End of Life Disposal for Three Libration Point Missions Through Manipulation of the Jacobi Constant and Zero Velocity Curves

Jeremy Petersen (a.i. solutions)
Jonathan Brown (a.i. solutions)

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Agenda

- Introduction/Mission Overview (ACE, SOHO, WIND)
- End of Life Disposal Requirements
- Circular Restricted Three Body Problem Analysis
- Full Ephemeris Analysis
- Operational Challenges
- Conclusion
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Introduction

- **Flight Dynamics Facility (FDF) located at NASA Goddard Space Flight Center (GSFC) provides the flight dynamics expertise for three Sun-Earth/Moon L1 missions.**
  - Advanced Composition Explorer (ACE)
    - Launched August 1997
  - Solar and Heliospheric Observatory (SOHO)
    - Launched December 1995
  - Global Geospace Science WIND satellite
    - Launched November 1994
    - Entered Lagrange point orbit in 2004
Mission Overview

- **SOHO – Large Amplitude Halo**
  - X/Y/Z Amplitude ≈ 206,000/667,000/120,000 km

- **WIND – Large Amplitude Lissajous**
  - Similar size to SOHO

- **ACE – Small Amplitude Lissajous**
  - X/Y/Z Amplitude ≈ 80,000/260,000,158,000 km
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End of Life Requirements

• NASA has established requirements for end of mission planning which include standards for limited debris in the orbit regimes that are most densely-populated with active missions. [NPR 8715.6A]
  – Spacecraft must be removed from these protected regions within 25 years after the mission is completed; or,
  – If the mission lasts longer than five years, the spacecraft must be removed 30 years after launch.

• For LEO missions, the requirement is most frequently accomplished by lowering the orbit, either actively with thrusters or passively due to atmospheric drag, and re-entering the atmosphere.

• For medium or geosynchronous Earth orbits, several altitude bands have been defined for graveyard orbits.

• Interplanetary missions, including heliocentric trajectories, have a distinct set of requirements with the primary goal of preventing inadvertent biological contamination. [NPR 8020.12 D]

• Deep space missions that do not target celestial objects (such as libration point orbiters) do not have these restrictions imposed on them unless an Earth return is planned.

• Given the age of these missions, it is prudent that a proper post-mission disposal strategy has been developed.
Previous Libration Missions

• **11 missions sent to Sun-Earth/Moon L1/L2**
  
  – Five active
    • ACE/WIND/SOHO/DSCOVR – Active at L1
    • GAIA – Active at L2
  
  – Six decommissioned
    • ISEE-3 – Sent to make first-ever flyby of a comet
    • Genesis – Solar wind sample return mission
    • Chang’e 2 – Visited an asteroid
    • WMAP, Herschel, and Planck – Placed into heliocentric orbits outside Earth’s orbit

• **The focus for this investigation is heliocentric orbit disposal through closing the L1 gateway with a large ΔV.**
  
  – Done to reduce complexity and risks

9/4/2015
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Circular Restricted Three Body Problem

Operational Orbit and Associated Zero Velocity Curves

Closed L1 Gateway Zero Velocity Curves
Departure Arcs / Departure Phase

Ensure Mission Success
Minimum ΔV Solution

Minimum ΔV costs 8 m/s with a corresponding time of flight of 370 days.
SOHO – Required $\Delta V$

- Minimum $dV$ (m/s) vs. Departure Phase (deg)
- Time to Minimum $dV$ (days) vs. Departure Phase (deg)
- RLP X vs. RLP Y
Minimum ΔV solution occurs at maximum RLP velocity
WIND – Required ΔV

Departure Phase (deg) vs. Minimum dV (m/s)

Departure Phase (deg) vs. Time to Minimum dV (days)

RLP X vs. RLP Y
ACE – Required \( \Delta V \)

![Graph showing minimum \( \Delta V \) and time to minimum \( \Delta V \) as a function of departure phase.](image)

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Ensure Mission Success
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Full Ephemeris Model
Monte Carlo Results - SOHO

Increase in close approach distance as ΔV increases

Significant decrease in percentage around 15 m/s
Monte Carlo Results - WIND

- Increase in close approach distance as $\Delta V$ increases

Significant decrease in percentage around 13 m/s
Monte Carlo Results - ACE

Increase in close approach distance as $\Delta V$ increases

Significant decrease in percentage around 15 m/s
Monte Carlo Results – SRP Effects

Little correlation between close approach distance and Cr coefficient

Unexplained grouping behavior
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Operational Challenges

• **SOHO**
  – Long maneuver duration due to 5% duty cycle limitation.
  – Duration could exceed a single view period with the DSN.
  – Attitude would need to be changed from Sun pointing to Earth pointing.

• **WIND**
  – History of performing large maneuvers, would offer the fewest operational challenges.

• **ACE**
  – Would require updated attitude control strategy to maintain Earth pointing cruise portion.
  – Largest consumer of fuel during operations.
  – Lowest amount of fuel remaining.
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Conclusion

• Based on analysis performed in the Circular Restricted Three Body Problem, reasonable ΔV values are achievable for closing the L1 gateway.
  – SOHO: 6-12 m/s
  – WIND: 6-10 m/s
  – ACE: 1-2 m/s

• Monte Carlo analysis shows a dramatic drop in percentage of simulations returning to the Earth/Moon system at ΔV values in line with the CR3BP model.
  – SOHO: 15 m/s
  – WIND: 13 m/s
  – ACE: 5 m/s

• Little correlation between the SRP force and the close approach distance.
  – Further investigation is warranted

• Discussion with the each mission needs to occur to adapt strategy to real world limitations.