What to do when re-entry just isn't hot enough?

Aerothermodynamics and Design for Demise (ATD3) Workshop 2021

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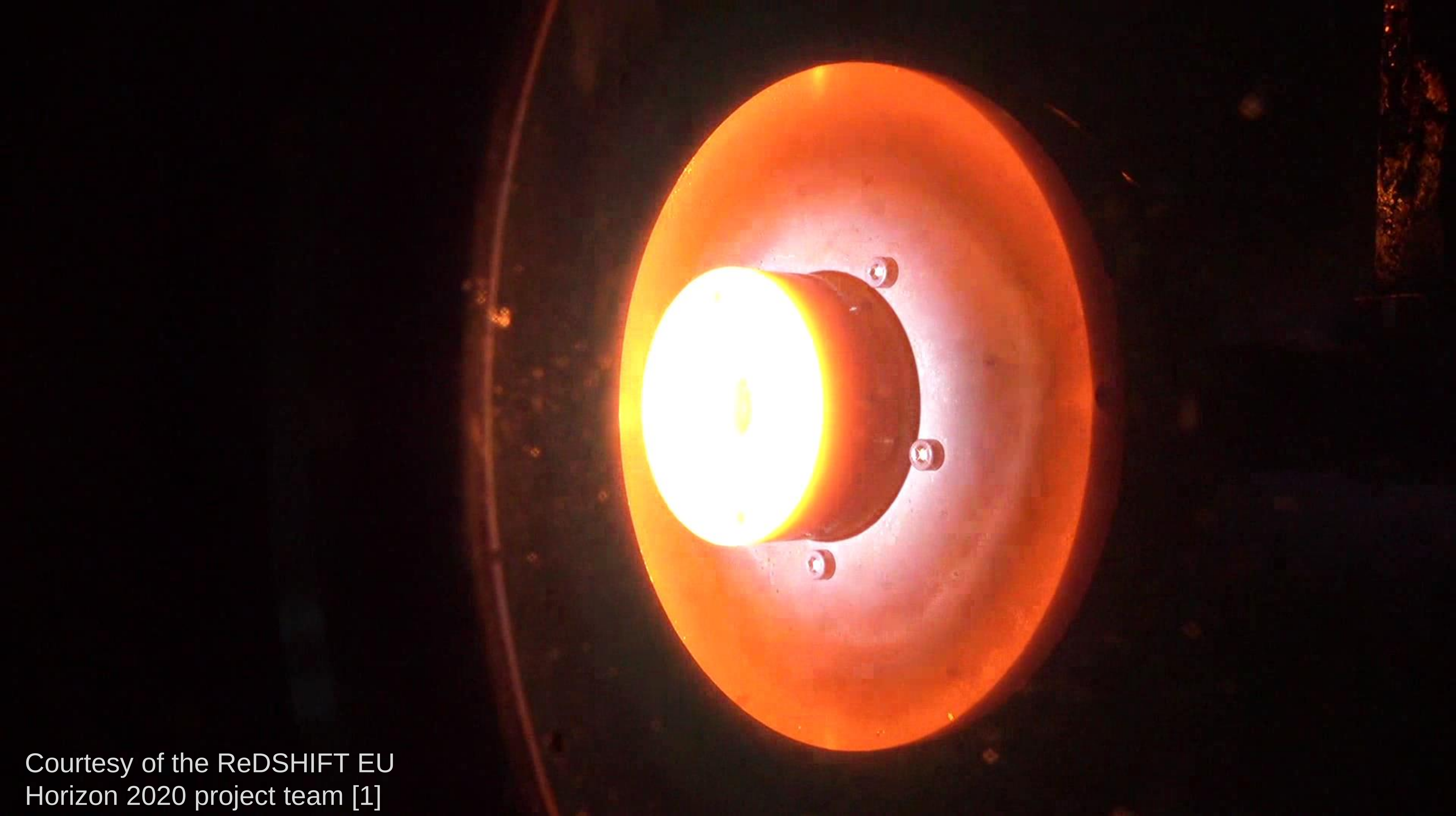


Courtesy of the ReDSHIFT EU
Horizon 2020 project team [1]

D4D techniques

Minimize Required Heat

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

Maximize Available Heat

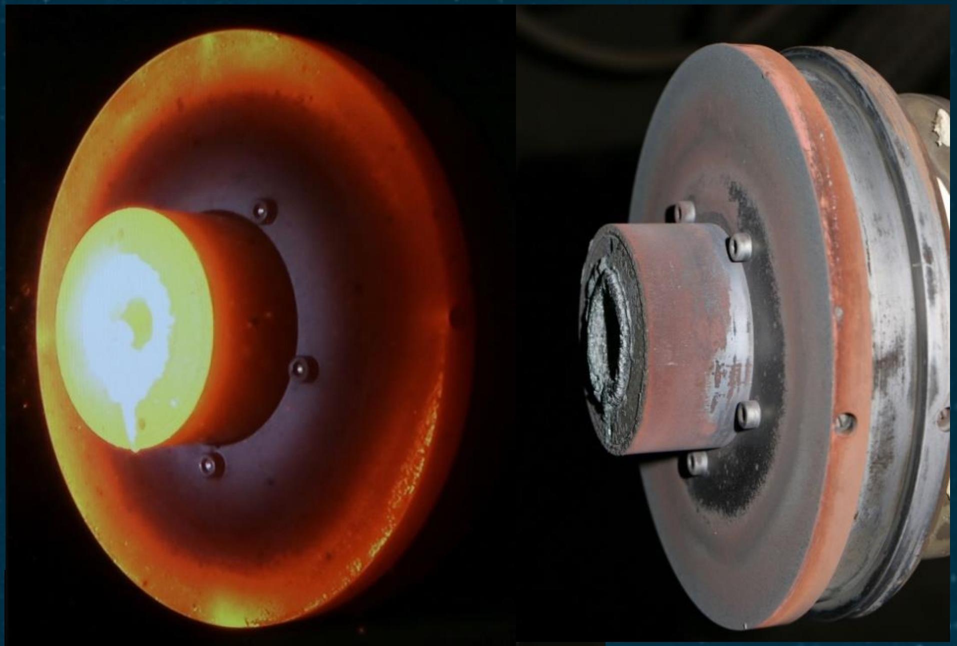
- Ballistic coefficient
- Increase local heat flux – Shapes of objects

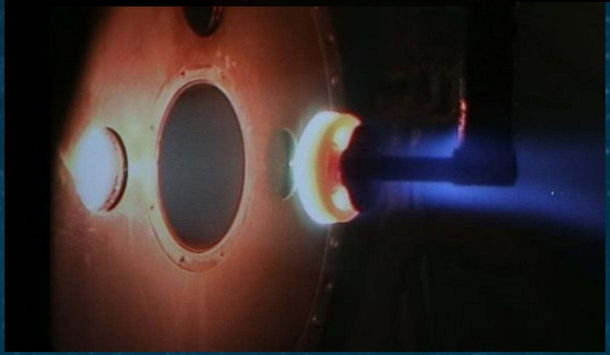
Optimize Heat Transfer

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

Minimize Casualty Area

- Keeping re-entry fragments together - Containment





Left: RW during 800kW/m^2 demise test.

Right: RW after demise test

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esa

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Maximize Available Heat

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- Add energy – Exothermic reactions

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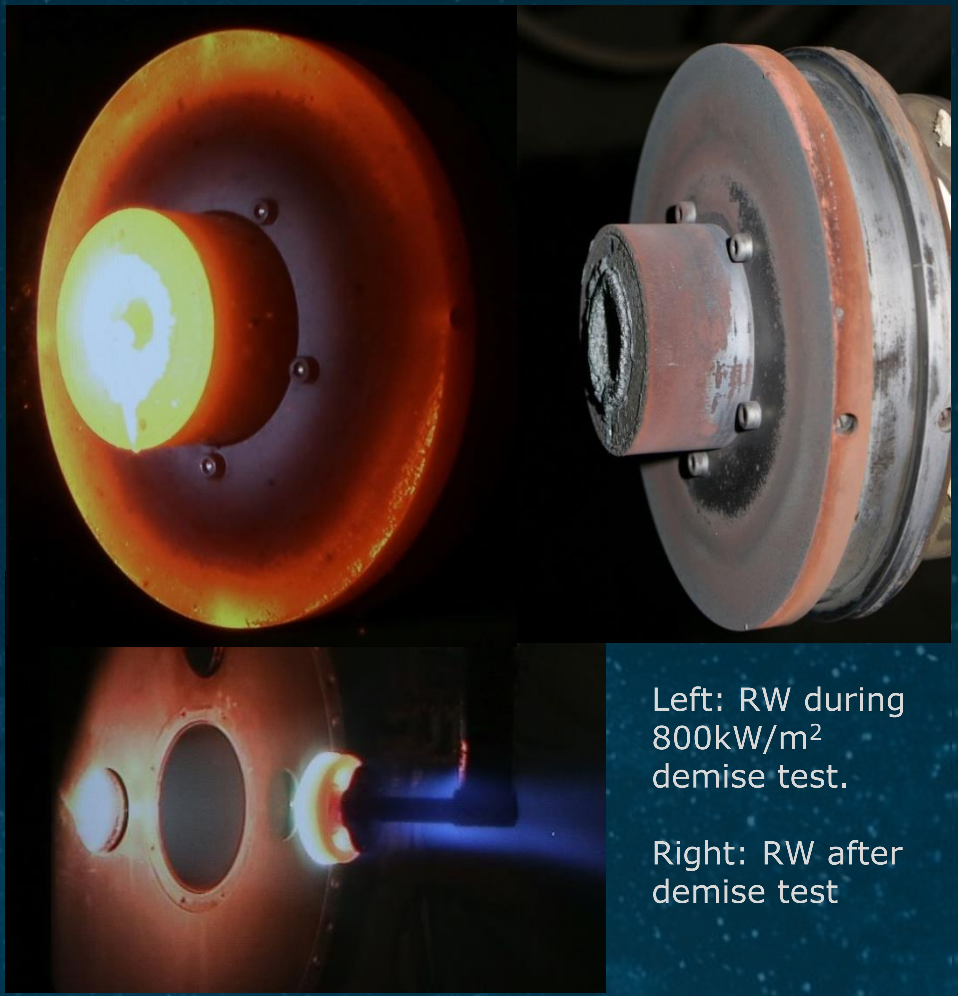

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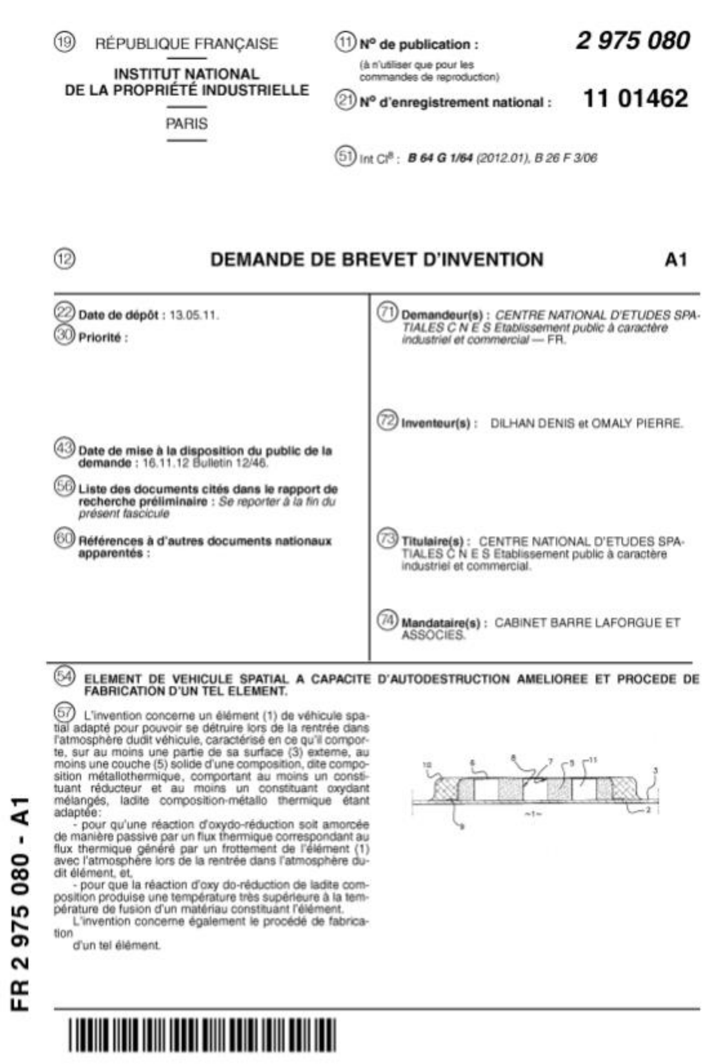
Make it hotter!

Exothermic reactions as a D4D technique

- CNES patent FR2975080-A1 [2]
  'Élément de véhicule spatial à capacité d'autodestruction améliorée et procédé de fabrication d'un tel élément'
- ESA patent EP3604143-A1 [3]
  'Exothermic reaction aided spacecraft demise during re-entry'



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(12) DEMANDE DE BREVET D'INVENTION A1

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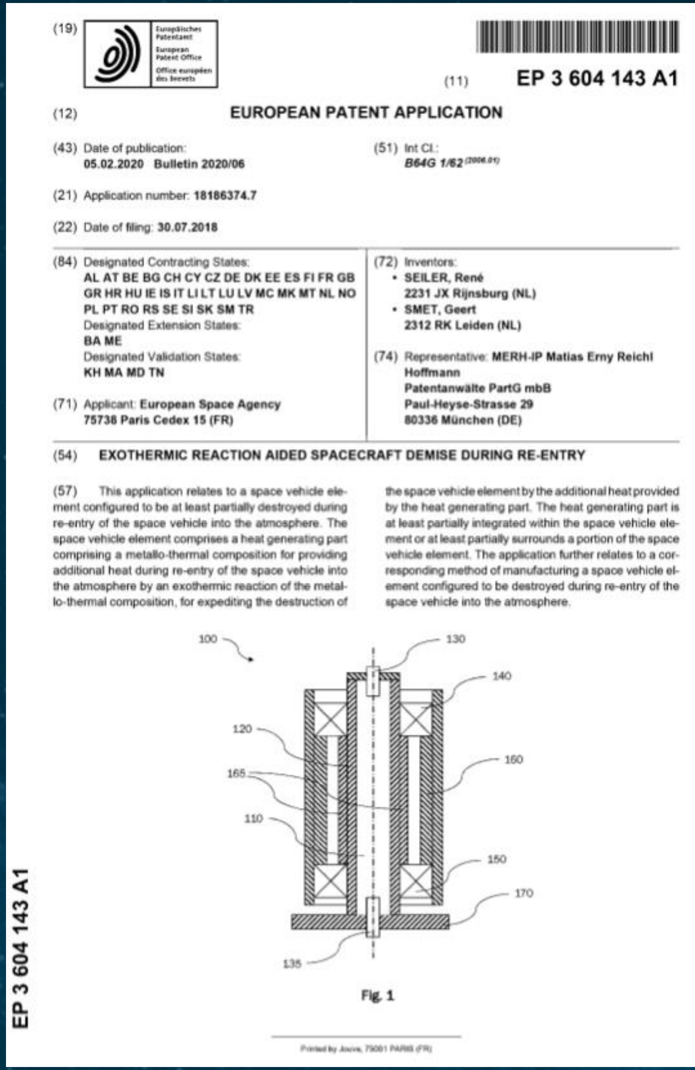
(71) Demandeur(s) : CENTRE NATIONAL D'ETUDES SPATIALES C N E S Etablissement public à caractère industriel et commercial — FR.
(72) Inventeur(s) : DILHAN DENIS et OMALY PIERRE.
(73) Titulaire(s) : CENTRE NATIONAL D'ETUDES SPATIALES C N E S Etablissement public à caractère industriel et commercial.
(74) Mandataire(s) : CABINET BARRE LAFORGUE ET ASSOCIES.

(54) ELEMENT DE VEHICULE SPATIAL A CAPACITE D'AUTODESTRUCTION AMELIOREE ET PROCEDE DE FABRICATION D'UN TEL ELEMENT.

(57) L'invention concerne un élément (1) de véhicule spatial adapté pour pouvoir se détruire lors de la rentrée dans l'atmosphère dudit véhicule, caractérisé en ce qu'il comporte, sur au moins une partie de sa surface (3) externe, au moins une couche (5) solide d'une composition, dite composition métallothermique, comportant au moins un constituant réducteur et au moins un constituant oxydant mélangés, ladite composition-métallo thermique étant adaptée :
- pour qu'une réaction d'oxydo-réduction soit amorcée de manière passive par un flux thermique correspondant au flux thermique généré par un frottement de l'élément (1) avec l'atmosphère lors de la rentrée dans l'atmosphère dudit élément, et,
- pour que la réaction d'oxy do-réduction de ladite composition produise une température très supérieure à la température de fusion d'un matériau constituant l'élément.
L'invention concerne également le procédé de fabrication d'un tel élément.

FR 2 975 080 - A1



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(71) Applicant: European Space Agency 75738 Paris Cedex 15 (FR)
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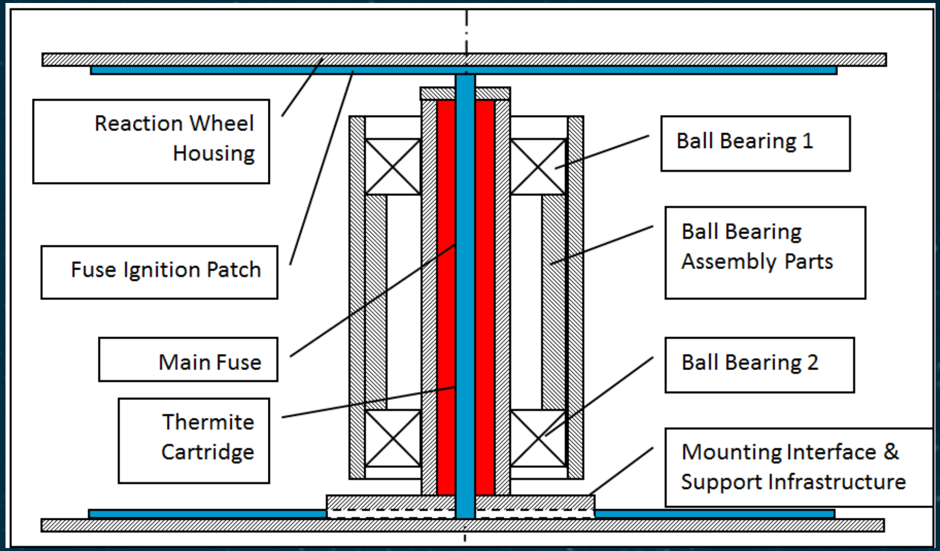
- SMET, Geert 2312 RK Leiden (NL)
(74) Representative: MERH-IP Matias Erny Reichl Hoffmann Patentanwälte PartG mbB Paul-Heyse-Strasse 29 80336 München (DE)
(54) EXOTHERMIC REACTION AIDED SPACECRAFT DEMISE DURING RE-ENTRY
(57) This application relates to a space vehicle element configured to be at least partially destroyed during re-entry of the space vehicle into the atmosphere. The space vehicle element comprises a heat generating part comprising a metallo-thermal composition for providing additional heat during re-entry of the space vehicle into the atmosphere by an exothermic reaction of the metallo-thermal composition, for expediting the destruction of the space vehicle element by the additional heat provided by the heat generating part. The heat generating part is at least partially integrated within the space vehicle element or at least partially surrounds a portion of the space vehicle element. The application further relates to a corresponding method of manufacturing a space vehicle element configured to be destroyed during re-entry of the space vehicle into the atmosphere.

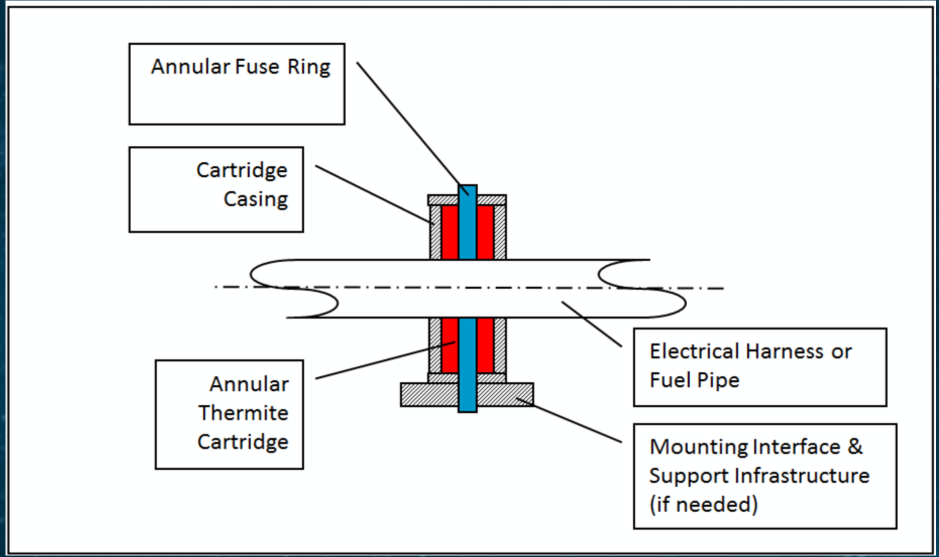
Fig. 1

EP 3 604 143 A1

Exothermic reactions as a D4D technique

- Providing extra energy to undemisable equipment
- Severing the interface between the spacecraft and equipment
- Fragmenting equipment in two or more parts
- Severing secondary mechanical interfaces, e.g. harness, propulsion or heat pipes
- Combination of several of the above, where for example the interfaces are severed, the equipment is fragmented and additional energy is added to the remaining fragments. This use case requires predetermined sequencing of events, e.g. by using fuses
- Altering the aerodynamic properties of equipment, e.g. creating a hole in a propellant tank [6]
- Severing joints in the spacecraft to enable break up, e.g. by introducing energetic materials in the joint or in the spacecraft structural panels surrounding the joint/insert
- Creating thermo-elastic stresses that lead to fracture or rupture



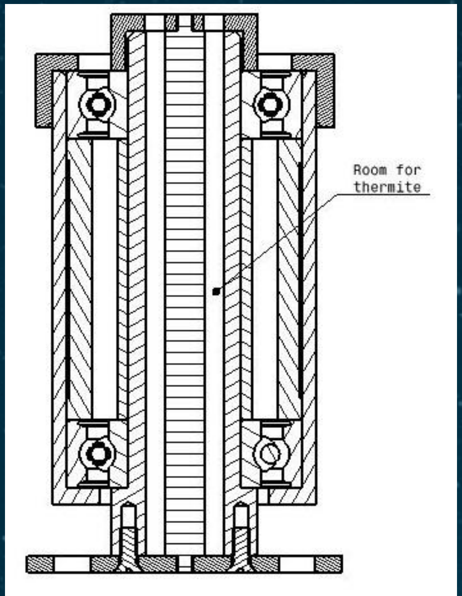


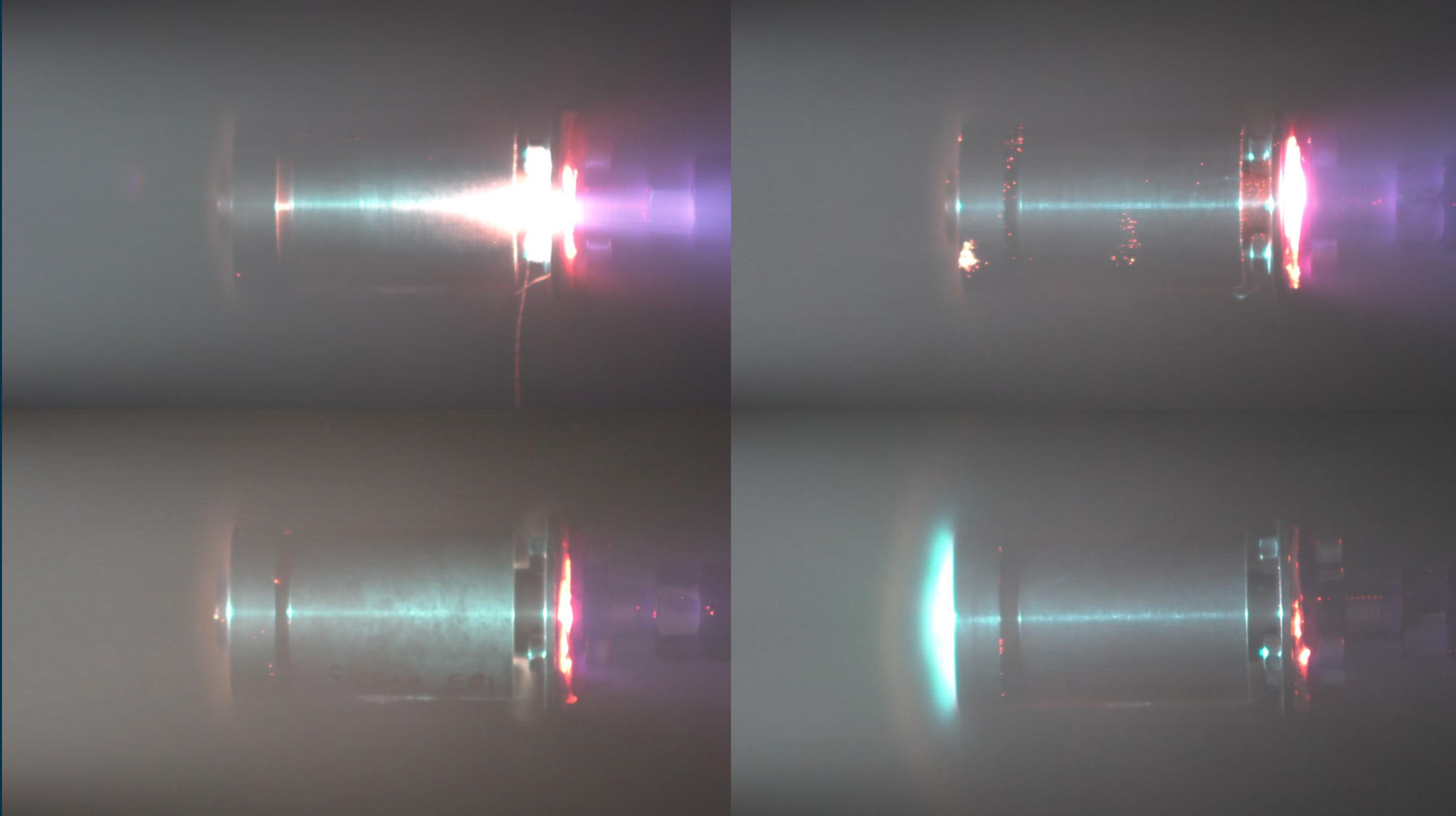
Implementation

- Thermite or thermite-like substances (providing reactant and oxidizer)
  - Composition of metal powder and metal oxide, e.g. Fe_2O_3+Al
  - Non-explosive highly exothermic redox reaction
  - Limited mass impact
  - Safe
  - Physically and chemically inert
  - Very high ignition temperatures (> 600 degC), only during re-entry
- Fuse technology
  - Thermal conductor
  - Energetic fuse: Hypergolic reaction
  - Energetic fuse: Metallic fuel, oxidizer, binder

First trials

- Internal ESA assessment in three phases [4]
  - Pathfinder tests at ambient
  - Tests at temperature
  - Tests in plasma wind tunnel [5]
- Test sample inspired by reaction wheel BBU
  - Tests limited to one thermite composition





First trials - Results

- First test campaign yielded mixed results
  - Thermite ignition in PWT
  - Release of additional energy demonstrated
- Limited impact on demise
  - Insufficient thermite for the test sample
  - Complicated test sample
  - Issues with test predictions and correlation
  - Sub-optimal test set-up, yielding a non-representative temperature distribution

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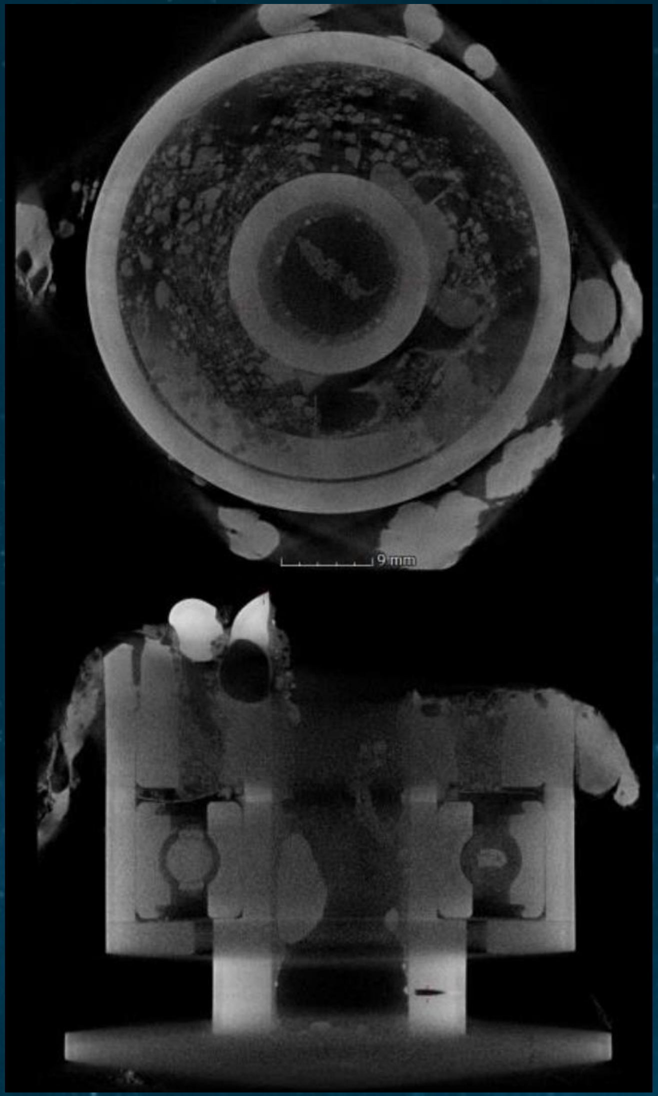
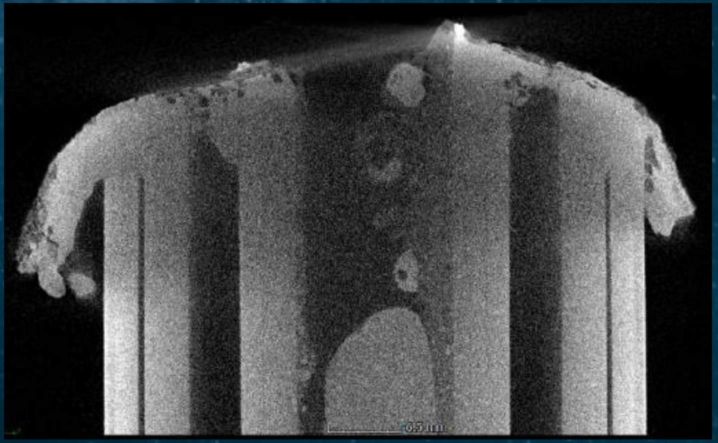
  - Sub-optimal test set-up, yielding a non-representative temperature distribution
  - Sub-optimal thermite composition
  - Impact of the formation of slag





Future development

- ESA activity ‘Spacecraft demise during re-entry using various exothermic reactions’ has just started
  - Design, optimization and proof of concept by simulation and test at breadboard level in a representative environment of the use of exothermic reactions for demise purposes. The desirability/viability of different use cases needs to be assessed
    - The correct sizing of the quantity to be used for a given application
    - The optimal mixture (compounds, binder, particle size) to achieve the maximum possible energy release, as well as a reliable burn process
    - The optimal timing/temperature of the ignition, potentially making use of fuses
    - The potential negative influence of the reaction products (slag)
  - Design and verification of different fuse concepts to provide the energy needed for ignition at various temperatures
  - Devising design guidelines for use of the technology in various equipment
- Two parallel contracts running
  - Consortium 1: HTG Hyperschall Technologie Göttingen GmbH, Politecnico Milano 1863, ReActive Powder Technology, DLR
  - Consortium 2: OHB, FGE, Belstead, T-Minus Engineering, IRS

Future development

- Task 1: Theoretical framework and material selection
    - Task 1.1: Perform a literature review
    - Task 1.2: Assess potential use cases and derive the requirements for the energetic material
    - Task 1.3: Establish the required theoretical framework for use of energetic material as a D4D technique
    - Task 1.4: Select the materials for further use in this study
- Task 2: Design of proof of concept breadboards
    - Task 2.1: Design fuse concepts for testing
    - Task 2.2: Design proof of concept breadboards for testing
- Task 3: Breadboard test campaign
    - Task 3.1: Test predictions
    - Task 3.2: Test campaign
    - Task 3.3: Test correlation
- Task 4: Design guidelines
    - Task 4.1: Establish design guidelines
    - Task 4.2: Collect lessons learned and provide recommendations for further development of this D4D technique

Conclusions

- D4D usually requires a combination of several techniques
- Exothermic reactions could be used as a new, additional D4D technique
- Compared to re-entry, exothermic reactions add a relatively small additional amount of energy
  - The energy can be released where and when it is necessary
- Using exothermic reactions to facilitate demise could provide a paradigm shift, from trying to design all equipment for demise, to demising existing equipment with minor changes while leveraging existing heritage

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Questions?

Feel free to contact the authors for questions: geert.smet@esa.int, rene.seiler@esa.int

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2. *Élément de véhicule spatial à capacité d'autodestruction améliorée et procédé de fabrication d'un tel élément*. **Dilhan, D and Omaly P.** Centre national d'études spatiales. FR2975080-A1.
3. *Exothermic reaction aided spacecraft demise during re-entry.* **Seiler, R and Smet, G.** European Space Agency. EP3604143-A1.
4. *German Trainee Programme Final Report*, **Nico Reichenbach (TEC-MSM)**, 20/03/2019.
5. *ERASD - Exothermic Reaction Aided Spacecraft Demise - Proof of Concept Testing – Final Report*, Contract No. 4000126547/19/NL/AR/ig, Issue 1, Revision 2, 10/05/2019.
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