CleanSat Building Blocks

Technology assessment and Concurrent Engineering in support of LEO platform evolutions

Clean Space Industrial Days *ESTEC , October 24th 2017*

AIRBUS OHB ThalesAlenia Space
a Thales / Leonardo company

Summary

- Introduction to the CleanSat Concurrent Engineering Phase
- Building Blocks presentation
  - Design for Demise
  - Deorbit technologies
  - Passivation
- Presentation of LSI priorities
- Conclusion and next steps

Objectives of the CleanSat Concurrent Engineering study

- **Objectives**
  - Mature the specifications of selected Building Blocks for future LEO spacecrafts, through concurrent engineering work between ESA, the satellite integrators and the suppliers

- **Building Block (BB) selection process**
  - CleanSat BB phase 1 (requirements) done end 2014 with the 3 Large Satellite Integrators (LSI) –namely Airbus, OHB, and TAS (by alphabetical order) - to identify the most promising items and their requirements
  - Discussions between ESA and Small Satellite Integrators (SSI) to identify the SSI needs
  - In 2015, call for opportunities opened by ESA to all potential European partners
  - 50 proposal received (from equipment suppliers and also laboratories)
  - 28 relevant Building Blocks finally selected by ESA on the basis of (in decreasing order of priority):
    a) Compliance with Space Debris Mitigation requirements
    b) Compliance with new European regulations relevant to S/C design (like REACH)
    c) Increase performance and competitiveness of European platforms

- **Overall schedule** of the BB concurrent engineering phase
  - Start: September 2015
  - Completion: April 2017 with a final presentation at ESTEC

Study logic and roles

Roles

- Airbus Defence and Space (France), OHB-System (Germany), and TAS-I (Italy):
  - have cooperated within a consortium
  - have shared evenly the management of the different suppliers.

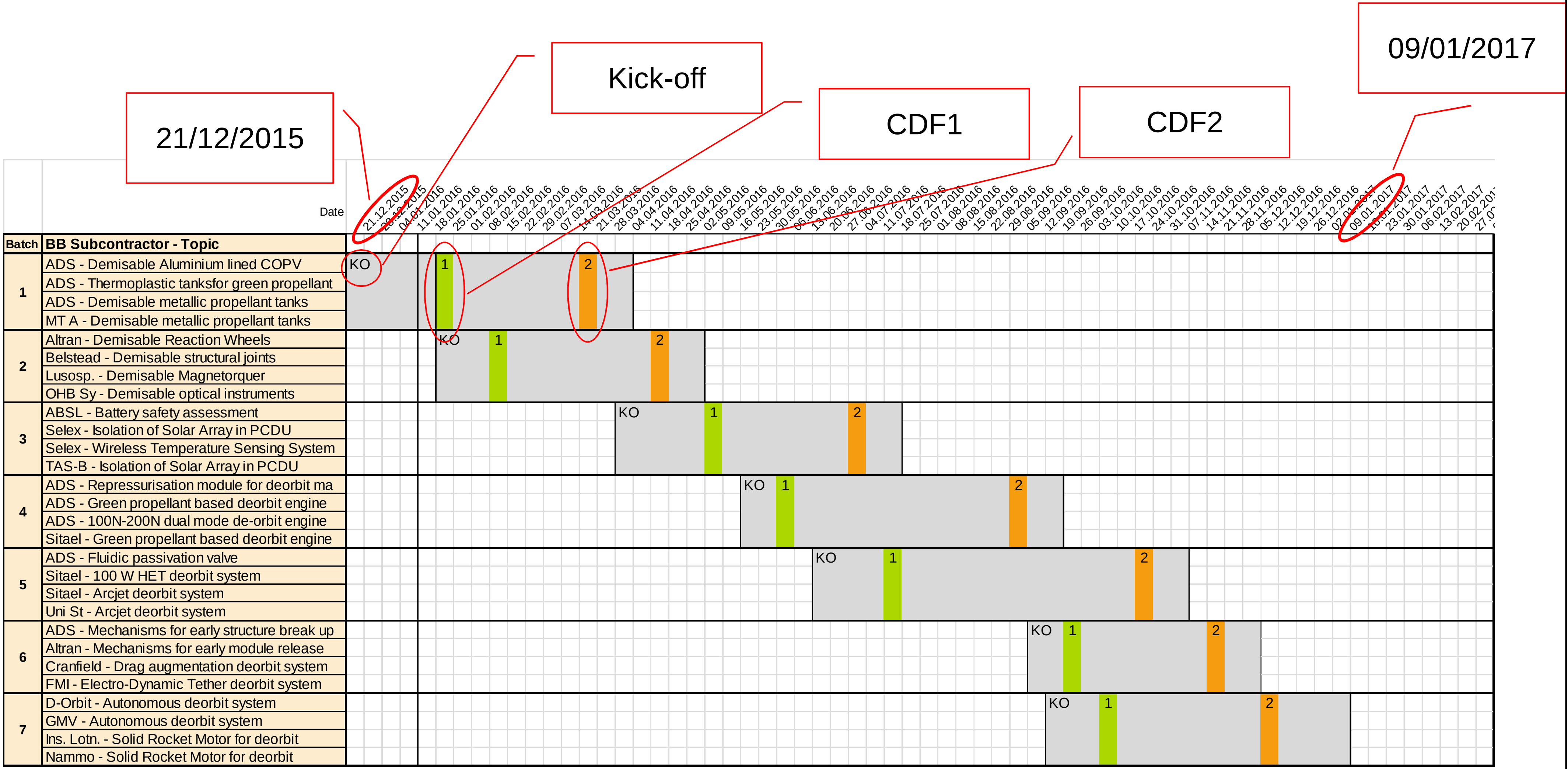
Organisation of the activity for each building block (duration typically 12 weeks):

- **Initial kick-off** (T0)
- **CDF session 1** (T0 + 2 weeks) in ESTEC premises
  - Consolidation/harmonisation of the requirements proposed independently by the 3 LSIs
  - Identification of the main trade-offs
- **Supplier's analyses** (between T0 + 2 weeks and T0 + 10 weeks):
  - Proposal of a preliminary design,
- **CDF session 2** (T0 + 10 weeks):
  - Review of the design and the roadmap proposed by the supplier
- **Final suppliers report delivery** (T0 + 12 weeks):
  - Including a consolidated preliminary design of the building block and a development roadmap.

Organisation of the 28 BBs into 7 batches

BATCH	TOPIC	BB #	BB TITLE	MANAGING LSI
1	*Tanks*	*2*	*Airbus Safran Launchers SAS - Demisable Aluminium lined COPV*	*ADS*
		3	*Airbus Safran Launchers SAS - Thermoplastic tanks for green propellant*	*ADS*
		5	*Airbus Safran Launchers GmbH - Demisable metallic propellant tanks*	*ADS*
		19	*MT Aerospace (Germany) - Demisable metallic propellant tanks*	*OHB*
2	*Demisability*	*11*	*Altran (with RCD) - Demisable Reaction Wheels*	*ADS*
		12	*Belstead - Demisable structural joints*	*OHB*
		18	*Lusospace - Demisable Magnetorquer*	*OHB*
		21	*OHB System - Demisable optical instruments*	*OHB*
3	*Electrical*	*1*	*ABSL - Battery safety assessment*	*OHB*
		22	*Selex - Isolation of Solar Array in PCDU*	*TAS*
		23	*Selex - Wireless Temperature Sensing System*	*TAS*
		27	*TAS-B - Isolation of Solar Array in PCDU*	*TAS*
4	*Chemical propulsion*	*7*	*ADS GmbH - Repressurisation module*	*OHB*
		8	*ADS GmbH - Green propellant based deorbit engine*	*ADS*
		9	*ADS GmbH - 100N-200N dual mode deorbit engine*	*ADS*
		26	*Sitael - Green propellant based deorbit engine*	*TAS*
5	*Chemical propulsion*	*4*	*ADS GmbH - Fluidic passivation valve*	*ADS*
	Electrical propulsion	*24*	*Sitael - 100 W HET deorbit system*	*ADS*
		25	*Sitael - Arcjet deorbit system*	*TAS*
		28	*University Stuttgart - Arcjet deorbit system*	*ADS*
6	*Demisability*	*6*	*ADS GmbH - Mechanisms for early structure break up*	*OHB*
		10	*Altran - Mechanisms for early module release*	*OHB*
	Passive de-orbiting	*13*	*Cranfield - Drag augmentation deorbit system*	*ADS*
		15	*FMI - Electro-Dynamic Tether deorbit system*	*OHB*
7	*Solid propulsion*	*14*	*D-Orbit - Autonomous deorbit system*	*TAS*
		16	*GMV - Autonomous deorbit system*	*TAS*
		17	*Ins. Lotn. (Poland) - Solid Rocket Motor for deorbit*	*TAS*
		20	*Nammo (Norway) - Solid Rocket Motor for deorbit*	*TAS*

Schedule overview



Building Blocks presentation

Design for Demise

- Demisable Tanks
- Demisable Reaction Wheels
- Demisable Magnetorquers
- Demisable Optical Payloads
- Early structure break-up

Demisable tanks (4 Building Blocks)

Requirements overview

Propellant or pressurant tanks that fully demise during re-entry, to be used by LEO missions with uncontrolled re-entry

Topic	Metallic Tank (2BBs)	Aluminium Lined COPV Tank (1BB)
	Requirement	Requirement
Volume and Envelope	100 to 200 litres (for propellant)	30 litres (for pressurant or EP propellant)
Enveloppe	∅ < 600mm	∅ < 300mm
Operating pressure	MEOP : 24bar EOL pressure : 5.5 bars	MEOP : 200 bars
Propellant compatibility	Propellant : - Hydrazine - Green propellants (e.g. LMP103S, H2O2, American green propellant HAN)	Propellant or pressurant : - Gaseous helium - Gaseous nitrogen - Xenon - Krypton
Mass	Mass penalty < 15% of reference mass (titanium tank)	Mass penalty < 15% of reference mass (titanium lined COPV tank)
Demisability	Full	Full

Note: 1 BB relative to **Thermoplastic tank technology** considered not mature enough for current and near-future LEO propulsion applications

Demisable tanks

Baseline and Critical areas (Metallic tanks)

- **Baseline**
  - Titanium shell material 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

Al 2219 Demisable tank

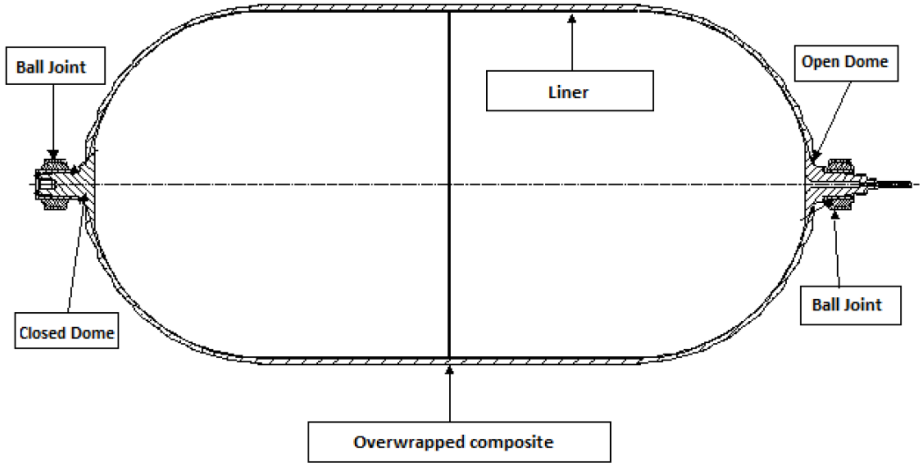
- **Critical areas**
  - Design modularity (tank volume) to cover some mission needs not demonstrated
  - Significant mass penalty if stringent design factors are considered
  - No PMD solution as a back-up

Demisable tanks

Baselines and Critical areas (COPV tanks)

❑Baseline

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



High pressure tank general design

❑ Critical areas

- Tank shell demisability not fully proven
  - Aluminium liner will probably reach its melting T° but the remaining Carbon fibres shell will land on ground with an energy >15J even if this is a 'soft' landing : real danger is not currently known (no sufficient knowledge – by test or by simulations - on the real behaviour of such composite element)
  - 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.

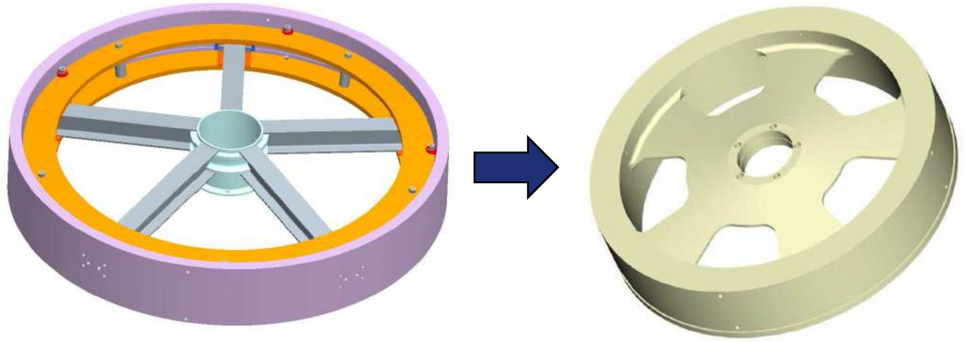
Demisable Reaction Wheels (1 Building Block)

Requirements overview

Reaction Wheel that fully demise during re-entry, to be used on LEO missions with uncontrolled re-entry

Topic	Requirement
Mass	Mass penalty < 15% of reference design (target)
Volume - Dimensions	Volume penalty < 15% of reference design (target)
Angular momentum	10 Nms to 20 Nms (TBC) for class M satellites
Torque	200 to 400 mNm for class M satellites.
Performance - Microvibrations	Microvibration levels not higher than for the existing wheels.
Demisability	Demisability with S/C break-up altitude: • 78 km required • 65 km goal

Demisable Reaction Wheels
Baselines and Critical areas



- **Baseline Option 1 : aluminium flywheel**
  - Large Stainless steel flywheel (spokes and rim) replaced by a large monoblock aluminium flywheel
  - Unchanged housing case (iso-volume) with some inertia loss w.r.t. to the existing wheel (-10%)

- **Baseline Option 2 : increased motor capacity**
  - Small Monoblock aluminium flywheel (unchanged w.r.t. the existing wheel) coupled with Enhanced High Power electronics delivering more power (allowing higher wheel torque)

Critical areas

- Option 1
  - Same performance = larger mass and volume
- Option 2
  - Potential increase of microvibrations
  - Power consumption increase

- Additional options (not selected by supplier because considered too complex)
  - Innovative options for the Core design aiming at improving demisability

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Demisable Magnetorquers (1 Building Block)

Requirements overview

Magnetorquer that fully demise during re-entry, to be used on LEO missions with uncontrolled re-entry

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

Demisable Magnetorquers
Baselines and Critical areas

- **Baseline (4 options investigated for the baseline)**
  - Considered 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 integrity of the coil winding
  - Further options investigated for qualitative comparison

- No critical area identified

Demisable Optical Payloads (1 Building Block)

Requirements overview

Optical payload that fully demises or reduces the casualty risk during re-entry

Topic	Requirement
Cost	Cost penalty to be compared to cost of a controlled re-entry
Performance criteria	• Opto-mechanical performance • Structural performance • Thermal performance • Mass • Volume • Power consumption • Reliability • Safety (accidental break-ups)
Demisability	Demisability with S/C break-up altitude: • 78 km required • 65 km goal

Note : this BB study has focused on Optics

Demisable Optical Payloads
Baselines and Critical areas

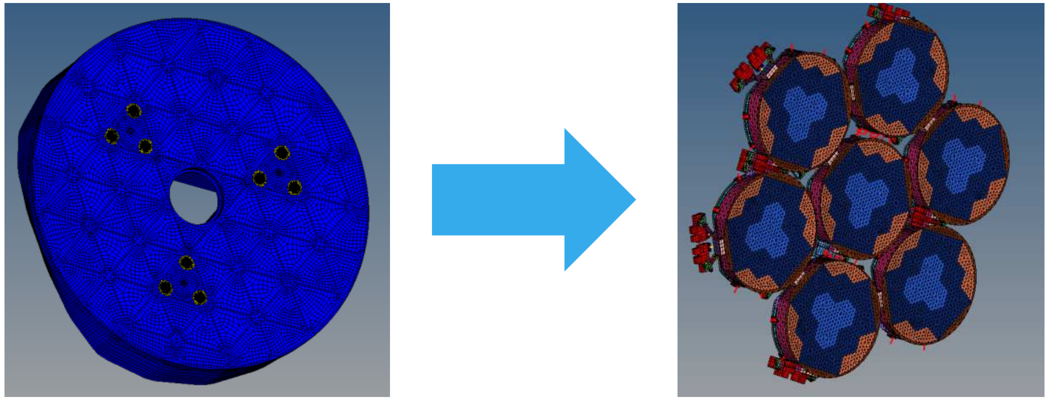
❑Baseline (3 options investigated)

- Option 1: Optics design for disintegration
  - Segmentation of mirrors into 7 segments
- Option 2: Pyro bolts (active or passive)
  - To separate non-demisable elements
- Option 3: Thermal structure break-up
  - Temperature gradient induced stress to break-up optical elements

❑ Critical areas

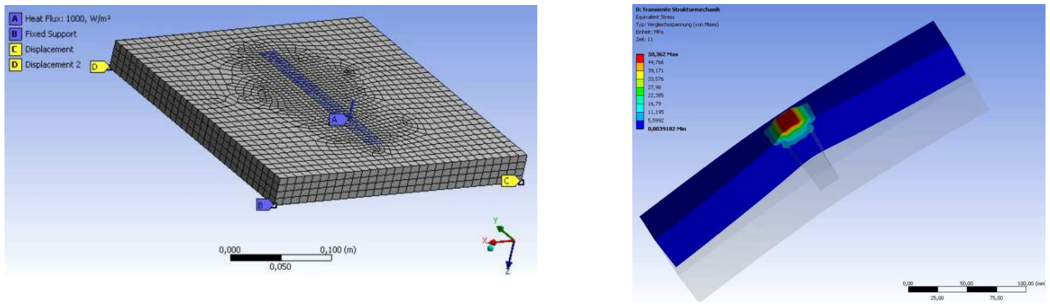
- Potential mass increase
- High cost increase for mirror manufacturing
- Impact on AIT activities (alignment procedures, additional parts)
- Efficiency in terms of demisability not obvious to demonstrate and not sufficient for large size mirrors

Option 1



Option 2

Option 3



Early structure break-up (3 Building Blocks)

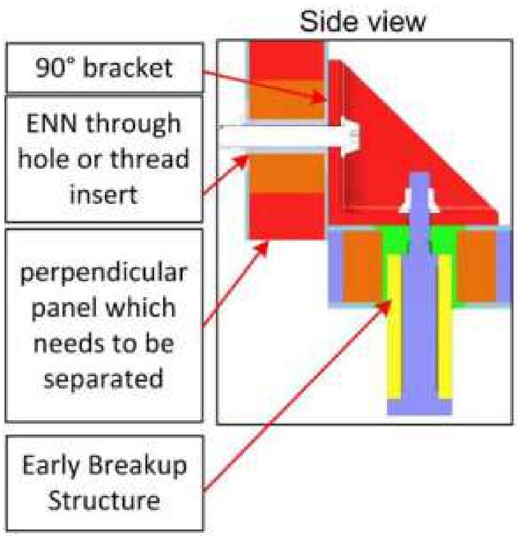
Requirements overview

Development of satellite structure joints that during re-entry create an earlier break-up of the structure to improve demisability of inner components

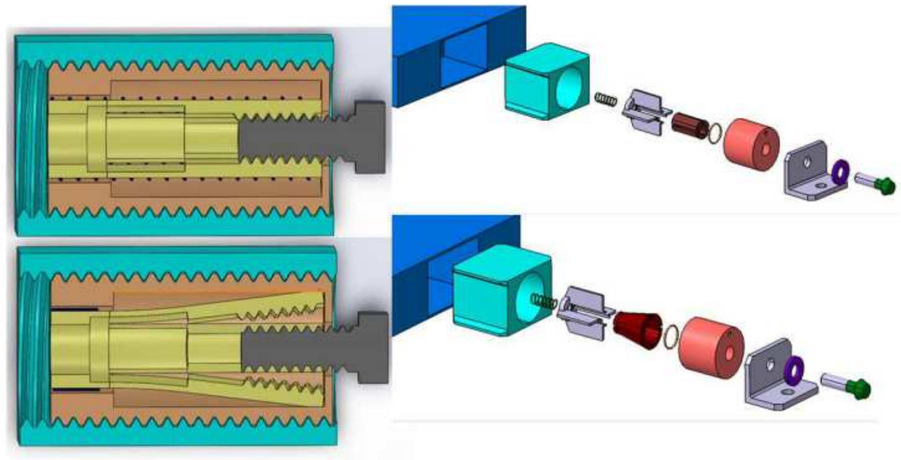
Topic	Requirement
Break-up altitude	Maximisation of break-up altitude
Temperature range	Activation temperature +120°C to 200°C Environment -40°C to +90°C
Safety	Low risk of unplanned activation ($<10^{-3}$)
Reliability	High reliability for activation (>0.9999)
Mechanical performance	Maximum transferable axial load 500 N (TBC)
Operation	Passive option: by aero-thermal heat flux Active option: mechanism actuation within 10 to 30 min after command

Early structure break-up
Baselines and Critical areas

Baselines



Replacement of standard bolts



Replacement of standard inserts

Critical areas

- Potential mass increase if a significant amount of bolts/inserts have to be replaced
- Reliability of activation mechanism to be assessed
- Accidental break-up safety to be assessed
- Cost increase depending on number of joints to be replaced

Building Blocks presentation

Deorbit technologies

- 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

2 BBs aimed at the definition of a green propulsion engine and 1 BB aimed at the definition of a low cost hydrazine engine to be used for controlled re-entry of LEO S/C

Green Propellant Requirements	
Propellant	Monopropellant H2O2 (Baseline)
Propellant Concentration	H2O2 (concentration from 85% to 100% wt)
Propellant	ADN-based monopropellant LMP-103S RCT (Alternative)
Operating Modes	Regulated or Blowdown
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)
Operating Temperature	The operating temperature of the propellant shall be 10-50°C
Operating Pressure	[5.5 22] bar
MEOP	24 bar
Functional Compatibility	IPA - GHe - GN2 - GAr - Deionised water

Low Cost Monopropellant Thruster Requirements	
Propellant	Hydrazine
Operating Modes	Regulated or Blowdown
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)
Operating Temperature	The operating temperature of the propellant shall be 10-50°C
Operating Pressure	[5.5 22] bar
MEOP	24 bar
Functional Compatibility	IPA - GHe - GN2 - GAr - Deionised water

High Thrust Monopropellant Engines (3 BBs)

Baseline and Critical Areas

Different thruster configurations (propellant, thrust level, pressure) were analyzed, resulting in slightly varying designs.

Green Propulsion

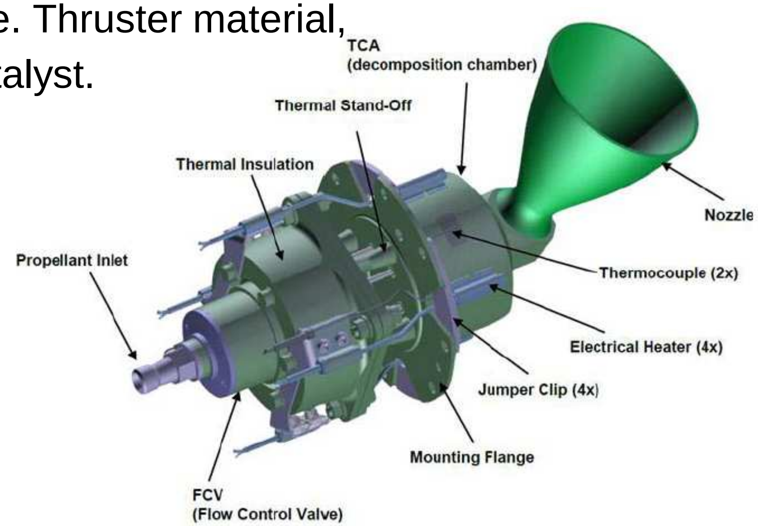
Compatibility of propellant and thruster material and related reliability might be critical:

- 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.

Low Cost De-orbit Engine

- Hydrazine technology is state-of-the-art and well known
- Higher performance by higher expansion ratio of the nozzle
- The cost of the deorbit engine can be reduced by approximately one third compared to the reference thruster
- Design options have been identified (low risk design but also higher performing, lower cost design)

Thruster 3D proposed design



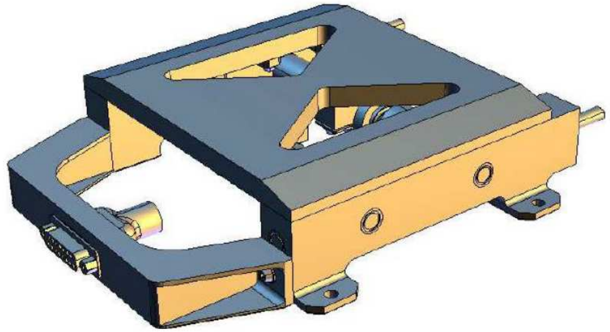
Design Reference (METOP 2G 400N)

Repressurisation Module (1 Building Block)

Requirements, Baseline and Critical Areas

Module for repressurisation of the chemical propulsion subsystem (mono- and bi-propellant).

Repressurisation Module Requirements	
Media compatibility	Compatibility with following media: •N2H4, N2O2, MON, MMH, N2H3, ADN •IPA, deionized water •Helium, nitrogen
Operation	2 commands for activation
Tank volume	Repressurised volume between 200 l and 800 l
Pressure tolerance	Pressurisation tolerance +/-1 bar
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
Cycles	Maximum number of pressurisation cycles over mission: 10



Critical Areas:

- Temperature drop in pressurant tank to be controlled
- Lifetime performance and reliability TBD
- Pressure regulation accuracy drives number of valve cycles
  - Higher accuracy → more cycles
- Leakage requirements to be tested
- Programmatic risks such as challenging time schedule

Arcjets (2 BBs) – Requirements

Definition of an Arcjet propulsion system to be used for nominal mission and for disposal phase of LEO S/C

Arcjets Requirements	
Operating media	Hydrazine (baseline), LMP-103S ADN-based propellant (option) and other gaseous propellants such as GN_2, GHe, Ar, Xe, Kr
Test Media Compatibility	Isopropyl alcohol (IPA), deionized water, Gas Helium and Gas Nitrogen
Compatibility with Tank	Baseline: Aluminium tank (for ADN); Option: Titanium tank (for Hydrazine)
Thruster Input Power	≤ 750 W
PPU Voltage Input	The PPU input voltage shall be about 28V unregulated.
Total number of Cold Start	>10 cold start @ 10°C propellant temperature (from the catalytic point of view)
Flow barriers	The thruster shall equip two monostable flow barriers normally closed in series mechanically and electrically independent
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
Thruster Mass	The thruster shall be below 1.2 kg/kW
Specific Impulse	≥ 400 s (Stand Alone System); ≥ 600 s (Hybrid System)
Thruster On/Off Cycles	• 10000 (Stand Alone System) • 2600 (Hybrid System)
Thrust Level	≥ 100 mN

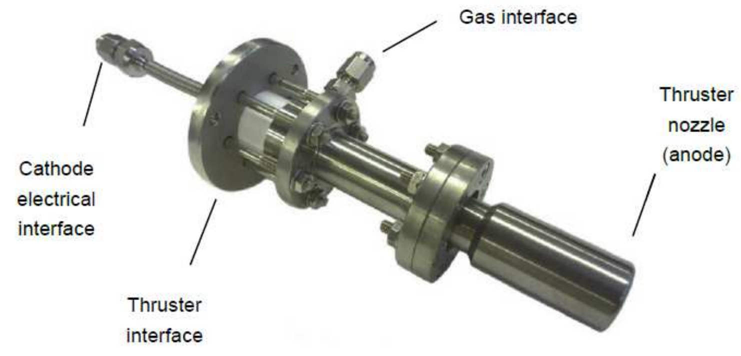
Arcjets (2 BBs) – Baseline and Critical Areas

Baseline

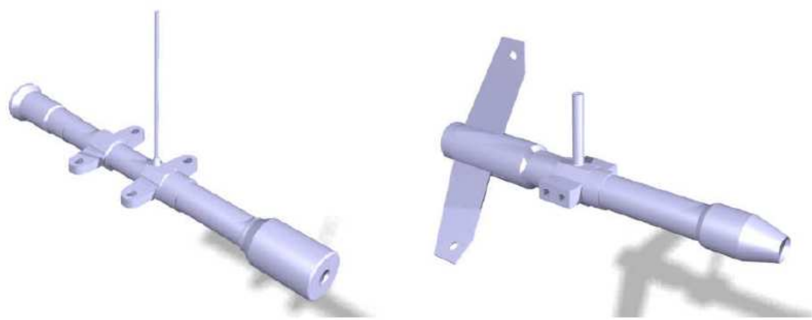
- Stand Alone System (Case 1) used for nominal mission and for uncontrolled re-entry and Hybrid System (Case 2) used for orbit rising and for controlled re-entry
  - Different use cases cause different thruster configurations

Critical Areas:

- Thruster number of cycles and lifetime and performance degradation (i.e. erosion of electrodes)
- 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 of such propellants
- PPU development (considered as new development)
- 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



AT-1KW Arcjet Thruster



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

Low Power HETs – Requirements

HET thruster (electric propulsion) that will contribute to orbit raising , nominal mission and deorbiting of a LEO spacecraft

Low Power Hall Effect Thrusters Requirements	
Media Compatibility	Xe, Kr, GHe (leak test), GN2 (purging)
Specific Impulse	Average Isp over the lifetime ≥1200s
Thrust	Average thrust over the lifetime ≥ 15mN
Total Impulse	- at least 150kNs-200kNs (Case 1) - Orbit Raising : 400 kNs /Nominal Operation: 225 kNs/ Perigee lowering: 400 kNs (Case 2)
Thruster On/Off Cycles	8000 - 10000 cycles
Thruster Power Consumption	≤ 750 W

Low Power HETs – Baseline and Critical Areas

Baseline:

Case1

- 500kg all-electric platform: orbit raising, nominal mission and EoL disposal for un-controlled re-entry
- Use of two MSHT100 thrusters (N+1)
- Xenon as baseline propellant
- Subsystem mass to be around 18 kg (w/o tank)
- Overall power consumption 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)
- Xenon as baseline propellant
- Subsystem mass to be around 27 kg (w/o tank)
- Overall power consumption to be around 970 W

Critical Areas:

- Proposed products are promising, but limited on-ground validation
- High technical (i.e. lifetime) and programmatic risks

MSHT100 coupled with HC1

Drag Augmentation Sails – Requirements

Drag augmentation device to ensure deorbiting in less than 25 years, to be used for LEO missions with uncontrolled re-entry

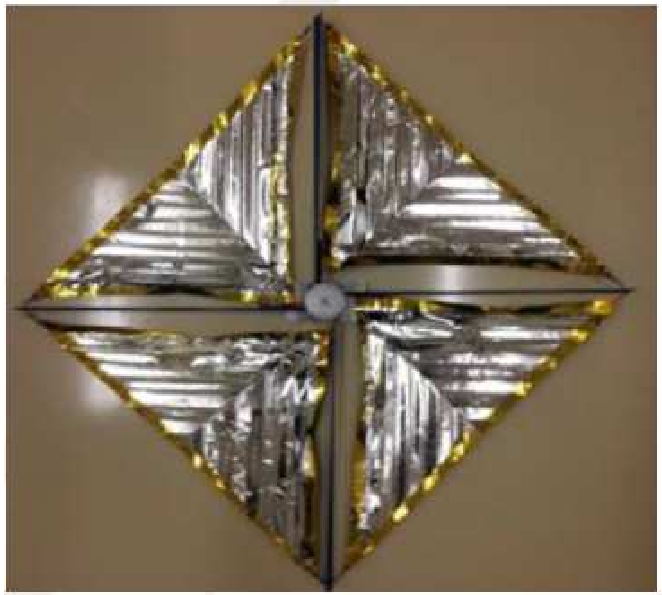
Drag Augmentation Sails Requirements	
Mass	< 5 kg as a goal <10 kg as a maximum
Volume - Dimensions	Volume of the undeployed device < 10 liters
Functional	device triggered through TC
Performance	for orbits up to 850km altitude, with any orbit inclination.
Performance	Once deployed, satellite uncontrolled re-entry in less than 25 years
Lifetime On-Ground	10 years ground storage
Lifetime In-Orbit	successful operation after 10 years in LEO
Environment - ATOX	compatible with ATOX environment (worst-case of de-orbit from 600 km, 25 year re-entry time).

Drag Augmentation Sails – Baseline and Critical Areas

Baseline:

Several designs have been considered:

- 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



DOM

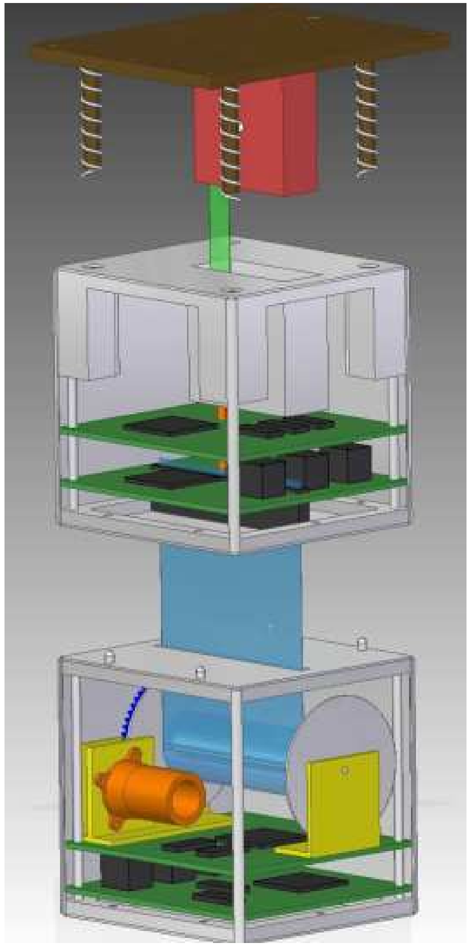
Critical Areas:

- 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)

Electro-static tether – Requirements and Baseline

Tether charged electrically to create a drag force accelerating the orbital decay to a value compliant with SDM requirements.

Electro-static Tether Requirements	
Mass	< 5 kg
Volume	< 6U-cubesat
Power	No resources (e.g. power) required from spacecraft during disposal phase
Perf.	Ensure re-entry within <25 years: •200kg from 850km orbit •800kg from 850km orbit (goal) •200kg from 1200km orbit (performance to be analysed)
Reliability	>0.95
Safety	Safety against premature deployment <1E-3



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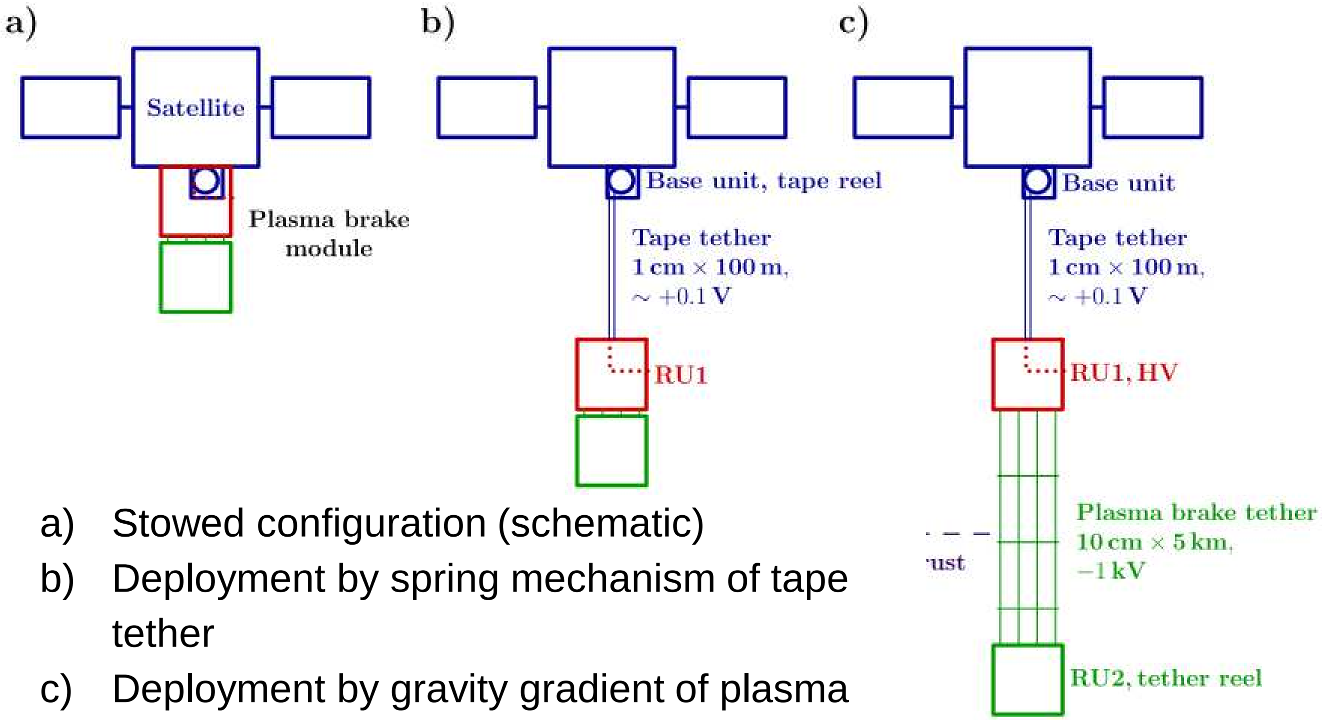
Electro-static tether –Baseline and Critical Areas



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 !

Critical Areas:

- 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 tether mechanical properties
- Danger of deployed tether to other spacecraft was assessed and concluded to be very small (only surface scratches)
- Risk of tether rupture due to MMOD impacts
  - Single device 5.6% over 11 years
  - Two devices 1.9% over 5.5 years

Solid Rocket Motors (2 BBs) – Requirements

Solid Rocket Motor (SRM) to provide decommissioning by controlled re-entry

Solid Rocket Motors Requirements	
Mass	Dry mass shall < 25% of the wet mass (10% as goal)
Dimensions	Outer diameter < 850 mm (for the whole cluster) Maximum nozzle length 300 mm (outside of S/C)
Isp	> 280s
Max. acceleration	Maximum acceleration level of 0.04 g (initial target of 0.02g)
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
DeltaV	DeltaV = 200 m/s; 100 m/s; 50 m/s
TVC	Thrust vector direction accuracy < 0.1° TVC method considered, default angle range wider than ±5°
Stiffness	first mode frequency > 120Hz
Reliability	> 0.95 for the whole cluster (with maximum 8 SRMs), using ECSS safety factors
Debris generation	No debris larger than 1mm in diameter are allowed.

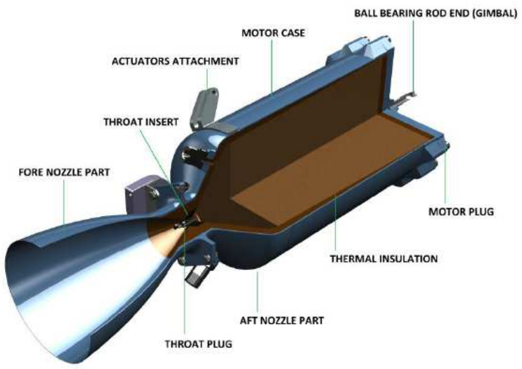
Solid Rocket Motors (2 BBs) – Baseline

Baseline 1:

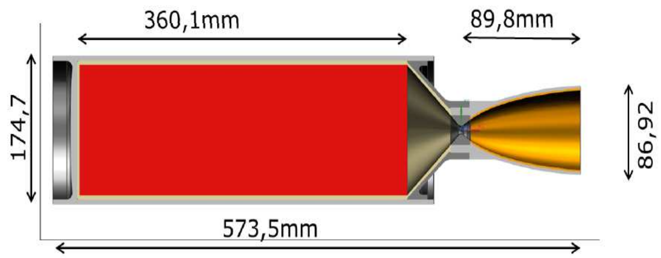
- SRM maximum thrust 588 N
- Propellant mass 44 kg
- 3 SRMs in cluster
- Total cluster mass 58 kg
- Propellant composition AP-HTPB-Oxamide (4% Oxamide as preliminary theoretically estimation)

Baseline 2:

- Maximum burn time not exceeding 120 sec
- Slow burning propellant
- Propellant mass 13,1 kg
- Thrust level 294 N
- SRM mass 16,4 kg
- Motor structure is assumed to be an aluminum tube



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



TVC (left) and SRM Baseline Overview (right)

Solid Rocket Motors (2 BBs) – Critical Areas

Critical Areas:

- Maximum acceleration limits due to S/C appendages imply using large quantities of SRM
- High SRM thermal insulation mass
- SRM long burn durations: max. burn time of 120 seconds (or very long burn times)
- Thruster allocation within the S/C
- Emissions of generated solid particles
- Possible non-compliances with demisability
- Rough estimations indicate the acceleration level of at least 0.1 g allows to lower dry mass fraction below 25%.

Autonomous De-orbit System – Requirements

De-commissioning System (DS) to be installed on spacecraft and used in case of loss of the S/C

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

Autonomous De-orbit System – Baseline and Critical Areas

Baseline:

- Autonomous from the host S/C and ground controlled and commanded

Critical Areas:

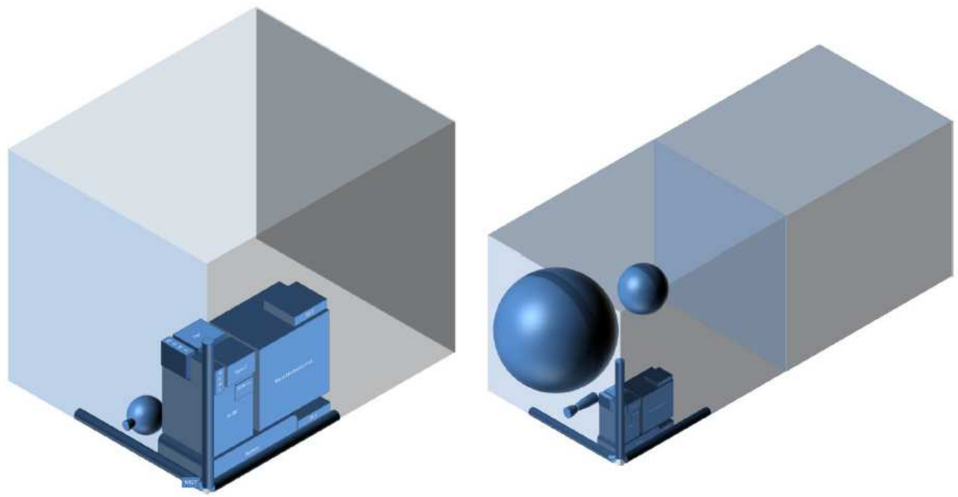
- The system delayed 'activation' (the system is dormant for years before its mission start); the identified potential risks are related to:
  - Primary battery (primary battery not only for the ageing and degradation EOL but also for the de-passivation mechanisms);
  - Solid propellant (for solid propellant systems);
  - Latch valves (for liquid propellant systems);
  - Pyro-igniters;
- 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

Option 1

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;

Option 2

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;



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

Building Blocks presentation

Passivation

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

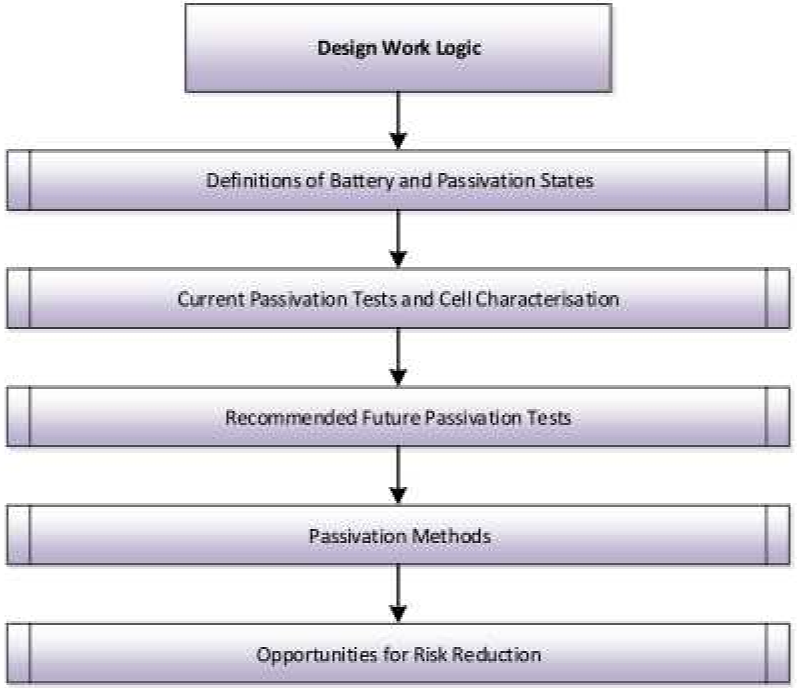
Battery safety

Baseline

The BBs aimed at reviewing and recommending approaches to battery passivation

- 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
- Proposed solution of passivation circuit with bleed resistors
- Overdischarge as preferred passivation method



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

PCDU Upgrade for Passivation

Requirement overview

Architecture solution for power/electric passivation, isolating the Solar Array (SA) within the Power Control and Distribution Unit (PCDU).

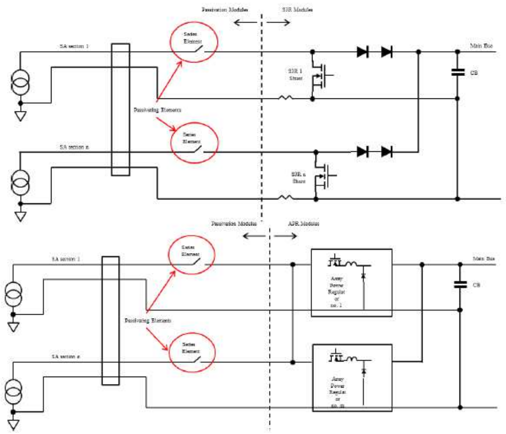
Topic	Driving Harmonized Requirements
Functional	The SA isolation function shall be applicable to both S3R and MPPT conditioning functions.
Functional	The passivation shall be reversible upon the reception of a single command.
Functional	The SA passivation function shall be applicable to both regulated and unregulated bus architecture.
	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

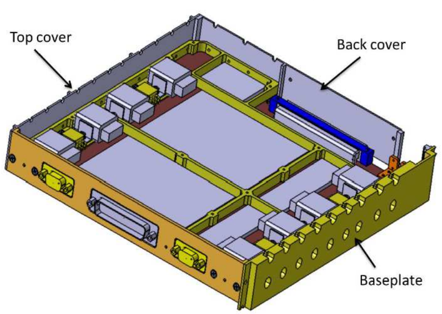
PCDU Upgrade for Passivation

Baselines

Passivation by electro-mechanical device in PCDU

- 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.

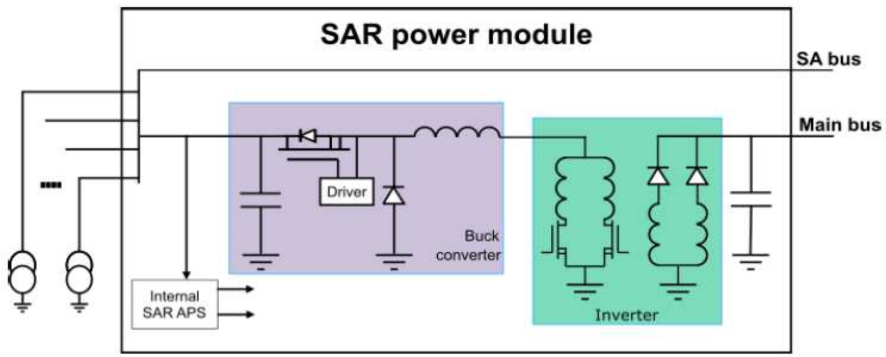




Passivation Module Layout

Passivation by electrical device for SA isolation in PCDU

- 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

Critical areas

Passivation by electro-mechanical device in PCDU

- 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.

Passivation by electrical device for SA isolation in PCDU

- 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.

Fluidic passivation valve

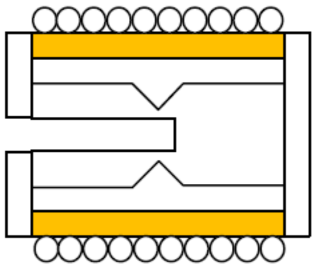
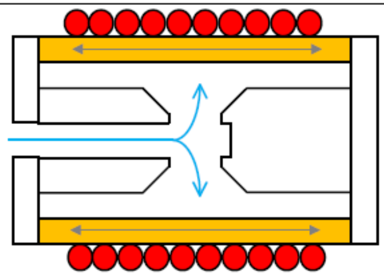
Requirements overview

Fluidic passivation (propellant or pressurant) at the end of the operational mission, to be used by LEO missions with uncontrolled re-entry and by GEO missions

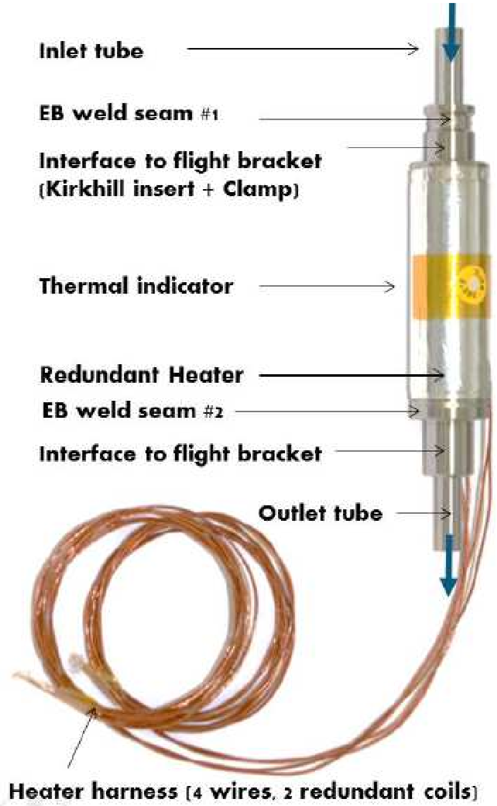
Topic	Requirement
Operating media	N2H4, MON, MMH, LMP103S/HAN/ADN, He, N2, Xe, Kr
Inlet operating pressure	310 bar MEOP, Proof 1.5x, Burst 4x
Number of barriers	Provision of two internal safety barriers
Power	< 20W (with identified impacts if targeting 10W)
Mass	Mass < Pyrovalve
Generated shock	To be minimised and << equivalent pyro valve
Reliability	> 0.99 single unit (passivation) / >.9999 for PV equivalent application

Fluidic passivation valve
Baseline and Critical areas

- **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
- **Critical areas**
  - Need to prove hydrazine compatibility through testing

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

Single-actuation SMA Valve operation principle



Presentation of LSI priorities

Summary of the 3 LSI priority rankings

Ranking details have been 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		High
Thermoplastic tanks for green propellant	Demisability			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		High	High
Battery abuse conditions testing	Passivation		Medium	High
SMA Fluidic passivation valve for propellants and pressurant	Passivation	High	Medium	Medium
Electronic pressure regulator (repressurisation module)	Deorbit systems	High	Medium	High
Low cost high thrust monopropellant engine	Deorbit systems		Medium	
High thrust green propellant deorbit engine	Deorbit systems			Medium
Low power HET for small satellites	Deorbit systems	Medium	High	High
Hydrazine Arcjet	Deorbit systems	Medium	Medium	High
Ammonia Arcjet	Deorbit systems			Medium
Solid propellant re-entry motor	Deorbit systems		Medium	Medium
Solid propulsion autonomous deorbit system	Deorbit systems			
Drag augmentation deorbit system	Deorbit systems			
Electrodynamic/electrostatic deorbit Tether	Deorbit systems			

Conclusion and next steps

Conclusion of the Concurrent Engineering phase and next steps

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 a series of selected Building Blocks.

As Large Satellite Integrators, Airbus DS, 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!