DESIGN-FOR-DEMISE RESEARCH AT DLR IN THE FRAME OF THE TEMIS-DERBIS PROJECT

Ali Gülhan, Thorn Schleutker, Patrik Seltner, Pawel Goldyn, Niklas Wendel, Dominik Quantius, Bryan Lovrinovic, Sebastian Jack, Sebastian Karl

German Aerospace Center (DLR e. V.)

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Background

The German Aerospace Center (DLR) is committed to sustainability at an economic, environmental and societal level.

This commitment also applies to the space flight, one of DLRs main research areas, and spans from the design and manufacturing of spacecraft and rockets, over space operations and to the disposal of spacecraft at the end of their mission.

DLR thus addresses the topic in an internal, three-year project called “Technologies for Mitigation of Space Debris” or TEMIS-DEBRIS. The project kicked off in January 2024. The focus is on spacecraft removed by uncontrolled re-entry at the end of the life time.

The alternatives to making satellites demisable, the controlled re-entry and the design-for-containment approach, will not be regarded.

Objectives

The project aims to contribute to the design-for-demise community in three ways:

- Novel approaches to make satellites compliant to the space debris regulation will be investigated. This includes the end-of-life concept and technologies for improving the demisability by structural design, selection of suitable materials, demisable joining solutions and generic approaches for increasing demisability of given components.
- The state-of-the-art tools for the design of the de-orbiting flight phase, numerical prediction of the destructive entry flight and demisability evaluation will be advanced.
- In the last phase of the project, a detailed concept for a sustainable satellite will be created. We hope that a demonstration mission can be flown in a subsequent project.

Scope

For achieving the ambitious goals, the project will include:

- Analysis of the system and mission with the end-of-live concept and impact-analysis of the developed techniques for improvement of demisability.

- Thermophysical characterization and ground experiments on candidate materials, joints and technologies for characterization of these elements and creation of validation data for numerical tools.

- Both low-fidelity approaches and high-fidelity numerical simulations using multidisciplinary coupling.

- Combined experimental and numerical activities on the aerothermal and flight dynamic behavior of spacecraft fragments.

Project Consortium

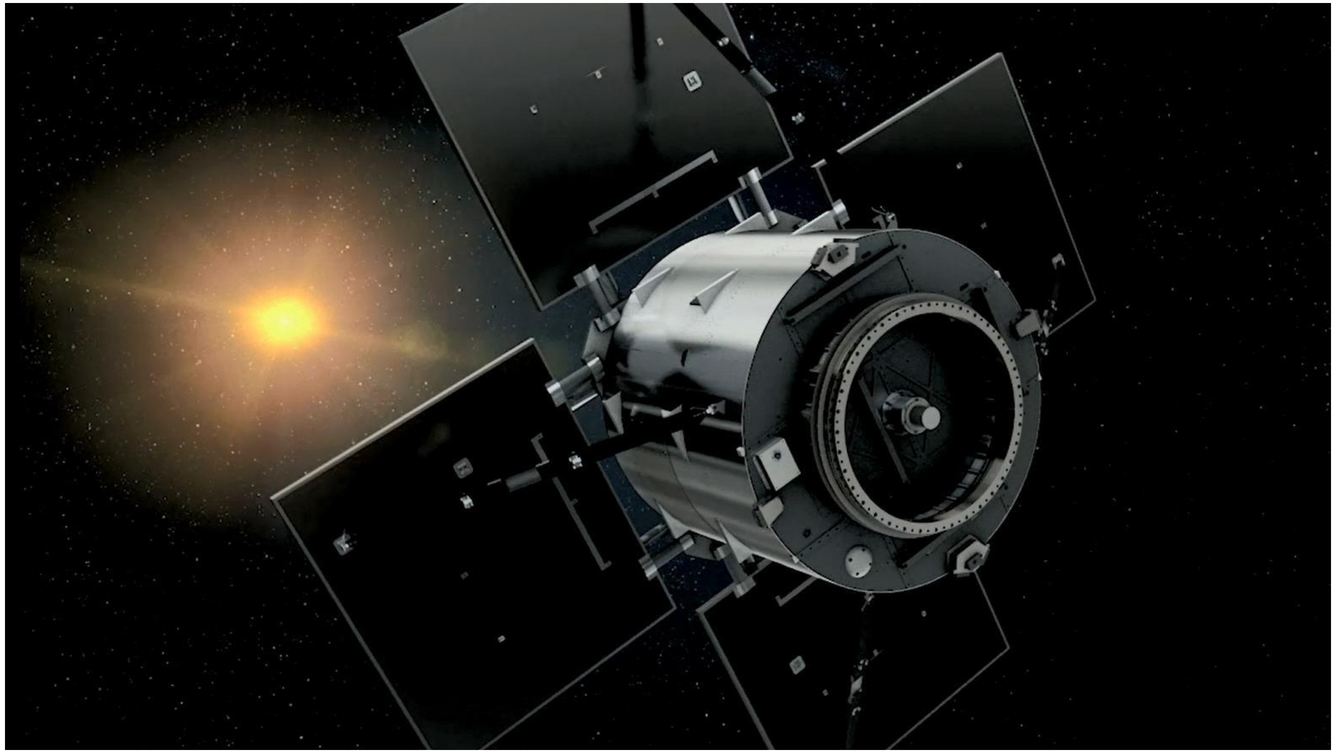
The consortium combines the expertise of six different institutes:

- Institute of Space Systems
- Institute of Aerodynamics and Flow Technology
- Space Operations and Astronaut Training
- Institute of Materials Research
- Institute of Structures and Design
- Institute of Lightweight Systems

Reference Configurations – Eu:CROPIS

For streamlining all project activities, two spacecraft that are considered representative for the space debris problem were selected, modelled and will act as reference missions.

- Eu:CROPIS is a small satellite with a mass of 230 kg,
- measures 2,9 x 2,9 x 1,1 m^3 (main body ⌀1,0 m x 1,1 m) and
- flies in a 600 km sun synchronous low earth orbit.
- The greenhouse experiment has 3 supporting science payloads.
- The satellite is made by DLR
    → Access to CAD files, materials etc.



Ref. 1

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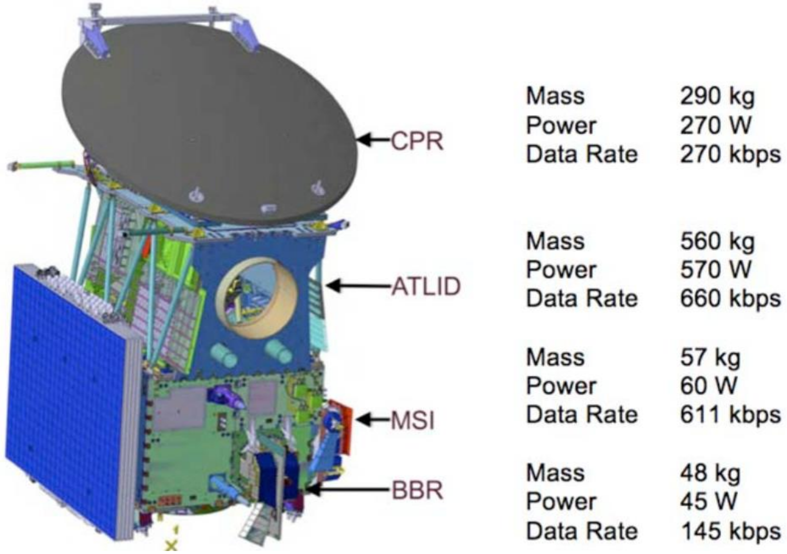
Reference Configurations – EarthCARE

- Medium-sized earth observation satellite from ESA, 2200 kg and 17,2 x 2,5 x 3,5 m^3, flying in LEO (393 km).
- Includes 4 instruments for observations of clouds and aerosols.
- Contains many interesting parts for D4D.
- Use of publicly available information
  - → Models will differ from the real satellite.



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Ref. 2, 3

Approaches for Improving the Demisability

We will investigate different types of D4D solutions, some of which are based on new ideas, some on the implementation of old concepts:

- Improving the demisability on material level using coatings that alter the optical and chemical properties of the surface or form an eutectic with the base metal.
- Joints that will break or separate at a designed trigger temperature.
- Ideas for satellite structures with inherent demisability.
- Semi-active solutions for separation and/or early exposure.
- Approaches to demisable composites that could not be investigated in the limited frame of the ESA project COMP2DEM.
- One concept for a specific satellite component with challenging demise behavior.

This is work in progress. The results will be shown in the coming years.

Characterization and Qualification

The diverse approaches investigated in TEMIS-DEBRIS require various ground testing concepts.

Thermophysical properties will be measured in the laboratory using standard methods and instruments (e.g. DSC and TGA).

Material investigation will utilize the well established stagnation and tangential setups previously used in many ESA projects.

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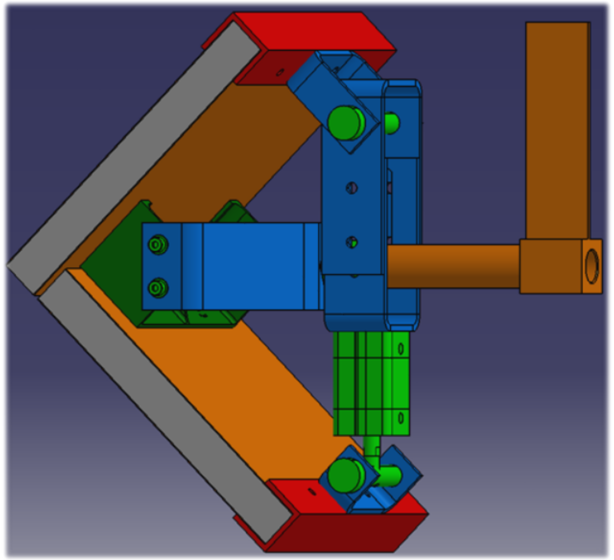
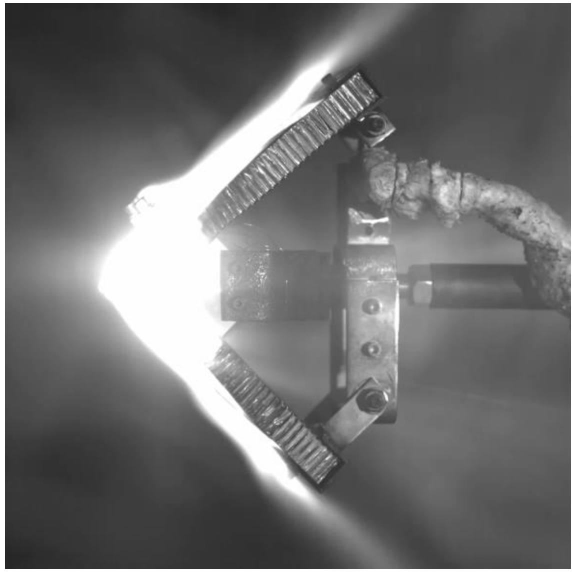
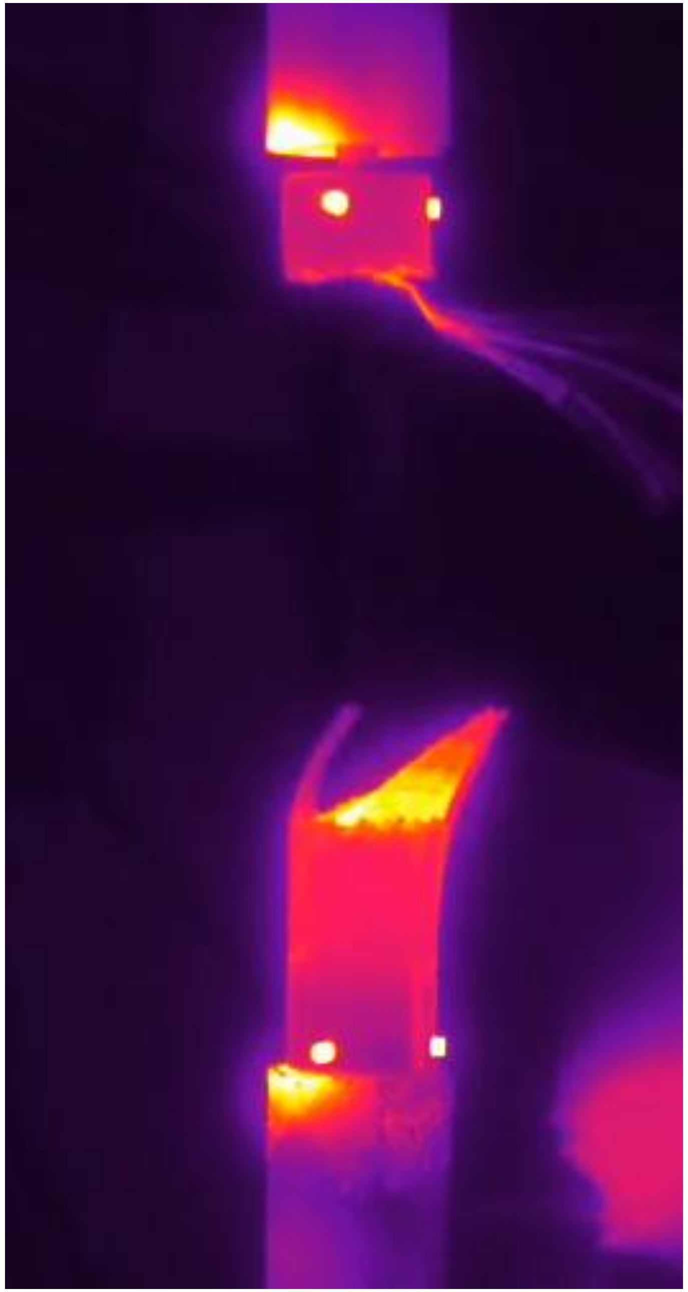
Characterization and Qualification

For investigation of demisable joints, a setup similar to that of D4DBB (below) will be used. Dynamic simulations (right) will be conducted where necessary.

Demise characterization will employ the arc-heated wind tunnels L2K and L3K.







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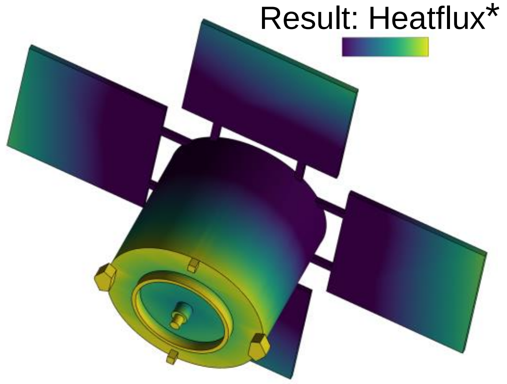
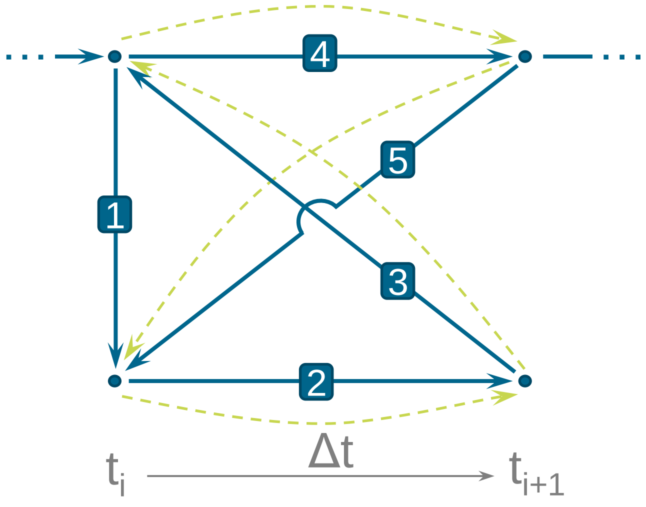
Coupled Simulation – Methodology

- Partitioned individual solvers 2 4 …
  Example: „CFD solver sees neither FEM solver nor coupling, compute heat flux from temperature boundary condition“
- Interpolation at the Interface 1 3 5 …
  Example: „Solver CFD → Boundary condition FEM“
- Preditor corrector method
  - Predictor actions
    1. Heat flux from CFD as boundary condition for FEM
    2. Compute the time step with FEM
    3. Temperature from FEM as boundary condition for CFD
    4. Compute the time step with CFD
  - Corrector actions
    „ Repeat the steps until the results no longer change significantly“

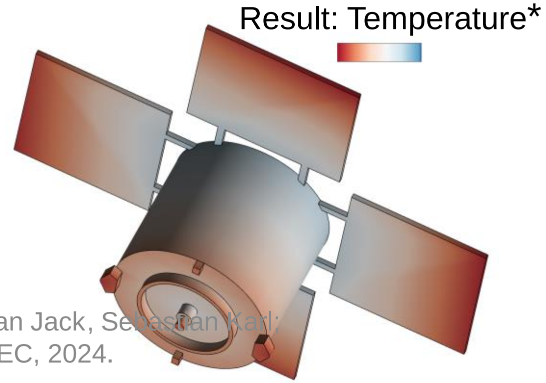
➢ Strong two-ways coupling

CFD simulation
BC: Temperature





FEM simulation
BC: Heatflux



* Artist impression (kein Simulationsergebnis)

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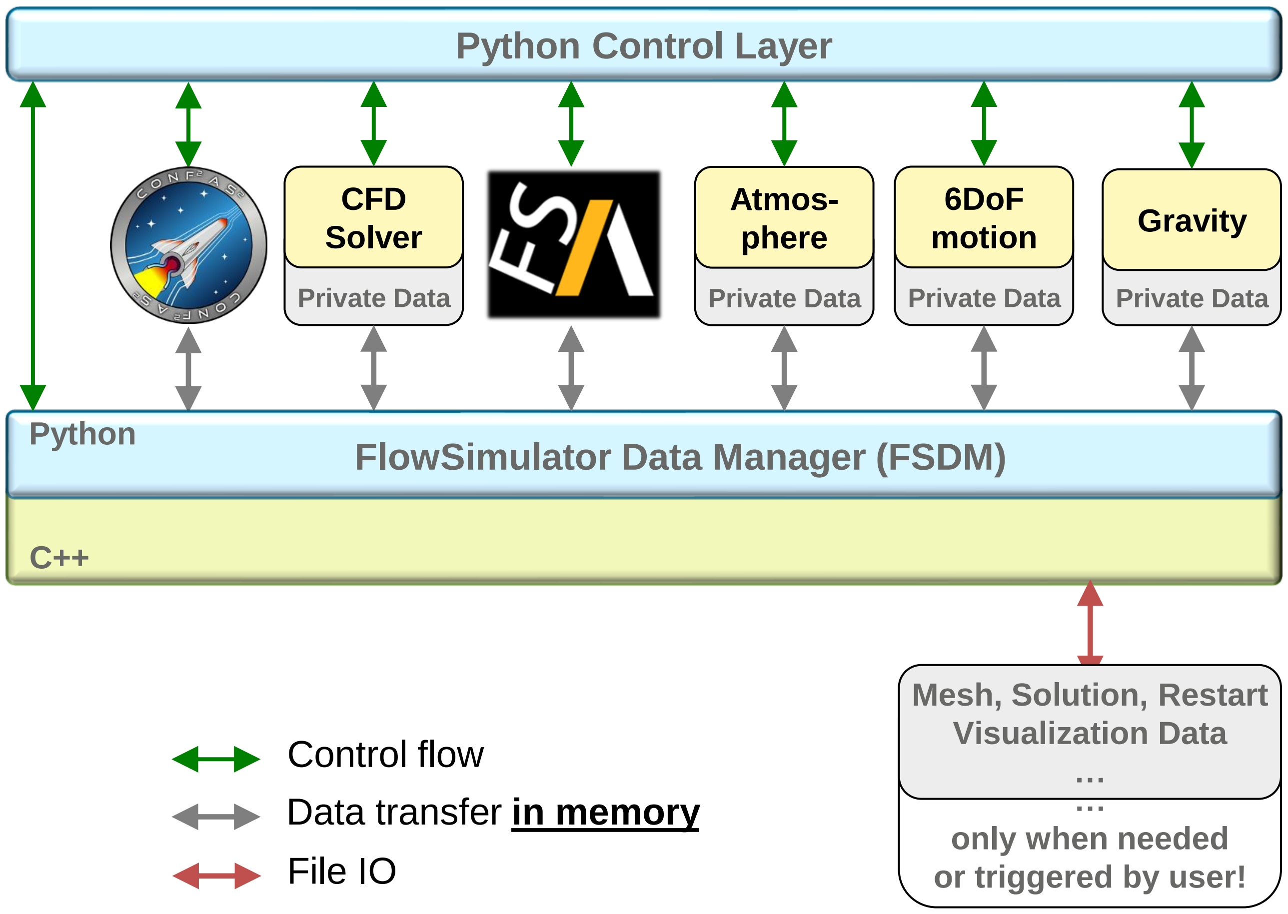
Coupled Simulation – FlowSimulator

- FlowSimulator Framework
  Paradigm: "Every solver is only connected to the FSDM"
  - Modular (Solver replacable)
  - Efficiency (FileIO is minimized)
  - Parallelizable (Cluster Systems)
- Building blocks (FlowSim Plugins)
  - CONF²AS²
    Solver control, interpolation, sequence, termination criteria, time integration, restart data, etc.
  - CFD Solver
    TAU-RF
  - FEM Solver
    Ansys
  - 6DoF Flight Dynamic Solver
    Development by AS-CASE with adaptation for orbital mechanics
  - Atmosphere model
    MSISE 2.0
  - Gravitation model
    To select: Earth [EGM96], Moon, Sun, Planets



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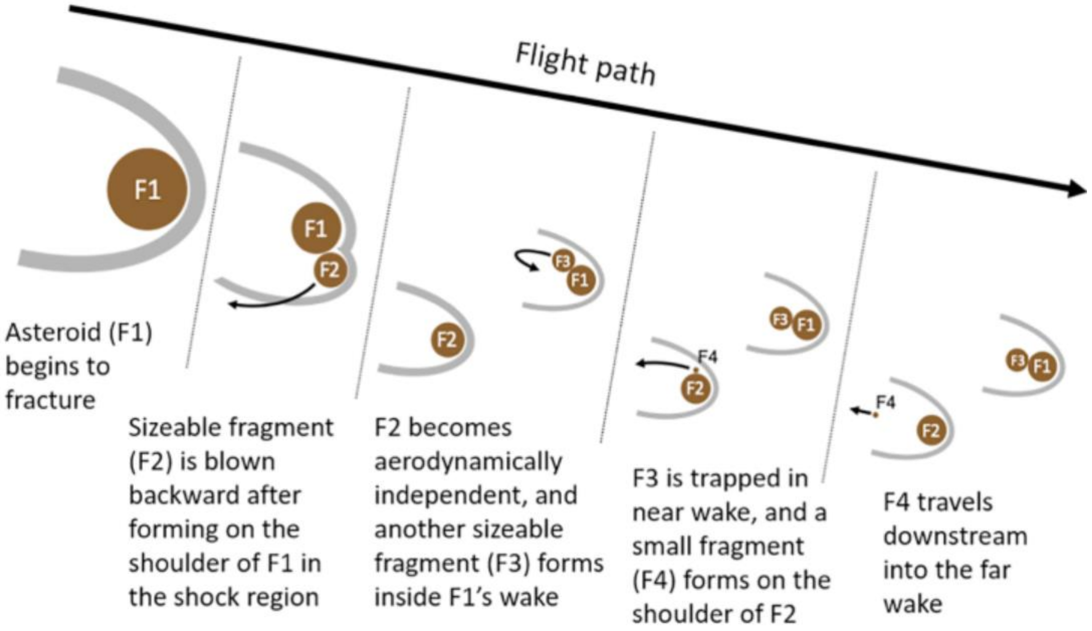
Aerodynamic Interaction of Fragments

- Occurrence of different types of aerodynamic interaction after atmospheric breakup, e.g. shock-shock interaction and wake-shock interaction.
- High separation velocities and extensive impact footprints of re-entering space debris due to aerodynamic interaction (especially shock-wave surfing).
- Planed aerodynamic model with different shapes and orientations as a two-body problem without impact of the children body on the parent body.

Credit: ESA



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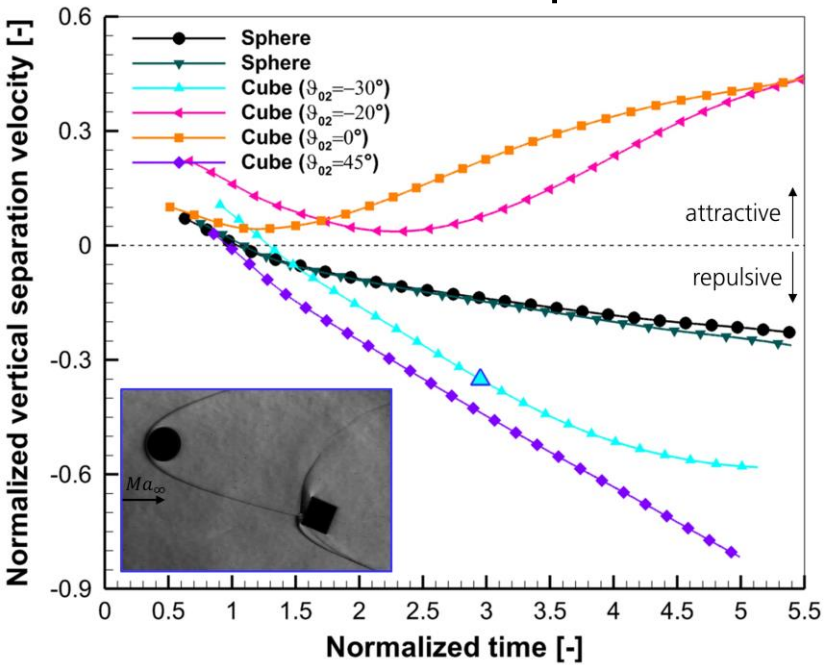
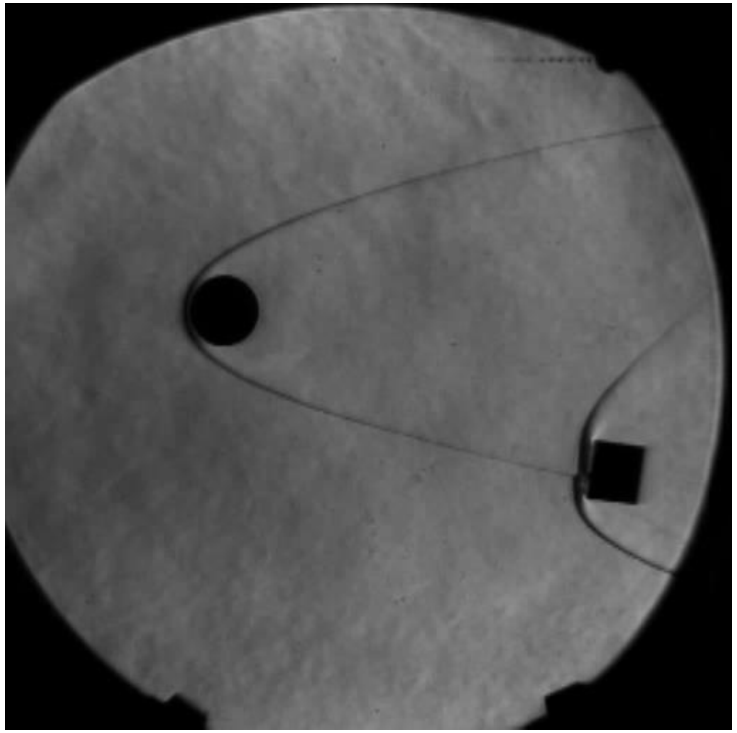
Aerodynamic Interaction of Fragments

Free-flight tests have already been performed in hypersonic wind tunnel H2K:

- Experimental studies on two-body interaction with sphere-sphere, sphere-cube and cube-cube arrangements.
- Result of a three times higher separation velocity of trailing cubes during shock-shock interaction than of spheres.

→ Effect on size of impact footprint





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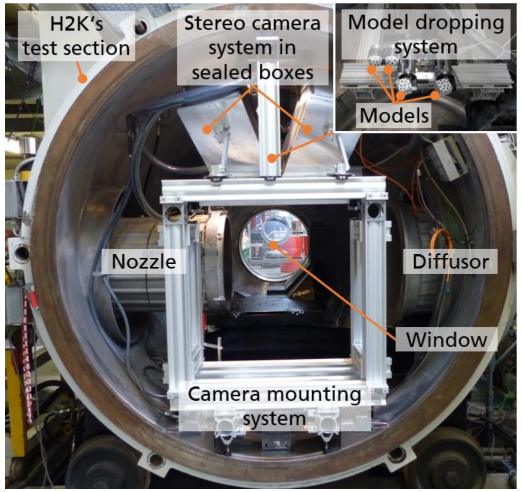
Aerodynamic Interaction of Fragments - Planned Tests

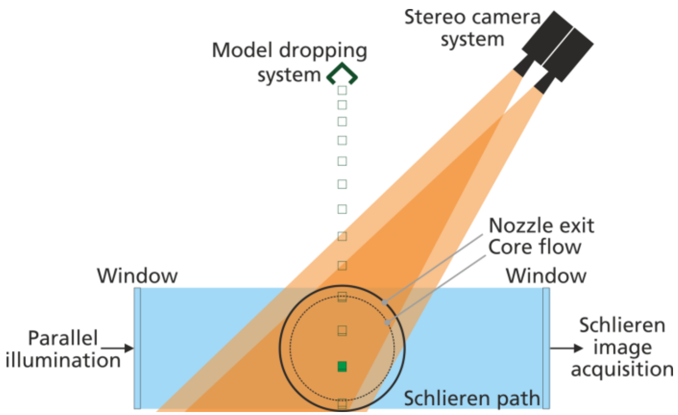
Single-body experiments

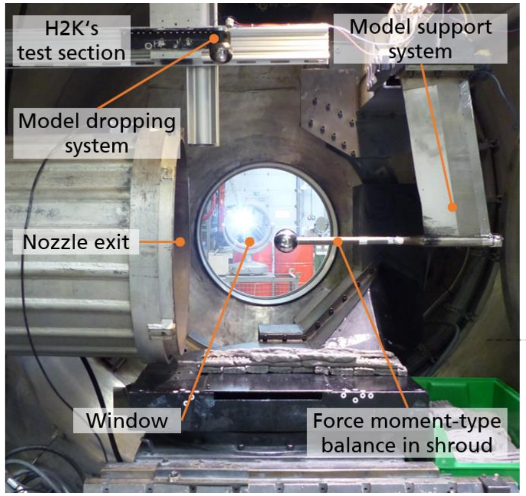
- Free-flight tests with stereo tracking measurement on spheres, cubes, boxes, plates, cylinder, cones and spherical caps at different angles of attack
- Output of an aerodynamic database for single and leading bodies

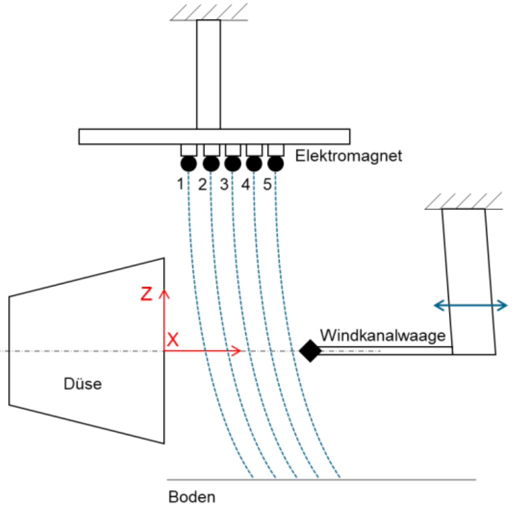
Multi-body experiments

- Semi-free-flight tests on leading spheres and trailing blunt bodies of different shapes and angles of attack
- Wind tunnel balance in trailing body
- Output of an aerodynamic database for trailing bodies









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Future Work

- Refinement of de-orbiting concepts and improvement of the required technologies by means of ground demonstrators.
- Design and manufacturing of samples for the concepts for demise enhancement and characterization in arc heated facilities.
- Sample manufacturing and characterization of the demisable composite solutions.
- Coupled thermo-mechanical numerical simulations of the entry-flight and fragmentation sequence of the reference satellites.
- Improvement of aerothermal models regarding demise process and numerical rebuilding of experiments.
- Free flight experiments in the hypersonic wind tunnel on test models of spacecraft fragments and comparison with numerical simulations with regard to flight dynamic behavior.
- Finalization of demisable satellite structure concept and its interior components like avionics, power units, etc.
- Design of a demonstrator flight mission for a fully demisable satellite in the third year.

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