Experimental Investigation of Space Debris Fragmentation During Re-entry

Dániel G. Kovács*, Olivier Chazot§, Gaëtan Kerschen¶, Guillaume Grossir‡

* Ph.D. Candidate, von Karman Institute for Fluid Dynamics and Université de Liège

§ Supervisor, Full Professor and Head of the Department, von Karman Institute for Fluid Dynamics

§ Promoter, Professor, Department of Aerospace and Mechanical Engineering, Université de Liège

§ Advisor, Senior Research Engineer, von Karman Institute for Fluid Dynamics

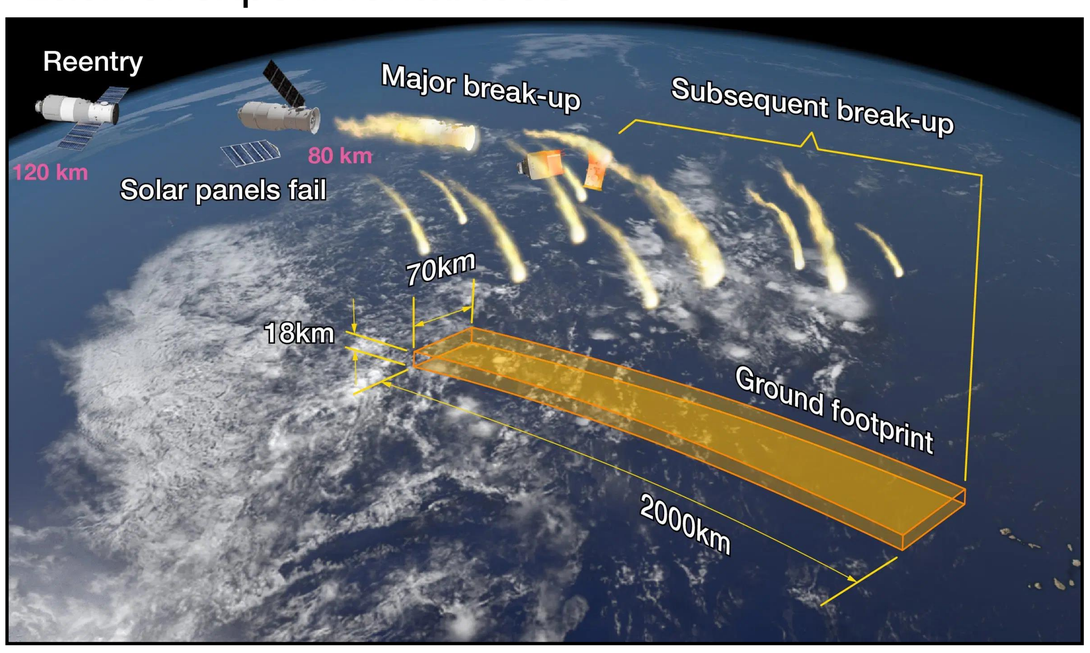
Framework

- The accumulation of space debris is rising environmental and safety problems.
- Guidelines for the mitigation of space debris by promoting their reentry for better use of the space environment.
- Risk assessments must be performed in order to accurately predict the demiseability of the objects to avoid causing damage on the ground or any harm to the population.

By 2021 the number of debris objects larger than 1 cm orbiting around Earth is almost reaching 1,000,000. [1-2]

Motivation

- Trajectory predictions of enhanced accuracy are required to minimize on-ground risk.
- Fragmentation has a high impact on the demiseability of the debris and on the ground footprint.
- Literature concerning fragmentation is incomplete.
- Lack of experimental tools



Conceptual illustration of the Tiangong-1 space station's re-entry. [3]

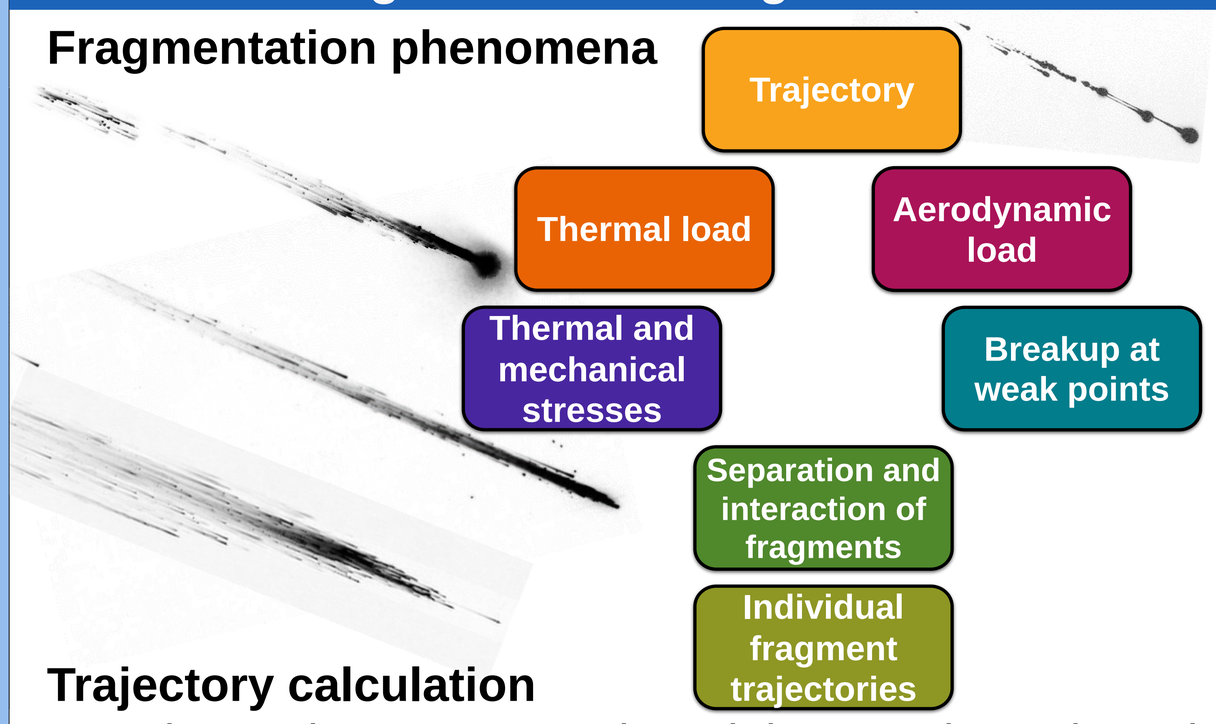
Research Objectives

- Characterize the process leading to breakup and determine where the loads concentrate
- Determine scaling for mechanical properties
- Develop an experimental methodology for fragmentation analysis
- Improve method of fragmentation altitude prediction

Fragmentation of ATV [4]

Investigation of the Fragmentation

Fragmentation phenomena



Trajectory calculation

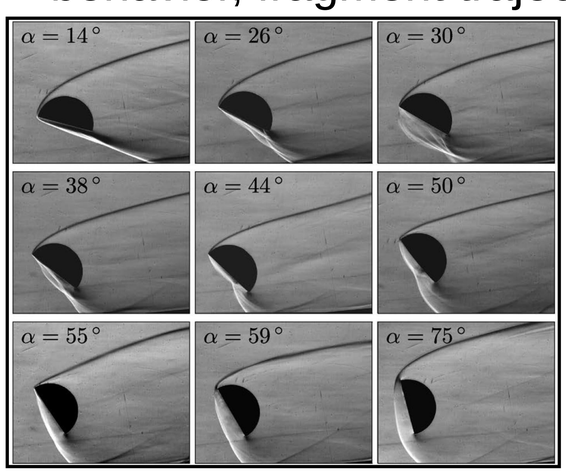
- Estimate the re-entry path and the aerodynamic and thermal load with the VKI Trajectory code.

Structural analysis

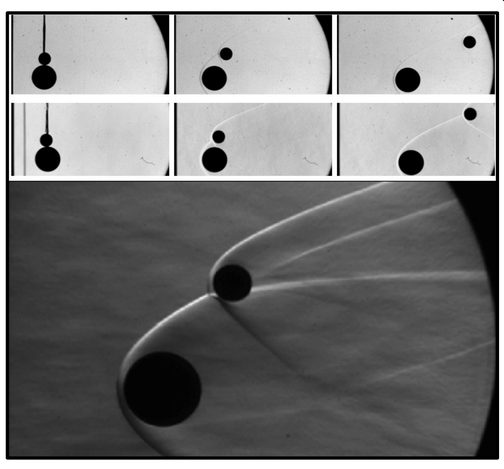
- Calculate how the loads are acting on the body, identify the weak points, investigate the appropriate mechanical scaling.

Wind tunnel tests

- <u>Free-flight tests in Longshot:</u>
  Identify the aerodynamic characteristics, separation behavior, fragment trajectories, limitations of testing.



Free-flight test in the Longshot [5]



Free-flight of proximal spheres [6]

- <u>Stationary model tests in Longshot and in H-3:</u>
  Investigate specific points of the fragmentation trajectory in terms of aerodynamic characteristics, flow topology, and heat-fluxes.

Causes and consequences of the fragmentation

- Analyze the pre- and post-breakup aerodynamic and thermal loads, the motion of the objects, their interactions, and extrapolate to flight.

Acknowledgement

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References

[1] European Space Agency, "Distribution of space debris around Earth", 2019
[2] European Space Agency, "Space debris by the numbers", 2021.
[3] The Aerospace Corporation, "Re-entry illustration of the Tiangong-1", 2018
[4] European Space Agency, D. Durcos, "Artist's view of ATV-5's destructive reentry into Earth's atmosphere", 2007
[5] Grossir et al., "Aerodynamic characterization of space debris in the VKI Longshot hypersonic tunnel using a free-flight measurement technique", *Experiments in Fluids*, 2020
[6] Laurence et al., "Dynamical separation of spherical bodies in supersonic flow", *Journal of Fluid Mechanics*, 2012

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