WEBINAR

Design for Demise: rationale, status and vision

TODAY'S SPEAKERS

TIAGO SOARES

ESA System Engineer for:

- CleanSat – debris mitigation
- End-of-life activities
- OOS/ADR Mission Studies and technologies

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AGENDA

1. RATIONALE
2. ASSESSMENT
3. TECHNIQUES
4. DEMISE VERIFICATION
5. VISION
6. Q&A

Design for Demise Rationale

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Space Debris falling on-ground






Space Debris Mitigation Requirements

End-Of-Life Measures in LEO

ATMOSPHERIC RE-ENTRY — within 25 years of mission completion

ON-GROUND CASUALTY RISK — The probability of serious injury or death on ground (casualty risk) shall not exceed 1 in 10,000 for any re-entry event

Design for Demise — Design for Demise (D4D) is the intentional design of space system hardware such that it will disintegrate during an uncontrolled atmospheric re-entry

Space Debris Mitigation Policy for Agency Projects

1. INTRODUCTION

As a consequence of spaceflight activities, the number of functional and non-functional (i.e.: space debris) human-made objects in Earth orbit continues to grow. To minimise the impact of space operations on the orbital environment, to reduce the risk of collision on orbit and to ensure the safety of the public on ground during re-entry, mitigation and safety measures must be anticipated as from the conception of a space system.

End of Life - Controlled vs Uncontrolled re-entry

D4D

NO DEMISE - Controlled reentry

VS

DEMISE - Uncontrolled reentry

- Simpler system
- Reduction in mass
- Reduction in costs

Design for Demise Concept

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The calculation of the casualty risk

Fragments are considered to be hazardous if their kinetic impact energy is above 15J.

Casualty expectancy

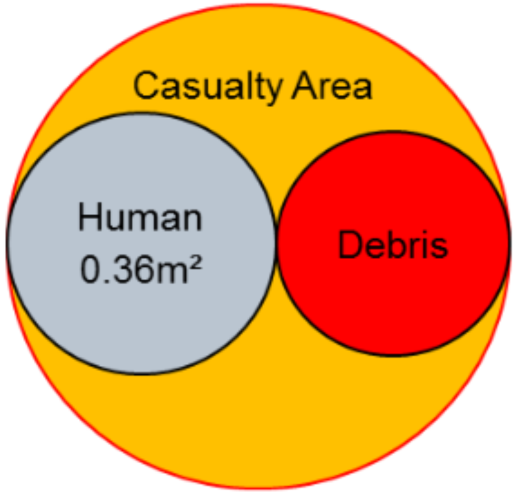
$$E_c = \sum_n \sum_m (P_i)_{n,m} \cdot (\rho_p)_{n,m} \cdot (A_C)_{n,m}$$

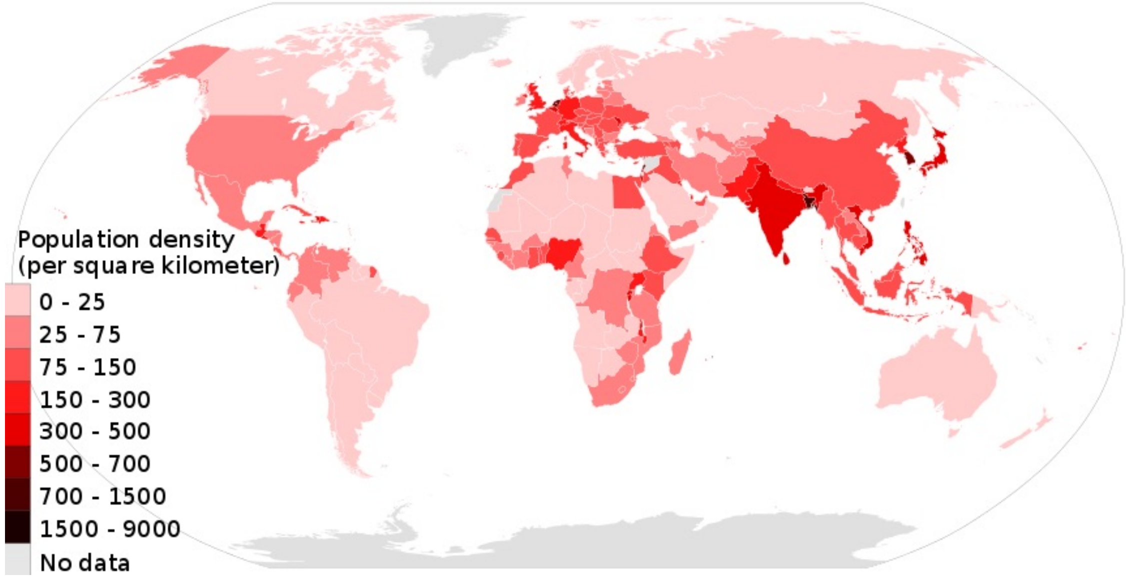
Bins on Earth surface

Impact probability

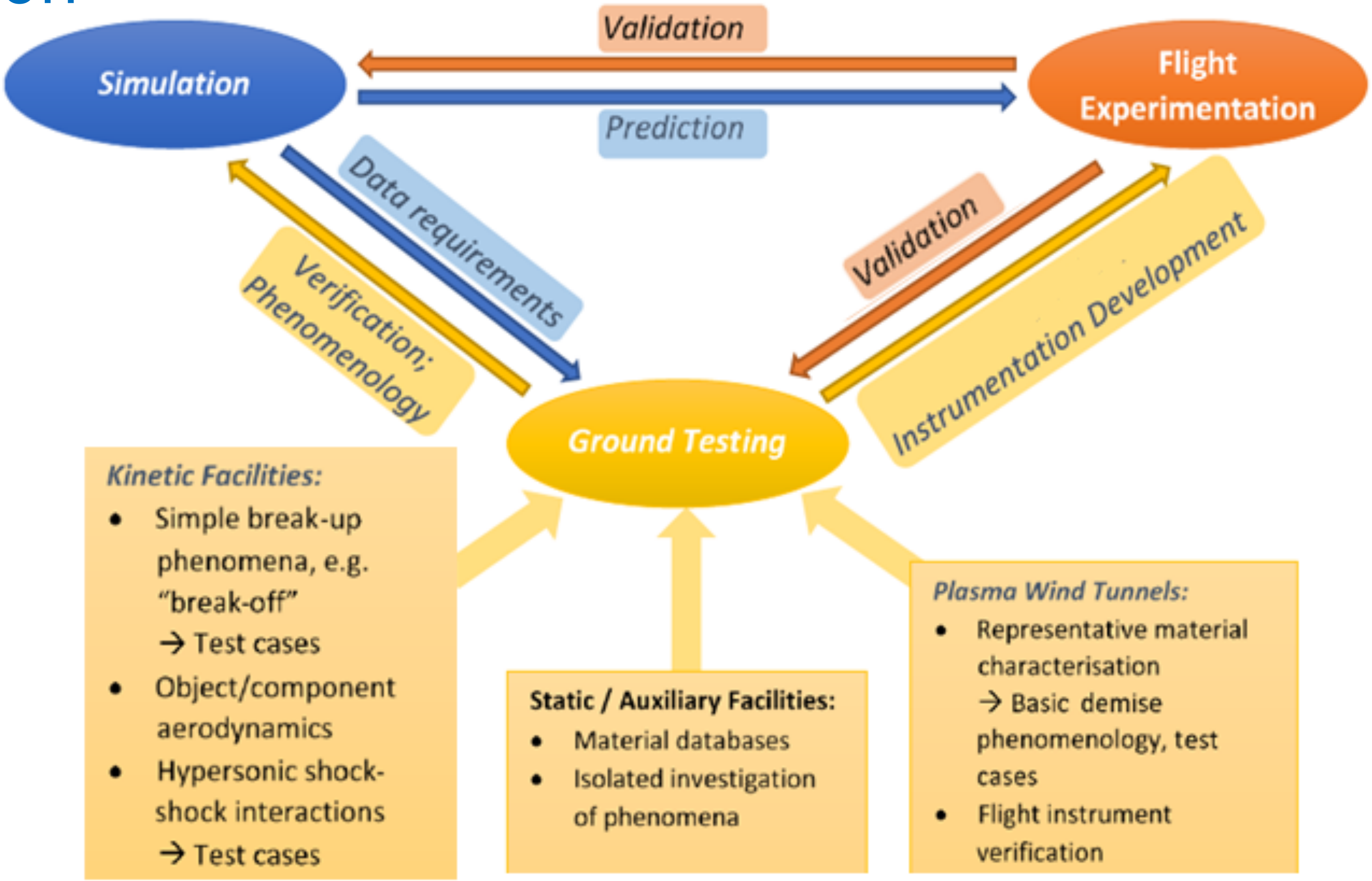
Population density

Casualty cross-section





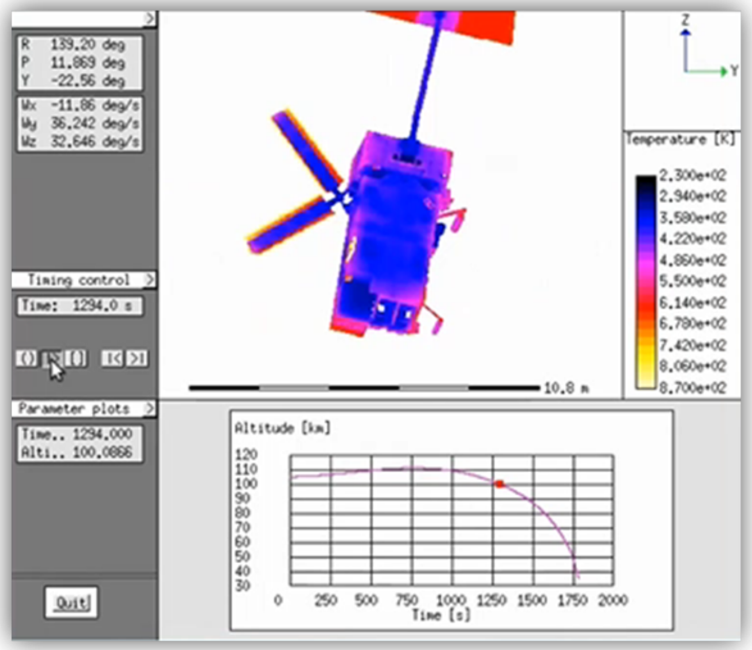
The strategy for demise assessment and verification

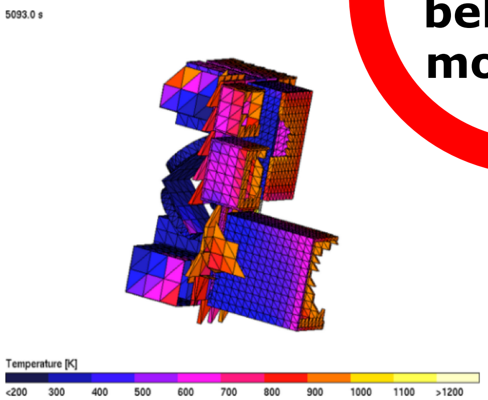


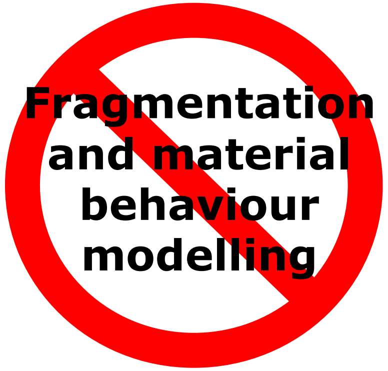
Simulations in re-entry analysis tools

Models:

- flight dynamics
- aero-thermo-dynamics
- heat transfers
- mechanical stress
- fragmentation
- casualty risk





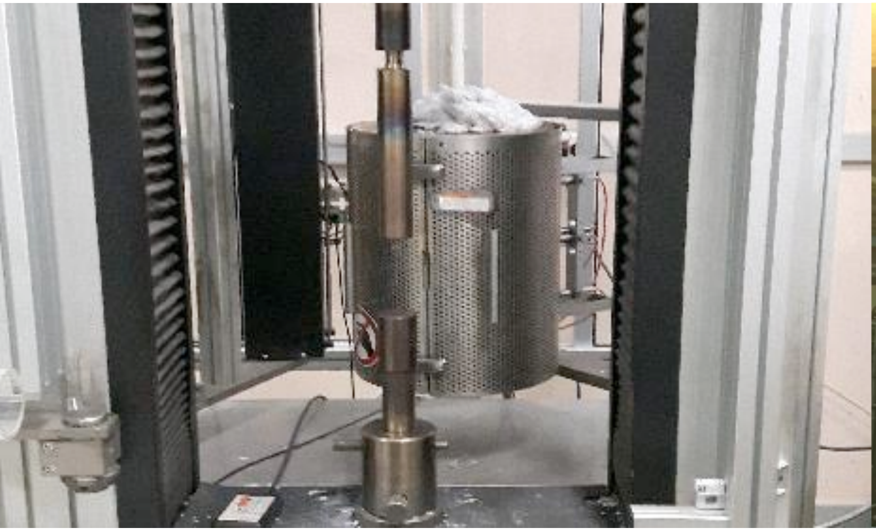


Example of a re-entry simulation (credit SCARAB-HTG)

Simulations are able to assess the re-entry trajectories, heating flux, casualty risk…but there are many uncertainties in the models assumptions

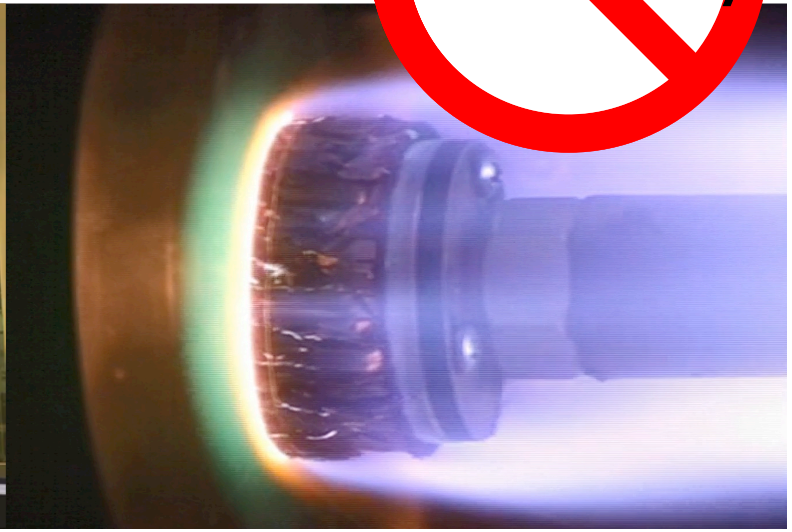
Ground testing

STATIC FACILITY
THERMOMECHANICAL TESTS



PLASMA WIND TUNNEL
AEROTHERMAL TESTS

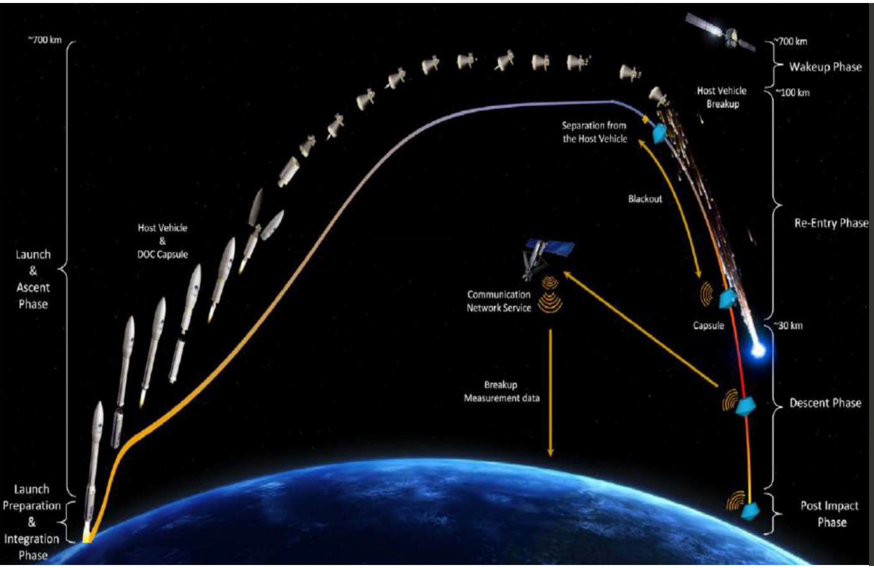
Conditions representative of full re-entry



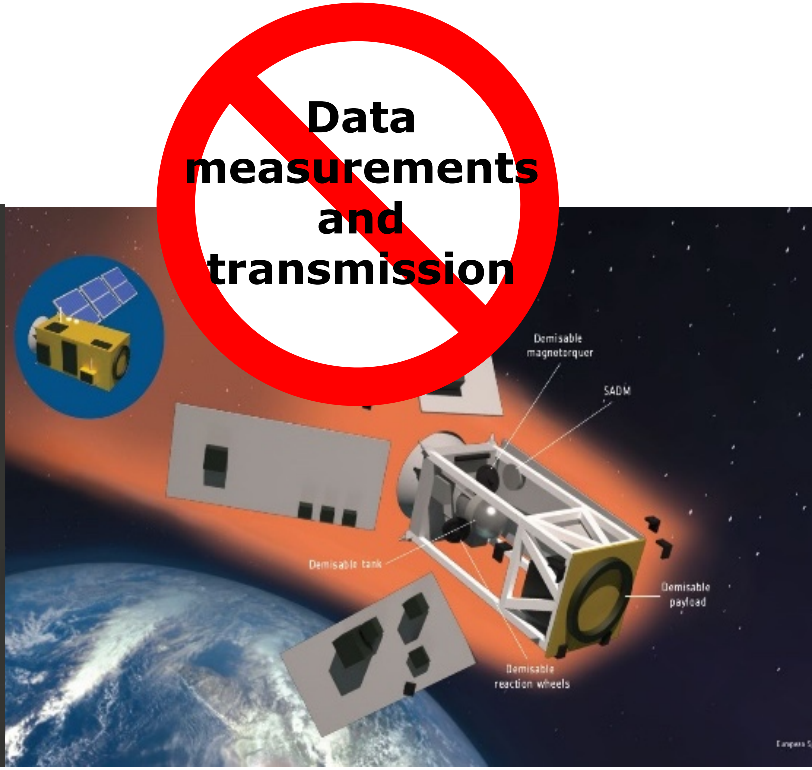
On-ground tests are able to assess material properties, melting behaviors, shape effects…but there are many uncertainties in the test conditions

Flight experimentation

RE-ENTRY CAPSULE



RE-ENTRY OBSERVATION



Flight experimentation are able to assess the break-up events, tumbling behavior, aerothermodynamic effects…but there are many uncertainties in the experiment set-up

Design for Demise Techniques

The strategy to develop the technologies

$Casualty\ risk < 10^{-4}$

Design for Demise

System level – the system has to ensure the break-up and the exposure of the equipment to the heat flux

Equipment level – the equipment have to ensure the demise of all the parts/fragments

The design for demise techniques

Minimize Required Heat

- Minimize mass
- Replacing materials
  - C_p
  - T_m
  - ε
  - q_m

Maximize Available Heat

- Ballistic coefficient
- Increase local heat flux
  - Shapes of objects
- Add energy
  - Exothermic reactions

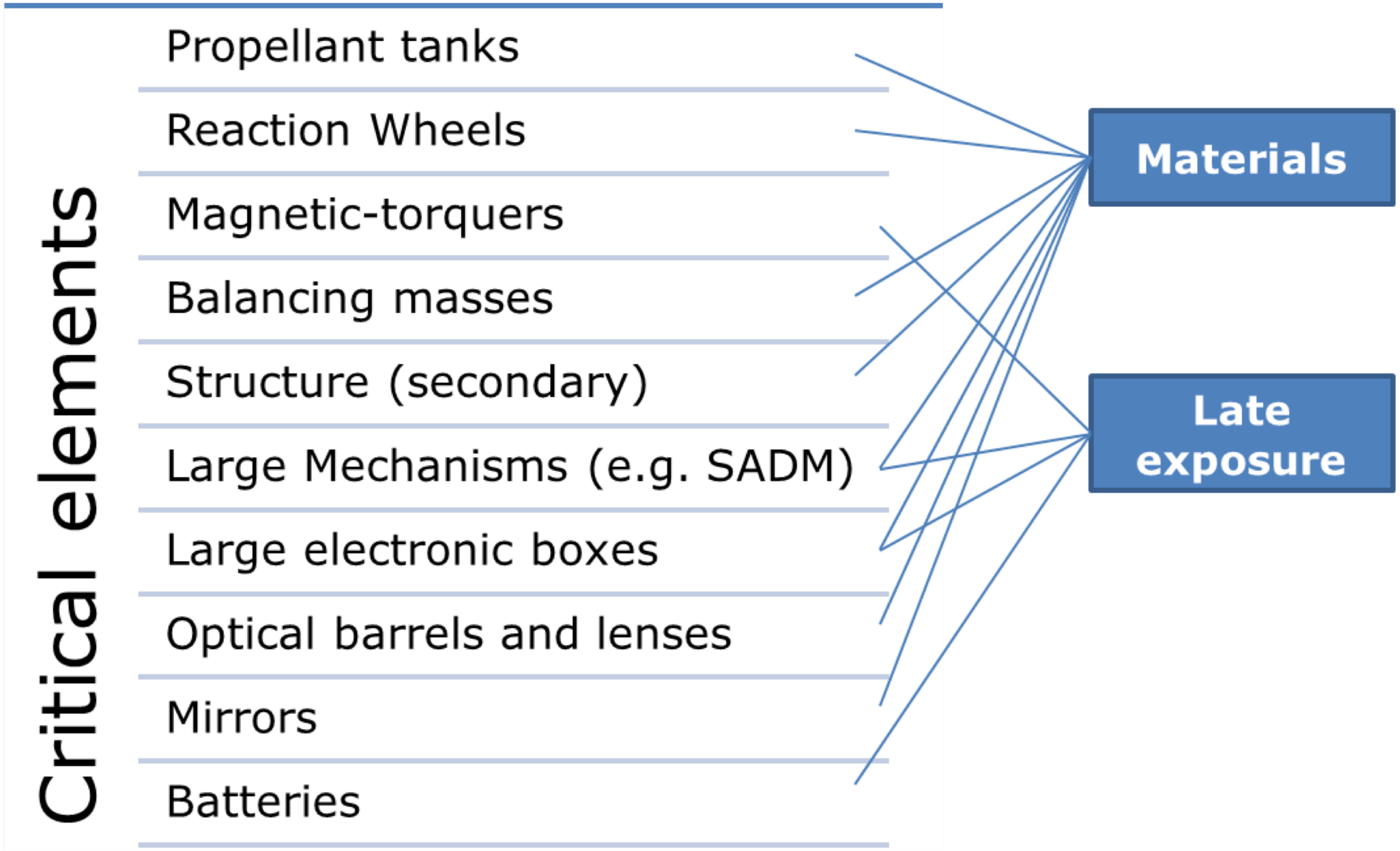
Optimize Heat Transfer

- Early break-up - Fragmentation
  - Dedicated mechanism
  - Demisable attachment points
- Orifices, lattice structure

Minimize Casualty Area

- Keeping re-entry fragments together - Containment

The critical elements identified



Q&A

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Design for Demise Verification

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Why demise verification guidelines?

Casualty risk < 10^{-4} requirement

System

Need to cross-check the results of re-entry analyses

Equipment

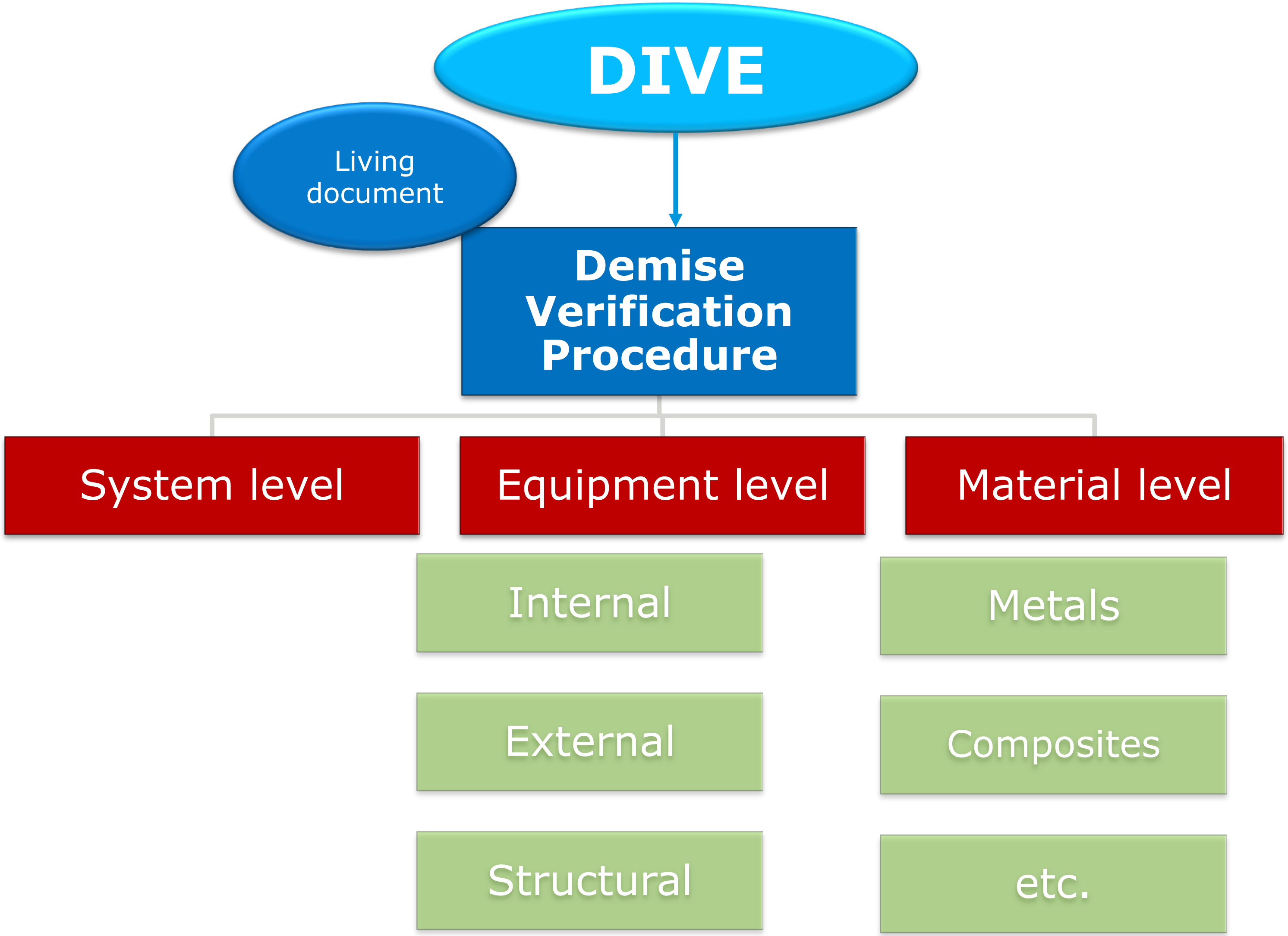
Need to flow down requirements at equipment level

Models & Test

Need procedures to combine test and simulation

Need for **modelling and testing guidelines for demise verification** commonly accepted and validated.

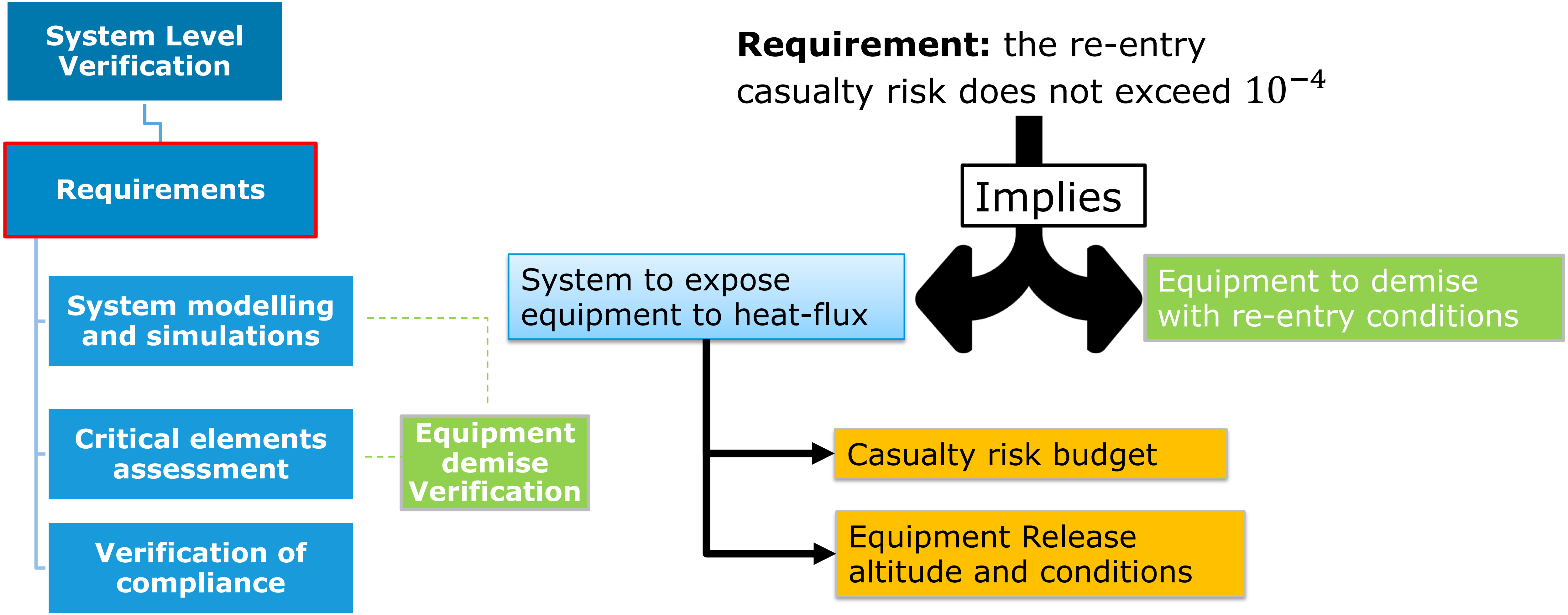
Demise Verification Guidelines



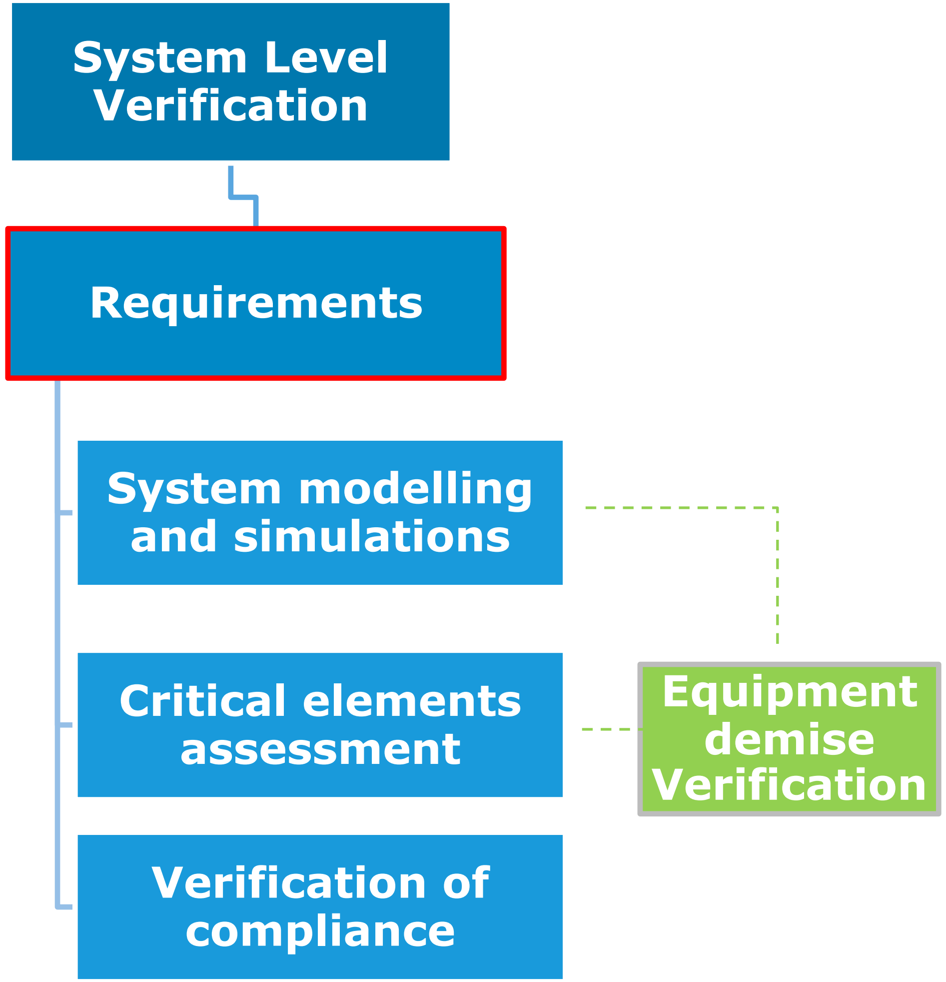
TECHNICAL NOTE

DIVE - Guidelines for Analysing and Testing the Demise of Man Made Space Objects During Re-entry

System level procedure



System level procedure



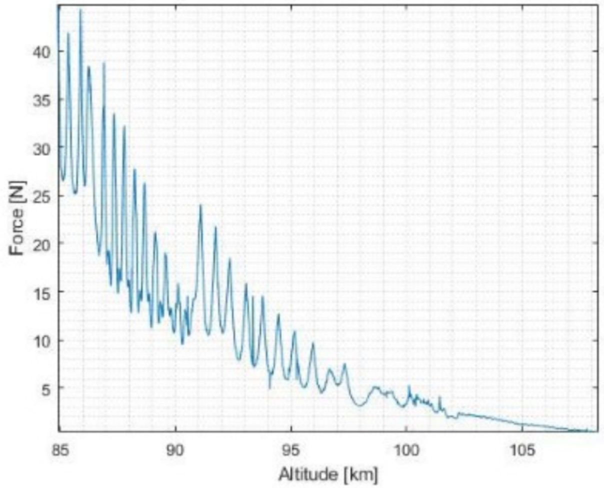
Simulations: DIVE defines system level modeling rules. These simulations will define:

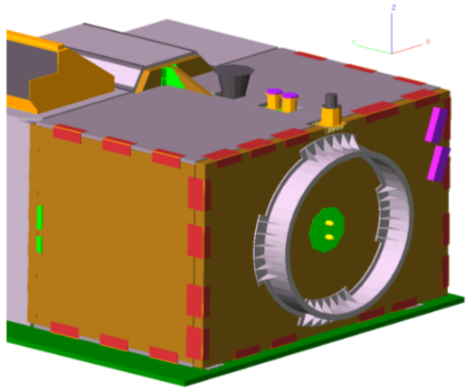
→ **Critical parts/equipment**

→ **Trajectory & equipment release conditions**

Uncertainties: atmospheric parameters, trajectory, loads, materials behavior, fragmentation process, etc.

→ **Statistical approach**





System level procedure

System Level Verification

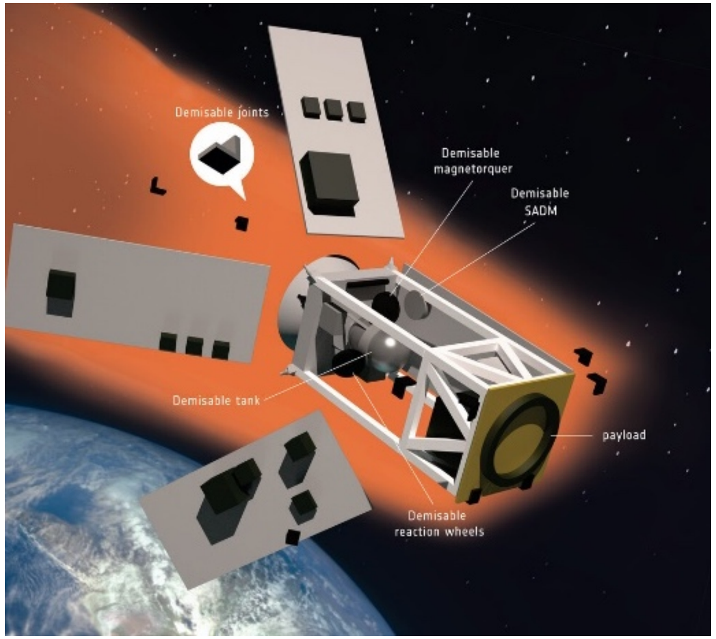
Requirements

- **System modelling and simulations**
- **Critical elements assessment**
- **Verification of compliance**

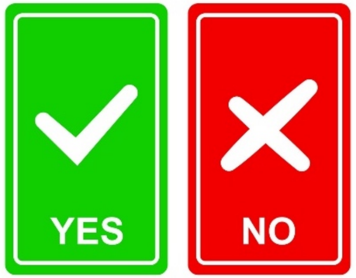
Equipment demise Verification

Verification of compliance - Reentry simulation with:

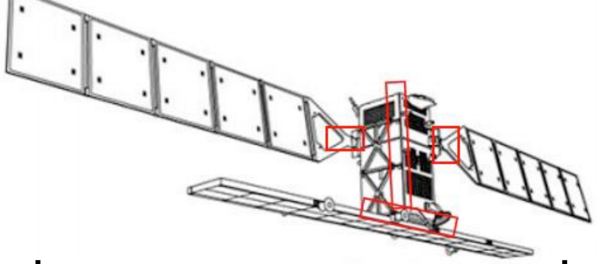
- Verified critical equipment models
- Verified break-up sequence
- Uncertainties taken into account



COMPLIANT ?



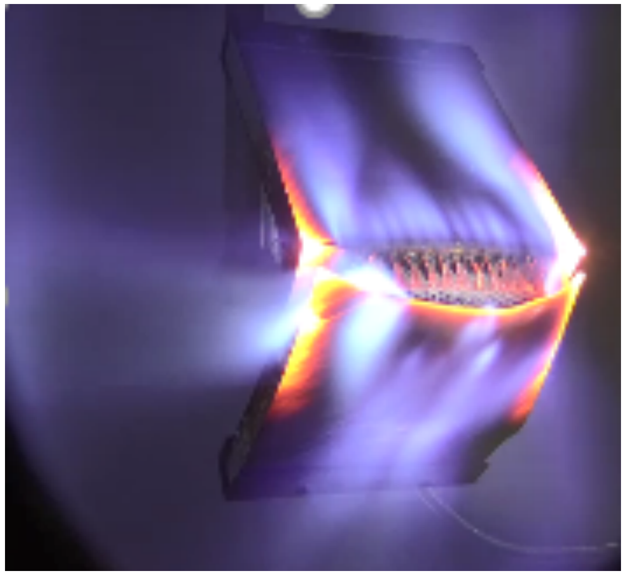
Design for Demise System level

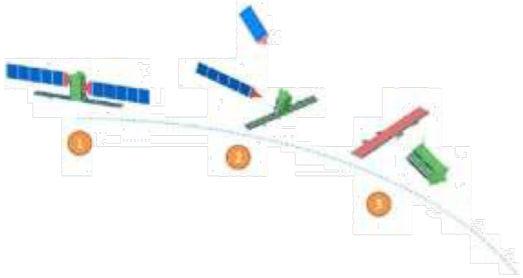


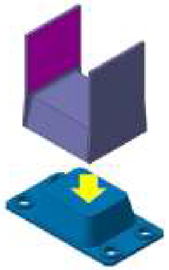
System Design for Demise means to ensure break-up sequence needed for critical equipment to demise

Example: *development of demisable structural joints for early break-up of external panels (e.g. >90km instead of ~80km)*

Sentinel 1 C/D study case:
Demisable joint to release SAR antenna
Soldered joint – low melting temperature
*Early separation → **SAR mostly demises***







Equipment level procedure

- **Equipment Level Verification**
  - **Requirements**
    - **Modelling and simulations**
    - **Demise Tests**
    - **Verification and model correlation**

How to define Equipment level Requirements?

Specific mission? → Release conditions? ← Generic Technology?

Release conditions? → Altitude | Trajectory | Temperature

Example: *the equipment shall demise when released at geodetic altitude of TBC km or above for a re-entry corridor TBD, assuming an initial release temperature of TBC K.*

Propellant tank (internal equipment):

78km | LEO | 300K

Equipment level procedure

Equipment Level Verification

Requirements

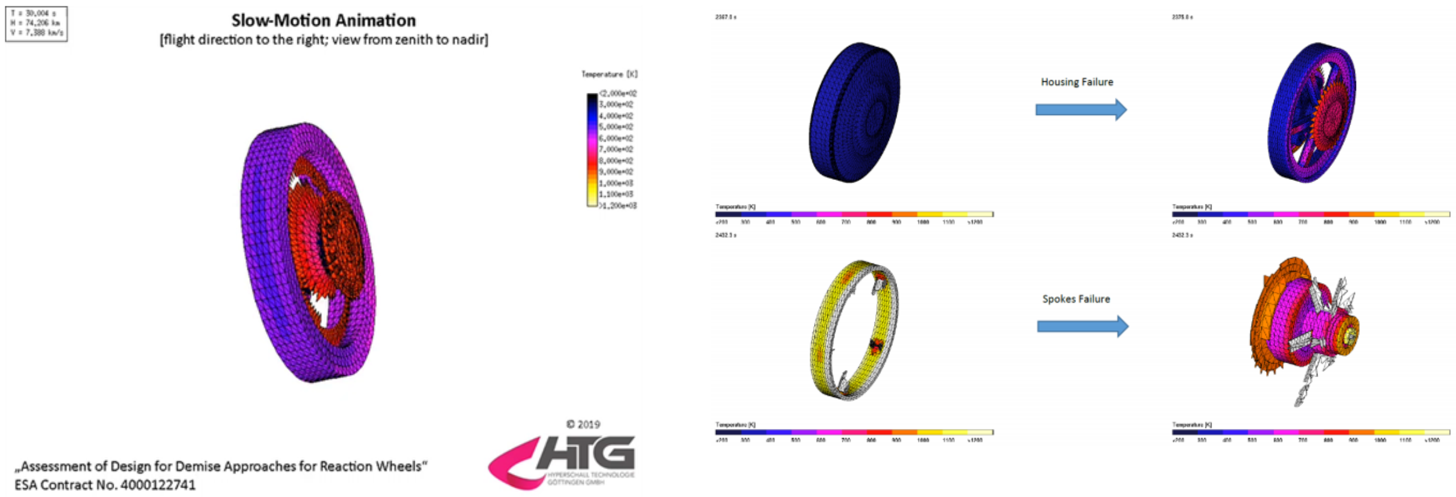
- **Modelling and simulations**
- **Demise Tests**
- **Verification and model correlation**

Material level Verification

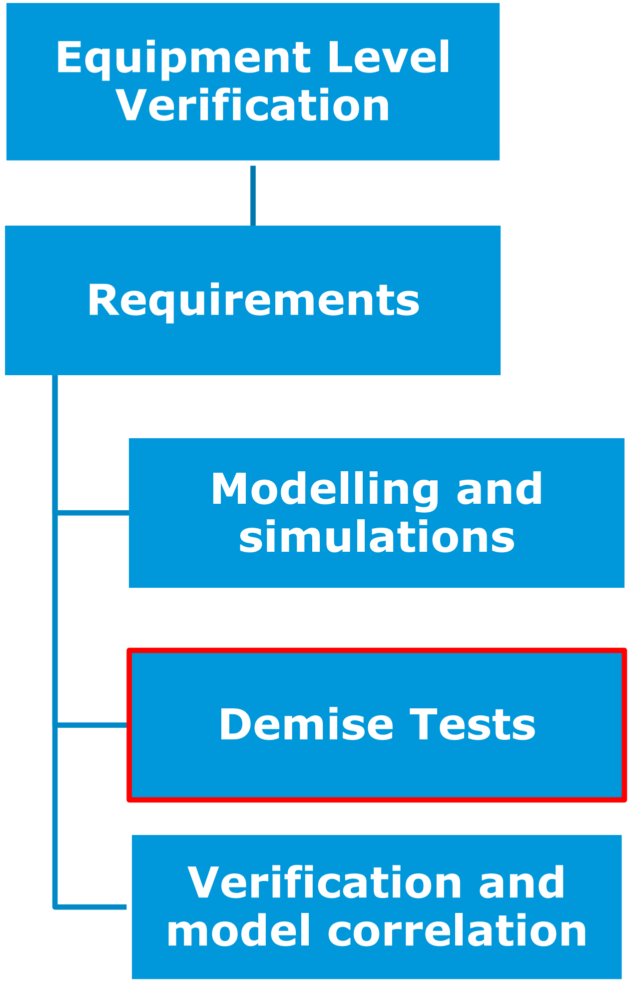
Do we have the right model?

- All relevant parts modelled?
- All materials properties known?
- All uncertainties considered?
- Simulation of demise events representative?

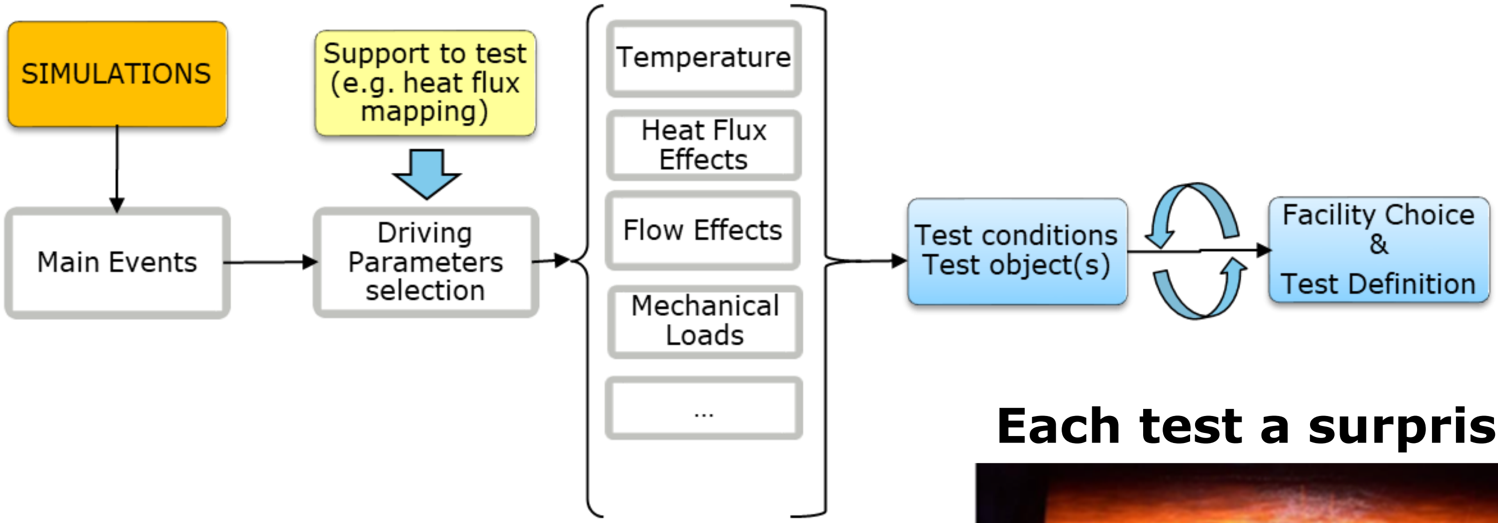
Example: RW demise events of interest: *e.g. housing melt, flywheel separation, BBU/central shaft separation, etc.*



Equipment level procedure



How to define the tests?



Example: *MTQ demise test*

1. *Housing "pealing"*
2. *Potting material regression*
3. *Coil melt layer by layer*
4. *Core material emissivity change*

Model couldn't foresee such effects

Each test a surprise?

Equipment level procedure

Equipment Level Verification

Requirements

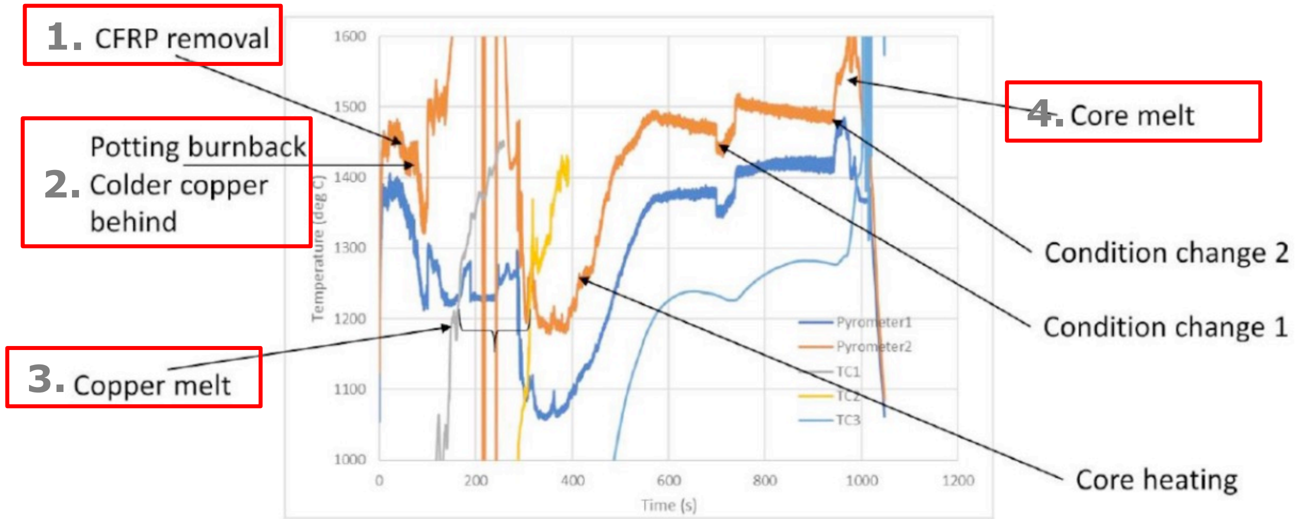
- **Modelling and simulations**
- **Demise Tests**
- **Verification and model correlation**

How can tests be correlated with full re-entry?

Ground Test Event A → Simulation Event A → Simulation Reentry

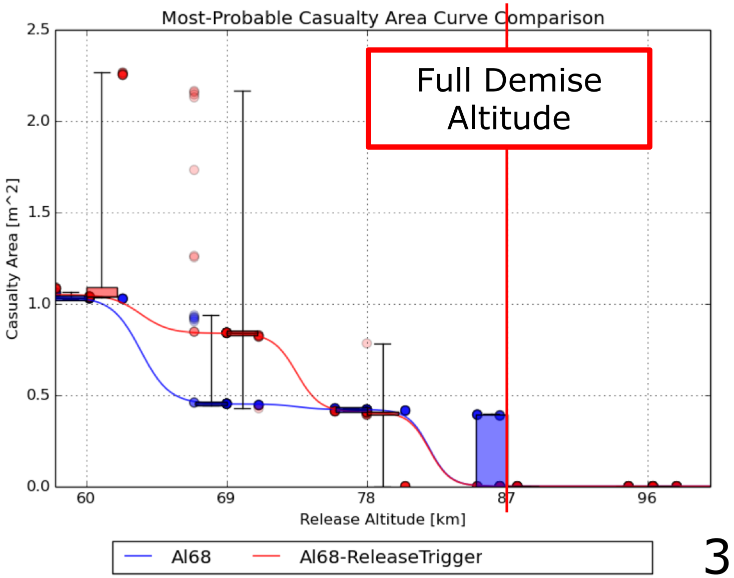
1. Test prediction Simulation
2. Ground tests w/ specific conditions
3. Modify Models to mimic test
4. Extrapolation to Reentry conditions

Example: *MTQ Plasma Wind Tunnel observed phenomena*



Design for Demise at Equipment level

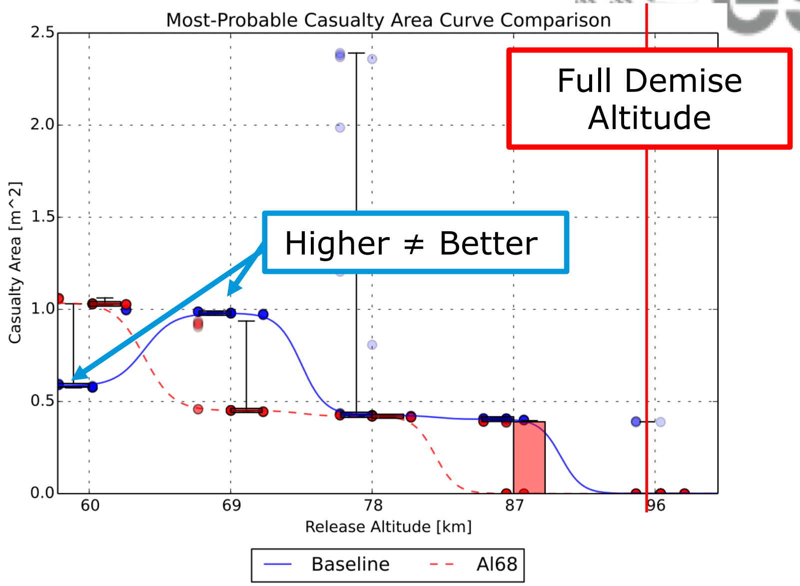
Example:
Reaction Wheels design for full demise when released at 78km

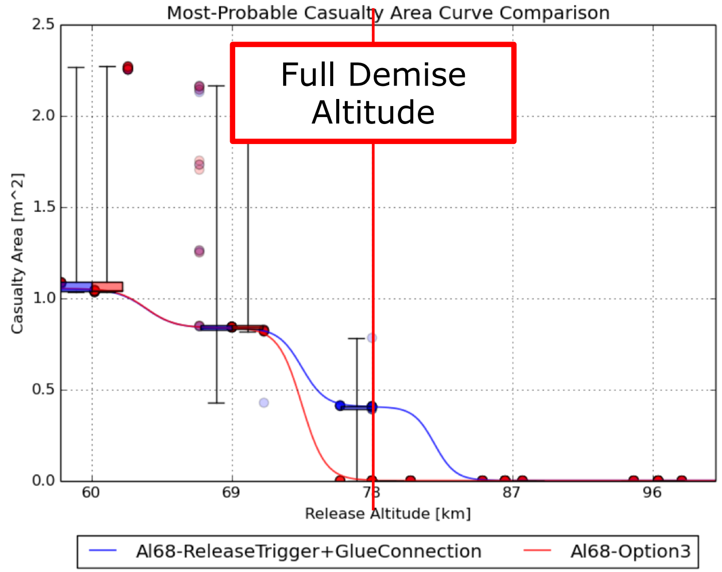


1: Fly-wheel material change →

← 2: BBU/motor disintegration

3: Oil Chamber material change →





Avoid preconceived ideas!

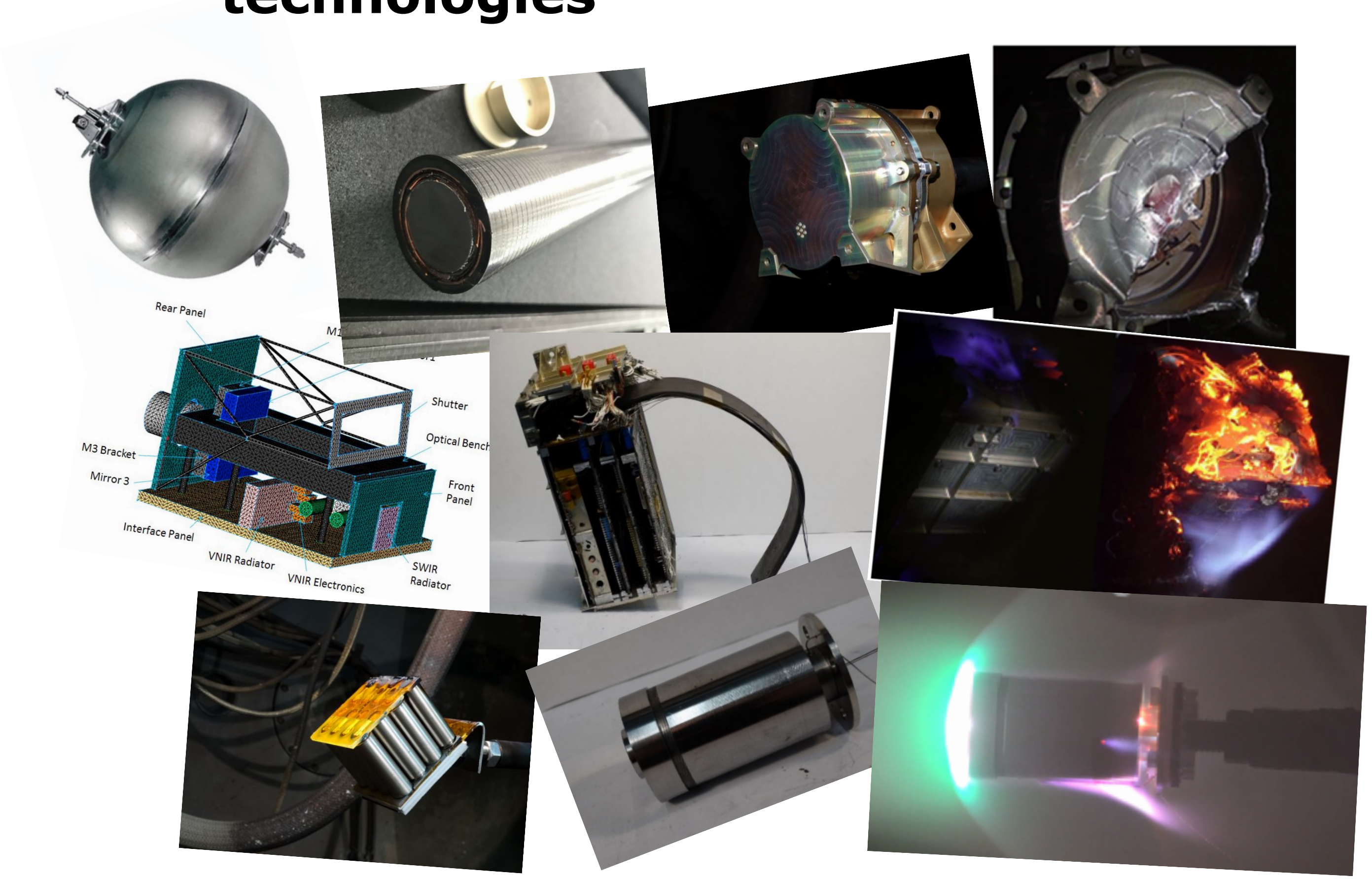
Highly iterative process

Combination of techniques & disciplines

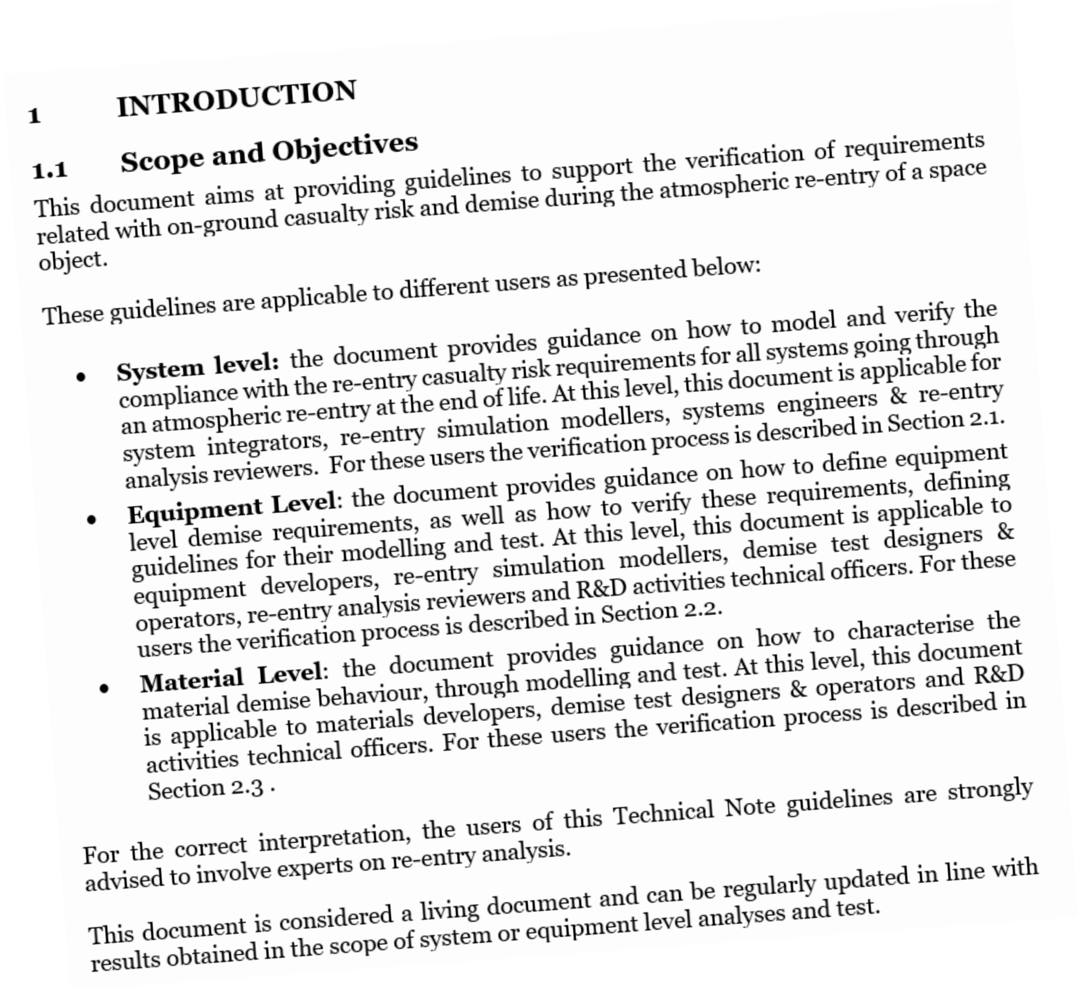
Equipment level procedure

More elements have been tested and will be tested to develop demisable technologies

- Reaction Wheels
- Magnetorquer
- Electronic box
- Batteries
- Propellant tank
- Pressured gas tanks
- Optical Payloads
- Composite materials….



DIVE – The living document


1 INTRODUCTION

1.1 Scope and Objectives

This document aims at providing guidelines to support the verification of requirements related with on-ground casualty risk and demise during the atmospheric re-entry of a space object.

These guidelines are applicable to different users as presented below:

- **System level:** the document provides guidance on how to model and verify the compliance with the re-entry casualty risk requirements for all systems going through an atmospheric re-entry at the end of life. At this level, this document is applicable for system integrators, re-entry simulation modellers, systems engineers & re-entry analysis reviewers. For these users the verification process is described in Section 2.1.
- **Equipment Level**: the document provides guidance on how to define equipment level demise requirements, as well as how to verify these requirements, defining guidelines for their modelling and test. At this level, this document is applicable to equipment developers, re-entry simulation modellers, demise test designers & operators, re-entry analysis reviewers and R&D activities technical officers. For these users the verification process is described in Section 2.2.
- **Material Level**: the document provides guidance on how to characterise the material demise behaviour, through modelling and test. At this level, this document is applicable to materials developers, demise test designers & operators and R&D activities technical officers. For these users the verification process is described in Section 2.3 .

For the correct interpretation, the users of this Technical Note guidelines are strongly advised to involve experts on re-entry analysis.

This document is considered a living document and can be regularly updated in line with results obtained in the scope of system or equipment level analyses and test.

- DIVE report available for ESA MS stakeholders (contact us!)
- Feedback and comments are welcome

Material level - ESTIMATE Database

European Space material demisability daTabasE (ESTIMATE)

Material level tests will feed the database.

Equipment level tests will also feed the database soon.

Web page to collect measurement data to characterise material parameters:
https://estimate.sdo.esoc.esa.int/database

Includes:
- Tested Materials descriptions
- Test Facilities descriptions
- Tests Summary
- Downloadable Material properties

Design for Demise Vision

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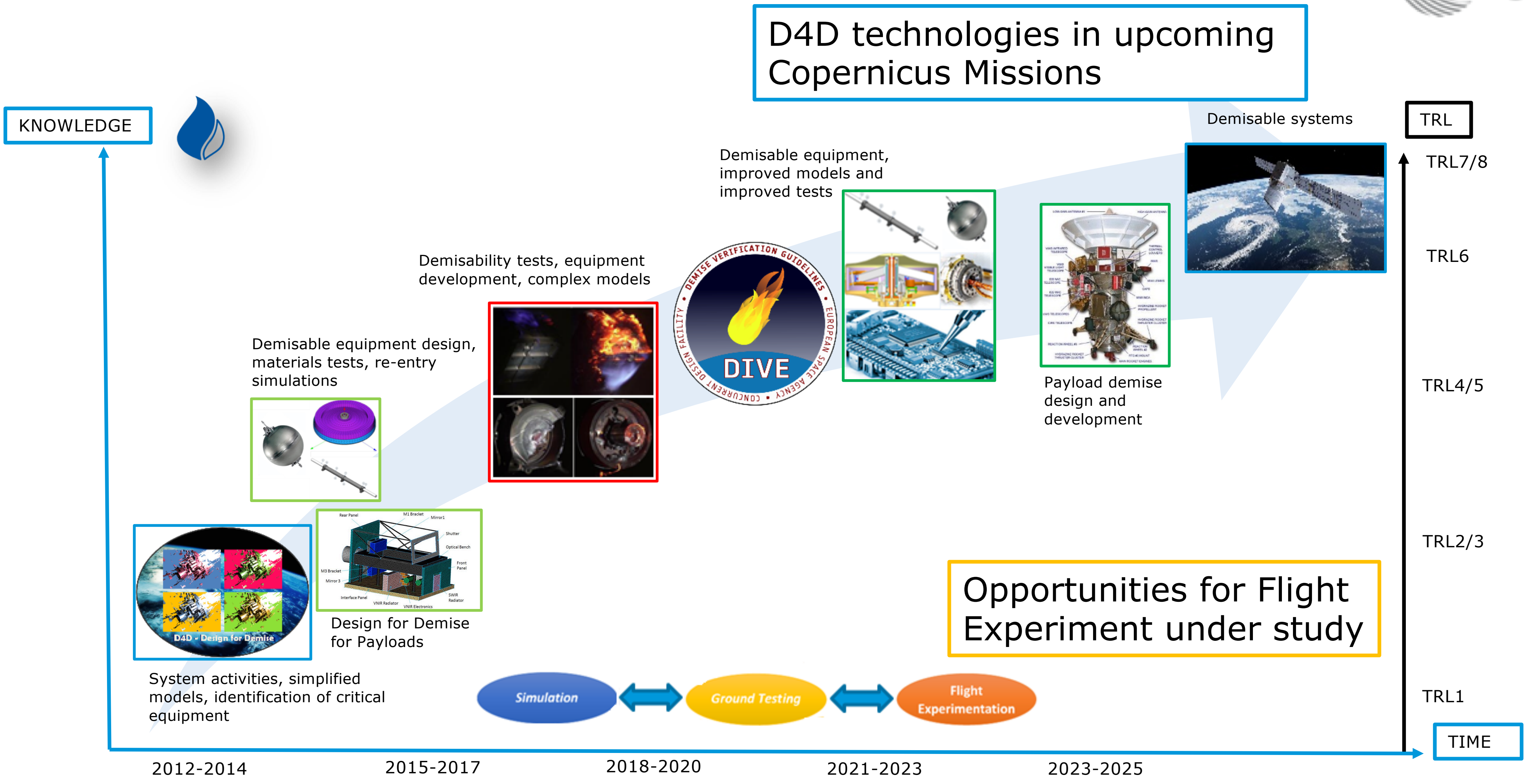
The vision


D4D technologies in upcoming Copernicus Missions
KNOWLEDGE
Demisable systems
TRL
TRL7/8
TRL6
TRL4/5
TRL2/3
TRL1
TIME
Demisable equipment, improved models and improved tests
Demisability tests, equipment development, complex models
DEMISE VERIFICATION GUIDELINES • EUROPEAN SPACE AGENCY • CONCURRENT DESIGN FACILITY •
DIVE
Demisable equipment design, materials tests, re-entry simulations
Payload demise design and development
D4D - Design for Demise
Design for Demise for Payloads
System activities, simplified models, identification of critical equipment
Opportunities for Flight Experiment under study
Simulation
Ground Testing
Flight Experimentation
2012-2014
2015-2017
2018-2020
2021-2023
2023-2025

Summary

1. There is an urgent need and a high demand for new solutions aiming to on-ground casualty risk reduction lower than 10^{-4}
2. Design for Demise is the intentional design of space systems & hardware such that they will disintegrate during an atmospheric re-entry
3. Future platform will benefit of design for demise with an uncontrolled re-entry.
4. Several activities on-going at ESA for the development of new technologies and knowledge in the areas of design for demise
5. ESA has prepared the first Guidelines for Demise Verification (DIVE) that are now available for the ESA Member States stakeholders

Clean Space Webinar Series

ecodesign

→ REDUCING IMPACTS

management of end of life

→ SPACE DEBRIS REDUCTION

Webinar: EcoDesign

Date: 24th of June

Time: 15:00 CEST

in-orbit servicing

→ ACTIVE DEBRIS REMOVAL

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