Clean Sat Concurrent Engineering Final Presentation (public version)

Noordwijk
April 7th 2017

Agenda

- 09h30 Introduction to the CleanSat program (ESA)
- 10h00 Building Blocks presentation - Design for Demise (LSIs)
- 11h25 *Coffee break*
- 11h35 Building Blocks presentation - Deorbit technologies (LSIs)
- 13h00 *Lunch Break*
- 14h00 Building Blocks presentation - Passivation (LSIs)
- 15h00 *Coffee break*
- 15h10 Presentation of LSI priorities (LSIs)
- 16h40 Conclusion and next steps (All)
- 17h00 Wrap up

Building Blocks presentation - Design for Demise

- Introduction
- Demisable Tanks
- Demisable Reaction Wheels + outcome from the HTG CCN
- Demisable Magnetorquers
- Demisable Optical Payloads
- Early structure break-up

Demisable tanks (4 Building Blocks) Requirements overview

These BBs are aimed at the definition of propellant or pressurant tanks that will demise on entering the atmosphere. They are designed for LEO missions with uncontrolled re-entry.

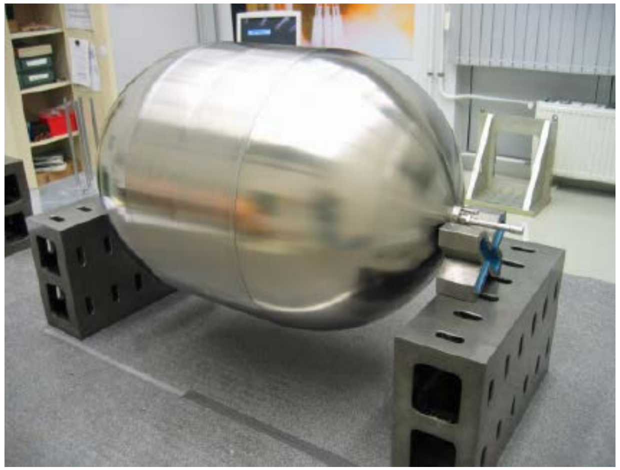
Topic	Metallic Tank (2BBs)		Aluminium Lined COPV Tank (1BB)	
	Requirement text	Compliance	Requirement text	Compliance
Volume and Envelope	Volume 100 to 200 litres with a diameter not exceeding 600mm 177litres for BB19	C	Volume 30 liters with a diameter not exceeding 300mm	C
Functionality-Operating pressure	MEOP (Maximum Expected Operating Pressure) 24bar. The EOL pressure shall be at 5.5 bars.	C	MEOP (Maximum Expected Operating Pressure) of 200 bar with any of the operating fluids.	C
Functionality - Propellant Delivery System	Delivery system able to provide gas free propellant to the thruster throughout the mission lifetime. Delivery system can be either a diaphragm or a Propellant Management Device (PMD)	C		
Propellant compatibility	Compatibility with the following propellants : - Hydrazine - Green propellants (e.g. LMP103S, H_2O_2, American green propellant HAN)	C (TBC)	Compatibility with the following propellants/pressurants : - Gaseous helium - Gaseous nitrogen - Xenon - Krypton	C
Design factors	Burst factor of 1.5 and a proof factor of 1.25	C	Burst factor of 1.5 and a proof factor of 1.25	C
Pressure cycles	≥12 @ MEOP ≥3 @ proof pressure	C	≥10 @ MEOP followed ≥3 @ proof pressure	TBC
Mass	Potential mass penalty introduced by the demisable tank materials (different from Ti6Al4V), shall not exceed 15%.	PC (BB05) C (BB19)	Tank dry mass shall not exceed by more than 15% the dry mass of the reference, the reference being titanium lined COPV	NC
Demiseability	The tank shall be demisable.	C	The tank shall be demisable.	NC

Note: **Thermoplastic tank technology** is considered not mature enough for current and near-future LEO propulsion applications so the presentation is limited to the baseline description.

Demisable tanks
Baseline BB05 (ASL - Metallic tanks - Propellant)

Proposed tank baseline focuses upon a design that uses the established supplier's heritage having the following main features:

- Titanium shell material is replaced by aluminium alloy: baseline is Al2219 that is concluded to provide acceptable, proven performance and is easier to process than other more exotic alloys that could offer slight mass advantages.
- Tank shell built up by a welded assembly of two end domes separated by an optional central cylinder to allow volume adjustment.
- The tank can be equipped with either an elastomeric diaphragm or an aluminium PMD
- The tank will be supported by an equatorial flange as per the Vega AVUM tank



Current LEO technology
(Ti6Al4V Non-demiseable)

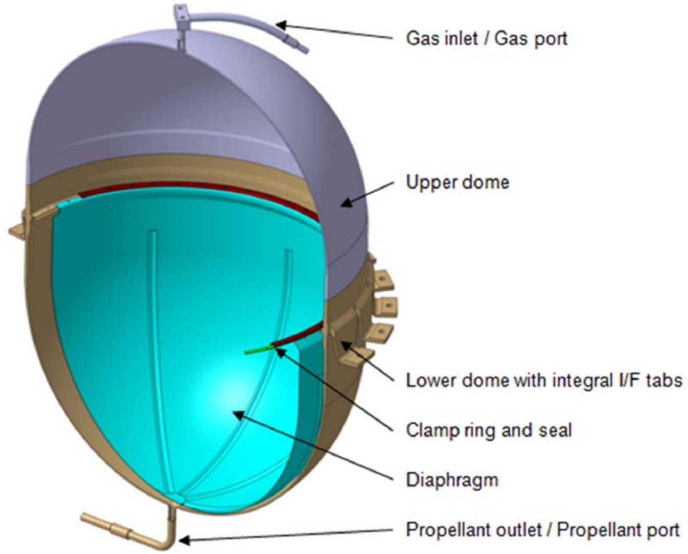
Launcher technology
(Al 2219 Demiseable)

Demisable tanks
Baseline BB19 (MT Aerospace - Metallic tanks - Propellant)

The design concept is characterized by one of the titanium reference tanks and specified with following main features:

- The titanium shell material replaced by an aluminium alloy (baseline is Al2219)
- The tank is equipped with a diaphragm that is mounted to the lower tank half prior to its final assembly with the upper half.
- The assembly of both tank halves is managed as baseline by means of a welded connection
- Structural connection of the tank either at its poles or equator to the load frame (e.g. central tube) of the satellite.
- The tank shell will be built up by a welded assembly (baseline) of a cylindrical part and two dome shells

Reference Tank design made of Titanium alloy

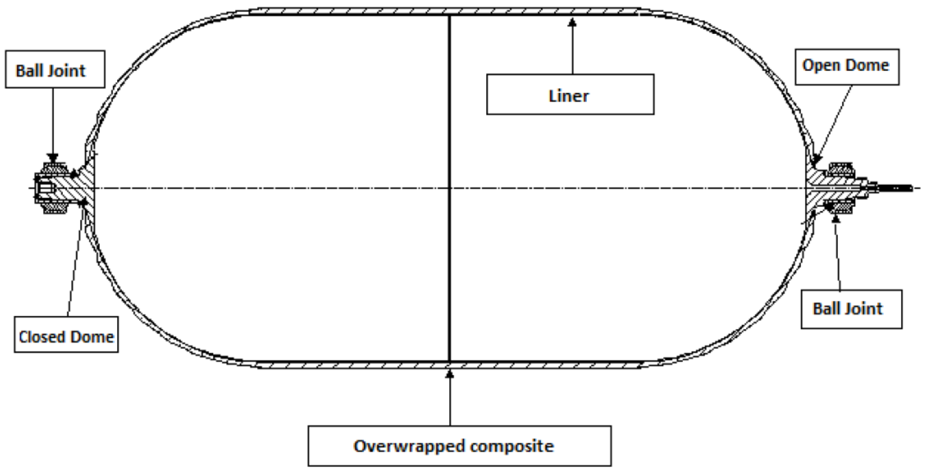


Tank with diaphragm – design principle

Demisable tanks
Baseline BB02 (ASL - COPV tanks – EP application)

Proposed baseline focuses upon a design that uses supplier's established heritage having the following main features:

- Titanium liner material replaced by aluminium alloy (baseline is Al2219)
- Tank overwrapped with standard T800 carbon fiber (thermoset epoxy resin used as matrix)
- Tank mounted and supported via ball-joints (one fixed and one sliding)



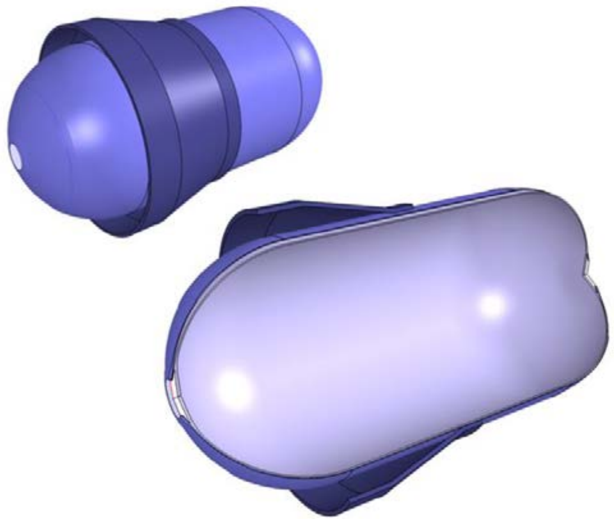
High pressure tank general design

Polar mounting design

Demisable tanks
BB03 (ASL - Thermoplastic tanks – Standard and green propellant)

Proposed baseline focuses upon a design that uses supplier's established heritage having the following main features:

- Titanium liner material replaced by a thermoplastic grade.
- Tank overwrapped with carbon fibres. The selection of the fibre is strongly driven by the tank level manufacturing aspects as a minimum overwrap thickness is required regardless of the fibre material properties.
- Carbon-fibre overwrap secured using a thermoplastic matrix material
- Tank equatorially mounted
- The tank is only compatible with a membrane (PED) propellant management device.



Note: Thermoplastic tank technology is considered not mature enough for current and near-future LEO propulsion applications so the presentation has been limited to the proposed baseline.

Demisable tanks
Compliance and system impacts (Metallic tanks)

There are several non-compliances:

- Compliance only w.r.t. reduced design factors (burst =1.25 and proof=1.5)
  ➔Additional complexity of ground operations for safety reasons
  ➔Additional mass penalty if more stringent safety factors are considered

- Mass penalty > 15%
  ➔Potential impact on launch costs, mission duration …

Demisable tanks
Compliance and system impacts (COPV tanks)

There are several non-compliances:

- Compliance only w.r.t. reduced design factors (burst =1.25 and proof=1.5)
  ➔Additional complexity of ground operations for safety reasons

- Mass penalty > 15%
  ➔Potential impact on launch costs, mission duration …

- Demisability not complete
  ➔Aluminium shell is expected to melt but overwrapped fibers will not demise

Demisable tanks
Critical areas and main options

<u>Metallic tanks</u>

- Critical areas (BB05)
  - Significant mass penalty if stringent design factors are considered

- Critical areas (BB19)
  - Design modularity (tank volume) to cover some mission needs not demonstrated
  - Significant mass penalty if stringent design factors are considered
  - No PMD solution as a back-up

<u>COPV tank</u>

- Critical areas
  - Unproven demisability of carbon fibres
    - carbon fibres although not a solid mass will land on ground with an energy >15J although this is a ‘soft’ landing (which ASL consider acceptable, but which is not yet commonly agreed by regulations authorities).
    - All other shell options do not demise fully or even melt.
  - Demisability of bearings
    - Options of the bearing must be checked as the current stainless steel versions are not considered to be demisable.

Demisable tanks
Development plan BB05 (ASL - Metallic tanks)

All required technologies appear to be available for the manufacture of the proposed tank (derived from launcher tank roadmap).

- Roadmap
  - Activities detailed in the development roadmap are minimal and centred upon the long-term characterization of the selected shell and PMD/PED materials compatibility with primarily hydrazine
  - Potential to extend the demonstration to all other specified (green) propellants.

- Schedule
  - Derived from launcher tank development schedule
  - Qualified tank (TRL6) for LEO application available in 2019 at the latest

- Cost
  - The recurring cost of the demisable tank shall not exceed existing tank costs (titanium).

Demisable tanks
Development plan BB19 (MTA - Metallic tanks)

- Roadmap
  - The development plan is oriented towards the common approach and content usually applied for propellant spacecraft tanks.
  - The road map is dedicated to the whole sub-system, i.e. the tank equipped with either diaphragm or PMD

- Cost
  - The proposed tank design is expected to be produced with recurring costs that are competitive with the state-of-the art titanium tanks.

Demisable Reaction Wheels
Requirements overview

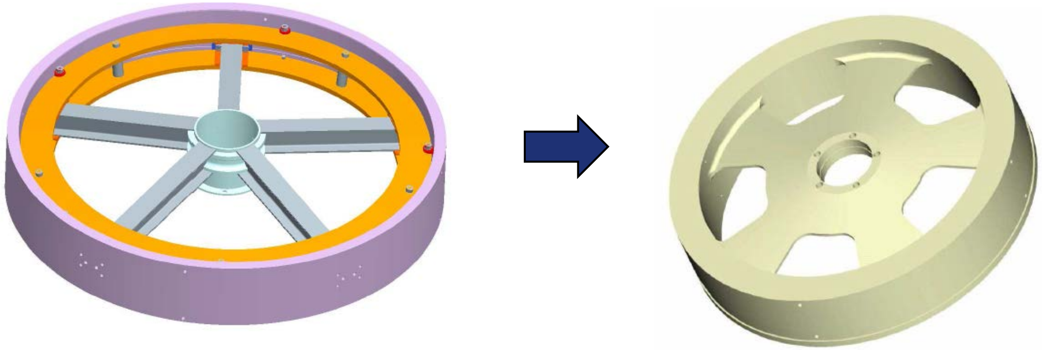
This BB is aimed at the definition of reaction that will demise on entering the atmosphere. It is designed for LEO missions with uncontrolled re-entry.

Topic	Requirement text	Compliance
Mass	Mass shall not exceed that of the equivalent non-demisable wheel by more than 15% (target).	C
Volume - Dimensions	Volume shall not exceed that of the equivalent non-demisable wheel by more than 15% (target).	C
Functional - Angular momentum	Angular momentum in the range 10 Nms to 20 Nms (TBC) for class M satellites,	PC
Functional - Torque	Delivered torque in the range 200 to 400 mNm for class M satellites.	PC
Performance - Microvibrations	Microvibration levels not higher than for the existing wheels.	PC (TBC)
Performance - Power consumption at steady state	After sufficient run-in time, but no more than 1 hour, the steady-state (3 sigma value) maximum average input power shall not exceed 12 W at constant momentum of +/-10 Nms.	PC
Demisability	Any component of the reaction wheel surviving re-entry should reach the ground with a kinetic energy of less than 15 J. The reaction will shall totally demise when exposed to thermal flux from an altitude of 78 km. The reaction will should totally demise when exposed to thermal flux from an altitude of 65 km.	PC

Demisable Reaction Wheels
Baseline BB11 (Altran + RCD)

Two design options for a demisable wheel are proposed:

- **Option 1**: mechanical modification of the existing Rockwell Collins RSI 68 wheel:
  - The stainless steel flywheel (spokes and rim) replaced by an aluminium flywheel
  - Unchanged housing case (iso-volume) with some inertia loss w.r.t. to the existing wheel (-10%)
  - Motor and the ball bearings unchanged



- **Option 2**: electrical modification of the existing Rockwell Collins RSI 45 wheel:
  - Monoblock aluminium flywheel (unchanged w.r.t. the existing wheel)
  - Enhanced High Power electronics delivering more power (allowing higher wheel speed)

Demisable Reaction Wheels
Compliance and system impacts

- Potential increase of microvibrations for option 2 (high power electronics)

  ➔Impact on satellite performances

- Higher power consumption for option 2

  ➔Impact on S/C power budget

- Demisability may not be sufficient if release altitude is 65 km

Demisable Reaction Wheels
Critical areas and main options

Critical areas

- Microvibrations for option 2

Additional options (not selected by supplier because considered too complex)

- Innovative options for the Core aiming at improving demisability

Demisable Reaction Wheels
Development plan

- The proposed roadmap relies on the developments already on-going within RCD:
  - Mechanical modification (option 1):
    - Part of an internal RCD development project for a XXL class flywheel, already initiated.
    - The know-how gained from this project should reduce the development risk and shorten the development time for a monoblock aluminium XL class size flywheel.
  - The 50V-High Power electronics (option 2) is an on-going project at RCD

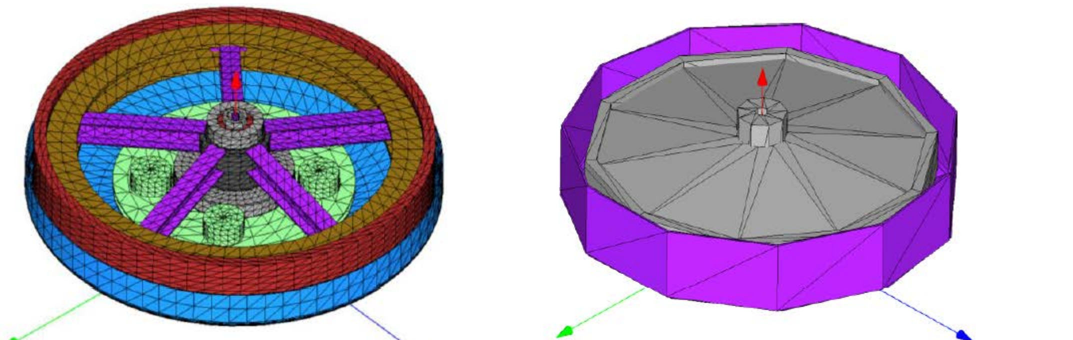
- The roadmap provides a detailed list of the steps to be performed in order to reach a qualified design.

- Schedule
  - Obtain a qualified wheel (TRL 8) in a time span of 2 years typically.
  - The schedule looks rather realistic given that significant parts of the wheels already exist and have a high TRL.

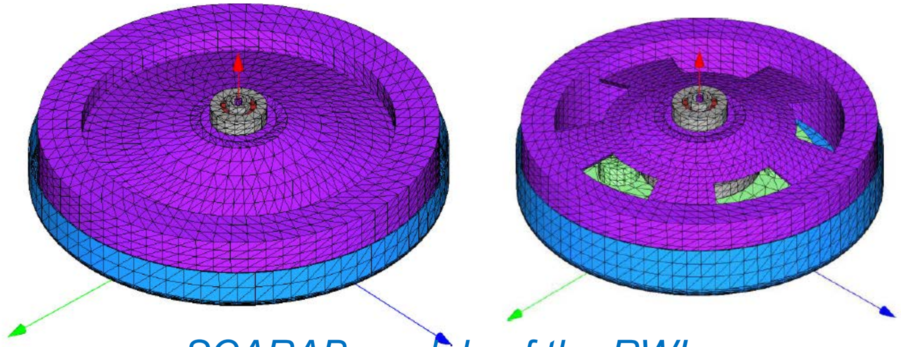
Demisable Reaction Wheels
Outcomes from HTG CCN (1/3)

- CCN objective
  - Conduct detailed SCARAB simulations in order to assess the breakup and demise behavior of reaction wheels
  - Identify the influence of different release conditions on the demisability of RWLs

- Considered models
  - RWLs with three different flywheel types have been analyzed:
    - *Stainless Steel flywheel with brazed/bolded spokes (based on RSI 20-215/18)*
    - *Aluminum monobloc flywheel (68 Nms)*
    - *Aluminum flywheel with machined spokes and smaller diameter (45 Nms)*



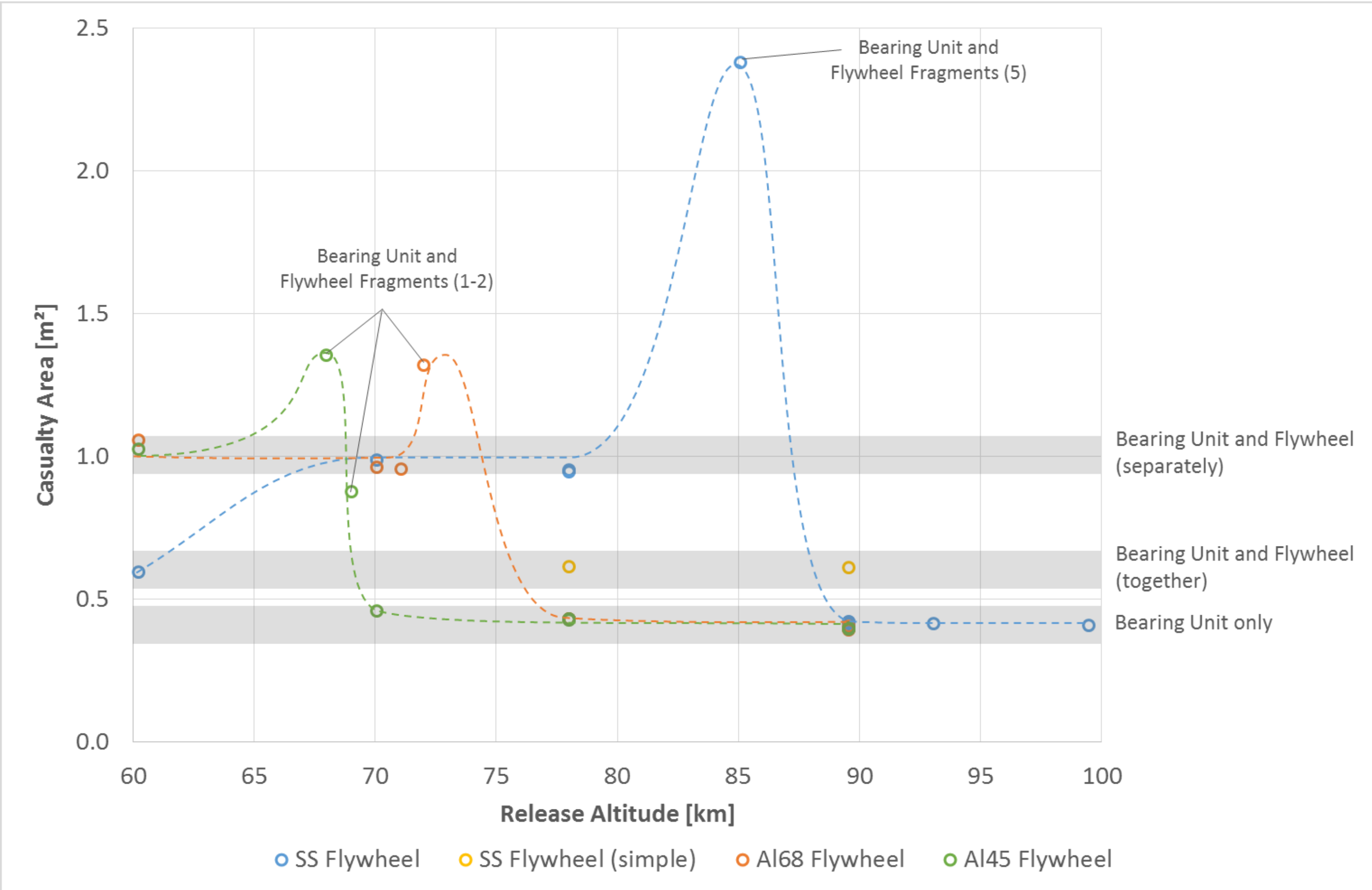
SCARAB models of the RWLs with Stainless Steel flywheels



SCARAB models of the RWLs with Aluminum flywheels

- Initial release conditions
  - Varied along the reference re-entry trajectory of the CleanSat activity (60-100 km altitude)

Demisable Reaction Wheels
Outcomes from HTG CCN (2/3)



Casualty Area

Demisable Reaction Wheels Outcomes from HTG CCN (3/3)

- Conclusions
  - Ball bearing unit ALWAYS survives:
    - In all SCARAB simulations,
    - For all release altitudes,
    - For all types of reaction wheels,
  - Steel flywheels demise if the RWL is released high enough
  - If an aluminum flywheel is used, the release altitude limit can be lower from 85 to 70 (45 Nms) or 78 km (68 Nms).
  - To achieve a full demise of the RWLs, including the bearing unit, this unit needs to be redesigned

Demisable Magnetorquers
Requirements overview

The BB aims at the development of a magnetorquer that demises when released from the spacecraft during reentry.

BB18	Requirement Text
Dipole moment	Dipole moment of +/-200 Am² with linear error <2%
Cost	Cost increase below 10% w.r.t. non-demisable MTQ
Mass and volume	Mass and volume penalty of <10%
Length	Length <750mm
Power	Power consumption <6W for MTQ of 200 Am²
Demisability	Demisability with break-up altitude: • 65 km required • 50 km goal

Demisable Magnetorquers
Baseline

- A baseline has been proposed by the supplier
- Detailed information can be found in the final report

Demisable Magnetorquers
Compliance and system impacts

- Demisability:
  - All investigated concepts (see next slide) **demise** when released at 65 km
  - All investigated concepts (see next slide) **survive** when released at 50 km

- Detailed information can be found in the final report

Demisable Magnetorquers
Critical areas and main options

- Components and functions:
  - Coil – Magnetic field generation
  - Core – Enhancement of the magnetic field generated by the coil.
  - Feet – Mechanical support and interface
  - Housing – Physical protection and insulation typically for coil and core
  - Potting – Mechanical integrality of the coil winding
- Four options investigated for the baseline
- Further options investigated for qualitative comparison

Demisable Magnetorquers Development plan

- TRL 7/8 expected by 2020
- Detailed test plan is not presented to the LSIs

Demisable Optical Payloads
Requirements overview

The BB aims at the development of an optical payload that demises or reduces the casualty risk when released from the spacecraft during reentry.

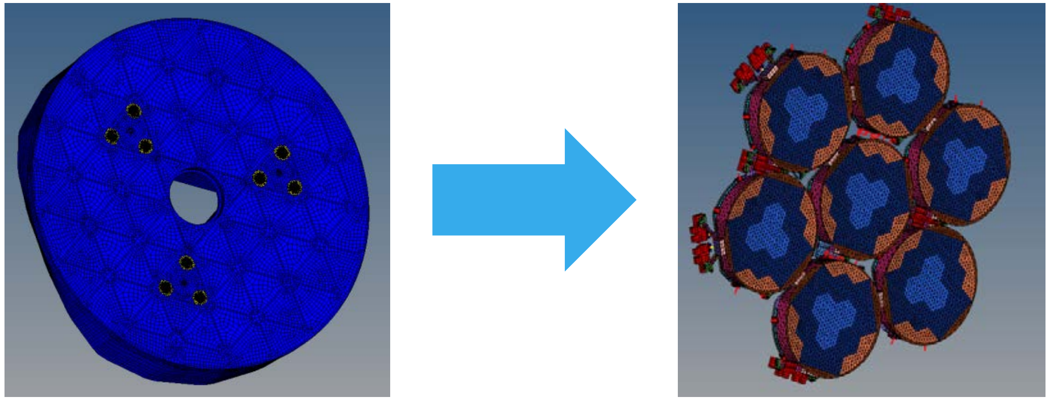
BB21	Requirement Text	SOC
Dipole moment	Target cost to remain below that of a controlled re-entry	C
SoW	List of assessments to be performed as part of the study: • Opto-mechanical performance • Structural performance • Thermal performance • Mass • Volume • Power consumption • Reliability • Safety (accidental break-ups)	C (*)
Demisability	Demisability (DRAMA) • 78km break-up altitude required • 65km break-up altitude goal	PC

(*) : BB21 study focused on Optics

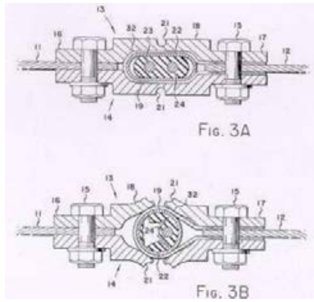
Demisable Optical Payloads Baseline

- Investigation of 3 options
  - Optics design for disintegration
    - Segmentation of mirrors into 7 segments
  - Pyro bolts (active or passive)
    - To separate non-demisable elements
  - Thermal structure break-up
    - Utilise temperature gradient induced stress to break-up optical elements

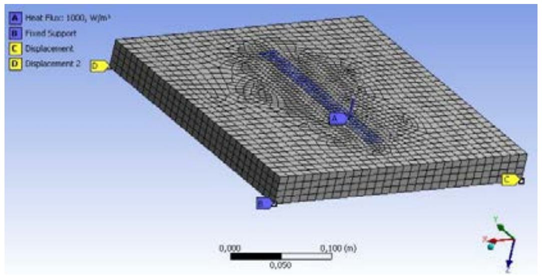
Option 1

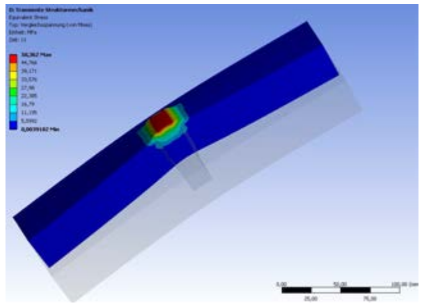


Option 2



Option 3

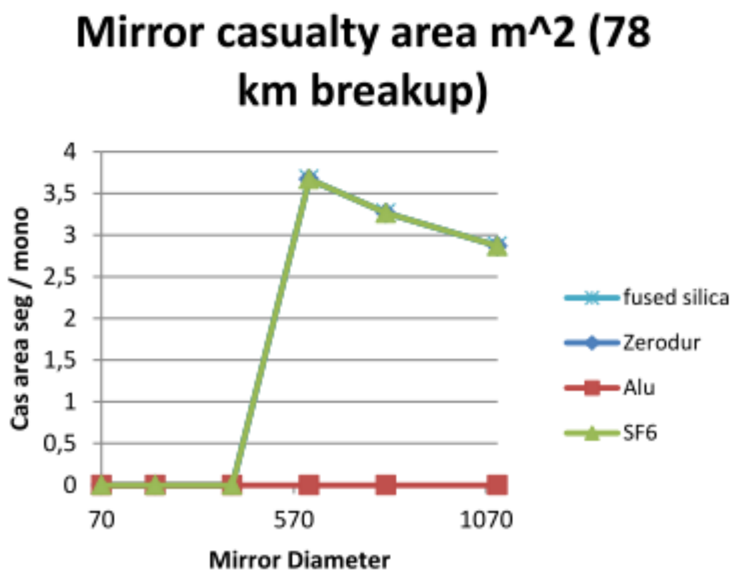




Demisable Optical Payloads
Critical areas and main options

Option 1

- Different mirror materials considered
  - Fused silica
  - Zerodur
  - Aluminum
  - SF6
- Optical performance (wave front error) can be improved with segmented mirror
- Mass can increase or decrease
- Improved demisability observed for segmented mirror
  - Depending on material mirror segments might need to be very small → limited efficiency of the solution
- High cost increase for mirror manufacturing and AIT (alignment) procedures



Demisable Optical Payloads
Critical areas and main options

Option 2

- No impact on optical performance
- Small mass increase (2-5% of instrument mass)
- Cost increase due to added AIT efforts and additional parts (pyro elements)
- Lifetime constraints for pyro techniques
  - Electrical initiators qualified for 7 years only
- On-ground risk due to use of pyro techniques

Option 3

- Material selection
  - High CTE combined with low thermal conductivity
- Particularly suitable for SF6 mirrors
- High heat flux required locally (50 kW/m²)
- Design will have to include predetermined breaking points

Demisable Optical Payloads
Compliance and system impacts

- Technical compliance claimed by supplier
  - Exception: Pyro bolts are not compliant with lifetime requirements
  - LSIs have doubts of feasibility and viability of the proposed concepts

- Three options have different areas of application:
  - Design for disintegration provides most benefits for mirrors smaller than 500mm optical aperture. Aluminium increases effectiveness of this option
  - No limits on application of pyro devices, but drawbacks include lifetime and added ground risk
  - Thermal break-up works best for brittle materials

- System impacts to the spacecraft are generally low
  - But optical payloads are built-to-performance
  - Cost increase could become a driver for the mission
  - Large AIT impacts expected

- General results of this study and other demisable optical payload concepts will need further investigation in concrete example projects

Demisable Optical Payloads
Development plan

- Current TRL is only high for baseline
  - Option 1 TRL 9 (flight proven)
  - Option 2 TRL 2
  - Option 3 TRL 1

- No estimation of development schedule has been presented
  - Option 1 could be adapted to a specific mission directly

- In general demisable optical payload can be considered a long-term development

Early structure break-up
Topic overview

1 BB for understanding

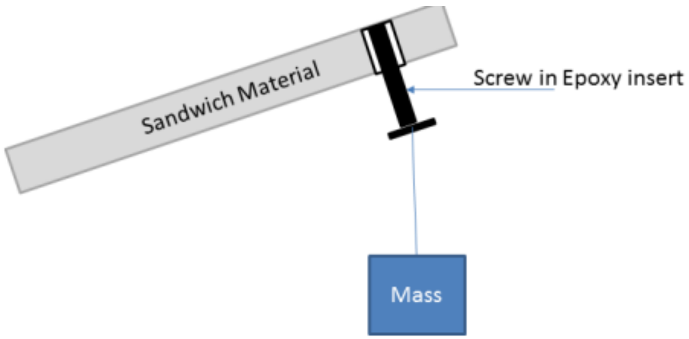
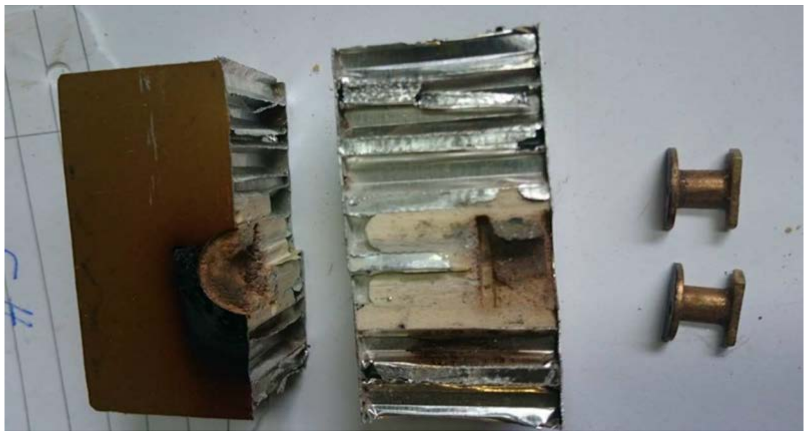
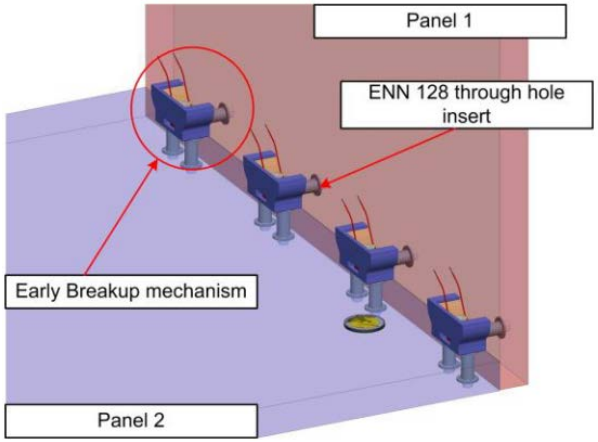
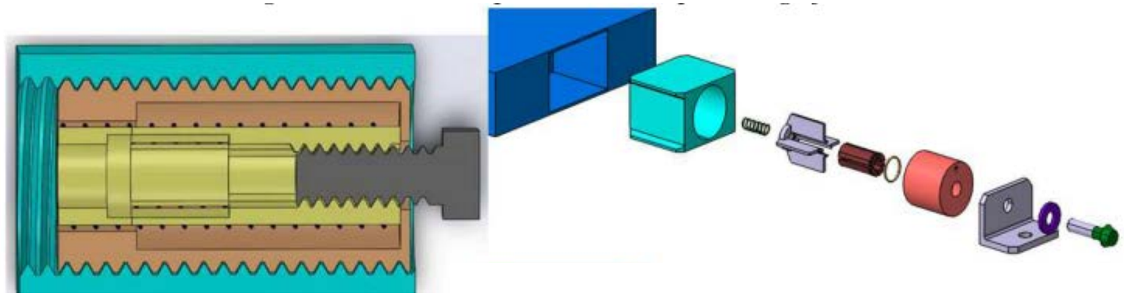


Figure 11: Test Setup Schematic

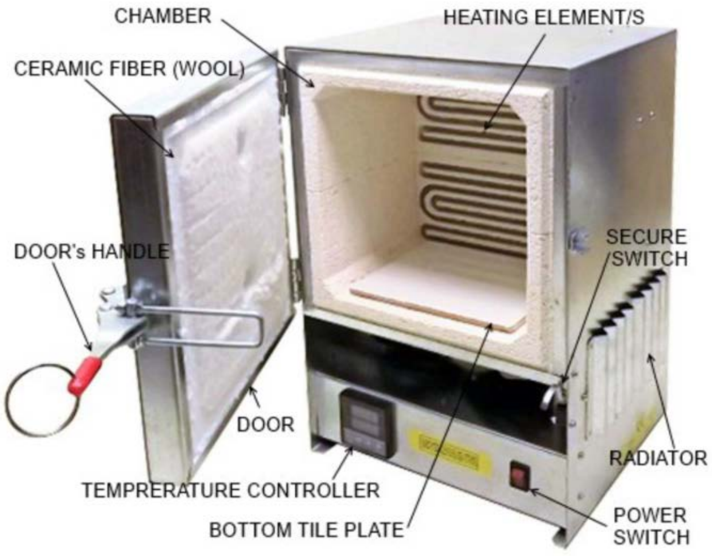


2 BBs for design





Early structure break-up
Test results



- Phenomenological tests to understand behaviour of strucuture elements during re-entry
- Weakening of all structure elements at elevated temperatures
  - No separation with only heating – (small) force is required
- Facesheet adhesive weakening at 180°C
  - CFRP facesheet more resistant than aluminium
- Higher heat required for insert failure
  - Chemical denaturing of potting starts at 270°C
  - CFRP facesheets allow easier release of insert than Al-FS
- Preloaded bolts loosen at about 350°C

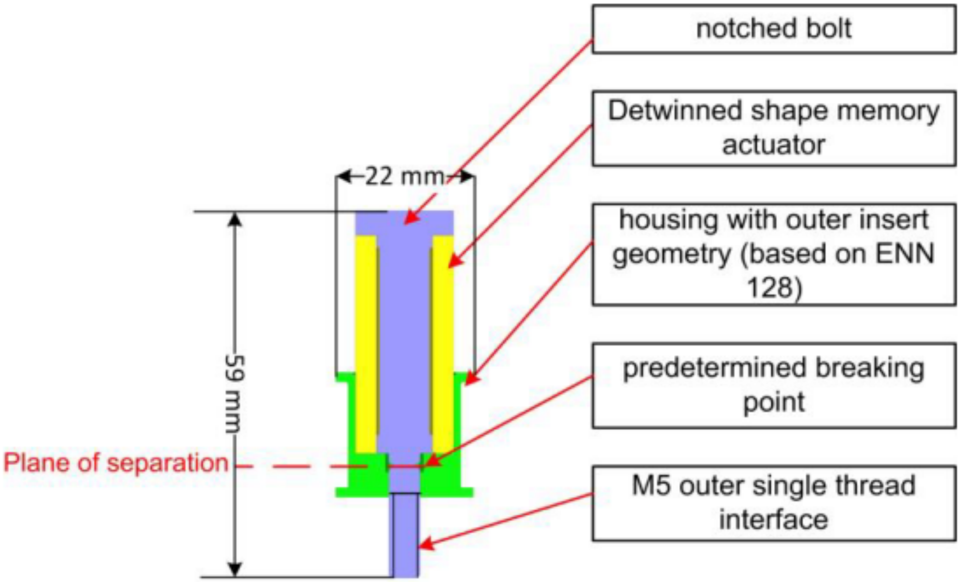
- Hints towards loose-but-not-detached joints during hot phase of re-entry
- Detachment could happen later when aerodynmic forces are dominating
  - In support of break-up around 78 km

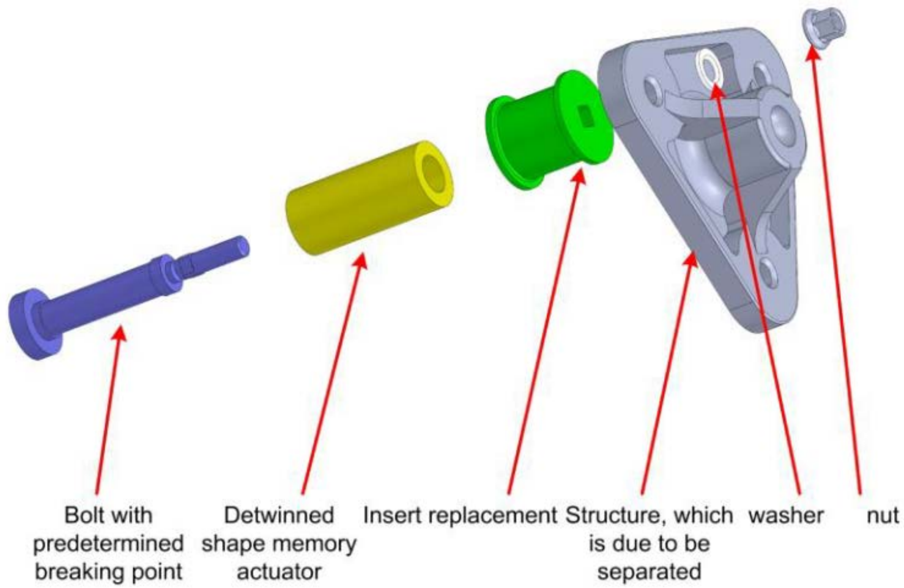
Early structure break-up
Requirements overview

The BB aims at the development of satellite structure joints that during reentry create an earlier break-up of the structure to improve demisability of inner components.

BB06 / BB10	Requirement Text	SOC BB06	SOC BB10
Break-up altitude	Maximisation of break-up altitude as a goal	C	C
Temperature range	Temperature ranges: •Environment -40°C to +90°C •Activation temperature +120°C to 200°C	? C	C
Safety	Low risk (<1E-3) of unplanned activation	C	TBD
Reliability	High reliability for activation (>0.9999)	TBD	TBD
Mechanical performance	Maximum transferable axial load 500 N (TBC)	C	N/A
Operation	Active option: Activation of mechanism within 10 to 30 min after command	C	C

Early structure break-up
Baseline BB06

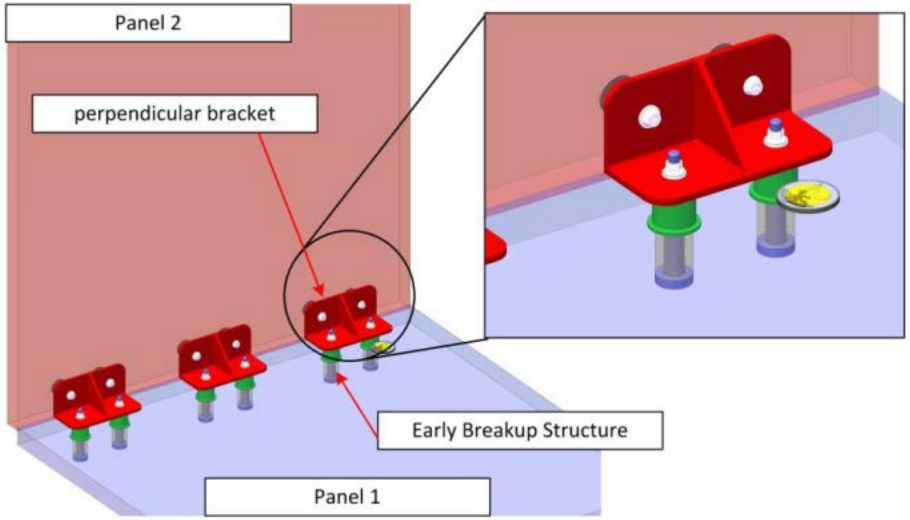


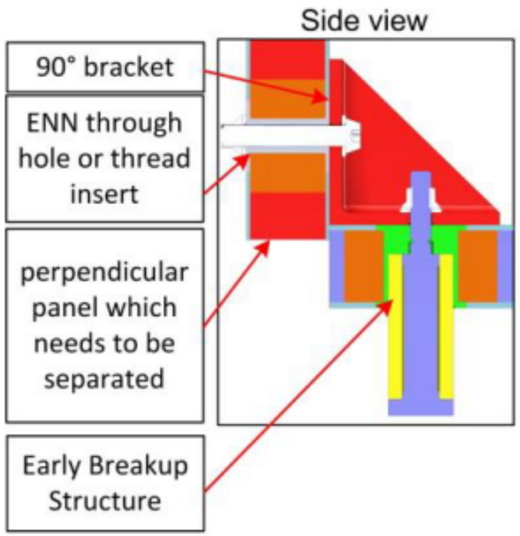


- Supplier: Airbus Safran Launchers, Lampoldshausen

Early structure break-up
Compliance and system impacts BB06

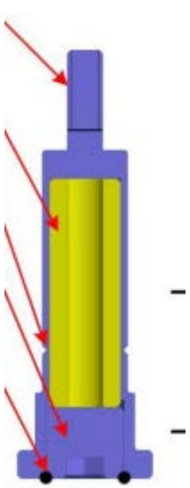
- Very low system impacts
- Increased mass if many standard bolts are to be replaced
- Actuator needs to be adapted to thickness of sandwich panels
- Separation detectors have to be additionally implemented on system side if required
- Reliability of activation to be assessed in future phases
- Cost increase depending on number of joints to be replaced

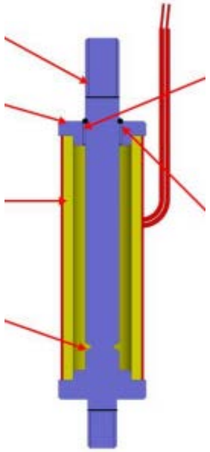


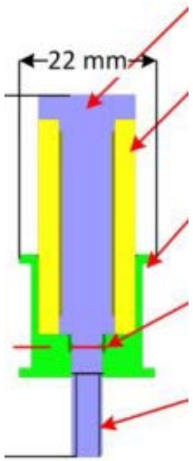


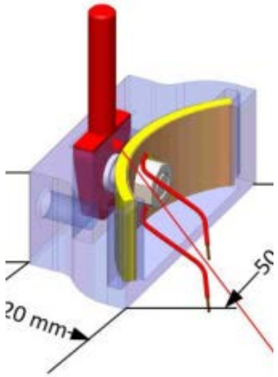
Early structure break-up
Critical areas and main options BB06

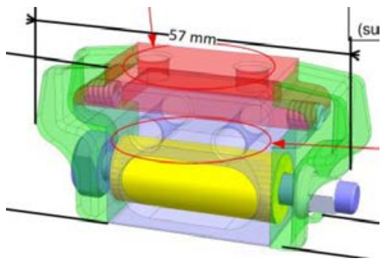
I material closure			II shape connection		
concept I/1 bolt with internal actuator	concept I/2 bolt with external actuator (two thread interfaces)	concept I/3 bolt with external actuator (panel insert interface)	concept Ii/1 Pin Puller Concept	concept Ii/2 clamped interfaces (combined with bracket)	concept I/3 clamped interfaces (not combined with bracket

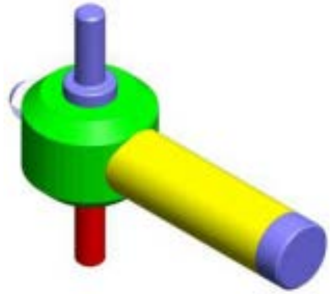






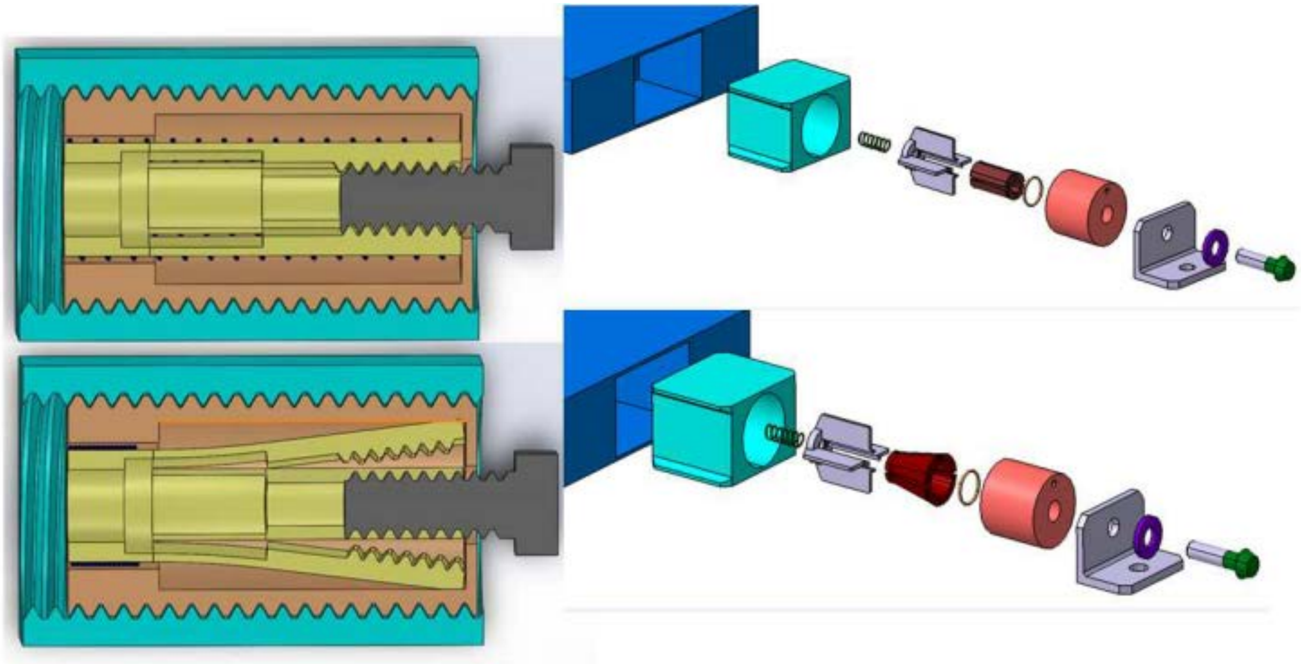






Early structure break-up Baseline BB10

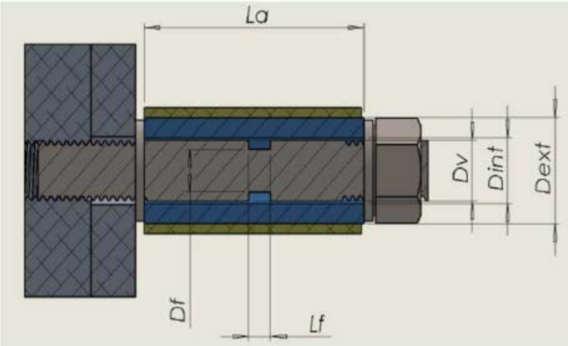
- Replacement of standard inserts
- Release of bolt after retraction of SMA-spring and opening of thread-petals
- Remaining doubt w.r.t. force margins and cold welding effects between parts
- Supplier: Altran
  - SMA expertise: NIMESIS

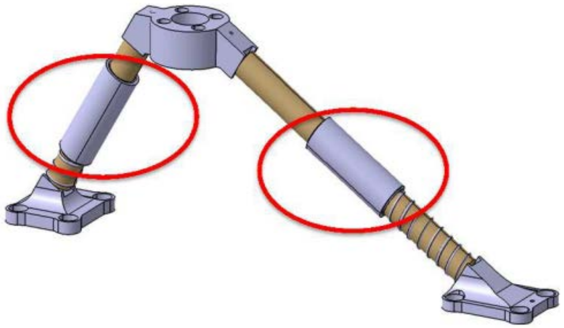


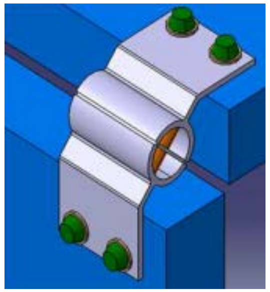
Early structure break-up
Compliance and system impacts BB10

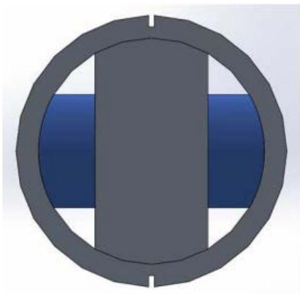
- Increased mass if many standard inserts are to be replaced
- Separation detectors have to be additionally implemented on system side if required
- Reliability of activation to be assessed in future phases
- Accidental break-up safety to be assessed in future phases
- Cost increase depending on number of joints to be replaced

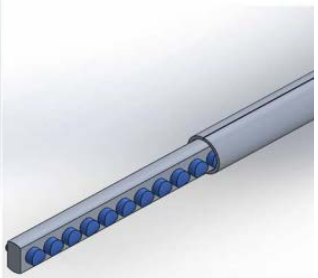
Early structure break-up
Critical areas and main options BB10









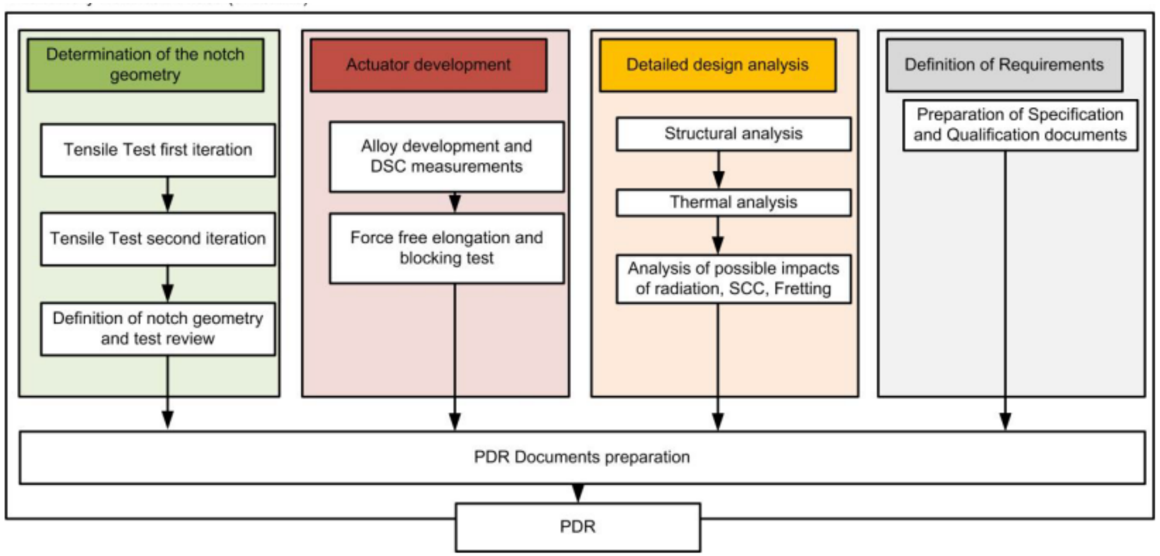


- Detailed trade-off of SMA alloys:
  - TiNi
    - Most common
    - -50°C to +100°C transition temperature
    - Recoverable strain 6-8%
  - TiNiX
    - Limited data available
    - Transition temperature +250°C to +300°C
  - Cu-based alloys
    - Expensive
    - Recoverable strain ~10%
  - CuAlNi
    - Transition temperature up to +160°C
    - Better workability than CuZnAl
  - Others also considered

Early structure break-up Development plan

- Estimated timeframe 22 months in total (for baseline concept in BB06)
  - 7 months up to PDR
  - 10 months to CDR
  - 5 months to QR
- BB10 development plan can be found in final report

- General:
  - Complex multi-scale problem to be carefully analysed on system level
  - Statistical process to be included in design to derive proper requirements (system and component)



Building Blocks presentation - Deorbit technologies

- Introduction
- High thrust monopropellant engines
- Repressurisation module
- Arcjets
- Low power Hall Effect Thrusters
- Drag augmentation sails
- Electro-static tether
- Solid Rocket Motors
- Autonomous de-orbiting systems

High Thrust Monopropellant Engines (3 BBs) Requirements overview

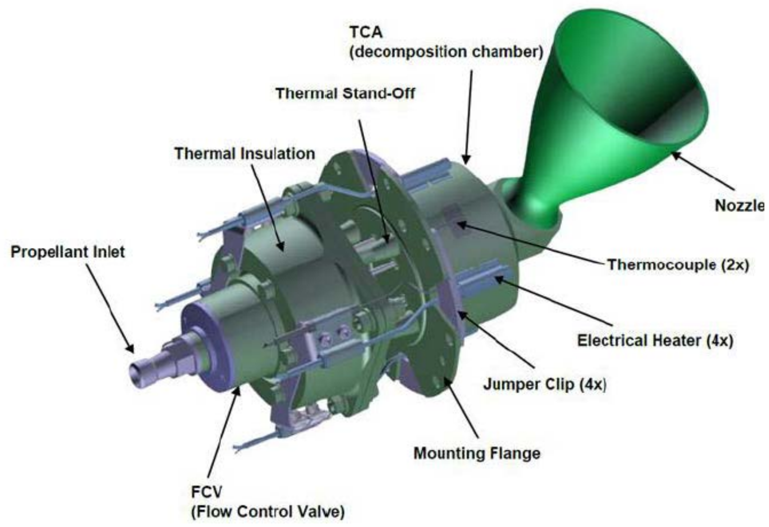
The BBs are aimed at the definition of a monopropellant thruster powered by green propellant to be used for Controlled Re-entry of LEO S/C.

Topic	Driving Harmonized Requirements	BB08	BB26
Propellant	Monopropellant H2O2 (Baseline)	N/A	C
Propellant Concentration	H2O2 (concentration from 85% to 100% wt)	N/A	C
Propellant	ADN-based monopropellant LMP-103S RCT (Alternative)	C	PC
Operating Modes	Regulated or Blowdown	C	C
Operating Modes	The RCT shall be operated either in Steady State (@SS) operations or in Pulse Mode (@PM) under an unregulated propellant inlet pressure (blow-down)	C	C
Operating Temperature	The operating temperature of the propellant shall be 10-50°C	C	C
Operating Pressure	[5.5 22] bar	C	C
MEOP	24 bar	C	C
Functional Compatibility	IPA - GHe - GN2 - GAr - Deionised water	C	C

High Thrust Monopropellant Engines (3 BBs) Requirements overview

The BB is aimed at the definition of a low cost monopropellant thruster powered by Hydrazine to be used for Controlled Re-entry of LEO S/C.

Topic	Driving Harmonized Requirements	BB09
Propellant	Hydrazine	C
Operating Modes	Regulated or Blowdown	C
Operating Modes	The RCT shall be operated either in Steady State (@SS) operations or in Pulse Mode (@PM) under an unregulated propellant inlet pressure (blow-down)	C
Operating Temperature	The operating temperature of the propellant shall be 10-50°C	C
Operating Pressure	[5.5 22] bar	C
MEOP	24 bar	C
Functional Compatibility	IPA - GHe - GN2 - GAr - Deionised water	C



Design Reference (METOP 2G 400N)

High Thrust Monopropellant Engines Baseline

BB08 – Green Propellant

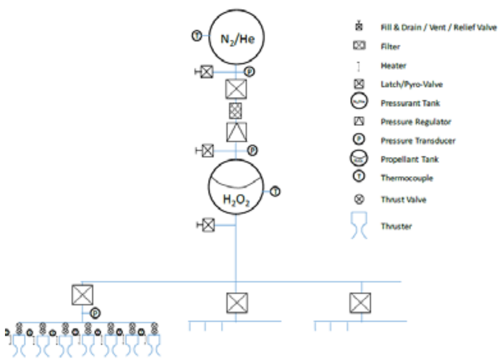
Monopropellant RCT Thrust Level	Baseline Characteristics
150N@5.5 bar LMP-103s (Case1)	• Expansion ratio: 80 • Nozzle length of 205 mm • Outer diameter of 152 mm • Estimated performance of 248 s.
150N@18 bar LMP-103s (Case2)	• Expansion ratio: 200 • Nozzle length of 220 mm • Outer diameter of 148 mm • Estimated performance of 256 s.
200N average LMP-103s (Case3)	• Expansion ratio: 90 • Nozzle length of 205 mm • Outer diameter of 150 mm • Estimated performance of 249 s.

Thruster 3D proposed design

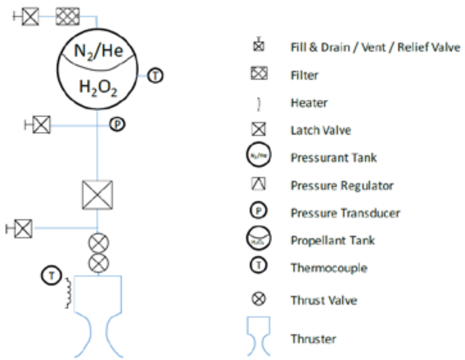
Item	Configuration / Design Parameter
Thrust Level	3 cases defined
Operation, Cat bed heater	Preheating done via four catalyst bed heaters
Heat Barrier	ALM printed design
Feed Tube	Single, elastic tube
Trimming and sealing	Trim orifice and COTS seal
Injector	Multi showerhead
Catalyst bed	Combination of heat bed and catalyst bed for dedicated propellant conditioning
Flow control valve	ASL
Flight Sensor	Thermocouple
Manufacturing	Mix of ALM with classical manufacturing
Chamber Material	PtIr
ALM Material	Hastelloy X

BB26 – Green Propellant

Monopropellant RCT	Baseline Characteristics
22N H2O2 (Case2)	• Concentration of H2O2 (X) 98% • Isp 183.6 sec • Total Throughput 180 kNs • RCT mass 0.45 kg • Expansion ratio 80 • Outer Diameter 31 mm • Total Length 199 mm • Target Price per unit 60 k€
150N H2O2 (Case3)	• Concentration of H2O2 (X) 98% • Isp 179.6 sec • Total Throughput 1290 kNs • RCT mass 2.23 kg • Expansion ratio 70 • Outer Diameter 120 mm • Total Length 378 mm • Target Price per unit 95 k€



Pressure regulated 22 N cluster propulsion system architecture.

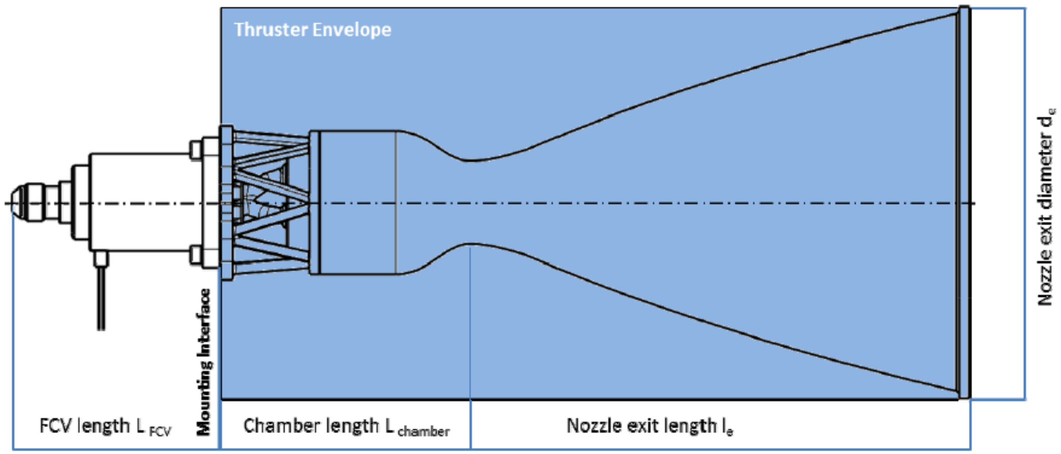


Blowdown propulsion system architecture.

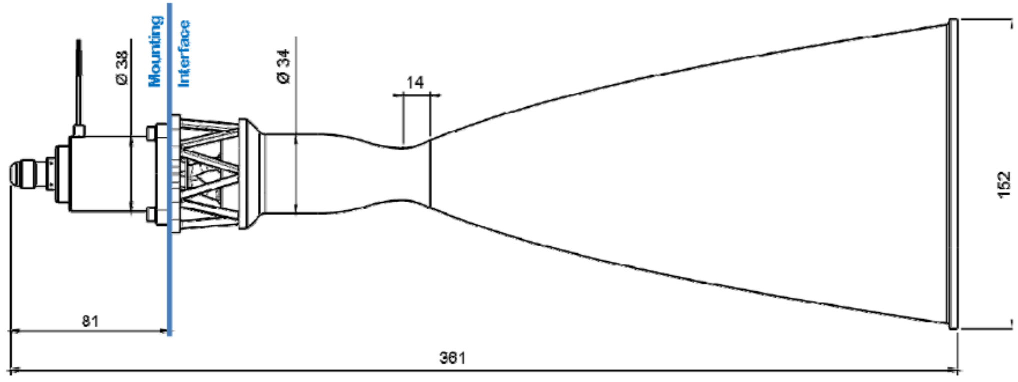
High Thrust Monopropellant Engines Baseline

BB09 – Hydrazine

Monopropellant RCT Thrust Level	Baseline Characteristics
(Case1) 150N@5.5 bar	• Expansion ratio: 80 • Nozzle length of 200 mm • Outer diameter of 151 mm • Estimated performance of 239 s.
(Case2) 150N@18 bar	• Expansion ratio: 150 • Nozzle length of 170 mm • Outer diameter of 128 mm • Estimated performance of 244 s.
(Case3) 200N average	• Expansion ratio: 90 • Nozzle length of 195 mm • Outer diameter of 149 mm • Estimated performance of 240s.



Item	Configuration / Design Parameter
Thrust Level	3 cases defined
Operation, Cat bed heater	Preheating done with dedicated preheat-ing pulses
Heat Barrier	ALM printed design
Feed Tube	Single, elastic tube
Trimming and sealing	Trim orifice and COTS seal
Injector	Multi showerhead
Catalyst bed	Combination of two beds based on Ir and Ru
Flow control valve	ASL
Flight Sensor	Thermocouple
Manufacturing	Mix of ALM with classical manufacturing
ALM Material	Hastelloy X



Case 2 (150N@18 bar) Baseline unit in [mm]

High Thrust Monopropellant Engines
System impacts

BB08

Case	Case 1	Case 2	Case 3
Reference operation mode	> 150N at 5,5 bar	150N at 18 bar	200N average
Reference Thruster ISP	248 s	256 s	249 s
Length chamber + nozzle ($L_{chamber}$ + l_e)	295 mm	280 mm	295 mm
Outer Chamber diameter	56 mm	36 mm	52 mm
Total length incl. FCV	376 mm	361 mm	376 mm
Exit Diameter d_e (incl. stiffener ring)	152 mm	148 mm	150 mm
Thruster mass	1,7 kg	1,3 kg	1,6 kg

BB09

Case	Case 1	Case 2	Case 3
Reference operation mode	> 150N at 5,5 bar	150N at 18 bar	200N average
Reference Thruster ISP	239 s	244 s	240 s
Length chamber + nozzle ($L_{chamber}$ + l_e)	300 mm	239 mm	295 mm
Outer Chamber diameter	56 mm	36 mm	52 mm
Total length incl. FCV	375 mm	340 mm	370 mm
Exit Diameter d_e (incl. stiffener ring)	153 mm	130 mm	151 mm
Thruster mass	1,5 kg	1,1 kg	1,5 kg

BB26

22 N H_2O_2 Monopropellant Thruster (Option 2)							
$X_{H_2O_2}$	$\bar{I}_{sp}$	$m_{p@I=180kNs}$	System Dry Mass	Propellant Mass	Total Mass	Propellant / Pressurant Tank Volume	System / Propellant Cost
[w/w]	[s]	[kg]	[kg]	[kg]	[kg]	[dm³]	[€]
98%	183.56	100	57.7	724.2	783.6	553.9/26.5	1.021 M€ / 55.8 k€
90%	161.44	114	61.7	823.4	887.2	650.5/31.2	1.014 M€ / 24.7 k€
85%	145.48	126	66.1	913.8	982.2	736.4/35.3	1.043 M€ / 21.9 k€

Mass budget for a pressure regulated propulsion system cluster of seven 22 N thrusters.

150 N H_2O_2 Monopropellant Thruster (Option 3)							
$X_{H_2O_2}$	$\bar{I}_{sp}$	$m_{p@I=1.2MNs}$	System Dry Mass	Propellant Mass	Total Mass	Propellant / Pressurant Tank Volume	System / Propellant Cost
[w/w]	[s]	[kg]	[kg]	[kg]	[kg]	[dm³]	[k€]
98%	179.55	681	44.0	705.1	749.7	631.1/-	484.4 /54.2
90%	157.68	776	47.7	802.9	851.3	742.3/-	486.4 /24.0
85%	142.07	861	51.0	891.1	942.9	840.4/-	519.3 /21.3

Mass budget for 200 N (average thrust) propulsion system architecture operating in blowdown mode.

High Thrust Monopropellant Engines
Critical areas and main options

BB08/BB26

The main technical challenges related to compatibility of propellant and thruster material and related reliability:

- Case H2O2: performance and long term storability of the propellant (e.g. material compatibility issue);
- Case LMP-103s: is a new technology due to different decomposition mechanism and thermal behavior/operation of the thruster itself compared to hydrazine. Thruster material, thruster reliability and total impulse. Propulsive performance of the catalyst.

The main options:

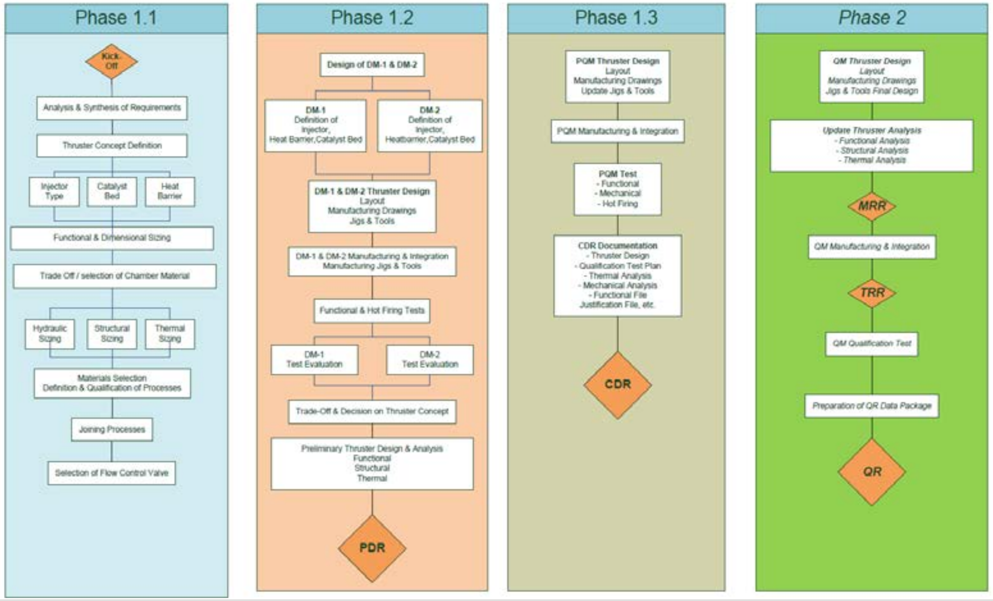
Options	Case 1	Case 2	Case 3
Operating mode	Blow-Down	Pressure Regulated	Blow-Down
Operating inlet pressure	5.5 bar	18 bar	14 ÷ 5.5 bar
Thrust level	150 N (@5.5 bar)	150 N (@18bar) or 22 N arranged in a cluster of 7 thrusters);	mean thrust level of 200 N

High Thrust Monopropellant Engines Development plan

BB08

The development is divided in two phase (over at least 36 months):

- Phase1: Design activities for the 3 thruster models (DM1, DM2 and PQM) to verify design options (Phase1 end @CDR);
  a) DM-1: based on ECAPS technology and cooperation.
  b) DM-2: based on outcome of the RHEFORM project (ESA study)
- Phase2: Formal qualification and verification of requirements;
- Timeframe identified is considered a bit optimistic for the associated activities.



BB26

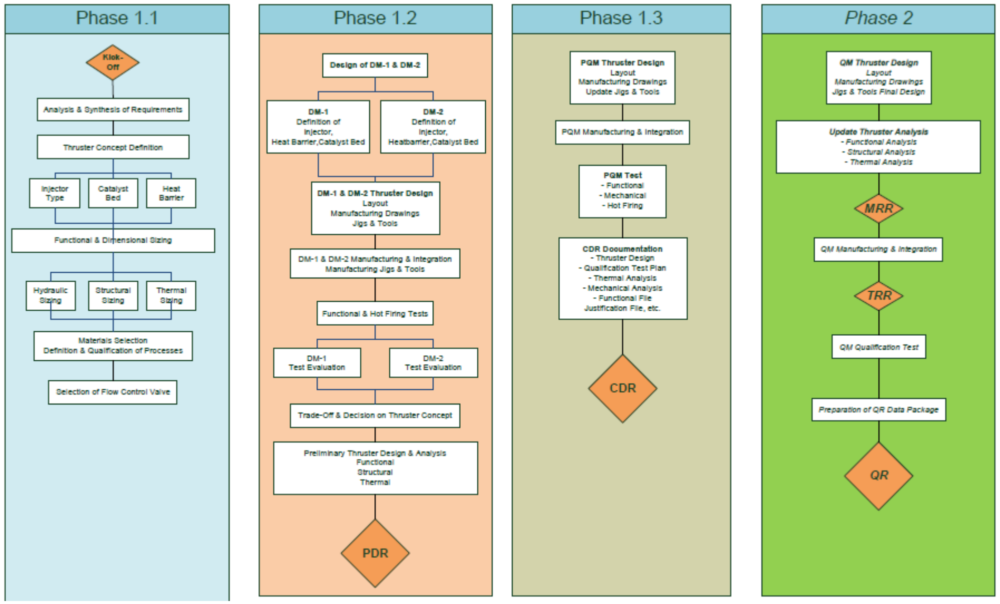
- Thruster unit (performance, cost, mass and volume) optimization according to consolidate Platform requirement specifications (on-ground test with an Engineering Model (EM) of the thruster unit)
- Design and production of Engineering Qualification Model (EQM) of the thruster;
- Performance and Qualification plan;
- Qualification campaign performed on the (EQM)
- 36 months and it is roughly divided in two phase:
  - Optimization of the EM (18 months);
  - Design, production and qualification of the EQM (18 months)
- Experimental Campaign

High Thrust Monopropellant Engines Development plan

BB09

The development plan 36 months, roughly divided in two phase:

- Phase 1: Design activities for the 3 thruster models (DM1, DM2 and PQM) to verify design options (Phase1 end @CDR).
  - a) DM-1: re-use as much as possible the heritage data and design parameters. To scale the injector based on the SCA heritage thruster
  - b) DM-2: Optimizing the injector and catalyst bed parameters.
- Phase 2: formal qualification and verification of requirements;

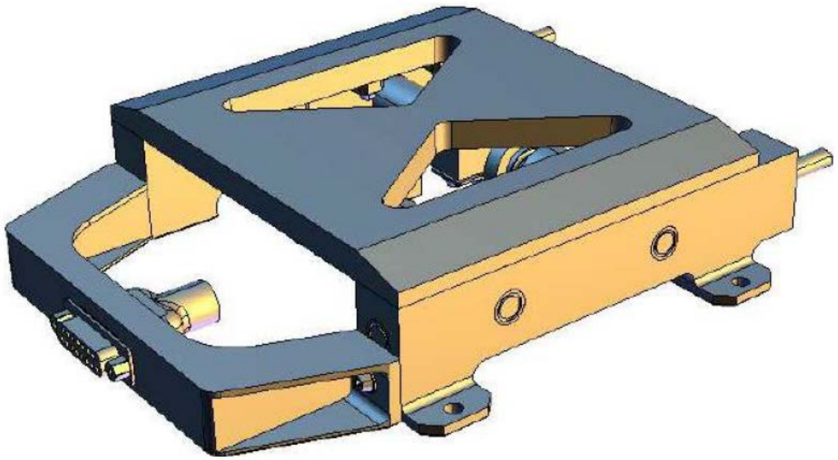


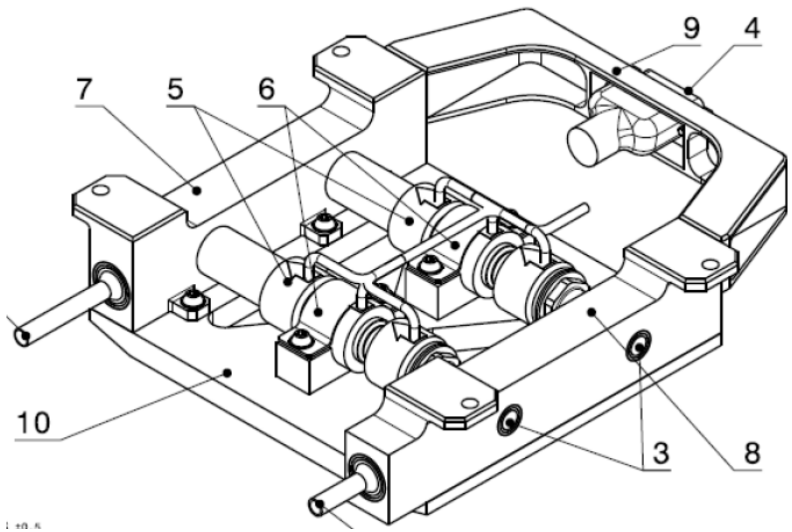
Repressurisation Module
Requirements overview

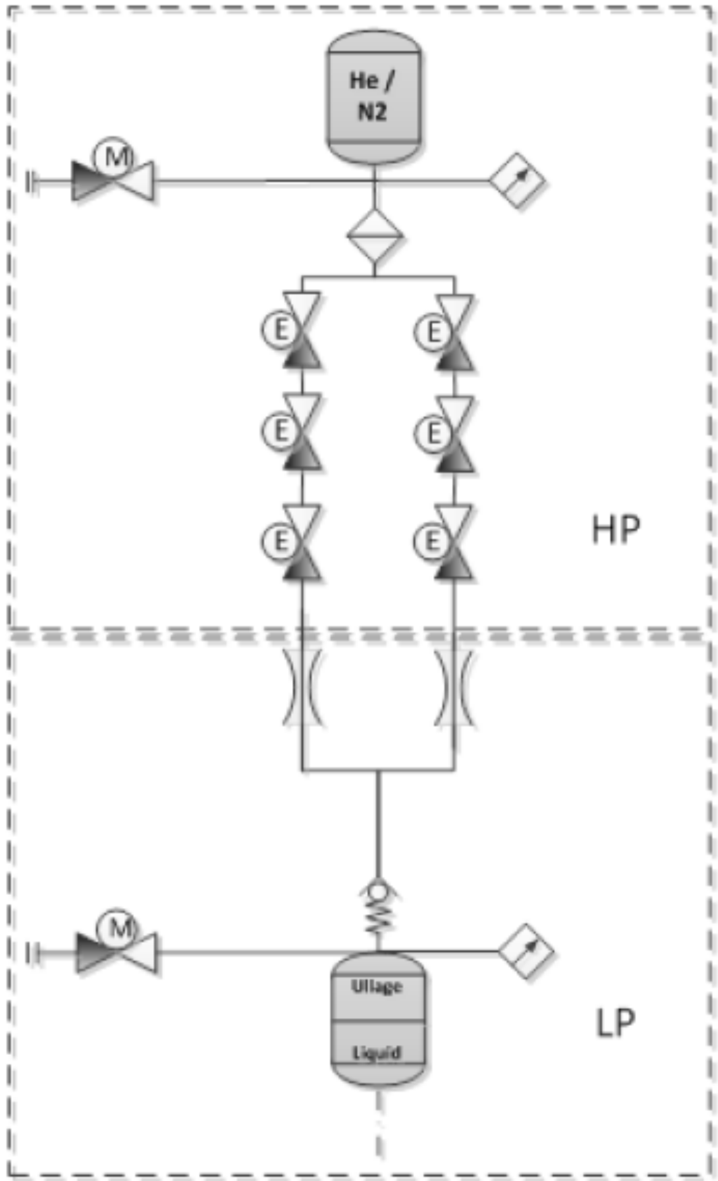
The BB aims at the development of a module for repressurisation of the chemical propulsion subsystem (mono- and bi-propellant).

BB07	Requirement Text	SOC
Media compatibility	Compatibility with following media: •N2H4, N2O2, MON, MMH, N2H3, ADN •IPA, deionized water •Helium, nitrogen	C
Operation	2 commands for activation	PC
Tank volume	Repressurised volume between 200 l and 800 l	PC
Pressure tolerance	Pressurisation tolerance +/-1 bar	C
Analysis cases	Two cases to be considered for pressurisation rate: •400N @ 22bar plus 10% margin for RCTs – 220 g/s •4 x 20 N – 40 g/s	C
Cycles	Maximum number of pressurisation cycles over mission: 10	C

Repressurisation Module Baseline





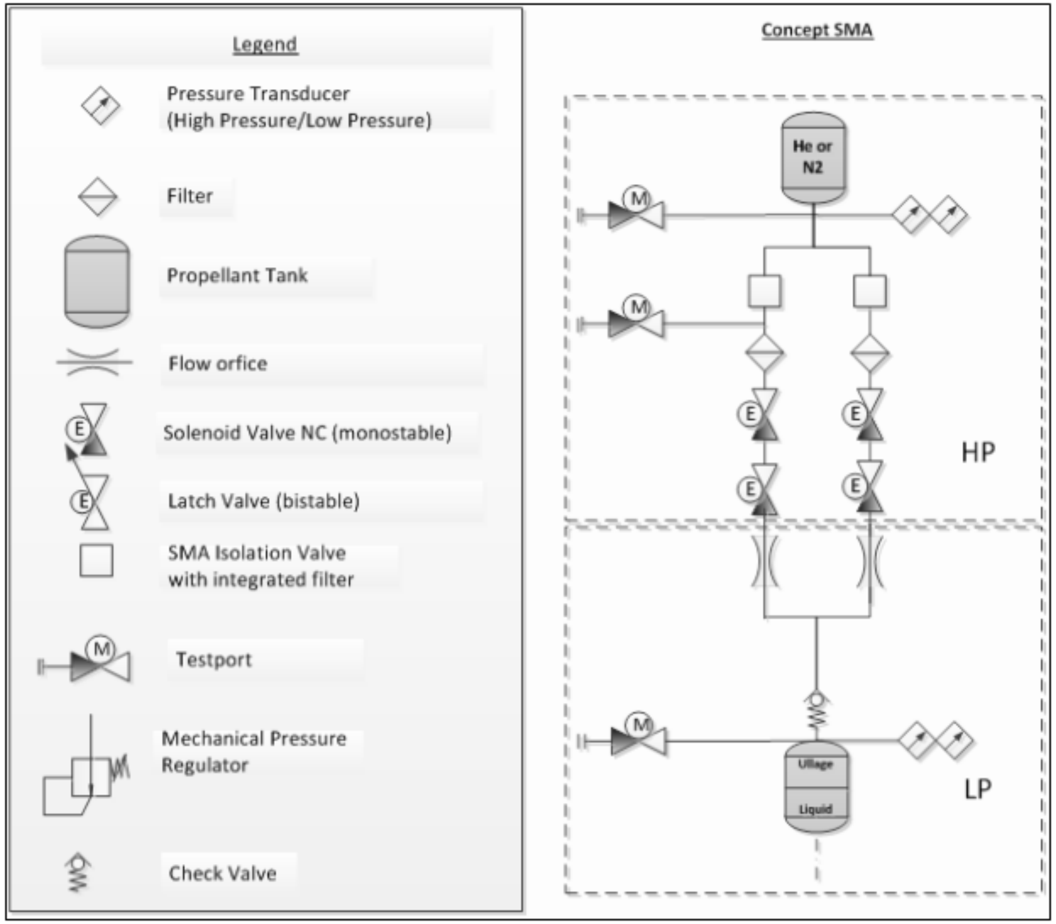


Repressurisation Module
Compliance and system impacts

- Pressure drop in low pressure part drives regulation accuracy
  - System design to consider maximum suggested length of piping
- Mass of unit ~2.5kg
  - External equipment (e.g. pressurant tank) to be added for performance comparison
- Lifetime performance and reliability to be determined
  - Valve MTBF is 5200h – to be analysed in more detail
- Leakage requirements to be tested
- Electronics to be upgraded to include two-command activation
- Compact design inhibits test ports between valves
- Partial compliance stated to ullage volume requirements
- Low volume required could be further reduced by considering direct mounting of RPM to high pressure tank

Repressurisation Module
Critical areas and main options

- Alternative concept proposed including SMA valves

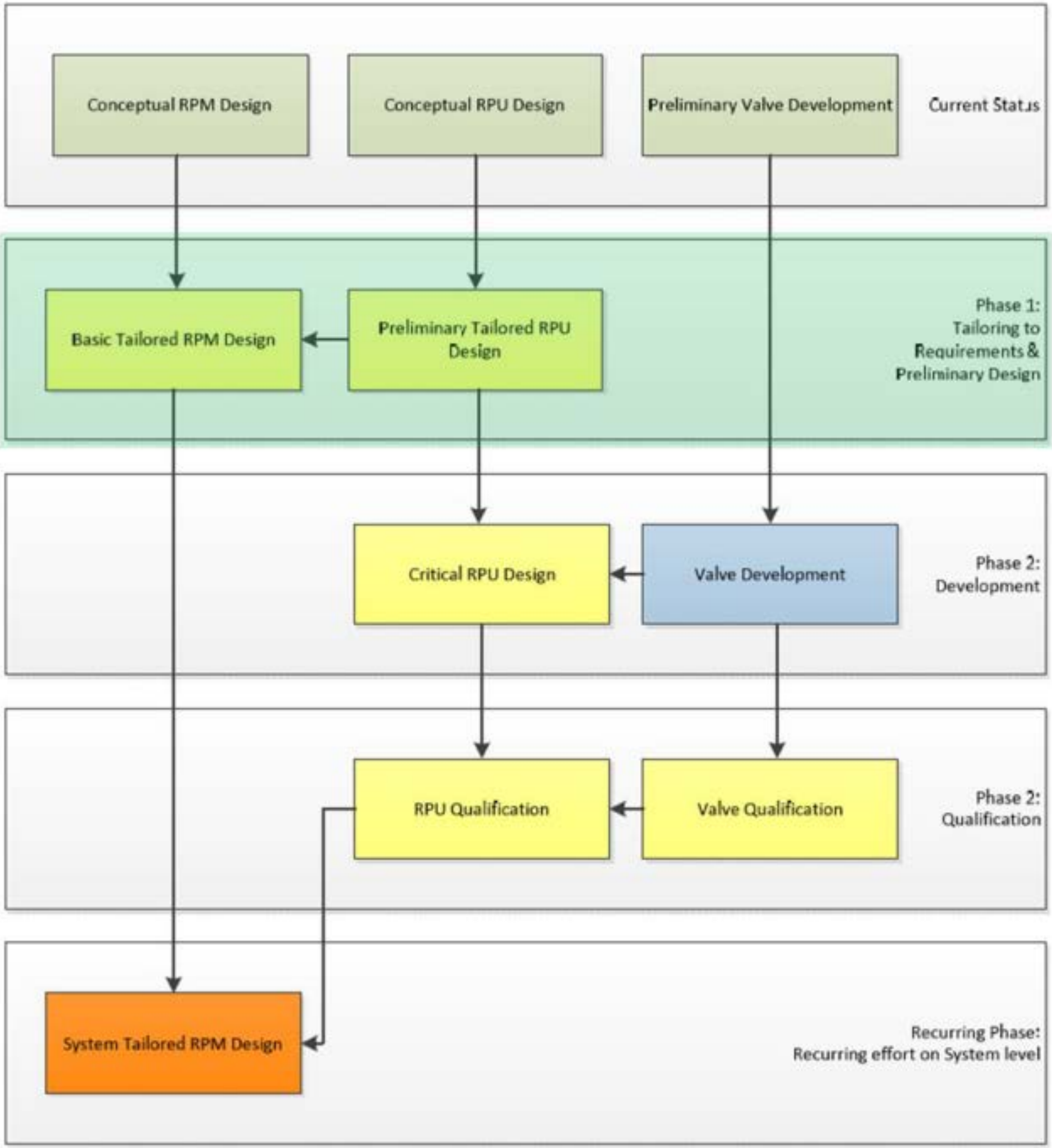


Further options
- Cartridge vs coaxial design
- Component selection for
  - High pressure tank
  - Pressure transdurcers
  - Fill and drain valves
  - Check valves
  - Regulation valves

Critical area
- Temperature drop in pressurant tank to be controlled
- Pressure regulation accuracy drives number of valve cycles
  - Higher accuracy → more cycles

Repressurisation Module Development plan

- Current TRL 4-5
- Estimated duration up to TRL 7:
  – 33 months



Arcjets (2BBs)
Requirements overview

The BBs are aimed at the definition of an Arcjet propulsion system to be used for nominal mission and for disposal phase of LEO Spacecraft (S/C).

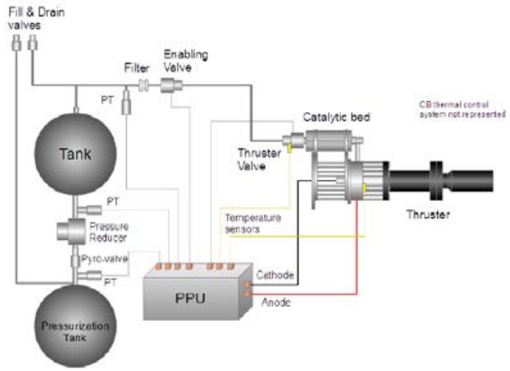
	Driving Harmonized Requirements	
Operating media	The arcjet de-orbiting system shall be able to operate with Hydrazine (as baseline), LMP-103S ADN-based propellant (as option) and other gaseous propellants such as GN2, GHe, Ar, Xe, Kr.	PC (ADN)
Test Media Compatibility	The Thruster shall be able to cope with the following testing media: Isopropyl alcohol (IPA), deionized water, Gas Helium and Gas Nitrogen.	C
Compatibility with Tank	The arcjet system piping shall be compatible with aluminum (for ADN) tank; as option, the arcjet system piping shall be compatible with titanium (for Hydrazine) tank.	C
Thruster Input Power	≤ 750 W	
PPU Voltage Input	The PPU input voltage shall be about 28V unregulated.	C
Total number of Cold Start	The thruster (from the catalytic point of view) shall demonstrate >10 cold start @ 10°C propellant temperature.	C
Flow barriers	The Thruster shall equip two monostable flow barriers normally closed in series mechanically and electrically independent	C
Thermal Control	The catalytic assembly shall be thermally controlled with two redundant heater lines. The system shall be equipped with one temperature sensor and a heat shield	C
Thruster Mass	The thruster shall be below 1.2 kg/kW	C
Specific Impulse	≥ 400 s (Stand Alone System) ≥ 600 s (Hybrid System)	C PC
Thruster On/Off Cycles	• 10000 (Stand Alone System) • 2600 (Hybrid System)	TBC
Thrust Level	≥ 100 mN	C

Arcjets
Baseline

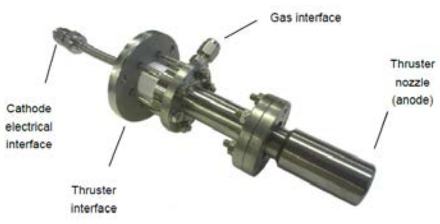
BB25

S/S architecture	S/C class mission	S/S propulsion configuration
Stand Alone System (case 1)	S/C 800 kg orbit 800 km, Arcjet system to be used for nominal mission and for uncontrolled re-entry.	AT-1kW one single thruster configuration
Hybrid System (case 2)	S/C 1500 kg, orbit 800 km, Arcjet system to be used for orbit rising from 300km to 800 km and for controlled re-entry from 800 km.	3 kW (Three cluster of 1 kW thrusters)

- Propellant: Hydrazine as baseline propellant (Ammonia as option);
- Power Processing Unit (PPU) internally redundant
- Catalytic Bed: outside thruster configuration and pressure regulation feeding system.



S/S architecture

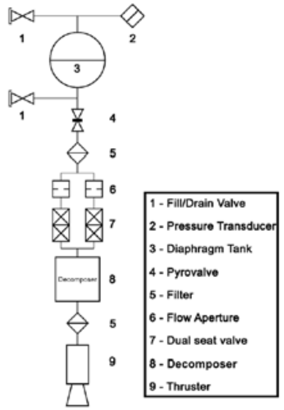


AT-1KW Arcjet Thruster

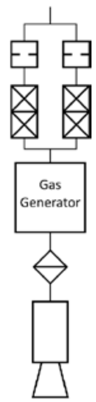
BB28

S/S architecture	S/C class mission	Baseline S/S propulsion
Stand Alone System (case 1)	S/C 800 kg orbit 800 km, Arcjet system to be used for nominal mission and for uncontrolled re-entry.	Hydrazine Blow-Down (dual branch) system. Two flow branches to manage high tank pressures and low tank pressures.
Hybrid System (case 2)	S/C 1500 kg, orbit 800 km, Arcjet system to be used for orbit rising from 300km to 800 km and for controlled re-entry from 800 km.	Dual Branch - design without active flow control.

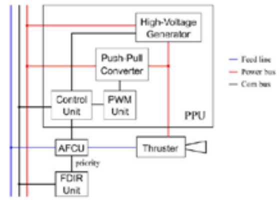
- Hydrazine as baseline propellant (ammonia as option);



Case 1



Case 2



Power Processing Unit

ARTUS IM – Hydrazine (left), ATOS ammonia (right)

AIRBUS OHB ThalesAlenia Space a Thales / Leonardo company

Arcjets
System impacts

BB25

1kW class Arcjet Systems - Mass and Power Budget Budget		
Unit	**Mass [kg]**	**Power [W]**
Power Processing Unit (PPU) with internal redundancy	8	73
Harnesses	1.6	/
Thruster Unit (TU)	1.1	1020.4
Feeding System	2.275	24.4
Arcjet Propulsion System	12.975	1117.8
Tank and Pressurization System	9.68	/
Arcjet Propulsion System (including tank and press. system)	22.655	/
Arcjet Propulsion System Full Redundant (including 2 TU, tank and press. System,)	27.245	/

3kW class Arcjet Systems - Mass and Power Budget Budget		
Unit	**Mass [kg]**	**Power [W]**
Power Processing Unit (PPU) with internal redundancy	11	179
Harnesses	2.4	/
Thruster Unit (TU)	2	3020.4
Feeding System	2.275	24.4
Arcjet Propulsion System	17.675	3223.8
Tank and Pressurization System	27.180	/
Arcjet Propulsion System (including tank and press. system)	44.855	/
Arcjet Propulsion System Full Redundant (including 2 TU, tank and press. system)	51.145	/

BB28

	N_2H_4 ARTUS Blow Down
Power / W	750
Initial pressure / bar	24
Final pressure / bar	12.0
Tank Volume / l	91.1
Propellant volume / l	45.5
Mean I_{sp} / s	443.6
Mean thrust / N	0.112
Propellant mass / kg	45.963
Helium mass / kg	0.193
Tank mass / kg	6.4
Feed system mass / kg	1.061
PPU mass / kg	3.021
Thruster mass / kg	0.4
Total mass / kg	**57.038**
Total mass with 10 % margin / kg	**62.742**

Case 1

	N_2H_4 ARTUS IM dual branch
Power / W	1000
Initial pressure / bar	24
Final pressure / bar	7
Propellant volume / l	146
Mean I_{sp} / s	463.2 (431.8 – 495.8)
Mean thrust / N	0.131 (0.149 – 0.113)
Propellant mass / kg	147.447
Feed system mass / kg	0.616
PPU mass / kg	3.69
Thruster mass / kg	0.4
Total mass / kg	**152.153**
Total mass with 10 % margin / kg	**167.368**

Case 2

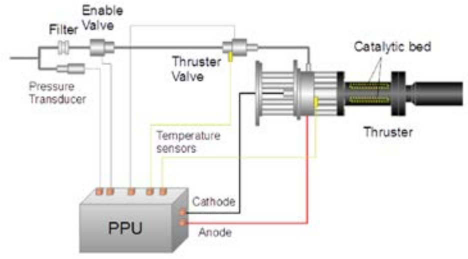
Arcjets
Critical areas and main options

Critical Areas

a) Thruster number of cycles and lifetime and performance degradation (i.e. erosion of electrodes)
b) Use of green propellant: neither ADN nor other green propellants have been tested yet. Electrode development and thruster characterization would be required to assess the use such propellants.
c) PPU development (considered as new development)
d) Flow control approach: Limit/optimize mass flow rate for optimization of Isp and maintaining the mass flow rate within the operational envelope of the thruster;

Main Options

BB25	
Propellants	1. Ammonia 2. Green Propellant (LMP-103S, green-monopropellant derived from ADN (ammonium dinitramide).
Thruster Configuration	Catalytic Bed integrated thruster



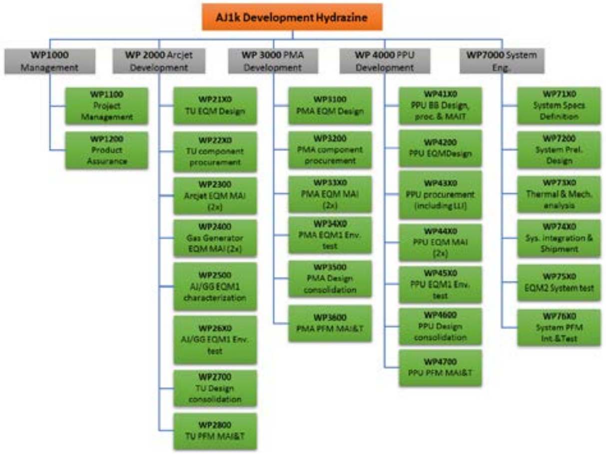
Catalytic Bed Integrated Thruster

BB 28	
Stand Alone System Architecture (case 1)	1. Hydrazine Blow Down 2. Hydrazine Flow Control 3. Hydrazine Pressure Control 4. Ammonia
Hybrid System architecture (case 2)	1. Dual Branch 2. Flow Control

Arcjets
Development plan

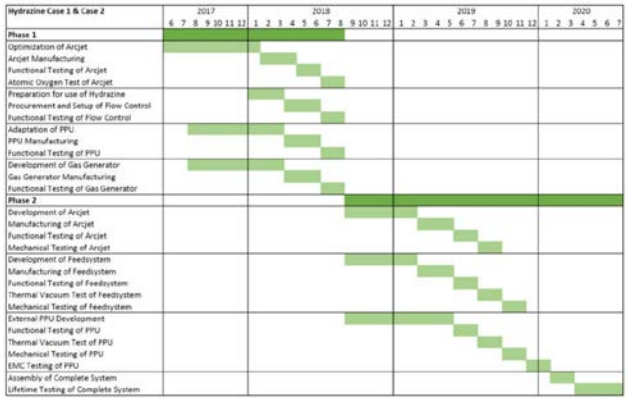
BB25

1. Consolidate Platform requirement specifications;
2. Design Definition of the propulsion system;
3. PPU breadboard definition and Manufacturing, Assembly, Integration and Test;
4. Manufacturing, Assembly, Integration and Test of the thruster unit, PPU and feeding system EQMs.
5. Review of the test campaign result and Critical Design Review (CDR);
6. Design refinement for PFM Manufacturing, Assembly, Integration and Test;
7. Integration of a Proto-Flight Model of the system;
8. Acceptance;



BB28

1. **Electrode technology development phase**: assessment of new oxygen-resistant materials such as titanium nitride or possibly promising materials that are less reactive to oxygen such as compact C-C electrodes (this phase only applies to the green propellant configuration).
2. **Bread-Boarding phase:** in which the main subsystems (PPU, arcjet, propellant feeding) will be developed on laboratory model level, where needed.
3. **Engineering Qualification Model (EQM) phase**: aiming at the advancement of the former breadboards towards flight capability. It includes EQM development and qualification tests (such as mechanical, electromagnetic compatibility, and shock testing and lifetime test).



Low power Hall Effect Thrusters (1 Building Block) Requirements overview

This BBs is aimed at the definition of a HET thruster (electric propulsion) that will contribute to orbit raising , nominal mission and deorbiting of a LEO spacecraft.

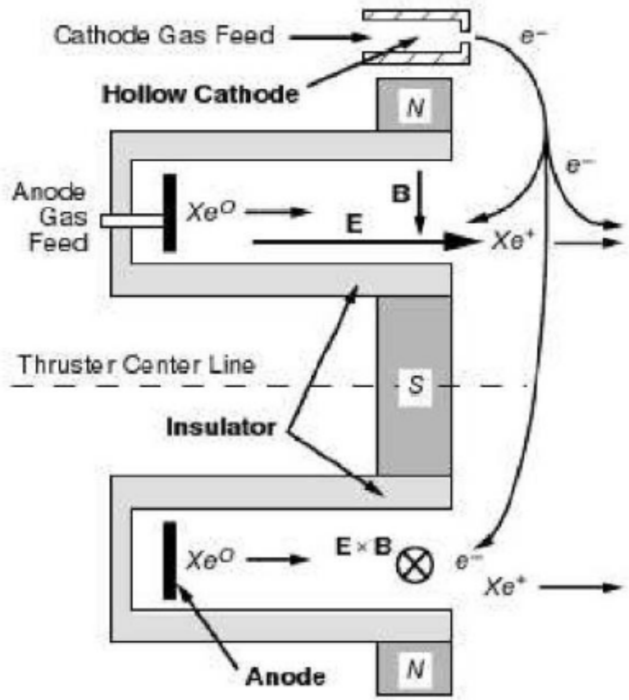
Topic	Requirement text	Compliance
Functional - Media Compatibility	Xe, Kr, GHe (leak test), GN2 (purging)	C
Performance - Specific Impulse	The thruster shall guarantee an average specific impulse over the lifetime ≥1200s	PC
Performance - Thrust	The thruster shall guarantee an average thrust over the lifetime ≥ 15mN	PC
Performance - Total Impulse	The thruster shall demonstrate a total impulse of : - at least 150kNs-200kNs (Case 1) - Orbit Raising : 400 kNs /Nominal Operation: 225 kNs/ Perigee lowering: 400 kNs (Case 2)	PC
Performance - Thruster On/Off Cycles	The thruster shall be able to be restated at least 8000 - 10000 times	TBD
Performance - Thruster Power Consumption	≤ 750 W	C

Low power Hall Effect Thrusters Baseline

Two baseline architectures are proposed:

- CASE1 (*500kg all-electric platform: orbit raising, nominal mission and EoL disposal for un-controlled re-entry*)
  - Use of two MSHT100 thrusters (N+1 configuration at thruster level), each equipped with two HC1 hollow cathodes (N+1 at component level).
  - Xenon selected as propellant
  - Use of a redundant proportional pressure regulator and a fully-redundant Power Processing Unit (PPU).
  - Subsystem mass expected to be around 18 kg without the tank for a total wet mass
  - Overall power consumption is estimated to be around 420 W.

- CASE2 (*1500kg hybrid platform: electric obit raising, nominal mission and deorbiting; chemical final burst for controlled re-entry*)
  - Use of three HT400 thrusters (2N+1 configuration at thruster level), each equipped with two HC3 cathodes (N+1 at component level).
  - Xenon selected as propellant
  - Use of a redundant proportional pressure regulator and a fully-redundant PPU.
  - Subsystem mass is expected to be around 27 kg without the tank
  - Overall power consumption is estimated to be around 970 W.



HET working principle

MSHT100 coupled with HC1

Low power Hall Effect Thrusters
Compliance and system impacts

- Thruster performances at EOL have to be demonstrated
  - Average specific impulse
  - Average thrust

➔Risk = limitation of the mission in terms of total impulse

- Capacity to perform the required number of ON/OFF cycles is not demonstrated

➔ Development risk

Low power Hall Effect Thrusters
Critical areas and main options

Critical areas:

- Proposed products are promising, but limited on-ground validation

➔High technical and programmatic risks

Low power Hall Effect Thrusters
Development plan

<u>MSHT100 development plan</u>:

- Roadmap
  - Design consolidation
  - Manufacturing of two EM thrusters with the aim of performing
    - Extended endurance test (total impulse)
    - Environmental (thermo-structural) tests in parallel
  - Upon successful conclusion of these two parallel test campaigns, design of an MSHT100 QM to move to a full on-ground thruster qualification test campaign.
  - In addition, a HC1 cathode is submitted to cycle lifetest in advance of the PDR (at least 2000 cycles).

<u>MSHT400 development plan</u>:

  - Initial phase devoted to the design, manufacturing and test of a first engineering model (TRL 5)
  - Second phase that is instead focused on the propulsion system as a whole, including PPU, PMA, a 3A Hollow Cathode, a thruster EQM
- Schedule
  - 9 months typically up to an EM for the initial phase

Drag augmentation sails
Requirements overview

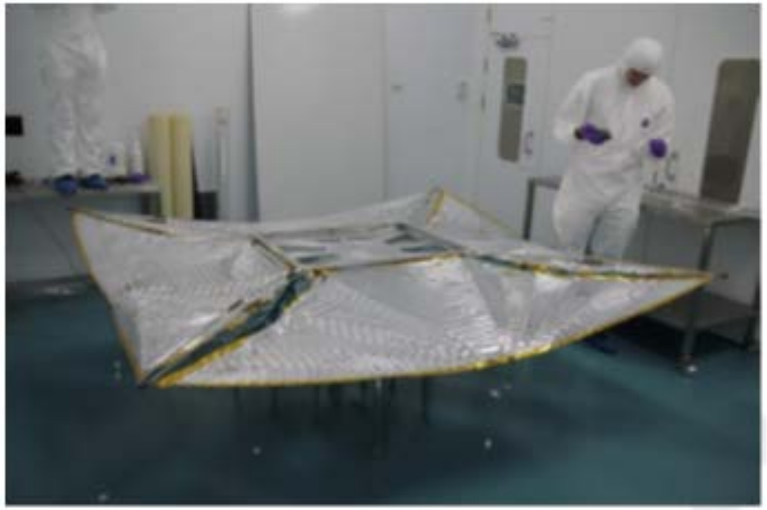
This BB is aimed at the definition of a drag augmentation device to ensure deorbiting in less than 25 years. It is designed for LEO missions with uncontrolled re-entry.

Topic	Requirement text	Compliance
Mass	The device mass shall be inferior to 5 kg as a goal, 10 kg as a maximum.	C
Volume - Dimensions	The volume of the undeployed device shall not exceed 10 liters.	C
Functional	The device shall be triggered through ground TC.	C
Performance	The device performances shall be ensured for orbits up to 850km altitude, with any orbit inclination.	PC
Performance	Once deployed, the device shall ensure a satellite uncontrolled re-entry in less than 25 years	PC
Lifetime On-Ground	10 years ground storage.	NC
Lifetime In-Orbit	The device shall be able to operate successfully after an operational host satellite period of 10 years in LEO.	NC
Environment - ATOX	The deployed device shall be compatible with atomic oxygen environment (worst-case of de-orbit from 600 km, 25 year re-entry time).	PC

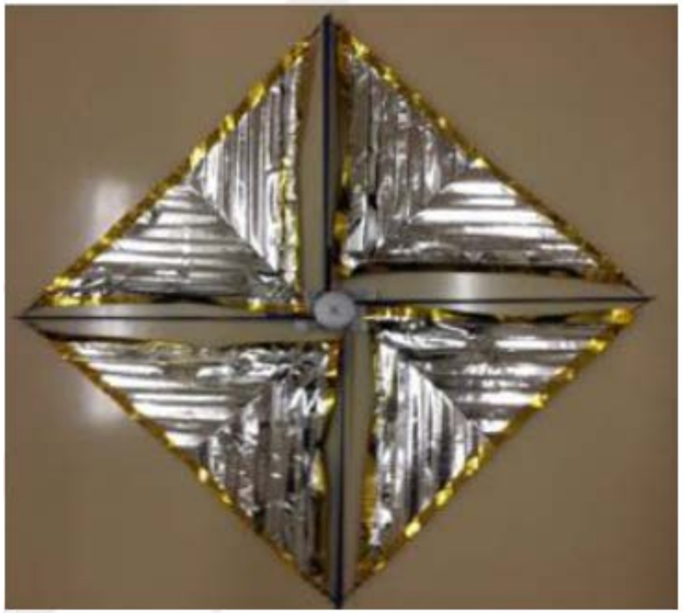
Drag augmentation sails
Baseline BB13

Several designs have been considered by Cranfield University:

- Icarus concept: Rectangular frame around panel edge
- DOM (De-Orbit Mechanism) concept: 4 coiled tape spring booms & sails housed within compact box
- DOM evolution concept: 1-3 sail segments (2-4 booms), potentially deploys out of panel plane, sail edges can be rounded to increase area ➔ **selected baseline**
- Hybrid concept: DOM-type booms and separate sail cartridges



Icarus



DOM

Drag augmentation sails
Compliance and system impacts

Compliance status:

- Proposed design has a limitation in terms of deployed surface (random tumbling considered)
  - ➔ 25-year constraint only achievable for altitudes < 700 km
  - ➔ Solution adapted for small satellites

- Compliance of current designs with 10 years on-ground storage and 10 years in-orbit not demonstrated
  - ➔ Risk of deployment issues

- Marginal compliance w.r.t. ATOX environment for long deorbit times from low altitudes

Drag augmentation sails
Critical areas and main options

Critical areas:

- Demonstration of sail deployment capability after 10 years of ground storage and 10 years in orbit

- Performance not sufficient to fulfil LSIs mission needs (satellite size and orbit altitude)

Main options:

- Development of the hybrid design:
  - Combines aspects of the Icarus and the DOM devices to reduce the limitations of the respective individual devices and improve scalability, adaptability and manufacturability.
  - Design composed of discrete self-contained modules, which can be integrated in a variety of configurations to adapt to different host satellite architectures

Drag augmentation sails
Development plan

- Roadmap
  - Development of the hybrid concept
  - Assessment of non-pyrotechnic actuators to replace the current cable cutters
  - Storage lifetime (pre-launch):
  - Storage lifetime (on-orbit)
  - Deployed lifetime (e.g. atomic oxygen erosion, micrometeoroid damage, debris impacts, thermal cycling)

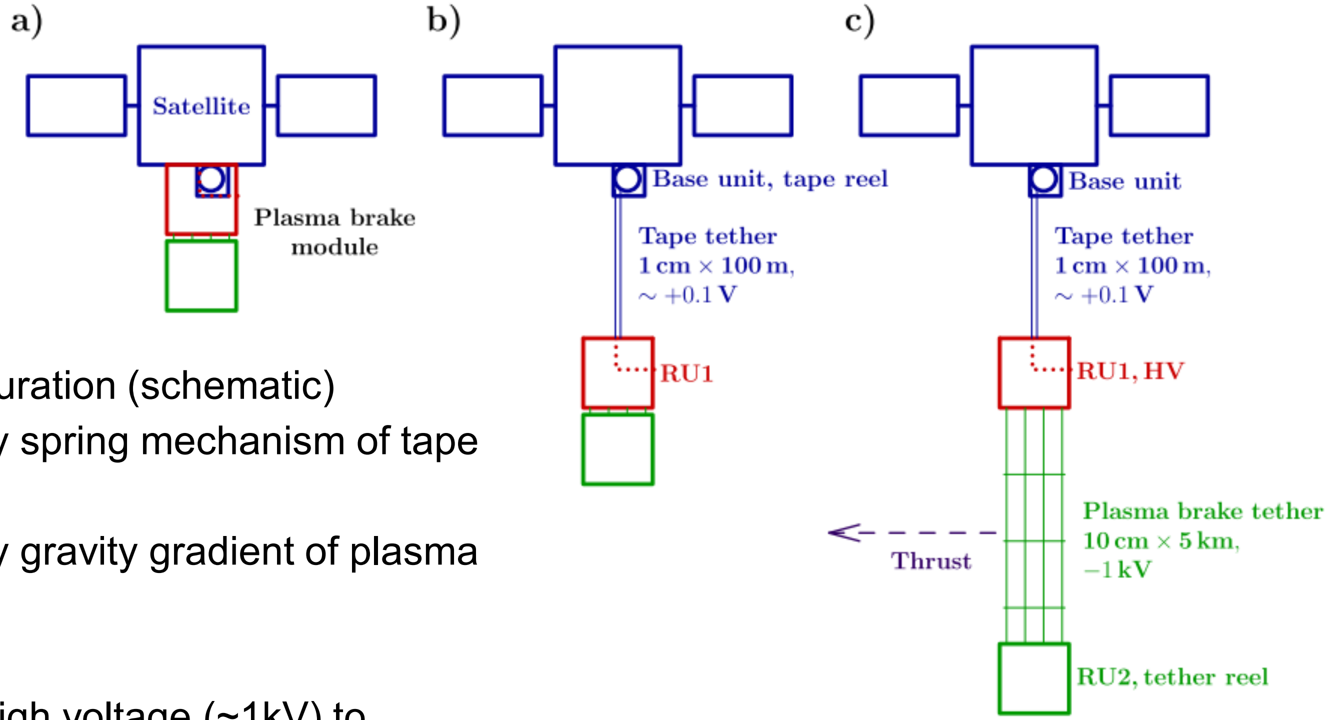
Electro-static tether
Requirements overview

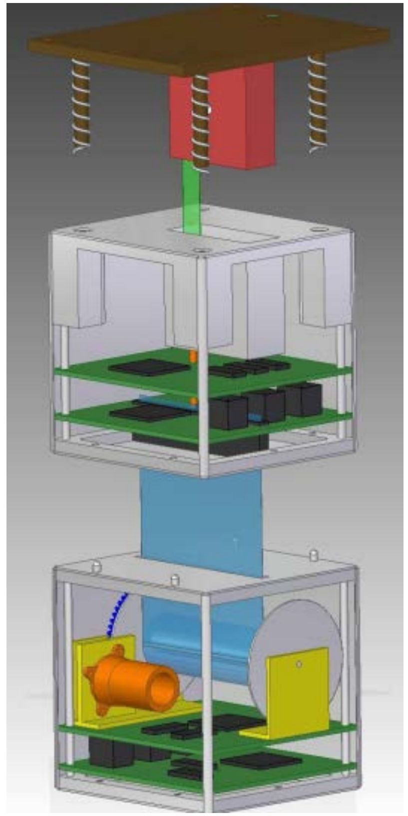
The BB aims at the development of a tether charged electrically to create a drag force accelerating the orbital decay to a value compliant with SDM requirements.

BB15	Requirement Text	SOC
Mass	Mass lower than 5 kg	C
Volume	Volume smaller than 6U-cubesat	C
Power	No resources (e.g. power) required from spacecraft during disposal phase	C
Performance	Deorbit performance (i.e. ensure reentry within <25 years): •200kg from 850km orbit (required) •800kg from 850km orbit (goal) •200kg from 1200km orbit (performance to be analysed)	C
Reliability	Reliability of operations >0.95	PC
Safety	Safety against premature deployment <1E-3	PC

Electro-static tether

Baseline





a) Stowed configuration (schematic)
b) Deployment by spring mechanism of tape tether
c) Deployment by gravity gradient of plasma bake tether

- RU1 creates high voltage (~1kV) to accelerate high atmosphere ions
- Negligible current means almost no power required (<1W)
- Total mass of 2U device is ~2kg
- Two devices can deorbit an 800kg satellite from 850km in 5.5 years !

Electro-static tether
Compliance and system impacts

- No major system impacts
  - Nickel as tether material might lead to magnetic cleanliness limitations
  - ACS needs to counteract any torque exerted through spring deployment
- Power only required during deployment
  - Thermal knife current
  - Cycle counter for tape tether reel
  - Brake of tape tether reel
- Satellite can be passivated after deployment

Electro-static tether
Critical areas and main options

- Tether material trade-off based on ATOX resistance, mechanical strength, electric conductivity and manufacturability:
  - Baseline material aluminium
  - Gold is feasible alternative (more expensive but within cost requirements)
- Power supply ensured by body mounted solar cells
- No battery included so no operation during eclipse
  - Trade-off showed no benefits of this option
- Tether deployment is a critical part of the operation
  - To be designed, simulated and tested carefully
- Tether dynamics in deployed configuration were analysed
  - Can be steered through mass ratios between RUs and thether mechanical properties
- Danger of deployed tether to other spacecraft was assessed and concluded to be very small (only surface scratches)
- Risk of thether rupture due to MMOD impacts
  - Single device 5.6% over 11 years
  - Two devices 1.9% over 5.5 years

Electro-static tether
Development plan

- Currently overall TRL 2-3 (depending on tether material)
- Aalto-1 satellite (3U-cubesat) carrying 100m aluminum tether to be launched in Q1/2017

	Activity	Target	k€
WP1	Development of generic low-cost tether manufacturing technology which can be applied to at least aluminium or nickel and preferably other metals.	TRL 3	200
WP2	Prototyping of tape tether and its opening mechanism (spring, brake, study of tape perforation option).	TRL 3	30
WP3	Production of several sample tethers and demonstration that they deploy correctly.	TRL 4	150
WP4	Build TRL 5 plasma brake module model and perform standard TRL 5 environmental testing for it.	TRL 5	300
	Total to reach TRL 5		*680*
WP5	Option A: Test mission where plasma brake module is deployed from a satellite, operated for a while and then released while continuing to deorbit itself. Option B: Self-contained 3-U cubesat test mission where 2-U part is the plasma brake module and 1-U part is the satellite.	TRL 7	2000 600
	Total to reach TRL 7: Option A *Option B*		*2680* *1280*

Solid Rocket Motors (2BBs)
Requirement overview

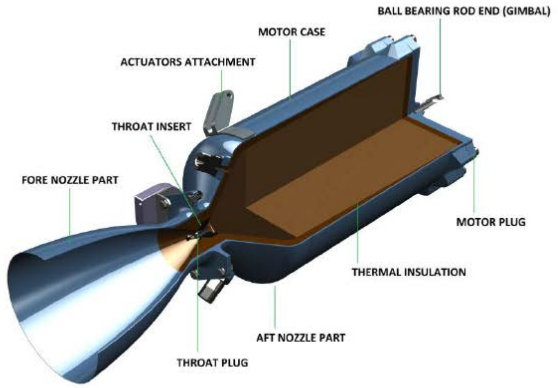
The BBs are aimed at the definition of a Solid Rocket Motor (SRM) to provide decommissioning of the host platform by controlled re-entry.

Topic	Driving Harmonized Requirements	BB17	BB20
Mass	The solid propellant system Dry mass shall not exceed 25% of the wet mass. With 10% as goal.	NC	C
Dimensions	Outer diameter smaller than 850 mm (for the whole cluster) Maximum nozzle length 300 mm (outside of S/C).	C	C
Isp	Isp delivered (vacuum)> 280s	NC	NC
Maximum acceleration	Maximum acceleration level of 0.04 g* (*It was originally desired to use a level of 0.02g).	C	C
Target S/C	• S/C 750 kg with 0.04 g max acceleration • S/C 2.000 kg with 0.04 g max acceleration • S/C <150 kg with >1 g max acceleration	C	C
DeltaV	DeltaV = 200 m/s; 100 m/s; 50 m/s	C	C
TVC	Thrust vector direction accuracy lower than 0.1° TVC method considered, default angle range wider than ±5°	C	C
Stiffness	Any first mod of the natural frequency should be above 120Hz	C	C
Power	Default power input voltage 28V (unregulated). Minimized power consumption	C	TBC
Ignition system	Single point failure redundancy (two-command line for the ignition). Safe & Arm device included	C	C
Thermal environment	Nominal thermal control inside the S/C (-20/+60°C, 15 cycles/day) In case of S/C failure down to -60°C (two events of 2 weeks each).	C	TBC
Reliability	Higher than 0.95 for the whole cluster (with maximum 8 SRMs), using ECSS safety factors	TBC	C
Debris generation	No debris larger than 1mm in diameter are allowed.	C	C

Solid Rocket Motors
Baseline

BB17

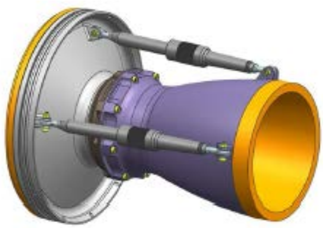
- SRM maximum thrust 588 N, total propellant mass 44 kg and 3 SRMs in cluster. Total cluster mass 58 kg.
- Propellant composition AP-HTPB-Oxamide (4% Oxamide as preliminary theoretically estimation.
- Frame concept as mouthing interface since it allows for an easy adaptation for (any) TVC system and offering the most standard solution in terms of volume for different classes of SC platforms.
- Gimbal TVC, to enable 5 degrees of adjustment during operation. The control of the SRM thrust direction is provided by two identical electromechanical actuators.

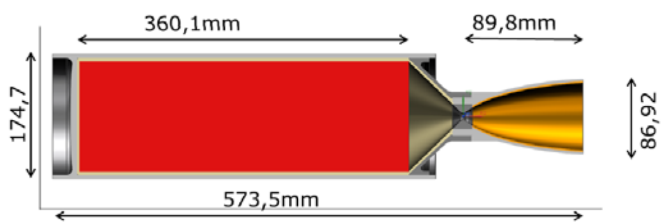


Mounting Interface and TVC (left) and SRM Baseline Overview (right)

BB20

- Maximum burn time not exceeding 120 sec;
- Propellant candidate (slow burning):
  - Density = 1.706 g/cm3;
  - Isp, vac (e = 75) = 2813 m/s = 286.7 s;
  - Burn rate = 3.0 mm/s (@ 2.0 MPa);
  - Nozzle efficiency = 0.96;
- Burn rate 3 mm/s;
- Propellant mass 13,1 kg;
- Throat diameter 10,04 mm;
- Thrust level 294,3 N;
- SRM mass 16,4 kg;
- Motor structure is assumed to be an aluminum tube
- TVC a solution based on a moveable nozzle.



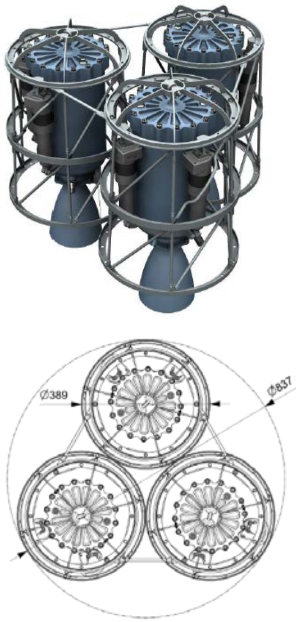


TVC (left) and SRM Baseline Overview (right)

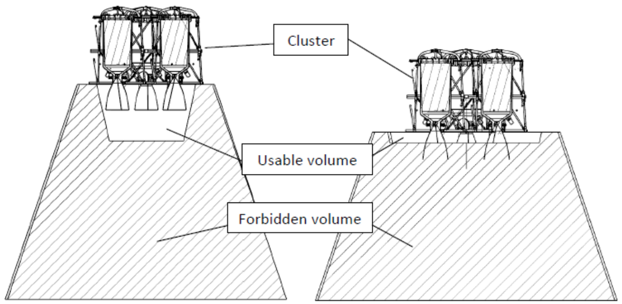
Solid Rocket Motors
System impacts

BB17

- TVC capability possibility motor axis direction adjustment (±2°) during integration with the S/C (critical in terms of SRM-TVC-S/C interfaces and has a strong impact on the mass budget).
- S/C Launcher Integration Impact (the SRM's nozzles that stick out of the S/C's envelope);



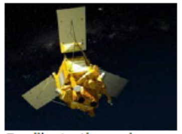
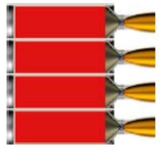
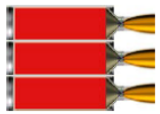
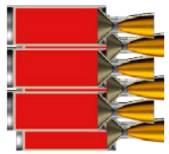
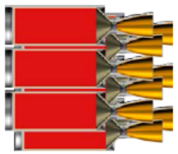
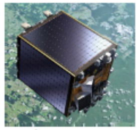
Three Thrusters Envelope



VG Usable Volume with Cluster:

- **(Right) PLA 937 VG is fully Compatible**
- **(Left) PLA 1194 VG Incompatibility**

BB20

Space craft	ΔV≈50m/s	ΔV≈100m/s	ΔV≈200m/s
Medium size S/C mass ≈750kg  For illustration only Minimum no. of SRM required Accumulated motor mass* Acceleration sequential burns Acceleration burn in pairs	1 baseline motor  1.0x baseline motor 16,4kg a≈0,04g -	2 baseline motors  2.0x baseline motor 32,8kg a≈0,04g a≈0,08g	4 baseline motors  4.0x baseline motor 65,6kg a≈0,04g a≈0,08g
Large size S/C mass ≈2000kg  For illustration only Minimum no. of SRM required Accumulated motor mass* Acceleration sequential burns Acceleration burn in pairs Acceleration burn in triples	3 baseline motors  2.7x baseline motor 49,2kg a≈0,015g a≈0,03g a≈0,045g	6 baseline motors  5.4x baseline motor 98,4kg a≈0,015g a≈0,03g a≈0,045g	9 baseline motors  8,1x baseline motor 147,6kg a≈0,015g a≈0,03g a≈0,045g
Small size S/C mass ≈145kg  Proba-V Accumulated motor mass* Total motor mass Acceleration single burn	Not practical based on Baseline Motor - - -	Not practical based on Baseline Motor - - -	1 baseline motor (shortened)  0,8x baseline motor 12,4kg a≈0,3g

Solid Rocket Motors
Critical areas

BB17/BB20

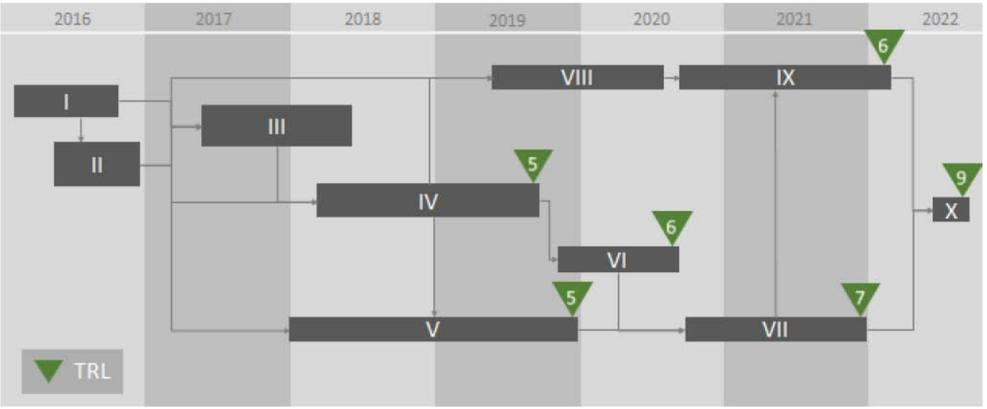
- System impact is very dependent on the S/C envelope and accommodation.
- Maximum acceleration limits (acceleration levels are limited to 0.04 g or lower) due to S/C appendances (i.e. Solar Array Wings and S/C Payloads) imply using large quantities of SRM.
- SRM thermal insulation: high insulation mass.
- SRM long burn durations: max. burn time of 120 seconds (or very long burn times)
- Thruster max envelope and allocation within the S/C;
- Limit the emission of solid particles generated;

- Possible non-compliances with demisability requirements for structural components (e.g. nozzle (mainly due to material and dimensions), throat insert (mainly due to material and surrounding elements) and initiators (mainly due to material)).

- Rough estimations indicate the acceleration level of at least 0.1 g allows to lower dry mass fraction below 25%. Therefore, one of the most promising applications of the SRM should be for small satellites, where acceleration limits are not so strict and shorter burn times are acceptable. In that case the mass ratio of SRM will be better due to the lower mass of required thermal insulation.

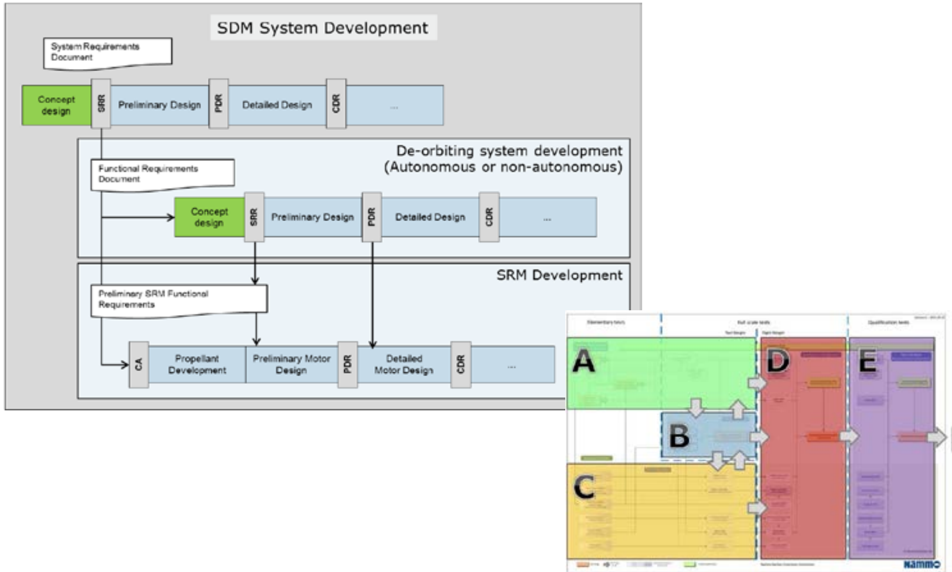
Solid Rocket Motors Development plan

BB17



I. Internal research in Poland (past)
II. CleanSat ”SRM for Deorbitation” (current)
III. Pre-Qualification of Aluminum-free Solid Propellant (announcent),
IV. SRM Engineering Model (EM) Development,
V. TVC design & test,
VI. SRM Qualification Model Development,
VII. SRM Flight Model Development,
VIII. Phase A Design of autonomous de-orbit system
IX. Autonomous de-orbit system development
X. In-orbit demonstration

BB20



A. Propellant formulation and grain configuration, igniter design ù
B. Initial test firings for ballistic verification and to obtain input to the detailed design of the sub-systems
C. Sub-system development tests
D. Development testing
E. Qualification testing
F. Flight Models manufacturing

Autonomous De-orbit System
Requirement overview

The BBs are aimed at the definition of a preliminary architecture of a De-commissioning System (DS) to be installed on spacecraft and used in case of loss of the S/C.

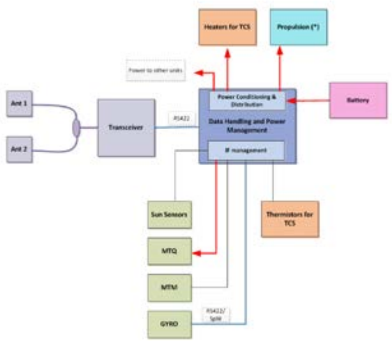
Topic	Driving Harmonized Requirements	BB16	BB14
Activation	Two independent command line shall be implemented to activate autonomous de-orbit start.	C	C
Check point before each firing	Satellite operator has to have the control on the system and is in charge of operating the deorbit system.	C	C
Functional - S/C AVS dependent Configurations	The system should be fully autonomous.	C	C
Functional - Unit Activation Redundancy	Decommissioning Operation shall be activated by a (at the least) triple command redundancy mechanism from ground.	C	C
Maximum acceleration	Maximum thrust shall be define so that Sentinel-1 S/C acceleration is <0.2 m/s2 at any firing.	C	C
Electrical Interfaces	The Device shall be compliant with MIL-1553-STD Bus and 28V Regulated and unregulated Power Bus.	C	C
Power Demand	The power required by the autonomous deorbit trigger from the host spacecraft throughout the nominal mission shall be lower than 0.1 W (TBC).	PC	NC
Power Supply	The decommissioning system shall have a power supply independent of the host spacecraft for the operation.	C	C
Operation max tumbling	The max tumbling rate at the beginning of the operations shall be 1.5 [deg/s].	C	C
Reliability	90% overall reliability at system level shall be demonstrated at end of life.	N/A	C

Autonomous De-orbit System Baseline

BB16

Host S/C class	Target Re-entry Strategy	Proposed Solution
Proba-V: 145 kg (EoL) SSO 820 km	Un-controlled de-orbiting;	Solid Propulsion de-orbit System (400N);
Sentinel: 2000 kg (EoL) SSO 700 km	Controlled deorbiting (to perigee 40 Km);	Liquid Propulsion Deorbit System;

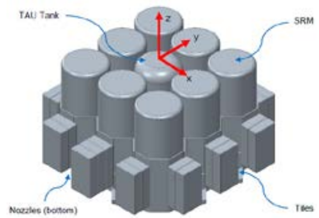
- The system baseline is autonomous from the host S/C and ground controlled and commanded.
- It is mainly composed by:
  - a) S-band (antennas and transceiver);
  - b) Data Handling and Power Distribution unit;
  - c) Primary Battery;
  - d) AOCS sensors (sun sensors, magnetometer, gyro) and actuators (magnetorquers);
  - e) Thermistor and heaters for Thermal Control System;
  - f) Propulsion subsystem;
  - g) RF Cables and DC harness;

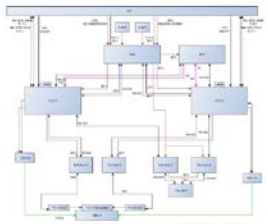


BB14

Host S/C class	Target Re-entry Strategy	Proposed Solution
MetOp: 4000 kg (EoL) SSO 820 km	Un-controlled de-orbiting	Solid Propellant: Cluster 4 x SRMs
Sentinel: 2000 kg (EoL) SSO 700 km	Controlled deorbiting (to perigee 40 Km);	Solid Propellant Cluster 8 x SRMs

- The system baseline is autonomous from the host S/C and ground controlled and commanded.
- The system baseline is mainly composed by:
  - a) S-band (antennas and transceiver);
  - b) Primary Battery;
  - c) TVC subsystem;
  - d) Attitude control performed with Nitrogen Cold Gas propulsion;
  - e) Sensors: Sun sensor + magnetometers + gyroscopes + GPS;





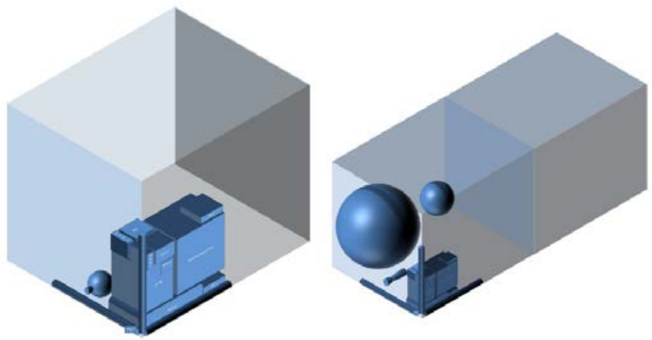
Autonomous De-orbit System
System impacts

BB16

Host S/C	Wet Mass [kg]
Proba-V (uncontrolled re-entry)	~50
Sentinel (controlled re-entry)	~300

Interactions between the IDT and the host S/C are related to physical design but also to the nominal development and test activities to achieve flight readiness.

a) Design impacts on the host Spacecraft (allocation, configuration, main dimensioning budgets and analyses (e.g. link, mass, power and thermal budgets).
b) Integration and tests of IDT on the host spacecraft (e.g. functional and environmental test);

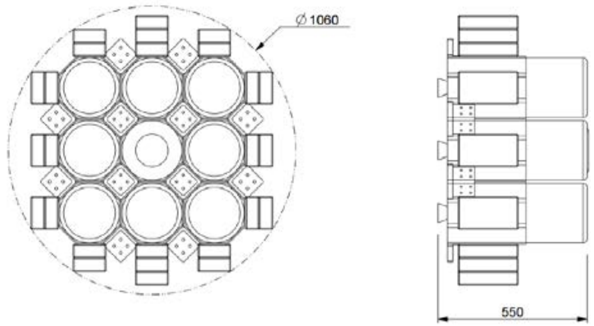


Accommodation and volumes Proba-V (left) and Sentinel (right)

BB14

Host S/C	Wet Mass [kg]
Metop (uncontrolled re-entry)	~740
Sentinel (controlled re-entry)	~380

Case Study	SRM	Total Mass [kg]	Envelope [mm]	Reliability EoL
Sentinel-class	8 x S50	< 380 kg	Ø1060x550 mm	> 0.979
MetOp-class	4 x S200	< 740 kg	Ø1055x1205 mm	> 0.979



Proposed Accommodation for Sentinel Class S/C

Autonomous De-orbit System
Critical areas and main options

BB16

The system delayed 'activation' (the system is dormant for years before it mission start); the identified potential risks are related to:

a) Primary battery (primary battery not only for the ageing and degradation EOL but also for the de-passivation mechanisms);
b) Solid propellant (for solid propellant systems);
c) Latch valves (for liquid propellant systems);
d) Pyro-igniters;

Main point to be investigate to reduce mass, complexity and impacts of the system:

a) Re-using the commonalities between host platform and IDT
b) Re-use of units/electronics from similar mission (e.g. Philae, Hayabusa)
c) Use FPGA based system instead of a computer based system;

BB14

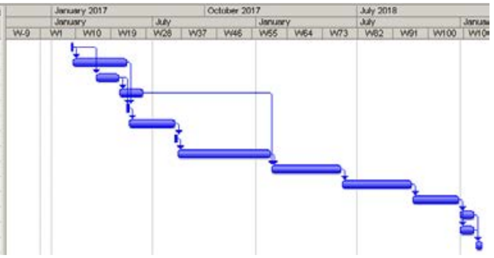
- Autonomous solution requires doubling many of S/C S/Ss (i.e. avionics, TTC, power etc.)
- Acceleration Limits due to SC appendances (i.e. Solar Array Wings and S/C Payloads);
- Thrusters envelope and allocation;
- SRM internal thermal insulation;
- SRM long burn durations;
- Limit the emission of solid particles generated

Autonomous De-orbit System Development plan

BB16

- Standard ECSS development plan is considered;
  - Delta or full qualification programme for Off-the-shelf product with modifications;
  - Full qualification programme for newly designed and developed product;
- No launch campaign activities are taken into account;
- No environmental test at satellite level are taken into account;
- Overall project development is ~24 months for a miniplatform.

	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1	Kick Off	1 day	Mon 06/02/17	Mon 06/02/17		
2	Preliminary Design preparation	70 days	Tue 07/02/17	Mon 15/05/17	1	
3	EGSR preparation/colocation/closeout	30 days	Tue 21/03/17	Mon 01/05/17	1FS+30 days	
4	LLI procurement	30 days	Tue 02/05/17	Mon 12/06/17	3	
5	System PDR	2 days	Tue 16/05/17	Wed 17/05/17	2;3	
6	System CDR preparation	60 days	Thu 18/05/17	Wed 09/08/17	5	
7	System CDR	2 days	Thu 10/08/17	Fri 11/08/17	6	
8	Procurement of units for ATB	120 days	Mon 14/08/17	Fri 26/01/18	7	
9	Avionics Test Bench AIT	90 days	Mon 29/01/18	Fri 01/06/18	8;4	
10	Procurement of units for PFM	90 days	Mon 04/06/18	Fri 05/10/18	9	
11	PFM AIT (stand alone)	60 days	Mon 08/10/18	Fri 28/12/18	10	
12	PFM AIT (on host spacecraft)	20 days	Mon 31/12/18	Fri 25/01/19	11	
13	Qualification Review	20 days	Mon 31/12/18	Fri 25/01/19	11	
14	Flight readiness	10 days	Mon 28/01/19	Fri 08/02/19	12;13	



BB14

- Standard ECSS development plan is considered;
- No launch campaign activities are taken into account;
- No environmental test at satellite level are taken into account;
- Overall project development is ~24 months for a miniplatform.

		Year 1				Year 2			
Item	**Activity**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Avionics (CCU + EES + PDU + BAT)	Design								
	EQM Manufacturing and SW development								
	EQM Validation								
Propulsion (Motor + TVC)	Design and TVC Breadboarding								
	EM Manufacturing								
	EM Validation								
TAU	Design								
	EQM Manufacturing								
	EQM Validation								
System									

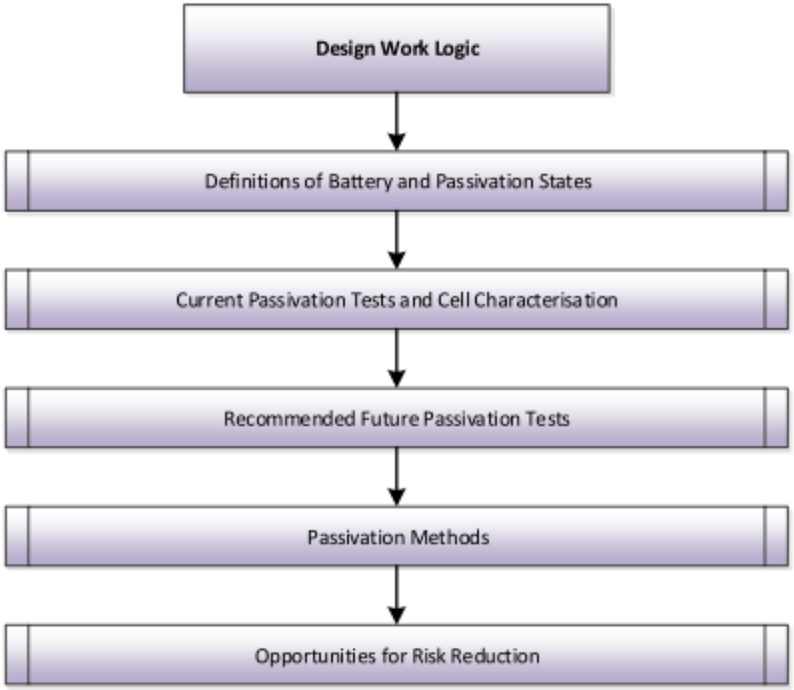
Building Blocks presentation – Passivation

- Introduction
- Battery safety
- PCDU upgrade for passivation
- Fluidic passivation valve

Battery safety
Baseline

- Existing standard qualification tests:
  - Overcharge
  - External short
  - Over discharge
    - Damage below 0.5 V
  - Vent/burst
  - Module overcharge
  - Module short-circuit

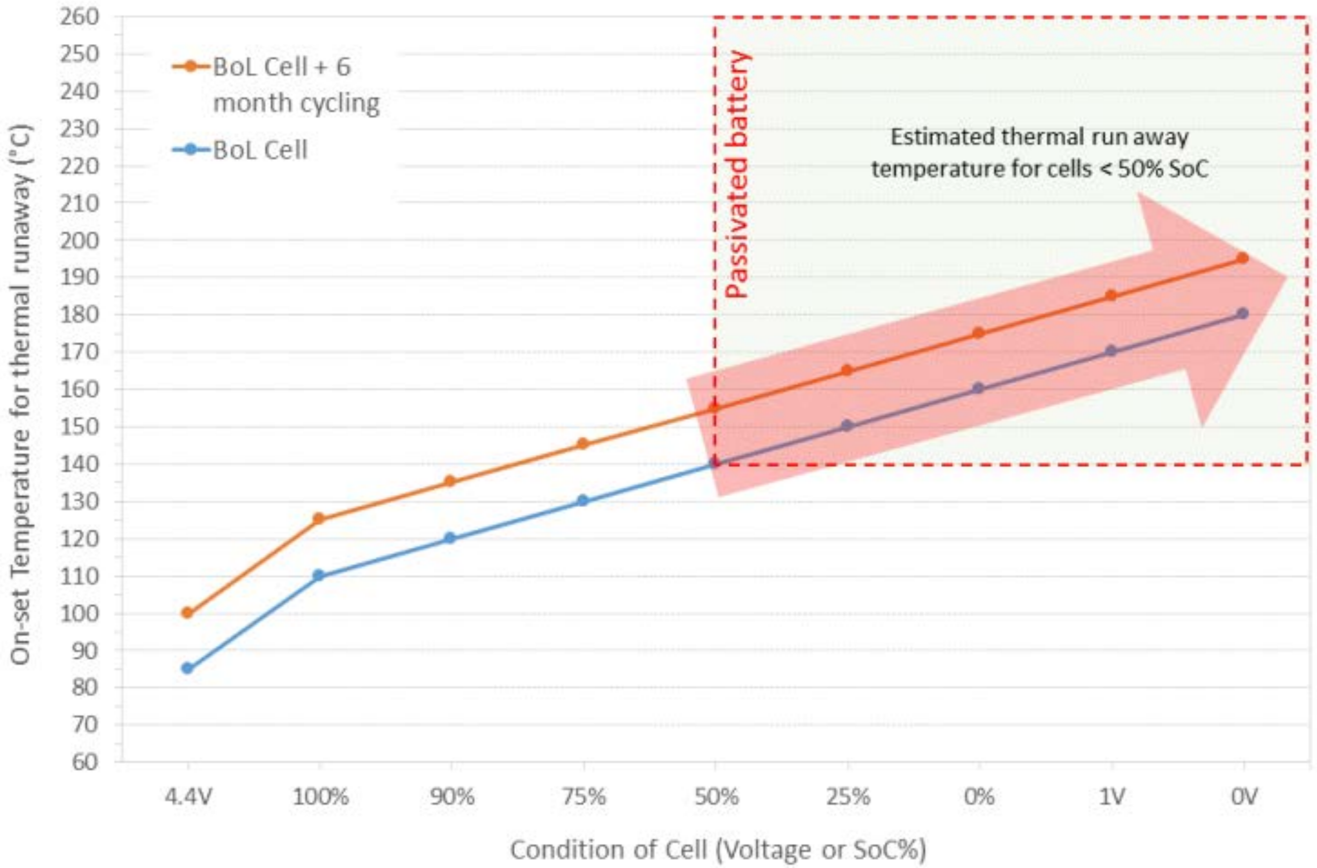
- Need to passivate the battery at end of life
  - Battery <140°C and 50% SoC would not lead to any breakage (see next slide)
- Proposed solution of passivation circuit with bleed resistors
- Overdischarge as preferred passivation method



Battery safety
Compliance and system impacts

- Mission and system design need to ensure conditions according to graph on the right
- Time to discharge needs to be designed to allow detection and reversal in case of unwanted activation

- Internal accommodation of battery can increase the robustness of passivation
  - Trade-off to be performed during satellite design

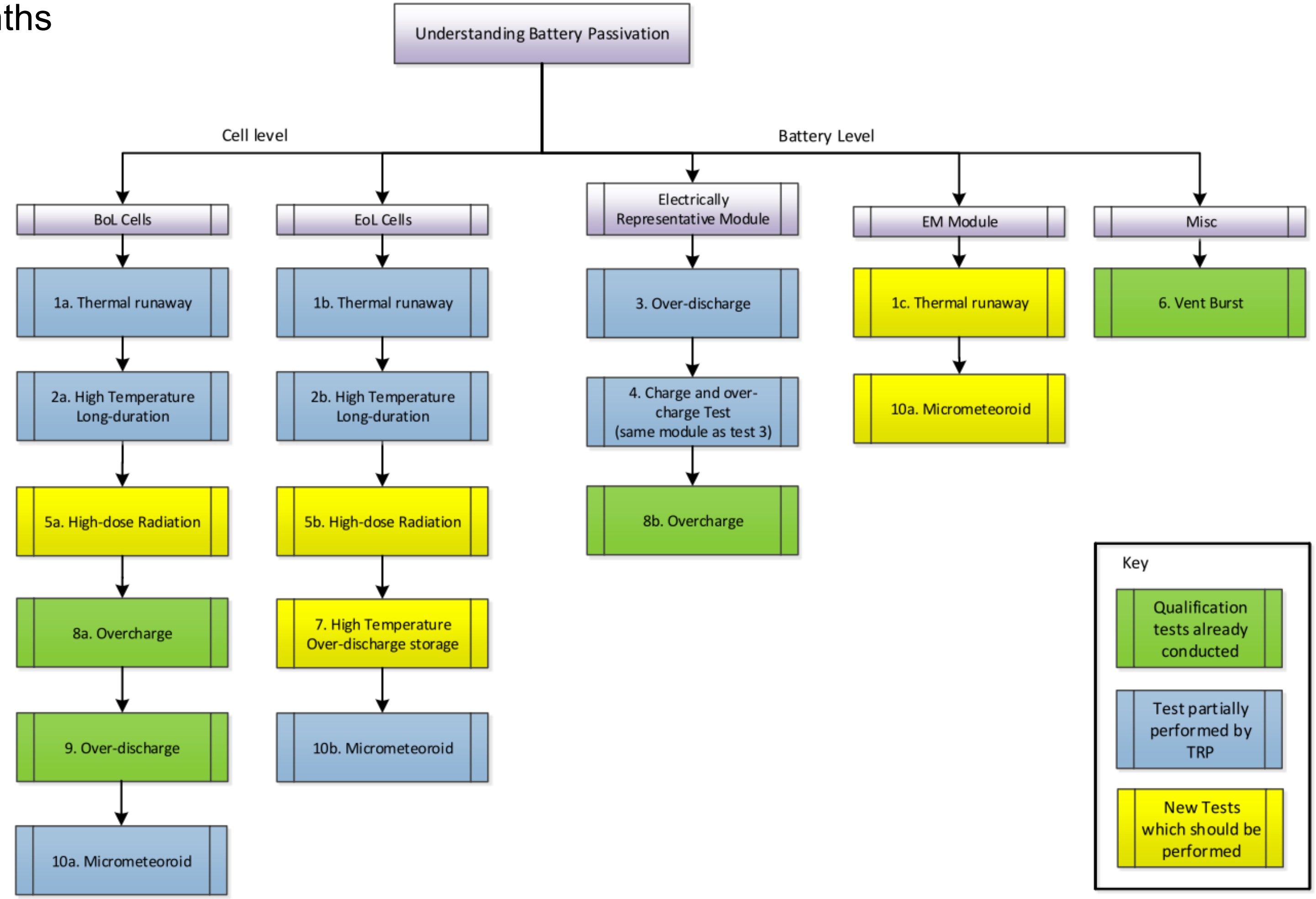


Battery safety
Critical areas and main options

- The following battery failure modes were tested or are under test
  - Overcharge
  - Overcurrent
  - Over discharge
  - Mechanical vent and bursting
  - Temperature
  - Radiation
  - Vacuum
  - Micrometeoroid and debris impact
- 4 Case studies of passivation mission scenarios
  - Small LEO
  - Standard LEO
  - Standard LEO sun-synchronous
  - Standard GEO

Battery safety
Development plan

- Foreseen tests will take ~18 months
- Increase of TRL from 5 to 7



PCDU Upgrade for Passivation
Requirement overview

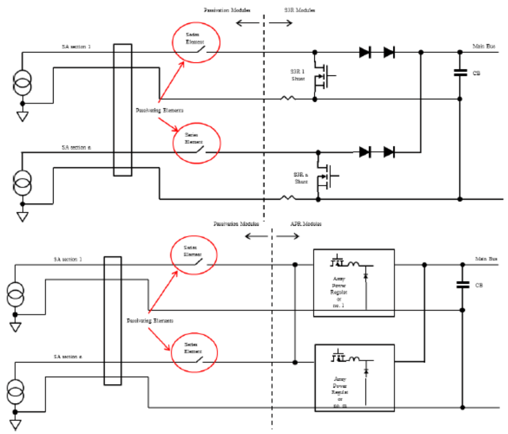
The BBs are aimed at the definition of a preliminary architecture solution for power/electric passivation, isolating the Solar Array (SA) within the Power Control and Distribution Unit (PCDU).

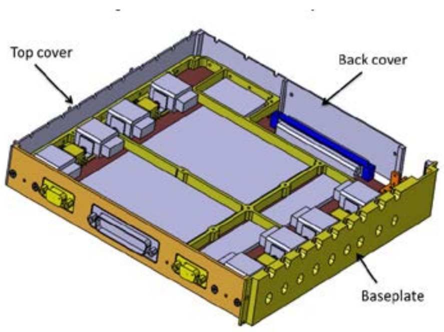
Topic	Driving Harmonized Requirements	BB22	BB27
Functional	The SA isolation function shall be applicable to both S3R and MPPT conditioning functions.	C	NC
Functional	The passivation shall be reversible upon the reception of a single command.	C	C
Functional	The SA passivation function shall be applicable to both regulated and unregulated bus architecture.	C	C
	Passivation of SA in PCDU shall be compatible with the following features before passivation: 28 V bus: • Max current (short-circuit) 9.5A per section • Number of sections 6 • Max Voltage (Open-circuit) 64V • Max power 1.5 kW 50 V bus: • Max current (short-circuit) 7A per section • Number of sections 20 • Max Voltage (Open-circuit) 125V • Max power 7kW 65 V bus: • Max current (short-circuit) 3-5A per section • Number of sections 16-24 • Max Voltage (Open-circuit) 150 V • Max power 5 kW 100 V bus: • Max current (short-circuit) 10A per section • Number of sections 16 • Max Voltage (Open-circuit) 250V (@120°C) • Max power 20 kW	C	C
Performance	The barriers which prevent against unwanted activation of SA isolation function during the operational lifetime shall be realized by at least one hardware and one software barrier.	C	C
Reliability	The reliability of activating the passivation at the end of the operational lifetime shall be at least 0.99	C	C

PCDU Upgrade for Passivation Baseline

BB22

- Passivation function embedded in PCDU.
- The proposed passivation method is based on the interruption of the Solar Array (SA) power to the spacecraft by interposition of electro-mechanical devices.
- The SA isolation is performed on each section separately, to reduce the impacts on the isolating device sizing (i.e. very big current devices necessary);
- It is applicable to both Series Switching Shunt Regulation (S3R) and Maximum Power Point Tracking (MPPT) conditioning functions.

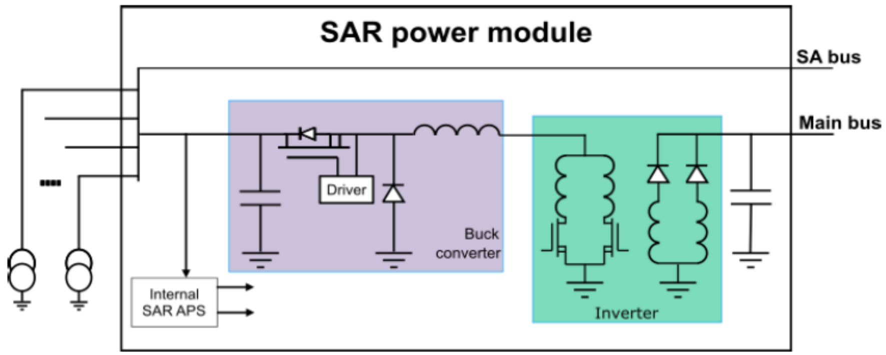




Passivation Module Layout

BB27

- Passivation function embedded in the Solar Array Power Regulator of the PCDU.
- The baseline passivation method is based on Galvanic Isolation architecture.
- The solution bases the Solar Array (SA) isolation on the introduction of a transformer in the SAR topology. SA power transfer is possible only when the converter is in switching mode and in a defined switching frequency range.



PCDU Upgrade for Passivation
System impacts

BB22

- The number of passivation modules necessary may range from 1 to 3. (Depending on the total number of SA to passivate i.e. depending mission and bus characteristics);
- The mass of a single passivating module, including the portion of the baseplate and the external (box) structure is 1,6 kg; (The final mass increase is proportional to the number of passivating modules identified as necessary);
- The increase in volume due to a single module is about 2 dm^3 .
- The max. power consumption to activate the passivation is ~10 W per module; Taken directly from Main Bus;

BB27

- The increase of complexity and mass due to the use of a transformer to provide galvanic isolation in the Solar Array Regulator (SAR) of the PCDU is to be quantified.
- The increase of mass can be estimated between 100gr and 300gr per KW of system maximum allocated power.
- Increase of size would depend on the actual PCDU design and maximum power allocated, varying from a null increase up to a 5%.

PCDU Upgrade for Passivation
Critical areas and main options

BB22

- Acceptability of the N+1 redundancy approach (1 SA section lost acceptable). If this is not true, the hot redundancy of the passivating elements is necessary. The passivating elements double.

Main Options	
Disconnection methods	SA Isolation, SA Permanent Shunt and Battery Disconnection.
Passivation Function Allocation	Passivation function embedded in PCDU or external.
Commanding	Centralized function for commanding all the sections or separately a single command to each section.

BB27

- The main drawback of the galvanic isolation as passivation solution is that it is only applicable to MPPT architectures and not to S3R architectures (for the Solar Array passivation, the galvanic isolation can be implemented only in power chains based on MPPT, where the presence of power converter permits to allocate a transformer).
- The baseline solution applicability is dependent on the platform solar array interface (MPPT) and the platform size.
- Thermal cycling: the transformer implementation shall be assessed to demonstrate the suitability for passivation.

Main Option Analyzed
(3 passivation techniques):

1. Electronic switch
2. Mechanical relays
3. Galvanic isolation

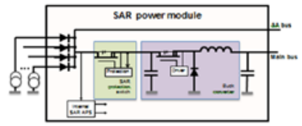


Figure 2-2: SAR with semi-conductor isolation block diagram

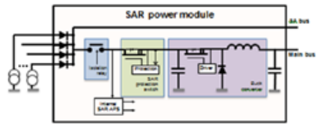
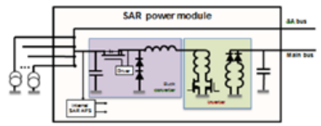


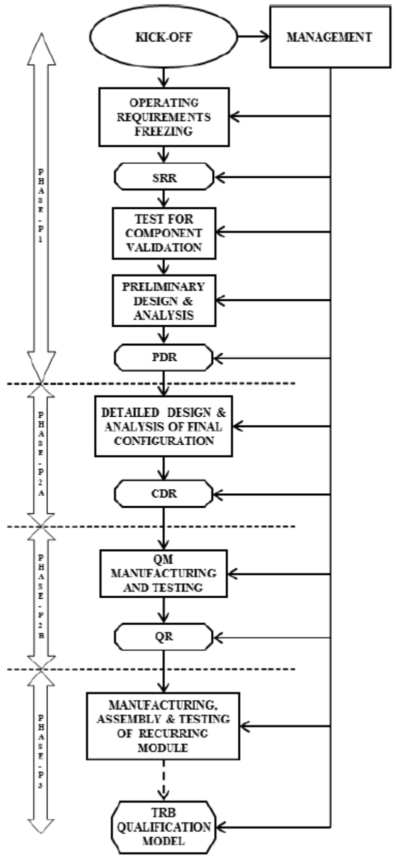
Figure 2-3: SAR with mechanical isolation block diagram



PCDU Upgrade for Passivation Development plan

BB22

- The total duration is 1.5 years;
- **Phase-1: Confirmation of the Preliminary Design (8 months)** Demonstration the validity of the proposed design concept up to preliminary design completion and verification.
- **Phase-2: Detailed Design and Qualification (10 months)**
  - a) Phase P2A – Detailed design up to the Qualification Model definition up to MRR.
  - b) Phase P2B – Qualification Achievement, including manufacturing, assembly and qualification testing of the Qualification Model.
- Further **Phase-3**: Product Master Plan, expected to achieve TRL8 (flight hardware).
- **Reasonable Roadmap.**
- **Preliminary TRL2/3 declared and expected to reach TRL5/6 in 2020.**



BB27

- **Phase-1: Architecture and Technology Consolidation**. Technological consolidation of the selected passivation technique and selection of converter topology to implement the passivation solution.
- **Phase-2: Electrical Bread Boards Design and Development:** Design and the development of the EBB (electrical Bread-board) of a Built-in-Block Solar Array Regulator (SAR) module;

- Reasonable roadmap.
- Preliminary TRL3 declared and expected to reach TRL5 in 2020.

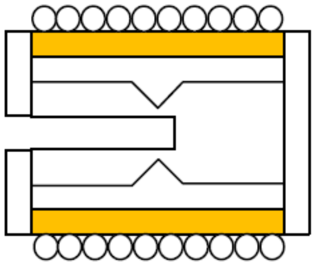
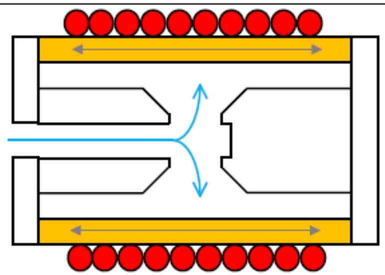
Fluidic passivation valve
Requirements overview

This BB is aimed at the fluidic passivation (propellant or pressurant) at the end of the operational mission. It is designed for LEO missions with uncontrolled re-entry and for GEO missions.

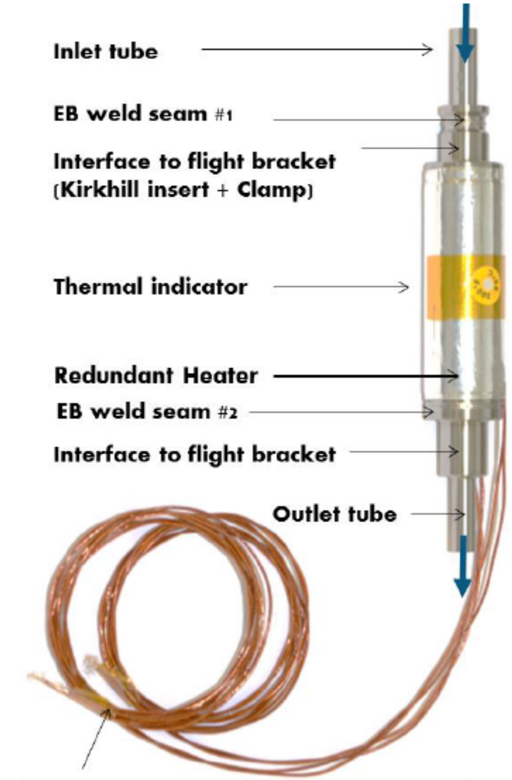
Topic	Requirement text	Compliance
Functional - Operating media	N_2H_4, MON, MMH, LMP103S/HAN/ADN, He, N_2, Xe, Kr	C (TBC for N_2H_4)
Functional - Inlet operating pressure	310 bar MEOP, Proof 1.5x, Burst 4x	C
Functional - Number of barriers	Provision of two internal safety barriers	NC
Performance - Power	< 20W (with identified impacts if targeting 10W)	C
Functional - Mass	Mass < Pyrovalve	NC
Functional - Generated shock	To be minimised and << equivalent pyro valve	NC
Reliability	> 0.99 single unit (passivation) / >.9999 for PV equivalent application	C

Fluidic passivation valve
Baseline

- Actuator based on a Shape Memory Alloy (SMA):
  - One-shot end of life venting
  - Thermally actuated device that opens by heating up above an activation temperature (typ. above 110°C)
  - Used for chemical and electrical propulsions systems (propellant and pressurant, gas and liquid).
  - Alternative to expensive and lifetime limited pyro valves

Closed / before activa-tion	Open / after activati-on
 Heater off	 Heater on

Single-actuation SMA Valve operation principle



Fluidic passivation valve
Compliance and system impacts

Some points to be further assessed:

- Two internal safety barriers: to be further analysed

  ➔Risk of an « open failure » scenario leading to a mission loss

- Mass constraint not fulfilled (bracket needed in addition to the SMA valve)

- Generated shock level is TBC

Note: added value of the design is having relatively slow heating which allows chance to reverse in case of accidental activation

Fluidic passivation valve
Critical areas and main options

- Critical areas
  - Need to prove hydrazine compatibility through testing

- Main options
  - Two additional options considered initially:
    - Design with a media separation between the hot actuator and the transported media (but additional costs)
    - Valve without a seal and screwed connection but with externally procured tube transition joints (high cost of externally procured tube transition joints that are subject to ITAR regulations)

Fluidic passivation valve
Development plan

- Roadmap
  - Stress Analysis and test of the valve and the bracket
  - Thermal design and analysis / Testing (in particular w.r.t. hydrazine compatibility but not only)
  - Configuration / Design Work
  - SCC (Stress Corrosion Cracking) Testing of SMA Material
  - Radiation testing / assessment (TBC/TBD)

- TRL
  - Initial TRL is 4/5
  - Target TRL after successful qualification is TRL 8

Presentation of LSI priorities

- LSI priorities overview (public session)
- Airbus priorities (private session)
- OHB priorities (private session)
- TAS priorities (private session)

Summary of the 3 LSI priority rankings

Ranking details will be provided by each LSI in private sessions with ESA

Building Block	Topic	ADS ranking	OHB ranking	TAS ranking
Demisable metallic propellant tanks	Demisability	High	High	High
Demisable high pressure COPV tank	Demisability	Medium	Low	High
Thermoplastic tanks for green propellant	Demisability	Low	Low	High
Demisable Optical Payloads	Demisability	High	High	High
Demisable Reaction Wheels	Demisability	Medium	High	High
Demisable Magnetorquer	Demisability	Medium	Medium	Medium
Active mechanisms for opening structural panels or breaking joints at EoL	Demisability	Medium	Medium	Medium
Early breakup structural joints	Demisability	Medium	High	High
Upgraded PCDU with SA isolation	Passivation	Low	High	High
Battery abuse conditions testing	Passivation	Low	Medium	High
SMA Fluidic passivation valve for propellants and pressurant	Passivation	High	Medium	High
Electronic pressure regulator (repressurisation module)	Deorbit systems	High	Medium	High
Low cost high thrust monopropellant engine	Deorbit systems	Low	Medium	Low
High thrust green propellant deorbit engine	Deorbit systems	Low	Low	Medium
Low power HET for small satellites	Deorbit systems	Medium	High	High
Hydrazine Arcjet	Deorbit systems	Medium	Medium	High
Ammonia Arcjet	Deorbit systems	Low	Low	Medium
Solid propellant re-entry motor	Deorbit systems	Low	Medium	Medium
Solid propulsion autonomous deorbit system	Deorbit systems	Low	Low	Low
Drag augmentation deorbit system	Deorbit systems	Low	Low	Low
Electrodynamic/electrostatic deorbit Tether	Deorbit systems	Low	Low	Low

Conclusion and next steps

Conclusion and next step

Airbus Defence and Space, OHB System and Thales Alenia Space are very glad to have participated to the challenging CleanSat Concurrent Engineering Phase.

The demanding Concurrent Engineering process has involved many actors over two years: the Agency, the 3 LSIs and 28 European suppliers.

The results are clearly positive: CleanSat phase 2 has been very fruitful to address the future Clean spacecraft technologies.

The 3 LSIs are of course very interested by participating to the next phase of the CleanSat study that will see the start of the development of selected Building Blocks.

As Large Satellite Integrators, ADS, OHB and TAS will:

- Refine their BB requirements (performances, interfaces)
- Analyze precisely the impacts of implementing such BB in their platforms
- Provide expertise on the BB design (pending visibility provided by the supplier)

Thank you
for your attention!