lunar cycle 180 degree repositioning of a relay-bus-mounted “yoke” on which the antennas are mounted.

Lunar Polesitter

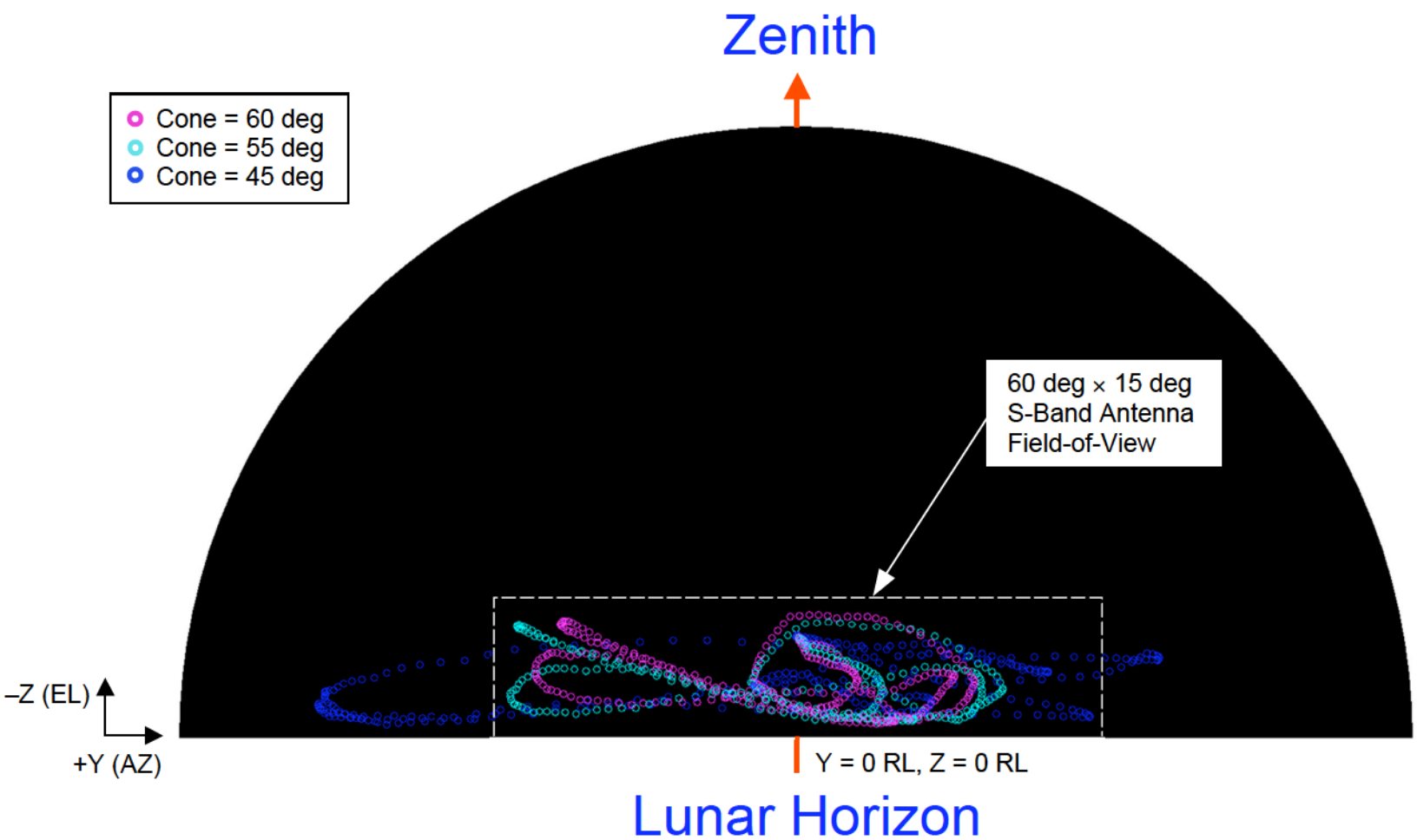
The Polesitter Concept - Mission and Operations Description (Cont'd)

View from Space: Earth-Moon L2 Vicinity Polesitter Trajectory.
(Representative initial station location: X = –37 RL, Y = 0 RL, Z = –7.25 RL).



The Polesitter Concept - Mission and Operations Description (Cont'd)

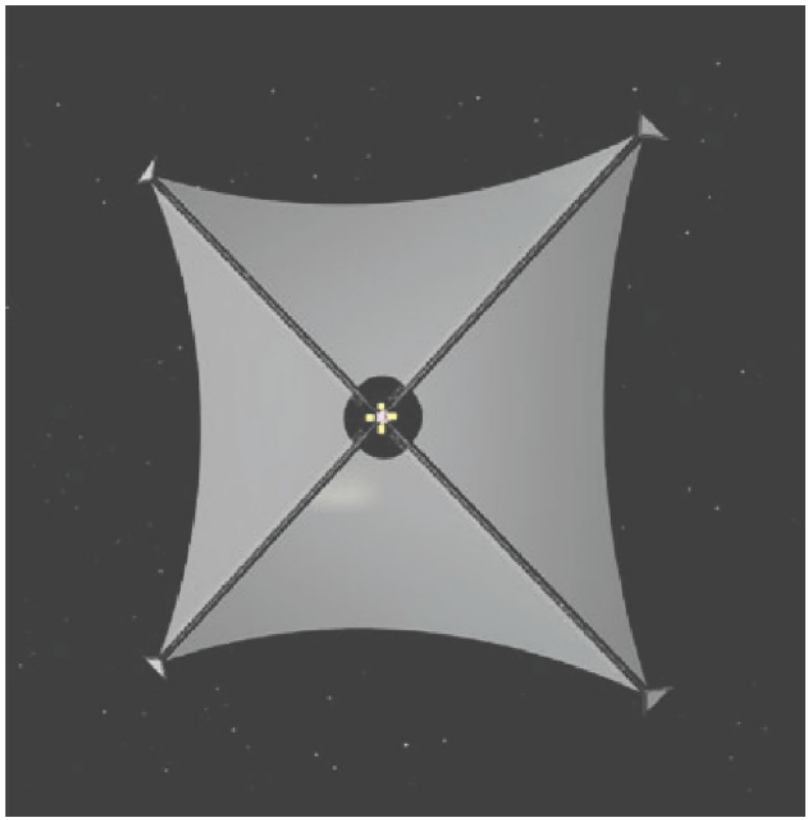
View from the Lunar South Pole: Earth-Moon L2 Vicinity Polesitter Trajectory.
(Representative initial station location: X = –37 RL, Y = 0 RL, Z = –7.25 RL).



The Polesitter Concept - Relay Satellite

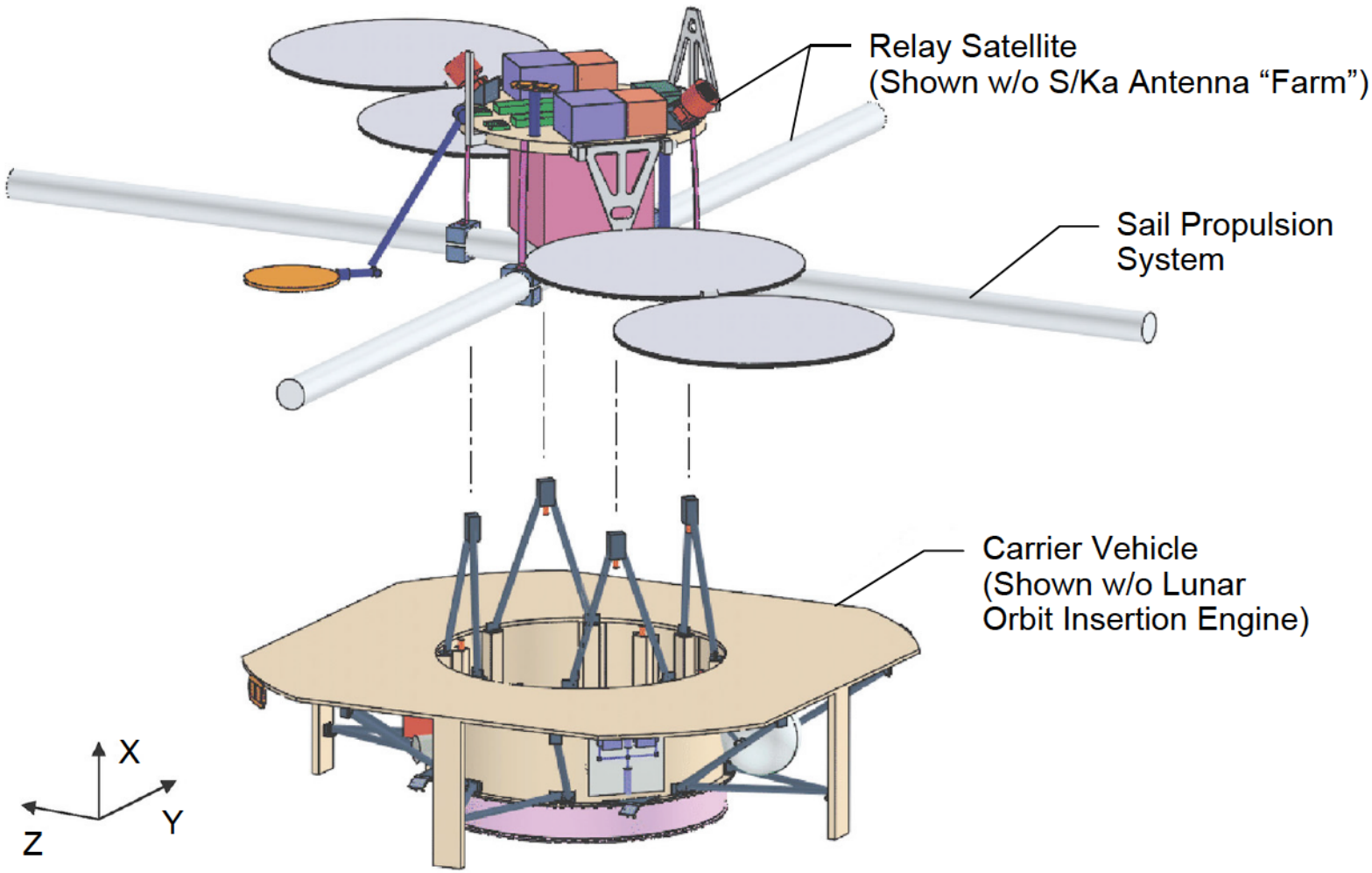
- **Configuration**
  - **Relay Satellite** (as communications engineers see it) **or Sailcraft** (as propulsion engineers see it) **= Relay Bus + Sail Propulsion System.**
    - On-station configuration.
    - Mass: 195 kg with 20% contingency.
    - Communications equipment contained in relay bus.
  - **Flight Vehicle = Relay Bus + Sail Propulsion System (SPS) + Carrier Vehicle.**
    - Launch configuration.
    - Mass: 235-255 kg with 20% contingency, including propellant for mid-course delta-V, orbit insertion.
    - Carrier vehicle accommodates launch loads, houses lunar orbit insertion engine and sail deployment H/W. Carrier jettisoned after orbit insertion / sail deployment to reduce mass, improve sailcraft propulsive performance, enable station keeping at the desired location with the smallest possible sail size. Carrier vehicle mass: 40-60 kg including propellant for mid-course delta-V, orbit insertion.

The Polesitter Concept - Relay Satellite (Cont'd)



- Relay Satellite showing deployed solar sail, relay bus at the center of the sail, attitude control vanes at the sail tips.

The Polesitter Concept - Relay Satellite (Cont'd)



The Polesitter Concept - Relay Satellite (Cont'd)

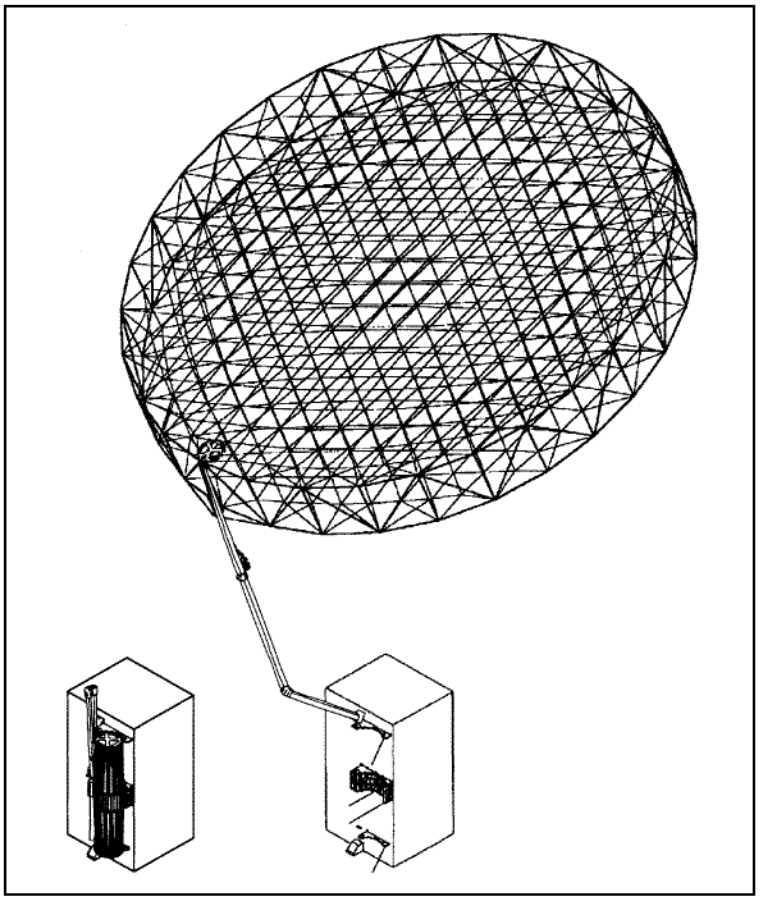
- **H/W and S/W Technology Readiness / Heritage**
  - **Relay Bus and Carrier Vehicle**
    - All elements TRL 9.
    - Conventional high-flight-heritage small-sat satellite elements closely following the designs developed for the JPL-led New Millennium Program (NMP) Space Technology (ST)-5 and GSFC-led ST-9 flight demonstration proposals and the NASA In-Space Propulsion Technology (ISPT) Program's FY 2003-2005 Solar Sail Ground Demonstrator Program.
    - High-flight-heritage Northrop Grumman (NG) S-band AstroMesh antenna.
  - **Sail Propulsion System**
    - TRL 5-6.
    - Inflatable sub-Tg space-rigidized boom technology developed by L'Garde, Inc., Tustin, CA in FY 2003-2005 under the ISPT Program's Sail Ground Demonstrator Program and proposed for the NMP ST-9 flight demonstration by the GSFC-led GSFC/JPL/L'Garde, Inc./Orbital Sciences ST-9 Team.
    - Total ISPT Program Solar Sail Ground Demonstrator Program investment in solar sail technology: ~ $37.5 M.
      - ~ $17.5 M for the inflatable boom technology specifically underpinning the Polesitter concept.
      - ~ $2.5 M for the required navigation tools: JPL-developed Solar Sail Spaceflight Simulation Software (S5) tool.
    - Risk reduction program recommended to retire outstanding risks.

The Polesitter Concept - Relay Satellite (Cont'd)

- **Relay Bus**
  - **Description**
    - Houses all required bus elements including the critical communications system elements.
    - Mates to the Sail Propulsion System to form the relay satellite.
    - Mass: 135 kg including 20% contingency and 64 kg for the communications system.
  - **Communications Subsystem**
    - Two antennas:
      - 3.4-m-diameter two-axis-gimbaled S-band NG AstroMesh deployable mesh antenna for the relay-to/from-lunar-surface and relay-to/from-CEV links. Antenna sizing based on lunar surface assets having notional 60 deg x 15 deg field of view shaped-beam antennas with presumed antenna area equivalent to that of a 0.37-m-dia antenna with 10 W of transmit power.
      - 0.2-m-diameter two-axis gimbaled Ka-band fixed dish antenna for the relay-to/from-Earth trunk link.
      - Antennas mounted on a relay-bus-mounted "yoke" which requires twice per lunar cycle 180 degree repositioning to maintain com links.
    - Design accommodates data from two lunar surface assets simultaneously.
    - S-band lunar-surface-to-relay satellite link operates at a nominal 150 kbps uplink data rate with selectable lower data rates.
    - S-band link design supports a data volume of 13 Gb per day from the lunar south pole to Earth adequate to meet NASA's notional requirement of 10 Gb per day from the lunar surface.
    - Ka-band trunk link operates at a nominal downlink data rate to Earth of 150 kbps in bent-pipe mode and 1 Mbps in store and forward mode.
    - Relay-to-CEV S-band link operates at 8 kbps and CEV-to-relay link at 28 kbps, assuming the CEV S-band omni antenna and link parameters documented in the Constellation Master Link Book.
    - 3dB minimum link margin, all links.

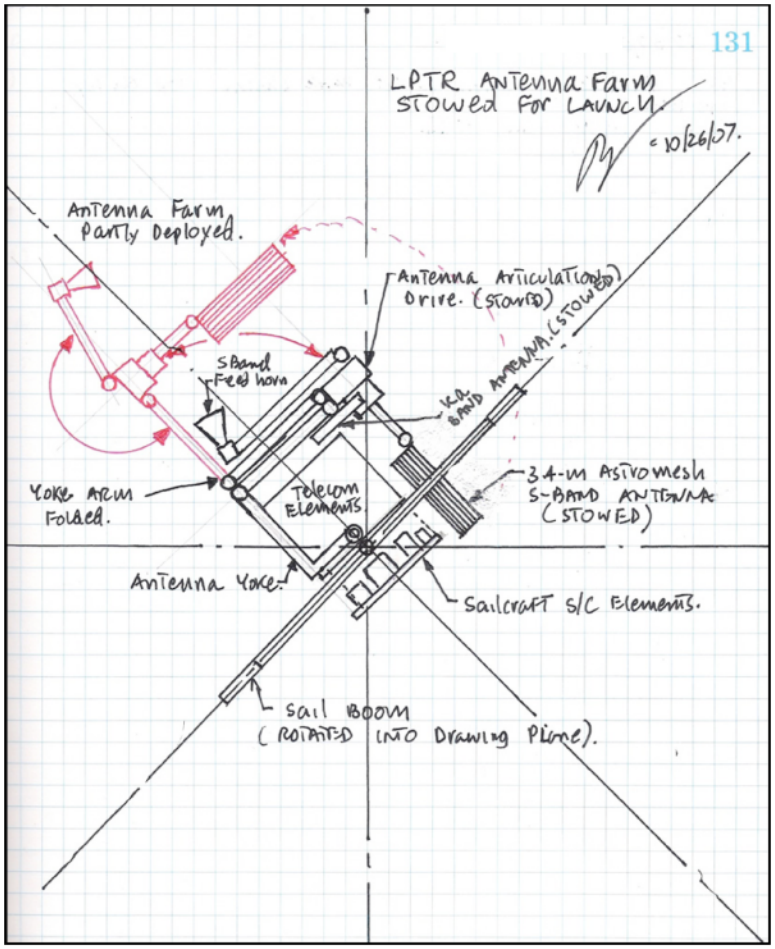
The Polesitter Concept - Relay Satellite (Cont'd)

S-Band NG AstroMesh Antenna

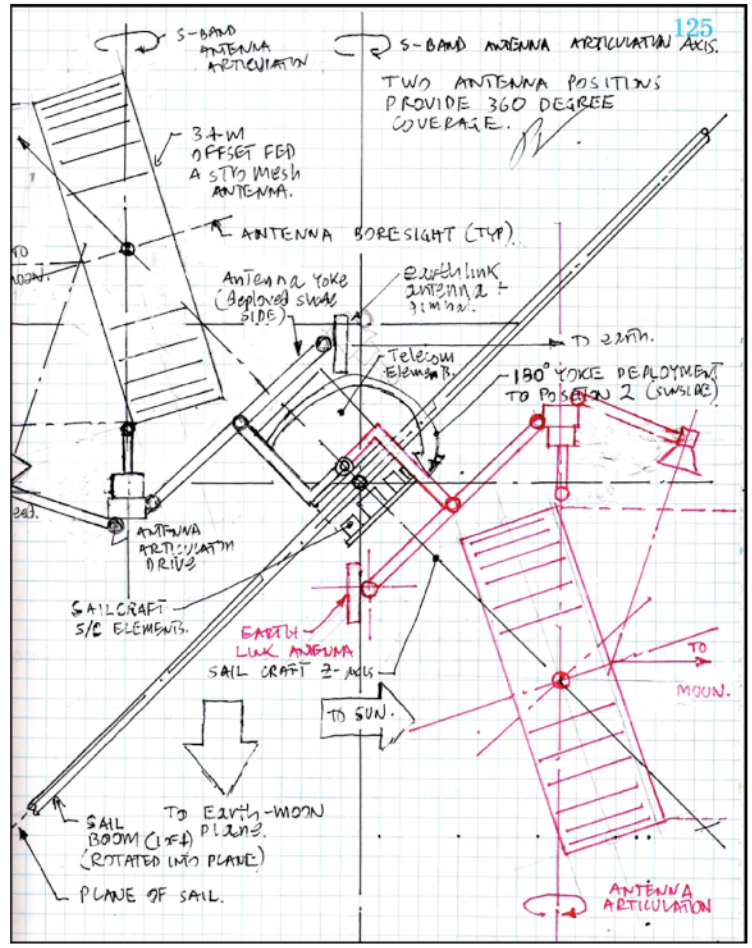


- Generic NG AstroMesh antenna showing stowed and deployed configurations.

The Polesitter Concept - Relay Satellite (Cont'd)



- Relay satellite antenna farm stowed. Near-L1 station location.



- Relay satellite antenna farm deployed. Near-L1 station location.

The Polesitter Concept - Relay Satellite (Cont'd)

- **Sail Propulsion System**
  - **Description**
    - Sail configuration: Square.
    - Sail membrane: 0.9-micron-thick Mylar.
    - Sail size: 165-m on-a-side.
      - Provides 1.2 mm/s2 max characteristic acceleration (a0) to the 195-kg relay satellite to enable maintenance of the desired near-L2 operational station location.
      - Size similar to that required for the first envisioned NASA Science Roadmap mission requiring solar sail propulsion: Solar Polar Imager.
    - Mass: 60 kg including 20% contingency.
    - Also required: Two features developed under the ISPT Sail Ground Demonstrator Program not proposed for the NMP ST-9 sail flight demonstration due to cost constraints:
      - Spreader system: Adds the necessary rigidity to the sail to permit its scaling up from the 35-m on-a-side design proposed for the ST-9 flight demonstration to the 165-m on-a-side size required by the Lunar Polesitter.
      - Control vanes: Permit autonomous, propellantless control of the relay satellite's attitude and position.

The Polesitter Concept - Relay Satellite (Cont'd)

Sail Propulsion System

- Deployed, ISPT-Program-developed, 20-m on-a-side solar sail at NASA Plum Brook, 2004.

Lunar Polesitter

Notional Schedule

Date (CY)	Activity/Decision
• Now-2008 End	• Concept refinement studies. – Mission, nav, com, SPS, & flight vehicle system design, coverage analysis, L/V, cost. Study portability to Mars.
• 2009	• Continue concept refinement studies. Explore partnering opportunities.
• 2010-2013	• Continue refinement studies. Develop partnerships. Define risk reduction program.
• 2013	• NASA decision to implement risk reduction program.
• 2013-2016	• Implement risk reduction program. – Sail Propulsion System: H/W & S/W risk reduction (spreader system / sail boom inflation system); sail deployment/performance prediction tool dev/val. – Navigation Tools: Trajectory design and analysis tool dev/val.
• 2016-2020	• NASA project start decision / project implementation.
• 2020	• Launch first relay satellite.
• 2025-2027	• Add additional, optional relay satellite. – Complete lunar far side coverage / higher bandwidth.
• 2030-2035?	• Port relay satellite to Mars (if viable).

Opportunities for International Cooperation

- NASA interest is high in international cooperation in the Human Exploration Initiative (HEI) with an "open architecture" plan to encourage participation
  - US/NASA to build the transportation infrastructure, the initial surface mobility capabilities, and the initial basic mission support communications and navigation capabilities.
  - Participation encouraged once initial capabilities are established.
  - Augmented and high bandwidth com & nav specifically identified in NASA plan for potential participation.
- World interest in solar sail technology is high with the area ripe for potential participation
  - Russia's recent partnership with the Planetary Society in attempting the first space deployment of a solar sail.
  - Japan's recent successful first space deployment of a solar sail.
  - Germany's longstanding support for solar sail technology development, particularly in booms and structures.
  - The UK's longstanding leadership role in solar sail mission and navigation studies.
  - Canada's recently expressed interest in a solar sail demonstration mission, with particular interest in Earth polesitter missions and communications applications.
- Areas for potential participation include:
  - L/V: Japan/Russia/France/European Space Agency.
  - Sail Propulsion System:
    - Sail membrane: Japan.
  - Relay Satellite:
    - Relay Bus components: Star trackers/reaction wheels: France/Germany.
    - Communications equipment/subsystem: Canada.
  - Mission Design/Navigation: UK.
  - Trade of downlink bandwidth from the lunar surface for contributions-in-kind: Japan/Russia/All.

Summary

- Preliminary JPL/industry studies show Lunar Polesitter Relay Satellite concept is:
  - Viable.
  - Meets NASA's needs for communications and navigation at the Moon.
  - Offers better coverage, lower resource demand on surface assets, lower cost, and greater operational simplicity than other alternatives.

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