Demise for Containment Executive Summary

Written by	Responsibility + handwritten signature if no electronic workflow tool
TAS Team	J. BECK (BLS)
	T. SCHLEUTKER (DLR)
	M. WEIHRETER (ADS)
	T. LIPS (HTG)
	A. SITA (TAS-I)
	P. LAURENTI (TAS-F)
Verified by	
Study manager	P. LAURENTI (TAS-F)
Approved by	
	C. BILLOT (TAS-F)

Approval evidence is kept within the document management system.

CHANGE RECORDS

ISSUE	DATE	§ CHANGE RECORDS	AUTHOR
01	31/01/2023	First issue	Study Team

TABLE OF CONTENTS

1. INTRODUCTION 5
2. DOCUMENTS 6
2.1. APPLICABLE DOCUMENTS 6
2.2. REFERENCE DOCUMENTS 6
2.3. DEFINITIONS AND ACRONYMS 6
3. ASSESSMENT OF CONTAINMENT TECHNIQUES FOR DIFFERENT STUDY CASES 8
3.1. LITERATURE REVIEW 8
3.2. STUDY CASES AND CRITICAL ELEMENTS 8
3.2.1. Study cases 8
3.2.2. Critical items 9
4. D4C DESIGN FOR CONTAINMENT 9
4.1. D4C CRITICAL MATERIALS 10
4.2. STUDY CASES MODELLING APPLICABILITY 11
4.3. SCARAB ANALYSES ON STUDY CASE 11
4.3.1. SCARAB scenario 11
4.3.2. SCARAB ROSE-L Analyses results 12
4.4. D4C CONCEPTS TRADE-OFF AND SPECIFICATION 12
4.4.1. Trade-off 12
4.4.2. D4C Technology Requirement 14
5. TESTS PLAN OF CONTAINMENT TECHNIQUES AND DEVELOPMENT OF PROTOTYPE 15
5.1. TEST FACILITIES 15
5.1.1. Optical setup 16
5.1.2. Test Sample and Set-Up configuration 16
5.1.2.1. TEST TYPE 1 CONFIGURATION 16
5.1.2.2. TEST TYPE 2 CONFIGURATION 17
5.1.3. Test Matrix 18
6. TESTS OF A PROTOTYPE AND DATA ANALYSIS 19
6.1. TEST ANALYSES AND REBUILDING SUMMARY 19
6.2. DRAMA MODEL CONSTRUCTION RECOMMENDATION 19
6.3. DIVE OVERALL RECOMMENDATIONS 20
7. CONCLUSION 20

List of Figures

Figure 1-1 D4C logic develppement appraoch 5
Figure 4-1 : ROSE-L SCARAB model (external and internal) 12
Figure 5-1 : D4C task 3 activities flow..15
Figure 5-2 : D4C LK facility diagram..15
Figure 5-3 : Setup of optical instruments. 16
Figure 5-4 : Titanium Holder for Thin Samples (type 1) 16
Figure 5-5 Heat shield configuration (left to right: test 1 – test 2 - Tests 3 up to 6 – test 9)..17
Figure 5-6 : Titanium Plate for Eyelet and Bolt Testing (Type 2)...17

List of Tables

Table 3-1 : D4C study cases critical items...9
Table 4-1 : Preliminary D4C technology Overview List 10
Table 4-2 : Scenario comparison...12
Table 4-3 : Study cases techniques and methods applicability 13
Table 4-4 : Multi-criteria analysis summary 14
Table 5-1 : Flow conditions during the demisability tests. 18
Table 5-2 :D4C Test Matrix 18

1. INTRODUCTION

The executive summary at hand summarizes the work performed in the study "Containment techniques to reduce spacecraft re-entry foot print", funded by the European Agency (ESA under contract no. 40000133213/20/NL/AS).
This study aims at continuing the coordinated effort to support the European industry to comply with the space debris mitigation requirements (defined in the standard ECSS-U-AS-10C/ ISO 24113, by evolving LEO platforms, considering possible containment concepts that would reduce casualty debris areas at re-entry
It covers the following tasks included in the AD [1]:

- **Task 1** – Identification of critical items in several study cases and different methods for containment.
- **Task 2** – With selection study case, selection of the best containment method modelling and establishment of preliminary specification and update of the trade-off.
- **Task 3** – with test plan design and delivery of test tools and samples.
- **Task 4** – With the prototypes, preform the test in preliminary re-entry conditions. Based on the results provide a recommendation update for DIVE with DRAMA model update.

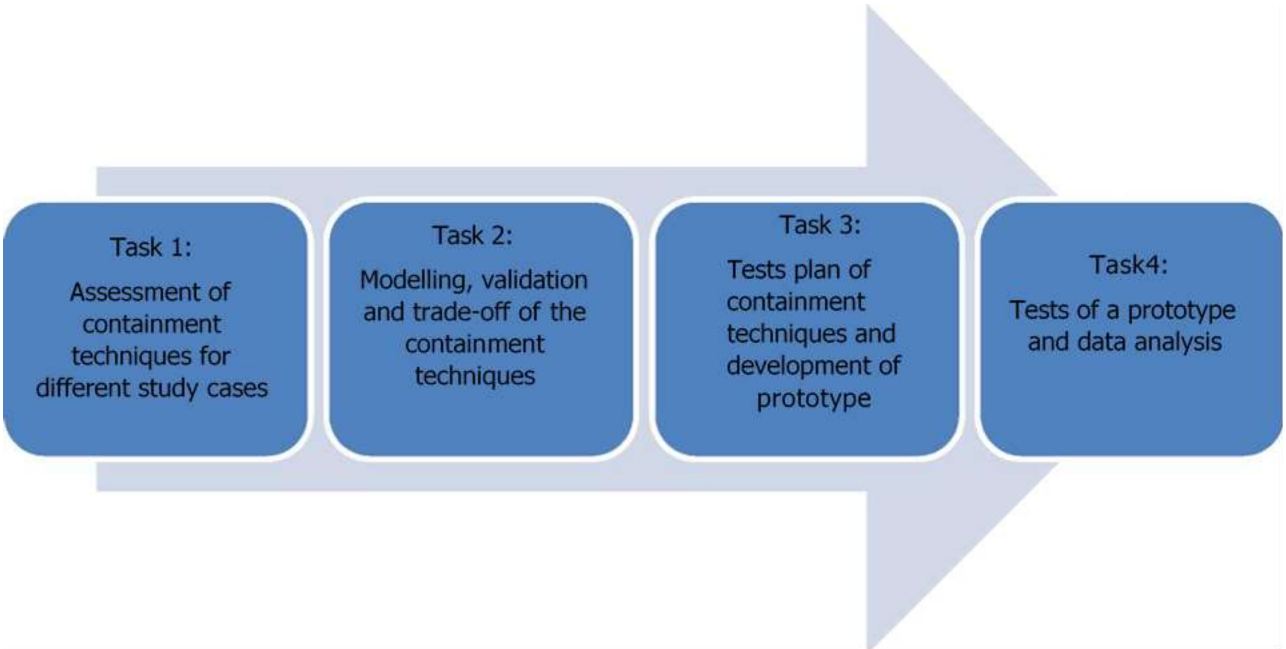

Figure 1-1 D4C logic develppement appraoch

2. DOCUMENTS

2.1. APPLICABLE DOCUMENTS

Internal code / DRL	Reference	Issue	Title
AD [1]	ESA-TEC-SYE-SOW-2018-005	Is. 1 Rev. 1	SOW Containment Techiques to Reduce Spacecraft Re-Entry Footprint
AD [4]			

2.2. REFERENCE DOCUMENTS

Internal code / DRL	Reference	Title	Location of record
RD [1]	DOS-APS-F01538-TN3	Tests plan of containment techniques and development of prototype	Issue 01

2.3. DEFINITIONS AND ACRONYMS

AD	Applicable Documents
ADS	Airbus Defense and Space GmbH, Friedrichshafen, Germany
D4C	Design for Containement
D4D	Design for Demise
DCA	Debris Casualty Area
DLR	Deutsches zentrum für Luft-und Raumfahrt
ESA	European Space Agency
HR	High Resolution
LBK	Lichbogenbeheizter Windkanal Köln
LK3	6.0 MW segmented type arc heated facility of DLR
RD	Reference document

RW	Reaction wheel
S/C	Spacecraft
SCARAB	SpaceCraft Atmospheric Re-entry and Aerothermal Breakup
SOW	Statement Of Work
TAS-F	Thales Alenia Space France
TAS-I	Thales Alenia Space Italie

3. ASSESSMENT OF CONTAINMENT TECHNIQUES FOR DIFFERENT STUDY CASES

In the first task of the study, based on previous study under D4D activities preformed in 2013, was focused on a literature research, with the review of potential consortium satellite projects and missions, in order, in the second step, to identify suitable study cases that would benefit from containment methods and techniques. Among, it has been extracted a technique to regroup platform critical element but also to identify some others containment techniques elements with some potential materials.
With study cases, critical satellite elements regarding casualty risk were identified and suitable containment methods were determined. The influence of the methods on system and equipment level were assessed and evaluated as well as the benefits in terms of casualty area and kinetic energy.
A preliminary trade-off with multi-criteria was performed to compare the different containment methods and applicable techniques. Then methods for further investigation were selected and conceptual designs established.

3.1. LITERATURE REVIEW

Several investigations from the partners have been led with investigations of re-entry and break-up analysis of four spacecraft, to determine critical components and materials, as well as other influences on the survivability (or demisability) of satellite components. Some methods have been studied according to the proper design of the S/C and included in the SCARAB or DRAMA models of the following domains:

- Sentinel 1
- Sentinel 2 with MSI
- DEIMOS
- Sentinel 3 (only for PF study)

3.2. STUDY CASES AND CRITICAL ELEMENTS

3.2.1. Study cases

Study cases have been reached according to the missions and programs followed by each partners, in order to cover the maximum critical items used on the spacecraft's. According to the variable missions it is not possible to have only one generic S/C were all the critical items are grouped but after establishment of the methods, the techniques and the preliminary conclusion of the trade-off at the end of the task 2, it was possible to select one study case who will provide the most important critical items linked to these D4C's methods and techniques identified.
To be able to establish an assessment of the containment techniques, four study cases have been selected to build DRAMA models and associated analyses, extracting critical items. Based on them and the associate analyses, a list of techniques and methods have been established for trade-off to select a study case with selection of the techniques applied for the tests. 4 cases have been selected:

- Sentinel-1
- ROSE-L
- CO3D
- FLEX

3.2.2. Critical items

The extraction of the critical items, from all the study cases, was beside on several models and analyses performed on each case by the partners. Mainly SCARAB or DRAMA models have been built to achieve this list and to extract the mains contributors of casualty for the re-entry phase.

Mission	Casualty risk	Critical items
Sentinel 1	The final casualty area is largely affected by the number of fragments, that varies from 4 to 22 surviving fragments.	SAR Antenna Propellant tank RW GYRO
ROSE-L	Casualty risk verification ,approximately 110 interconnected primitives have been used, representing 100% of the total satellite dry mass.	SAR antenna Battery (initial simulation) RW Tank Central tube
CO3D	Casualty risk verification with a mass around 66% of the total mass. Initial model and analysis under DEBRISK.	RW Instrument parts (Mirror ; support frame ;….)
FLEX	The on-ground casualty risk obtained for the un-controlled re-entry scenario (9.35·10^-5) is compliant with the risk threshold of 10-4 with the modelling assumptions taken. 10 surviving fragments have been identified (in total, composed by 17 objects)	Propellant Tank RW STR

Table 3-1 : D4C study cases critical items

4. D4C DESIGN FOR CONTAINMENT

Task 2, based on the critical items extracted from the study cases analyses, identified suitable methods and techniques of containment.
D4C methods can be classified in four technical families. Several methods under these techniques can be cumulated in order to meet the final objective. The methodology suggests then to try one method after the other up to find a possible one.

The techniques are defined as:

- D4C Technique: “REGROUP”: This technique deals with the architecture/accommodation change with respect to the standard design in order to regroup re-entry debris. This modification may be applicable through the following methods: Architecture Change & Adaptative Change
- D4C Technique: “ATTACH” : consisting in joining several surviving elements, including the addition of new specific joining elements (such as tethers, brackets) associated to the following methods: Specific Attachment, Change of Interfaces & Change of Design.

- D4C Technique: "PROTECT", involve the modification or the addition of a specific protection to prevent the exposure of certain element(s) to the heat flux , associated to the following methods : Protection upgrade, Protection addition & Heat shield implementation.
- D4C Technique: "ENCAPSULATE" includes dedicated device to enclose re-entry surviving elements (mechanical containment). This technique is associated to both following methods: Partial Encapsulation & Total Encapsulation

For each study case, the techniques and methods has been implemented according to theirs proper S/C design and missions to establish a preliminary applicable technologies and material.

D4C : Design For Containement N°ID	Techniques	Methods	Study Case	Study Case Detailed	Technos	H/W Technos
1	REGROUP	Architecture Change (For Flight)	P/F	4 RWA	Equipements Block	By Standard Design or with implementation of below Technos (Some , Several or All)
2				4 RWA + TANK		
3			P/L	All Elements on Bench	Module Block	
4				All OP/L Elements		
5			P/L + P/F	RWA+ OP/L	S/C Core Block	
6				Tank+ OP/L		
7				P/F + P/L		
8		Adaptative Change (For Reentry)	P/L + P/F	RWA + TANK ?	Foldables Frames ?	SMA Hinges + TPS
				RWA + OP/L ? (CO3D)		EOL Activated Mechanisms
				De/Reployable Telescope ?	Folding Mechanisms ?	SMA Frames + TPS
9				De/Reployable SAR Antenna		EOL Activated Mechanisms
10	ATTACH	Specific Attachment	P/F & P/L	OP/L Brackets	Magic Rope	Wire Link (+ TPS ?)
11					Magic SMA Spring	SMA Spring + TPS
12		I/F Change		OP/L Elements	Ceramic I/Fs	UHT Materials
13					Ti I/Fs	SMA Materials + TPS
14		Design Change		RWA Ti Mounting Base	Material Change	Standard HT Materials
15						
16	PROTECT	Protection Upgrade (HT)	P/L	CO3D Enveloppe	Enveloppe Protection	Titanium Envelope
17						Ceramics materials TPS
18		Protection Addition			Added TPS	Ablative Materials
19						Flexible TPS
20		Heat Shield Implementation		CO3D Baffle -> Reentry Cone	Inflatable Shield	SMA Mesh & mechanisms
						EOL Activated inflation device
21				CO3D Baffle -> Reentry Cone	Deployable Shield	SMA Hinge
22						EOL Activated Mechanisms
23	ENCAPSULATE	Partial Encapsulation	P/L + P/F	CO3D Tube Closure	Panel Closure	SMA Hinge
24						EOL Activated Mechanisms
				CO3D Encapsulation	Net	Wire Mesh
25			P/F	RWA + Tank with C/C Panels	Bird Cage	Retaining Strips
26						Foldable Shields / Panels
27		Total Encapsulation	P/L	CO3B encapsulation	Box	Ceramic Sunshield
28						
29			P/F	RWA + Tank in Central Tube/Cone		C/C Central Tube / Cone
30			P/L	CO3D _ Pleiade Design		
31				CO3D_FPA Encapsulation		Adapted heatshield
32						

Table 4-1 : Preliminary D4C technology Overview List

4.1. D4C CRITICAL MATERIALS

Several materials have been studied in the amount of potential material currently used. Four domains have been selected and implemented in the models, regrouping the following materials or technics:

- **Ceramics**
- **Metallic alloys**
- **Ablative materials**

- **Flexible TPS**
- **Mechanisms**

4.2. STUDY CASES MODELLING APPLICABILITY

For the 4 study cases, DRAMA model has been built with some modification compared the initial model established in task 1 and with the implementation of some different potential application for containment, as reported in the following bullets:

- Case 1: Sentinel 1
  - SAR antenna structure (attach with specific attachment method)
  - RW (regroup with architecture change with tank)
  - Propellant tank (regroup with architecture change with RW)
- Case 2 ; ROSE-L
  - Central cylinder (attach with specific attachment method)
  - Tank (total encapsulation inside central cylinder)
  - SAR structural panels (attach with change of interface)
  - RW (regroup with architecture change)
- Case 3 : C03D
  - HR instrument shell (total encapsulation)
  - RW (regroup technique by “magic” wire)
- Case 4 : FLEX
  - RW (regroup technique by “magic” wire or encapsulate with partial encapsulation)

4.3. SCARAB ANALYSES ON STUDY CASE

Task 2 was finishing by to investigate the efficiency of the D4C techniques identified in the previous phases of the study, applying the most promising one to the study case selected. After the preliminary trade-off it has been decided with ESA that the applicable study case will be ROSE-L.

Within the activity, a number of different concepts have been proposed, covering four areas:

- Grouping undemisable objects together to land as a single part.
- Attaching undemisable objects to each other to land as a single part.
- Thermally protecting objects such that they do not separate into multiple landing objects.
- Encapsulation of a set of objects which can survive re-entry.

From these four concepts, simulations were performed to assess the potential benefits allowing to select subset cases:

- A cage to contain the low demisability parts of a reaction wheel.
- A tether connecting different low demisability parts together.
- A rigid attachment of parts using titanium struts.
- A net encapsulating some low demisability parts.

4.3.1. SCARAB scenario

The SCARAB model has been prepared based on the inputs as the CAD files, mass budget and material list (data provided by ADS). The DRAMA model external and internal components is presented as it has been modelled:

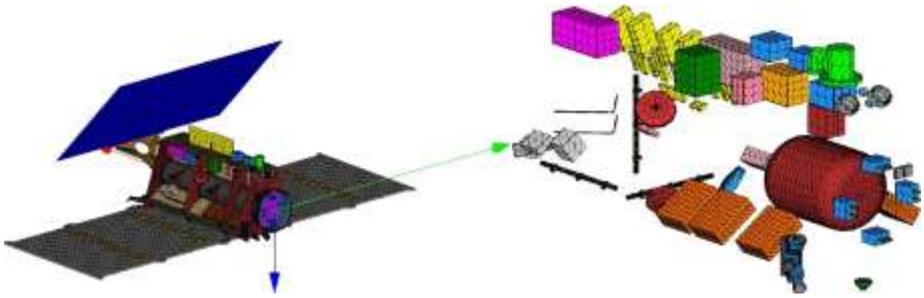

Figure 4-1 : ROSE-L SCARAB model (external and internal)

For the purpose of this task the baseline model has been extended in 4 D4C scenarios:

- Scenario #1: Containment of critical elements with a tether and cages
- Scenario #2: Containment of critical elements with a rigid structure and cages
- Scenario #3: Containment of (additional) telescope structure parts with a tether
- Scenario #4: Containment of electronic boxes with a net

4.3.2. SCARAB ROSE-L Analyses results

SCARAB simulations for the four D4C scenarios showed promising results. All D4C techniques simulated worked, no (critical) failure (melting) of the containment elements (tether, net, rigid structure, cages) was observed. No fragments were released from the contained parts.

The following table provides a comparison of the results for 4 scenarios under the ROSE-L's baseline scenario.

Scenario	Heat flux (KW/m²)	Mean Casualty Area [m²]	Reduction
Baseline		10.08 ± 1.18	
Scenario #1 (tether & cages)	750	9.35 ± 1.33	-7.2%
Scenario #2 (rigid structure & cages)	680	8.51 ± 1.39	-15.6%
Scenario #3 (tether)	1000	No reduce casualty area has been extracted.	No réduction observed (Melting T° > Tmax)
Scenario #4 (net)	550	10.12 ± 0.61	None

Table 4-2 : Scenario comparison

4.4. D4C CONCEPTS TRADE-OFF AND SPECIFICATION

4.4.1. Trade-off

The following criteria have been agreed to be used to compare the different D4C methods and techniques of containment:

1. **Applicability of the Containment Concepts**
2. **Benefits of the Method**
3. **Design and system impacts**
4. **Modelling Aspects**

5. Testing Aspects

With the four scenario and the preliminary DRAMA analyses have been estimated the casualty area and the applicability of some methods. With the update of ROSE-L design, the method "change design" was considered. All scenario have implemented several design (see Table 4-3) like cage on RW in the #1 and #2 as partial encapsulated method. The Task 3 (test plan) and Task 4 (tests) are based on the results and design applied in these simulations.

Techniques	Methods	Applicable to CO3D	Applicable to ROSEL	Applicable to FLEX	Applicable to S1
Regroup	Architecture Change	NO	YES	NO	YES
	Adaptative Change	NO	NO	NO	NO
Attach	Specific Attachment	YES	YES	YES	YES
	Change of interfaces	NO	YES	NO	YES
	Change of design	YES	YES	YES	NO
Protect	Protection upgrade	YES	NO	NO	NO
	Protection addition	YES	NO	NO	NO
	Heat Shield implementation	YES	NO	NO	NO
Encapsulate	Partial encapsulation	YES	YES	YES	YES
	Total encapsulation	YES	YES	NO	YES

Table 4-3 : Study cases techniques and methods applicability

The following table includes all design update and the results of the SCARAB analyses done on ROSE-L, The weight indicated in this table are based on the weighting of sub-criteria associated to the criteria weighting.

			REGROUP		ATTACH			PROTECT			ENCAPSULATE	
		Weight	Architecture Change	Adaptative Change	Specific Attachment	Change of Interfaces	Change of Design	Protection Upgrade	Protection Addition	Heat Shield Implementatio	Partial Encapsulation	Total Encapsulation
Applicability of method	Applicability for future missions	6,00	7	1	9	6	5	1	6	2	6	8
	Applicability to different SC units	6,00	7	2	10	6	4	2	7	1	7	8
	Programmatic aspects	8,00	7	5	7	6	9	7	7	2	7	10
Benefits of method	Number of surviving fragments	1,33	6	6	6	6	4	6	6	7	7	7
	DCA variation	10,67	8	8	8	8	7	5	5	7	6	7
	KE variation	8,00	1	1	1	1	1	5	5	2	6	1
	Reliability/ Confidence level	6,67	5	5	5	5	5	5	5	5	5	5
Design and System impacts of method	Accommodation	6,67	3	3	9	10	10	10	7	1	7	2
	Mass	6,67	10	4	5	3	3	5	4	1	4	1
	Cost	6,67	8	5	9	5	8	7	6	1	7	5
	Manufacturing complexity	3,33	10	4	7	7	8	5	5	1	7	8
	Structural, thermal electromagnetic, other	5,00	5	4	5	7	8	5	4	4	5	4
	System reliability	5,00	10	3	8	8	10	8	8	1	8	5
Modelling aspects	Modelling effort	2,22	10	3	9	9	10	5	5	9	3	9
	Modelling limitations	2,22	10	1	6	6	10	5	5	5	2	10
	Confidence in modelling approach	2,22	10	1	7	7	10	5	5	1	2	10
Testing aspects	test sample representativeness	4,00	3	0	2	9	8	7	9	0	7	1
	test sample procurement	4,67	3	9	2	5	6	7	9	7	5	10
	Test sample cost	2,67	2	7	3	6	6	5	7	5	5	10
	Test facility compatibility	2,00	5	10	3	9	5	10	10	5	8	10
SCORE (out of 10)			6,31	4,13	6,27	6,15	6,57	5,64	6,09	3,05	5,93	5,88

Table 4-4 : Multi-criteria analysis summary

With the four scenario selected, only 2 (1&2) gave a significant gain on the casualty area. The tradeoff shown that the use of tether is a solution who will offer the best results.

Finally from this trade off, the most promising methods, according to this first multi-criteria analysis iteration, were :

1. **Change of Design**.
2. **Architecture Change**
3. **Specific Attachment**
4. **Change of Interfaces**

4.4.2. D4C Technology Requirement

According the results of DRAMA analyses and the behaviour of the critical elements, conceptual design and preliminary design specification for the different containments methods, and for eachstudy cases, have been issued. The ROSE-L specification has been updated from SCARAB analyses results.

5. TESTS PLAN OF CONTAINMENT TECHNIQUES AND DEVELOPMENT OF PROTOTYPE

The third task of the study involved the preparation of the test campaign. Based on the development process where the first step is based on the simulations of the 4 scenario to prepare the frame of the tests. For each investigated concept, the test strategy was defined and representative test samples were developed. The test samples were designed to enable the investigation of the functional performance of containment concept in plasma wind tunnel tests. Predicative simulation were performed with the SAMj/ DRAMA model in order to assess the behaviour of the test samples and determine the test conditions.

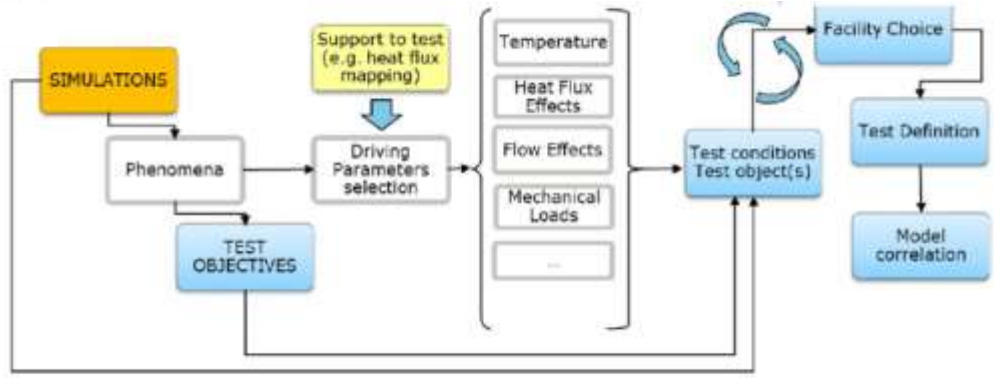

Figure 5-1 : D4C task 3 activities flow

test set-up and instrumentation determined to capture the driving parameters odf sample and holders

5.1. TEST FACILITIES

The wind tunnel tests were performed in the L3K facility, which is one the two legs of DLR's arc heated facilities LBK. The setup is schematically plotted in **Figure 5-2**.

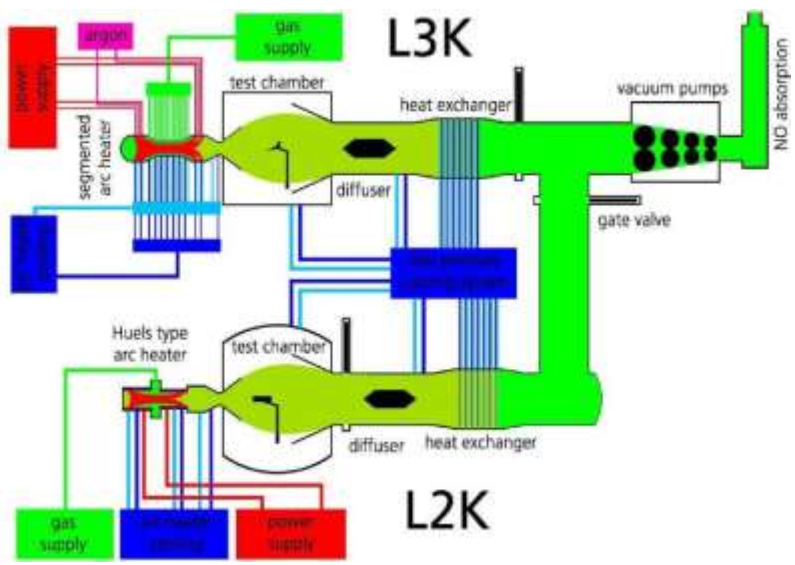

Figure 5-2 : D4C LK facility diagram

5.1.1. Optical setup

In demise testing, the observation of the actual demise behavior is of the highest interest. Consequently, the measurement techniques focus on visual and thermal recording of the sample during the test. Optical instruments provide non-intrusive remote access. The setup is sketched in Figure 5-3.

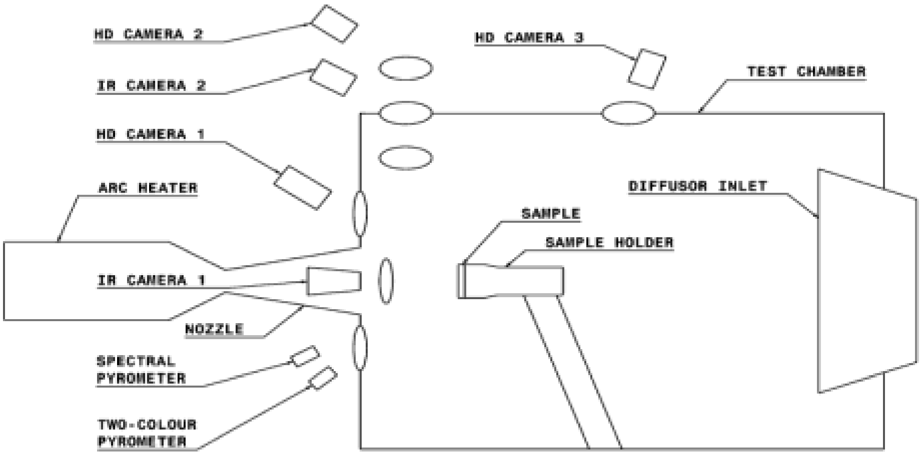

Figure 5-3 : Setup of optical instruments.

5.1.2. Test Sample and Set-Up configuration

Two basic types of test objects were used.

5.1.2.1. TEST TYPE 1 CONFIGURATION

Type 1 is a titanium sample holder to hold the thin structure material samples.

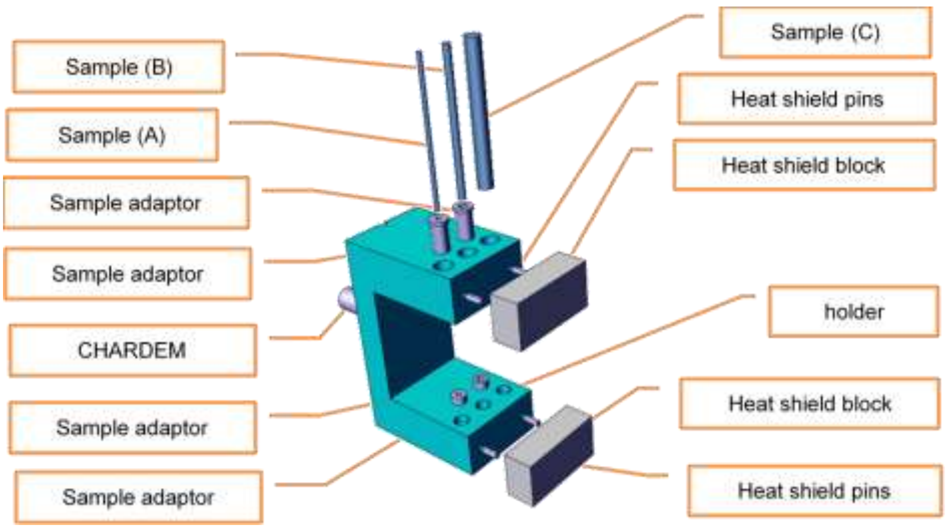

Figure 5-4 : Titanium Holder for Thin Samples (type 1)

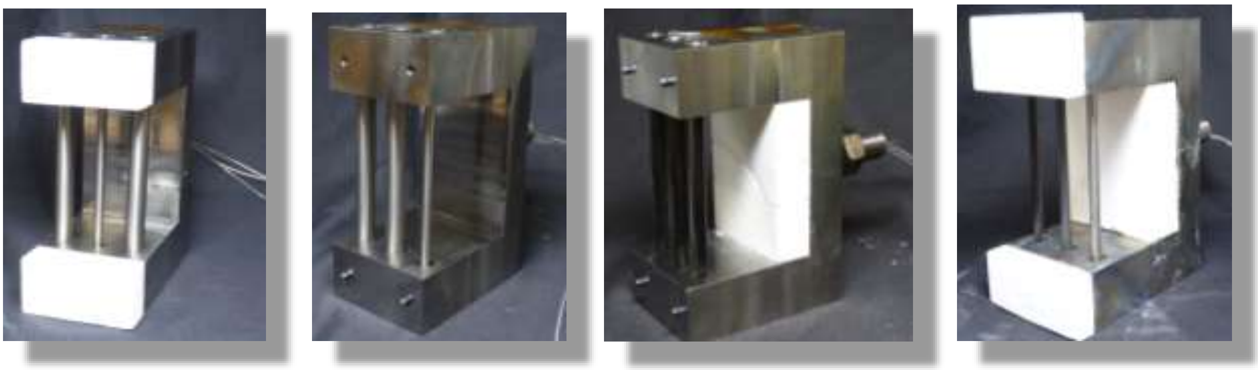

Figure 5-5 Heat shield configuration (left to right: test 1 – test 2 - Tests 3 up to 6 – test 9)

For this type 1 tools, 5 rod materials have been selected :

- Titanium
- Tungsten
- Silicon Carbide
- Aluminium Oxide
- Carbon

5.1.2.2. TEST TYPE 2 CONFIGURATION

The second type is a titanium plate which has four eyelets, two internal and two external, and four bolts attached to masses (1kg and 0,5Kg – see Figure 5-6).

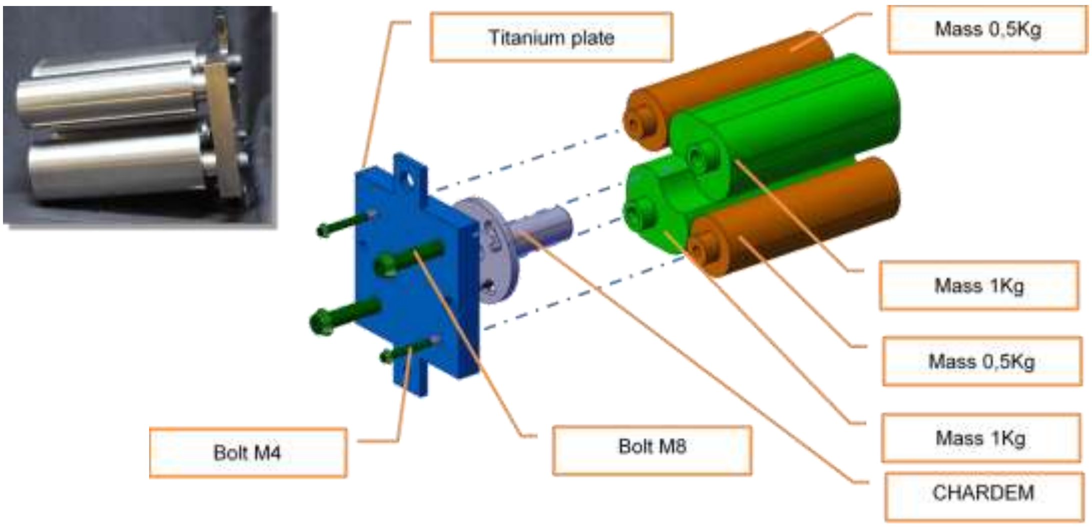

Figure 5-6 : Titanium Plate for Eyelet and Bolt Testing (Type 2)

For this type 2 tool, 2 bolts materials have been selected :

- Titanium
- Molybdenum

5.1.3. Test Matrix

The nine tests used two different setup for the screening test: the C-shaped titanium holder that exposed three rod to the flow and the titanium plate with weight attached to the rear with the screw being the test article. Based on the flow condition of the test facilities, the test matrix of the wind tunnel test campaign was adjusted during the test campaign based on the knowledge gained from previous tests.

Test condition		200H	200L	300H	300L
Test gas	[-]	Air+Ar	Air+Ar	Air+Ar	Air+Ar
Gas mass flow rate*	[g/s]	102+4	102+4	102+4	102+4
Reservoir pressure*	[hPa]	3800	3500	3800	3500
Reservoir temperature*	[K]	6796	6250	6796	6250
Diameter of nozzle throat / exit*	[mm]	29 / 200	29 / 200	29 / 200	29 / 200
Distance to nozzle exit*	[mm]	200	200	300	300
Free stream static pressure*	[Pa]	127	120	84.4	79.6
Free stream static temperature*	[K]	752	708	658	621
Free stream density*	[kg/m³]	$439 \cdot 10^{-6}$	$466 \cdot 10^{-6}$	$333 \cdot 10^{-6}$	$352 \cdot 10^{-6}$
Free stream velocity*	[m/s]	4382	4053	4408	4078
Mass fraction of N2*	[-]	$643 \cdot 10^{-3}$	$715 \cdot 10^{-3}$	$643 \cdot 10^{-3}$	$715 \cdot 10^{-3}$
Mass fraction of O2*	[-]	$0.0 \cdot 10^{-3}$	$0.1 \cdot 10^{-3}$	$0.0 \cdot 10^{-3}$	$0.1 \cdot 10^{-3}$
Mass fraction of N*	[-]	$123 \cdot 10^{-3}$	$50.1 \cdot 10^{-3}$	$123 \cdot 10^{-3}$	$50.1 \cdot 10^{-3}$
Mass fraction of O*	[-]	$235 \cdot 10^{-3}$	$235 \cdot 10^{-3}$	$235 \cdot 10^{-3}$	$235 \cdot 10^{-3}$
Mass fraction of NO*	[-]	$0.0 \cdot 10^{-3}$	$0.0 \cdot 10^{-3}$	$0.0 \cdot 10^{-3}$	$0.0 \cdot 10^{-3}$
Measured pitot pressure+	[hPa]	-	-	-	-
Measured cold wall heat flux+	[kW/m²]	1.96	1.34	1.34	1.00

Table 5-1 : Flow conditions during the demisability tests.

Test	Type	Material	Condition test	Test duration (s)	Calibrated Flux (MW/m²)	Description
1	Thin Structure	Titanium	300L	12.1	1.0	Titanium rods, baseline setup
2	Thin Structure	Titanium	300L	47.7	1.0	Titanium rods, ceramic blocks removed
3	Thin Structure	Tungsten	200H	31.8	1.95	Tungsten rods, ceramic blocks on the base of the holder
4	Thin Structure	Silicon Carbide	200H	32.8	1.95	Silicon carbide rods, ceramic blocks on the base of the holder
5	Thin Structure	Graphite	200H	33.2	1.95	Graphite rods, ceramic blocks on the base of the holder
6	Thin Structure	Aluminium Oxide	300H	21.6	1.35	Alumina rods, ceramic blocks on the base of the holder
7	Plate	Titanium Bolts	300L	72.3	1.0	Plate with titanium screws
8	Plate	Titanium Bolts Molybdenum Bolts	200H	37.7	1.95	Plate with titanium and molybdenum screws
9	Thin Structure	Silicon Carbide Graphite Tungsten	200H	43.3	1.95	Graphite, silicon carbide and tungsten rods, improved ceramic insulation.

Table 5-2 :D4C Test Matrix

6. TESTS OF A PROTOTYPE AND DATA ANALYSIS

The Task 4 and the screening test campaign concentrated only on the peak heating phase of the entry flight. A total of 9 tests were conducted on the two different screening test setups and the 6 candidate materials. Both setups used for the screening test campaign worked, but the c-shaped rod-holder was not demise resistant enough and the early melting of that holder limited the test duration.

6.1. TEST ANALYSES AND REBUILDING SUMMARY

A set of tests have been performed on building blocks for containment techniques to reduce the risks from destructive re-entry. The tests assess a number of thin structures of candidate materials which are expected to be highly resistant to demise during re-entry, and also assess some joining technologies, such as bolts and tether eyelets. These tests provide excellent data on the demise processes of resistant materials, and demonstrate the importance of the small length scales of joining technologies for containment as these receive very high heat fluxes. Tungsten, silicon carbide and molybdenum show the most promising behaviour for use in containment techniques.

6.2. DRAMA MODEL CONSTRUCTION RECOMMENDATION

Modelling of the length scale has been determined as a key factor in capturing of the performance of a containment technique. With DRAMA being a component-based destructive re-entry tool, the reference length considered is automatically at the local scale, which fortunately means that no architectural change of DRAMA is necessary in order to capture the correct length scales. It does mean, however, that the models for containment techniques cannot be represented using the simple, virtual joints in DRAMA, as these cannot capture the small length scale, nor the correct heating to the thin joining structures. The recommendation on the DRAMA model construction have been directly implemented on the updated ROSE-L's DRAMA model with :

- A Modelling approach
- Suggested Models for Containment Concepts
- Material Models from Testing
- DRAMA Extensions with;
    - Mass Loss Model
    - Network Joint Capability
    - Oxidation Mass Loss Model
- Length Scale Adaptation.

6.3. DIVE OVERALL RECOMMENDATIONS

There are several key lessons which have been learned from the test campaign. They concern the material tested, the concept tested and the design and modelling. Taking into account all of them, the DIVE recommendations highlight three main areas:

- Discussion with spacecraft engineers provided a large number of constraints which made several concepts impractical.
- The majority of containment techniques involved the use of thin structures (tether, connecting rod, net or cage). These have very small length scales, which have been observed in the tests to have very high incident heat fluxes, and to reach very high temperatures. This means that the constraints on the materials that can be used are extremely strict, which significantly limits the choice of material. This also has implications for the modelling of the techniques, with the length scale representation being a critical requirement.
- A successful connection between the parts is essential in any containment technique. The current understanding of fragmentation, and thus connection failure, in destructive re-entry is limited, and therefore significant effort is required to develop a reliable connection, and to demonstrate that this connection remains intact during the re-entry.

This under-estimation of the complexity of the problem makes it important that strong justification of the effectiveness of the technique is obtained.

General and specific recommendations have been established taking the lessons learned as well as from the analyses than from the tests. All these recommendations have been submitted for the update of the chapter 4 of RD [1].

7. CONCLUSION

All D4C activities and especially the tests, have demonstrated clearly that it will be very difficult to construct and verify a containment technique which is suitable for the system, and is likely to survive re-entry. Clearly, there is potential in the concept, but the difficulties were significantly underestimated. Thennure are also a number of lessons learned on the modelling side from this test campaign.

Overall, TAS fully supports the ESA Cleanspace initiative that includes Design For Containment and will continue to work together with ESA and suppliers towards the sustainability of the space activities. It is in TAS' best interest to be able to continue developing space solutions and applications for the Earth population.

END OF DOCUMENT