DESIGN FOR CONTAINMENT TECHNIQUES TO REDUCE SPACECRAFT RE-ENTRY FOOTPRINT

CSID 2022, 10-14 OCTOBER 2022

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Date: 19/09/2022
Ref: Not referenced
Template: 83230347-DOC-TAS-EN-010

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INTRODUCTION

- Current launch rate between 100 and 150 launches per year. Some inject up to 50 satellites into orbit at once. The number of objects in space increases steadily and so does the probability of casualty due to the re-entry of spacecraft and space debris.
- The most effective long term means to stabilise the space debris environment at a safe level is compliance to post-mission guidelines. For Low Earth Objects :
  - Controlled re-entry if casualty risk $>10^{-4}$
  - **Un-controlled re-entry** if casualty risk $<10^{-4}$
    - Casualty Area can be reduced using :
      - Design for Demise
      - **Design for Containment**

Several parts of the spacecraft may, due to performance requirements or long development cycles not be suitable to be made demisable by change of materials or design.

Design for Containment *attempts to reduce on-ground casualty risk by using specific* ***hardware*** *or* ***design principles*** *to maintain* ***several critical elements as one single object****.*

This way, the probability of collision with a human is reduced by reducing the number of independent fragments reaching ground.

ATV-1 re-entry (source: ESA)

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PROJECT OBJECTIVES AND APPROACH

/// **Objective**: Identify and validate containment techniques that can be broadly applied to spacecraft critical elements to reduce the casualty area of the spacecraft re-entry event.

- Investigate, asses, trade-off, prototype and test methods to contain critical elements
- Provide an update to the current material database for re-entry models (ESTIMATE) and feedback to the ESA guidelines for demise verification DIVE (Demise Verification Guidelines for Analysing and Testing the Demise of Man Made Space Objects During Re-entry)

/// **Approach**:

- Assessment of containment methods based on a literature review and preliminary re-entry simulations of several different satellite missions as study cases
- Detailed simulations and trade-off between the different identified containment methods
- Elaboration of a test plan and prototypes of the best containment methods and predictive re-entry simulations
- Test and analysis of the results, modelling recommendations and updates to DIVE and ESTIMATE

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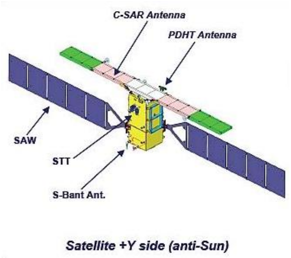
CRITICAL ELEMENTS

/// **LEO Radar satellites**, such as Sentinel 1 and ROSE-L

/// Large satellites with a chemical propulsion

- Platform
  - Reaction Wheels
  - Magnetotorquers
  - Large Electronic Boxes
  - Titanium propellant tanks
  - Star Tracker parts
- Payload
  - SAR antenna

ROSE-L (source : ESA)



Sentinel 1 (source : ESA)

/// **LEO High Resolution small satellites** (constellation)

/// Small satellites with an electric propulsion, payload integrated in the platform

- Platform
  - Reaction Wheels
- Payload
  - Telescope
    - Mirrors
    - Ceramic structural slats
    - Titanium inserts and parts

Examples of critical elements

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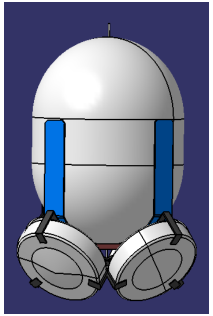
CONTAINMENT TECHNIQUES : CLASSIFICATION

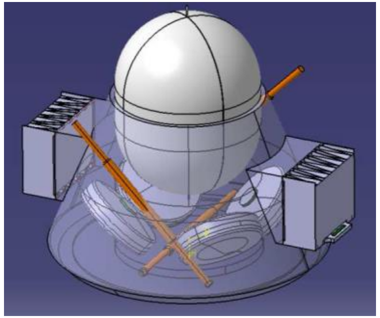
/// Regroup

- Architecture change - Regroup demise-critical elements from an architecture point of view in a configuration that is suitable for flight as well.
- Adaptative change - Regroup demise-critical elements from an architecture point of view only for re-entry configuration.

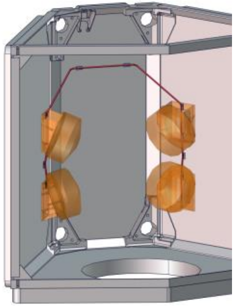
/// Attach

- Specific attachment - Attach demise-critical elements with a specific attachment link (only for re-entry purposes, with no need for flight).
- Interface change - Attach demise-critical elements with a specific interface upgraded on purpose to survive for re-entry purpose and containment techniques.
- Design change - Change the design of structural parts to obtain a single surviving assembly.





Examples: regrouping of tank and reaction wheels (left) and titanium frame holding together tank, reaction wheels and magnetorquers (right)



Example: attachment of reaction wheels using a tether

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CONTAINMENT TECHNIQUES : CLASSIFICATION

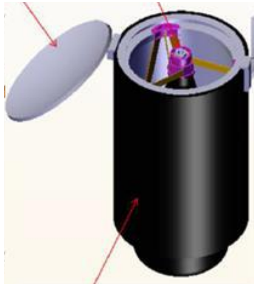
/// Protect

- Protection Upgrade - Improve the thermal protection to the aerothermal flux to ensure the survival of the protected block. Current design already implements a protection (thermal, mechanical…).
- Protection Addition - Add specific thermal protections to ensure the survival of the protected surface to the aerothermal flux. Assuming standard design never required such protection.
- Heat Shield Implementation - Add a thermo-mechanical heatshield protection to the current design.


Examples: Aerogel and protective foam (source : NASA)

/// Encapsulate

- Partial Encapsulation - Provide a mechanical containment but not a full thermal protection, allowing some mass of the internal elements to be further demised, so as to reduce the final kinetic energy.
- Total Encapsulation - Provide a complete (and perfect) mechanical containment and therefore thermal protection of parts to avoid the release of several debris.




Examples: total encapsulation and net for partial encapsulation

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CONTAINMENT TECHNIQUES : ENABLING TECHNOLOGIES

/// Metal alloys

- Titanium (1670°), tungsten (3400°), molybdenum (2620°), tantallum (2980°)

/// Ceramics

- SiC, Si3N4, SiSiC, HBCeSiC, C/C

/// Ablative materials

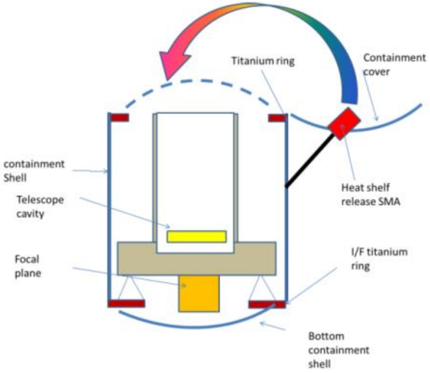
- Cork, Phenolic-Impregnated Carbon Ablator (PICA)

/// Flexible thermal protection

- Ceramic fiber (1800°C), alumina fiber (2000°C)

/// Mechanisms

- Shape memory alloy based actuators



Example : SMA based capsule closing system

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TRADE-OFF CRITERIA

Applicability of the Containment Concepts

- Applicability for future missions
- Applicability of the same method to different SC units
- Programmatic aspects

Benefits of the method

- N° of surviving fragments
- DCA reduction
- KE reduction
- Confidence level

Design and System impacts

- Accommodation
- Mass
- Costs
- Manufacturing complexity
- Structural/thermal/electromagnetic
- Reliability

Modelling aspects

- Modelling effort
- Modelling limitations
- Confidence in modelling

Testing aspects

- Test sample representativeness
- Test sample procurement
- Test facility compatibility

ID		1	2	3	4	5
		Applicability of method	Benefits of method	Design and System impacts of method	Modelling aspects	Testing aspects
1	**Applicability of method**		2	3	1	1
2	**Benefits of method**			3	2	2
3	**Design and System impacts of method**				3	3
4	**Modelling aspects**					5
5	**Testing aspects**					
	Criteria priority count	2	3	4	0	1
	Weights	20,0	26,7	33,3	6,7	13,3

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TRADE-OFF EVALUATION

- The most **applicable** methods have been found to be :
  - Regrouping and attaching for structural parts, small equipment
  - Encapsulation (total or partial) for optical elements (lens, mirrors) and equipment’s internal parts (fly wheels)
- **Benefits** have been evaluated through DRAMA simulations
  - Specific attachment (tethers and reinforced interfaces) → ~1 to 2,5 m² DCA reduction, ~5 to 10 kJ KE increase
  - Encapsulation → ~10 m² DCA reduction, ~10 kJ KE increase
- Design and **system** impacts
  - Architecture change and specific attachment have low mass, volume and reliability impacts
  - Encapsulation has high accommodation and mass impacts
  - Mechanisms have a negative impact on reliability
- Modelling and **simulation** aspects
  - Architecture change and encapsulation can follow DRAMA classic modelling approach
  - The possibilities to model tethers, partial encapsulation are limited. A post-processing approach may be used in some cases.
- **Testing** aspects
  - Limitations include size and unrealistic dynamic behaviour

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FUTURE WORKS

/// The most promising D4C techniques identified in the frame of the trade-off **simulated with the ESA SCARAB software** on system/spacecraft level.

- A critical comparison with the results obtained for the unmodified scenario, i.e. without any D4C, will help quantify the effectiveness of the simulated techniques. Results will allow a new iteration of the trade-off.

/// A **test campaign in the LBK high enthalpy wind tunnels** (at DLR) will be performed within this activity.

- Screening test: to test the feasibility of the fundamental concept,
- Prototype test : to test and demonstrate the complete containment concepts.
- Both tests in L3K facility

Arc heated facilities L2K (right) and L3K (left). (Source : DLR)

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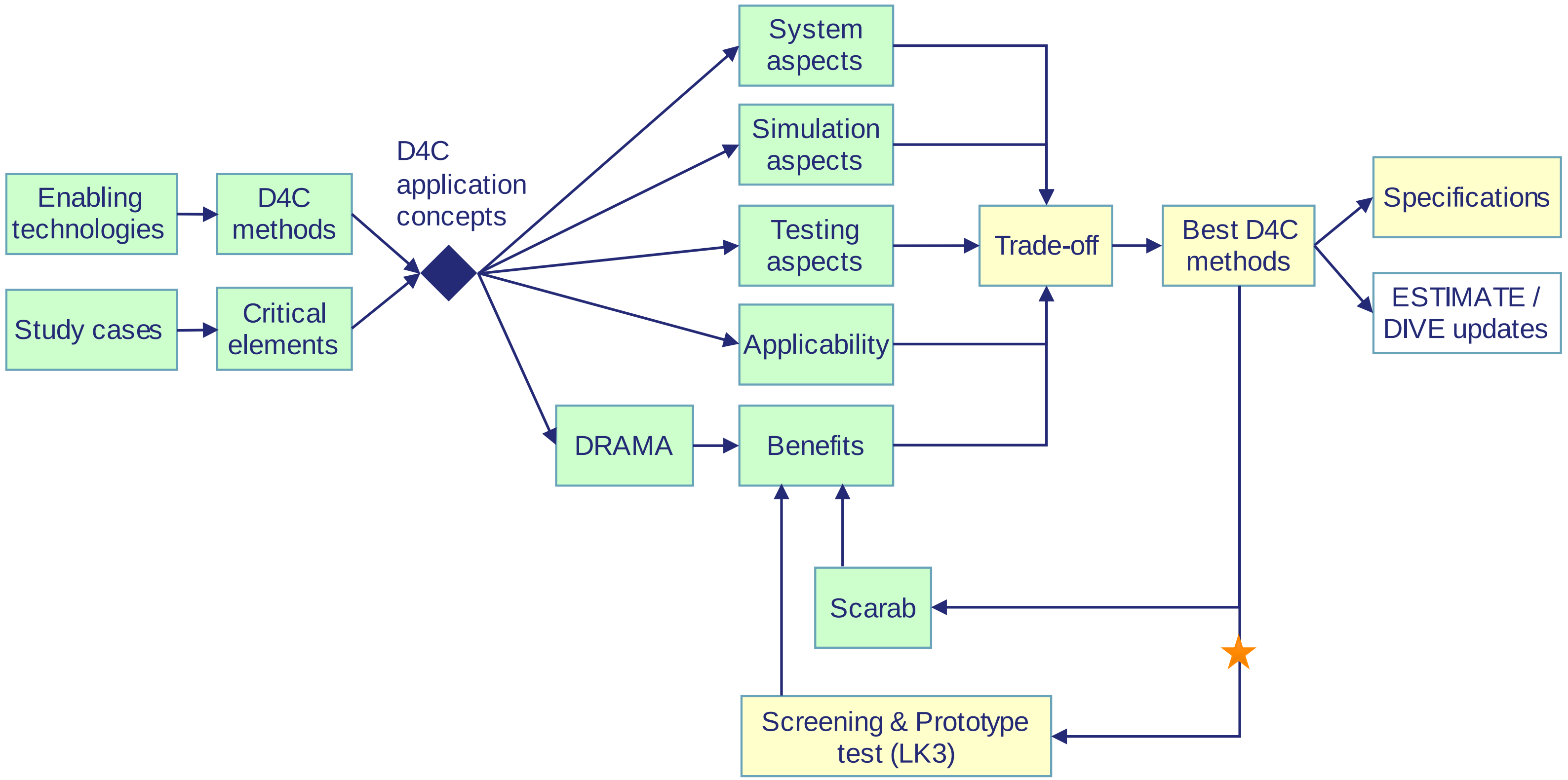

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Thank you!