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The Polluting Potential of Space Debris Demise in the Atmosphere

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Context

Recent concerns with small-satellite mega-constellations:

- Apr 2021: FCC replies to complaints filed against Starlink Gen.1 and acknowledges the «*Potential Effect on Earth's Atmosphere from Satellite Launch and Reentry*»
- Dec 2022: FCC grants approval to part of Starlink Gen.2, linking subsequent approvals to the company's «commitment [...] to explore methods to collect observational data on formation of alumina from satellite reentry»

Re-entry mass expected to grow at least 4 times in the coming years

(Organski et al, 2020)

- Spacecraft: 800 – 3200 tonnes* /year
- Launch Vehicles: 1000 tonnes/year

60 – 90 % of re-entry mass burns in the atmosphere

Polluting potential of Aluminum (Al) and its oxides (AlO) in the atmosphere

- *In situ* measurements present evidence of Al and AlO during re-entry (Lips et al, 2010)
- Stratospheric reaction with ozone may increase its depletion (Boley & Byers, 2021)

* 1 tonne = 1000 kg (CIPM, 1880, p. 41). Also referred to as *metric ton* (NIST, 2008, p. 28433).

Approach

Reactive Molecular Dynamics Simulations

Reentry scenario from Low-Earth Orbit:

- USC's RXMD Framework (Nomura et al, 2020)
- Reactive Force Field for Al and O (Hong & van Duin, 2014)
- Validation against literature for liquid AlO

Output

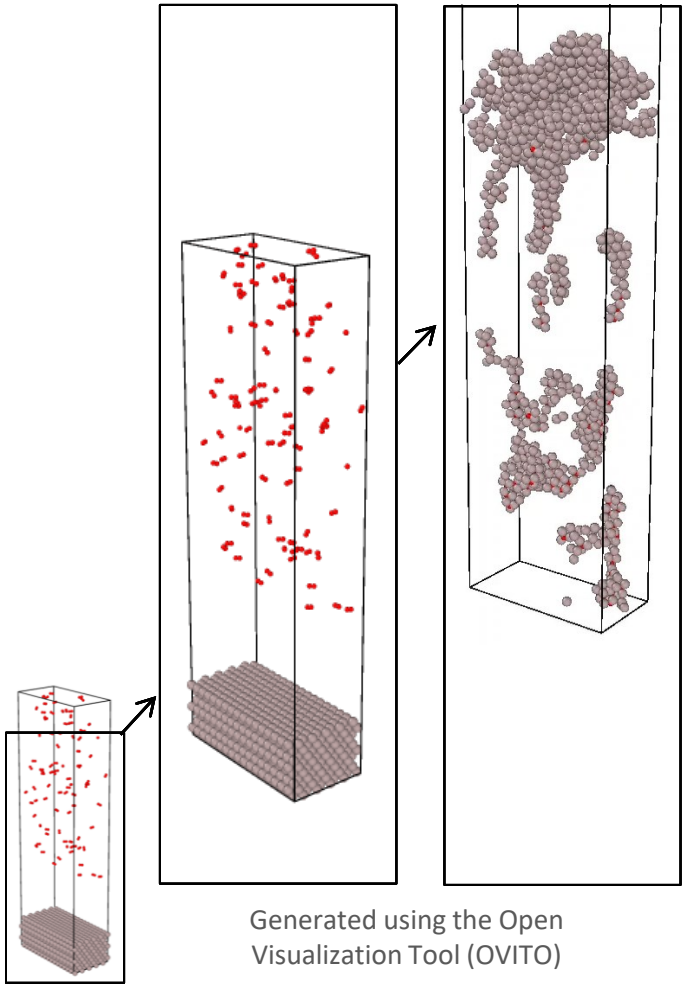
- Particle size distribution for clusters of Al and AlO
- Clusters' mass

1D Atmospheric Model (NOAA, 1976)

- Force balance resorting to the particle size distribution corrected for free molecular flow

Output

- Particle settling time: up to centuries before reaching the Ozone layer (upper stratosphere)



Generated using the Open Visualization Tool (OVITO)

Preliminary Results

Long-term Extrapolation

Micrometeoroid (MM) reentry figures

- Daily: 32.2 tonnes/day
  <1 % Aluminum mass
  (Drolshagen et al, 2017)

Anthropomorphic objects reentry figures

- 2022: 2022: 309 tonnes/year
  (ESA Space Debris Office, 2022)
- Future, worst-case scenario:
  4200 tonnes/year
  (Organski et al, 2020)

Comparing MM vs. Anthropomorphic objects before reentry:

- 2022: 120+ tonnes from man-made objects
  Excess Ratio = 87 %
- Future, worst-case scenario:
  1400+ tonnes from orbital vehicles
  Excess Ratio = 1001 %

Aluminum Oxide mass injected in the mesosphere:

- 2022: 49+ tonnes
- Future, worst-case scenario:
  500+ tonnes/year

Remarks

Overview

- Almost inexistant publicly available data on re-entry byproducts
- Multivariate problem with potential for long-term consequences in the atmosphere
- Industry players shall implement best practices and report new findings
- Scientific results shall support evidence-based policy development

Collaborators

- Prof. Joseph Wang
- Dr. Ken-ichi Nomura
- Dr. Ziyu Huang

Funding

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Find more in

- Ferreira, José P., Ferreira, M. (2021). APPROACHING A NEW ERA IN ORBITAL DEBRIS MITIGATION: A HOLLISTIC OVERVIEW OF ECONOMIC AND ENVIRONMENTAL FACTORS. *72nd International Astronautical Congress*. International Astronautical Federation.

- Ferreira, José P. et al. (2022). QUANTIFYING SPACECRAFT DEMISE BYPRODUCTS IN THE ERA OF MEGA-CONSTELLATIONS. *73rd International Astronautical Congress*. International Astronautical Federation.

- Ferreira, José P. et al. (2022). IMPACTS OF SATELLITE REENTRY ON ATMOSPHERIC COMPOSITION IN THE ERA OF MEGA-CONSTELLATIONS: MOLECULAR DYNAMICS SIMULATIONS. *AGU Fall Meeting 2022*. American Geophysical Union. DOI: 10.22541/essoar.167214515.55390432/v1

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