Active Space Debris Removal an Inevitability

Major Nathan Arleigh Burgess
Communications & Electronics Engineering Officer
Royal Canadian Air Force /
Royal Military College of Canada
Manfred Lachs International Conference on Global Space Governance
May 30, 2014
Montreal ,Canada

TRUTH • DUTY • VALOUR
VÉRITÉ • DEVOIR • VAILLANCE

Outline

- Purpose
- Space debris definition, sources, sizes, velocities, and impact on spacecraft
- LEO has reached a "tipping point" requiring ADR
- Potential ADR Techniques
- Conclusion

TRUTH • DUTY • VALOUR
VÉRITÉ • DEVOIR • VAILLANCE

Purpose

- To demonstrate that the space debris situation in LEO has reached a “tipping point”, thus requiring active debris removal (ADR).
- Provide a non-esoteric overview of some potential ADR techniques

Space Debris Definition

- Space debris is defined as defunct manmade objects in space.
- Includes defunct spacecraft, launch vehicle stages, mission debris, and fragmentation debris [1]

Space Debris Sizes and Velocities

- Space debris comes in varying sizes ranging from less than 1cm to full size defunct spacecraft
- Tremendous impact speeds - up to 15km/s in LEO [2]

Space Debris Impact

- “debris as small as 10 cm in diameter carries the kinetic energy of a 35,000-kg truck travelling at up to 190 km per hour. While objects have lower velocities in Geostationary Earth Orbit (GEO), debris at this altitude is still moving as fast as a bullet—about 1,800 km per hour. No satellite can be reliably protected against this kind of destructive force” [3]

TRUTH • DUTY • VALOUR

VÉRITÉ • DEVOIR • VAILLANCE

Space Debris Persistence

- Space debris can persist in orbit for a few days or for an indefinite period, depending on altitude

VÉRITÉ • DEVOIR • VAILLANCE

Kessler Syndrome

- Space debris collides with other space debris or objects (i.e. functional satellites), creating more space debris, thus increasing the likelihood of further collisions.

Tipping Point

- Debris persistence combined with the Kessler Syndrome has resulted in a situation where LEO has become dangerously polluted.
- Recent studies by NASA and ESA have indicated that the space debris population in LEO will continue to increase even if no further debris is added [4]
- The long term viability of LEO is therefore threatened

Problem LEO Regions

- LEO regions with the highest space debris mass and collision probability:
  - 600km
  - 800km
  - 1000km [5]

- Large objects in these regions represent logical targets for active debris removal (ADR) [6]

TRUTH • DUTY • VALOUR

VÉRITÉ • DEVOIR • VAILLANCE

Active Debris Removal

- NASA simulations estimate that, starting in 2020 [7]
  - The removal of 5 large objects per year would maintain debris levels at, or slightly above, current levels for 200 years
  - given uncertainty and the possibility of future collisions, it is wise to err on the side of caution and remove of more than five objects per year

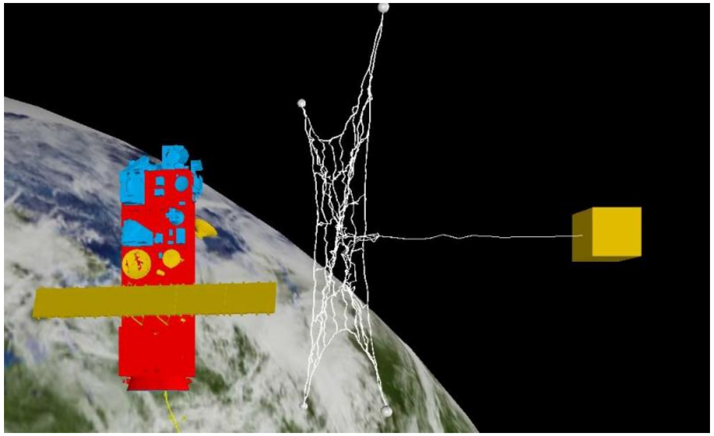
VÉRITÉ • DEVOIR • VAILLANCE

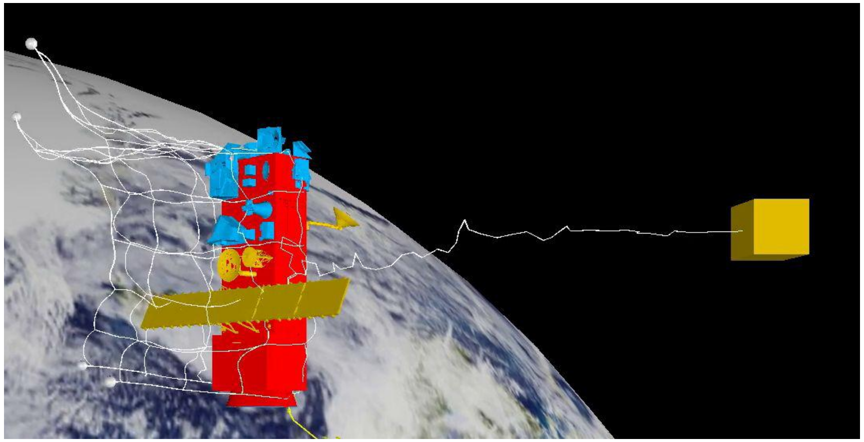
Active Debris Removal Techniques [8]

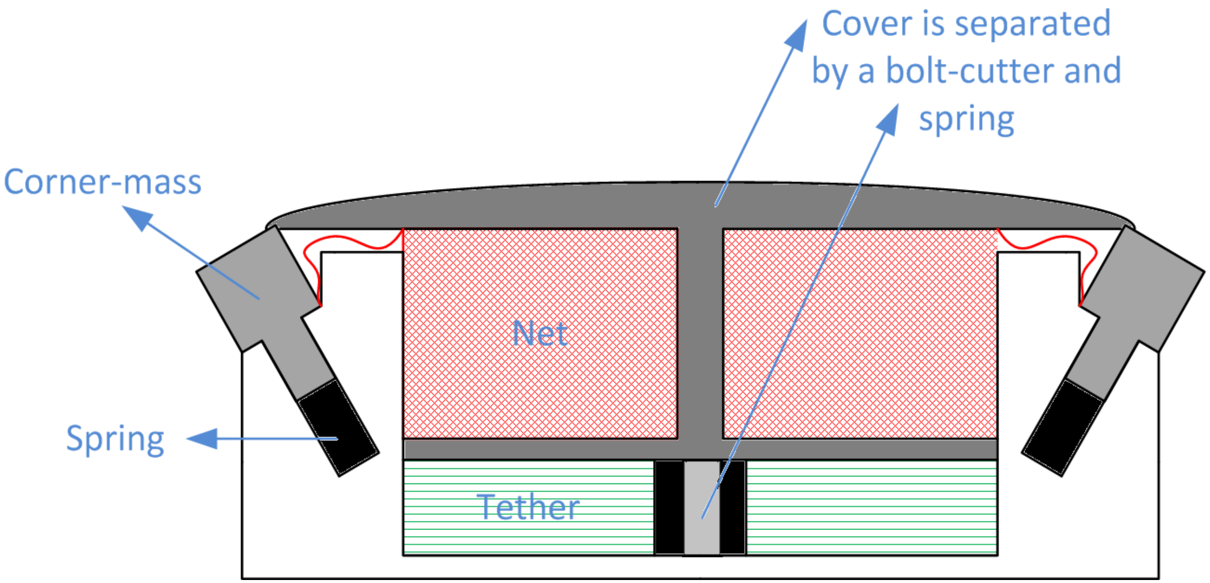
- Contact
  - Pushing
    - Robotic arm
  - Pulling
    - Harpoon
    - net
- Contact-less
  - Ion-beams
  - Dust
  - Lasers
  - Foam
  - Air burst vortex

TRUTH • DUTY • VALOUR
VÉRITÉ • DEVOIR • VAILLANCE

Throw-nets [9]



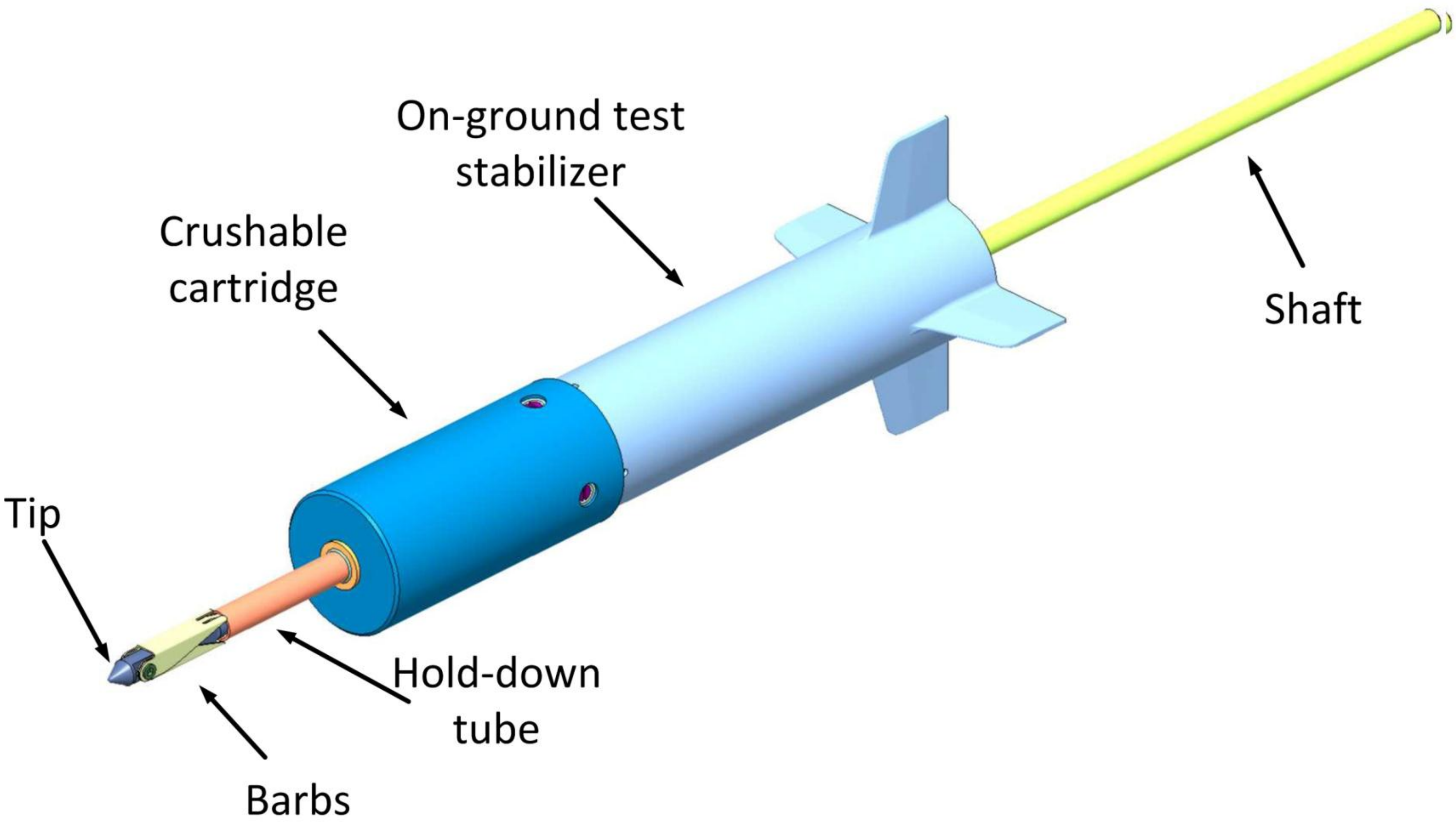



Cover is separated by a bolt-cutter and spring
Corner-mass
Net
Spring
Tether

Throw-nets [10]

- Pros:
  - Can handle objects of any:
    - Shape
    - Attitude
    - Spin rate
  - No complex docking with a rapidly moving/spinning target
- Cons:
  - thruster plume is directed towards tether and net
    - Require heat resistant material such as Zylon for the portion of the tether and net exposed to plume
  - Potential fragmentation
- throw-nets are very promising

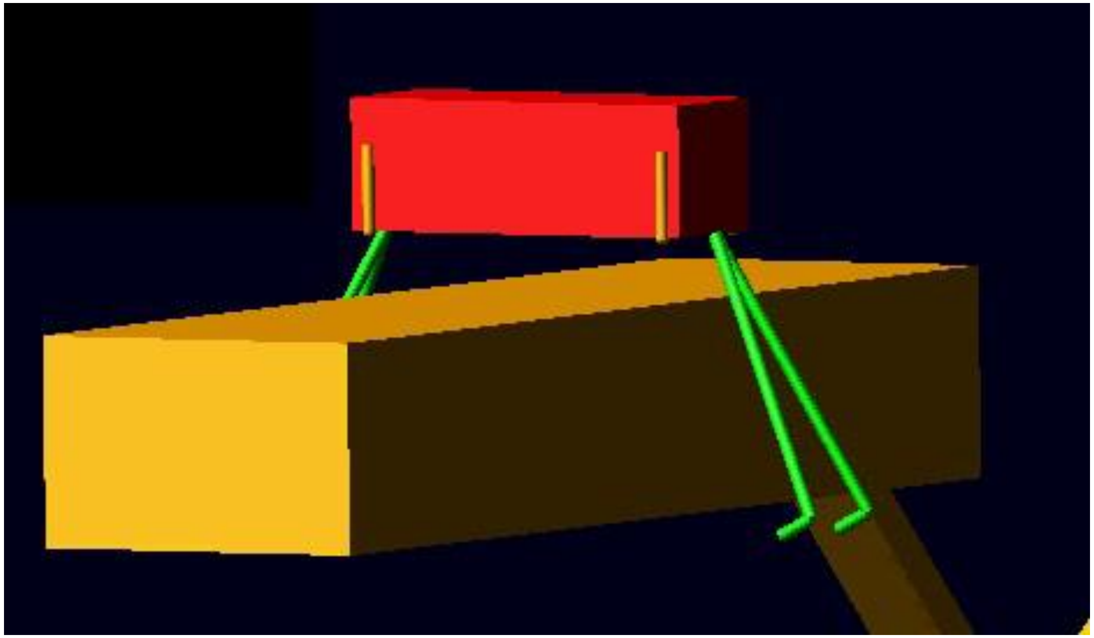
Harpoons [11]


On-ground test stabilizer
Crushable cartridge
Shaft
Tip
Hold-down tube
Barbs

Harpoons [12]

- Pros (similar to throw nets):
  - Can handle objects of any:
    - Shape
    - Attitude
    - Spin rate
  - No complex docking with a rapidly moving/spinning target
- Cons:
  - Ability of the harpoon to penetrate the object
  - Anchor strength once penetration is achieved
  - Potential creation of more debris if fragmentation occurs

Clamping Mechanisms [13]



Clamping Mechanisms [14]

- Cons:
  - require great precision during rendezvous and capture phases
  - Risk of collision or fragmentation

Contact Techniques

- Pros:
  - Ability to control re-entry into the Earth's atmosphere [15]
    - ensure the safe re-entry of objects likely to survive Earth's atmosphere
- Cons:
  - Risk of exploding debris energy stores [16]
    - Most extant debris has not been subject to passivation
    - Propellant tanks are located inside main cylinder; therefore, somewhat protected from clamping mechanism
    - Harpoons pose a greater risk of puncturing propellant tank
    - Throw-net poses lowest risk

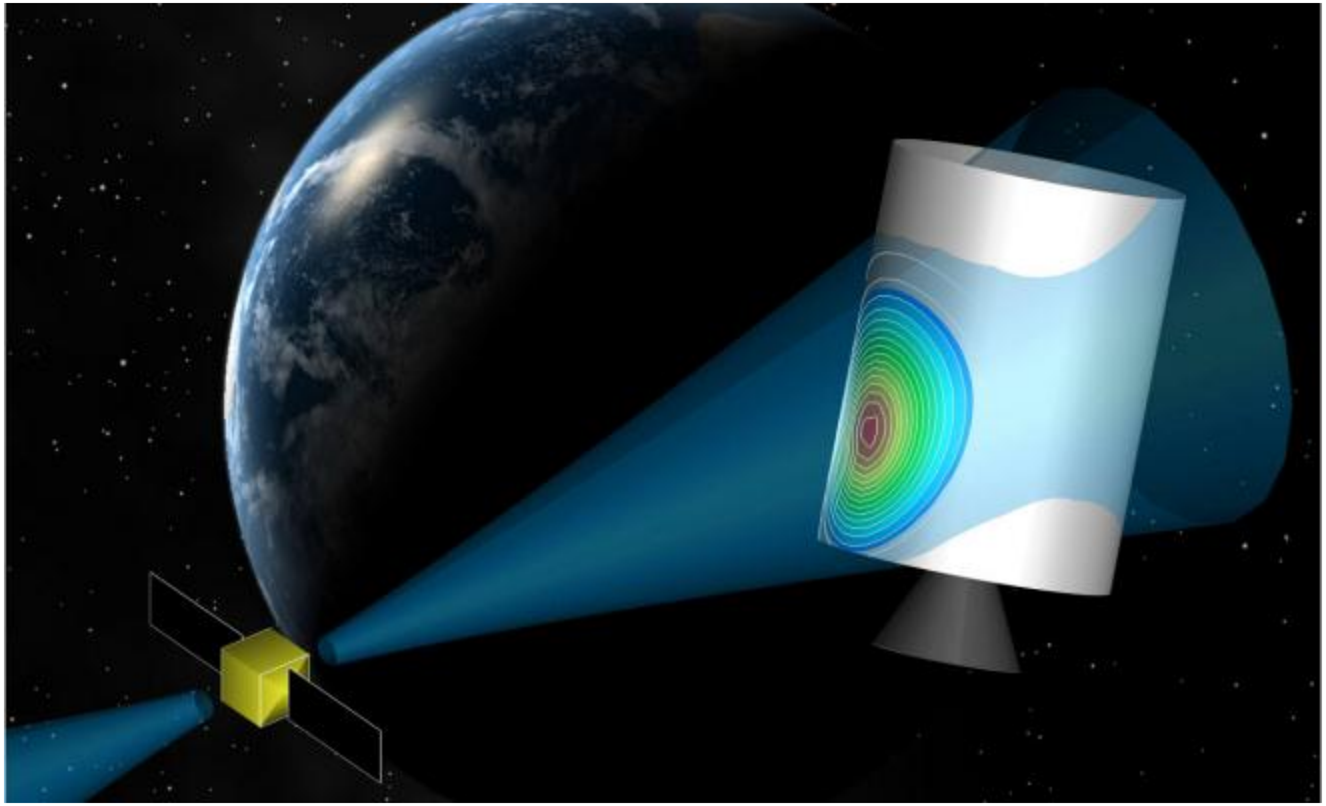
TRUTH • DUTY • VALOUR
VÉRITÉ • DEVOIR • VAILLANCE

Contact-less Techniques

- Various contact-less techniques are under exploration
  - Ion-beams
  - Dust
  - Lasers
  - Foam
  - Air burst vortex

VÉRITÉ • DEVOIR • VAILLANCE

Ion-beam Shepherd [17]



Expanding Foam [18]

- Rendezvous with space debris, then spray it expanding foam or embed foam in all spacecraft
- Increases area-to-mass ratio in order to increase drag (in LEO)
- 1 ton piece of debris could be de-orbited from 900km altitude within 25years (vice hundreds)

TRUTH • DUTY • VALOUR

VÉRITÉ • DEVOIR • VAILLANCE

Air Burst Vortex Rings [19]

- Technique places air molecules in the path of space debris
- Drag force lowers altitude to enable re-entry
- Ground or rocket-based
- Very unlikely to create more debris

Dust [20]

- US Naval Research Laboratory
- Rocket would carry dust payload into path of debris
- Drag force lowers altitude to enable re-entry
- Tungsten dust a prime candidate due to its high density, abundance, and relatively low cost

Lasers [21]

- Ground based lasers
- Laser irradiates space debris, vaporizing its surface
- causing a change in orbit and subsequent re-entry into Earth's atmosphere

Conclusion

- Space debris situation in LEO has a reached a "tipping point", thus requiring intervention in the form of active debris removal
- Examined various contact and contact-less techniques are being studied around the globe
- promising results

Conclusion (Cont'd)

- However, the technical feasibility of ADR is only part of the challenge that lies ahead
- Perhaps of equal or greater difficulty are the regulatory, economic, political, and legal challenges related to ADR
- These areas require further study as part of a broader effort to understand global space governance requirements

Questions?

Major Nathan Arleigh Burgess
Royal Canadian Air Force /
Royal Military College of Canada
nathan.burgess@forces.gc.ca

Notes

1. NASA, "Orbital Debris Management & Risk Mitigation," *NASA,* http://www.nasa.gov/offices/oce/appel/curriculum/courses/appel_odm.html (accessed Nov 20, 2013), 6.
2. K Wormnes et al, "ESA Technologies for Space Debris Remediation," *Proceedings of the 6th IAASS Conference: Safety is Not an Option,* (Montreal: European Space Agency, 2013), 1.
3. Cesar Jaramillo, *Space Security Index 2012* (Waterloo, On: Project Ploughshares, 2012), 27-28.
4. Wormnes et al, "ESA Technologies for Space Debris Remediation," 1; Ali S. Nasseri, Matteo Emanuelli, Siddharth Raval, and Andrea Turconi, "Active Debris Removal Using Modified Launch Vehicle Upper Stages," *Proceedings of the 6th IAASS Conference: Safety is Not an Option* (Montreal: European Space Agency, 2013), 1-2; Georgakas, *Sweeping Away Space Debris With Dust*, 1; J.C. Liou, "An Update on LEO Environment Remediation", 4; Aghili, *Active Orbital Debris Removal Using Space Robotics,* 1; Brito, Celestino, and Moraes, "space pollution", 4; J.C. Liou, "A Note on Active Debris Removal", 7-8; Adilov, Alexander, and Cunningham, *Earth Orbit Debris: An Economic Model*, 5, 19.
5. J.C. Liou, "An Update on LEO Environment Remediation with Active Debris Removal," *Orbital Debris Quarterly News, Vol 15 Issue 2*, (2011): 4.
6. Ibid.
7. Ibid.
8. Robin Biesbrock, Tiago Soares, Jacob Hüsing, and Luisa Innocenti, "The E.Deorbit CDF Study: A Design Study for the Safe Removal of a Large Space Debris," *Proceedings of the 6th IAASS Conference: Safety is Not an Option* (Montreal: European Space Agency, 2013), 3; Wormnes et al, "ESA Technologies for Space Debris Remediation", 1-2,4,5.
9. K Wormnes et al, "ESA Technologies for Space Debris Remediation," *Proceedings of the 6th IAASS Conference: Safety is Not an Option,* (Montreal: European Space Agency, 2013), 3-4.

Notes

10. K Wormnes et al, "ESA Technologies for Space Debris Remediation," *Proceedings of the 6th IAASS Conference: Safety is Not an Option,* (Montreal: European Space Agency, 2013), 3-4.
11. Ibid, 4.
12. Ibid.
13. Ibid, 4-5.
14. Ibid.
15. Ibid, 5.
16. Ibid, 2.
17. Ibid, 5.
18. Ibid, 7.
19. Matthew A. Noyes, Peetak Mitra, and Antariksh Dicholkar, "Propagation of Surface-to-Low Earth Orbit Vortex Rings for Orbital Debris Management," *Proceedings of the 6th IAASS Conference: Safety is Not an Option* (Montreal: European Space Agency, 2013): 1-2.
20. Daniel Parry, *NRL Scientists Propose Mitigation Concept of LEO Debris,* Jun 20, 2012, http://www.nrl.navy.mil/media/news-releases/2012/nrl-scientists-propose-mitigation-concept-of-leo-debris (accessed Dec 7, 2013), 1.
21. Claude Phipps, "SPIE," *Clearing Space Debris with Lasers,* Jan 20, 2012, https://spie.org/x84761.xml (accessed Dec 6, 2013), 1.