Solar Sails and Artificial Lagrange Orbits for Remote Sensing, Telecommunications, and Space Weather Applications

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1. Introduction

- Solar sails propel spacecraft continuously and without propellant or power using the momentum of sunlight. They enable new orbits that are otherwise impossible.
- Solar sails can change the location of Lagrange orbits (LOs), creating Artificial Lagrange Orbits (ALOs).
- ALOs have a many applications to remote sensing, space weather monitoring, and telecommunications.
- Solar sail technology has matured greatly in the past few years and is ready for flight test.

2. Solar Sails

- Light has a small amount of momentum that transfers to objects that absorb or reflect it. Reflective objects are propelled by both the incident and reflected light.
- Solar sails are large and lightweight mirrors that maximize the otherwise small effect of solar pressure.
- The sail angle determines the angle of the total solar pressure force. Controlling this angle allows a sail to navigate through space or maintain new orbits. Solar sail travel can be competitive with other technologies despite solar pressure being only 9 µPascals at Earth.
- Many new orbits are enabled by using the continuous thrust of the sail to counteract gravity or continuously modify an orbit over time.

3. Artificial Lagrange Orbits

- Natural Lagrange points are equilibrium points in the rotating frame of two large co-orbiting bodies that a small object can orbit with minimal propulsion.
- Solar sails add a controllable force from solar pressure to the problem. The solutions become 3-D surfaces attached to the natural Lagrange points that the sail can sit on without moving relative to the two large bodies.
- Figure 2 shows a slice through these surfaces for 85% reflective sails with a range of performances (mass / area ratio) represented by the colored contours. Dashed lines show corresponding sail angle in 10° increments.

4. Technology Development

- NOAA GOES I-M satellites use small solar sails and trim tabs for momentum management.
- Government and private research & development programs have greatly advanced solar sail technology in the past few years. It is ready for flight test.
- Many ground and space deployments of solar sail prototypes have been performed since the 1980's.
- The Cosmos 1 solar sail spacecraft, a joint Russian/US, private/non-profit venture, was built but lost at launch.

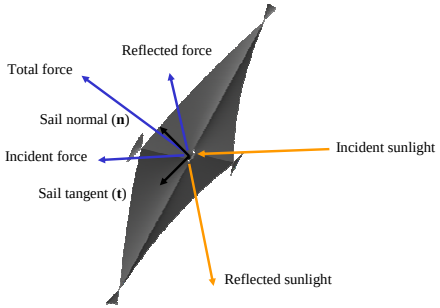

Figure 1. Solar sail forces (NOAA)

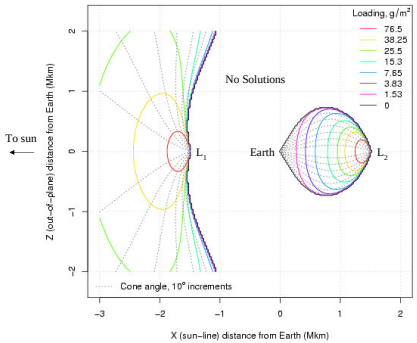

Figure 2. Artificial Lagrange orbit contours (NOAA)

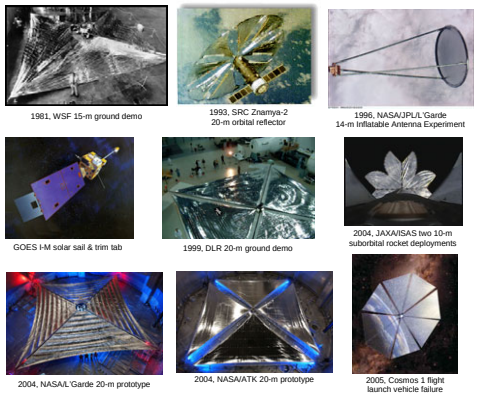

Figure 3. Solar sail technology demonstrations

5. Remote Sensing

- Excellent temporal and spatial coverage: hemispheric, polar, real-time, year-round, and global from two L1 & L2 satellites.
- Very stable thermal and dynamic environment.
- Constant illuminated/shadowed portions of view.
- Near constant solar scattering angle.
- Periodic lunar visibility for calibration.
- Resolution reasonable (multiple km) for many data products despite large distance (100,000's to a few million kilometers).
  - 8 km resolution from DSCOVR EPIC.
- Data products studied by NOAA:
  - Earth radiation budget, total & spectral solar irradiance, aerosols, clouds, sea surface temperature, winds, carbon gases, ozone, aurora, and ionospheric scintillation.
- Question to answer: If spatial resolution is coarser than current requirements, are the advantages more important? That is: data latency, refresh rate, solar scattering angle, polar coverage, and fewer elements in the space & ground architecture.

Figure 4. DSCOVR EPIC simulated view from L1 using MODIS data (NASA Langley, 2002)

6. Telecommunications

- 20+ Mbps with near-term communication systems.
- **Satellite crosslink** - 2 satellites in opposing L1 & L2 orbits view all satellites in Earth orbit. Polar satellites can crosslink data in real-time to a small number of ground stations.
- **South pole communications** - South pole station uses old inclined orbit GEO satellites for several hours per day coverage. One ALO satellite >23.5° south of L1 or L2 at the summer solstice provides year-round, 24-hour coverage.
- **Space exploration** – Complete lunar communications coverage possible from ALOs. ALOs also work well at Mars and other planets. All Earth-based applications may apply.

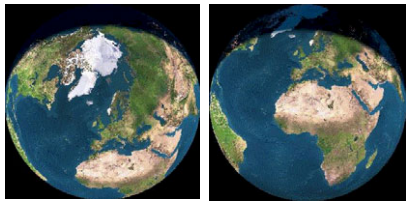

Figure 5. Earth views from ALO 66°30' North of L1, summer & winter (SMRC, 2003)

7. Space weather

- **Solar Wind Monitor** – NASA's Advanced Composition Explorer (ACE) monitors the solar wind from orbit around L1 for disturbances leading to geomagnetic storms 30 minutes to 1 hour later when they reach Earth's magnetic field. Current solar sail technology can position a spacecraft 2X closer to the sun than L1, as shown in Figure 2, doubling the warning time.
- **Solar observation** – Natural and artificial Lagrange orbit spacecraft are stable and in full sunlight - well suited for instruments coronagraphs, imagers, and irradiance sensors.
- **NPOESS SESS** – The NPOESS Government Advisory Team (GAT) in 2003 identified several SESS requirements that would be exceeded by, met, or benefit from UV imagers and RF beacons on ALOs north or south of L1 or L2.
  - Excellent: Auroral boundary, energy deposition, and imagery - real-time, polar, hemispheric measurement.
  - Good: Ionospheric scintillation.
  - Marginal/partial/ancillary: Electric field, electron density profile, neutral density profile, neutral winds.

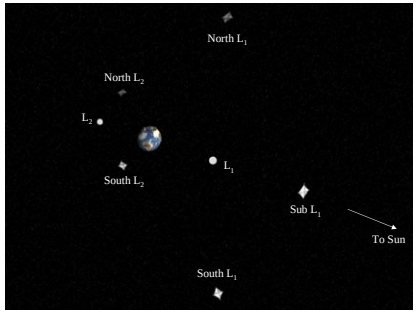

Figure 6. Illustration of ALOs (NOAA)