CONTAINMENT TECHNIQUES FOR RE-ENTRY EVENTS

OHB SYSTEM AG

D4D-CONT TEAM, 12.10.2022

D4D CONTAINMENT TECHNIQUES

INTRODUCTION

Study Objective

- Identify and validate containment techniques that can be broadly applied in spacecraft critical elements designs to reduce the re-entry casualty area –

Study Overview

- Identify containment methods based on existing literature and OHB's experience with past missions. These methods will be both applied to platform and payload elements.

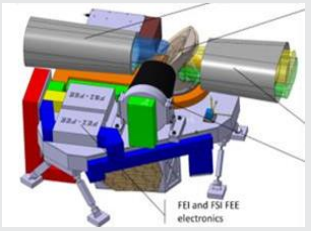
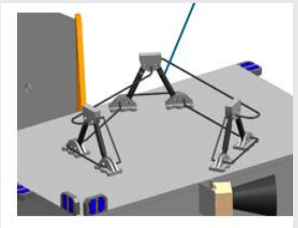
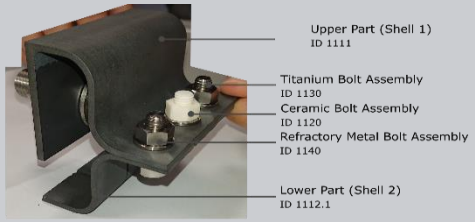
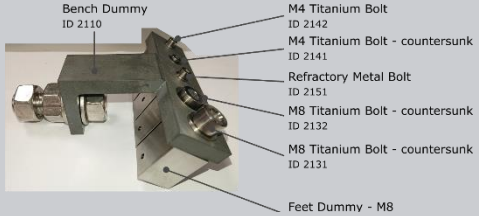
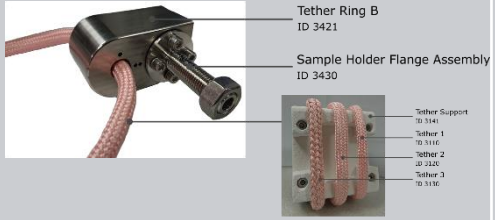
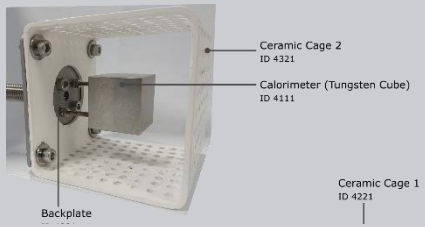
- The second and main part of this activity will be the validation of the selected containment methods:
  - utilising modelling on spacecraft level and in further detail
  - **the design and testing of concepts**

- In the final steps the results are then translated into an update of both modelling (DRAMA), processes (input to the next generation of DIVE) and databases (ESTIMATE).

OVERVIEW OF TEST CAMPAIGN

D4D CONTAINMENT TECHNIQUES

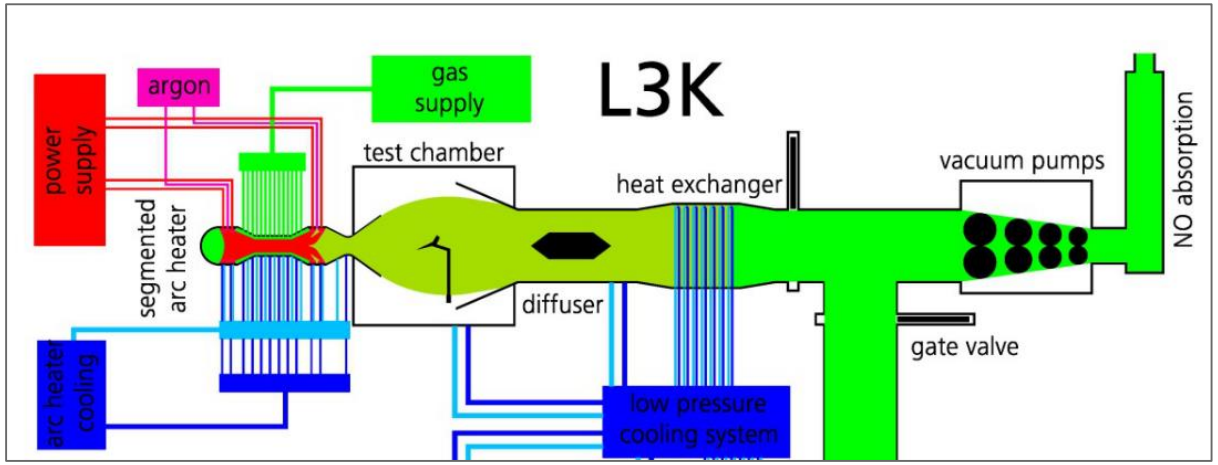
TEST CAMPAIGN OVERVIEW

Concept #	Concept 1	Concept 2	Concept 3	Concept 4
Containment Concept	Spectrometer thermal guard	Optical mounts connected in optical bench	Feet / Bipods connected by tether	Electronic units in cage
Description				
Test Sample				
Sample Material	C/SiC (carbon fibre-reinforced SiC)		Aluminium oxide fibres / fabric	
Concept Design Aspects	• Two shells • Bolted joint	• SiC: through-hole • Titanium bolts	Braid, or a “tube” of fibres passing through hole in baseplate feet / bipods	Cage Structure made of Aluminium oxide fibres, fixated to thermal doubler, which interfaces between satellite panel and unit

D4D CONTAINMENT TECHNIQUES

TEST CAMPAIGN – TEST FACILITY & INSTRUMENTATION

- Tests are conducted in DLR's L3K arc-heated wind tunnel
- Allows the use of relatively large samples, up to 100mm diameter, with "nominal" testing flux levels up to approximately 1.9MW/m^2



- Test Sample Instrumentation
  - Type K thermocouples are used to monitor the temperatures experienced during testing

- Test Facility Instrumentation
  - Two pyrometers (Maurer, KTRD 1085 and QKTRD 1085) - calibrated to a temperature range of 900-3000°C
  - Up to 3 HD cameras used in tandem with 2 IR-cameras (same spectral range as the Maurer pyrometers)
  - Both the IR-cameras observe the test samples from the side.

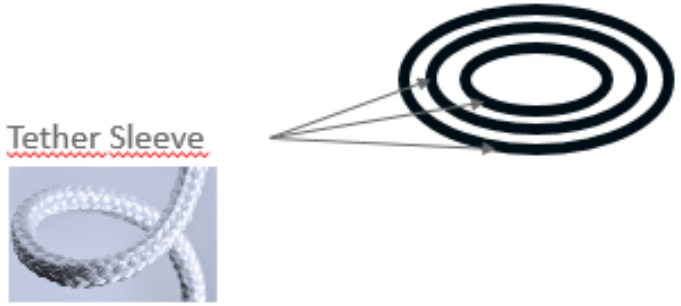
TEST SAMPLE DESCRIPTIONS AND TESTING

D4D CONTAINMENT TECHNIQUES

TEST SAMPLE DESCRIPTION

Concept 3: Tether Connecting Bipods / Feet (Test 3 – Test 6)

- Test Objectives:
  - gain a better understanding of the tether material behaviour during re-entry
  - to investigate and assess the failure of different tether configurations
- Sample Materials:
  - Tethers are made of **aluminium oxide fibres**
- Sample Test Configurations
  - Basic Tether Test Sample (Test 3 & Test 4)
  - Tether Connection Test Sample (Test 5 & Test 6)
- Tether Configuration
  - Concentric Sleeves
  - Rope



Tether Sleeve Test Sample Concept

Tether Rope Test Sample Concept

	Test 3	Test 4
Tether 1	Sleeve OD 12 mm	Sleeve OD 12 mm
Tether 2	Sleeve OD 8 mm	Sleeve OD 8 mm
Tether 3	Rope OD 12 mm	Rope OD 12 mm

D4D CONTAINMENT TECHNIQUES

TEST SAMPLE DESCRIPTION

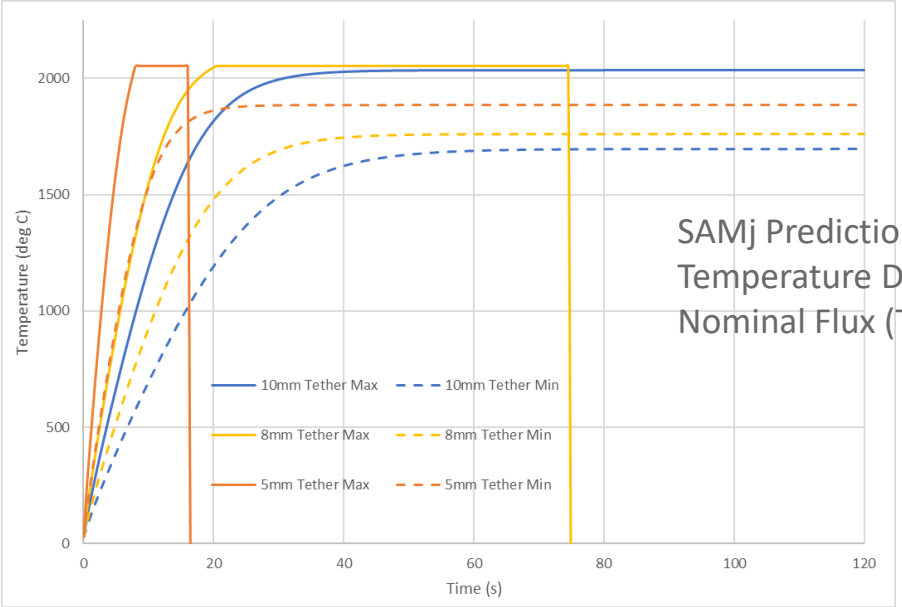
Concept 3: Basic Tether Test Sample (Test 3 & Test 4)

- Predictive Simulation Results
  - temperatures are given for the front of the tether
  - **open question as to the effectiveness of the conduction in the tether**

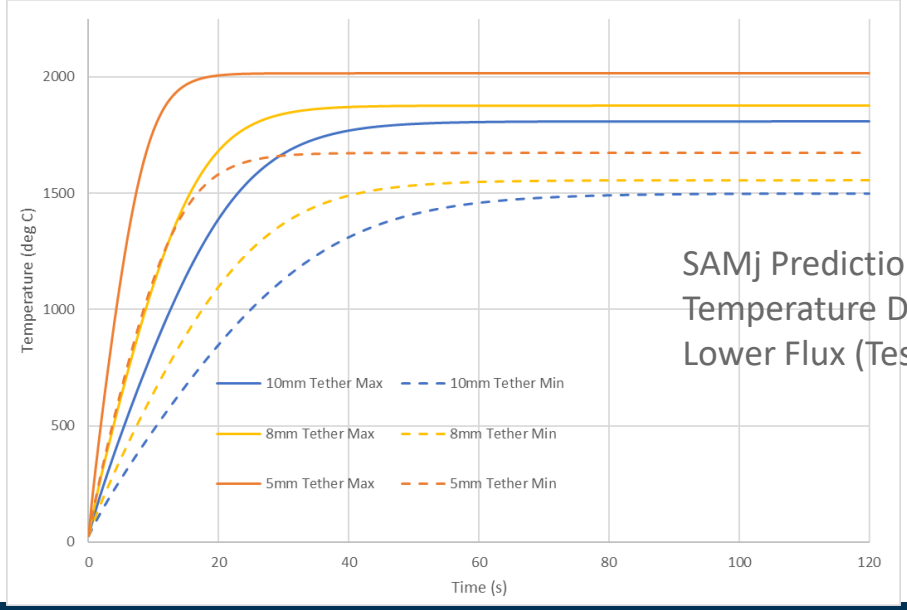
  - material model:
    - standard catalycity ceramic bolt, (silicon carbide catalycity)
    - emissivity 0.8.

  - for nominal heat flux condition, temperatures reached are high:
    - with minimal conduction, the thinner tethers will both reach the aluminium oxide melt temperature.
    - **test time to equilibrium or tether failure is quite short**

  - test 4 run at the lower flux condition:
    - will provide a good idea of the maximum temperature at which the tether can survive
    - no prediction of aluminium oxide melt is made, but there could still be failures of the tether



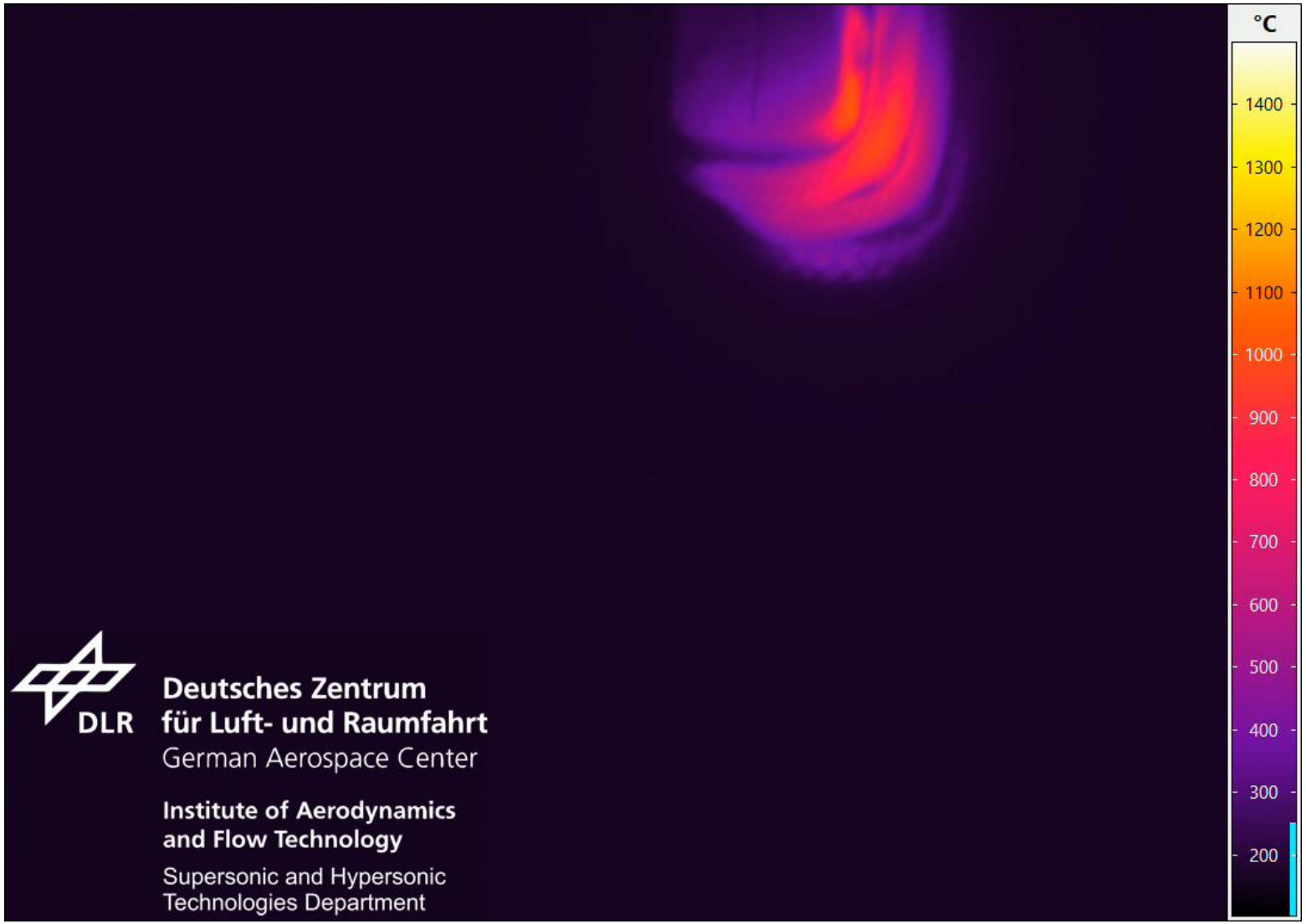
SAMj Predictions of the Temperature Data at Nominal Flux (Test 3)



SAMj Predictions of the Temperature Data at ¾ Lower Flux (Test 4)

D4D CONTAINMENT TECHNIQUES

– TETHERS TEST #1 VIDEO



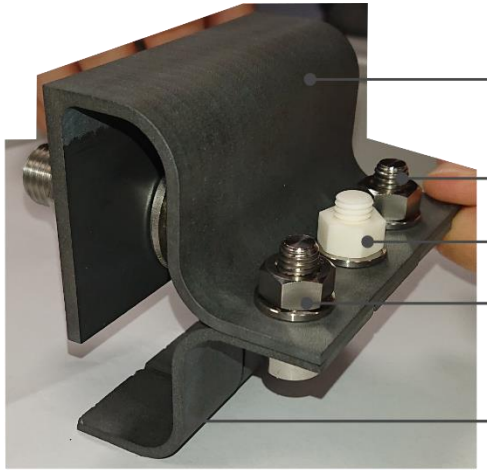
D4D CONTAINMENT TECHNIQUES

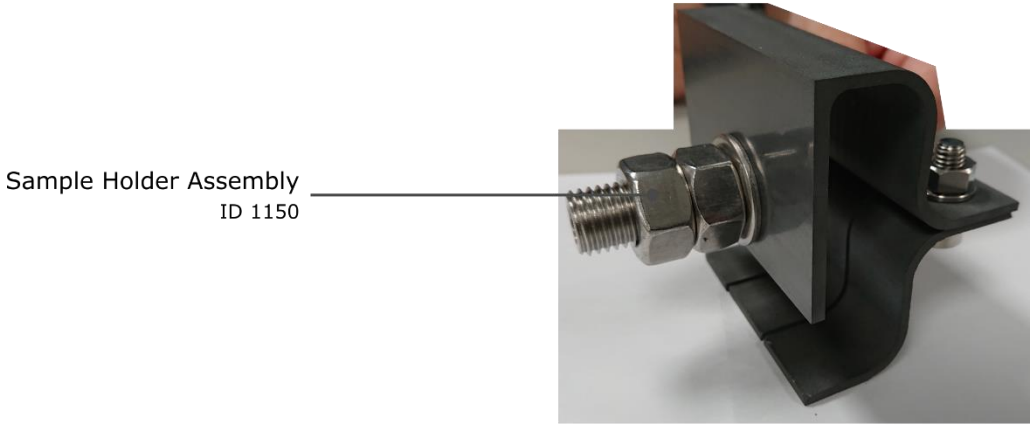
TEST SAMPLE DESCRIPTION

Concept 1: C-SiC Spectrometer Thermal Guard (Test 1)

- Test Objectives:
  - gain a better understanding of the material behaviour during re-entry
  - to investigated the bolts connection of the shells
  - to assess the failure of different bolt connections
  - to determine the most suitable bolt material to maintain the connection of the shells

- Sample Materials:
  - Shells are made of **HB-Cesic® - carbon reinforced silicon carbide**
  - M8 bolt made of different materials:
    - **Titanium**
    - **Aluminium Oxide**
    - **Molybdenum**





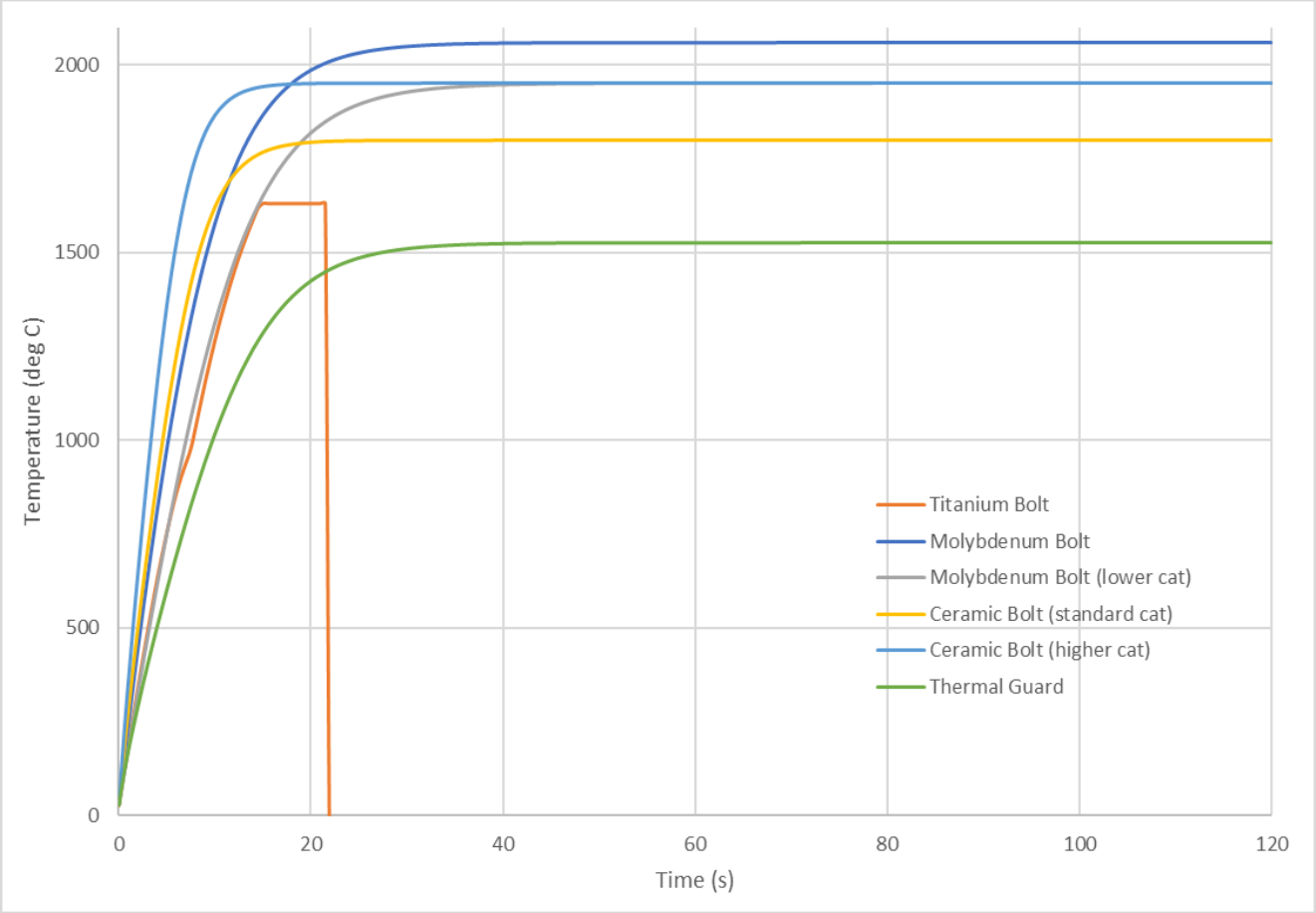
D4D CONTAINMENT TECHNIQUES

TEST SAMPLE DESCRIPTION

Concept 1: C-SiC Spectrometer Thermal Guard (Test 1)

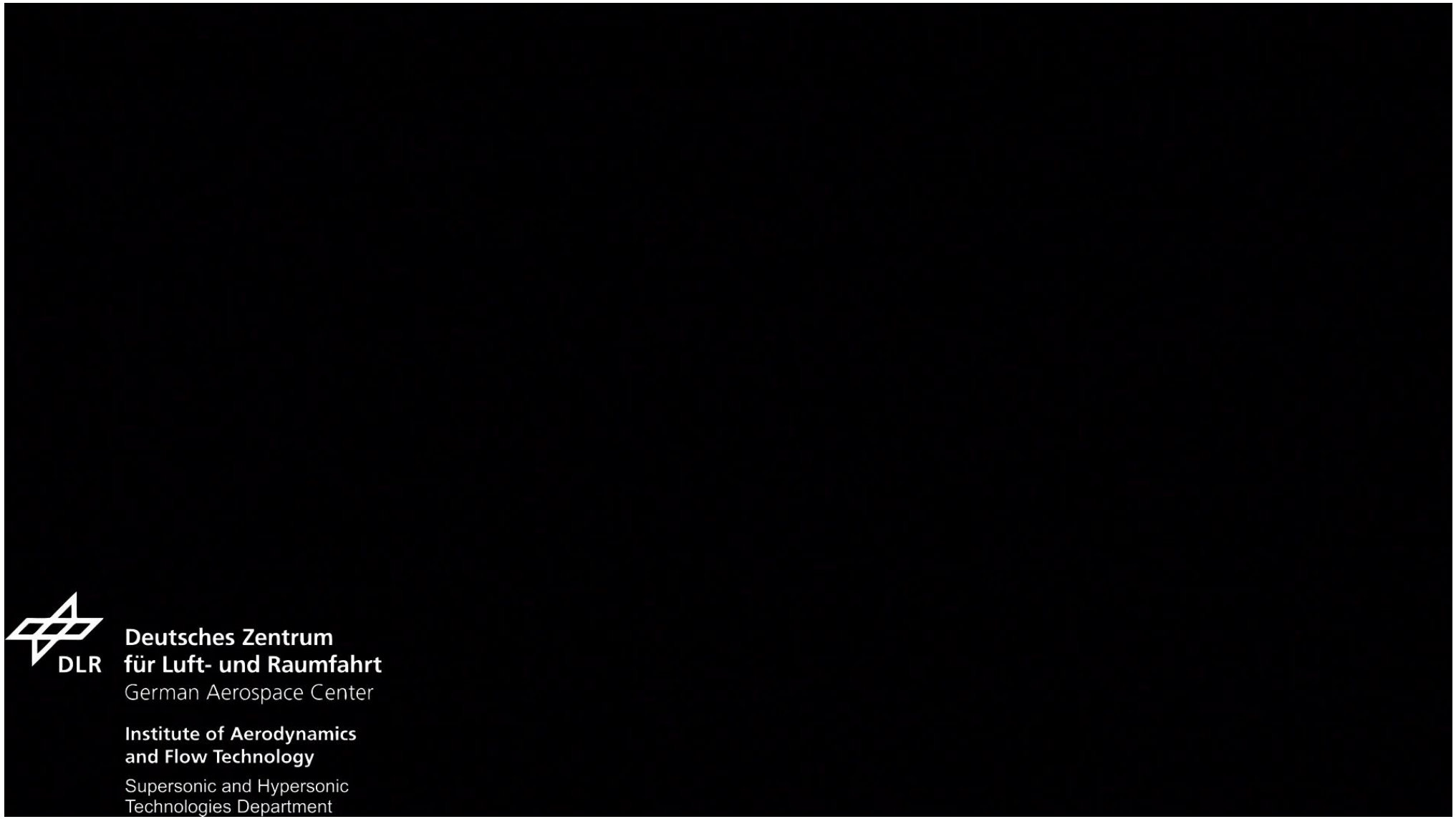
- Predictive Simulation Results
  - Melting of the titanium bolt is observed to occur very quickly, suggesting that a failure could be seen inside 30s.
  - Other bolts, and the silicon carbide thermal guard are expected to survive the test.
  - other interesting aspect is that the equilibrium occurs very quickly in the prediction - it is of interest to see whether this accurate

SAMj Predictions of the Temperature Data



D4D CONTAINMENT TECHNIQUES

– CESIC THERMAL GUARD VIDEO



D4D CONTAINMENT TECHNIQUES

WHAT HAPPENED?

T = approx. 3.6 sec

T = approx. 4.2 sec

T = approx. 5.6 sec

Note: Times taken from beginning of HD video playback

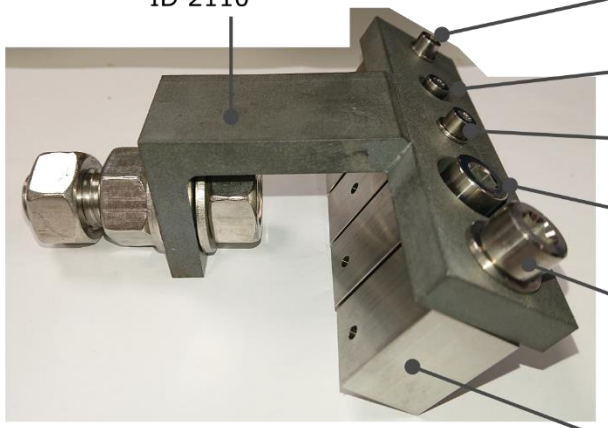
D4D CONTAINMENT TECHNIQUES

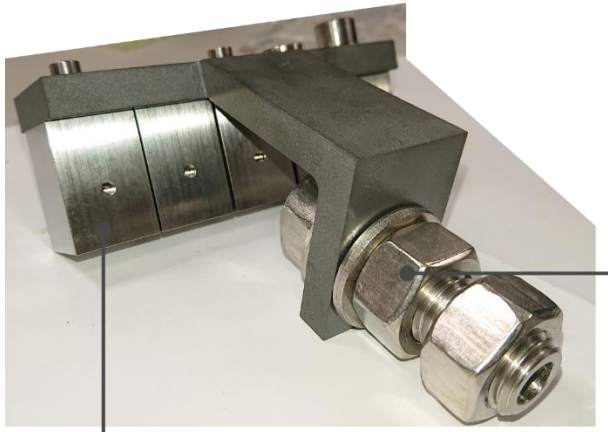
TEST SAMPLE DESCRIPTION

Concept 2: Optical Bench & Mounting Solutions (Test 2)

- Test Objectives:
  - gain a better understanding of the material behaviour during re-entry
  - to investigated the bolt connections of the optical unit feet
  - assess the failure of different bolt connections
  - determine the most suitable bolt size and configuration for unit attachment

- Sample Materials:
  - Bench is made of **HB-Cesic® - carbon reinforced silicon carbide**
  - Feet Dummy are made of **Titanium**
  - M8 and M4 bolt made of:
    - **Aluminium Oxide** (M4)
    - **Titanium** (M4 & M8)
    - **Molybdenum** (M8)





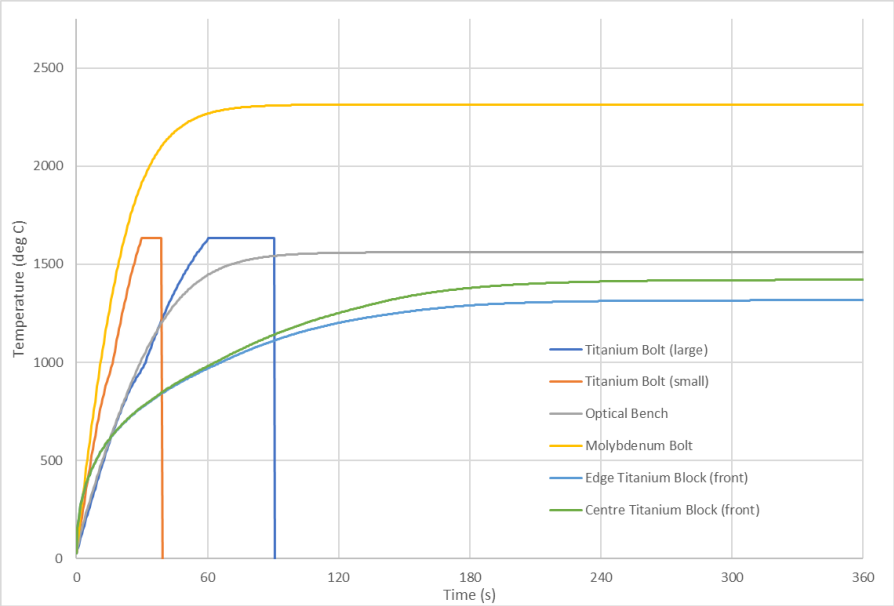
D4D CONTAINMENT TECHNIQUES

TEST SAMPLE DESCRIPTION

Concept 2: Optical Bench & Mounting Solutions (Test 2)

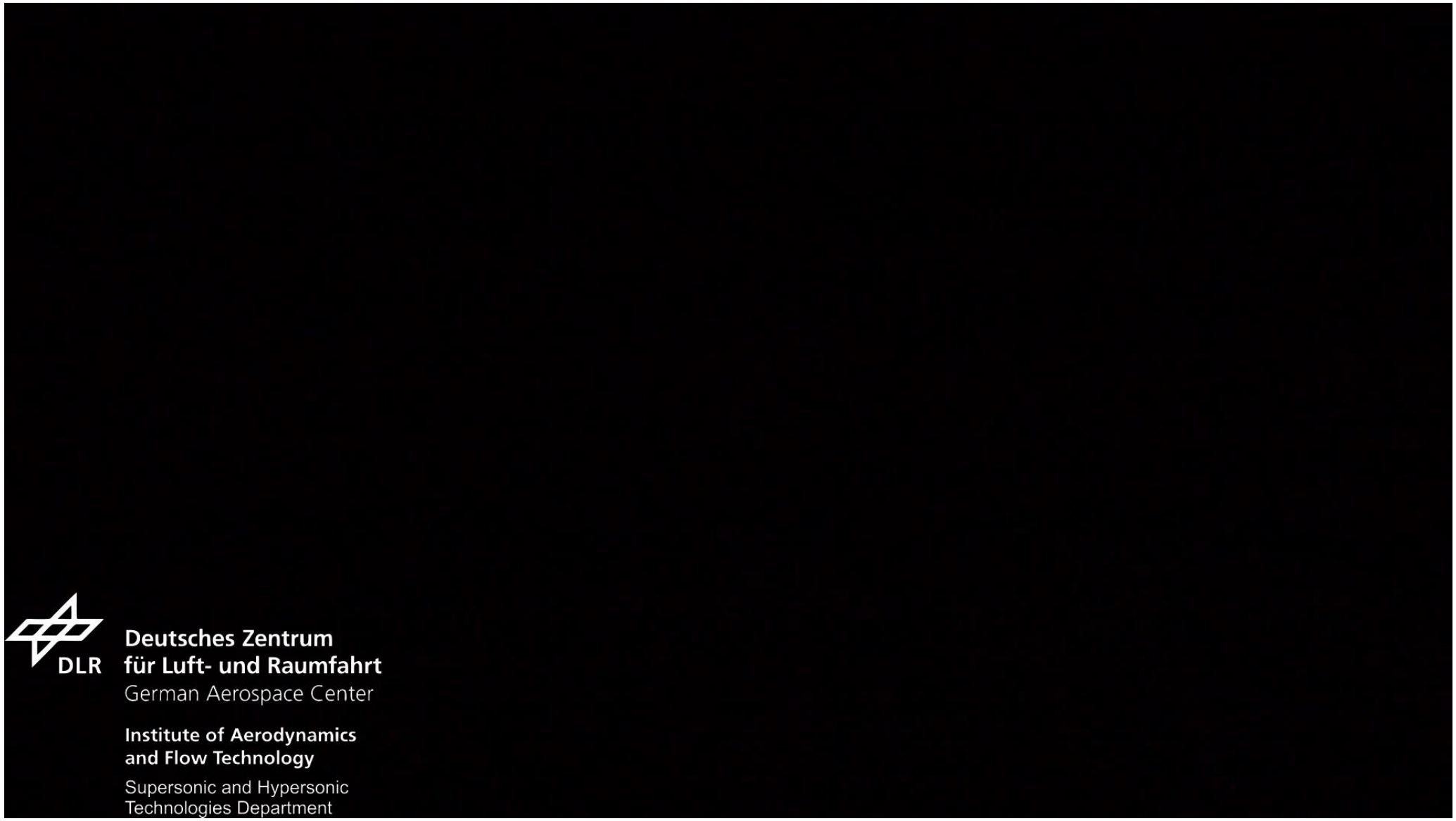
- Predictive Simulation Results
  - simulation also run at a 50% nominal heat flux level to assess the potential impact:
    - prediction still shows a very fast failure of the exposed titanium bolts, but a molybdenum bolt would survive.
    - titanium blocks are shown not to reach melt, such that the failure of the bolts is the only driver of any disconnection
  - predictions are relevant to the exposed bolts only – behaviour of the recessed bolts is not known
    - some risk in shifting to a lower heat flux condition, as recessed bolt failure may not be observed
    - on balance, the lower heat flux condition is preferred as there is a longer test time which will provide more useful data

SAMj Predictions of the Temperature Data at Half Flux



D4D CONTAINMENT TECHNIQUES – TEST READINESS REVIEW

- CESIC BOLTED CONNECTIONS VIDEO



D4D CONTAINMENT TECHNIQUES

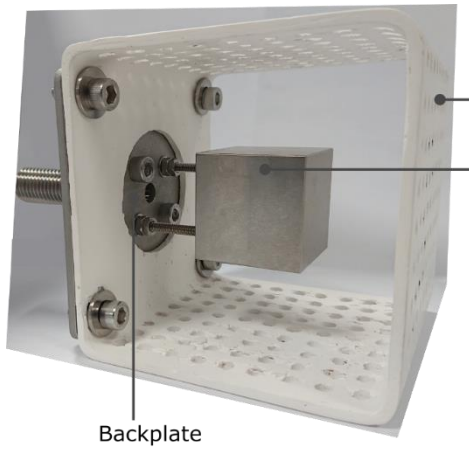
TEST SAMPLE DESCRIPTION

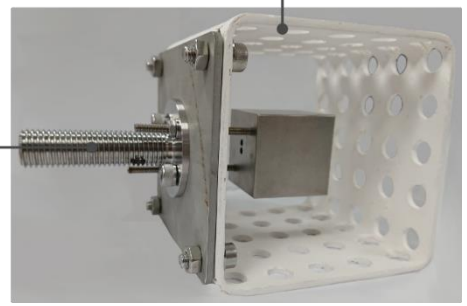
Concept 4: Cage Containing Electronics Unit (Test 7 – Test 10)

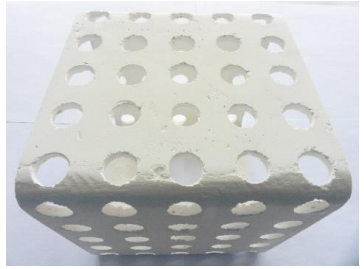
- Test Objectives:
  - gain a better understanding of the cage material behaviour during re-entry
  - to investigated and assess the failure of cage configurations
  - to investigated and assess influence on the electronic units

- Sample Materials:
  - Cages are made of **99% aluminium oxide fibres (Cerafib 99)** provided by Cerafib
  - Calorimeter is made of **Tungsten**

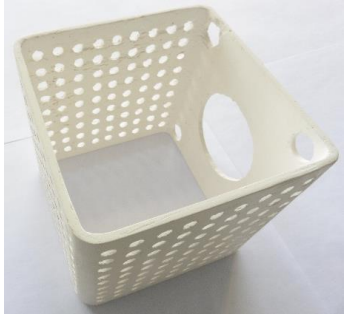
- Cage Configurations:
  - Test 7 – reference test calorimeter w/o cage
  - Test 8 – Cage 1 – 10 mm holes / 10 mm spacing
  - Test 9 – Cage 2 – 5 mm holes / 5 mm spacing
  - Test 10 – Cage 3 – 10 mm holes / 5 mm spacing



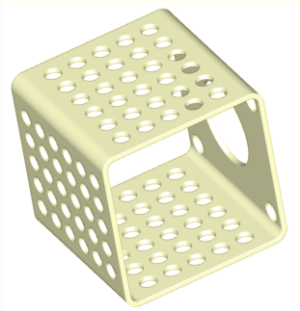




Cage 1
10mm holes / 10mm spacing



Cage 2
5mm holes / 5mm spacing



Cage 3
10mm holes / 5mm spacing

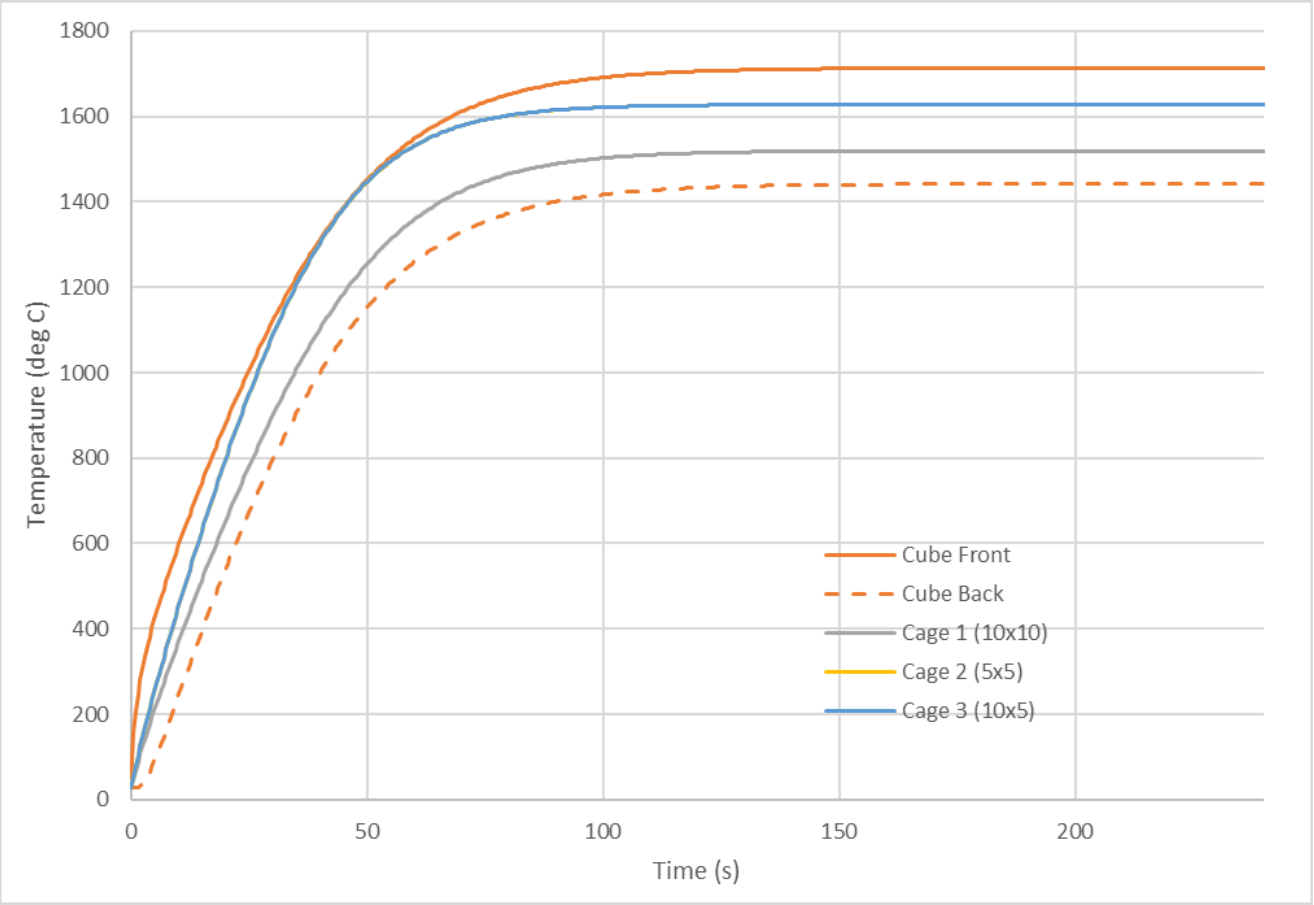
D4D CONTAINMENT TECHNIQUES

TEST SAMPLE DESCRIPTION

Concept 4: Cage Containing Electronics Unit (Test 7 – Test 10)

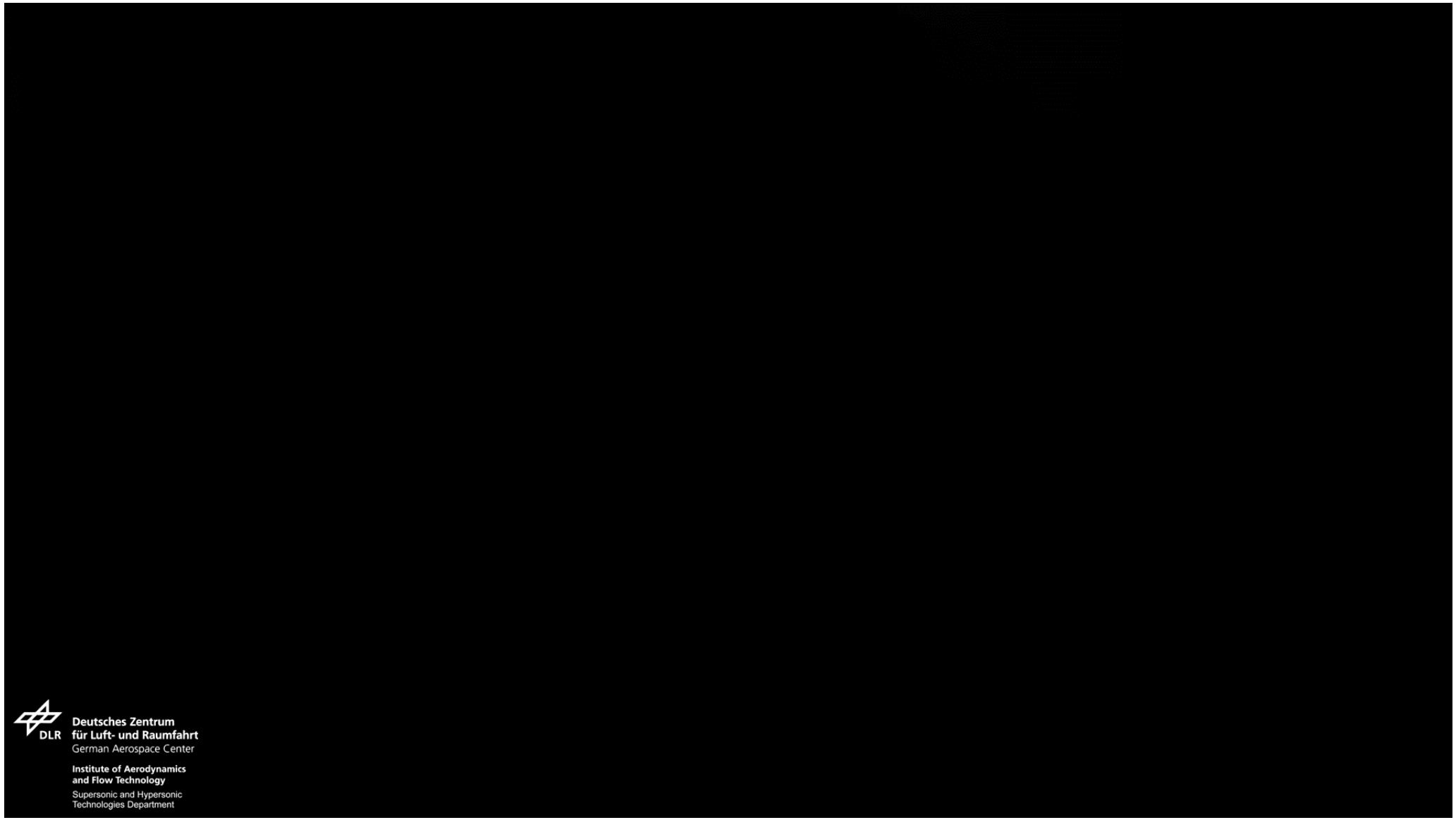
- Predictive Simulation Results
  - most difficult set of tests to assess, the predictions are highly approximate
  - cube retains a significant temperature difference front to back, due to the back face being allowed to radiate
  - cage equilibrium temperatures are within the range of the equilibrium assessment and higher than the low catalycity/high emissivity model
  - The low catalycity is of key interest for the use of ceramics in containment solutions, as this increases the survivability
  - Improved catalycity model target of the post-test analysis.

SAMj Predictions of the Temperature Data



D4D CONTAINMENT TECHNIQUES

– ALUMINIUM OXIDE CAGE #1 VIDEO



D4D CONTAINMENT TECHNIQUES

- REFRACTORY AND CERAMIC BOLTS IN TUNGSTEN VIDEO

THANK YOU!

ANY QUESTIONS?

D4D CONTAINMENT TECHNIQUES

TEST CAMPAIGN – CHRONOLOGICAL ORDER

Test Day	Test Concept	Test Title	Heat Flux [MW/m²]	Test ID
DAY 1	Concept 3.1	Basic Tether Test	1.9	Test 3
DAY 2	Concept 1.1	C-SIC Thermal Guard Test	1.9	Test 1
DAY 3	Concept 2.1	C-SiC Optical Bench Test	1.3	Test 2
DAY 3	Concept 4.4	Cage 3 Test	1.3	Test 10
DAY 4	Concept 4.1	Calorimeter Cube Control test	1.3	Test 7
DAY 4	Concept 4.2	Cage 1 Test	1.3	Test 8
DAY 5	Concept 3.2	Basic Tether Test	1.0	Test 4
DAY 6	Concept 4.3	Cage 2 Test	1.0	Test 9
DAY 7	Concept 3.3	Tungsten Calorimeter Cube with Mo and AlOx Bolts	1.0	Test 5
DAY 7	Concept 3.4	Tungsten Calorimeter Cube	1.5	Test 6