Low-Energy Transfers for Expanding the Orbital Regime of CubeSat Missions
This presentation discusses a method for small satellite missions to potentially reach regions of space that are unreachable by traditional methods.

By taking advantage of “Low Energy Transfers” between the Earth’s and Moon’s Lagrange points, CubeSat missions are able to extend their reach into space.
The majority of CubeSats are designed for Low-Earth orbit missions.

Mass and volume constraints are the limiting factor because of fuel considerations.

Previously, propulsion systems either were not allowed or could not support much more than attitude control at the sizes required by CubeSats.
Motivation

- As the CubeSat community grows, the level of sophistication of CubeSat missions continues to increase.
- By expanding the orbital regime of potential CubeSat missions, we can further the impact that these missions have on the scientific community.
Traditional Orbital Mechanics

- Two-body problem
  - Simple, practical, fairly accurate for some orbits
  - Limited to a small class of orbits and trajectories
  - Generally used to determine orbits about a massive central body (i.e.- satellite around Earth)
Hohmann Transfer

- Traditional orbital transfers
- Offers the most energy efficient* transfer between two coplanar orbits
  * Under certain assumptions!
Lagrange Points

- Gravitational “balance” points
- In a rotating system, there are 5 Lagrange points
  - $L_1$ – $L_3$ are unstable
  - $L_4$ and $L_5$ are stable
Low Energy Transfers

- Also known as “Weak-Stability Boundary” trajectories
- Takes advantage of the complex dynamics around planetary Lagrange points
- They form gravitational “pathways” that link the Lagrange points between planets and moons
The collection of low energy trajectories that link Lagrange points throughout the Solar System
Japanese spacecraft targeted at the Moon
An error at orbit insertion caused a delta-V deficiency
Edward Delbruno (Princeton) designed a low-energy transfer trajectory to guide the spacecraft into lunar orbit with nearly ZERO delta-V
Genesis Mission

- Scientific mission sent to the Earth-Sun L₁ point to collect samples
- Employed a low-energy transfer to return to Earth at the end of mission for very little fuel
Genesis Trajectory

- **Solar Wind Collection in Halo Orbit About L1 (29.3 mos.)**
- **Return and Recovery (5.3 mos.)**
- **Outward Leg (2.7 mos.)**
- **Moon**
- **Lunar Orbit**
- **Positioning for Daylight Reentry**

**Total Flight Time (37.3 mos.)**
The Lunar-L₁ Lagrange point serves as a “gateway” to Lunar and interplanetary space.

For instance, Lunar-L₁ is separated by Earth-L₁ by only 50 m/s delta-V!
  - i.e.- the gravitational potential difference of the two points can be bridged with 50 m/s delta-V
In other words, if a spacecraft is able to reach Lunar-L$_1$, it will be able to reach Earth-L$_1$, provided that it can produce 50 m/s thrust!
Advantages of Low-energy transfer
- Low fuel requirements
- Access to interplanetary space
- More flexible mission profile (can stall at Lagrange points if needed)

Disadvantages
- Longer time of flight (if time is a constraint)
Since CubeSats generally “piggy-back” on rocket launches with primary payloads, we can use common parking orbits as a baseline.

From a Geostationary Transfer Orbit (GTO), about 5 km/s delta-V is needed to reach the Lunar-L\(_1\) Gateway.
Can a CubeSat propulsion system generate enough delta-V to get to $L_1$?

- Electric propulsion (uPPT):
  - $\sim 1000$ s Specific Impulse

- Micro-ion engines:
  - $\sim 3000$ s Specific Impulse
Electric propulsion (uPPT):
- ~1000 s Specific Impulse
  - Delta-V = ~2.2 km/s

Micro-ion engines:
- ~3000 s Specific Impulse
  - Delta-V = ~5.4 km/s
If you equip your CubeSat with a propulsion system, you may be able to reach interplanetary space by passing through the Lunar-L$_1$ Gateway.
Conclusion

- CubeSat missions are no longer restricted to Low-Earth orbit
- Keep the Low-energy transfers in mind when designing new CubeSat missions
- Go out and do some awesome science!
Questions?

Thank you!