Co-funded by
the European Union

Focus on African Space Science and
Technology for Future Development

WP6:

D6.1 - Work plan for the design and assembly of nanosatellites

Version 1.1

The participants to the Final WP6 Workshop, CPUT, Aug. 16th 2025

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INDEX

INDEX 4

1 EXECUTIVE SUMMARY 7

2 WORK PACKAGE 6 ACTIVITIES 8

3 WORKPLAN FOR THE DESIGN AND ASSEMBLY OF NANOSATELLITES 11

3.1 IDENTIFYING USER NEEDS FOR A NANOSATELLITE PROGRAM IN AFRICA 11

3.2 MISSION DESIGN PRINCIPLES 11

3.2.1 Mission design in a Concurrent Design approach 11

3.2.2 Systems Engineering Flow 12

3.2.3 Requirements Flow-Down 13

3.2.4 Concept of Operations – ConOps 14

3.2.5 CubeSat Standard and Buy-vs-Build Decision – Context for African Missions 15

3.2.6 Orbit–Payload–Subsystem Dependency 16

3.2.7 Review Milestones 16

3.3 MISSION PHASES AND DELIVERABLES 17

3.3.1 ECSS Lifecycle Adaptation for Nanosatellites 17

3.3.2 Phase Transitions and Reviews 17

3.4 WORK PLAN FOR DESIGN AND DEVELOPMENT OF THE NANOSATELLITE SUBSYSTEMS 18

3.4.1 Attitude Determination and Control Subsystems 19

3.4.1.1 Functional Role and Mission Context 19
3.4.1.2 Design Inputs 20
3.4.1.3 Design Process 20
3.4.1.4 Verification and Testing 21
3.4.1.5 Deliverables 22
3.4.1.6 Workflow Checklist – ADCS Design & Development 22

3.4.2 Electrical Power System (EPS) 22

3.4.2.1 Functional Role and Mission Context 22
3.4.2.2 Design Inputs 22
3.4.2.3 Design Process 23
3.4.2.4 Verification and Testing 24

3.4.2.5 Deliverables ... 24
3.4.2.6 Workflow checklist – EPS Design & Development ... 24
3.4.3 Propulsion ... 24
3.4.3.1 Functional Role and Mission Context ... 25
3.4.3.2 Design Inputs ... 25
3.4.3.3 Design Process ... 25
3.4.3.4 Verification and Testing ... 26
3.4.3.5 Deliverables ... 26
3.4.3.6 Workflow Checklist – Propulsion Design & Development ... 26
3.4.4 Communications (TT&C) ... 26
3.4.4.1 Functional Role and Mission Context ... 26
3.4.4.2 Design Inputs ... 27
3.4.4.3 Design Process ... 27
3.4.4.4 Verification and Testing ... 28
3.4.4.5 Deliverables ... 28
3.4.4.6 Workflow Checklist – TT&C ... 28
3.4.5 Onboard Data Handling (OBDH) & Software ... 29
3.4.5.1 Functional Role and Mission Context ... 29
3.4.5.2 Design Inputs ... 29
3.4.5.3 Design Process ... 29
3.4.5.4 Verification and Testing ... 29
3.4.5.5 Deliverables ... 30
3.4.5.6 Workflow Checklist – OBDH ... 30
3.4.6 Structure and Thermal subsystem ... 30
3.4.6.1 Functional Role and Mission Context ... 30
3.4.6.2 Design Inputs ... 31
3.4.6.3 Design Process ... 31
3.4.6.4 Verification and Testing ... 31
3.4.6.5 Deliverables ... 31
3.4.6.6 Workflow Checklist – Structures & Thermal ... 32
3.4.7 Ground Segment ... 32
3.4.7.1 Functional Role and Mission Context ... 32
3.4.7.2 Design Inputs ... 32
3.4.7.3 Design Process ... 32
3.4.7.4 Verification and Testing ... 33
3.4.7.5 Deliverables ... 33

3.4.7.6 Workflow Checklist – Ground Segment 33

3.5 Assembly, Integration, and Testing 34

3.5.1 Integration workflow 34

3.5.2 Verification 34

3.6 Implementation plan 35

3.6.1 Resources and Responsibilities 36

3.7 Training and capacity building 37

4 Conclusions 37

5 Annexes 38

5.1 FAST4FUTURE Workshop 1 Syllabus And Agenda 39

5.1.1 Workshop 1: List of participants and pictures 42

5.2 FAST4FUTURE VIRTUAL WORKSHOP SYLLABUS 43

5.3 FAST4FUTURE WP6 Final Workshop Syllabus 44

5.3.1 Final Workshop List of Participants and pictures 45

5.3.2 Training Material for the Final Workshop 46

5.3.3 WP6 Final Workshop attendance register 47

5.4 WP 6 Outputs from trainees 51

5.4.1 Mass Budget Assignment prepared by AFIT Team 51

5.4.2 Mass Budget Assignment prepared by CBSS Team 52

5.4.3 Research activities from WITS MSc students (extract from presentations) 53

5.4.4 Mission Design Research Activities at AFIT (extract from presentation) 57

5.4.5 Mission Design Research Activities at CBSS (extract from presentation) 61

5.5 WP6 Output - Internship technical report 65

5.6 ITS worksheets 84

1 Executive Summary

This deliverable presents the creation of a bespoke work plan for the design and assembly of nano-satellites, as per WP6 Deliverable D6.1 of the FAST4Future project.

The document is organised in three main parts:

- **Part I** (section 2)**:** a summary of the WP6 activities and key achievements, including a mapping of the WP objectives and verifiable indicators to the activities carried out during the training and knowledge transfer events, particularly the three dedicated workshops.
- **Part II** (section 3)**:** a structured work plan for nanosatellite development. The plan integrates principles of mission design, system engineering, subsystem specification, assembly integration verification (AIV), and capacity-building elements, making it directly adoptable by African higher education institutions (HEIs), research organisations, and industry partners.
- **Annexes:** non-exhaustive collection of outputs produced during WP6, including events organisation material, assignments, technical reports, and presentations prepared by the trainees[1].

The proposed work plan is designed to be adaptable for various mission needs within the nanosatellite class, with a particular focus on CubeSat-standard systems. It consolidates the knowledge transferred during the workshops into a development roadmap.

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[1] The detailed learning material developed within WP6 is not included here for the sake of conciseness, but can be made available as a separate data package if required.

2 Work Package 6 Activities

The work package revolved around three main events aimed at laying down the foundation of a workplan for the design and assembly of nanosatellites in Africa, namely:

a) A starting, on-site workshop, held at Cape Town University of Technology (CPUT) form the 10th to 16th of March 2024
b) An intermediate, virtual workshop, held from the 10th to 16th of February 2025.
c) A final, on-site workshop, held at Cape Town University of Technology (CPUT) from August 10th to August 16th 2025.

The aim of the events was to promote knowledge transfer towards Africa in the field of space missions science and technology using small satellite platforms.

Thanks to a combination of frontal lectures and hands-on sessions, the workshops addressed the following topics:

- Fundamentals of astrodynamics
- Lifecycle of a space mission, requirements and systems engineering
- Nanosatellites mission design
- Concurrent Design Facility approach to mission design
- Nanosatellites subsystems
- EMC and Finite Elements Analysis
- Sensors for space exploration
- Environmental aspects

Highlights of the two on-site workshops included:

- 2+2 days of training sessions with several nanosatellite educational kits
- Visits and demo sessions at CPUT facilities, which include clean rooms, thermal cycle chambers, RF equipment testing.
- One-day visit to SANSA, the South African National Space Agency
- One-day visit to Howteq Assembly Integration and Testing facility
- Mission design case studies

This first workshop has been the start of a continuing learning path lasting 18 months, being followed by progress meetings, an intermediate virtual workshop, and a final on site workshop.

The aim of virtual Workshop 2, intended to hosting the participants from the March 2023 Workshop at CPUT, plus new attendees from within the consortium, was to give the attendees the chance to present their work in topics related to Space Engineering faced during the homework assignments originated from Workshop 1, or at their home institutions.

Work Package 6 culminated in the Final Workshop, which completed the learning path thanks to new mission design activities using state-of-the art software for concurrent design, along with new hands-on training sessions and learning skills on the topic of electromagnetic compatibilities.

The visit to the Houwteq Assembly Integration and Testing (AIT) facility allowed trainees to appreciate how the lifecycle of a satellite does not end with its design, but requires specialised skills and infrastructure for AIT.

As an outcome of the continuous learning path fostered within the WP, participants are now able to transfer the knowledge gained during the workshops into projects at their home institutions.

Some of the key outcomes are summarized as follows:

- **Homework/presentations** prepared by the trainees (see Annex)
- 2 MSc thesis produced by students involved in the work package, namely:
  - Nick Warren, topic "Earth's magnetic field, magnetic reversals, and asteroids" (WITS)
  - Emily-Rose Steyn, topic: "Measuring quality of life in South Africa from satellite images using machine learning" (WITS)
- **Hands-on activities** on real nanosatellite components
- **Interaction with** relevant **stakeholders** of the Space sector in Africa, especially industry and research institutes, not limited to those directly involved in the WP. Notable contributions included:
  - **AAC Space South Africa**, with Managing Director Dr. Robert Van Zyl, being an instructor at the first workshop and organizer of the hands-on training session at the final workshop.
  - NMD - **Nanosatellite Missions Design**, with founder Dr. Ifriky Tadadjeu, being an instructor during the final workshop.
  - **ISIS Space South Africa** – with the manager of the South Africa premises, Mr Johan Erasmus, being an instructor during the final Workshop for hands-on training on **real nanosatellite components**.
  - **Spaceteq** company hosting a visit on Aug. 13th 2025 at its Houwteq **assembly and integration** facilities, including clean rooms, thermal-vacuum ovens, anechoic chamber, mechanical and vibration.
  - South Africa National Space Agency (SANSA), hosting a visit at its Hermanus facilities on March 13th 2024, delving into **space science** and **sensors for space missions**.

In the following table, a mapping is provided to confirm that all relevant WP6 indicators tied to D6.1 were addressed through the workshop series, with verifiable outputs in the form of training materials and participants' work.

WP6 Activities and Coverage of Objectives/Indicators

WP6 Objective / Indicator	**Related Activity**	**Workshop Content**	**Evidence / Verification**
Creation of a project plan for designing and assembling nanosatellites (D6.1)	Design-focused lectures, case studies, group exercises	Mission Analysis & System Engineering; subsystem design; AIV; ground segment, Concurrent Design Facilities	Workshop slides and learning material (e.g. 5.3.2, 5.5), attendance lists (5.1.1, 5.3.1, 5.3.3); this deliverable
Training of at least 20 research staff from African HEIs	In-person WP6 workshops at CPUT, March 2024 and August 2025	Mission design ADCS, Power Systems, Communications, Propulsion	Attendance lists (5.1.1, 5.3.1, 5.3.3)
Promotion of collaborative actions between African and EU partners in satellite science and technology	Site visits, networking and social events	Integration of industry experts; joint design exercises;	Workshop agendas (5.1, 5.2, 5.3.1)
MSc theses and internships	MSc final project work and internships' related activities	MSc students' presentations on Day 1 of the Virtual Workshop	MSc project abstracts (5.4.3), internship reports (5.5)
Creation of nanosatellite components for training	Lab-based, hands-on training (ESAT platform, ISIS Space training kits)	Embedded hardware / software integration	Lab session notes (5.6), software in support of the training sessions

3 Workplan for the Design and Assembly of Nanosatellites

3.1 Identifying User Needs for a Nanosatellite program in Africa

The need for Nanosatellite programs in Africa stems from the need to solve problems for which space missions provide the most efficient and cost effective solutions over time. These problems are already partially solved with data from existing satellites operated by friends and partners of Africa. However, sustainability of space-based solutions for Africa has to be secured by sufficient sovereignty at institutional level, business competitiveness at economic level, and scientific research independence at a more fundamental knowledge creation level.

Since their invention, nanosatellites have been a consistent educational vehicle for the acceleration of human capacity development globally. While they have also become a pivotal part of the space industry from a business perspective, they still remain the most effective vehicle to develop human capacity in space technologies.

Be it for needs of sovereignty, business, R&D, or human capacity development, the particularities and specificities of African challenges require a fast, affordable, low risk and effective way to access space. Today, Nanosatellites are still the best way to meet these needs with African space-based solutions.

3.2 Mission Design Principles

The successful development of a nanosatellite begins with a clear and methodical mission design process. While small satellites offer the advantages of reduced cost and shorter development times compared to larger spacecraft, they still require the same rigour in defining objectives, allocating resources, and ensuring subsystem compatibility. A robust mission design framework ensures that all engineering activities are guided by coherent, verifiable requirements and that trade-offs are made consciously, with a full understanding of their impact on mission performance.

This work plan adopts a **systems engineering approach**, following the principles defined in the European Cooperation for Space Standardization (ECSS) and structured around the **V-model lifecycle**. This methodology enables the team to progress from high-level needs identification to detailed subsystem design and, ultimately, to integration, verification, and operations, while maintaining traceability between requirements, design decisions, and verification activities.

3.2.1 Mission design in a Concurrent Design approach

At its core, Concurrent Engineering Design is used for the design of multidisciplinary systems which are inherently relatively complex, and involve a wide range of stakeholders from various backgrounds (technical, institutional, financial, managerial, socio-economic, etc).

It involves designing technological systems with the simultaneous contributions of all stakeholders such that each understands how others are affected by them, how they affect others, and how the entire system integrates. Everyone understands the “big picture” and participates in a process whereby efforts are made to converge towards a common goal taking into account all constraints and interfaces (technical, legal, financial, socio-economic, etc). This is achieved by organized Concurrent Design Sessions, carried out periodically in a specifically designed room called a Concurrent Design Facility (CDF).

A well executed concurrent design implementation reduces the cost and time of design while increasing the reliability of the designed system. This is because the process itself significantly reduces the probability of any part of the whole system being redesigned or rebuilt.

Concurrent design of spacecrafts and space missions has been known to increase the reliability of nanosatellite space systems while reducing the design time from an average of 2 years down to about 3 months. This scale of efficiency is true for all categories of satellites and space missions.

With the right tools, efficiency can further be increased with the creation of subsystem and component catalogs from successful designs. This allows for the reuse of work that has been known to be previously successful, without omitting any potential modifications where necessary. Such tools include (but are not limited to) the CNES Concurrent Design Tools which include packages such as IDM-CIC, IDM-VIEW, SIMU-CIC, VTS Timeloop, RF-Comlink, OPALIS, and more. These tools are open to use and customizable. They are therefore ideal for both training and real-world applications, even in environments with very distinct specificities.

As part of the Final WP6 workshop held at CPUT in August 2025, participants undertook a **two-day concurrent design training session**. The activity provided practical experience with the CNES CDF software tools and demonstrated their application to representative mission scenarios.

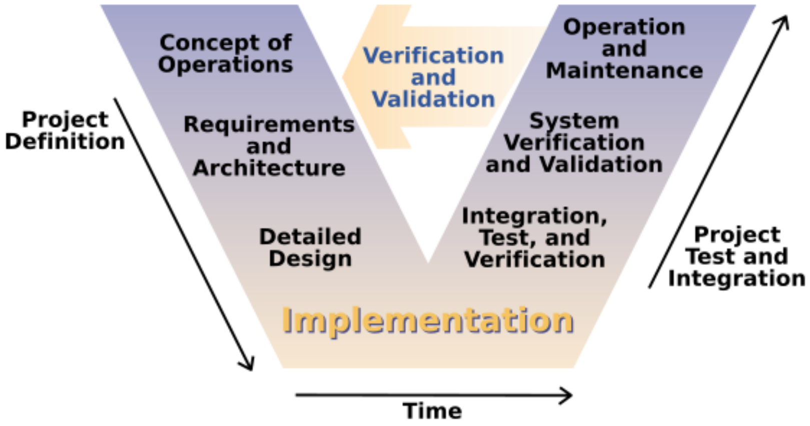
3.2.2 Systems Engineering Flow

The development process starts with the mission’s overarching goals and progresses through several well-defined steps:

1. **Needs Identification** – Understanding user needs and mission drivers, whether scientific, technological, or commercial, and defining clear success criteria.
2. **Requirements Definition** – Translating these needs into measurable and verifiable system-level requirements, then cascading them down to subsystem specifications.
3. **Concept of Operations (ConOps)** – Describing how the mission will be conducted to meet the requirements, including mission phases, operational scenarios, resource allocation, and contingency strategies.

4. **Preliminary Design** – Generating possible technical solutions, performing feasibility analyses, and identifying key trade-offs.
5. **Detailed Design** – Finalising subsystem configurations, materials, and processes, and documenting interface definitions.
6. **Implementation** – Manufacturing, assembly, and integration of components into the flight model.
7. **Operation and Disposal** – Conducting the mission according to the operations plan and executing an end-of-life strategy that complies with space debris mitigation guidelines.

This flow is represented in the **V-model** diagram, which illustrates the parallel development of requirements and verification plans. The left-hand side of the "V" defines and decomposes requirements, while the right-hand side integrates and verifies them, ensuring that each requirement is validated against the original mission needs.



V-model lifecycle adapted for nanosatellites

3.2.3 Requirements Flow-Down

A critical element of systems engineering is **requirements traceability**. Every subsystem requirement must link directly to a mission or system-level requirement. This ensures that no unnecessary features are designed and that every design choice supports a verified mission need.

The following table provides few examples of flow-down form Mission objectives to subsystem requirements

Mission Objective	System Requirement	Subsystem Requirement
Capture 5 m GSD multispectral images	Pointing accuracy ≤ 0.1°	ADCS shall achieve 3-axis stabilisation with jitter ≤ 20 arcsec
Download 500 MB/day	S-band downlink ≥ 1 Mbps	Communications subsystem shall use QPSK modulation, coding rate ≥ 1/2

Such a flow-down approach allows for consistent design decision-making, early detection of requirement conflicts, and systematic preparation for verification activities.

In formal project documentation, these requirements must given **unique alphanumeric identifiers** following common standards (such as ECSS-E-ST-10-06). This coding facilitates easy reference, change tracking, and automated requirements management. The table below shows an example of traceability for the same requirements using a simplified ECSS-like coding structure:

Requirement ID	Description	Requirement Level	Parent Requirement(s)
M-001	Capture 5 m GSD multispectral images	Mission	–
SYS-ADCS-010	The system shall have a pointing accuracy ≤ 0.1°	System	M-001
SUB-ADCS-020	The ADCS shall achieve 3-axis stabilisation with jitter ≤ 20 arcsec	Subsystem	SYS-ADCS-010
M-002	Download 500 MB/day	Mission	–
SYS-COM-030	The system shall provide an S-band downlink ≥ 1 Mbps	System	M-002
SUB-COM-040	The communications subsystem shall use QPSK modulation, coding rate ≥ 1/2	Subsystem	SYS-COM-030

This approach ensures that for any given subsystem-level requirement, its origin and purpose can be traced back to a higher-level mission driver, supporting effectively the technical reviews.

3.2.4 Concept of Operations – ConOps

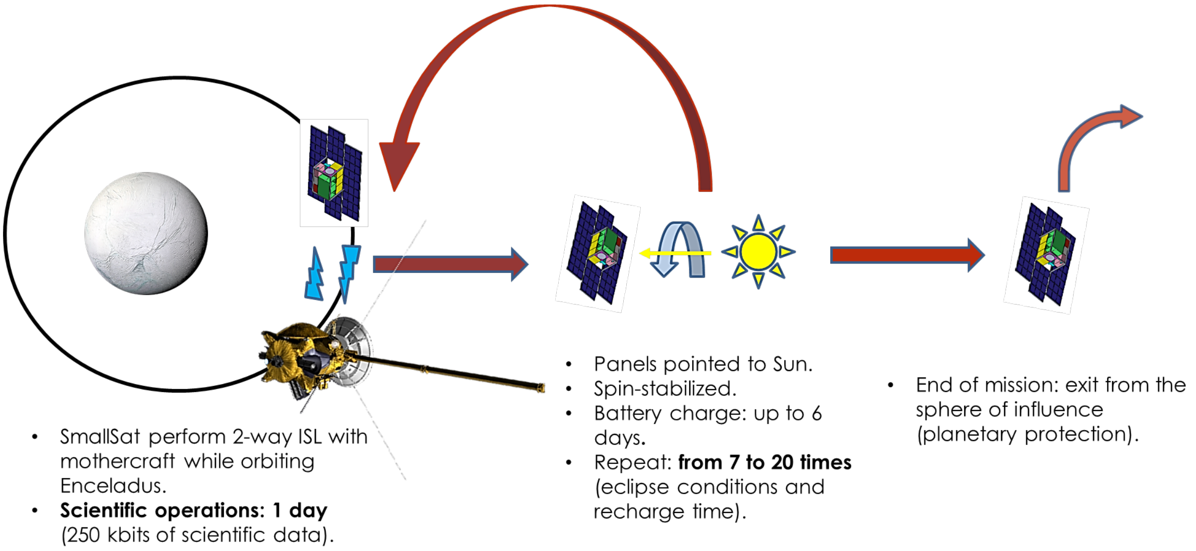
The Concept of Operations (ConOps) describes how the nanosatellite mission will be executed from launch through disposal, linking high-level mission objectives to the detailed technical and operational requirements. It provides a clear, shared understanding of the mission's intended use and the operational environment for all stakeholders. For nanosatellite projects, the ConOps typically defines:

- **Mission phases** – Launch and Early Orbit Phase (LEOP), commissioning, nominal operations, and deorbit/disposal.
- **Operational timelines** – key events such as payload activation periods, communication windows, and maintenance activities.
- **Resource planning** – allocation of power, data handling capacity, and ground station access for each phase.

Within the work plan for developing a nanosatellite mission, the ConOps serves primarily to:

1. **Align stakeholders** – ensuring that universities, agencies, and industry partners share a consistent vision of the mission operational goals and constraints.
2. **Support requirements definition** – providing the operational basis for deriving measurable technical specifications for the satellite subsystems.
3. **Guide training activities** – acting as a practical reference during workshops and hands-on sessions, facilitating knowledge transfer of operational best practices to African HEIs.

In practice, a ConOps is often summarised through a diagram or infographic that captures mission phases, key interactions, and operational timelines at a glance, making it easier for all stakeholders to interpret and providing a visually engaging reference for the entire team. It is advised to establish the ConOps very early in the design process, to reduce the risk of misaligned expectations.



- SmallSat perform 2-way ISL with mothercraft while orbiting Enceladus.
- **Scientific operations: 1 day** (250 kbits of scientific data).

- Panels pointed to Sun.
- Spin-stabilized.
- Battery charge: up to 6 days**.**
- Repeat: **from 7 to 20 times** (eclipse conditions and recharge time).

- End of mission: exit from the sphere of influence (planetary protection).

Example of a ConOps infographic for a CubeSat companion mission to Enceladus.

3.2.5 CubeSat Standard and Buy-vs-Build Decision – Context for African Missions

The **CubeSat Design Specification (CDS)** has become the de facto standard for nanosatellite platforms worldwide. It defines the physical dimensions, mounting interfaces, and deployment constraints for standardised unit sizes such as 1U (10×10×10 cm), 3U, 6U, 12U, and beyond. This standardisation has fundamentally transformed access to space for smaller organisations, including universities, research institutes, and emerging space agencies.

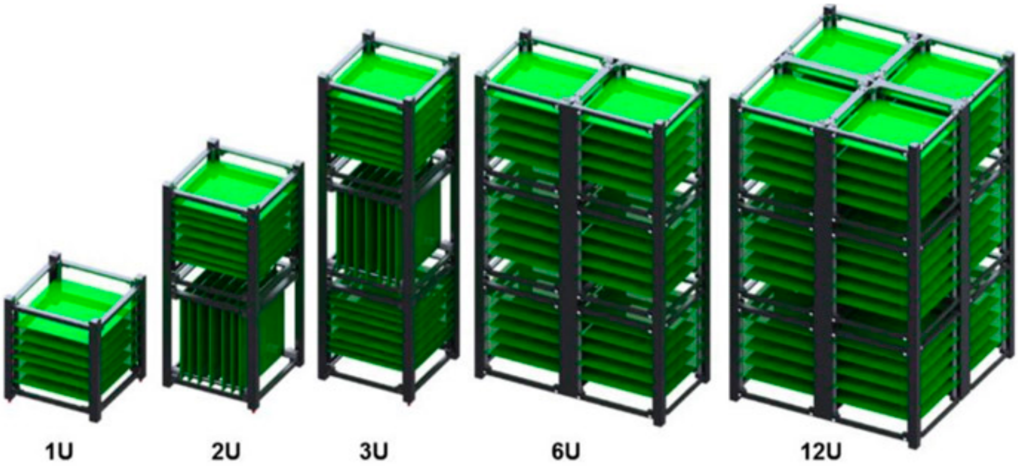
In the African context, the relevance of the CubeSat standard to the creation of a bespoke work plan is particularly strong:

- Lower development costs – CubeSat hardware benefits from a competitive global market with multiple suppliers, reducing the cost barrier for new entrants.
- Faster development times – Availability of commercial off-the-shelf (COTS) modules shortens the design and manufacturing phase, enabling missions to be realised within academic or funding cycles.
- Launch opportunities – Many launch providers and rideshare programmes offer standardised CubeSat deployers, increasing the frequency and affordability of launch slots.
- Capacity building – CubeSat projects provide hands-on experience for students and early-career engineers, accelerating skills transfer in both systems engineering and subsystem-specific expertise.
- Modular scalability – Designs can start with a 1U demonstrator and evolve into larger 3U/6U platforms for more complex missions, leveraging the same work plan structure.

Within the CubeSat framework, teams must still decide between purchasing integrated COTS subsystems (“buy”) and developing them in-house (“build”). This decision is especially critical in environments where supply chains, import/export regulations, and local manufacturing capabilities vary widely.

- **Buy** – Faster deployment and lower technical risk, with the trade-off of higher dependence on external suppliers and potential vulnerability to export control restrictions.
- **Build** – Greater control over the design, increased local manufacturing capability, and stronger knowledge retention, but at the cost of longer development times and potentially higher technical risk.

For the purposes of this deliverable, the CubeSat standard is adopted as the main platform baseline, as it provides the most viable path for African space stakeholders to develop and launch operational missions within realistic budget and schedule constraints, while building local capability for future, more ambitious spacecraft projects.



CubeSat size variants (source: https://www.asi.it/wp-content/uploads/2023/01/Satellite_form-1.jpg)

3.2.6 Orbit–Payload–Subsystem Dependency

Orbit selection affects every subsystem and must therefore be considered early in the mission design process. Parameters such as altitude, inclination, and local solar time influence coverage, revisit time, radiation environment, and thermal cycles.

For example:

- Higher altitudes reduce atmospheric drag but lower imaging resolution for a given payload.
- Sun-synchronous orbits ensure consistent lighting for Earth observation and stable solar array performance.
- High-inclination orbits maximise ground coverage for high-latitude regions but require more ΔV for injection.

3.2.7 Review Milestones

At defined points in the development lifecycle, formal reviews are conducted to ensure that requirements are met and risks are understood:

- **System Requirements Review (SRR)** – Confirms that mission and system-level requirements are complete, consistent, and verifiable.
- **Preliminary Design Review (PDR)** – Validates that the preliminary design meets requirements with acceptable technical and programmatic risk.

- **Critical Design Review (CDR)** – Confirms that the detailed design is mature, all risks are mitigated, and manufacturing can proceed.
- **Flight Acceptance Review (FAR)** – Verifies that the integrated satellite meets all acceptance criteria and is ready for launch.

These reviews serve as a key opportunity to engage stakeholders, identify potential issues before they escalate, and formally document design maturity. Each review typically results in an action list that must be addressed before the next project phase can begin. In the context of nanosatellite development, where timelines are often compressed, careful preparation for each milestone is essential to avoid delays in integration and launch.

3.3 Mission Phases and Deliverables

The development of a nanosatellite follows a structured set of phases, each with specific objectives, activities, and outputs.

While the underlying logic is similar to that of large spacecraft, nanosatellite programmes often operate under tighter schedules and budgets, which means the phases are shorter and sometimes partially overlapped.

Nevertheless, adhering to a clear phase structure helps maintain project discipline, ensures that all stakeholders share a common understanding of progress, and enables timely identification of technical or programmatic risks.

3.3.1 ECSS Lifecycle Adaptation for Nanosatellites

The European Cooperation for Space Standardization (ECSS) defines a standard lifecycle for space systems, broken down into Phases 0 through F.

In the context of nanosatellite development, this lifecycle is typically adapted to reflect the reduced scale of the platform and the need for agile decision-making, while retaining the essential logic of progressive design maturation, risk reduction, and verification.

Although the typical mission lifecycle is inherently sequential, nanosatellite-based projects often benefit from an *agile* approach within phases. For example, while subsystem requirements are still being refined, early hardware prototypes can be built and tested to reduce technical risk ("protoflight" or "flat-sat" approaches). This parallelism accelerates learning and allows earlier detection of integration issues, but it must be carefully managed to avoid redesigns and multiple iterations.

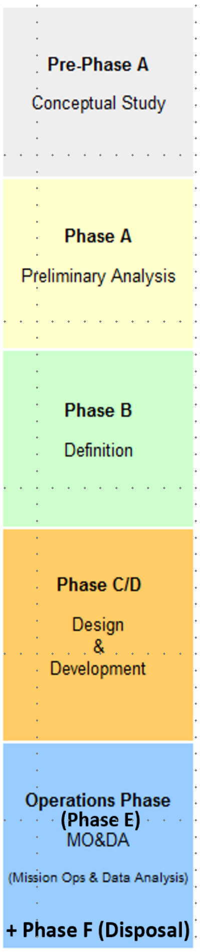
3.3.2 Phase Transitions and Reviews

Each phase concludes with a formal review to confirm readiness to proceed to the next stage. These reviews are essential for maintaining quality and ensuring that no critical steps are overlooked. In nanosatellite projects, review packages are often streamlined compared to large missions, but they should still capture:

- The current status of design maturity
- Updated risk assessments
- Any open actions from previous reviews
- A plan for the upcoming phase, including schedule and resources

Review outcomes typically fall into one of three categories:

1. **Go** – proceed as planned.
2. **Conditional Go** – proceed once specific actions are completed.
3. **No-Go** – hold progression until major issues are resolved.



Phase	Objective	Typical Duration	Key Deliverables
0 – Mission Analysis	Define user needs, assess feasibility, explore options	Weeks to a few months	Mission Needs Statement, Preliminary CONOPS, Feasibility Assessment
A – Feasibility	Select baseline mission concept, assess risks	2–3 months	Feasibility Report, Initial Requirements Baseline
B – Preliminary Definition	Develop preliminary design for all subsystems	3–6 months	System Requirements Document (SRD), Preliminary Design Review (PDR) data package
C – Detailed Definition	Finalise detailed design and prepare for manufacturing	4–8 months	Critical Design Review (CDR) data package, Assembly Integration and Verification (AIV) Plan
D – Qualification & Production	Manufacture, integrate, and test flight hardware	4–6 months	Assembly and Test Reports, Flight Acceptance Review (FAR) data package
E – Utilisation	Operate the satellite and payload in orbit	Mission lifetime	Operations Procedures, Anomaly and Performance Reports
F – Disposal	Safely dispose of spacecraft at end-of-life	Weeks to months	End-of-Life Report, Passivation Confirmation

Space mission lifecycle.

3.4 Work plan for design and development of the nanosatellite subsystems

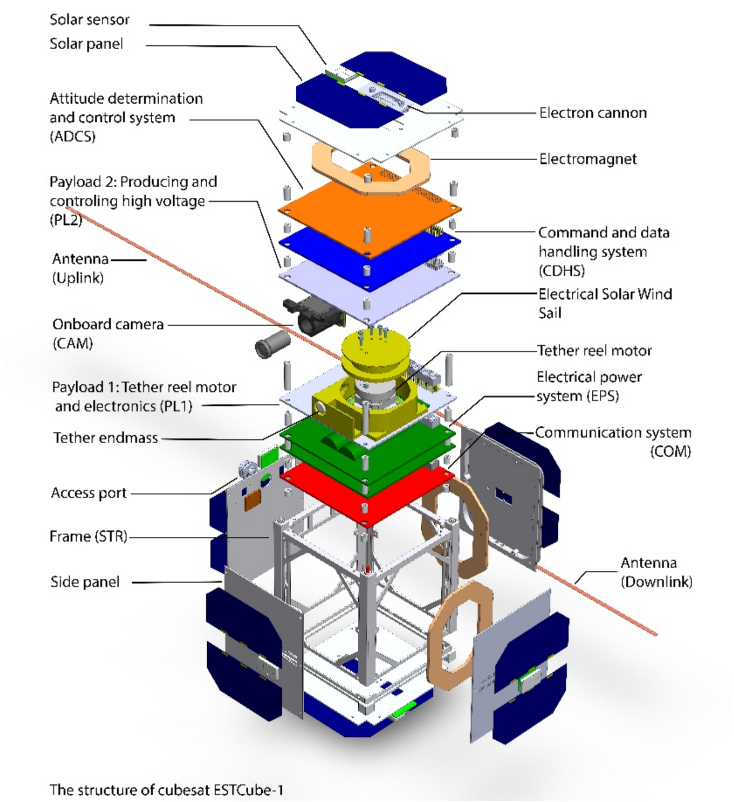
This section outlines the work plan for the design and development of the nanosatellite platform subsystems.
The presentation is intentionally structured around bullet points and checklists to provide a clear, step-by-step reference framework. This format is intended to facilitate systematic progress monitoring and verification at each stage of the design, development, and implementation process.

The following subsystems are covered in detail in the subsequent sections:

- Structure & Thermal Control
- Electrical Power System (EPS)
- Attitude Determination & Control System (ADCS)
- Communications Subsystem (TT&C & Payload Downlink)
- Onboard Data Handling (OBDH) & Software

- Propulsion (if applicable)
- Ground Segment

As an illustrative example, below is an exploded view of the EST-1 CubeSat highlighting the subsystems and their physical arrangement within the inherently modular structure.



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3.4.1 Attitude Determination and Control Subsystems

The Attitude Determination and Control System is responsible for knowing and controlling the orientation of the satellite in space. In a nanosatellite, ADCS performance directly influences mission success: imaging payloads require precise pointing to achieve the intended resolution; communications links depend on antenna alignment; and solar arrays must be oriented to maximise energy generation.

For these reasons, ADCS design must be approached early in the project, in parallel with payload definition and orbit selection, since these parameters set the baseline pointing requirements.

3.4.1.1 Functional Role and Mission Context

A nanosatellite in orbit is subject to a variety of forces and torques, some beneficial and some disruptive. Beneficial effects, such as gravity-gradient stabilisation, can sometimes be exploited to passively maintain orientation, reducing the need for active control. However, for most modern missions—especially those involving high-resolution imaging, narrow-beam antennas, or agile retargeting—active control is required to counteract disturbances and execute slewing manoeuvres.

The ADCS can be functionally divided into two tightly coupled parts:

1. **Attitude Determination** – the estimation of the satellite's current orientation relative to a defined reference frame, using a combination of onboard sensors and estimation algorithms.
2. **Attitude Control** – the generation of control torques via actuators to adjust or maintain the desired orientation.

3.4.1.2 Design Inputs

Several mission parameters drive the ADCS design:

- **Orbital parameters** – altitude, inclination, and local lighting conditions influence the available sensor options (e.g. sun sensors require line-of-sight to the Sun) and the magnitude of environmental disturbances.
- **Payload pointing requirements** – define the required steady-state accuracy, stability (jitter), and agility (slew rate).
- **Lifetime and operational modes** – determine actuator lifetime requirements and the level of redundancy needed.
- **Disturbance environment** – includes gravity-gradient, aerodynamic drag, solar radiation pressure, and geomagnetic torque. For a CubeSat-class satellite, these can be significant relative to the available control authority.

3.4.1.3 Design Process

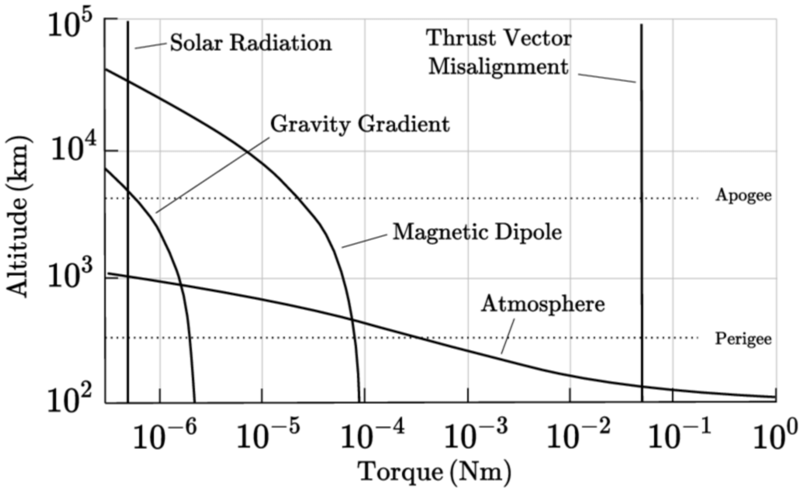
The ADCS design process follows a logical sequence, starting from mission needs and ending with validated hardware and software ready for integration:

1. **Definition of Operational Modes**

   Each mission phase is associated with an ADCS mode. Immediately after deployment, the priority is to reduce any residual angular rates imparted by the launcher ("detumbling"), often using a simple magnetic control law such as B-dot. Once stabilised, the satellite may switch to coarse Sun-pointing to ensure power generation. During nominal payload operations, modes such as nadir-pointing (Earth observation) or inertial-pointing (astronomy, inter-satellite links) are used.

2. **Disturbance Torque Budget**

   A disturbance budget quantifies all significant torques acting on the spacecraft. For example, aerodynamic torque dominates in very low Earth orbit (VLEO), while solar radiation pressure can be important for satellites with large deployable panels. These estimates are essential for sizing actuators.



Sources of disturbance torque (Credits V. Tuttas, doi: 10.13140/RG.2.2.31214.89927).

3. Sensors Selection

Attitude sensors vary in complexity, accuracy, and cost:

- Low-accuracy, low-cost: coarse sun sensors, magnetometers.
- Medium accuracy: horizon sensors, MEMS gyroscopes.
- High accuracy: star trackers, fibre-optic gyroscopes.

CubeSat-class ADCS modules often integrate several of these to allow for sensor fusion, improving robustness.

4. Actuator Selection and Sizing

Common options include reaction wheels for precise 3-axis control, magnetorquers for coarse control and wheel desaturation, and small thrusters for high-torque manoeuvres. Actuators must be sized so that their maximum torque exceeds the worst-case disturbance by a comfortable margin—typically 10× for reaction wheels. Momentum storage capacity must also cover the accumulation between desaturation opportunities.

5. Control Law Development

Control algorithms range from simple proportional-derivative (PD) loops to advanced model predictive control. For small satellites, PID controllers are common due to their simplicity, but the control gains must be tuned to the spacecraft's inertia and actuator capabilities. Magnetic control laws must account for the variation in the geomagnetic field along the orbit.

6. Integration with Onboard Data Handling

ADCS performance is influenced by the OBC's processing speed and available data bus bandwidth. Sensor measurements and actuator commands must be synchronised within the control loop's sampling period. Real-time operating systems are often used to ensure deterministic timing.

3.4.1.4 Verification and Testing.

Testing occurs in incremental steps:

- Software-in-the-loop (SIL) to verify algorithms against a simulated spacecraft dynamics model.
- Hardware-in-the-loop (HIL) to include real sensors and actuators in a simulated orbital environment.
- Specialised facilities such as Helmholtz cages (for magnetic systems) or air-bearing tables (for free-rotation tests) are used to validate control performance before flight.

3.4.1.5 Deliverables

By the end of the ADCS design phase, the following output should be produced:

- Disturbance torque budget spreadsheet.
- Sensor and actuator selection rationale, including datasheets.
- Control law description and tuning parameters.
- ADCS interface control document (ICD) with the On-Board Computer.
- Test reports from SIL and HIL verification campaigns.

3.4.1.6 Workflow Checklist – ADCS Design & Development

The following checklist is recommended to be used to guide the development workflow

- Define mission pointing needs from payload and communication requirements.
- Select operational modes (detumbling, coarse pointing, fine pointing, safe mode).
- Build disturbance torque budget based on orbit and geometry.
- Select sensors meeting accuracy, power, and cost constraints.
- Select and size actuators to exceed worst-case torque/momentum demands.
- Develop and tune control laws for each mode.
- Integrate ADCS hardware/software with OBC and other subsystems.
- Verify performance via simulation (SIL), hardware-in-the-loop (HIL), and environmental tests.

3.4.2 Electrical Power System (EPS)

The Electrical Power System is the spacecraft's energy backbone. It is responsible for generating, storing, conditioning, and distributing electrical power to all onboard subsystems and payloads. For nanosatellites, where volume and mass constraints are severe, the EPS design must balance efficiency, reliability, and simplicity.

A robust EPS ensures uninterrupted operations during orbital eclipse periods, provides sufficient peak power for high-demand modes (e.g., payload imaging and downlink), and maintains healthy battery operation over the mission lifetime.

3.4.2.1 Functional Role and Mission Context

In low Earth orbit, a nanosatellite typically spends 30–40% of each orbit in Earth's shadow, during which it must rely solely on stored energy. The EPS therefore has two primary functions:

1. **Power Generation** – converting solar energy into electrical energy, usually via photovoltaic (PV) arrays.
2. **Energy Storage and Management** – storing excess power in batteries when generation exceeds consumption, and delivering it during eclipse or high-load conditions.

Secondary functions include voltage regulation, load protection, and power distribution, often via multiple regulated and unregulated buses.

3.4.2.2 Design Inputs

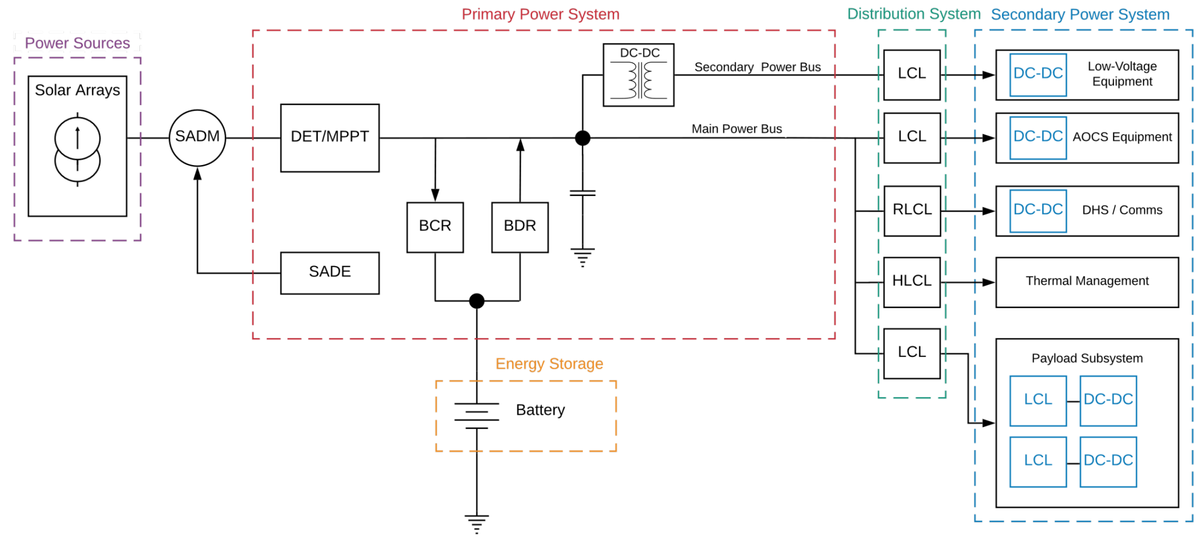
EPS design depends on:

- **Power budget** – a detailed profile of average and peak loads for all modes of operation.
- **Orbit profile** – affects eclipse duration, solar incidence angle, and temperature cycles.
- **Mission lifetime** – determines required battery cycle life and degradation margins.

- **Thermal environment** – influences solar cell efficiency and battery performance.
- **Redundancy and fault tolerance** – dictated by mission criticality.

3.4.2.3 Design Process

1. **Power Budgeting**
   The first step is to construct a comprehensive power budget, allocating average and peak power to each subsystem. This budget must account for operational modes (commissioning, nominal, safe mode) and include margins for uncertainties.
2. **Solar Array Selection and Sizing**
   Photovoltaic cells are the primary energy source. For CubeSat-scale missions, two technologies dominate:
    - Silicon (Si) cells – lower cost, moderate efficiency (up to 25%).
    - Gallium Arsenide (GaAs) cells – higher efficiency (up to 30%), better radiation tolerance, but more expensive.
    - Arrays are sized to meet end-of-life (EOL) power needs, factoring in radiation degradation, seasonal variations in solar incidence, and shadowing from antennas or deployables.
3. **Battery Selection and Sizing**
   Energy storage must sustain all loads during eclipse. Lithium-ion batteries are the preferred choice for nanosatellites due to their high specific energy and relatively low self-discharge. Sizing is based on:
    - Eclipse duration × average load.
    - Depth of discharge (DoD) limits to extend battery life.
    - Cycle life requirements over mission duration.
4. **Power Regulation and Control**
   Two common strategies for solar array regulation are:
    - Direct Energy Transfer (DET) – simpler, efficient under steady conditions, but may waste available power under variable loads.
    - Maximum Power Point Tracking (MPPT) – optimises power extraction under varying conditions, particularly beneficial for large payloads or variable illumination.



5. **Distribution and Protection**
   Power is distributed via regulated and unregulated buses (e.g., 3.3 V, 5 V, unregulated battery voltage). Latching Current Limiters (LCLs) isolate faulty loads, preventing bus collapse and cascading failures.
6. **Thermal and Mechanical Considerations**
   EPS hardware, especially batteries, must be placed to ensure acceptable temperature ranges. Excessive cold reduces capacity, while overheating accelerates degradation. Mechanical layout must also consider harness routing to minimise voltage drops.
7. **Integration with OBC and AOCS**
   EPS telemetry (voltages, currents, state-of-charge) is continuously monitored by the Onboard Computer (OBC) to support safe-mode decisions and fault recovery. Some missions allow OBC-controlled load shedding to extend survival time in degraded conditions.

3.4.2.4 Verification and Testing

EPS verification involves:

- Electrical interface testing with all loads to validate bus stability.
- Thermal-vacuum cycling to assess performance across expected temperature ranges.
- Endurance cycling of battery packs to confirm capacity retention.
- Sun simulator tests for solar array performance.

3.4.2.5 Deliverables

At the end of EPS design, the following must be delivered:

- Complete power budget with margins.
- Solar array sizing analysis and EOL performance estimates.
- Battery sizing calculations, DoD and cycle life justifications.
- Power regulation topology diagrams.
- Interface Control Document (ICD) for all power buses.
- Test reports from thermal-vacuum, cycling, and interface verification.

3.4.2.6 Workflow checklist – EPS Design & Development

The following checklist is recommended to be used to guide the development workflow

- Establish detailed power budget for all operational modes.
- Select primary power source (PV cell type, configuration).
- Size solar arrays for end-of-life output with degradation margins.
- Select and size batteries to sustain eclipse loads with acceptable depth of discharge.
- Choose regulation topology (DET, S3R, MPPT) based on mission profile.
- Design distribution system with appropriate buses and protection (LCLs, fuses).
- Implement telemetry interfaces for health monitoring and fault management.
- Verify performance via load tests, thermal-vacuum cycling, and endurance testing.

3.4.3 Propulsion

The propulsion subsystem provides controlled thrust to alter the satellite’s obital velocity or attitude. For nanosatellites, propulsion is not always mandatory, but when included it enables key capabilities:

orbit maintenance, collision avoidance, constellation phasing, controlled de-orbit, and, in some cases, attitude control.

The choice of propulsion technology for a nanosatellite is highly constrained by volume, mass, safety regulations, and available power. Small satellites must achieve these functions with limited propellant and modest thrust levels, often balancing performance against simplicity and cost.

3.4.3.1 Functional Role and Mission Context

In low Earth orbit, natural orbital decay due to atmospheric drag is significant, especially below 500 km. For missions requiring extended lifetimes or precise orbital control, on-board propulsion becomes essential. Beyond orbital manoeuvres, propulsion can also support attitude control when integrated into the AOCS, typically for high-torque slews or to desaturate reaction wheels.

3.4.3.2 Design Inputs

- **ΔV budget** – total velocity change needed over the mission, broken down by manoeuvre type.
- **Thrust level requirements** – to meet manoeuvre timelines or control bandwidth needs.
- **Propellant storage constraints** – mass, volume, and tank placement.
- **Safety and handling** – compliance with launch provider and regulatory constraints.
- **Mission lifetime** – to set propellant quantity and hardware durability.

3.4.3.3 Design Process

1. **Define ΔV requirements** using mission analysis (e.g., orbital phasing, drag compensation, de-orbit).
2. Select propulsion class:
    - Cold gas – simple, low ΔV, safe.
    - Chemical monopropellant – higher ΔV, moderate complexity, hazardous.
    - Bipropellant – high performance, generally unsuitable for very small satellites due to complexity.
    - Electric propulsion – high Isp, low thrust, suitable for long-duration burns.
    - Alternative – such as sublimating propellants or water propulsion.

COLD GAS

Courtesy of VACCO

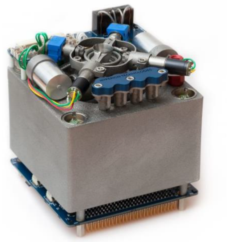
WARM GAS

Courtesy of VACCO

MONOPROPELLANT

Courtesy of VACCO

BIPROPELLANT



Courtesy of AAC Clyde Space

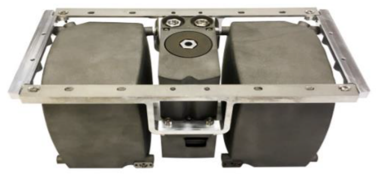
FEEP

Courtesy of ENPULSION

ION

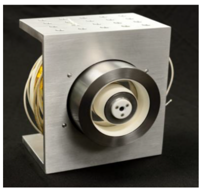
Courtesy of Pale Blue

ELECTROTHERMAL (water)



Courtesy of SteamJet Space Systems

HALL EFFECT



Courtesy of ExoTerra Resources

3. **Propellant mass estimation** using the rocket equation and chosen Isp.
4. **Tank and feed system design**, ensuring compatibility with spacecraft structure and thermal environment.
5. **Thruster placement** for desired torque authority and plume impingement avoidance.
6. **Thermal considerations** for propellant and valve operation.
7. **Integration with AOCS** for coordinated manoeuvres.

3.4.3.4 Verification and Testing

Propulsion testing includes leak checks, valve cycling, thrust stand performance verification, and, if possible, end-to-end firing tests in vacuum conditions. For electric systems, lifetime testing of thruster components is essential.

3.4.3.5 Deliverables

At the end of propulsion subsystem development, the following should be available:

- Mission ΔV budget with breakdown by manoeuvre type.
- Propulsion concept trade-off report with rationale for the chosen system.
- Propellant sizing calculations and tank layout drawings.
- Thruster placement diagram.
- Interface Control Document (ICD) to AOCS, structure, and EPS.

3.4.3.6 Workflow Checklist – Propulsion Design & Development

The following checklist is recommended to be used to guide the development workflow

- Define mission ΔV budget by manoeuvre type.
- Select propulsion class meeting ΔV, safety, and integration constraints.
- Estimate propellant mass and specific impulse (Isp).
- Design tank, feed system, and thruster configuration.
- Analyse structural and thermal interfaces.
- Integrate with AOCS control logic.
- Conduct component-level and integrated system testing.

3.4.4 Communications (TT&C)

The communications subsystem is the lifeline between the satellite and the ground. It enables telemetry, telecommand, and, where applicable, payload data downlink. In nanosatellites, the TT&C link is usually low-rate and omnidirectional (such as VHF,UHF bands) to ensure coverage during initial acquisition and safe mode, while the payload link may be high-rate and directional (such as S-/C-/X-bands).

3.4.4.1 Functional Role and Mission Context

A reliable communications system is essential for mission success. Even if all onboard systems are healthy, a loss of the communication link means the spacecraft can no longer be commanded or monitored. The design must therefore prioritise robustness, regulatory compliance, and compatibility with the ground segment.

CubeSat missions often face strict frequency allocation constraints. Common allocations are:

- VHF/UHF bands – widely used for TT&C, offering simple ground equipment and omnidirectional coverage.
- S-band/X-band – used for high-rate payload downlink, requiring directional antennas and accurate pointing.

For small satellites, link availability is constrained by short orbital passes (typically 5–15 minutes), so data rate, coding efficiency, and automation in ground station scheduling are crucial.

3.4.4.2 Design Inputs

- Payload data volume per orbit/day.
- Required latency for command execution.
- Ground network coverage and capabilities (antenna size, tracking precision).
- Regulatory constraints on frequency and power levels.

3.4.4.3 Design Process

1. **Define Link Requirements**

   Determine minimum data rate, acceptable bit error rate (BER), and allowable command latency.

2. **Link Budget Analysis**

   Include free-space path loss, antenna gains, transmitter power, atmospheric losses, and implementation margins.

3. **Frequency Band Selection**

   TT&C typically in amateur bands (e.g., VHF @145 MHz), or UFF @435 MHz) or commercial allocations; payload data often in S-band or X-band.

4. **Modulation and Coding**

   Simple FSK/AFSK for TT&C; higher-order schemes (QPSK, OQPSK) with CCSDS coding for high-rate payloads.

5. **Antenna Selection**

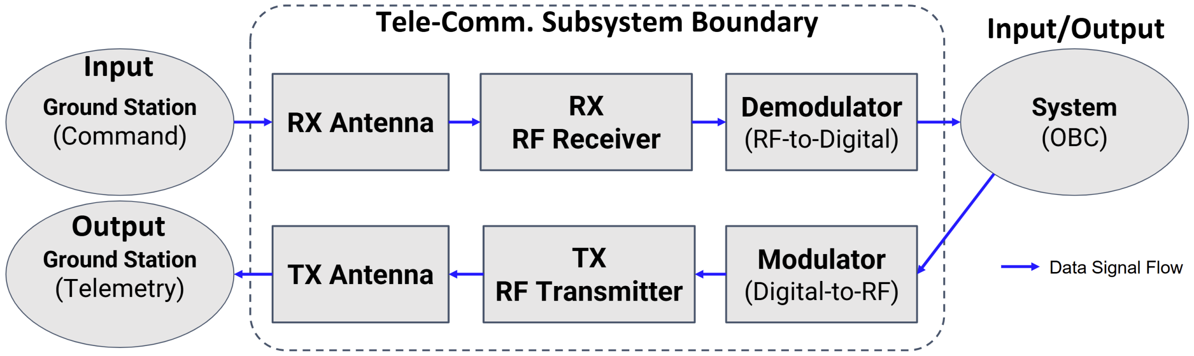
   Deployable high-gain antennas for high-rate links; patch or monopole antennas for omnidirectional coverage.

6. **RF Hardware Selection**

   SDR-based radios for flexibility, or dedicated transceivers for simplicity.

7. **Integration with OBC**

   Implement CCSDS packetisation, command decoding, and telemetry formatting.



Telecom subsystem architecture diagram (credits: https://www.unoosa.org/oosa/en/ourwork/psa/hsti/kibocube.html)

3.4.4.4 Verification and Testing

TT&C verification involves:

- Bench testing with spectrum analyser and signal generator.
- End-to-end ground station tests using a flat-sat setup.

3.4.4.5 Deliverables

At the end of the subsystem development, the following should be available:

- Link budget analysis for all mission modes and geometries.
- Regulatory licensing documentation for the selected frequency bands.
- Antenna configuration drawings and gain patterns.
- RF hardware datasheets and qualification test reports.
- ICD between Comms subsystem and OBC.
- End-to-end link test reports.

3.4.4.6 Workflow Checklist – TT&C

The following checklist is recommended to be used to guide the development workflow

- Define data rate, BER, and latency requirements.
- Perform link budget analysis for worst-case geometry.
- Select frequency band(s) and secure licensing.
- Choose modulation, coding, and antenna types.
- Select RF hardware.
- Integrate with OBC and ground station software.
- Conduct end-to-end link testing.

3.4.5 Onboard Data Handling (OBDH) & Software

The OBDH subsystem coordinates the operation of all other subsystems, manages data flows, and executes the mission timeline. In nanosatellites, the OBDH is typically built around a low-power microcontroller or processor board, running a real-time operating system for deterministic execution.

3.4.5.1 Functional Role and Mission Context

The OBDH handles:

- **Telemetry acquisition** from sensors and subsystems.
- **Telecommand execution**, controlling actuators and mode changes.
- **Payload data handling** – storage, compression, and scheduling for downlink.
- **Fault detection, isolation, and recovery (FDIR)**, allowing the spacecraft to autonomously enter safe mode and preserve basic functions.

A well-designed OBDH ensures smooth coordination of all subsystems without overloading processing resources or causing timing conflicts.

3.4.5.2 Design Inputs

- Processing load from ADCS control loops, payload processing, and communications.
- Data storage needs, including buffers for payload downlink delays.
- Electrical and logical interfaces to each subsystem.
- Reliability requirements, including redundancy and error recovery.

3.4.5.3 Design Process

1. **Hardware Selection**

   Choose an OBC with sufficient CPU power, memory, and I/O ports. Examples include ARM-based CubeSat OBCs or custom designs.
2. **Software Architecture**

   Partition tasks into periodic and event-driven processes. Use an RTOS (e.g., FreeRTOS) for real-time performance.
3. **FDIR Implementation**

   Include watchdog timers, anomaly counters, and recovery scripts.
4. **Telemetry and Telecommand Protocols**

   Implement CCSDS or custom formats, ensuring compatibility with ground systems.
5. **Integration with Subsystems**

   Develop ICDs defining commands, telemetry parameters, and timing.

3.4.5.4 Verification and Testing

OBDH verification involves:

- Software-in-the-loop simulations to validate algorithms.
- Hardware-in-the-loop with subsystems electronics.

- Long-duration reliability runs in a lab environment.

3.4.5.5 Deliverables

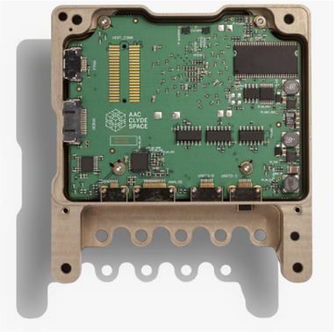
At the end of the subsystem development, the following should be available:

- OBC hardware specification sheet and acceptance test results.
- Software architecture documentation including task scheduling diagram.
- Telemetry and telecommand protocol description.
- FDIR logic flow diagrams and recovery sequence documentation.
- ICDs for all subsystem interfaces.
- Verification reports from SIL, HIL, and long-duration reliability tests.

3.4.5.6 Workflow Checklist – OBDH

The following checklist is recommended to be used to guide the development workflow

- Define processing, storage, and interface requirements.
- Select OBC hardware and operating system.
- Implement software architecture with RTOS.
- Develop FDIR routines.
- Integrate telemetry and telecommand protocols.
- Verify via SIL, HIL, and endurance tests.



Example of CubeSat On-board Computer

© AAC Clyde Space

3.4.6 Structure and Thermal subsystem

The structure provides the mechanical backbone, supporting and protecting all subsystems. The thermal control system ensures all components remain within their operational temperature limits across varying environmental conditions.

3.4.6.1 Functional Role and Mission Context

The structural subsystem must survive the high dynamic loads of launch, maintain dimensional stability, and allow for efficient assembly, integration, and maintenance.

Thermal control is critical for battery performance, payload optics, and electronics longevity. CubeSats typically rely on passive thermal control (surface coatings, insulation), but active heaters may be needed for extreme environments.

3.4.6.2 Design Inputs

- Launch vehicle constraints (envelope, interface, vibration environment).
- Mass budget and centre of gravity requirements.
- Thermal extremes for selected orbit.
- Component layout for accessibility, harness routing, and heat dissipation.

3.4.6.3 Design Process

1. **Structural Design**
   Select frame type (standard CubeSat kit or custom), materials (aluminium alloys are common), and fastening methods.
2. **Structural Analysis**
   Perform finite element analysis (FEA) for static, modal, and random vibration loads.
3. **Thermal Modelling**
   Use orbital environment data to simulate hot and cold cases.
4. **Thermal Control Implementation**
   Apply coatings, MLI blankets, or heaters as required.
5. **Integration Considerations**
   Provide mounting interfaces, harness supports, and access panels.

3.4.6.4 Verification and Testing

Structural/Thermal subsystem verification involves:

- Vibration testing to qualification levels.
- Thermal vacuum cycling to simulate on-orbit extremes.
- Measurement of centre of mass and moments of inertia.

3.4.6.5 Deliverables

At the end of the subsystem development, the following should be available:

- Structural design drawings and 3D CAD models.
- FEA reports for static, modal, and random vibration cases.
- Thermal analysis report with hot/cold case results.
- Thermal control implementation drawings (if applicable for the mission).
- ICDs for mechanical interfaces with all subsystems.
- Qualification test reports from vibration and thermal-vacuum campaigns.

3.4.6.6 Workflow Checklist – Structures & Thermal

The following checklist is recommended to be used to guide the development workflow

- Define mechanical and thermal requirements from launch provider and mission profile.
- Select frame, materials, and fastening methods.
- Perform Finite Element Analysis and thermal analysis.
- Implement passive and/or active thermal control.
- Integrate structural interfaces with subsystems.
- Verify via vibration and thermal-vacuum

3.4.7 Ground Segment

The ground segment comprises all facilities, equipment, and software needed to operate the spacecraft from Earth. For nanosatellites, this often includes a network of small, university-based ground stations.

3.4.7.1 Functional Role and Mission Context

The ground segment performs:

- **Tracking and contact scheduling** based on orbital predictions.
- **Telemetry reception and storage**.
- **Telecommand transmission** for mode changes or payload control.
- **Data processing and dissemination** to users.

In CubeSat operations, automation is essential to maximise the use of short, infrequent passes.

3.4.7.2 Design Inputs

- Contact frequency and duration based on orbit.
- Required data throughput.
- Available antenna types and sizes.
- Network architecture (single station or multi-station).

3.4.7.3 Design Process

1. **Ground Station Configuration**

   Select antenna type (Yagi-Uda for VHF/UHF, parabolic for S-band), rotators, and tracking control systems.
2. **RF Front-End**

   Design signal chain with LNAs, filters, transceivers, and switching matrices.
3. **Mission Control Software**

   Implement pass scheduling, automatic signal Doppler shift correction, and real-time telemetry display.

4. **Network Integration**

   Connect multiple ground stations to share data and increase coverage.

3.4.7.4 Verification and Testing

Ground Segment verification involves

- Over-the-air tests with spacecraft or an engineering model of the TMTC.
- End-to-end simulations of passes, including Doppler shifts and link degradation.

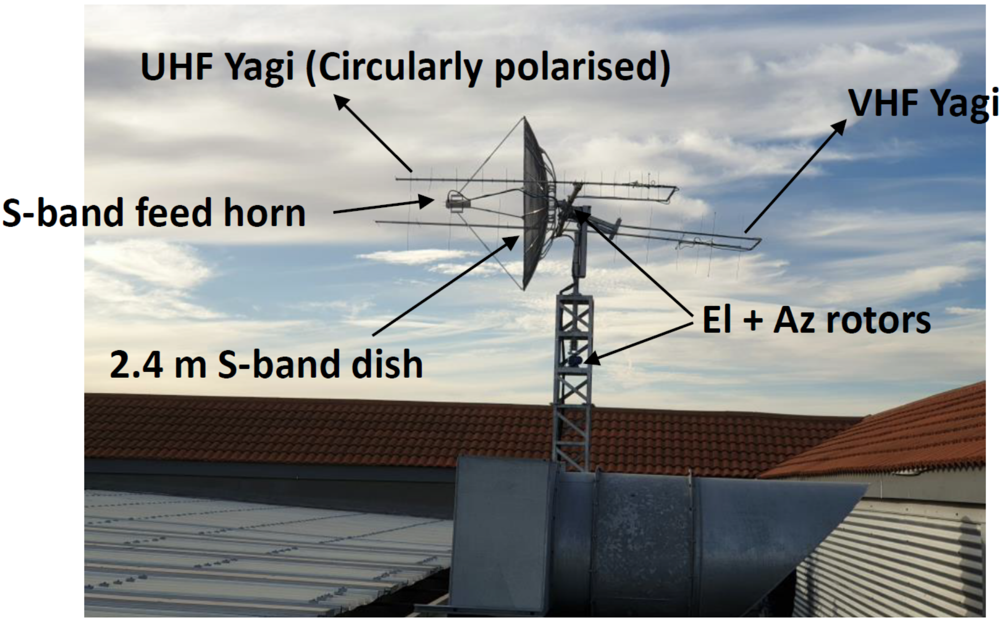
3.4.7.5 Deliverables

At the end of the subsystem development, the following should be available:

- Ground station configuration drawings and equipment list.
- RF front-end schematic.
- Mission control software user manual and interface specifications.
- Space to ground ICD.
- Network architecture diagram if multiple stations are used.
- End-to-end pass simulations and operational readiness test reports.

3.4.7.6 Workflow Checklist – Ground Segment

- Define contact schedule, data rate, and coverage requirements.
- Select antenna, rotator, and RF front-end.
- Implement mission control software.
- Integrate automation for pass scheduling.
- Verify via live or simulated spacecraft passes.



CPUT ground station system (Courtesy of CPUT)

3.5 Assembly, Integration, and Testing

The AIV phase ensures that all subsystems are assembled into a complete spacecraft and that the integrated platform meets all design requirements before launch. This process is critical to reducing technical risk and confirming that the satellite is ready for its operational environment.

3.5.1 Integration workflow

Assembly, Integration, and Verification activities follow a defined sequence to ensure subsystem compatibility, maintain configuration control, and facilitate troubleshooting.

During the participants' on-site visit to the **Howteq AIT premises**, state-of-the-art spacecraft integration facilities were observed, including clean room, thermal-vacuum chambers, optical test-benches.

Integration typically proceeds in three main stages:

1. **Subsystem Integration** – Each flight-qualified subsystem (ADCS, EPS, Comms, OBDH, Payload, Structures, Propulsion) is delivered with an acceptance test report and Interface Control Document (ICD). Integration begins with the mechanical assembly of the structure, followed by the sequential installation of subsystems according to the integration plan.
2. **Functional Testing** – After each integration step, functional tests confirm correct operation and interface compatibility. A "flat-sat" setup is often used prior to final assembly to validate electrical and data connections.
3. **System-Level Testing** – Once integration is complete, the spacecraft undergoes end-to-end testing, simulating nominal and contingency operational modes.

EO-SAT1 Flatsat at Howteq premises (August 13th 2025).

3.5.2 Verification

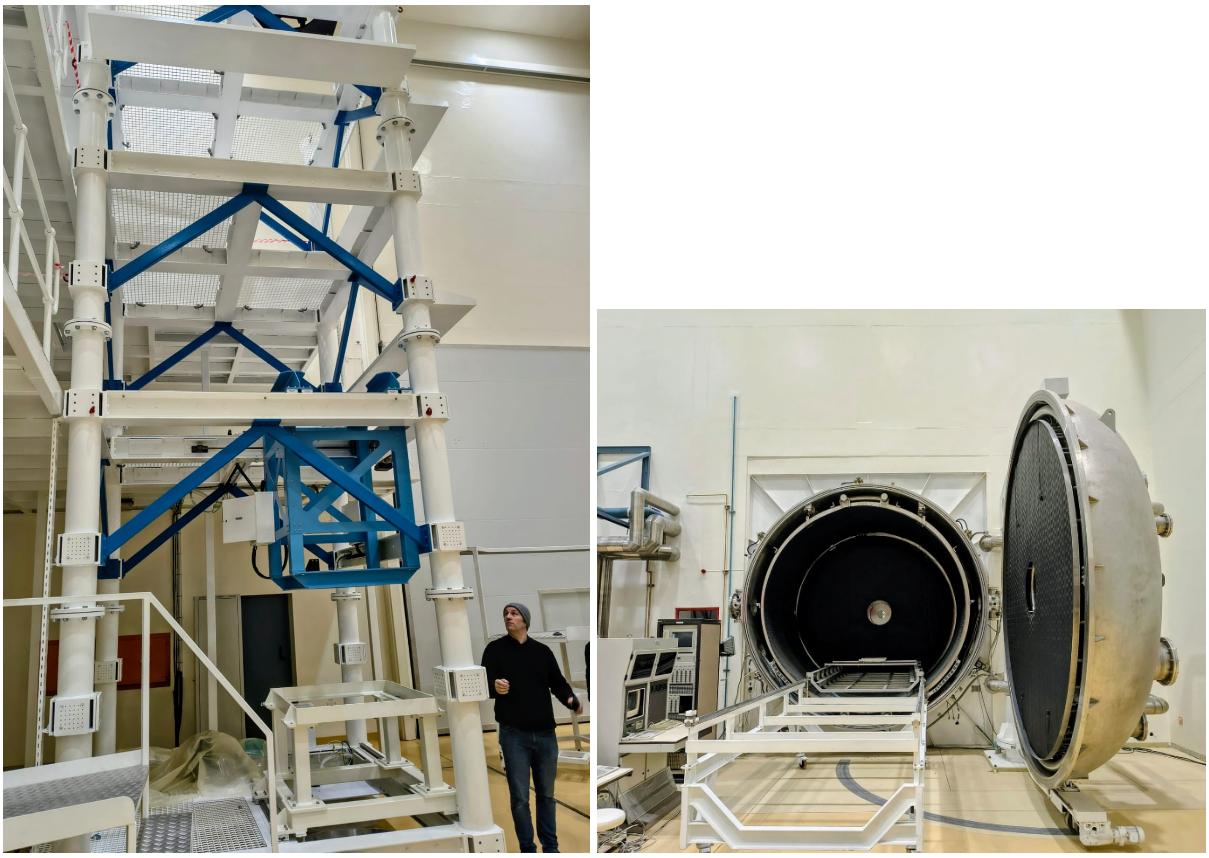
Verification confirms that the integrated spacecraft satisfies all specified requirements and is capable of performing its mission under the expected operational and environmental conditions.

The verification is a critical part of the development process, ensuring that potential issues are detected and addressed before launch. The facility tour demonstrated examples of the typical verification activities that are applied to validate design assumptions.

Typical verification activities include:

- **Vibration Testing** – To simulate launch loads and confirm structural integrity.
- **Thermal-Vacuum (TVAC) Testing** – To verify thermal performance in a vacuum environment under expected orbital temperature ranges.
- **Electromagnetic Compatibility (EMC) Testing** – To ensure subsystems operate without generating or suffering from unwanted interference.

All verification activities must be conducted according to formal test procedures and acceptance criteria, providing evidence of compliance with mission and system requirements.



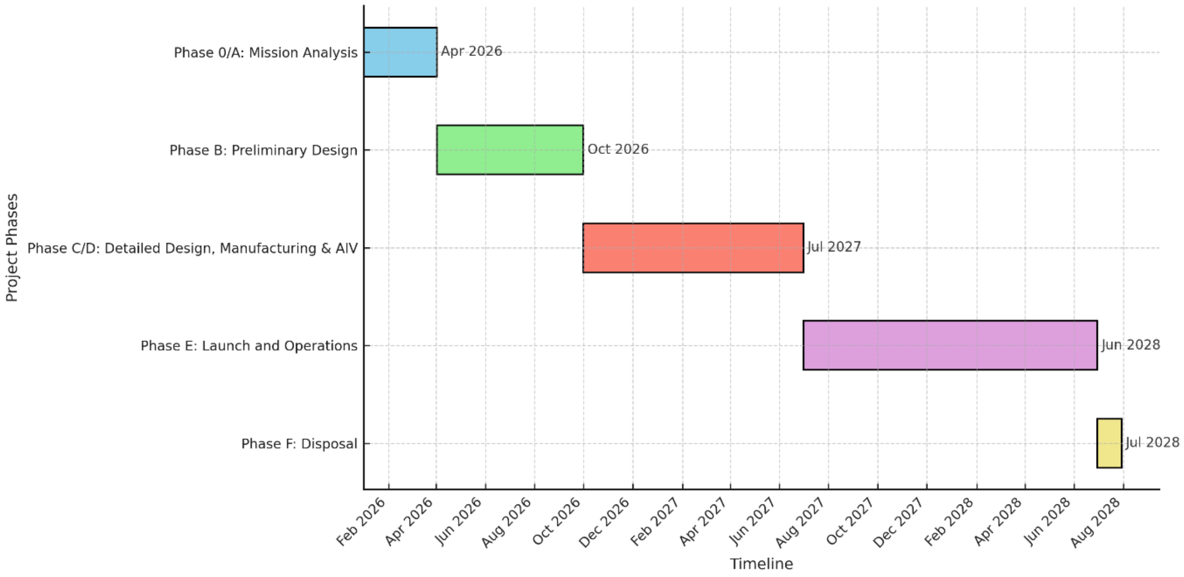
Optical Integration Facility and Thermal-Vacuum Chamber at Howteq premises (August 13th 2025).

3.6 Implementation plan

An implementation plan for the nanosatellite mission development lifecycle shall be set up, that provides a high-level schedule and resource allocation framework. The following temporal allocation of the lifecycle phases is provided as a reference only, aiming at a relatively compressed timeline, typical of nanosatellite projects, and shall be tailored for the specific mission and stakeholders' needs.

- **Phase 0/A**: Mission Analysis – *3 months*
  Define mission needs, perform trade-offs, select baseline concept.

- **Phase B**: Preliminary Design – *6 months*
  Develop preliminary subsystem designs, complete PDR.
- **Phase C/D**: Detailed Design, Manufacturing, and AIV – *9 months*
  Finalise subsystem designs, complete CDR, manufacture and assemble hardware, perform AIV.
- **Phase E**: Launch and Operations – *mission lifetime (e.g. 12 months)*
  Launch campaign, commissioning, nominal operations.
- **Phase F**: Disposal – *weeks to months*
  Execute end-of-life strategy (controlled/un-controlled de-orbit, passivation).



Example High-level Gantt Chart for a nanosatellite mission life-cycle development

3.6.1 Resources and Responsibilities

For effective project management, and to ensure adherence to schedule, budget, and technical requirements, a set of key project roles shall be formally identified and allocated. These include:

- **Project Manager (PM)** – Responsible for overall programme execution, budget management, and liaison with stakeholders and funding agencies.
- **System Engineer (SE)** – Technical lead, manages requirements flow-down, and oversees integration activities.
- **Subsystem Leads** – Manage the design, procurement, integration, and verification of their respective subsystems in accordance with the Interface Control Documents.
- **Product Assurance (PA) Manager** – Oversees quality assurance, configuration control, risk management, and compliance with applicable standards.
- **Ground Segment Lead** – Responsible for the design, implementation, and readiness of the ground segment, including mission control and ground station operations

3.7 Training and capacity building

Capacity building is an integral part of this work plan, as it is necessary to ensure long-term sustainability of nanosatellite development within African HEIs and partner institutions. In this respect, some actions have been initiated as part of this work package development, that are recommended to be further developed in the near future, namely:

a) Integration with HEI

- Embed practical exercises using nanosatellites training kits into undergraduate and postgraduate curricula to provide hands-on familiarity with CubeSat-scale systems.
- Develop MSc thesis projects linked to specific subsystems, ensuring alignment between the academic work and project needs.

b) Industry Collaboration

- Facilitate internships with African space companies and research centres, focused on subsystem design, manufacturing, and AIV.
- Encourage joint research projects between universities and local industry to foster technology transfer.

4 Conclusions

This deliverable presents both the knowledge transfer achieved under FAST4Future WP6 and the creation of a practical work plan for the development of a nanosatellite mission. The plan is intended to be:

- Modular – Applicable to missions of varying complexity, from technology demonstrators to operational/scientific platforms.
- Scalable – suitable for projects of different size, thanks to the inherent modularity of the CubeSat standard, without changing the fundamental workflow.
- Standardised – Aligned with recognised CubeSat and ECSS standards, ensuring compatibility with existing established space operational frameworks.

It is hoped that such a work plan can offer to African HEIs and stakeholders a reference guide to efficiently design, assemble, launch, and operate nanosatellites, while building the local expertise needed to sustain independent space missions.