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Assuring Space Mission Success

Space Debris Remediation & On-Orbit Servicing: Concepts, Considerations, Moving Forward

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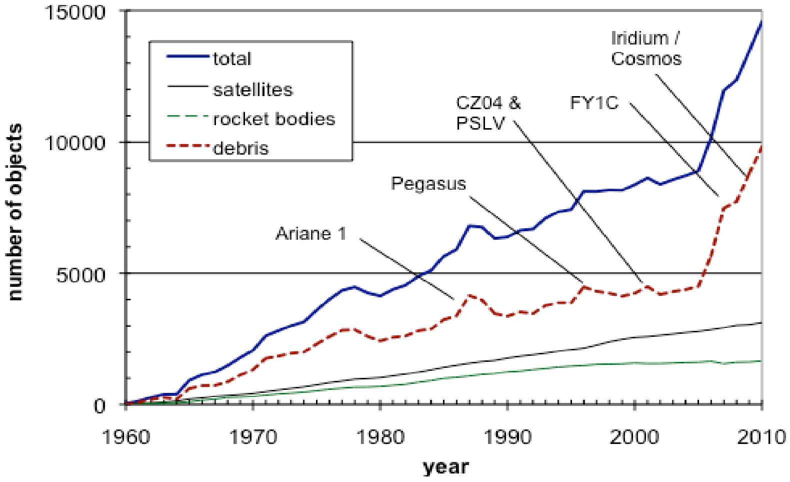
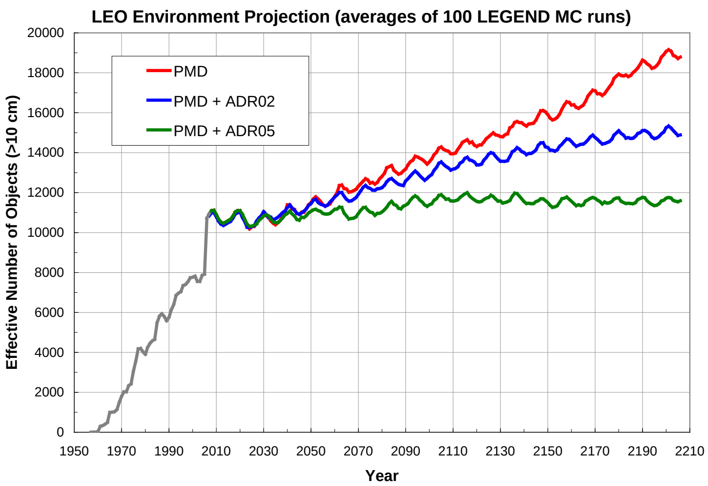
Presented at *Interdisciplinary Congress on Space Debris Remediation, McGill University*

November 11, 2011

Background





- **Concern about future near-Earth space debris environment increasing**
  - *"Kessler Effect"*
  - *Debris mitigation increasingly important (disposal at end of mission, passivation, etc.)*
  - *NASA predicts that Post-Mission Disposal (PMD) plus removal of ~5 large objects/year will stabilize LEO population*
- **Need to enforce PMD requirements, move forward with debris removal**

**J.-C. Liou and N.L. Johnson, "Active Debris Removal - The Next Step in LEO Debris Mitigation," 26th IADC Meeting, 14-17 April 2008, Moscow, Russia.*

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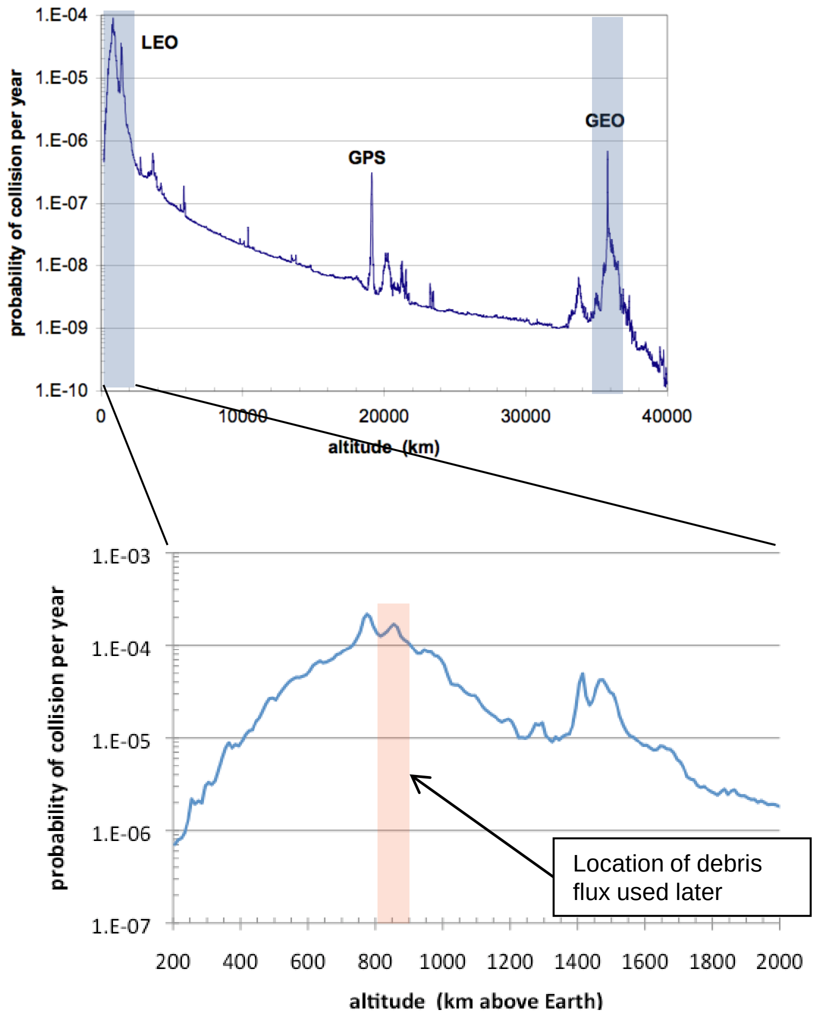
Two Regimes Considered: LEO (& GEO)



- **Low Earth Orbit (LEO) protected region (less than 2000 km altitude)**
  - *Highest population of small, untracked objects*
  - *Highest energy at collision; greatest potential for creating lots of debris*
  - *~500 operating satellites; ~12,000 tracked debris objects (>10 cm); ~500,000 untracked debris >1 cm*
  - *Satellite design lifetime ~5-10 years*
  - *Satellite cost (including launch)~$130M-$330M for commercial*
- **Region of greatest concern for uncontrolled growth of debris**

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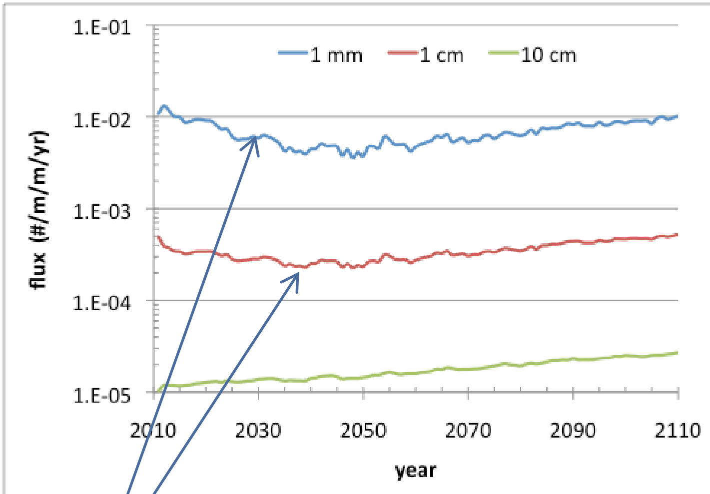
Two Regimes Considered: (LEO &) GEO

- **Geosynchronous Equatorial Orbit (GEO) protected region (35,786 ± 200 km)**
  - *Over 440 operating satellites*
  - *1000 tracked debris objects (>1 meter) and ? untracked debris objects pass through protected region*
  - *Collisions less energetic than at LEO*
  - *Satellite lifetime ~10-15 years*
  - *Large, tracked, maneuverable satellites operating in assigned "boxes"*
  - *Satellite cost (including launch)~$200-$400Million*
- **Operating satellites can avoid other operating satellites and tracked objects given accurate and timely notifications**
- **Operating satellites removed from service to comply with post-mission disposal requirements (may be a market for towing service)**

Debris Removal Considerations

Small Untracked Debris (<10 cm diameter) in LEO



Flux for 850 km altitude

- ~1E-2 1 mm particles passing through 1 m^2 area/year → Need 100-200 m^2 plate to intercept one 1-mm particle/year
- ~5E-4 1 cm particles passing through 1 m^2 area/year → Need 2500-5000 m^2 plate to intercept one 1-cm particle/year

- **Concepts include thin film or other method to remove momentum of small debris , lowering orbit**
  - *Impact frequency requires very large device (plate, balloon) for short term effect; large device would be threat to other objects, would require active control to maintain orbit for extended period*
  - *Other concepts include ground-based, space-based laser*
- **Effectiveness difficult to measure**
- **There is a cleansing mechanism for lower altitudes—atmospheric drag**

Removal of small, untracked objects may not be practical or cost effective

Better to remove possible sources of small debris via end of mission disposal & removal of large debris objects

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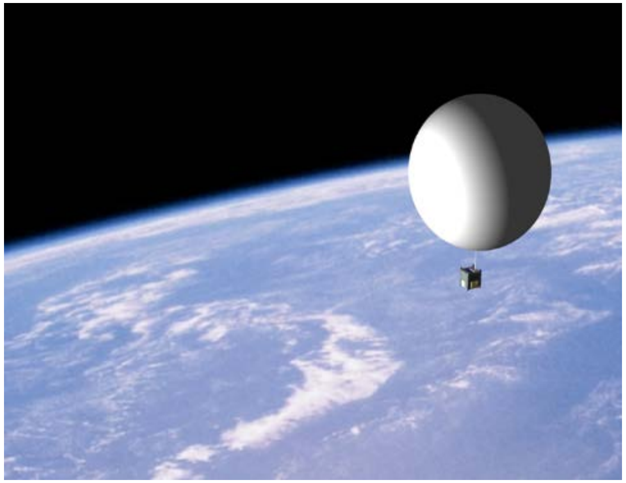
Debris Removal Considerations

Large Objects in LEO & GEO



Aerospace Corporation's Aerocube with deployed balloon

- **Only large (>10 cm in LEO, >1 m in GEO) objects are tracked**
  - *Satellites susceptible to serious damage by objects > ~1 cm in LEO, >~10 cm in GEO*
- **Large <u>debris</u> objects can't avoid collisions with other debris objects**
  - *Source of lots of tracked and untracked debris if impacted*
- **Challenges for removing large objects**
  - *Must rendezvous with object*
  - *Controlling target object (tumbling, unknown mass properties)*
  - *May be no convenient place to grab or attach a deorbit device*
  - *Removal attempt could create debris*
- **Concepts include**
  - *Momentum exchange or electrodynamic (LEO only) tether*
  - *Attach deboost motor*
  - *Inflate balloon/add device to increase drag*
  - *Reusable Tug that grapples and moves*
  - *Retrieval (return to earth, recycle in space)*

Debris Removal & Servicing Requirements

- “Cost effective” technique
- Proper legal, policy framework to protect both parties, deal with “alternative use” concerns
- Available, willing target for removal or customer for servicing
- Someone to pay
- Accurate tracking & necessary assistance during operations
- Capability to locate, approach, connect deorbit/servicing device, control orientation and move to desired destination

“Cost Effective” for Debris Removal?

- **Over the next 20-30 years, removal has minimal apparent benefit to operating satellites**
  - *Principal effect of debris is degradation of satellite lifetime due to small debris impacts on solar panels; Effects minimized by solar panel design*
  - *Few collisions involving operating satellites and large debris as collision avoidance services mature*
  - *Projections show no major cost increase for satellite operations*
- **Primary benefit is long term**
  - *Reduces possibility of uncontrolled debris growth and future limitations on space operations*
  - *Must be performed in conjunction with adherence to debris mitigation guidelines for maximum long term benefit*
  - *Is removal service less expensive than adding removal capability into new satellites?*

Conclusion:

- **Incentive must come from long view**
- **Need funding to cover development and testing of removal techniques**
- **Need source of long term funding for removal service**

“Cost Effective” for Spacecraft Servicing?

- **Servicing offers mission life extension**
  - *Fuel replenishment*
  - *Disposal services at end of life*
  - *Insurance that operator can meet disposal requirement*
- **Life extension directly affects income for commercial systems and extends capabilities of government satellites**
- **May be of particular interest for GEO regime due to minimal delta-V requirements to reach multiple satellites**
- **Servicing may be easier than removal**
  - *Generally dealing with stable spacecraft designed for servicing*
  - *Might not require moving satellites*
  - *Removal capability could be added as available*

Conclusion:

- **May be business case for satellite servicing, particularly for GEO satellites**
- **Add debris removal as service as techniques mature**

Moving Forward with Debris Removal

Possible Approach

- Develop legal framework and details to enable removal of each object (e.g., liability once object is touched by another entity, etc.)
- Develop international agreements that address concerns about “alternative uses” of servicing and removal resources
- Create **Debris Removal X-Prize** with reward for successful removal of identified object
- Identify and reach necessary agreements with owners for small number (1 to 3?) of debris objects (e.g., stage, small spacecraft, large spacecraft) to serve as targets for removal
- Develop “standard” fixtures and approaches to be required on new spacecraft and stages to facilitate servicing and removal
- Set and publicize goal for yearly removal beginning in ~2025 (incentive for near term private investment)
- Create clean-up fund to pay for removal service in long term (cover removal of existing debris plus spacecraft that fail in orbit)

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