CleanSat

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CleanSat study

"Technology assessment and concurrent engineering in support of LEO platform evolutions"

Consortium Executive Summary (CS-3-ExSum)

	NAME AND FUNCTION	DATE	SIGNATURE
Prepared by	**Saturnino VAL SERRA** **Daniel BRIOT** *Airbus CleanSat Technical Managers*	2017.06.21 '00'02+ 16:15:36	VAL SERRA Saturnino 2017.06.21 13:52:00 +02'00'
	Jan-Christian MEYER *OHB CleanSat Technical Manager*	27/06/17	
	Shila SHOJAEE *TAS-I CleanSat Technical Manager*	22/06/2017	

Summary

This document is the Consortium (AIRBUS, OHB System and THALES ALENIA SPACE) Executive Summary of the CleanSat study “Technology assessment and concurrent engineering in support of LEO platform evolutions”.

The purpose of this document is to present the main results and conclusions from the Building Blocks studied during the Concurrent engineering Phase.

- Chapter 1 presents the study logic and the roles of the different actors.
- Chapter 2 provides the list of applicable documents.
- Chapter 3 provides an overview of each of the 28 studied building blocks.
- Chapter 4 presents the LSI ranking (priorities) of the Building Blocks to be developed during the next phase.
- Chapter 5 provides an evaluation of the elapsed Concurrent Engineering phase and the LSI position for the next phase of CleanSat.

Document change log

ISSUE	DATE	MODIFICATION NB	MODIFIED PAGES	OBSERVATIONS
01	21/06/2017		All	First issue of the document

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GLOSSARY

ADS	Airbus Defence and Space
ASL	Airbus Safran Launchers
BB	Building Block
CDF	Concurrent Design Facility
COPV	Composite Overwrapped Pressure Vessel
COTS	Commercial-Off-The-Shelf
D4D	Design for Demise
EOL	End of Life
EP	Electric Propulsion
FMI	Finnish Meteorological Institute
HET	Hall Effect Thrusters
LSI	Large Satellite Integrators
MPPT	Maximum Power Point Tracking
MTQ	Magnetorquers
PCDU	Power Conditioning and Distribution Unit
PED	Propellant Expulsion Device
PIP	Project Implementation Plan
PMA	Propulsion Management Assembly
RCD	Rockwell Collins Deutschland
REACH	Registration, Evaluation, Authorization and restriction of CHemicals
RoHS	Restriction of Hazardous Substances
S3R	Sequential Switching Shunt Regulator
SA	Solar Arrays
S/C	Spacecraft
SDM	Space Debris Mitigation
SMA	Shape Memory Alloy
SOW	Statement of Work
SRM	Solid Rocket Motor
TAS	Thales Alenia Space
TVC	Thrust Vector Control
VC	Video Conference
WP	Work Package
wrt	with respect to

1 INTRODUCTION

This document is the Consortium (AIRBUS, OHB System and THALES ALENIA SPACE) Executive Summary of the CleanSat study “Technology assessment and concurrent engineering in support of LEO platform evolutions”.

1.1 Scope of the document

The purpose of this document is to present the main results and conclusions from the Building Blocks studied during the CleanSat Concurrent engineering Phase (as per [AD 01]).

The general objective of CleanSat's technology assessment and concurrent engineering phase was to mature the specifications for the selected Building Blocks for future LEO spacecraft, based on requirements consolidated during the first phase of the programme.

The 28 Building Blocks to be studied in this phase have been selected by ESA based on the proposals from the Announcement of Opportunity, taking into account the priorities identified by the systems integrators in the preparation phase.

Chapter 1 presents the study logic and the roles of the different actors.

Chapter 2 provides the list of applicable documents.

Chapter 3 provides an overview of each of the 28 studied building blocks.

Chapter 4 presents the LSI ranking (priorities) of the Building Blocks to be developed during the next phase.

Chapter 5 provides an evaluation of the elapsed Concurrent Engineering phase and the LSI position for the next phase of CleanSat.

1.2 CleanSat Study logic and roles

During the CleanSat concurrent engineering phase, Airbus, OHB, and TAS-I have cooperated within a consortium and have shared evenly the management of the different suppliers. Moreover, according to their priorities, each LSI had the possibility to be involved in the technical discussions with ESA, the other LSIs and the different BB suppliers.

The concurrent engineering phase started in September 2015 and ended in April 2017 with a final presentation at ESTEC.

For each of the building blocks, the concurrent engineering activity lasted typically 12 weeks and was organised as follows:

- Initial kick-off (T0),
- CDF session 1 (T0 + 2 weeks): aiming at consolidating the requirements proposed independently by the 3 LSIs and identifying the main trade-offs,
- Supplier analyses (between T0 + 2 weeks and T0 + 10 weeks): aiming at proposing a preliminary design,
- CDF session 2 (T0 + 10 weeks): aiming at reviewing 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.

In order to optimise the work organisation in terms of travels and experts participation, the 28 different building blocks were divided into 7 batches of 4 BBs, each batch addressing a specific topic.

Table 1-1 provides the list of the 20 selected Building Blocks and shows the organisation of the different batches (7 batches of 4 BBs).

Figure 1.2-1 presents a general view of the schedule for the different batches

Batch	Topic	BB #	BB title	Managing LSI
1	*Tanks*	*2*	*ASL SAS - Demisable Aluminium lined COPV*	*ADS*
		3	*ASL SAS - Thermoplastic tanks for green propellant*	*ADS*
		5	*ASL 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*

Table 1-1 Organisation of BBs into batches

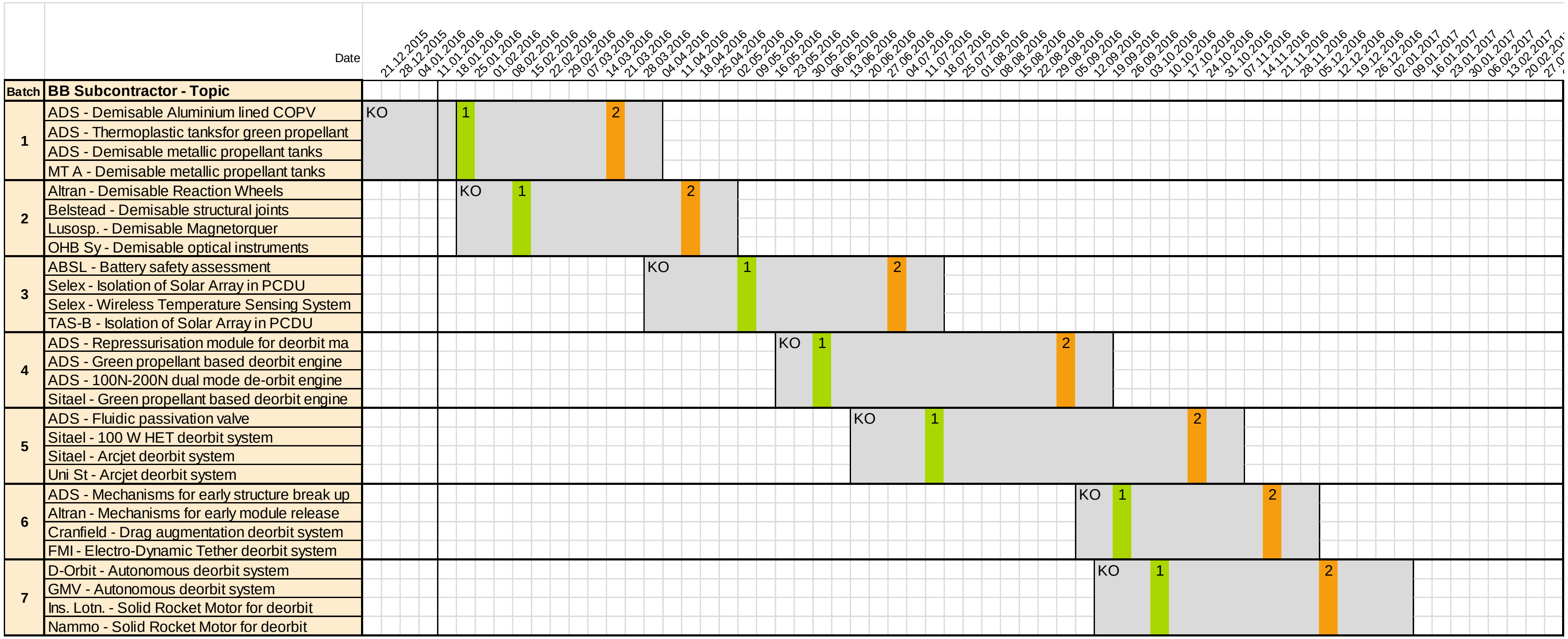

Figure 1.2-1 Schedule overview

2 APPLICABLE DOCUMENTS

In this section are defined the documents which are applicable associated to the present document.

Ad no.	Document number	Issue, date	Document title
[AD 01]	ESA-TEC-SC-SOW-2015-002	Issue 1 Rev 0, 26/05/2015	ESA SOW CleanSat: Technology assessment and concurrent engineering in support of LEO platform evolutions

3 CLEANSAT TECHNOLOGIES EVALUATION

3.1 BB01 - Battery Safety (ABSL)

This BB01 aims to provide a comprehensive summary and recommendations of current and future cell and battery passivation methods for existing and future CleanSat activities and ESA missions. This BB is applicable to all satellites and all Earth orbits undertaking passivation at End-of-Life (EOL). The aims of this BB are as follows:

- Determine a framework (or guidelines) for future passivation work to continue to improve
- Define the conditions of which a battery is deemed safe for passivation
- Recommend a passivation method from a battery manufacturers perspective
- Determine which tests should be performed as part of cell qualification to conform to these recommendations
- Identify and where possible reduce the risk of any potential hazards relating to mission EoL passivation

The objectives therefore are:

- Review of current methods of passivation
- Characterize the risks and safety concerns of batteries/cells at EOL
- Summarize and analyse current ABSL cell tests relating to passivation
- Investigate areas of collaboration with power system manufacturers and LSIs to limit accidental breakups
- Identify what tests need to be undertaken to qualify new cells and provide a roadmap to complete this

3.2 BB02 - Aluminium Lined COPV Tanks (ASL SAS)

BB02 study concerns the design of a high pressure vessel for use with xenon propellant or with helium for application on future LEO/MEO missions. The tank shall fully demise during re-entry.

In order to improve demisability of tanks is proposed to replace titanium components by aluminium which shows a lower fusion temperature. This study confirms that aluminium liner is a good candidate to improve demisability of high pressure xenon tank for electric propulsion.

3.3 BB03 - Demisable Propellant Tank Assembly (ASL SAS formerly ADS SAS)

BB03 study concerns the design of a Propellant Tank Assembly with thermoplastic liner for use with standard and green liquid propellants and for application on future LEO/MEO missions. The tank shall fulfil the specified technical requirements up to end of life and shall afterwards demonstrate full demise during re-entry.

The proposed propellant tank concept is based on composite overwrap pressure vessel (COPV) technologies, initially developed for pressurant tanks. With this concept Propellant shell is made of a liner (to ensure leak tightness) and a composite overwrap that sustain mechanical loads (pressure, dynamic loads). The liner is a made of thermoplastic.

Rotomoulding process has been identified as promising technologies to manufacture the liner.

3.4 BB04 - Fluidic Passivation Valve (ASL GmbH)

The BB04 study addresses the design, trade-off and further development road mapping (up to qualification) of an SMA (Shape Memory Alloy) based Fluidic Passivation Valve (one shot end of life venting) for use for chemical and electrical propulsions systems (propellant and pressurant, gas and liquid).

The proposed design consists in a thermally actuated device that opens by heating up above a certain so-called activation temperature (typ. above 110°C). The valve is intended to be activated for fluidic chains passivation needs. The valve is an alternative to lifetime-limited pyro valves. Because of its being in its basic principle a normally closed isolation valve, the valve is also looked at for its (claimed) low cost beginning of life isolation function.

3.5 BB05 - Demisable Metallic Propellant Tanks (ASL GmbH)

BB05 study concerns the design of a Propellant Tank Assembly for use with standard and green liquid propellants and for application on LEO/MEO missions. The tank shall demise during re-entry.

The replacement of Titanium by an aluminium alloy is confirmed to be the most promising approach given the major impact in terms of tank demisability.

In order to minimize development risks and cost, the recommended approach is to use the conventional 2219 alloy technologies, available from launchers, and to extend it to LEO platform application. It is expected that the mass penalty is acceptable when compared to the necessity of a controlled re-entry.

3.6 BB06 - Mechanisms for early module release (ASL GmbH, former ADS GmbH)

BB06 study concerns different assembly and separation principles based on the use of SMA (Shape Memory Alloys).

Within the frame of the Clean Sat study, there was a focus on thermally triggered shape memory actuators that could be actively triggered at end of life by an electric command, or passively by the heat generated during re-entry 25 years later.

Two concept families are proposed:

- Concept 1: “material closure”: a predetermined breaking point within the main load path (notch). Three variants are presented, with different accommodations of the actuator (internal / external), or associated with a structural insert
- Concept 2: “shape connection”: no breaking point within the main load path, separation done by release of a clamping between the two parts. Three variants are presented, pin puller, clamped interfaces combined or not with brackets

3.7 BB07 - Repressurisation Module for Deorbit Manoeuvres (ASL GmbH)

BB07 study concerns the design of a Repressurisation Module for De-orbit Manoeuvres and for application on LEO/MEO missions.

The proposed design for the repressurisation module includes a repressurisation unit (RPU) and he high pressure gas tank with fluidic connection to the RPU.

The initial idea for the development of the RPU is to provide a compact unit which could be used for pressure control and regulation of a propulsion tank to the extent as required for the Bi-Propellant missions. However, the developed concept shall also be used for monopropellant re-pressurizations for controlled and uncontrolled de-orbiting.

A first preliminary architecture for the RPU has been designed: the Re-Pressurization Unit (RPU) consists of six stacked valves arranged in two branches for redundancy (2x3), a gas filter at the inlet and orifices for control of the re-pressurization rate.

The RPU has been designed volume-efficient as one component, including tailored valves which are currently under development at ASL. The stacked valves are developed with focus on low cost and minimum volume.

3.8 BB08 - Green Propellant based De-orbit Engine (ASL GmbH)

BB08 study concerns the design of a Green Propellant Deorbit Engine for application on LEO/MEO missions.

The key features of the envisaged technologies are:

- LMP-103S has a 5s higher specific impulse compared to Hydrazine but a significant higher combustion temperature therefore standard high temperature alloys cannot be used.
- Hydrogen Peroxide has a 30s lower specific impulse compared to Hydrazine with a 40% higher density. Decomposition temperatures are below 1000°C therefore standard high temperature alloys can be used.

The LMP-103S technology is currently investigated in the frame of the EU funded RHEFORM project (to be completed in 2017) where drawbacks of this technology like high cost, no cold start capability and the use of ITAR limited chamber material shall be solved.

Based on the successful outcomes of this project and available experience of apogee motor manufacturing a green deorbit engine in a thrust class of 150N was designed.

In any case higher cost compared to a reference Hydrazine thruster have to be expected which are mainly caused by the high combustion temperatures of LMP-103S.

In case Hydrogen Peroxide as an alternative green fuel is used the design is significantly simpler taking benefit of the investigation that was performed in another clean space building block (BB09).

3.9 BB09 - Low Cost De-orbit Engine (ASL GmbH)

BB09 study concerns the design of a Low Cost Deorbit Engine in the 200N class for use with standard hydrazine propellant and for application on LEO/MEO missions. The target satellites are in the range 1 to 2 tons.

The proposed design includes the following features:

- The performance can be increased with a higher expansion ratio of the nozzle.
- The cost of the deorbit engine can be reduced by approximately one third compared to the reference thruster.

3.10 BB10 - Mechanisms for early module release (Altran with Nemesis)

BB10 study concerns different assembly / separation principles based on the use of SMA (Shape Memory Alloys).

Four concepts (either active or passive) are proposed:

- Concept 1: SMA washers / frangibolt screws
- Concept 2: SMA inserts / release screws
- Concept 3: SMA cutting cords / release panels
- Concept 4: SMA sleeves / release struts, bars and booms

In each case, SMA are used to release assembled structural parts by breaking an item on the load path introducing high stress level by temperature increase (concepts 1 and 3) or to release items by deformation under temperature (concepts 2 and 4).

3.11 BB11 - Demisable Reaction Wheel (Altran with Rockwell Collins)

BB11 study concerns the design of a demisable Reaction Wheel for application on LEO missions. The reaction wheel shall demise during re-entry.

Two design options have been proposed:

- A mechanical upgrade consisting in replacing the existing RSI-68 unit stainless steel flywheel by an optimised aluminium flywheel,
- An electronical upgrade consisting in enhancing the existing RSI-45 unit electronics to obtain a higher angular momentum.

3.12 BB12 - Demisable joints (Belstead Research Limited)

BB12 study concerns the enhancement of demise through the strategic use of joints and fasteners. To this end, three types of structural joints have been investigated:

- Adhesive link between skins and honeycomb core constituting sandwich panels
- Inserts potted in sandwich panels
- Bolted assembly of aluminium brackets through Titanium bolts

Tests have been performed on these three items, consisting of applying temperature and mechanical loads on representative samples. Qualitative and quantitative results have been produced, describing the conditions of failure (temperature, loads).

3.13 BB13 - Drag augmentation deorbit system (Cranfield University)

BB13 study concerns the design of a Drag Augmentation deorbit System (DAS) for application on LEO missions. The DAS shall ensure satellite re-entry in less than 25 years.

The study has focussed on de-orbit technologies based on Cranfield University's technology, which adopts the following approaches:

- Drag augmentation by deploying a lightweight membrane supported by rigid booms,
- Deployment is achieved using stored spring energy with no electrical actuation,
- Deployment is solely controlled by the host spacecraft,
- Technologies used are compatible with low-cost manufacturing and testing facilities.

3.14 BB14 - Autonomous Decommissioning Device for S/C Controlled Re-entry (D-Orbit)

BB14 study concerns the design of an autonomous Decommissioning System (DS) allowing a satellite controlled re-entry at the end of the operational mission.

The proposed design focuses on large LEO satellites aiming at a controlled re-entry in order to reduce their casualty risk at re-entry down to a level which is allowed by ESA guidelines and regulations.

The Decommissioning System is being developed in two versions:

- A fully autonomous one, i.e. independent from the host resources and capable to operate autonomously from it, also in case of major host failure,
- A non-autonomous one, which relies on the host resources and operability to complete the decommissioning function.

The DS is characterized by a modular architecture and is intended to operate through the implementation of the following constituting units:

- The electronics dedicated to the command and management of the Decommissioning System and the interfaces (data and power) with the hosting platforms,
- The TT&C unit, which allows the Decommissioning System to directly communicate to ground without relying on the platform (only autonomous version),
- The battery unit which allows the subsystems of the Decommissioning System to be safely powered during the operations,

- The fully independent ADCS unit which allows the Decommissioning System to control its attitude through sensors and actuators (only autonomous version).
- The PDU, which allows power distribution to the subsystems of the Decommissioning System;
- The TVC unit which allows the motor to control thrust direction,
- The Electro-Explosive Subsystem for safe ignition of the Solid Rocket Motor;
- The Solid Rocket Motor, to produce the decommissioning delta-V.

3.15 BB15 - Electro-Dynamic Tether deorbit system (Finnish Meteorological Institute)

BB15 study concerns the design of an Electrostatic Tether deorbit system for application on LEO missions.

The proposed device needs an electron collecting surface which can be either the satellite body or (as in FMI baseline case) a metal-coated plastic tape tether. The thrust is due to scattering of ram flow ions by the negative potential structure – it is not due to the current flowing in the tether as is the case in the traditional electrodynamic tether.

3.16 BB16 - Independent Deorbit Trigger (GMV)

BB16 study concerns the design of a dedicated module that will ensure the autonomous de-orbiting of a satellite at the end of its operational life.

The proposed system is composed by the following parts:

- S band antennas and S-band transceiver
- Data Handling and Power Distribution unit
- Primary Battery
- AOCS sensors (sun sensors, magnetometer, gyro) and actuators (magnetorquers)
- Thermistor and heaters for Thermal Control System
- Propulsion subsystem
- RF Cables and DC harness

3.17 BB17 - Solid rocket motor for de-orbiting (Institute of Aviation, Poland)

BB17 study concerns the design of a Solid Rocket Motor to be used at the end of the satellite operational phase in order to perform a controlled re-entry.

The proposed system design consists of the preliminary SRM including propellant (formulation, grain shape, performance), structure (case, insulation), ignition and conditioning (sealed chamber). Additionally, a higher level system integration (within S/C) was analysed.

The main functionalities of the system were identified: long burn time (around 100 s), no generation of particles over 1 mm in diameter during the SRM firing and a scalable design with a possible clustering TVC was also taken into account.

3.18 BB18 - Demisable Magnetorquer (Lusospace)

BB18 study concerns the design of a Magnetorquer for application on LEO missions. The magnetorquer shall demise during re-entry.

Several design options have been iterated upon in order to understand the potential and down falls of each of them in terms of performance (magnetic, mechanical, thermal), future implementation capability (cost, AIT concerns, production) and demisability.

The following components have been examined during the study:

- 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

3.19 BB19 - Demisable Metallic Propellant Tanks (MT Aerospace)

BB19 study concerns the design of a Propellant Tank Assembly for use with liquid propellants and for application on LEO missions. The tank shall demise during re-entry.

The design concept is based on one of the titanium reference tanks with the following main features and deviations:

- The titanium shell material is replaced by an aluminium alloy. The baseline is AA2219 that is concluded to provide better performance and feasibility than other alloys
- 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. The specific weld is identified.
- The tank will be supported either at its poles by means of off-the shelf bearings integrated to the bosses.
- The tank shell will be built up by a welded assembly (baseline) of a cylindrical part and two dome shells.

3.20 BB20 - Solid rocket motor for de-orbiting (Nammo)

BB20 study concerns the design of a Solid Rocket Motor to be used at the end of the satellite operational phase in order to perform a controlled re-entry.

For the design of the solid rocket motors the following sub-systems have been optimized:

- Propellant (low particle level)
- Motor case (pressure and radiation protection of the propellant)
- Insulation materials (which can resist long burn times)
- Ignition system (which can support the ignition of clustered solutions)
- Thrust Vectoring Control capability to allow for controlled re-entry
- Nozzle (low erosion)

3.21 BB21 - Demisable payload (OHB Munich)

BB21 study concerns the design of “Demiseable payloads”, proposed by OHB Munich (former Kayser Threde). Practically in the study the focus has been put on optics.

Different ideas have been developed in this study to prevent massive elements from falling to Earth by D4D of the optical payload, taking into account compliance with SDM requirements and new European regulations. The study has addressed optics only.

To propose a wide range of D4D Techniques to be compared and trade-off, a fast evaluation of a wide range of possible designs against more detailed analysis of a specific design was preferred.

Three different Building Blocks candidates were selected and analyzed during the study:

- Building Block 1: Optics Design for Disintegration
- Building Block 2: Pyro Bolts
- Building Block 3: Thermal break-up of structure

All analyses were performed as general and scalable as possible to enable ESA to derive general rules about D4D requirements for optical systems.

3.22 BB22 - PCDU Passivation (FINMECCANICA)

BB22 study concerns the identification of the most promising solution to perform the solar array passivation within the PCDU and to focus on the mains key issues in order to identify the main technical constraints it may face.

The proposed passivation method is based on the interruption of the SA power to the spacecraft by interposition of electro-mechanical devices as shown in Figure 1.

This passivation method is applicable to both the mainly used configurations of conditioning for the Solar Array (SA) power:

- The Series Switching Shunt Regulation (S3R) and
- The Maximum Power Point Tracking (MPPT).

In both applications the SA isolation is performed on each section separately, to reduce the impacts on the isolating device sizing.

3.23 BB23 - Wireless Temperature Sensing System (FINMECCANICA)

BB23 study concerns wireless temperature sensing system for spacecraft thermal mapping.

RF interrogation signals are used for the remote temperature measurement within payloads and platforms of satellites, instead of the traditional wired sensors (thermocouples and thermistors). The system is mainly composed of a reader (i.e. interrogation unit) together with a number of wireless sensors placed on the measurement points. This system is foreseen to obtain some significant advantages in terms of harness reduction and flexibility of installation compared to the traditional wired system.

3.24 BB24 - Hall Effect Thruster Deorbiting System (Sitael)

The aim of BB 24 study is to assess the capability of Hall Effect Thrusters to perform End-of-Life disposal manoeuvres for LEO satellites and to define a set of requirements at both equipment and subsystem level.

The main challenge is the need to perform a significant delta-V for the disposal manoeuvres, so the technical solutions must be compatible with a high total impulse and a high number of thruster actuations.

The following low power HET are initially proposed as thruster baseline:

- Sitael’s HT100 and its Magnetically Shielded version MSHT100 (HET in the power range of 100 to 300 W) coupled with two hollow cathodes (one redundant),
- Sitael’s HT400 (HET in the power range of 300 to 750 W) coupled with hollow cathodes (one redundant).

Since the magnetic field shapes plasma properties inside the HET channel, the topology of the magnetic field can affect the erosion rate of the walls that is one of the main constraints on the HET lifetime. For this reason, the magnetically-shielded versions (MS) of both thrusters have been taken into account to reduce the number of thruster units. These versions rely on a new magnetic field topology that limits the wall erosion and increments the HET lifetime.

3.25 BB25 - Arcjet De-orbiting and Auxiliary Propulsion System (SITAEL)

The aim of BB 25 study is to assess the capability of current and next-generation arcjet thrusters to perform orbit raising and End-of-Life disposal manoeuvres for LEO satellites.

The main challenge is the need to perform a significant delta-V for the disposal manoeuvres, so the technical solutions must be compatible with a high total impulse and a high number of thruster actuations.

Analyses of 2 arcjet-based propulsion systems were made for 2 different cases:

- Case 1: 800 kg S/C mass, orbit 800 km, nominal mission and de-orbit for uncontrolled re-entry. A trade-off has been conducted to select a propellant between hydrazine and LMP-103S;
- Case 2: 1500 kg S/C mass, orbit 800 km, orbit rising from 300km and de-orbit for controlled re-entry. Trade-off has focused on clustering 3 thrusters or on single thruster option.

For Case 1 a new design with respect to the SITAEL AT-1k can ensure the fulfilment of these requirements.

For Case 2 the single 3 kW thruster system has been selected as the baseline for the mission.

3.26 BB26 - Green Propellant De-orbiting System (Sitael)

BB026 study concerns the design of a Green Propellant Deorbiting System for application on LEO missions.

During this study, the investigated thrust levels have been 22 N and ≥ 150 N (mean thrust during the operational life of the thruster).

The proposed system is specifically applicable to medium and large LEO spacecraft (respectively between 500 kg and 1000 kg, and above 1000 kg) but it can be used also on Small LEO spacecraft and, in principle, on GEO platforms.

This deorbiting system is conceived to minimize the impact on the overall system architecture, since only some additional piping and the thruster units have to be incorporated in the spacecraft design. In addition, the system perfectly fits with the new trends of replacing the hazardous hydrazine with less hazardous green propellants (i.e. new regulations due to REACH or RoHS).

3.27 BB27 - Passivation of the solar array in the PCDU (TAS-B)

BB27 study concerns the identification of the most promising solution to perform the solar array passivation within the PCDU and to focus on the mains key issues in order to identify the main technical constrains it may face.

Several options have been considered:

- Electronic Switch,
- Series Mechanical Relay,
- Shunting Relay,
- Common SA shunting relay,
- Permanent activation of the S3R shunt,
- Galvanic Isolation.

3.28 BB28 - Arcjet Orbit Raising and Deorbit Module (IRS)

The aim of BB 28 study is to assess the capability of the current state-of-the-art arcjet thrusters to perform orbit raising and End-of-Life disposal manoeuvres for LEO satellites.

The main challenge is the need to perform a significant delta-V for the disposal manoeuvres, so the technical solutions must be compatible with a high total impulse and a high number of thruster actuations.

Two cases have been considered during the study:

- Case 1: Arcjet Based De-Orbit System as Stand-Alone System
- Case 2: Arcjet Based De-Orbit System as Hybrid System

For case 1 a total of four propellant feed system concepts have been proposed. Three of the concepts are based on hydrazine as propellant, while the other concept uses ammonia as propellant and is based on a previous ammonia propellant feed system which has been developed at IRS in the past. All feed systems have in common, that they (and the complete deorbit system) are stand-alone and do not require any other interfaces to the satellite than power and commands. Propellant tanks and full flow regulation are accomplished by the respective system.

For case 2 the flow control system is generally simpler, as the synergy with an existing hydrazine based propulsion system is used. Consequently no tank or respective pressurization system is required. Furthermore due to the synergy only hydrazine has been considered as propellant.

4 BB FINAL ASSESSMENT AND PRIORITIES

This chapter presents the building block priorities for the 3 LSIs at the end of the concurrent engineering phase.

Note that "Priority" must not be mistaken for "Interest":

- Priority clearly defines the order of preference/urgency in terms of BB development for Cleansat "phase 3"
- Interest in the item is wider and not linked to planning: some interesting building blocks may have a medium or low priority.

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

Table 4-1 Summary of the 3 LSI priority rankings

5 CONCLUSIONS OF THE CLEANSAT CONCURRENT ENGINEERING PHASE

This chapter provides first an evaluation of the completed CleanSat study and follows with an outline of future activities related to CleanSat.

5.1 Evaluation of CleanSat Concurrent engineering phase

This section provides an evaluation of the CleanSat CE phase on administrative and practical level.

5.1.1 Administrative evaluation

General contractual approach

The administrative approach of ESA for the CleanSat CE phase was to have the LSIs manage the contractual aspects with the suppliers of the BB technologies. This allowed ESA to focus on the technologies and thereby developing 28 studies in parallel. Globally this approach made the preliminary assessment of those BBs very efficient from a time perspective.

Overall the management effort especially on LSI side was very high. This could be handled by close collaboration of the LSIs and in particular by sharing the responsibility of managing the subcontracts. A clear contractual framework was set up allowing complete technical visibility of results within the consortium (supplier, LSIs, ESA) and keeping the management effort as low as possible. Each supplier only had a subcontract with one partner.

Contractual framework between ESA and the LSIs

The critical aspect of this contractual framework was the consortium contract between ESA and the three LSIs as Co-Primes. This legal work required many iterations that threatened the sensitive schedule at the beginning of the CleanSat study. It is suggested for future similar studies to allow more time for contractual iterations than the three months available for CleanSat.

Contractual framework between the LSIs and the suppliers

Handling subcontractors was a distributed task among the LSIs. Even though the same approach was followed for each subcontractor the level of actual work related to each one differs. The tight schedule for the individual BBs of about 3 months made it difficult in some cases to finish contractual negotiations in time because of a great number of iterations (a lot of subcontracts were signed after the start of the activity).

Activity schedule

In addition it was observed that the time between the two CDF sessions was often a strong constraint leading to unfinished results presented at CDF2. It is therefore proposed to increase the length of the individual BB studies. This will not necessarily lead to more expensive studies, but to more mature results being presented at CDF2. In return the level of after-work to be done by the supplier should be lower.

It is also remarked that during some periods the schedule of parallel studies was quite demanding. The most intense period shortly before summer saw 12 studies being executed in parallel. In retrospect this is also the period where many BBs have been seen to produce results that remain behind their expectations. A globally more stretched schedule could be more productive here.

Final report acceptance step procedure could be better defined. Sometimes comments from ESA and other LSI were provided with delay after the final report acceptance.

5.1.2 Practical evaluation

Concurrent engineering approach

CleanSat made use of many novel approaches to technology developments. The most notable one is the high intensity work associated with concurrent engineering. It allowed concentrated work and kept the people involved in a particular building block focussed. It also made it possible to use results of some BB studies for others starting later throughout the year. Some suppliers understood better than others the nature of the meetings as possibility to exchange expertise. This should be made clear to all participants that are involved in such a CDF session.

Audio and videoconference means

CleanSat made use of many video conferences to support the personal meetings in the CDF. With limited budgets on LSI side, but the willingness to follow as many BB studies as possible in many cases the option of joining a CDF session by videoconference was chosen. The most stringent constraint in this respect is industrial IT security restrictions. This typically lead to the fact that at least 30 minutes at the beginning of a meeting involving more than 2 partner sites were needed to connect all participants satisfactorily.

It became even more complicated when partners joined who did not own a videoconference system and therefore had to rely on phones and WebEx sessions.

ESA sharepoint

The use of a sharepoint server as central data storage area with specific access rights for each involved partner made many email exchanges obsolete. This successfully limited the number of emails exchanged within such a complex industrial set-up. Unfortunately, the initial version of sharepoint system was not accessible to everyone because of incompatible technical systems (proxy servers and sharepoint version). This in the end made the administrative effort actually higher than without a sharepoint server used. Towards the end of the study a new version of sharepoint was set-up at ESA that did not show these drawbacks and that made working as efficient as initially planned. For future projects, it is strongly recommended to select a basis for data exchange together with all involved stakeholders (at least up to LSI-level). Here the IT security restrictions are often very strict and cannot be modified to make a specific solution work. This is likely different for SME suppliers.

5.2 Next steps and way forward

This section describes the LSIs view on future activities in relation to CleanSat.

5.2.1 LSIs position about CleanSat

The LSIs consider CleanSat project of great interest and appreciate both the collaborative approach among the LSI and ESA and the work done so far. The study results are of good quality considering the number of technologies addressed and evaluated, the number of interfaces which have been managed and the scheduled.

The LSIs are interested in following and supporting further technology developments in the frame of CleanSat. The proposed approach of involving LSIs for the definition of requirements of units and review of interface documents is considered beneficial for all involved stakeholders.

5.2.2 System-level studies

During the next CleanSat phase, the LSIs intend to contribute to the technology developments by performing additional system level studies aiming to consolidate the requirements of the selected building blocks. These system level studies should also contribute to the refinement of use cases for the different technologies to be developed.