D4D PLATFORM OPTICS AND ELECTRONICS – D4D-ONE FINAL REVIEW

OHB SYSTEM AG

D4D-ONE TEAM, 16.07.2024

AGENDA

1. Introduction
2. Project Summary - Task 1 to Task 3
3. Design for Demise Proposals and Recommendations (Task 4)
4. Next Steps & Open Points

INTRODUCTION

Study Objective

- Characterization of the demise process of critical platform optics and electronic equipment and development of validated materials and equipment reentry models for the tested equipment
  - Characterization the fragmentation and demise process of critical equipment through simulations and tests
  - Development of equipment level models, potentially including updated materials ablation and aerothermal models
  - Proposal of design changes to improve the demise of these equipment and develop models to evaluate and verify their impact
  - Focus on star trackers, electronic boxes and batteries

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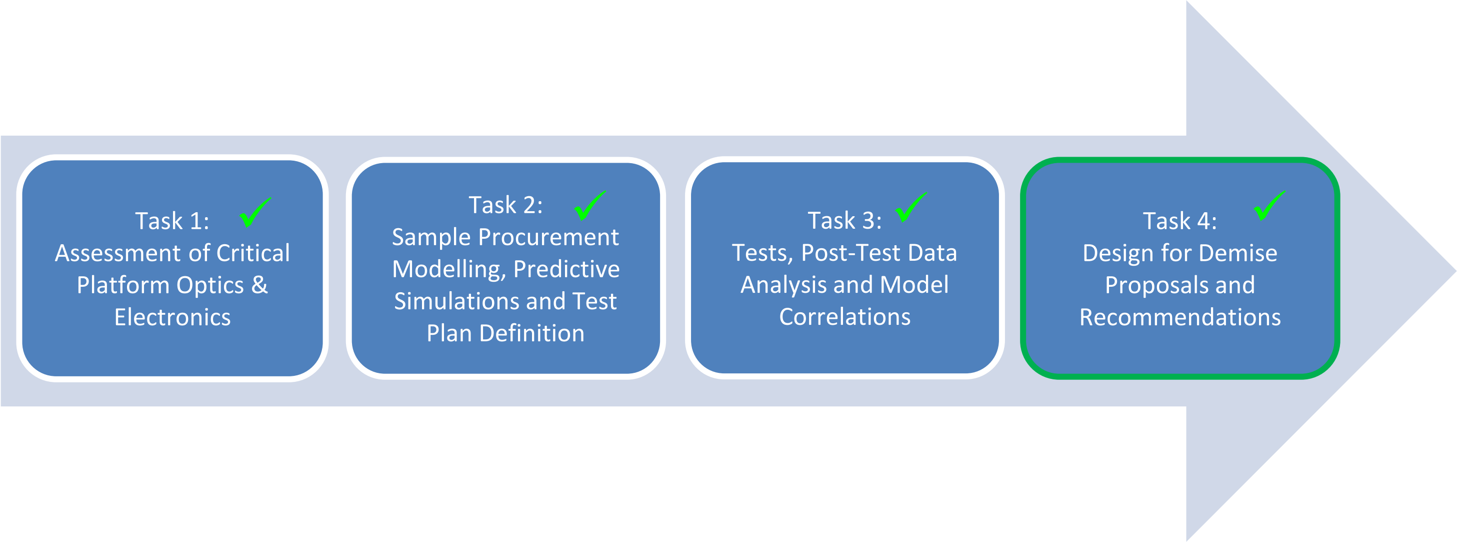
INTRODUCTION



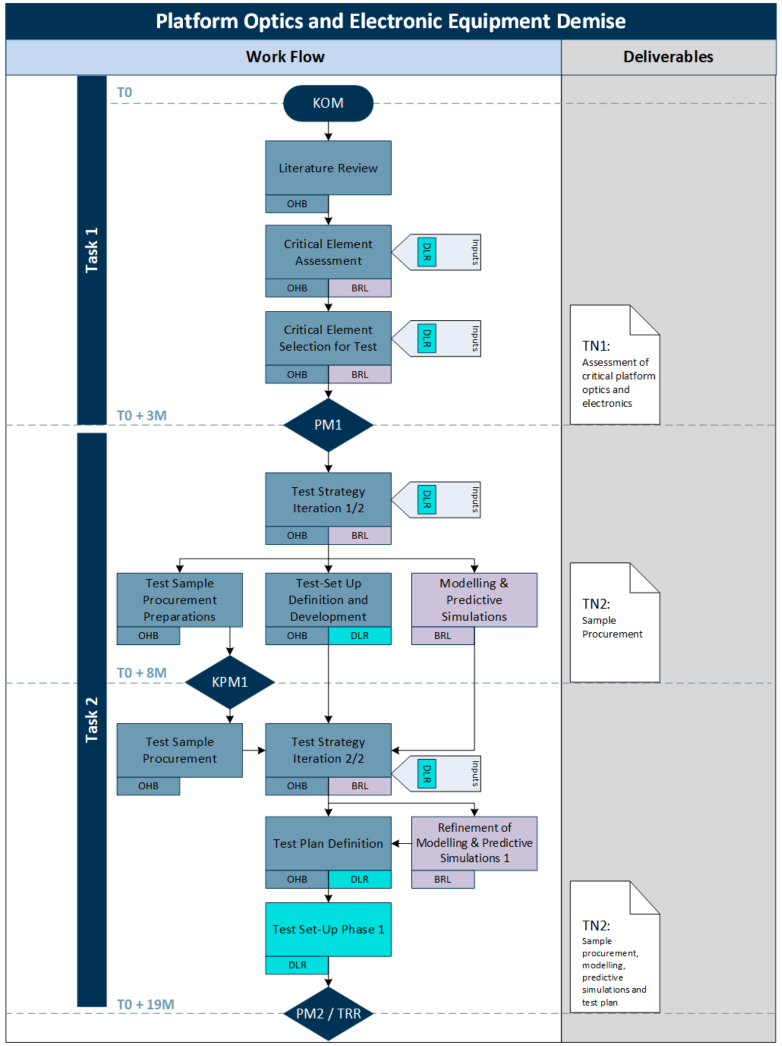
Task 4 Overview

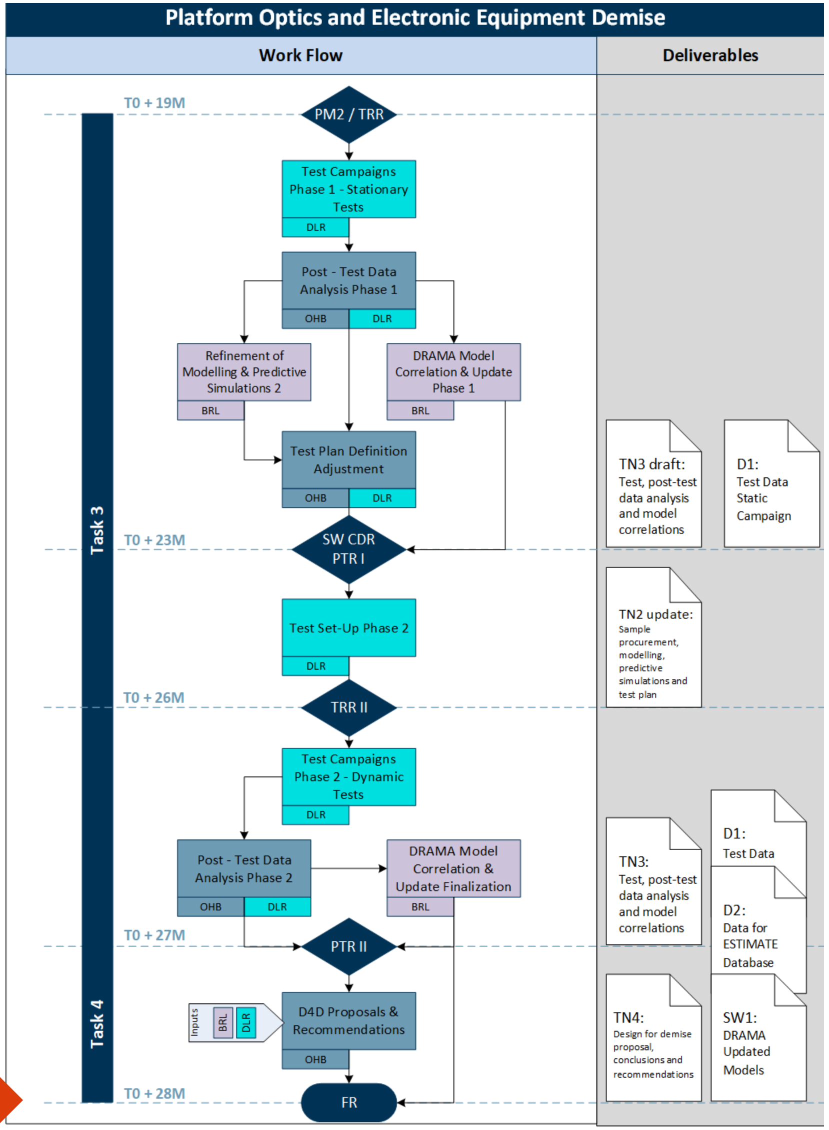
- Design ideas for the improvements of the demise of these equipment to be analysed in future activities
- Conclusions on the lessons learned derived from the predictive simulations, tests phase and model correlations.
- Provide and justify recommendations to the current logic and guidelines for the equipment of interest, for potential application in the ESA DIVE document
- Identify and document knowledge gaps and recommendations for future work on platform optics and electronics

PROJECT STATUS

D4D ONE – FINAL REVIEW

WORKLOGIC AND SCHEDULE –TASK 4





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MEETING SCHEDULE – UPDATED

Meeting		Relative Date	Tentative Date	Location
KOM	Kick-Off	T0	12.01.2022	Telecon
PM1	Progress meeting 1 Review *	T0 + 5M	12.05.2022	Telecon
KPM1	Key Point Meeting	T0 + 9M	09.09.2022	Telecon
D_KPM1	Delta Key Point Meeting	T0 + 13M	10.02.2023	Telecon
PM2 / TRR	Progress Meeting 2 / Test Readiness Review	T0 + 19M	14.08.2023	DLR
SW CDR / PTR 1	SW CDR + Post Test Review Part 1 *	T0 + 21M	24.10.2023	Telecon
TRR 2	Test Readiness Review 2	T0 + 27M	17.04.2024	Telecon
PM3 / PTR 2	Post Test Review Part 2*	T0 + 29M	18.06.2024	Telecon
FR	**Final Review ***	T0 + 30M	16.07.2024	Telecon

*** Payment Milestones**

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DELIVERABLES - UPDATE

ESA ID	Document Title	Type	Lead WP	KOM	PM1	KPM1	PM2 / TRR 1	SW CDR / PTR 1	TRR 2	PM3/ PTR 2	FR	CC	Format Updated Post Meeting
TN1	Assessment of critical platform optics and electronics	TN	1200		F								PDF, MS WORD
TN2	Sample procurement, modelling, predictive simulations and test plan definition	TN	2200			D	F		F				PDF, MS WORD
TN3	Tests, post-test data analysis and model correlations	TN	0100					D		F			PDF, MS WORD
TN4	Design for demise proposals, conclusions and recommendations	TN	4100								F		PDF, MS WORD
D1	Test Data	D	0100					X		X			
D2	Data for ESTIMATE Database	D	3300							X			
SW 1	DRAMA Updated Models	SW	3300								X		

Programmatic Deliverables:

- Final Report ✓
- Executive Summary ✓
- Technology Achievement Summary ✓
- Contract Closure Documentation

PROJECT SUMMARY TASK 1 TO TASK 3

PROJECT SUMMARY – TASK 1 ASSESSMENT OF CRITICAL PLATFORM OPTICS AND ELECTRONICS

Review Satellite Platforms (after 2010)

- LEO Satellites > 500 kg
  - EO Satellites
  - Telecom Satellites
  - Constellations

Sources:

- Satellite Databases
- Internal Sources
- Technical Literature / Websites

Review Platform Equipment Products

- Star Tracker
- Batteries
- Electronic Boxes

Sources:

- Internal Databases
- Datasheets
- Company Websites
- Correspondence

Determine Most Commonly Implemented Equipment Products

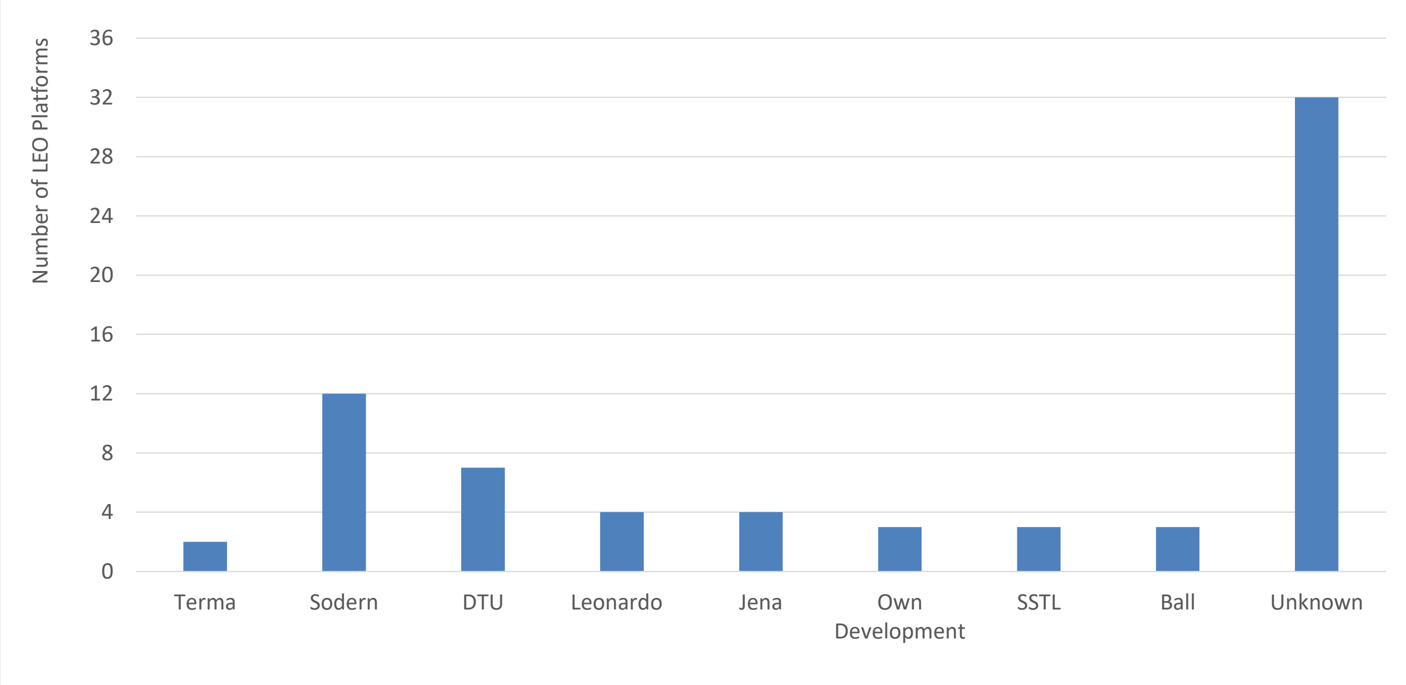
Identification of Parts and Materials

Past Studies

Future Developments

Review of 70 Satellite LEO Mission / Platforms (after 2010; > 200 kg) (w/o China and Russia)

- EO Satellites / Telecom Satellites / Constellations
  - Sodern more than 700 start tracker in orbit (mostly Aurigas in OneWeb)
  - **Jena-Optronik sold 400 star tracker , more than 100 in orbit (GEO, MEO, LEO)**
  - Leonardo, e.g. SpaceStar in Iridium Next (80+)
  - DTU (15+ missions)
- Star Tracker Masses: 40g to 4kg



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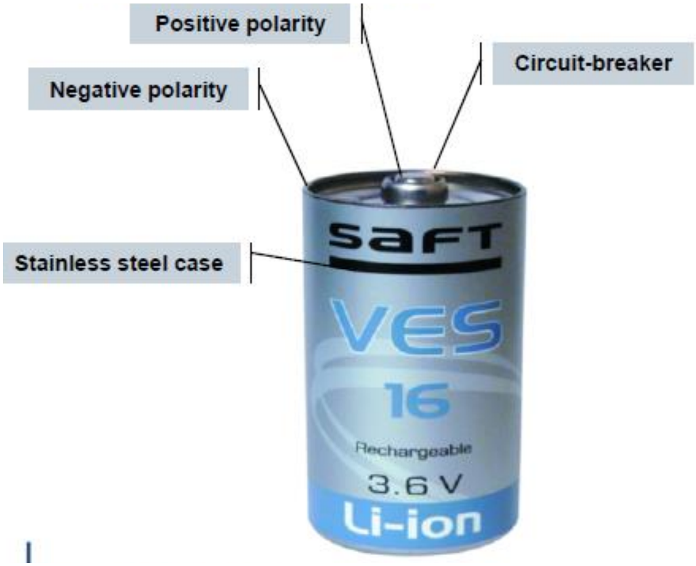
PROJECT SUMMARY – TASK 1 ASSESSMENT OF CRITICAL PLATFORM OPTICS AND ELECTRONICS

- Two of the main suppliers providing batteries for LEO satellite platforms are ABSL (now part of Enersys) and SAFT:
  - **ABSL: 340+ spacecraft (satellite + launch vehicle) in orbit**
  - SAFT: VES16 cells 200+ satellite

ABSL Single Battery Cell

ABSL Mini-Module with Bulk Wrapped Cells

ABSL Mini-Module with Individually Wrapped Cells



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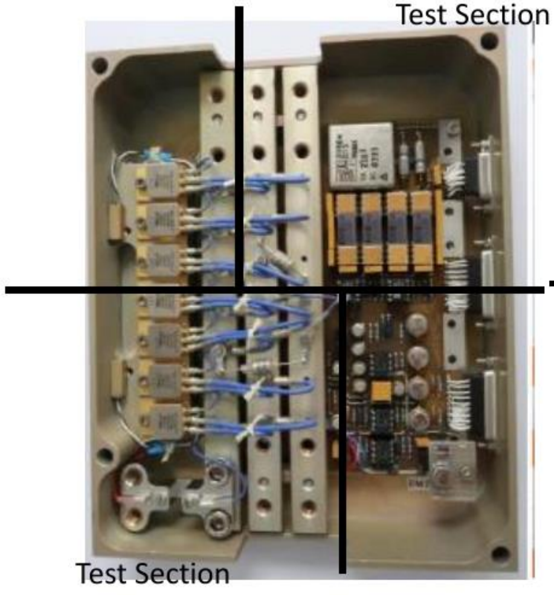
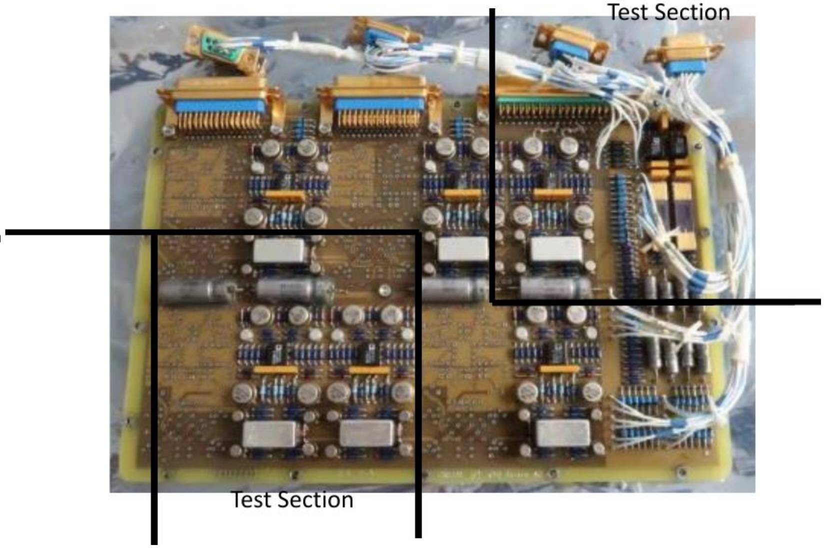
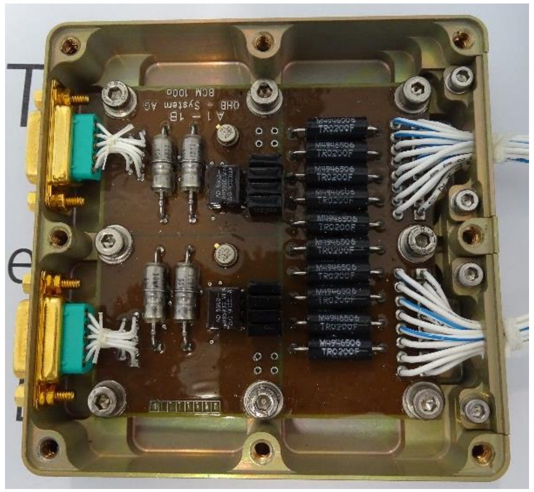
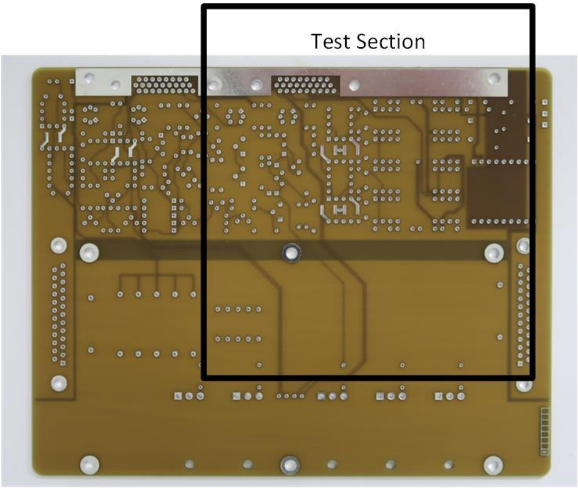
PROJECT SUMMARY – TASK 1 ASSESSMENT OF CRITICAL PLATFORM OPTICS AND ELECTRONICS

- Electronics boxes used for different purposes
- Various suppliers with numerous different design, form factors and sizes
- Suppliers adopt their design for the application in LEO constellations
  - units are usually smaller and lighter as conventional units for larger individual or high value LEO satellites









Preliminary Simulations Results

- Star Trackers
  - The critical elements are the focal plane array housing and the optical barrel.
    - These are the two titanium elements on the unit.
  - There is also a potential risk from the PCB.
- Batteries
  - Batteries with small cells are expected to demise completely from most release altitudes of interest.
  - The modelling of the GFRP modules has a relatively small impact on the demisability.
  - Larger cells show lower demisability. The larger Saft cells pose a risk.
- Electronics Boxes
  - The material model used for the GFRP cards is critical to any casualty risk prediction.
  - The model derived from the SECRET tests suggests that many electronics cards will land.
  - Use of an aluminium model suggests that the majority of cards will demise.
  - The el-mat model is demonstrated to be unrealistically demisable.
  - There is a potential risk from larger components, such as transformers, which should be accounted for. Other potential risk components should be tested, and analysed in this activity.

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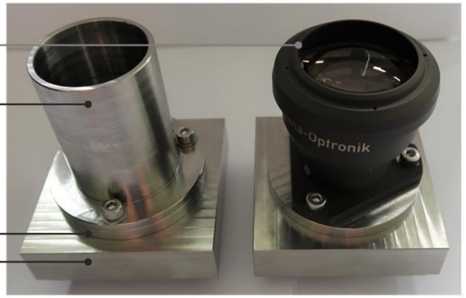
PROJECT SUMMARY – TASK 1 ASSESSMENT OF CRITICAL PLATFORM OPTICS AND ELECTRONICS

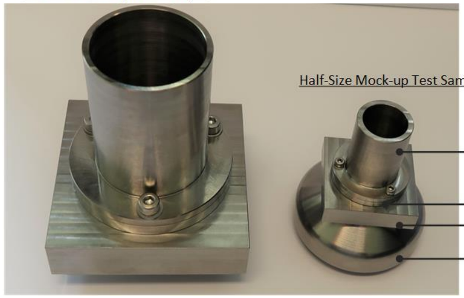
Equipment	Critical Elements	Events of interest	Equipment level tests	Availability	Suitability of geometries
Star Tracker	Titanium made the focal plane array housing and the optical barrel	Has not been tested before Behaviours of critical parts Fragmentation of unit	Feasible	Jenaoptronik ASTRO APS	Internal Parts ok Unit has to be adapted as mock ups
Batteries	GFRP Sheets ~~Larger Cells~~	Behaviours of critical parts Fragmentation of unit	Feasible	ABSL ~~SAFT~~	Single Cell ok Modules may have to be adapted
Electronics Boxes	PCB Cards (GFRP)	Behaviours of critical parts Fragmentation of unit	Feasible	OHB	Small Cards ok Modules have to be adapted

D4D ONE – FINAL REVIEW

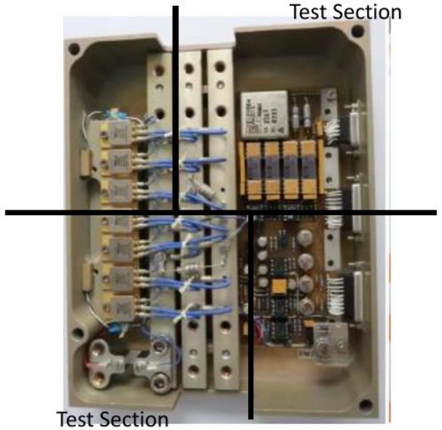
PROJECT SUMMARY – TASK 2 & TASK 3 TEST PREPARATION & TEST CAMPAIGNS

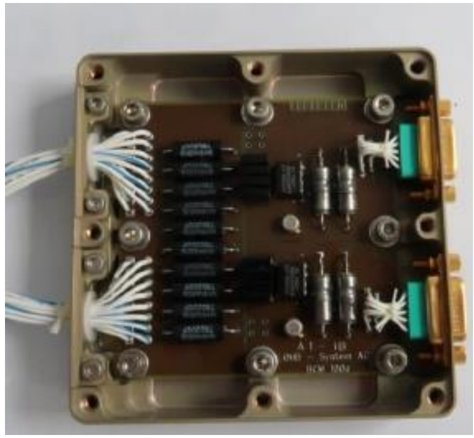


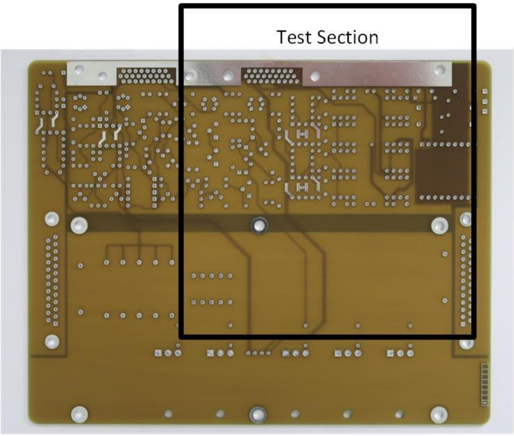
- Test Objects
  - Star tracker: Jena Optronik Astro APS imaging system
  - Batteries: ABSL batteries and battery modules
  - Electronics boards: OHB-manufactured LEO populated and unpopulated PCB’s

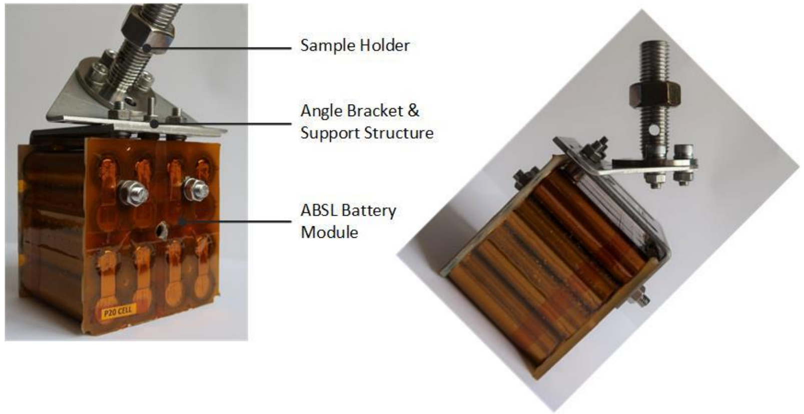


- Two test campaigns
  - First Campaign – Static test set-up
  - Second Campaign – Dynamic test set-up









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PROJECT SUMMARY – TASK 2 & TASK 3 TEST PREPARATION & TEST CAMPAIGNS

ID	Campaign	Test Type	Sample Type	Sample Description	Cold Wall Heat Flux (kW/m^2)	Purpose
S-01	1	Stationary	Star Tracker Imaging System	Full-Size Mock-up	400 - 500	Identify critical parts / differences to S02
S-02	1	Stationary	Star Tracker Imaging System	JOP Lens Tube / Mock-ups of plates and bolts	400 - 500	Identify critical parts
S-03	1	Stationary	Star Tracker Imaging System	Half-Size Mock-up	200 - 250 - 300 - 350	Identify critical parts
S-04	1	Stationary	Star Tracker Imaging System	Half-Size Mock-up	400 - 500 - 580	Retest critical parts based on results of S03
S-05	1	Stationary	Star Tracker Imaging System	Full-Size Mock-up	500 - 580	Assess fragmentation
S-06	1	Stationary	Battery Single Cell	ABSL IP 28 and P20 Cell provided by	100 - 200 - 300	Assess behaviour of different cells
S-07	1	Stationary	Battery Module	4 x 4 Module ABSL with Angle of attack 0° (perpendicular)	200 - 300 - 400	Assess fragmentation
S-08	1	Stationary	Battery Module	4 x 4 Module ABSL with Angle of attack 45°	200 - 300	Assess fragmentation
S-10	1	Stationary	Battery Module / GFRP Sheet	ABSL GFRP Sheet - Tufnol	100 - 200	Confirm observed behaviour
S-11	1	Stationary	Electronic Board	EnMap board section, 45° AoA	300	Assess different card types
S-12	1	Stationary	Electronic Board	PD board (bottom left), 45° AoA	100 - 200 - 300	Assess different card types
S-13	1	Stationary	Electronic Board	BCM board, 45°AoA	200 - 300	Assess different card types
S-14	1	Stationary	Electronic Board	PCDU board (top right), 45° AoA	200 - 300	Assess different card types
S-15	1	Stationary	Electronic Board	2 BCM boards mounted together, 45° AoA	200	Assess fragmentation

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PROJECT SUMMARY – TASK 2 & TASK 3 TEST PREPARATION & TEST CAMPAIGNS

Test ID	Test Campaign	Test Type	Sample Type	Sample Description	Calibrated Heat Flux (kW/m^2)	Rotation Speed (Hz)	Purpose
S09	2	Stationary	Electronics Board	Unpopulated EnMap Board Section	100, 200, 300	n.a.	Material Test
D01	2	Dynamic	Star Tracker Imaging System	Full-Size Mock-up	500	0.1 Hz	Assess fragmentation
D02	2	Dynamic	Star Tracker Imaging System	Half-Size Mock-up	500	2 Hz	Assess fragmentation
D03	2	Dynamic	Electronics Board	EnMap Board Section Angle of attack 0° to flow	200	0.5 Hz	Assess behaviour
D04	2	Dynamic	Electronics Board	PD Board Section Angle of attack 0° to flow	200	0.1 Hz	Assess behaviour
D05	2	Dynamic	Electronics Board	BCM Board with Lid Angle of attack 0° to flow	200	2 Hz	Assess behaviour
S16	2	Stationary	Electronics Board	PD Board Section	100, 200, 300	n.a.	Material Test
D07	2	Dynamic	Battery Module	4 x 4 Module provided by ABSL Angle of attack 0° to flow (perpendicular)	300, 400, 500	0.3 Hz	Assess fragmentation
D08	2	Dynamic	Battery Module	4 x 4 Module provided by ABSL Angle of attack 0° to flow (perpendicular	300, 400, 500	2 Hz	Assess fragmentation at different rotation speed than in D07

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PROJECT SUMMARY – TASK 2 & TASK 3 TEST PREPARATION & TEST CAMPAIGNS

Belstead
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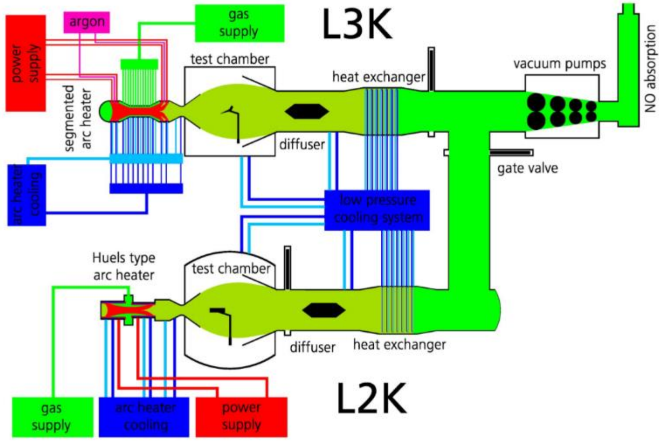
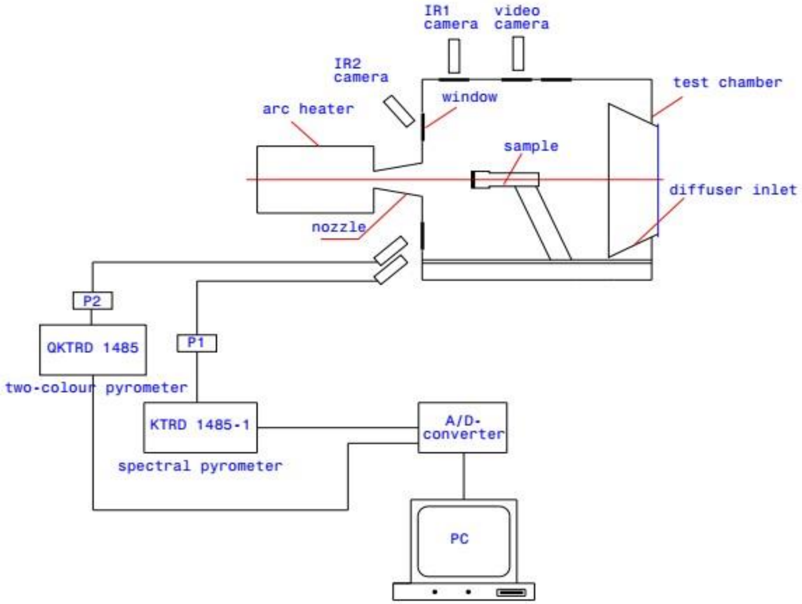
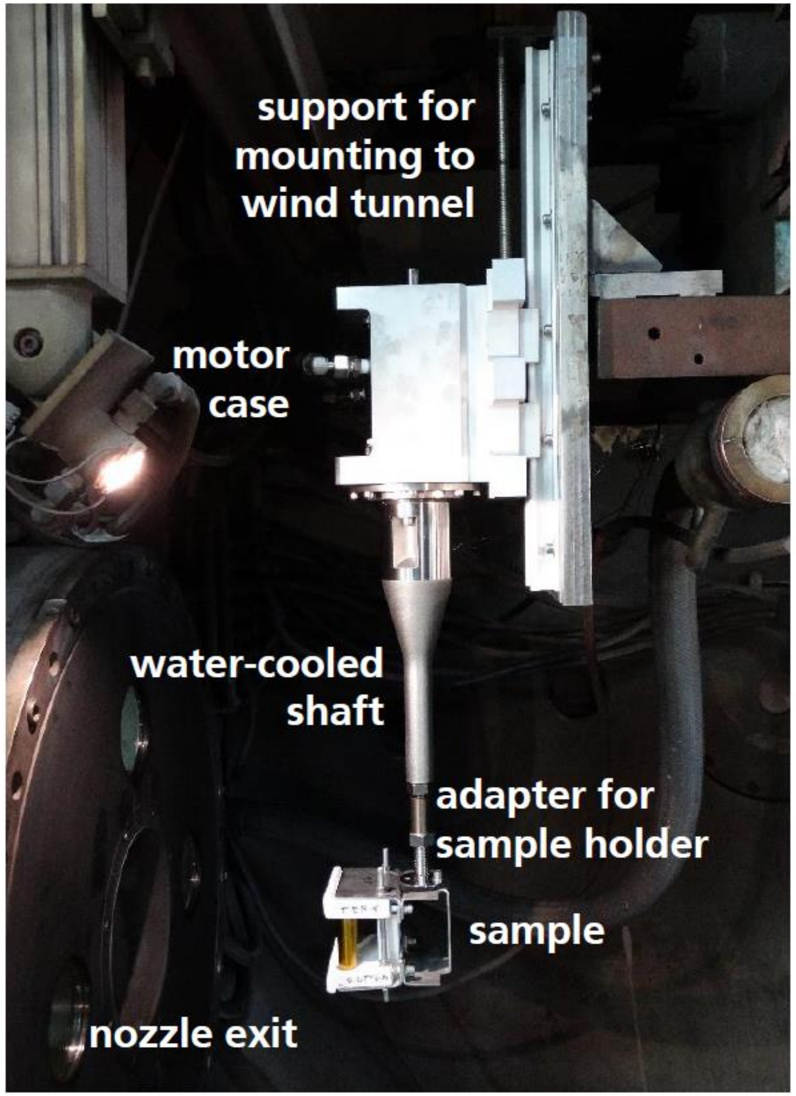
- DLR conducted the wind tunnel testing using the L2K arc heated wind tunnel
- Rotational Sample Holder used







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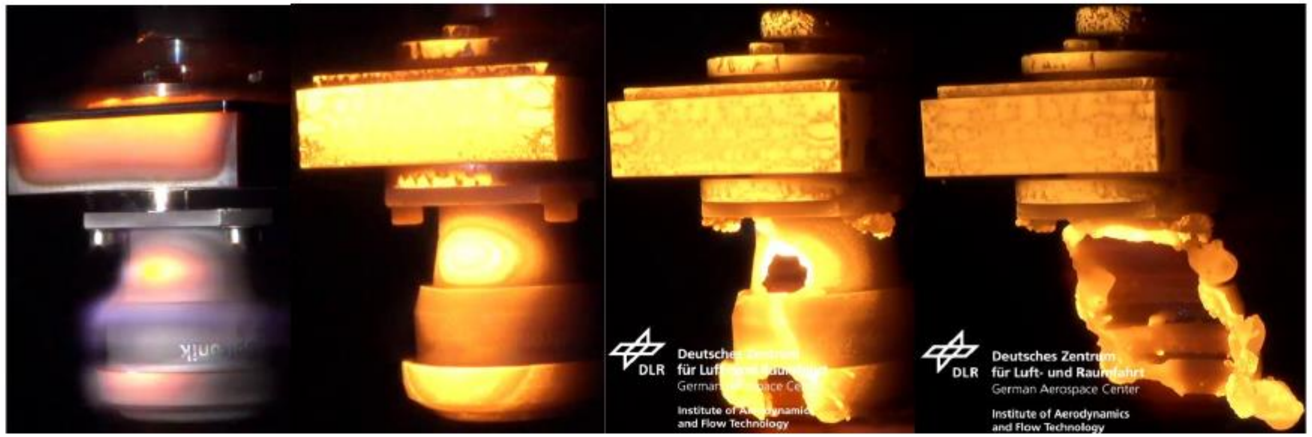
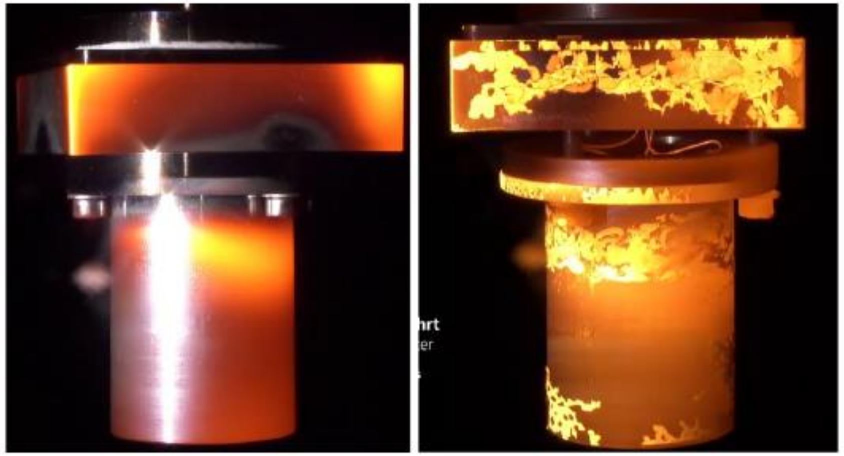
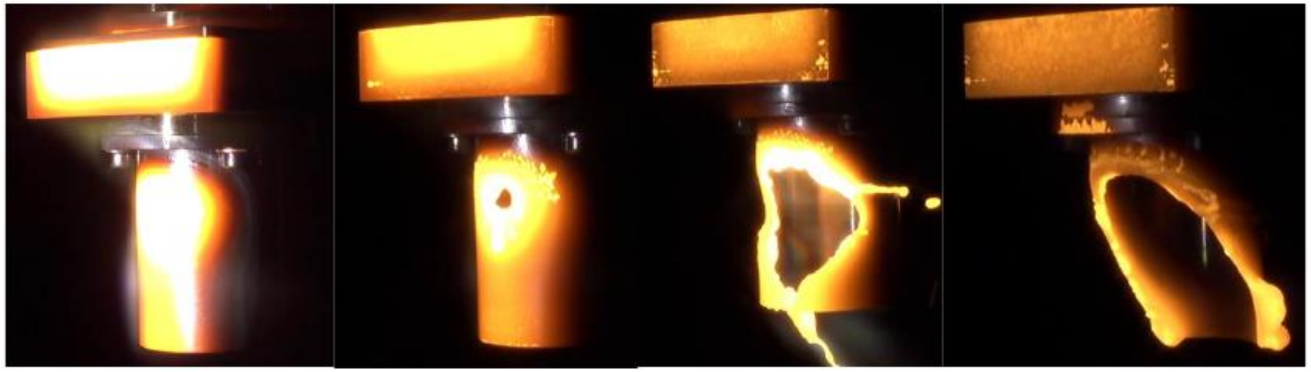
PROJECT SUMMARY – TASK 2 & TASK 3 TEST PREPARATION & TEST CAMPAIGNS

- Star Tracker Conclusions
  - Titanium parts are critical elements
  - Single (connected) titanium part
    - Possible separation with helicoil issue







D4D ONE – FINAL REVIEW

PROJECT SUMMARY – TASK 2 & TASK 3 TEST PREPARATION & TEST CAMPAIGNS

Belstead
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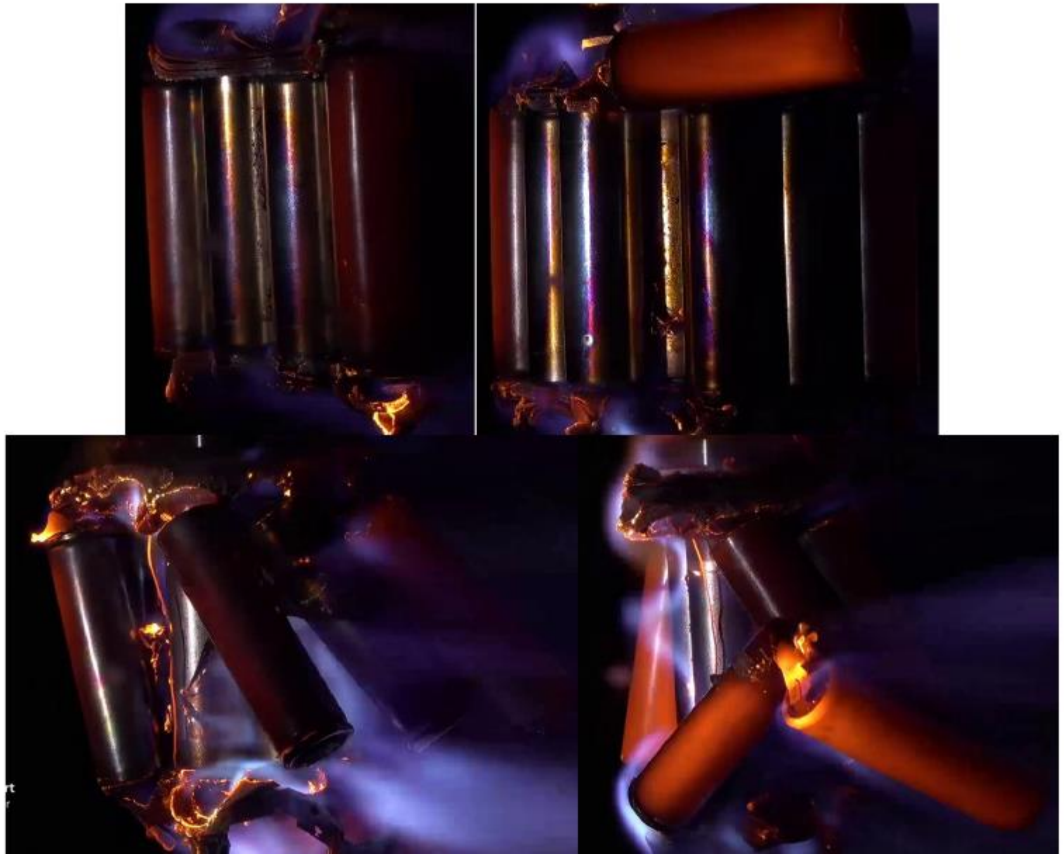
- Battery Conclusions
  - GFRP model has impact, but minor
  - Small cells expected to demise for all uncontrolled release altitudes of interest
  - Large potential risk as many cells



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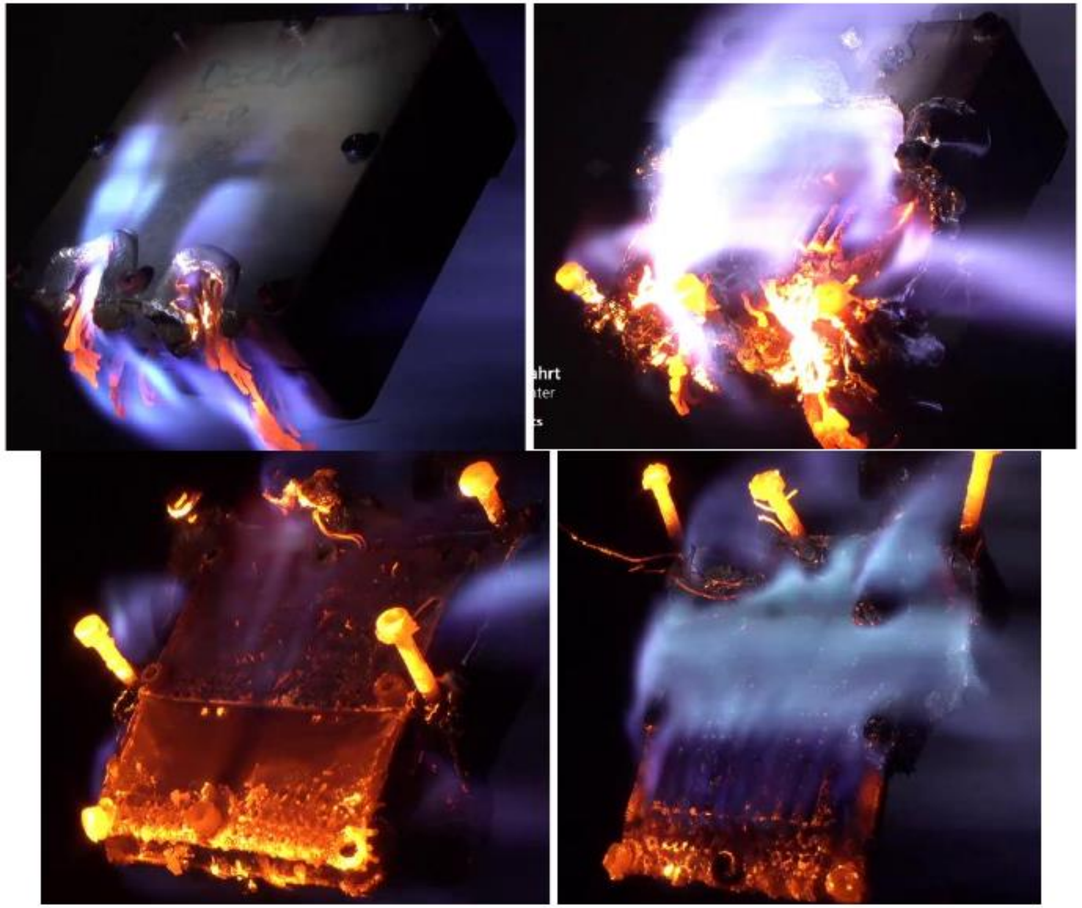
PROJECT SUMMARY – TASK 2 & TASK 3 TEST PREPARATION & TEST CAMPAIGNS

Electronics Card Conclusions

- GFRP likely to land
  - Will change shape and warp, may tear
  - Not evidence that tearing will occur for cards – would need different tests
  - Difficult to ignore as a risk



TASK 4 - DESIGN FOR DEMISE PROPOSALS AND RECOMMENDATIONS

LESSONS LEARNED FROM THE PREDICTIVE SIMULATIONS, TESTS PHASE AND MODEL CORRELATIONS

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LESSONS LEARNED

- Star Tracker
  - Basic modelling good
    - Single titanium part (connected barrel and focal plane housing)
    - One part is expected to land for larger star trackers
    - Some probability of demise for small star trackers
  - Titanium material model good
    - Separation of parts in dynamic tests
    - Helicoils – needs to be tested
    - Not enough data/evidence to include in models
  - Glass melting of interest
    - Material is not fused silica (borosilicate glass)
    - Testing of range of glasses is recommended
    - Developed model should be able to catch behaviour using viscosity data

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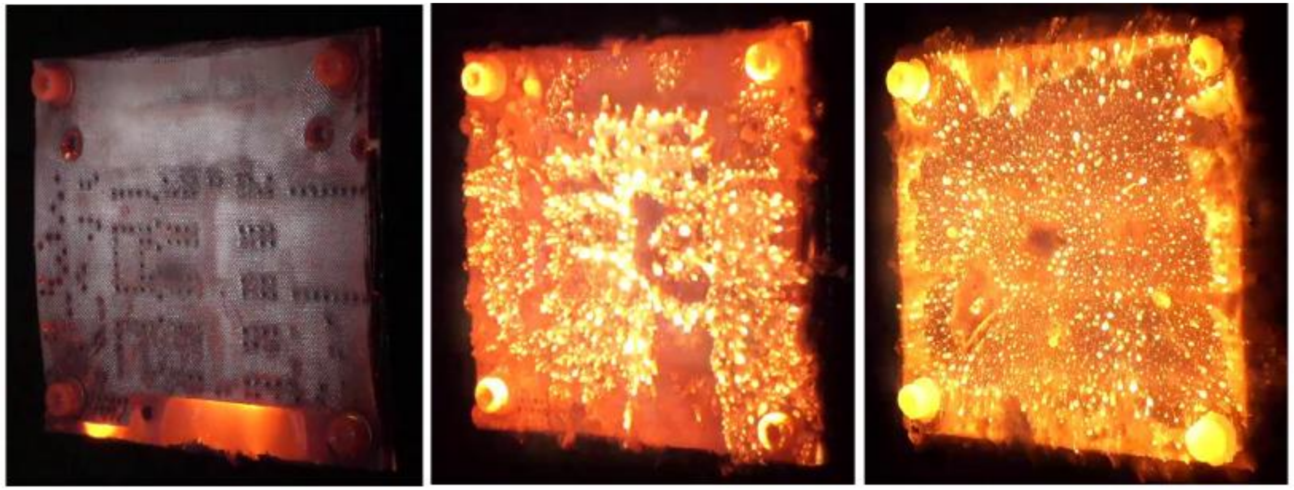
LESSONS LEARNED

- Batteries
  - ABSL behaviour consolidated
    - Material model based on steel can
    - Should be completely demisable for release altitudes above 80km
  - Fragmentantion driven by GFRP material
    - Should be included in model
    - As GFRP torn apart, does not need to be included in casualty risk
  - Other cells still required to be tested
    - Cells are larger – and are predicted to be higher risk
  - Median risk is not acceptable
    - There is a large risk if cells survive

LESSONS LEARNED

- Electronics Cards
  - Difficult to assess
    - GFRP is very low demisabiliy, but also very low strength when hot
    - Shape change will happen
    - Where there are forces (two masses) the material will tear
    - Cards will probably survive intact
    - Investigation into material tear at higher forces recommended (static facility sufficient)
  - Model based on glass balance integral model
    - Captures behaviour
    - Driven by glass response
    - Low catalycity, but higher catalycity than pure glass
  - Componentry
    - Some large components can be a risk, such as transformers



- Modelling
  - Material Models

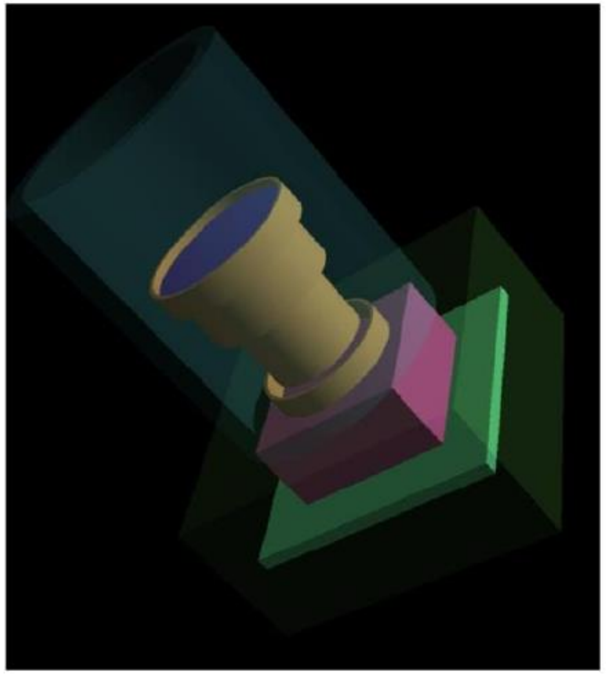
Material	Notes
Titanium	Current DRAMA material model good – included as consolidation
Battery Cell	Modified DRAMA steel material model to capture battery cell behaviour. Uses a reduced latent heat.
GFRP	Balance Integral Model: utilised in SAMj. Based on viscosity driven glass material demise models developed within the COPPER activity.
GFRP Proxy	Equivalent metal GFRP proxy model. Suitable for DRAMA, and consistent with the model recommended from the SECRET activity.

D4D ONE – FINAL REVIEW

LESSONS LEARNED

- Modelling
  - Star Tracker

Component	Notes
Housing	Aluminium. A single aluminium component can be used for the entire housing, or separate components can be considered for the barrel and housing. Where separate components are used, the barrel can be connected-to, otherwise it should be contained-in. Failure of the housing is preferred to be via a mass loss model (not currently available in DRAMA). Removal of housing at full demise is preferred to removal at melt temperature in a DRAMA-compatible model.
Barrel/Focal Plane	Titanium. The recommendation is to model this as a single titanium part, or as a collection of connected titanium parts with undemisable joints. The latter is used to capture the length scales of the model, as shown in Figure 4-1.
Lenses	Borosilicate glass. It is preferred that these are modelled using a balance integral approach (not currently available in DRAMA). Proxy 'equivalent metal' glass models can be acceptable, but must be demonstrated by test.

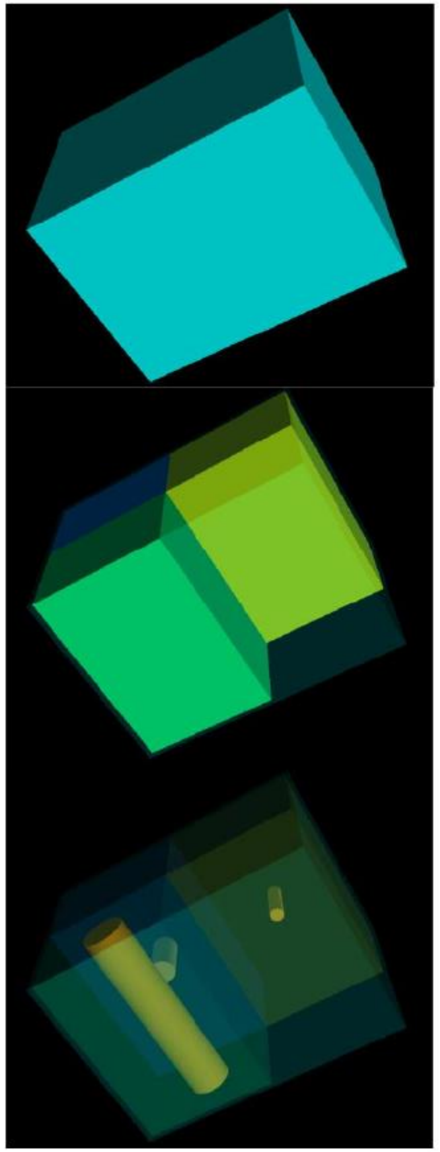


D4D ONE – FINAL REVIEW

LESSONS LEARNED

- Modelling
  - Battery

Component	Notes
Housing	Aluminium. A single housing is recommended for the whole battery. This is recommended to fail using a mass loss model (not currently available in DRAMA). The remainder of the battery components are contained-in the housing.
Module	GFRP. The battery should be separated into a number of modules which are representative of the architecture. Each of these modules should be modelled as GFRP (preferably a balance integral material, but a test-validated proxy is acceptable), and the correct total mass of GFRP should be considered. This is also recommended to fail using a mass loss model. The cells are considered as contained-in the GFRP modules. A suitable multiplicity can be used for identical modules.
Cells	Steel Proxy Material. The cells should be considered as contained-in the modules with a suitable multiplicity for the cell number. The test-validated battery cell proxy material should be used for the cells. This is currently applicable to all cells, although has only been validated for ABSL cells.

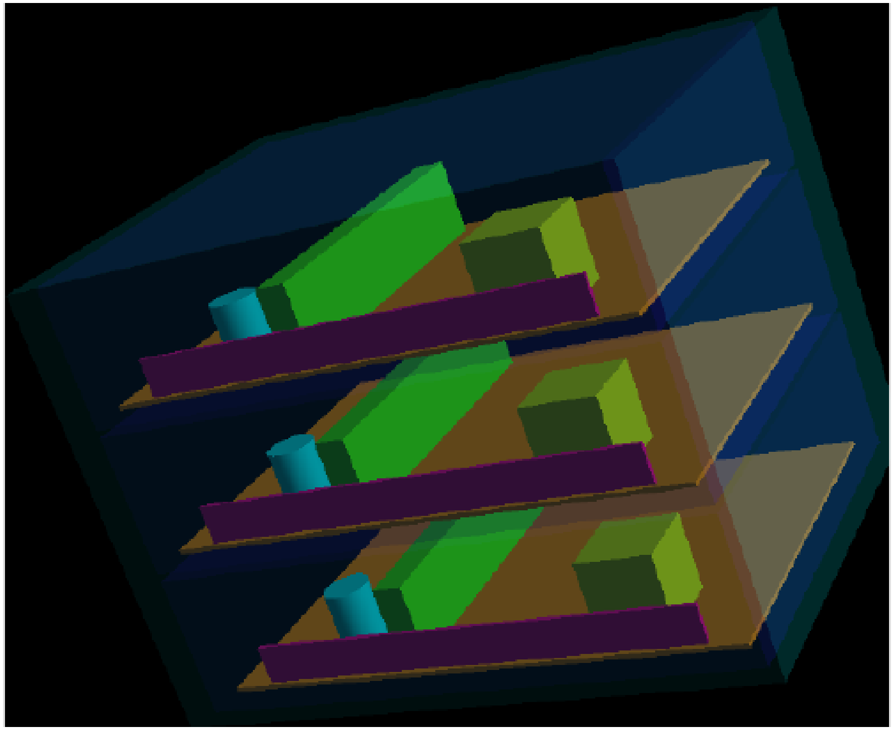


D4D ONE – FINAL REVIEW

LESSONS LEARNED

- Modelling
  - Electronics

Component	Notes
Housing	Aluminium. A single housing can be used for the whole electronics box. This is recommended to fail using a mass loss model (not currently available in DRAMA). The remainder of the electronic components are contained-in the housing. Where a stack-type electronics box is used, and there is an internal housing separating the electronics into similar units, this can be modelled as a multiplicity, in which case it is more efficient to model the inner housing as well. Failure of the inner housing is again recommended to be modelled using a mass loss model.
Electronics Card	GFRP. The GFRP card should be modelled with the correct mass of GFRP, which is expected to be approximately half the mass of the card, frame and componentry unless large components are present. If the componentry is small, it is acceptable to neglect their modelling. The GFRP is preferred to be modelled using a balance integral model (not currently available in DRAMA), but a test-validated 'equivalent metal' proxy model is acceptable.
Frames	Aluminium. This can be modelled in two ways. Either as a connected-to part, which is a single part representative of the frame length scale. To do this, the thickness and height of the frame should be represented, but the length should be a total length of all the frame attached to the card. This should be released using a mass loss model (not currently available in DRAMA). Alternatively, model as contained-in the GFRP as this maintains the ballistic coefficient of the card giving a more reasonable opportunity to demise. In this case multiple lengths of frame can be modelled using multiplicity. Note: DRAMA will currently disregard the parent component (card) at the point the children are released. This needs to be fixed in future versions to make use of the release capability reliably.
Electronic Componentry	This is recommended to be modelled when a large electronic component, such as a transformer is present on an electronic card. It is preferred that this component is connected-to the card. Where there are multiple similar components, these are more efficiently modelled as a multiplicity, in which case they must be considered contained-in the card. Release of the componentry is recommended at a card temperature of 1200^{0}C however modelled. Note: DRAMA will currently disregard the parent component (card) at the point the children are released. This needs to be fixed in future versions to make use of the release capability reliably.



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LESSONS LEARNED

- DRAMA Upgrades
  - Balance integral glass model
    - Viscosity based temperature model
    - Capture material removal
    - With consolidation, cheap viscosity test sufficient for characterisation of new glass materials
  - Mass loss model
    - Component failure at a given mass loss
    - Fragmentation model, allows separation between melt temperature and full demise
    - Child release similarly
    - Should be used with uncertainty as part of a stochastic model
    - Standard in SAMj
  - Parent object reschedule
    - Currently DRAMA does not reschedule a parent object on child release
    - If a release criteria is used, the remaining mass is vanished
    - Needs to be fixed, particularly if mass loss model is used

DIVE RECOMMENDATIONS

D4D ONE – FINAL REVIEW

DIVE RECOMMENDATIONS

- General Comments
  - Findings from SECRET consolidated
  - Process for testing and modelling followed DIVE procedures
    - Successful demonstration of existing guidelines
    - Stepped heat flux approach applied
  - Dynamic testing
    - Useful for fragmentation
    - Can be harder to assess
  - Static material demise tests of clear value
- Specific Recommendations
  - Testing
    - Simple material tests highly recommended
    - More than one test condition (can be stepped fluxes in one test) mandatory
  - Modelling
    - Star tracker has one titanium part
    - Battery models use a GFRP layer, but not include GFRP in casualty risk
    - GFRP electronics cards likely to remain contiguous, and thus a risk

RECOMMENDATIONS FOR FUTURE WORK ON PLATFORM OPTICS AND ELECTRONICS

D4D ONE – FINAL REVIEW

FUTURE WORK – TESTING AND MODELLING

- Investigation into demisable electronics cards
  - GFRP is low demise
- Investigation into bolted joints with helicoils
  - When doe this happen?
  - Can this be used as a fragmentation/demise technique
- Glass material database (inside SCORED)
  - Testing on a range of glasses should be performed
  - Assess whether modelling of viscosity captures all behaviour
  - Future glass demisability could be inferred with cheap viscosity-temperature tests
- Test larger battery cells
  - Intended but not performed here
  - Larger cells are larger risk – should be tested
- Assessment of potential GFRP disintegration in re-entry
  - Will the cards tear apart?
  - Test hot cards under force in static facility

DESIGN IDEAS TO IMPROVE THE EQUIPMENT DEMISE

General Notes on Equipment Design

- The main design requirements and constraints for equipment concern:
  - Function and Performance
  - Mass, Volume and Accommodation
  - Operational Environment
  - Power Budgets
  - Launch Loads

- Currently demisability of the equipment during atmospheric re-entry often is still an afterthought
- Design requirements resulting from demisability often entail change of materials and/ or design modifications that are often difficult to align with performance requirements
- Equipment suppliers begin to acknowledge the need for demisable equipment

DESIGN IDEAS TO IMPROVE THE EQUIPMENT DEMISE – STAR TRACKERS

Potential areas for demisability improvement:

- Change of materials
  - change to another more demisable material may impair performance
  - requires careful investigation

- Reduction in overall size
  - significant reduction of the overall size of the star tracker imaging system is not feasible for application where higher accuracy is required

- Early separation of the imaging systems
  - further investigation is required to determine the effectiveness of early separation
  - If effective, demisable inserts or helicoils could be incorporated in the design.

DESIGN IDEAS TO IMPROVE THE EQUIPMENT DEMISE – BATTERIES

- Demisability of battery packs using small individual cells is already good
- No further improvements are proposed at this point

- Demisability of battery pack comprising larger individual cells may pose a risk and need to be investigated further

Potential areas for demisability improvement:

- Change of materials
  - GFRP based PCB are currently standard and are currently hard to replace
  - Recent research groups are focusing on ecofriendly paper based PCB without the use of glass fibres or epoxy
    - Base material is treated “normal” paper but also specifically engineered cellulose nanofibers
    - Would also improve the overall environmental impact of the spacecraft life cycle (LCA)
    - the technology is currently not yet advanced enough for complex electronic boards
    - investigation is required to determine the feasibility of paper based electronic boards for space applications
- Size reduction of large cards - not feasible
- Fragmentation / break up of large cards
  - change the lay-out and arrangement of fiberglass cloth to implement breaking points
  - difficult to align with functional requirements and environment constraints

OPEN POINTS & NEXT STEPS

D4D ONE – FINAL REVIEW

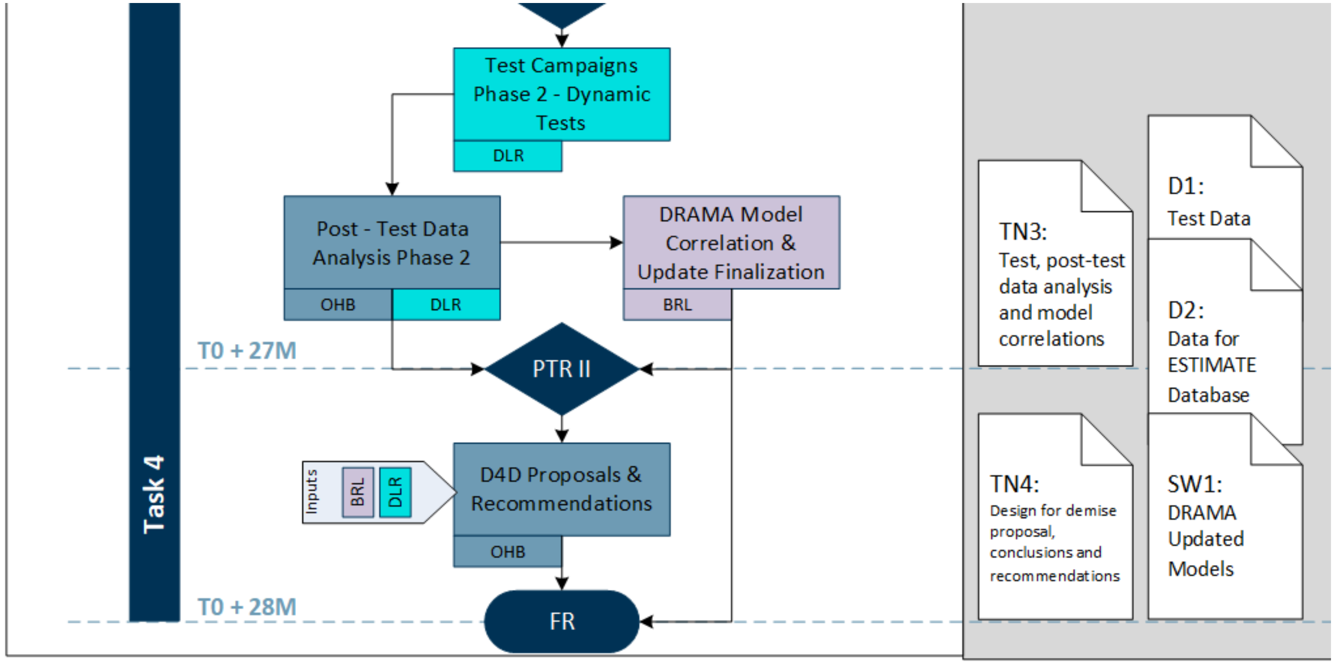
OPEN ACTIONS – PTR2

- Update Star Tracker Sample – Helicoil Usage / Material (noted in TN4)
  - Helicoils in star tracker sample were made of copper/tin alloy
  - JenaOptronik uses helicoils „for all connections made in aluminium base material” only

D4D ONE – FINAL REVIEW

NEXT STEPS & OPEN POINTS

- Next Steps – Project Wrap-up
  - Update of TN4 acc. comments ✓
  - Delivery of final data package with signatures
  - Contract Closure until end of July



AOB