CleanSat: European Space Agency's technological and programmatic response to support European industry to comply with Space Debris Mitigation requirements for Low Earth Orbit spacecraft

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ABSTRACT

There is an increased attention to safeguarding Earth's orbital environment, as reflected by the number of relevant regulations that are being set forward. European Space Agency (ESA) has published an update of the "Space Debris Mitigation Policy for Agency Projects"[1] in March 2014[1]. Its corresponding implementation guidelines are planned for publication by mid-2015. These complement national and international regulations on the matter, such as the French Space Operations Act (FSOA)[2] fully applicable to European launchers and satellites manufactured and/or operated from French territory as of 2020, and the Space Debris Mitigation Guidelines of the United Nations Committee on the Peaceful Uses of Outer Space (UN COPUOS). Other countries in Europe also have Space Debris Mitigation (SDM) requirements for space missions.

In this worldwide evolving regulatory context, support to the compliance with SDM requirements contributes to fostering European industry innovation and competitiveness, one of ESA's strategic priorities.

SDM requirements define Low Earth Orbit (LEO) as a protected region, being the most highly congested Earth orbit. Specifically, with today's technologies, most LEO spacecraft above 500 kg mass will contain parts that survive re-entry. Targeted re-entry, with a well-defined impact footprint, is an option, and likely necessary for spacecraft above the 1 ton, but with a price in complexity and mass that may well drive platforms in the higher ton mass range out of the Vega launch capability. One alternative for this class of spacecraft is to design the system so that it will not survive during re-entry, this approach is called Design for Demise (D4D). In September 2013, ESA carried out concurrent engineering sessions on D4D that were open to external industrial experts [5]. These sessions helped streamlining the technology activities in this domain.

Several other activities (e.g. power passivation, propulsion passivation, drag augmentation devices, solid motor de-orbiting system) are being pursued in strong coordination with users and, in particular, with the Directorate of Earth Observation.

Compliance with the SDM requirements has a strong impact on several subsystems and implies evolution of LEO platforms. The development of new building blocks through CleanSat paves the way for a coordinated European approach as it engages space agencies, system integrators and subsystem suppliers.

After briefly introducing Clean Space, this paper will give an overview of the CleanSat objectives, key areas of interest and its approach for technology assessment and concurrent engineering support of LEO platform evolutions.

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[1] ESA/ADMIN/IPOL(2014)2
[2] *Loi relative aux Opérations Spatiales (LOS)*

1 INTRODUCING CLEAN SPACE

In 2011, ESA's Agenda 2015 action plan recognised the need to guarantee the future of space activities by protecting the environment, which is affected by our activities both on Earth and in space. Thus in 2012 the cross-cutting Clean Space initiative was founded, organised along three distinct braches, addressing eco-design, space debris mitigation and space debris remediation as shown in Figure 1-1. The eco-design branch distinctly addresses the environmental impacts of space activities on Earth and looks into methods of assessing and reducing them, while the other two branches look into ways space debris and active space debris removal. Clean Space takes a system level approach to establish technology development roadmaps for each branch and builds on ESA's technology programmes such as Technology Research Programme (TRP) and General Support Technology Programme (GSTP) for their implementation[2].

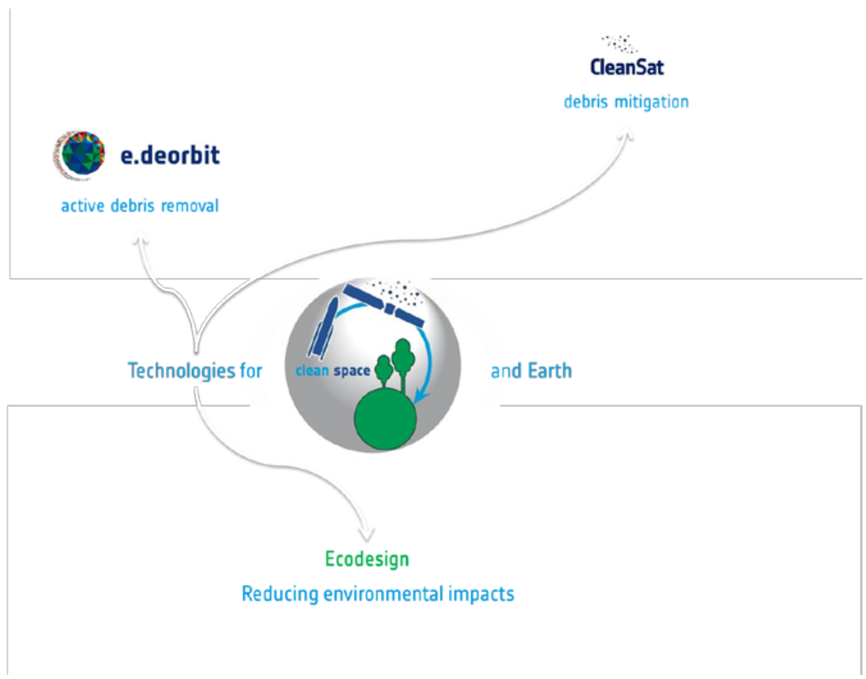

Figure 1-1: Clean Space's three branches

ESA, with its Clean Space initiative, will devote increasing attention to the environmental impact of its activities in the frame of ESA programmes, through the implementation of specific technology roadmaps. Since its creation in 2012, Clean Space has accumulated more than 100 activities under its umbrella, streamlining activities to give a pro-active answer to the environmental challenges both on ground and in space, including its own operations as well as operations performed by European space industry in the frame of ESA programmes.

2 CLEANSAT APPROACH

CleanSat, a is a technology programme coordinated by the Clean Space office, is ESA's technologic and programmatic response to support European industry complying with the worldwide market demand for

Space Debris Mitigation (SDM) compliant solutions for Low Earth Orbit (LEO) spacecraft. The CleanSat drivers are:

- evolution of LEO platforms to comply with SDM requirements, in a coordinated European approach.
- create an efficient framework for the fast implementation of innovative technologies in upcoming Earth Observation Programme (EOP) missions.
- development of common building blocks to stimulate the creation of shared supply chains, lowering development and recurrent costs.

Through CleanSat, ESA aims to implement a coordinated approach involving system integrators, subsystem and equipment manufacturers in the development of technology building blocks to support the evolution of the Low Earth Orbit (LEO) spacecraft in compliance with the SDM[3]. The approach that is being implemented is depicted in Figure 1-2:

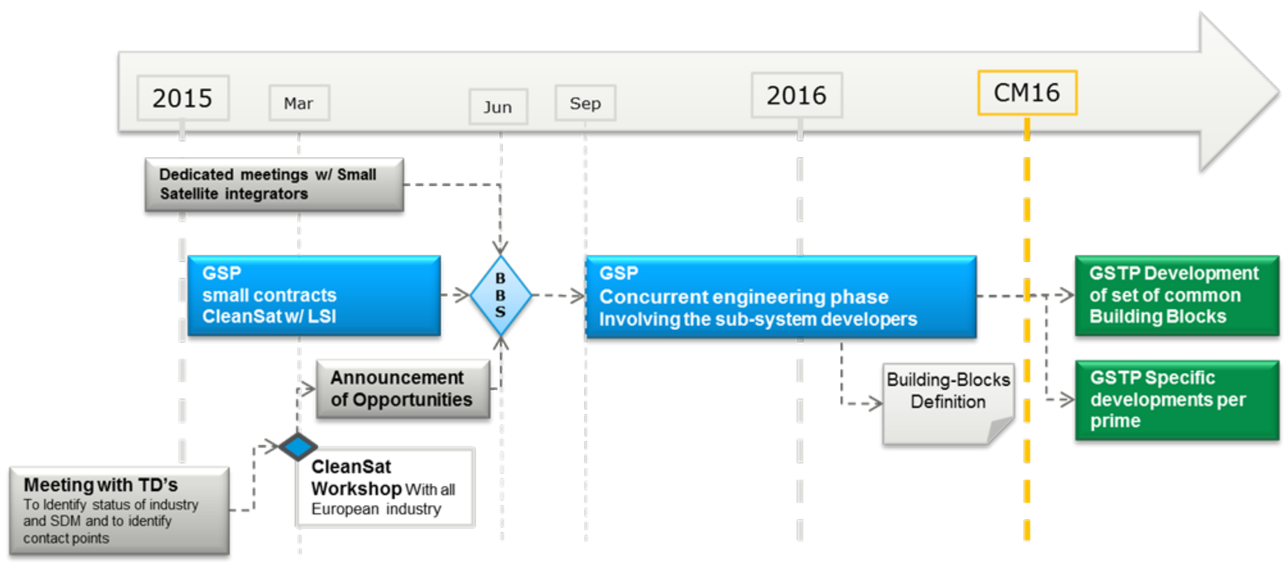

Figure 1-2: CleanSat implementation approach

The preparation of CleanSat is being carried out in close collaboration with the European System Integrators, both the Large Satellite Integrators (LSIs) and the Small System Integrators. The class of satellites which is most impacted by the SDM requirements is for spacecraft (S/C) above 700 kg being manufactured by the LSIs. This is due to the impact of the on-ground casualty risk requirement. This may drive the need to the implementation of D4D technologies on this class of satellites, an area where many developments may be needed in the future.

Currently the LSIs are carrying out 3 parallel studies to identify priority technology building blocks and their associated system requirements to support the evolution of the medium and large LEO platforms. Close links with the SSIs is established to allow synergies of technological solutions with smaller satellites.

Following the *CleanSat* Workshop[4] at ESTEC (18 March 2015), the European industry (subsystem and equipment manufacturers) had the opportunity to propose technologies and Building Block concepts to be further studied in close cooperation with the Agency and the systems integrators during the Concurrent Engineering phase.

The outcome of this is Concurrent Engineering phase is: consolidated Building Block preliminary designs and respective development roadmap. This will be the basis for the CleanSat proposal of 2016 for further technology maturation, up to TRL 7/8, within GSTP.
Besides SDM related developments, this efficient framework for the development of new technology for the future LEO spacecraft also creates an opportunity for the maturation of other innovative products enhancing the European platform performance and competitiveness.
The technology Building Blocks being developed through CleanSat shall aim at a fast integration in future LEO missions. In particular the upcoming ESA EOP missions, such as the Earth Explorer 8 and 9 from the Living Planet Programme as well as the Sentinel series C/D and following generation from the Copernicus Programme, shall already benefit from these developments.

3 OBJECTIVES

The general objective of CleanSat's technology assessment and concurrent engineering phase is to mature the specifications for the selected technology Building Blocks for future LEO spacecraft, based on requirements consolidated during the first phase of the programme.
The Building Blocks to be studied in this phase will be selected from the results of an Announcement of Opportunities, taking into account the priorities identified by the systems integrators in the preparation phase. The relevant technologies will be those selected on the basis of:

- Compliance with SDM requirements
- Compliance with new European regulations relevant to S/C design.
- Increase platform performance and competitiveness

These domains are further detailed in key areas of interest with examples in section 3.1.
Out of the proposals received, technology Building Blocks or technologies may be selected to be studied in Concurrent Technology Engineering & Design Studies, introduced and explained in section 4.1.

3.1 Key Areas of Interest

This section aims at helping reflection on innovative technology Building Blocks, including subsystems, equipment, technologies or engineering activities, to support the evolution of the LEO platforms limited to the following key areas of interest:

- Compliance with SDM requirements
  - End-of-Life Disposal
    - Targeted re-entry systems *e.g. development of autonomous deorbit systems, development of high thrust re-entry engines.*
    - Active or Passive Uncontrolled de-orbit systems *e.g. drag augmentation systems.*
  - D4D e.g. demisable tanks, demisable structures, demisable magneto-torquers, demisable reaction wheels, demisable elements or designs for payloads, mechanisms to enhance heat-flux on internal equipment during re-entry, payload modules separation mechanisms.
  - Passivation
    - Power passivation e.g. solar array isolation system.
    - Propulsion passivation e.g. pressurant or propellant venting systems.
- Compliance with new regulation e.g. due to Regulations on Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) or Restriction of Hazardous Substances (RoHS), green propulsion;
- Increase platform performance e.g. advanced avionics, high efficiency power generation and storage, Micro Electro-Mechanical Systems (MEMS), fibre-optical communication, high efficiency CAMs;

- Increase platform competitiveness e.g. low-cost technologies, advanced manufacturing, support to in-orbit servicing.

3.2 Concurrent Technology Engineering & Design Study

Concurrent Technology Engineering & Design Study (c.TEDS) will be performed for each selected Building Block. The c.TEDS will involve preparation and design work to be carried out by the proposer and 2 concurrent sessions involving the proposer, the LSIs and the Agency, to be carried out at ESA's Concurrent Design Facility (CDF) in ESTEC. The objectives of the 2 concurrent sessions are:

- 1st Session: Building Block requirements consolidation;
- 2nd Session: Review of the Building Block conceptual design and development roadmap.

The final output is:

- Consolidated Building Block preliminary design
- Development roadmaps.

In case the technology Building Block consists of an engineering activity the output to be reviewed in the 2nd session would consist of the analysis result or a test plan design.

The outcome will provide the basis for the GST P developments to be proposed in the following phase.

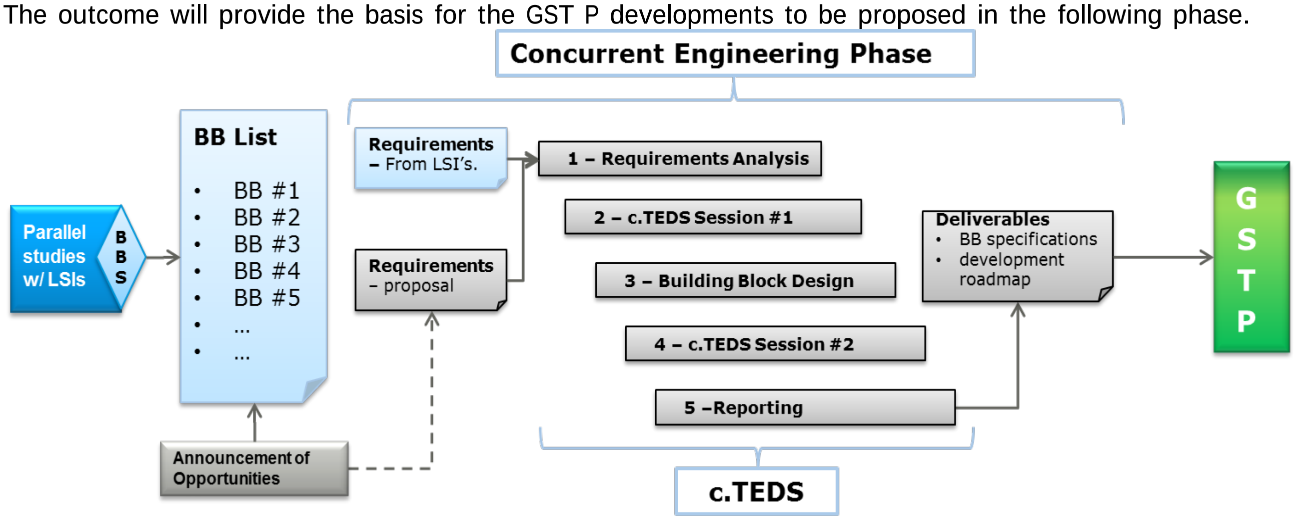

Figure 1-3: Concurrent Engineering Phase

4 APPROACH FOR CLEANSAT'S TECHNOLOGY ASSESSMENT AND CONCURRENT ENGINEERING IN SUPPORT OF LEO PLATFORM EVOLUTIONS

Following the publication of an Announcement of Opportunity, a maximum of 28 proposals fulfilling the acceptance criteria and addressing key areas of interest identified in section 4.1. will be selected.

Each c.TEDS shall take between 8 and 12 weeks and the Agency expects to complete the 28 c.TEDS in no more than 12 months.

4.1 C.TEDs approach

The c.TEDS aim at consolidating the requirements for each of the selected building blocks in coordination with the system primes for LEO spacecraft and at performing a design loop to consolidate the building block specifications and development roadmap.

The c.TEDS will be carried out following the work logic presented in Figure 1-4:

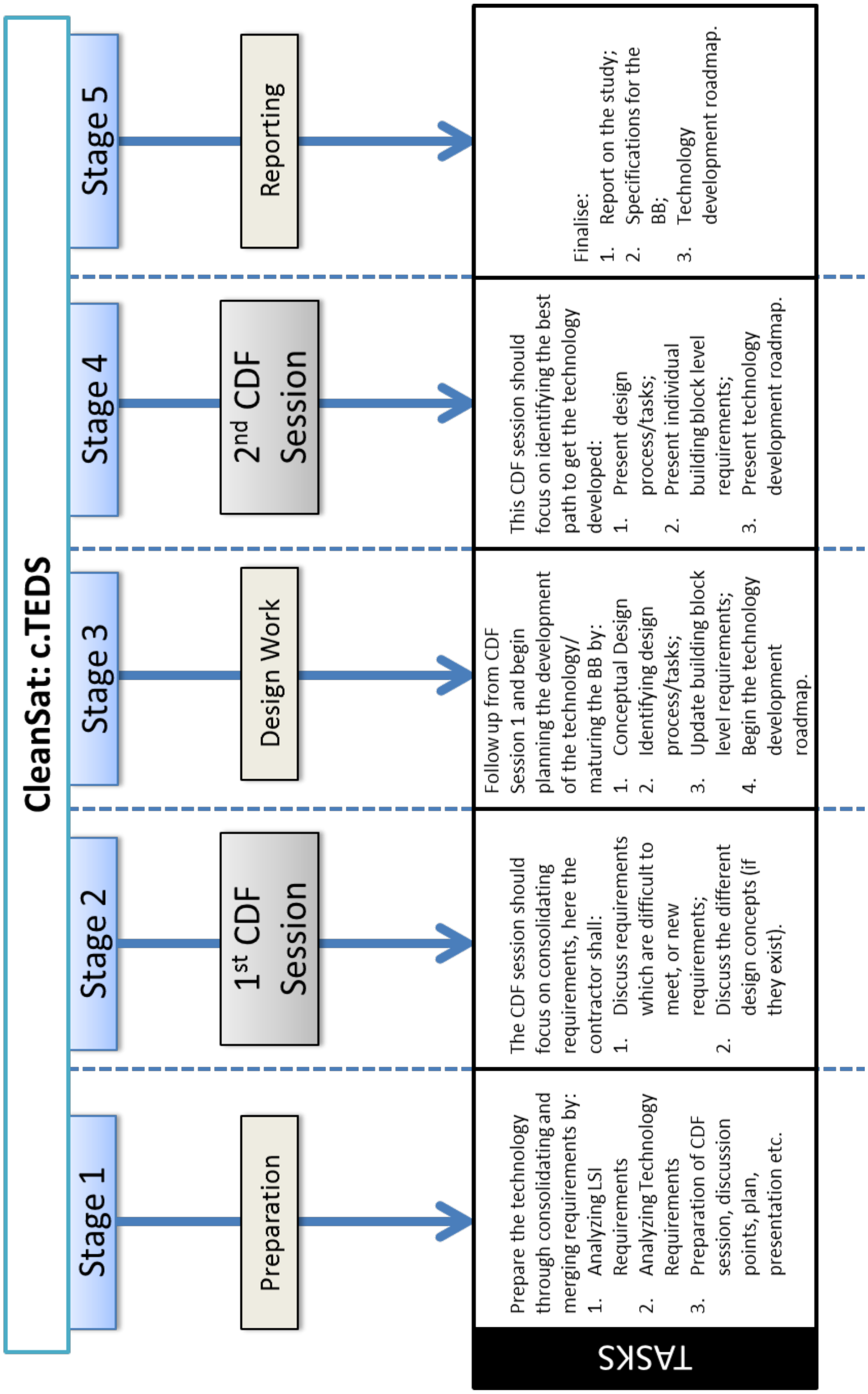

Figure 1-4: Concurrent Technology Engineering & Design Study

[redacted] Stage 1 – Preparation

- **Inputs** Building Block requirements provided by systems integrators
- **Tasks:** Prepare the technology through consolidating and merging requirements by:
  - Analyzing system integrators requirements at system and subsystem level,
  - Analyzing technology requirements at building block level,
  - Preparation of 1st CDF session, discussion points, plan, presentation etc.
- **Duration:** 2 weeks
- **Outputs** Inputs for 1st CDF session data package:
  - Presentation of technology concept
  - Proposed requirements to be considered during the Building Block design.
  - Presentation of Design Work (Stage 3) plan

[redacted] Stage 2 – 1st CDF Session

- **Inputs** 1st CDF Session data package.
- **Tasks:** The CDF session should focus on consolidating requirements, here the contractor shall:
  - Discuss possibilities of requirements harmonisation;
  - Propose complementary requirements;
  - Discuss different design concepts.
  - Discuss work plan for Stage 3.
- **Duration:** 1 day
- **Outputs** Consolidated requirements for the Building Block design and work-plan for stage 3

[redacted] Stage 3 –Design Work

- **Inputs** Consolidated requirements for the Building Block design.
- **Tasks:** Follow up from CDF Session 1 and begin planning the development of the technology/ maturing the BB by:
  - Conceptual Design
  - Execute design process/tasks, e.g.
  - Identification of problem areas;
  - Update building block level requirements;
  - Prepare preliminary technology development roadmap.
- **Duration:** 1 to 2 months
- **Outputs** 2nd CDF session data package:

- Draft Preliminary Building Block Design Description;
- Draft Preliminary Building Block Design Justification
- Draft Building Block requirements document
- Draft Building Block Development Plan

[redacted] Stage 4 – 2nd CDF Session

- **Inputs** 2nd CDF Session data package.
- **Tasks:** The CDF session should focus on identifying the best path to get the technology developed:
  - Present conceptual Building Block design;
  - Present Building Block design requirements;
  - Present technology development roadmap
- **Duration:** 1 day
- **Outputs** Review of Building Block Design, requirements and development plan

[redacted] Stage 5 – Reporting

- **Inputs** Comments on 2nd CDF session data package .
- **Tasks:** implement comments and open actions identified during the 2nd CDF Session
- **Duration:** 2 weeks
- **Outputs** Final Report and Executive Summary including:
  - Preliminary Building Block Design Description;
  - Preliminary Building Block Design Justification
  - Building Block requirements document
  - Building Block Development Plan

5 CONCLUSIONS

Considering the impact on several sub-systems, it becomes evident that the systematic compliance with SDM requirements implies evolution of the LEO platforms. The development of new building blocks – based on innovative technologies compliant with SDM requirements –, in a coordinated European approach, would lead to economies of scale, resulting from the creation of common supply chains. This is only possible by engaging the space agencies, the system integrators and the subsystem suppliers.

CleanSat is an unique opportunity for new technology concepts to be matured in coordination with the systems integrators and reach flight maturity in the short timeframe.

6 REFERENCES

[1] ESA/ADMIN/IPOL(2014)2, Space Debris Mitigation Policy for Agency Projects, 2014
[2] ESA Clean Space Team – Clean Space Implementation Plan 2015, April 2015
[3] ESA, Overview of technologies for evolution of LEO platforms in compliance with the SDM requirements, 2015
[4] CleanSat Workshop Presentations, 2015
[5] ESA CDF Team, D4D MiCRA CDF Study, 2013