

## SATELLITE DESIGN FOR DEMISE

### Thermal Characterisation in Early Re-entry for Dismantlement Mechanisms

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#### Abstract

Preliminary analyses at ESA have shown that space objects in LEO with masses above 500 kg might already imply an on-ground casualty risk higher than 1E-4 in case of uncontrolled re-entry. Compliance to this casualty risk requirement may be achieved through controlled re-entry, but this solution has a major impact at system level. Sometime it requires a full re-design of the spacecraft and may involve to switch to a completely different launcher performance (consequently a significant mission cost impact).

This option may be avoided with achievement of compliant ablation (demise) of the spacecraft upon uncontrolled atmospheric re-entry. The so-called Design-for-Demise discipline (D4D) is a highly multidisciplinary approach that can bring significant benefits in the future missions in the medium to long term.

ESA created in 2012 the “Cleanspace” initiative and team to promote actions on green aspects and debris remediation. Recently ALTRAN was involved inside THALES ALENIA Space consortium in those ESA activities on S/C D4D techniques and proposed several D4D concepts. This ESA D4D study had the objective to find D4D solutions for the Sentinel-1 study case (around 2 tons). This objective were about to be theoretically achieved.

The outcomes of those D4D studies performed in parallel at level of 3 LSI (Large System Integrator) were concluded in early 2016 [17] [18] and used mainly ESA Sentinels S/C as study cases. Those studies all demonstrated that S/C dismantlement (controlled and earlier to natural break-up) has a major benefit in reduction of S/C Debris Casualty Area (DCA). Then this technique has to be considered with high priority in a global approach for D4D improvement.

The proposed ALTRAN/NIMESIS study CLEANSAT Building Block 10: Shape Memory Alloys (SMA) Dismantlement Mechanisms has investigated several technological devices and SMA material options for their suitability to be implemented in LEO satellite H/W of main European LSI for dismantlement during atmospheric re-entry.

## 1 Introduction

The benefit of an early and controlled S/C dismantlement was already clearly identified at ESA CDF D4D in late 2013 [10]. During those webcasts open to industry, ALTRAN proposed several concepts including the AltranSat V2 introducing structural blocks release by mechanisms triggered by re-entry temperature.

This technique was clearly confirmed at end of ESA D4D Activity by TAS & ADS consortium even if elements such as propellant tanks or reaction wheels are design to demise; the late exposure of those elements in aerothermal flux could still jeopardize their demise.

So, historically ALTRAN investigated several options based on several technologies:

- Pyro-cut & Thermo activation
- SMA activation ,
- Glue sublimation on already existing H/W or dedicated glued path for dismantlement
- Easy-demise structural or joining elements

After preliminary assessment, the attention was concentrated on dedicated release mechanisms that can be triggered at SMA at higher temperature (as patented by NIMESIS)

The main advantage of this SMA options versus alternatives:

- Inert material non-sensitive to space environment (radiations, ageing, lifetime)
- Capability of a relatively low and accurate triggering temperature (few energy needed)
- Capability to be installed in a structural device or in a clean release mechanisms

The main problematic points to be investigated on this study:

- Clarification of S/C thermal environment in S/C early re-entry (External –Internal T°)
- Clarification of S/C Dismantlement needs (applicative study cases – preload/rupture)
- Clarification of SMA capabilities : Stress range vs Safe – Triggering T° (SAFE/TRIG)
- Engineering of dedicated innovative Concept to fulfil LSI S/C dismantlement needs

S/C re-entry environmental conditions considered by ALTRAN at the beginning of the study for rough assessment were:

**Phase 0\_Before Reentry: Altitude >150 km** (Solar Flux but Aerothermal flux negligible)

25 years max atmospheric decay period => No debris or release allowed

- ⇒ SAFE temperature to be assessed wrt to SMA transition
- ⇒ Max External T° assumed 120-150°C (TBC)
- ⇒ Max Internal T° assumed 75-100°C (TBC)

**Phase 1\_Pre-Reentry Altitude = 150-120km** (Aerothermal & Re-entry flux)

Start of SMA heating & transition phase (early re-entry period, several orbits and hours)

- ⇒ Max External T° assumed 250-350°C (TBC)
- ⇒ Max Internal T° assumed 90-120°C (TBC)

**Phase 2\_ Reentry : Altitude = 120-100km** (Mainly reentry flux before S/C Break-up)

Range of intended external release (the highest altitude, the better)

- ⇒ Min External T° assumed 0-50-100° (TBC)
- ⇒ Min Internal T° assumed 0-50°C (TBC)

**Phase3\_Reentry: Altitude = 100-80km** (Mainly reentry flux before S/C Break-up)

Range of intended internal release (the highest altitude, the better)

- ⇒ Min External T° assumed >100°C (TBC)
- ⇒ Min Internal T° assumed >100°C (TBC)

The intention of this paper is to present the SMA dismantlement mechanisms presented in CLEANSAT BB10 Study and relative thermal analysis investigated in order to ensure the study to determine the SAFE/TRIG Temperatures to be selected for those devices.

## 2 Applications

The applicative cases identified during ESA D4D activities [17][18] were investigated below.

### 2.1 Release External Panels

The early release of external S/C panels is obviously a global benefit for S/C demise. Different study cases have been investigated through a trade-off to determine what the most suitable solution for panel release is. Most proposed concepts are based on release screws or release inserts.

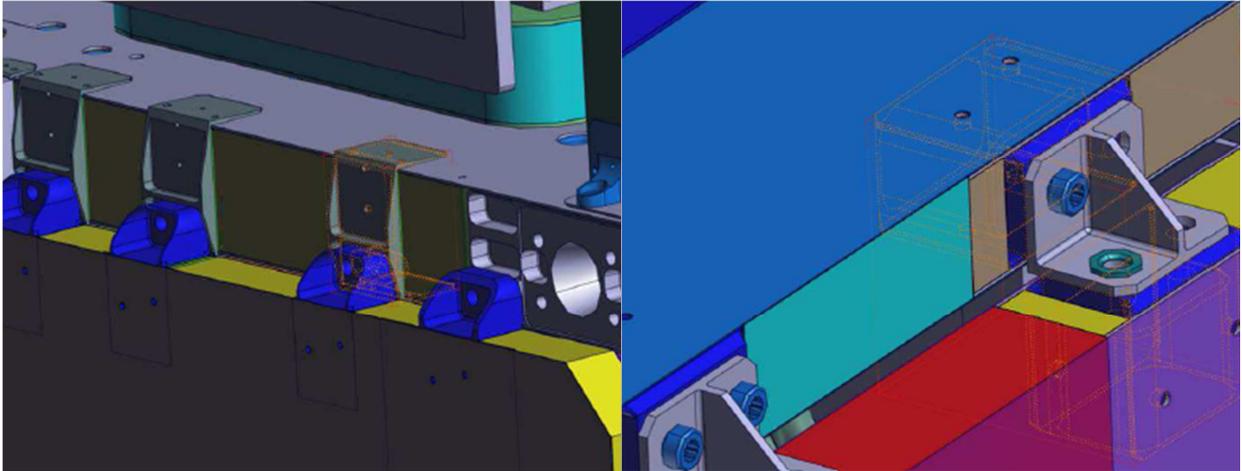
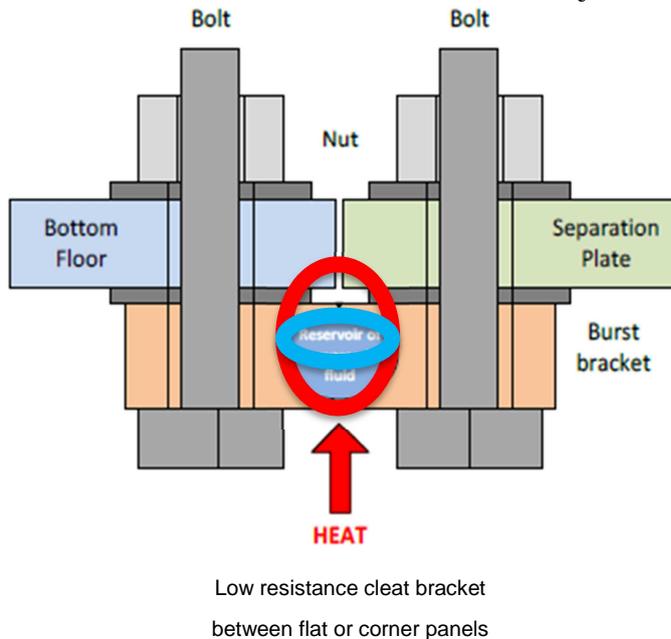


Figure 1: Panel junction with deck (end inserts) [18]

Figure 2: Panels junction with end & bobbin inserts [18]

3-4 Study Cases proposed by ESA and LSI have been investigated. Those solutions are all based on flat cleats or junction brackets.



Low resistance cleat bracket  
between flat or corner panels

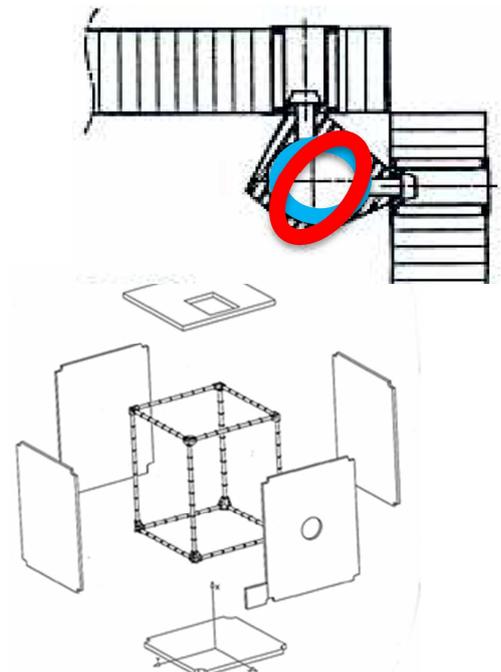


Figure 3: Cleat junction releasing in temperature [17]

Figure 4: Structural Bar cut in temperature

In this case, the external panels are maintained on a tubular frame bars and end brackets. The intention is to investigate how the structural frame can be dismantled by cut. The bars can be dismantled by end SMA sleeve or direct SMA brackets, but in order to release panel / panel the tubes have to be cut in longitudinal direction.

## 2.2 Release External Appendages

As investigated in the past on ESA D4D S/C activity [17] [18], it has been demonstrated that early release of external appendages of a re-entering spacecraft has a global demise benefit for the rest of the spacecraft.

A lot of LEO S/C have external appendage for scientific missions:

ENVISAT, ERS, METOP, SMOS, COSMO-SKYMED, Sentinel-1, LOFT, BIOMASS

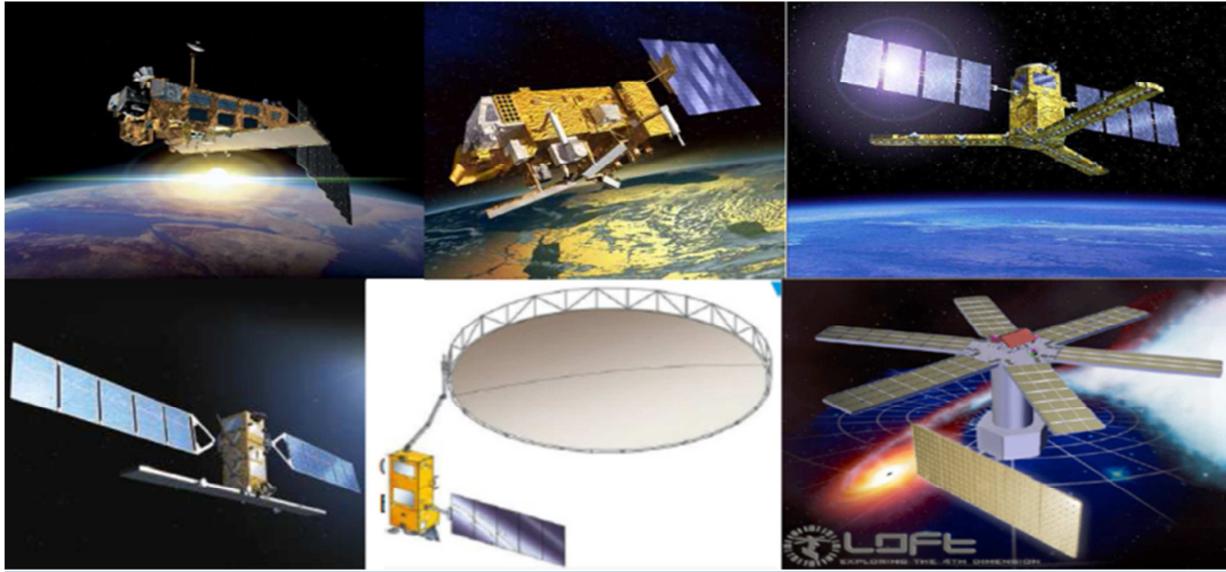


Figure 5: ESA Satellite with External appendages

Releasing those appendages implies to clarify what are the structural interfaces used for those appendages. If most of the elements are based on deployable (and lightweight) mechanisms, they also used standards interfaces such as screwed interfaces (compatible with frangibolts) but also some specific interfaces such as Yokes , bars and booms (pretty compatible with SMA Sleeve concepts with a ratio of one sleeve versus 4 frangibolts)

## 2.3 Release S/C Modules

As investigated in the past on ESA D4D S/C activity [17] [18], it has been demonstrated that early dismantlement of S/C modules ( P/L vs P/F etc...) of a re-entering spacecraft has a global benefit for the rest of the spacecraft demise.

Several devices have been investigated since ESA Micra Webcast on D4D S/C by ALTRAN.

Those concepts were inserted in the ALTRANSat V2 focusing early release/demise of external panels and on dismantlement capability of modules.

Main technological devices investigated were about:

- Glued I.Fs or glued path released at hot temperature
- Upper deck and tube junction with clamp band released by one single Frangibolt
- Struts assembly between modules released via frangibolts , inserts, sleeves , ..

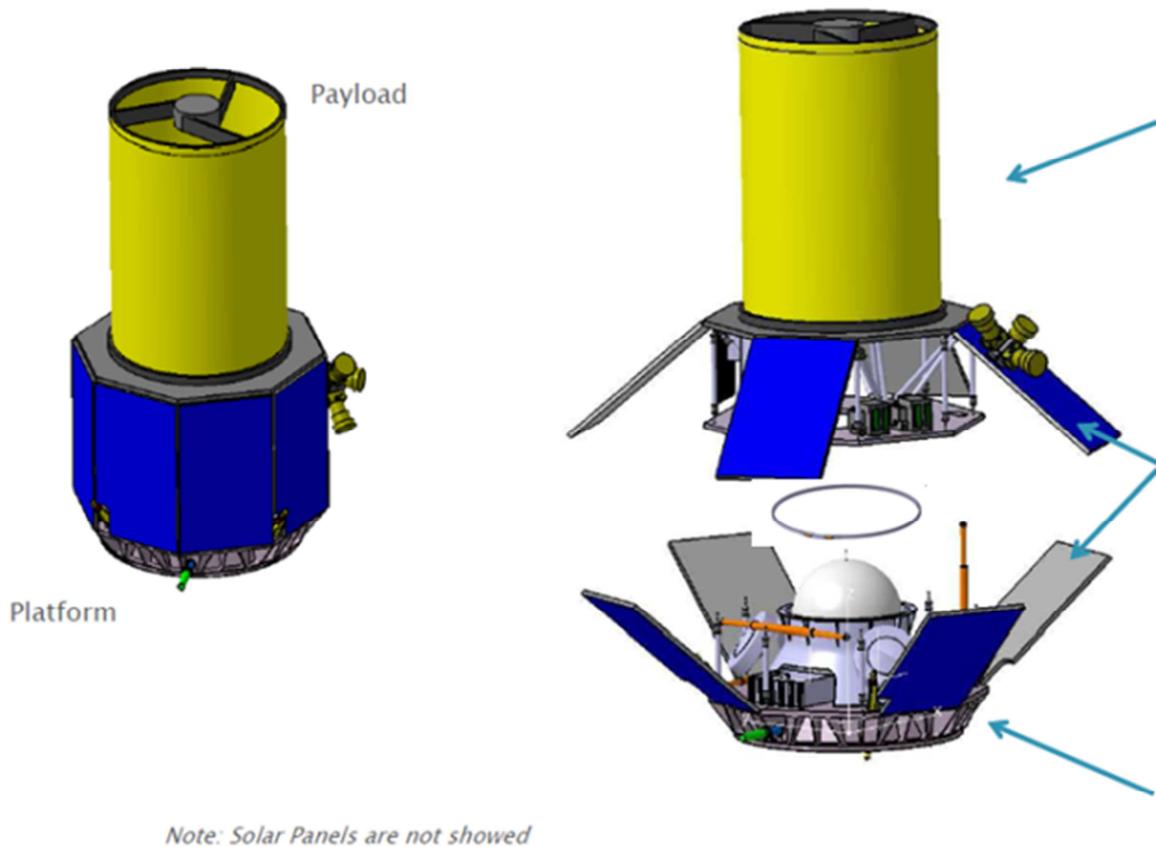


Figure 6: ALTRANSat Concept V2

Main concept suitable for this application was identified to use structural I/F struts. This element gives advantage to concentrate the loads in segregation points and then reduce the release interfaces. Several options can be proposed for a release at strut level: Frangible joints or release panel inserts at interfaces, release sleeve, adapted mechanism at interface:

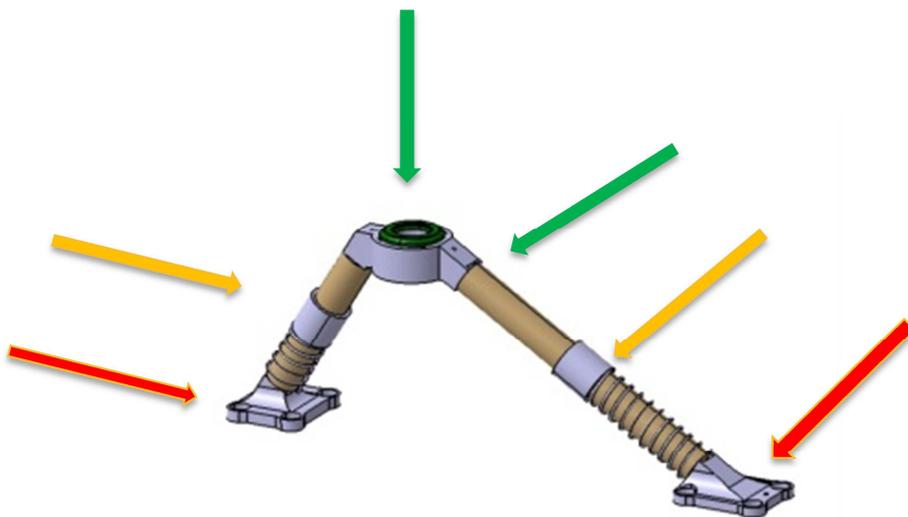


Figure 7: Strut release options (color code drive by mass efficiency)

### 3 Concepts design

#### 3.1 Concept 1: SMA Washers / Frangible Screws

Using the “Frangibolt” principle as for US TiNiAerospace [19] products, the screwed I/F uses a SMA washer expanding in hot temperature up to screw rupture.

The main mechanical data (diameter, load and tension for I/F screws) of NIMESIS-designed products were set within usual space standards, ECSS-E-HB-32-23A\_Annex1 and OHB and TAS standards.

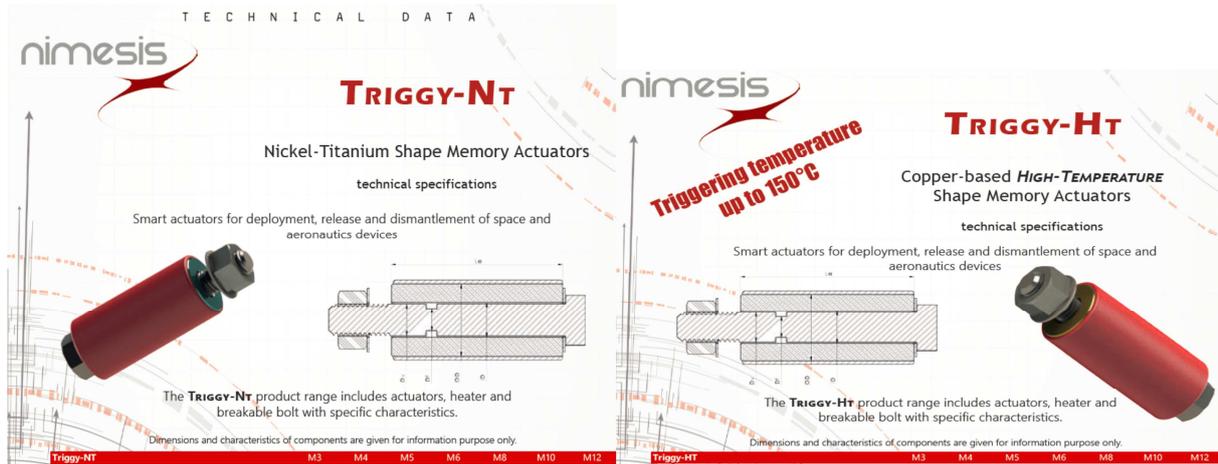


Figure 8. NIMESIS Triggys Devices Datasheet

A reminder of the geometry and the architecture of the SMA washer and the frangible screw is presented hereafter :

- “Frangibolts “ stands for US TiNiAerospace [19] elements presented for comparison
- Triggering time are considered for active device (with embedded heaters)
  - Assumption made on NIMESIS thermal assumption are assumed with no electrical and thermal dissipation (very best case approach)

Comparison		M3	M4	M5	M6	M8	M10	M12
Frangibolt	Length (mm)	13,7	25,4	31,8	38,1		50,8	56,0
	Internal Diameter (mm)	3,2	4,6	5,2	6,7		9,9	13,1
	External diameter (mm)	5,6	7,5	10,2	14,0		18,2	25,4
	Thickness (mm)	1,2	1,5	2,5	3,6		4,1	6,2
	Weight (g)	1,5	4,6	12,5	28,9		59,5	134,4
	Triggering time (s)	20,0	32,0	30,0	35,0		60,0	72,0
ACT-NT Nimesis NiTi	Length (mm)	16,1	21,3	27,0	32,2	43,3	54,6	66,3
	Internal Diameter (mm)	3,2	4,3	5,3	6,4	8,4	10,5	13,0
	External diameter (mm)	6,4	8,5	10,8	12,9	17,3	21,8	26,5
	Thickness (mm)	1,6	2,1	2,8	3,2	4,5	5,7	6,8
	Weight (g)	2,6	5,9	12,2	20,4	50,5	101,2	179,4
	Triggering time (s)	8,5	11,7	12,4	12,8	22,6	36,2	59,9
ACT-HTCu Nimesis CuAlNi	Length (mm)	18	24	30	36	49	61	74
	Internal Diameter (mm)	3	4	5	6	8	11	13
	External diameter (mm)	7	10	12	14	19	24	30
	Thickness (mm)	2,0	2,6	3,4	4,0	5,5	7,0	8,3
	Weight (g)	4,2	9,7	20,1	33,8	83,6	167,7	296,8
	Triggering time (s)	24,2	33,2	35,2	36,2	64,1	102,8	169,8
	Safety temperature (°C)	150	150	150	150	150	150	150
	Triggering temperature (°C)	224	224	224	224	224	224	224

Figure 9: NIMESIS geometrical and physical data of alternative products

### 3.2 Concept 2: SMA Inserts / Release Screws

Several designs were investigated. The main principle is based on a SMA part releasing a pre-tensioned thread part or deforming it in a screw shape allowing screw release.

This design is assumed to fit M4, M5, M6 classical requirements for end I/F panels

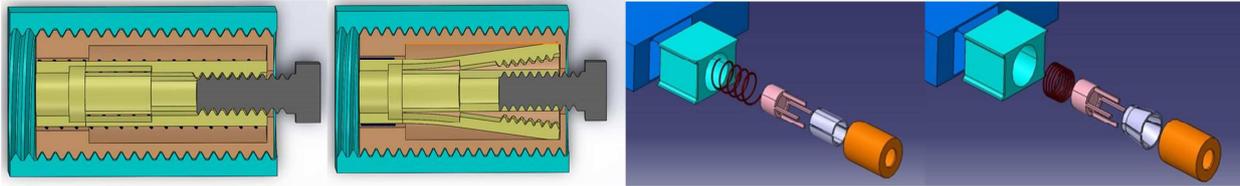


Figure 10: SMA insert design in cut and exploded view

This design is composed of the following parts performing following functions:

- The Panel insert glued inside honeycomb panel
- An housing cage maintaining all mechanism parts
  - part is screwed-mounted inside the insert panel for replacement capability
- A SMA Spring or a Ring
  - To maintain the expansible thread in cylindrical shape (SMA cold shape)
  - To release the expansible thread (SMA in hot shape)
- A part with inserted guides inside thread grooves
  - to avoid any interference between threads & screws during release)
- A petals thread in titanium (baselined ) or SMA alloy (as back-up solution)

The thread part shape and design shall be optimised and demonstrate the deflexion capability at acceptable internal stress level.

A shorter design was later designed to fit with Bobbin inserts and internal panel I/Fs.

This concept represents today the best attractive and mass efficient device.

### 3.3 Concept 3: SMA Cutting Cords / Release Panels

This concept can be proposed on 2 study cases:

- Inter Panel Cleats
- Structural tubular Frames carrying Panels

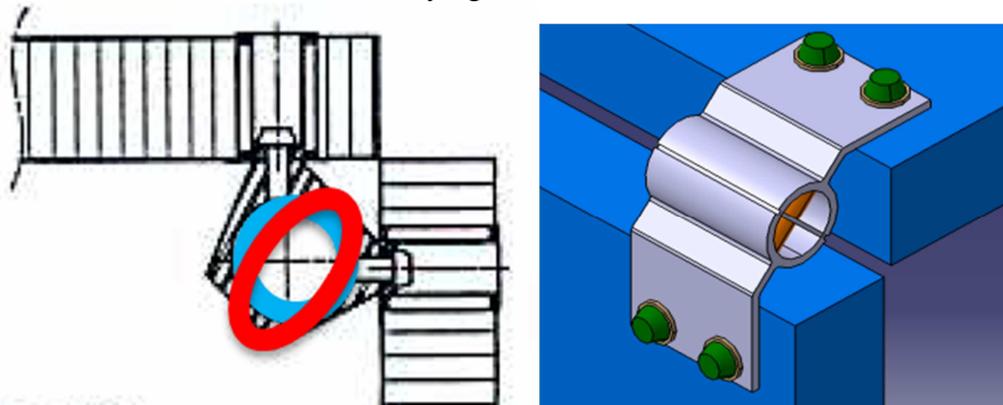


Figure 11: Concept 3 Applications

The following external design was proposed by ALTRAN:

- An slight external groove is performed on the tube
- Groove width is relevant to cope with ratio of Tube material extension at rupture (20% for Aluminium) and the expansion ration of SMA

- Groove depth is relevant to confirm that overall tube is still resistant enough to sustain the launch loads

The following internal design was proposed by NIMESIS:

- A series of SMA pins provide the needed strength to extend the tube up to rupture tension and groove restriction up to extension at rupture
- A central header (metal or plastic) inserted inside the tube is maintaining the SMA pins

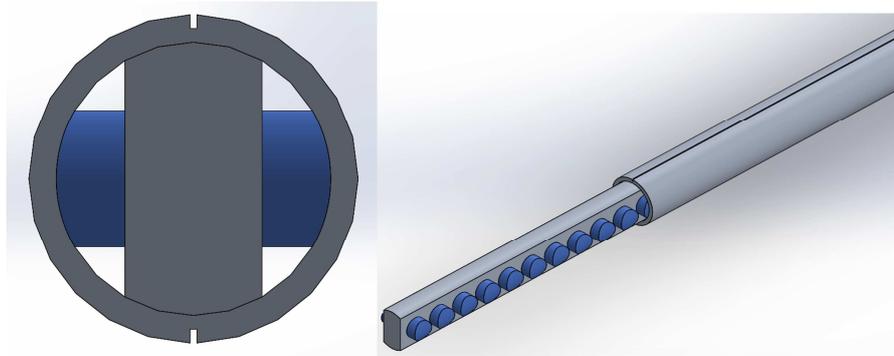


Figure 12: Concept 3 Design Description

No calculation were performed in the time of the study in cold shape assuming an iso-resistance of the bar with the cutting weakness added with internal stiffeners.

Calculation demonstrates the correct geometry of elements to obtain the required tension to break an Aluminium tube with acceptable SMA stress level in hot shape.

The design requires a large tube and significant number of SMA pins inside the tube and then a significant mass impact (to be compared with alternative solutions seen in a trade-off)

The same design can be extrapolated to cleat bracket with cutting cord tube down to a diameter of 15-20 mm.

### 3.4 Concept 4: SMA Sleeve/ Release Struts , Bars & Booms

The design is composed of SMA sleeves tightening carbon RTM tube ends. Both bars are in contact via those metallic end fittings. The overall SMA sleeve encapsulate in fact metallic end fittings in order to get friction factor under control which is essential to get a proper fitting to transmit loads. This concept requires a significant amount of SMA material and represent a less mass-efficient concept, but could in some case be competitive in case of large screwed I/F fittings. The large size of device induces to not select mostly Ti-Ni SMA (likely demise problematic)

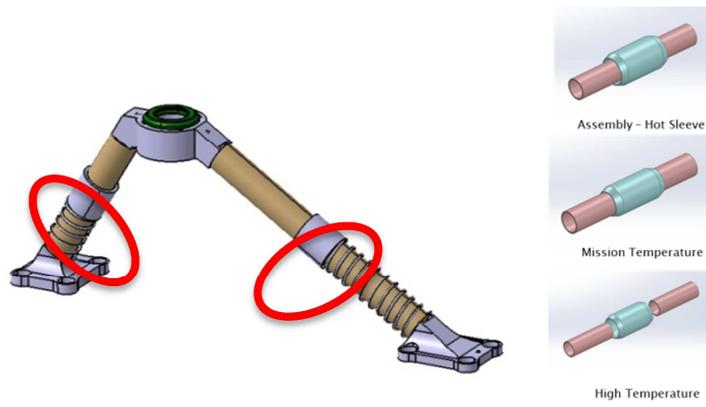


Figure 13: Concept 4 Design Description

#### 4 S/C Re-entry analysis & Thermal Characterisation

It has been investigated by ALTRAN the capability to couple DEBRISK re-entry analysis and ESATAN S/C models with addition of aerothermal flux (as already experienced in the past with simulation of launch sequence phase after fairing jettison).

DEBRISK allows to get trajectory elements during re-entry in order to determine early aerothermal flux and ESATAN is used to obtain thermal radiative and conductive coupling inside a S/C model after injection of input aerothermal data in an equivalent aerothermal flux injected as an additive solar heat flux.

The technique has the tremendous advantage

to be able to manage real standard S/C thermal models as used for S/C design justification (CDR Data package) and qualification test (Thermal balance correlated by vacuum tests). Then it should provide accurate external and internal data.

This technique should be a unique opportunity to assess S/C thermal characterisation in early re-entry without the need of HTG – SCARAB S/C which is unfortunately not accessible to industry. Moreover this S/W needs to completely remodel the entire S/C geometry and materials inducing a lot of thermal inaccuracies.

##### 4.1 Re-entry Analysis

The study case selected for this analysis was ESA Sentinel-3 S/C. This re-entry analysis has been performed on CNES DEBRISK S/W. Due to S/W restriction to process jobs less than 10 000 seconds, several jobs in cascade were necessary in order to obtain the 5-6 final orbits and the complete pre-reentry phase.

Below is presented the re-entry profile of a Sentinel-3-equivalent object in real and corrected altitude (Orbital trajectory is near-polar demonstrating the earth flatness via altitude “oscillations”)

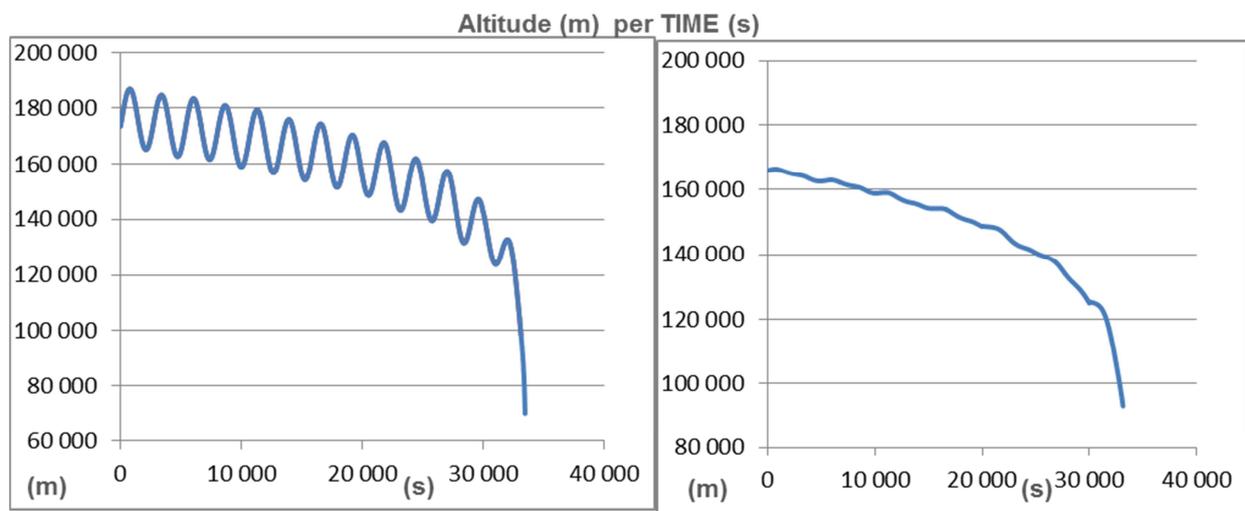


Figure 14: DEBRISK jobs for early re-entry trajectory

Thereafter the aerothermal is recalculated along the trajectory considering altitude, atmospheric density and reentry velocity considering the usual formulas for the free molecular regime:

This formula can be considered as applicable for spherical shape down to 100-90 km:

$$\dot{q}_{stfm} = \frac{\alpha_T \rho_\infty V_\infty^3}{2} \quad (1)$$

$\alpha$  is a thermal accommodation factor equal to 0,9 (ratio of energy getting inside the component)  
 $\rho$  is the atmospheric density as provided by DEBRISK (CIRA-MSIS 86 model available)  
 $V$  is the re-entry velocity as calculated by DEBRISK  
 A specific coefficient factor has to be applied to this formula to cope with our case of rectangular satellite simulated as a non-tumbling box element.  
 For convenience in this first study experimentation, this formula has been applied down to break-up altitude, (so set at 70 km as the DEBRISK lowest possible, then far below the applicable free molecular regime).

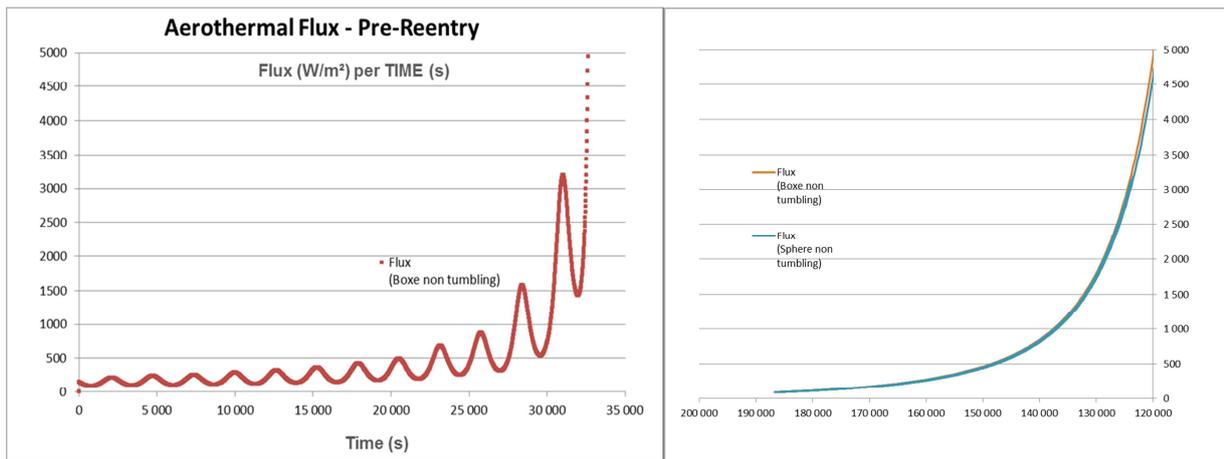


Figure 15: ALTRAN computed early re-entry flux ( $W/m^2$ ) per time(s) and altitude (km)

## 4.2 Thermal Characterisation

This simulation was performed on the ESA Sentinel-3 thermal models as already used by ALTRAN under an ESA Contract for TAS-F prime during development and testing phase.

A simplistic S/C stable attitude was considered in ESATAN simulation due to solar arrays panel acting as a tail drag until panel demise and break-up down to 100 km. (This rough assumption on S/C behaviour has been later confirmed by HTG based on their simulations performed on SCARAB S/W).

The S/C was tested in only one attitude: earth-face pointed nadir and solar panel face pointed backward the re-entry velocity direction. For simplification in this first experimentation, this attitude will be maintained in the complete simulation as well. If this can be considered simplistic with regard to full 6 DoF S/W such as SCARAB, it can be noticed that this non-tumbling attitude should be relevant and conservative for our work on temperature characterisation. It should involve worst cases in term of temperature gradients: higher temperature in hot case for SAFE  $T^\circ$  determination (SMA in cold shape before transition); lower temperature in cold case for TRIG  $T^\circ$  (SMA after full hot shape transition).

The previously calculated aerothermal flux was introduced in addition to the solar flux and earth albedo on the S-3 thermal model located along DEBRISK trajectory. This additive flux was interacting with the S/C thermal model with the same physical properties than a radiative solar flux.

The outcomes of simulations are presented hereafter:

**Sentinel-3 ESATAN Thermal Characterisation**



t DEBRISK (s)	Altitude (Km)	Aero Th (W/m²) Flux	Corrected Alt (Km)	t ESATAN (s)	Ext T° Max (°C)	Ext T° STR (°C)
32 222	131 115	1 638	110 860	32220	185	116
32 262	130 477	1 729	110 163	32260	190	120
32 302	129 734	1 842	109 454	32300	196	125
32 342	128 887	1 982	108 735	32340	234	156
32 382	127 938	2 158	108 006	32380	239	166
32 422	126 890	2 377	107 268	32420	245	178
32 462	125 747	2 652	106 522	32460	255	185
32 502	124 514	2 998	105 770	32500	269	197
32 542	123 194	3 433	105 012	32540	284	235
32 582	121 795	3 997	104 249	32580	302	250
32 622	120 323	4 733	103 481	32620	324	270
32 662	118 784	5 705	102 709	32660	350	292
32 702	117 185	7 005	101 933	32700	379	319
32 742	115 534	8 802	101 152	32740	415	351
32 782	113 837	11 290	100 366	32780	460	390
32 822	112 102	14 862	99 573	32820	512	436
32 862	110 334	20 246	98 771	32860	575	493
32 901	108 604	27 526	97 984	32900	648	514
32 942	106 740	35 608	97 295	32940	725	531
32 980	104 965	51 531	96 297	32980	809	594
33 022	103 005	72 499	95 351	33020	903	665
33 061	101 165	100 273	94 425	33060	1008	745
33 097	99 456	135 621	93 523	33100	1124	831

Figure 16: Sentinel-3 Thermal characterisation for SAFE T° (Pre-Re-entry Phase 1 before final orbit)

Figure 17: DEBRISK – ESATAN output results for External Temperature (Re-entry Phase 2)

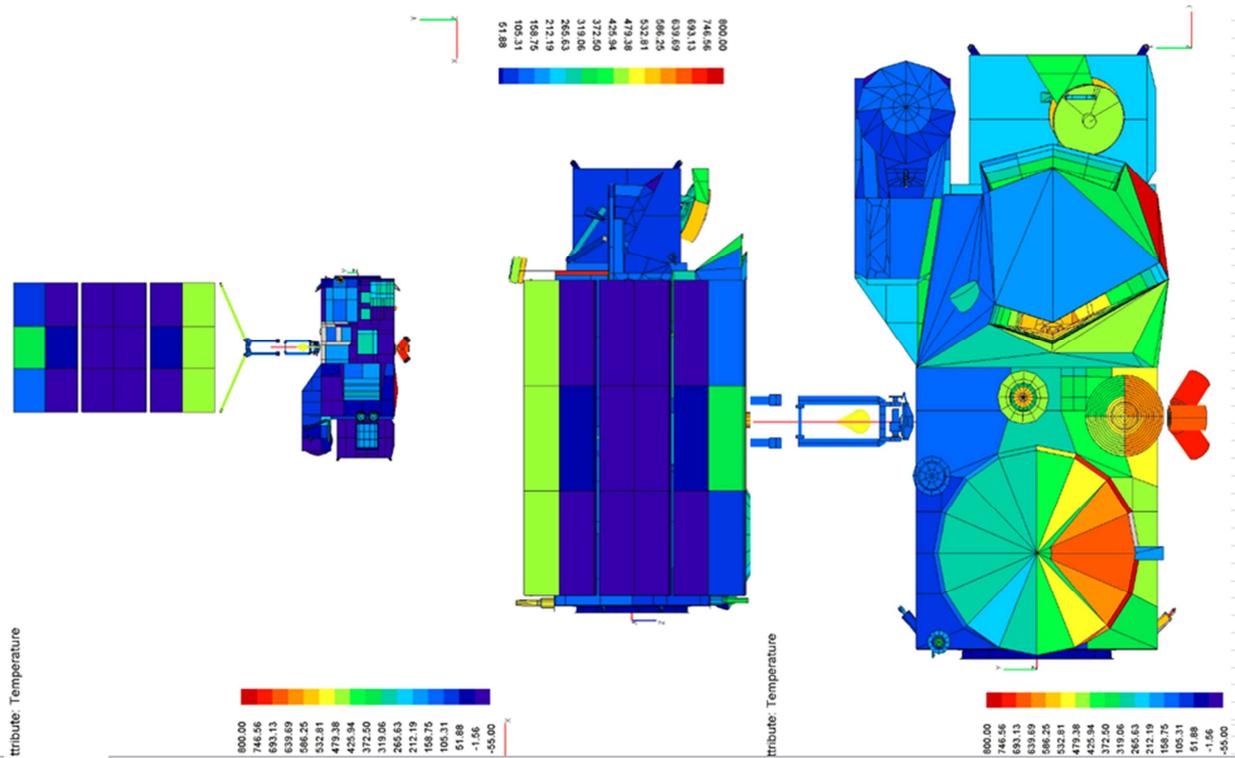


Figure 18: Sentinel-3 Thermal characterisation for TRIG T° (End of Phase 2)

The previous results are mostly related to external surfaces during phase 2 (Start of Reentry)  
 The below results are mostly related to internal elements presented with min / max temperature range during reentry phases 1, 2, 3.

Phase 3 results are given for information only, because the calculated flux used a free molecular formula and the simulated non-tumbling attitude is probably not representative in this phase.

The results data presented are related to thermal nodes representing the equipments thermal reference point set usually at mechanical mounting interface.

The radiative surfaces of satellite (MLI, OSR) were set at EOL conditions of physical thermo-optical parameters in order to be representative of the worst case in term of ageing (EOL MLI).

In order to simulate even worst conditions (MLI Damaged) assumed to be representative of a non-controlled reentry after 25 years, an additive set of simulations were done with the assumption of increasing physical conductance of the MLI by a factor 100.

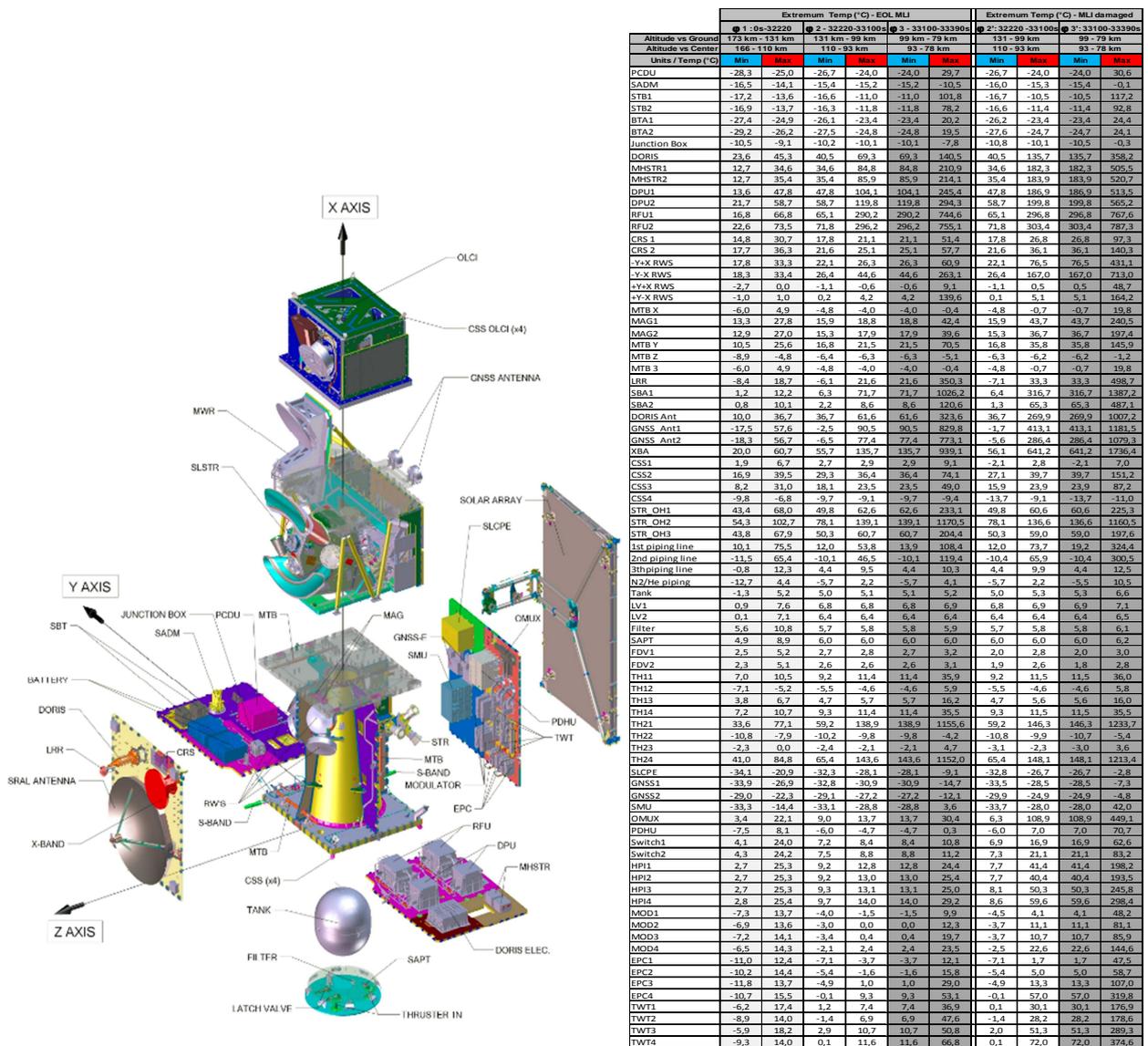


Figure 19: Thermal nodes designation and location on Sentinel-3 exploded view

Figure 20: ESATAN Post-Processing Temperature Data on thermal nodes representing equipment I/F

## 5 Thermal Analysis Outcomes

As a preliminary result on those thermal studies, it can be established that:

1. The triggering temperature of standard SMA (NiTi around 90-110°C as currently used in industry) are compatible with SAFE T° for internal spacecraft application.
2. The triggering temperature of specified SMA (CuAlNi around 170-210°C as patented by NIMESIS) are compatible with SAFE T° for most external spacecraft application.
3. The delta temperature between SAFE & TRIG temperature provided by SMA seems always compatible to the heating profile (internal / external) as experienced during those simulations. Considering SMA triggering temperature range (between 30-50°C), the heating profile observed associated with timing leads to the triggering altitude:  
 External Case: 30-50 °C => 10-30 Km Delta Altitude => SAFE T°=130 km- > TRIG T°=100 km  
 Internal Case : 30-50 °C => 20-40 Km Delta Altitude => SAFE T°=130,120 km -> TRIG T°=90-80 km
4. The applicative case of release panels and release modules seems achievable by thermo-activated devices based on SMA low and high temperatures. Correct temperature margin are available on SAFE Temperature (with regard to usual max operational temperature) and TRIG temperature (with regard to natural re-entry behaviour where almost 20 km altitude can be anticipated with those devices).
5. Nevertheless, with the conservative assumptions made in spacecraft attitude and thermal gradients a lot of applications located in internal and external of the spacecraft maybe not be able to be triggered by temperature whatever the device used.  
 Some external surfaces are almost never exposed to the aerothermal flux due to the tail-drag effect of the single solar panel. Those elements are found very cold by the simulation but SAFE/TRIG temperature of those device has to be set above all operational cases and worst case solar attitude during erratic 25 years reentry period.

By experience on D4D studies inside the THALES consortium on a Sentinel-1 case, the release of external appendage represented already a challenge. This appendage being the element we want to get rid of due to its large shape, it impacting the flux and put spacecraft attitude in position providing shadowing to the aerothermal flux and leading to maintain its interfaces pretty cold.

## 6 Lessons learnt and way forward:

S/C thermal characterization in early re-entry needs to be better characterized for the purpose of early release of elements (whatever the technology is used).

Investigation on tumbling effect as a best case should represent a first way forward to ease the capability of dismantlement of elements found very cold in this study

Those uncertainties may lead to reconsider some assumptions made in the present study on thermal internal / external worst case environment.

Nevertheless, it can be foreseen that thermo-activated device for appendage release (actuated only by local temperature) seems not provide significant improvement than natural behaviour to promote their implementation and other options shall be investigated.

ALTRAN intention to find an alternative way of simulation seems to be working with preliminary correlation performed on available SCARAB data. But added correlation with current S/W SCARAB would be fruitful for both methods:

- SCARAB increase of accuracy with S/C thermal model behaviours as tested
- ALTRAN increase of relevant S/C data provided at lower altitude and flight regime.

Another main lesson learnt is that behaviour before re-entry is definitively not well understood and characterized today. Even if some Safe Mode cases are substantiated during S/C development.

The need to further investigate the complete free-flight mode after disposal (25 years re-entry rule) remains mandatory. Several aspects are contributing to a lot of uncertainty:

- S/C attitudes
- S/C thermal geometry
- S/C architectural H/W (Alu Panel / Carbon Panels)
- S/C radiative surface status (MLI, OSR Ageing and degradation in this phase).

## **7 Conclusion**

ALTRAN has initiated the capability to analyse standard ESATAN S/C thermal model in this pre-reentry environment

ALTRAN has now the capability to investigate S/C thermal behaviour from an accurate way  
Lessons learnt on that study clearly highlighted the need to further characterise the thermal S/C environment in pre-re-entry Phase (25 years disposal) and early re-entry (150-120 Km).

## **8 Acknowledgment**

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  - TAS\_IT Team
  - ASD\_FR Team

## 9 Abbreviations and acronyms

ADS	AIRBUS Defense Space
CDF	Concurrent Design Facility
CFRP	Carbon Fiber Reinforced Panel
CNES	Centre National D' Etude Spatiales (French Space Agency)
D4D	Design For Demise
DCA	Debris Casualty Area
DEBRISK	CNES Low Fidelity Reentry S/W
DRAMA	Debris Risk Assessment and Mitigation Analysis
ESA	European Space Agency
HTG	Hyperscall Technology Goettingen (SCARAB S/W developer)
ITT	Invitation to tender
MLI	Multi Layer Insulation
NIMESIS	NIMESIS_FR SMA supplier and designer
OHB	Orbitale Hochtechnologie Bremen - Orbital High-Technology Breme
OSR	Optical Solar Reflector
P/F	Platform
P/L	Payload
R&D	Research & Development
S/C	Space craft
SAFE	Safe limit= in line with 0% of austenitic (hot SMA) phase
SCARAB	HTG High Fidelity Re-entry S/W for ESA programs
SMA	Shape Memory Alloy
S/W	Software
TADAP	TAS-I Reentry S/W
TAS	THALES ALENIA Space
TBC	To Be Confirmed
TBD	To Be Defined
TRIG	Triggering limit = in line with 100% of austenitic (hot SMA) phase
TRL	Technology Readiness Level

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