HOLARCH

CubeSat EO-1 System Specification

6U Earth-observation CubeSat · Configurations EO-1 Flight and EO-1 Lite

Document EO1-SPEC-100 · Revision C

Fictional document for demonstration. This specification describes an invented spacecraft. It was written to show model-based systems engineering in Holarch. It is not the specification of any real mission, organization or product, and its values are not for engineering use.

Contents

Document Control **7**
Approval 7
Revision Record 7
Open Items in This Revision 7
1 Introduction **8**
1.1 Purpose 8
1.2 Scope 8
1.3 Relation to SRS-001 10
1.4 Document conventions 10
1.5 Document structure 13
1.6 Revision notes 14
2 Applicable and Reference Documents **15**
2.1 Applicable documents 15
2.2 Reference documents 17
2.3 Order of precedence 18
3 Mission Overview and Concept of Operations **19**
3.1 Mission objectives 19
3.2 Reference orbit 20
3.3 Mission phases 21
3.4 Imaging concept 25
3.5 Day in the life 28
3.6 Ground contact concept 30
3.7 Operational scenarios 31
3.8 Use cases 34
4 Stakeholders and Needs **36**
4.1 Stakeholders 36
4.2 Needs 37
4.3 Measures of effectiveness 41
4.4 Mission success criteria 42
4.5 Constraints 43
5 System Architecture **45**
5.1 System Context 45
5.2 Product Breakdown Structure 46
5.3 Functional Architecture 48
5.4 Logical Architecture 56
5.5 Internal Structure of the Spacecraft 57
5.6 Configuration Differences 59
5.7 Design Drivers and Key Trades 60

6 Operational Modes 62
6.1 Mode Overview 62
6.2 ADCS Pointing Modes 62
6.3 Mode Definitions 63
6.4 Sub-Modes of Nominal Imaging 67
6.5 Transitions 68
6.6 Safe Mode Triggers 71
6.7 Mode Activities 71
6.8 Equipment State per Mode 73
6.9 State Machine 74
6.10 Mode Logic Requirements 75
7 System Requirements 80
7.1 Mission Imaging 80
7.2 Attitude Determination and Control 83
7.3 Electrical Power 85
7.4 Command and Data Handling 88
7.5 Communications 90
7.6 Ground Segment and Operations 92
7.7 Structure and Mechanisms 94
7.8 Thermal Control 96
7.9 Flight Software and Autonomy 97
7.10 Environments and Launch Compatibility 99
7.11 External Interfaces 101
7.12 Safety, Space Debris and Disposal 102
7.13 Security 104
7.14 Reliability, Quality and Lifetime 105
8 Payload Camera Specification 108
8.1 Description 108
8.2 Functions 110
8.3 Operating States 111
8.4 Interfaces 111
8.5 Requirements 112
8.6 Verification Approach 119
9 ADCS Specification 121
9.1 Hardware 121
9.2 Pointing Modes and Spacecraft Modes 123
9.3 Estimation and Control 124
9.4 Momentum Management 124
9.5 Pointing Error Budget 125
9.6 Interfaces 125
9.7 Requirements 126
9.8 Verification Approach 132

10 EPS Specification 134
10.1 Architecture 134
10.2 Power Generation 134
10.3 Energy Storage 135
10.4 Power Distribution 136
10.5 Protection 138
10.6 Interfaces 139
10.7 Requirements 139
10.8 Verification Approach 145
11 Structure and Mechanisms Specification 147
11.1 Body Frame and Layout 147
11.2 Primary Structure 147
11.3 Deployment Mechanisms 148
11.4 Mass of Structure and Mechanisms 149
11.5 Interfaces 150
11.6 Requirements 150
11.7 Verification Approach 155
12 Thermal Control Specification 157
12.1 Approach 157
12.2 Temperature Limits 158
12.3 Design Cases 159
12.4 Interfaces 160
12.5 Requirements 160
12.6 Verification Approach 164
13 Propulsion Specification 165
13.1 Study Summary 165
13.2 Why It Is Not Included 165
13.3 What Adding Propulsion Would Require 166
14 Command and Data Handling Specification 167
14.1 Overview 167
14.2 Flight Computer 168
14.3 Payload Data Storage 172
14.4 Requirements 174
14.5 Verification Approach 179
15 Flight Software Specification 180
15.1 Architecture 180
15.2 Command and Telemetry 184
15.3 Command Schedule 187
15.4 Fault Management 188
15.5 Payload Data Handling 190
15.6 File Delivery 191
15.7 Software Update 192

15.8 Software Criticality 192
15.9 Requirements 193
15.10 Verification Approach 200
16 Communications Specification 201
16.1 Overview 201
16.2 UHF Transceiver 202
16.3 UHF Antenna 203
16.4 S-band Transmitter (EO-1 Lite) 203
16.5 X-band Payload Radio (EO-1 Flight) 204
16.6 Link Budgets 204
16.7 Protocols 207
16.8 Link Security 208
16.9 Spectrum Coordination 208
16.10 Requirements 209
16.11 Verification Approach 214
17 Ground Segment Specification 216
17.1 Ground Station Service 216
17.2 Mission Operations Center 218
17.3 Requirements 221
17.4 Verification Approach 227
18 Mission Operations Specification 228
18.1 Organization and Staffing 228
18.2 Planning Cycle 229
18.3 Contact Plan 230
18.4 Procedures 231
18.5 Anomaly Response 232
18.6 Training and Certification 233
18.7 Requirements 233
18.8 Verification Approach 237
19 Interface Requirements 238
19.1 Interface Overview 238
19.2 Power Interfaces 239
19.3 Data Interfaces 245
19.4 RF Interfaces 252
19.5 Ground Interfaces 256
19.6 Mechanical Interface 258
19.7 Physical Paths 260
20 Technical Budgets and Margins 262
20.1 Margin Policy 262
20.2 Mass Budget 264
20.3 Power Budget 266
20.4 Orbit-Average Generation and Energy Balance 270

20.5 Data Volume 271
20.6 Link Margins 271
20.7 Pointing 272
20.8 Timing Budget for the Planning Cycle 272
20.9 Technical Performance Measures 274

21 Environmental Requirements 276
21.1 Environment Phases 276
21.2 Launch Environment 276
21.3 Orbital Environment 279
21.4 Electromagnetic Compatibility 282
21.5 Ground Environments 284
21.6 Test Levels and Margins 285

22 Verification and Validation 287
22.1 Approach 287
22.2 Model Philosophy 288
22.3 Test Campaigns 290
22.4 Test Suites 291
22.5 Verification Events 292
22.6 Verification Programme Requirements 299

Appendix A. Verification Cross-Reference Matrix 303
Operational Modes 303
System Requirements 304
Payload Camera Specification 309
ADCS Specification 310
EPS Specification 311
Structure and Mechanisms Specification 311
Thermal Control Specification 312
Command and Data Handling Specification 313
Flight Software Specification 314
Communications Specification 316
Ground Segment Specification 317
Mission Operations Specification 318
Interface Requirements 318
Technical Budgets and Margins 320
Environmental Requirements 321
Verification and Validation 322

Appendix B. Open Items 324

Appendix C. Traceability Index 327

Appendix D. Glossary and Acronyms 333
Glossary 333
Acronyms 336

Document Control

Approval

Role	Responsibility
Systems Lead	Author; owner of the system requirements and budgets
Mission Principal Investigator	Confirms that the requirements meet the customer imaging needs
Program Manager	Releases the document to the program
Product Assurance Lead	Confirms the verification approach and the open-item list

Approval of this revision

Revision Record

Rev	Milestone	Summary of change
A	System Requirements Review	First release. Incorporates SRS-001 as approved at the review.
B	Preliminary Design Review	Budgets updated with the preliminary design; S-band selected for the payload downlink (trade study TR-1); interface identifiers aligned with the interface control document.
C	Critical Design Review (this revision)	Two configurations, EO-1 Flight (X-band, encrypted downlink) and EO-1 Lite (S-band); SR-3.1 raised from 28 W to 30 W orbit-average power after the payload heater load grew; SR-4.4 Downlink Encryption and SR-5.5 X-band Downlink Rate added; open-item list refreshed.

Revision record

Open Items in This Revision

Values marked TBD (to be determined) or TBR (to be reviewed) are listed with their requirements in the appendix “Open Items”, with the requirements that carry them.

1 Introduction

1.1 Purpose

This document is the system specification of the EO-1 program. It states what the EO-1 mission system shall do and how well, under which conditions, and how each requirement will be verified. It is the technical baseline against which the spacecraft, the ground segment and the operations concept are designed, built, verified and accepted.

The specification serves four groups of readers:

- the **design teams**, who derive subsystem designs and lower-level specifications from it;
- the **verification team**, who plan tests, analyses, inspections and demonstrations from the verification method given with each requirement;
- the **Imagery Customer**, who confirms that the stated needs are captured and that the requirements will meet them;
- **reviewers and approval authorities** at the system milestones (SRR, PDR, CDR, the test readiness reviews, the pre-shipment review and the flight readiness review), who use it to judge whether the design is complete and consistent.

The document is written so that a model of the system can be built from it directly: each element of the product tree, each function, each operational mode and transition, each interface and each requirement has a fixed identifier, and the traces between them are stated explicitly.

1.2 Scope

1.2.1 System of interest

The system of interest is the **EO-1 Mission** (product 0): a single 6U CubeSat in a 500 km sun-synchronous orbit that images farmland in four spectral bands, and the ground segment that plans its collections, receives its data and turns the data into image products for the Imagery Customer.

The specification covers:

No.	Element	Covered by this specification
1	EO-1 Spacecraft	Fully: bus, Payload Camera, flight software, harness
2	Ground Segment	Fully: ground station service, Mission Operations Center, Mission Operator roles and procedures
3	Rideshare Launch Vehicle	Only the interface (IF-15) and the launch environments the spacecraft must survive
4	Orbit Environment	Only as the environment the system operates in
X.1	Imagery Customer	Only the interface (IF-14, IF-14.1) and the needs the customer states

Elements inside and outside the system boundary

The system boundary runs along the dispenser adapter interface (IF-15), the space-to-ground radio links (IF-10 and its children), the ground network between the partner stations and the Mission Operations Center (IF-13) and the customer interface (IF-14). Everything on the program's side of these interfaces is designed to this specification; everything on the far side (the launch vehicle and its dispenser, the partner stations' own antennas and site infrastructure, the customer's analytics systems) is treated as an external system whose behavior at the interface is specified here and in the interface control documents.

The ground stations (product 2.1) are a contracted service from a partner network. The specification states what the service shall provide (passes, apertures, data handling, availability); it does not specify the partner's equipment beyond that.

1.2.2 Configurations

The program builds one spacecraft design in two configurations. They share the bus, the Payload Camera, the UHF command link and the flight software; they differ in the payload downlink radio and the ground service plan.

Property	EO-1 Flight	EO-1 Lite
Serial numbers	1 and 2	3 onward
Payload downlink radio	X-band Payload Radio (1.5.3): 8.2 GHz, 100 Mbps OQPSK, 2 W RF, 16 dBi patch array	S-band Transmitter (1.5.2): 2.245 GHz, 10 Mbps OQPSK, 1 W RF, 6 dBi patch
Downlink encryption	Yes, 256-bit keys (SR-4.4)	No (link authentication of commands only)
Ground service plan	Three partner stations	One partner station
Payload data delivered per day	up to 9.87 GB capacity; full daily collection	at least 1 GB (SR-5.4 Lite value)
Launch mass with contingency	10.55 kg	10.40 kg

EO-1 Flight and EO-1 Lite configurations

A requirement applies to both configurations unless its `Applies:` field names one of them. Where the two differ, the specification states each value in its own requirement rather than writing one requirement with alternatives.

A cold-gas propulsion module for orbit maintenance was studied. It is not part of either configuration: the study showed it fits only beside the X-band radio, and neither configuration needs altitude control to meet the mission life. The study result is kept in the propulsion chapter for reference; that chapter contains no binding requirements.

1.2.3 Life cycle covered

The specification covers the system from the start of integration through launch, commissioning, two growing seasons of operations (730 days) and disposal. Manufacturing processes, ground support equipment and the test facilities are covered only where they affect the flight system (contamination, handling loads, inhibit verification).

1.3 Relation to SRS-001

The System Requirements Specification **SRS-001** is the program's original statement of system requirements, agreed with the Imagery Customer at SRR. This specification incorporates SRS-001 by number:

- System requirement **SR-*a*.*b*** in this document is SRS-001 requirement *a*.*b*, with the same intent. The wording is tightened where SRS-001 was not measurable (SR-2.5 Safe Mode Recovery and SR-6.4 Operator Interface are restated with measurable criteria). Where a value changed after SRS-001 was agreed (SR-3.1, raised from 28 W to 30 W after PDR), the requirement's rationale records the change.
- New system requirements continue the numbering inside each area (for example SR-1.8 after SRS-001's SR-1.7).
- Area 7 is not used: SRS-001 section 7 is its list of applicable documents, which this document replaces with its own chapter "Applicable and Reference Documents". Areas 8 to 15 are new in this specification.
- SRS-001 remains the record of what was agreed with the customer. A change to an SR requirement is made in this document through the change process of the Configuration Management Plan (EO1-PLN-350) and is reported to the Imagery Customer; SRS-001 is not reissued.

Subsystem, interface, environment, operations and verification-program requirements are new in this document and are derived from the SR requirements.

1.4 Document conventions

1.4.1 Requirement language

Word	Meaning
shall	A binding requirement. It is verified, and the system is not accepted until it is met or a deviation is approved.
should	A goal. The design team works toward it and reports the achieved value; it is not a condition of acceptance.
will	A statement of fact, of intent or of what another party does. It is not verified.
may	A permission: an allowed option, not an obligation.

Requirement keywords

Descriptive text in the operations, architecture and budget chapters uses "will" and the present tense. It explains the requirements and is not itself binding; where descriptive text and a requirement disagree, the requirement governs.

1.4.2 Requirement identifiers

Prefix	Meaning	Parent
SR-*a.b*	System requirement, area *a* (1 Mission Imaging, 2 ADCS, 3 EPS, 4 C&DH, 5 Communications, 6 Ground and Operations, 8 Structure and Mechanisms, 9 Thermal Control, 10 Flight Software and Autonomy, 11 Environments and Launch Compatibility, 12 External Interfaces, 13 Safety, Space Debris and Disposal, 14 Security, 15 Reliability, Quality and Lifetime)	Stakeholder needs N1–N11
PAY-, ADCS-, EPS-, CDH-, FSW-, COM-, STR-, THM-, PROP-, GND-, OPS- *nnn*	Subsystem requirement (STR covers structure and mechanisms)	SR requirements
ICD-*nnn*	Interface requirement	SR requirements
ENV-*nnn*	Environment requirement	SR requirements
VER-*nnn*	Verification-program requirement	SR requirements

Requirement identifier scheme

Identifiers are unique across the document and are never reused. A deleted requirement keeps its identifier with the text “Deleted” so that existing traces stay readable.

1.4.3 Requirement block layout

Every requirement is written as a block with a header line, one requirement sentence and a rationale. The header line carries these fields, in this order:

Field	Content
Identifier and title	For example “SR-1.2 Ground Sample Distance”. The title names the subject, not the value.
Verify	One or more verification methods (Test, Analysis, Inspection, Demonstration), primary method first
Trace	The parent or parents: need identifiers (N1…) for system requirements, SR identifiers for all others
Applies	All, Flight or Lite
Alloc	System requirements only, optional: the product-tree number(s) that carry the requirement (for example 1.1, or 1.2, 1.4)
TBD / TBR	Optional: the open-item identifier when the value is not final

Requirement header fields

The requirement sentence states one thing, with a value and units. Two sentences are used only when they cannot be separated without losing the meaning. The rationale states why the requirement exists and where its value comes from: a need, a budget, an analysis, a standard or a design decision. A requirement without a rationale is not accepted into the baseline.

1.4.4 Verification methods

Method	Code	Definition
Test	T	Operation of the item, or of a representative model, under controlled conditions with calibrated instruments, recording measured values against pass/fail criteria set in advance. Environmental tests (vibration, thermal vacuum, EMC) belong here.
Analysis	A	Use of calculation, simulation, modeling or similarity to a previously qualified item to show compliance, where a test is impractical or would not add confidence. The analysis report states its inputs, assumptions and uncertainty.
Inspection	I	Visual or dimensional examination of the item or of its documentation (drawings, data sheets, material lists, certificates) to confirm a physical or documented property without operating it.
Demonstration	D	Operation of the item to show a capability, observing whether it performs the function, without quantitative measurement beyond pass/fail. Operations rehearsals and usability checks belong here.

Verification methods

A requirement may list more than one method when no single method closes it (for example Analysis for the orbit case supported by a Test of the hardware). The first method listed is the one that closes the requirement; the others provide supporting evidence. The verification chapter allocates each requirement to a test suite (TS-1, TS-2, TS-3) and, where applicable, to a test case.

1.4.5 Open items: TBD and TBR

- **TBD** (to be determined): the value is not yet known. The requirement text shows `[TBD]` in place of the value, and the header carries the open-item identifier (for example `TBD-01`).
- **TBR** (to be reviewed): a value is given, but it is provisional and may change when the named analysis, test or decision is complete. The text shows the value followed by `[TBR]`, and the header carries the identifier (for example `TBR-03`).

Each open item has one owner, a closure method and a milestone by which it must close. All open items are listed with the requirements that carry them in the appendix “Open Items”, and are tracked under the Configuration Management Plan (EO1-PLN-350). A TBD in a requirement allocated to flight hardware shall close before CDR of that hardware; a TBR may remain open past CDR only when the design already covers the full range of values under review. Closing an open item is a change to this document.

The open items raised in this specification's introductory chapters (Introduction through Stakeholders and Needs) are:

Id	Subject	Closure
TBD-05	Which partner station serves the EO-1 Lite one-station plan	Service contract award for serial number 3, before its pre-shipment review
TBR-19	Orbital lifetime after end of mission (natural decay from the operational orbit; SR-13.4)	Lifetime analysis with the as-flown ballistic coefficient and the solar-activity forecast, at the flight readiness review
TBR-06	Duration of the commissioning phase (30 days)	Commissioning plan review, before the flight readiness review
TBD-06	Minimum target area and season for the minimum-success criterion	Agreement with the Imagery Customer, before the operations readiness review

Open items raised in the introductory chapters

1.4.6 Units and conventions

- SI units throughout. Angles in degrees (deg or °), with arcseconds for pointing budget contributors. Temperatures in °C. Power in W, energy in Wh, mass in kg.
- Data quantities: 1 GB = 10 ^ 9 bytes, 1 MB = 10 ^ 6 bytes; data rates in bit/s with decimal prefixes (1 Mbps = 10 ^ 6 bit/s).
- Link quantities in decibels: gain in dBi, power in dBW, noise temperature figure of merit in dB/K.
- Uncertainty is stated as 1σ or 3σ explicitly; a pointing value without a stated level is a 3σ value.
- Times: onboard time is UTC kept by the flight computer's real-time clock and corrected from the ground; mission phases are stated relative to separation (T+) or launch (L−, L+); program milestones by review name (SRR, PDR, CDR). Times of day in the operations concept are Mission Operations Center local time.
- Orbit-average values are averaged over one orbit of the stated case; "design case" means the Nominal Imaging orbit defined in the budgets chapter (eight 40 s strips and one payload downlink pass).
- "BOL" and "EOL" mean beginning of life (at separation) and end of life (after 730 days in orbit).

1.5 Document structure

The chapters follow the order in which the system is defined:

Part	Content
Introduction; Applicable and Reference Documents	Purpose, scope, conventions; the documents this specification depends on and their precedence

Part	Content
Mission Overview and Concept of Operations	Mission objectives, orbit, mission phases, imaging concept, ground contact concept, operational scenarios, use cases
Stakeholders and Needs	Stakeholders, needs N1–N11, measures of effectiveness, mission success criteria, constraints
System architecture and operational modes	Product tree, functional architecture (F0–F11), allocation of functions, the seven operational modes and their transitions
System requirements	SR requirements, areas 1–6 and 8–15, each traced to the needs
Subsystem specifications	Payload, ADCS, EPS, structure and mechanisms, thermal control, propulsion (study only), C&DH, flight software, communications, ground segment, operations
Interfaces	Internal and external interfaces IF-01 to IF-25
Budgets	Mass, power, energy, data volume, link and pointing budgets for both configurations
Environments	Launch, orbit and ground environments and the margins applied to them
Verification	Verification approach, model philosophy, test suites and test cases, the verification matrix

Structure of this specification

Budget tables are generated from the program's budget model and included unchanged; the text around them explains the cases and assumptions. The verification matrix and the traceability index are produced from the requirement blocks and are therefore always consistent with the requirement text.

1.6 Revision notes

The revision record in Document Control lists the changes of each revision. The changes of Revision C that matter most to a reader of the requirements are: the EO-1 Flight configuration (X-band Payload Radio, downlink encryption SR-4.4, X-band rate SR-5.5) for serial numbers 1 and 2, with the S-band design continuing as EO-1 Lite from serial number 3; SR-3.1 raised from 28 W to 30 W orbit-average power at end of life, with 28 W kept as the power allocation; SR-2.5 and SR-6.4 restated as measurable requirements; the new areas 8 to 15; the IF-03 rating changed from 4 W to 7 W; and the deviation against SR-4.3 (15 s accepted until flight software 2.4).

2 Applicable and Reference Documents

2.1 Applicable documents

Applicable documents form part of this specification to the extent stated where they are cited. A requirement that cites an applicable document makes the cited content binding for that requirement only; citing a document in a rationale or in descriptive text does not make it binding.

2.1.1 Program documents

The program documents below are configuration-controlled under the Configuration Management Plan. The issue that applies is the one in the program's configuration baseline at the time of the milestone being assessed.

Id	Title	Relevance
SRS-001	EO-1 System Requirements Specification	Parent of the SR requirements (see Introduction, "Relation to SRS-001")
STD-1	Small Satellite Design and Environment Standard	Program design rules and environments for the spacecraft side: derating, materials, workmanship, margins, test levels and durations
STD-2	Space-Ground Data Exchange Standard	Program profile of the space data link, file delivery and security protocols for the space-to-ground and ground links
EO1-ICD-200	Spacecraft Internal Interface Control Document	Electrical, data, mechanical and thermal interfaces inside the spacecraft (IF-01 to IF-09, IF-16 to IF-22)
EO1-ICD-210	Space-to-Ground Interface Control Document	RF links and protocols between the spacecraft and the partner stations (IF-10, IF-11, IF-12, IF-12.1)
EO1-ICD-220	Ground Segment Interface Control Document	Station-to-MOC network, the customer interface and the customer portal (IF-13, IF-14, IF-14.1), the operations console (IF-25)
EO1-ICD-230	Spacecraft-to-Dispenser Interface Control Document	Mechanical, electrical and inhibit interface with the 6U dispenser (IF-15), as agreed with the rideshare integrator
EO1-PLN-300	Systems Engineering Management Plan	Technical reviews, budget and margin policy, technical performance measures, MOE scoring
EO1-PLN-310	Verification and Validation Plan	Model philosophy, test suites TS-1 to TS-3, test case procedures, validation activities VAL-01 to VAL-03

Id	Title	Relevance
EO1-PLN-320	Mission Operations Plan	Mission phases, operator roles and shifts, procedures, contingency handling
EO1-PLN-330	Product Assurance Plan	Parts, materials and processes; nonconformance and deviation handling; workmanship
EO1-PLN-340	Space Debris Mitigation Plan	Debris mitigation measures, passivation and disposal analysis
EO1-PLN-350	Configuration Management Plan	Baselines, change requests, open-item tracking, deviations and waivers
EO1-PLN-360	Security Plan	Command authentication, downlink encryption, key management, ground system access control
EO1-PLN-370	Contamination Control Plan	Cleanliness levels, bake-out, handling of the optics and the star tracker
EO1-PLN-380	Frequency Management Plan	Frequency assignments, filings and coordination for UHF, S-band and X-band
—	Rideshare payload user's guide, issue for the assigned launch	Launch environments, dispenser envelope, inhibit and safety rules set by the launch provider
—	Ground station service agreement with the partner network	Station apertures, pass booking rules, availability and data delivery set by the partner

Applicable program documents

2.1.2 Standards

The public standards below apply as tailored by STD-1 and STD-2. Where this specification cites a standard directly, the citation states which part applies.

Standard	Use in this specification
CubeSat Design Specification (CDS), Rev. 14.1	6U form factor, rails, mass properties, deployment switches, remove-before-flight provisions, deployable and RF inhibit timing
GSFC-STD-7000 General Environmental Verification Standard (GEVS)	Basis of the environmental test levels and sequence in STD-1, where the rideshare user's guide does not set them
ECSS-E-ST-10-03C, Testing	Test definitions and the protoflight approach used on FM-1
MIL-STD-461G	Electromagnetic emission and susceptibility requirements, as tailored in STD-1
ECSS-Q-ST-70-71C	Selection of materials, processes and their data
ASTM E595	Outgassing screening of nonmetallic materials (total mass loss and collected volatile condensable material)
ISO 14644-1	Clean room classification for integration and optics handling

Standard	Use in this specification
CCSDS 131.0-B Telemetry Synchronization and Channel Coding	Coding and synchronization of the payload downlinks, as profiled in STD-2
CCSDS 132.0-B TM Space Data Link Protocol	Telemetry transfer frames, as profiled in STD-2
CCSDS 232.0-B TC Space Data Link Protocol	Telecommand transfer frames on the UHF uplink, as profiled in STD-2
CCSDS 122.0-B Image Data Compression	Onboard image compression
CCSDS 727.0-B CCSDS File Delivery Protocol (CFDP)	File delivery of image and telemetry files over the payload downlink
CCSDS 355.0-B Space Data Link Security Protocol	Command authentication and, for EO-1 Flight, downlink frame encryption, as profiled in STD-2
ISO 24113 Space systems — Space debris mitigation requirements	Debris release, passivation and post-mission disposal
ITU Radio Regulations	Frequency use, emission limits and filing obligations for the three radio bands

Applicable standards

2.1.3 National licenses and authorizations

The radio licenses for the UHF, S-band and X-band emissions, the license or authorization for the space operation issued by the responsible national authority, and the remote-sensing license where one is required, are applicable from the time they are granted. Their conditions bind the program even where this specification is silent. The Frequency Management Plan (EO1-PLN-380) tracks each filing; license timing is carried as risk RK-4 (S-band License Delay).

2.2 Reference documents

Reference documents give background, methods or data. They are not binding; a design that departs from them needs no deviation.

Id or title	Use
ISO/IEC/IEEE 15288, Systems and software engineering — System life cycle processes	Life-cycle process framework for the program's technical processes and reviews
NASA/SP-2016-6105 NASA Systems Engineering Handbook	Guidance on requirement writing, technical reviews, margin management and verification planning
ECSS-E-ST-10C, Space engineering — System engineering general requirements	Guidance on specification structure, budgets and technical performance measures
EO1-RPT-400 Budget Report (mass, power, energy, data, link, pointing)	Source of the budget tables in the budgets chapter
EO1-RPT-410 Trade Study TR-1, Downlink Band Selection	Basis for the S-band baseline and the X-band EO-1 Flight configuration
EO1-RPT-420 System Hazard Analysis	Hazards HAZ-001 to HAZ-004 and their controls
EO1-RPT-430 Risk Register	Risks RK-1 to RK-8
EO1-RPT-440 Propulsion Study	Cold-gas orbit maintenance study; not included in either configuration

Id or title	Use
EO1-RPT-450 Orbit and Lifetime Analysis	Reference orbit, ground-track repeat, eclipse, orbital decay after end of mission
EO1-RPT-460 Imaging Requirements Analysis	Derivation of ground sample distance, swath, bands, revisit and daily collection from the customer's crop monitoring workflow

Reference documents

2.3 Order of precedence

When documents disagree, the following order applies, highest first:

1. National licenses and authorizations, and the regulations they implement.
2. Launch safety rules in the rideshare payload user's guide and EO1-ICD-230 (they protect the launch vehicle and the other passengers, and the launch provider can refuse the spacecraft if they are not met).
3. This specification, EO1-SPEC-100.
4. The interface control documents EO1-ICD-200, -210, -220.
5. The program standards STD-1 and STD-2.
6. The program plans EO1-PLN-300 to -380, and the ground station service agreement.
7. Public standards, as tailored by STD-1 and STD-2.

This specification takes precedence over SRS-001, which it incorporates: where an SR requirement here differs from SRS-001, the difference results from an approved change and the text here applies. A conflict found between documents is raised as a change request under EO1-PLN-350. Until the change is approved, the design follows the higher-precedence document and the conflict is recorded as an open item, unless the Systems Lead directs otherwise in writing for a stated period.

3 Mission Overview and Concept of Operations

This chapter describes how the EO-1 system is used, from integration on the ground to disposal. It is descriptive: it explains the context of the requirements and the sequences they must support, but it contains no binding requirements. The operational modes and their transitions (T1–T9) are defined in the chapter on system architecture and operational modes; the requirements that make the sequences below possible are in the system requirements chapter and are cited by identifier.

3.1 Mission objectives

The EO-1 mission gives the Imagery Customer, an agricultural analytics company, its own source of multispectral imagery of farmland, so that it can tell growers about crop stress in time to act on it.

Id	Objective	Main needs
MO-1	Collect four-band imagery of the customer's farm regions at field-level resolution (4.5 m ground sample distance, 22 km swath)	N3, N6
MO-2	Revisit every target field at least every 72 h during the growing season	N2
MO-3	Deliver calibrated, orthorectified products to the customer portal within 6 h of downlink, so that alerts reach growers on the day of the overpass	N1
MO-4	Accept new tasking from the customer and fold it into the next imaging plan	N7
MO-5	Operate for two growing seasons (730 days in orbit) with a small day-shift team	N4, N11
MO-6	Protect the imagery and the command link, launch on a standard rideshare, use the radio spectrum lawfully and leave no debris behind	N5, N8, N9, N10

Mission objectives

Primary objectives are MO-1 to MO-3; they define mission success (see Stakeholders and Needs, "Mission success criteria"). MO-4 to MO-6 constrain how the primary objectives are met.

The program flies two configurations of one design (see Introduction, "Configurations"). EO-1 Flight (serial numbers 1 and 2) carries the X-band Payload Radio and delivers the full daily collection. EO-1 Lite (serial number 3 onward) carries the S-band Transmitter and works with one partner station, so it serves a reduced daily target list at lower cost. The concept below is written for both; differences are called out where they occur.

3.2 Reference orbit

The mission is designed for a 500 km circular sun-synchronous orbit with the descending node at 10:30 local time (the reference orbit assumption, SR-1.1). A morning descending node gives low-to-moderate Sun elevation for contrast, avoids the afternoon cloud build-up typical of growing-season weather over farmland, and keeps illumination nearly constant from one revisit to the next, which the vegetation indices depend on (N6).

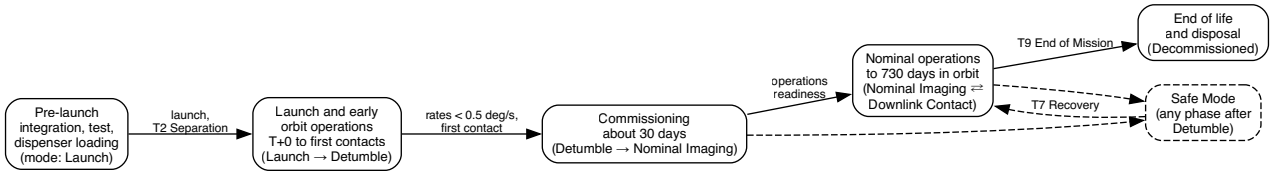
Parameter	Value
Mean altitude	500 km (circular)
Semi-major axis	6,878.1 km
Inclination (sun-synchronous)	97.40 deg
Local time of descending node	10:30
Orbital period	94.6 min
Orbits per day	15.22
Orbital velocity	7.61 km/s
Ground-track speed	7.06 km/s
Longest eclipse (bounding case, beta = 0)	35.8 min
Sunlit fraction, bounding case	62.2 %
Ground-track repeat	3 days (TBR, set by the final altitude choice)
Slant range at 10 deg elevation	1,695 km
Slant range at 5 deg elevation	2,078 km

Reference orbit parameters

Coverage follows from the orbit and the pointing range. At 25° off-nadir (SR-1.6.2) the camera reaches about 235 km either side of the ground track, so the accessible band is about 490 km wide including the swath. Adjacent ground tracks on one day are 23.7° of longitude apart (about 2,630 km at the equator). Over the three-day repeat cycle (SR-1.6.1) the tracks interleave to a spacing of about 576 km at the equator, which shrinks with the cosine of latitude to below the 490 km access width poleward of about 32° latitude. The customer's farm regions lie between about 32° and 55° latitude, so every target field can be reached at least once in 72 h (SR-1.6). The exact repeat depends on the altitude reached after launch and is open as TBR-01.

The orbit is not maintained: the spacecraft carries no propulsion. Drag lowers the orbit slowly over the mission; the orbit and lifetime analysis (EO1-RPT-450) shows that the altitude stays high enough for the imaging geometry over 730 days, and that the ground-track repeat drifts by a few kilometers per cycle, which flight dynamics absorbs in the off-nadir angle of each target.

3.3 Mission phases



Mission phases and the operational modes used in each

Phase	Starts	Ends	Modes	Main functions
Pre-launch	Start of spacecraft integration	Launch	Launch (after T1 Power On)	— (ground activities)
Launch and early orbit operations (LEOP)	Launch	Rates nulled and first two-way contact made	Launch, Detumble	F1, F2, F3, F6
Commissioning	End of LEOP	Operations readiness review closes	Detumble, Nominal Imaging, Downlink Contact	F3–F9, F11
Nominal operations	Operations readiness	End of mission decision (730 days in orbit, or earlier on failure)	Nominal Imaging, Downlink Contact, Safe Mode	F3–F11
End of life and disposal	T9 End of Mission	Reentry	Decommissioned	—

Mission phases

3.3.1 Pre-launch

The pre-launch phase covers spacecraft integration, the protoflight test campaign on FM-1 (EO-1 Flight serial number 1) and acceptance testing of later units, shipment, and integration into the rideshare dispenser. Its operational content is small but it fixes the state in which the spacecraft enters orbit:

1. **Integration and test.** The spacecraft is integrated in an ISO 14644-1 classified clean room under the Contamination Control Plan, with the camera aperture and star tracker baffle covered. Functional tests run through the umbilical connector; the flight software image loaded for flight is the one qualified in the test campaign.
2. **Pre-shipment review.** At about L−3 months the pre-shipment review confirms that verification is complete or that the remaining items can close at the launch site, and that the flight software, keys (EO-1 Flight) and onboard parameter tables are the configured flight versions.
3. **Final charge and inhibits.** The battery is charged to the storage state of charge set in the rideshare payload user's guide. The spacecraft is switched off through its deployment switches; the remove-before-flight pin is removed only as the last step before loading, after the inhibit check.
4. **Dispenser loading.** At the integrator's facility, typically L−6 to L−4 weeks, the spacecraft is loaded into the 6U dispenser and the separation switches are verified closed (IF-15). From this point the spacecraft cannot be charged or commanded; the battery capacity and self-discharge

analysis covers a storage period of up to 6 months in the dispenser, which bounds a launch slip (RK-3).

The mode at the end of pre-launch is **Launch**: powered off, inhibits closed, in the dispenser.

3.3.2 Launch and early orbit operations

LEOP begins at launch and ends when the spacecraft has nulled its rates, deployed its arrays and antenna and made two-way contact with the ground. Everything up to the first contact is autonomous, run from the flight software's separation sequence; nothing the ground does can influence it. The timeline below is measured from separation (T+0).

Time from separation	Event	Mode	Notes
T+0	Dispenser releases the spacecraft; separation switches open; the bus powers up and the flight computer boots	Launch → Detumble (T2 armed)	The separation timer starts. Only the PDU, flight computer and ADCS sensors are powered. All deployables and all transmitters are inhibited (CDS and the rideshare rules).
T+0 to T+30 min	Coast with inhibits held; magnetometer and sun sensor telemetry logged; battery-only power until arrays deploy	Launch	Tip-off rates up to 10 deg/s are expected. No actuator is used before T+30 min.
T+30 min	Separation timer exceeds 30 min with the separation switches released: transition T2 Separation to **Detumble**. Deployables enabled. UHF antenna burn-wire release fired (product 1.6.2)	Detumble	Earliest permitted deployment. Magnetorquers start the detumble controller.
T+35 min	Solar array deployment: burn-wire hold-downs fired, panels hinge out, deployment switches confirm	Detumble	Trigger timer versus rate threshold is open (TBR-02); either way the arrays are out by T+45 min (SR-3.6).
T+45 min	RF inhibit expires. UHF beacon begins (housekeeping telemetry every 30 s)	Detumble	Earliest permitted transmission. Payload downlink radios remain off.
T+45 min to T+3 h	Magnetic detumble continues until body rates are below 0.5 deg/s	Detumble	Required within 3 h from 10 deg/s (SR-2.3; detumble simulation TC-05). Bus load 14.1 W in Detumble.
After detumble	Coarse Sun-pointing with sun sensors and wheels to put the arrays on the Sun	Detumble	Positive energy balance from the first orbit after Sun acquisition.

Time from separation	Event	Mode	Notes
First pass over a partner station after T+45 min	Station receives the UHF beacon; first state-of-health assessment	Detumble	Depending on the deployment longitude, this is between the first and the eighth orbit; the station network is booked for every pass in the first 48 h.
First pass with a two-way link	First command uplinked and acknowledged; onboard time corrected; two-line element set replaced by the first orbit determination	Detumble	End of LEOP.

LEOP timeline from separation

The partner stations listen on every pass of the first two days, using the launch provider's predicted deployment state vector until the first orbit determination. If no beacon is received in the first 24 h, the operations team widens the search using the dispenser's reported separation time and the rideshare's published deployment sequence; the spacecraft keeps beaconing and stays in Detumble or Sun-pointing indefinitely without ground action.

3.3.3 Commissioning

Commissioning brings each subsystem into service in a fixed order, so that each step relies only on what is already proven. It is planned for 30 days [TBR-06]. During the bus steps the spacecraft stays in Detumble with its arrays on the Sun; T3 Rates Nulled to Nominal Imaging is taken once the attitude control steps are complete, and the payload and downlink steps run in Nominal Imaging and Downlink Contact under ground command.

Step	Days after separation	Activity	Exit criterion
C1 Bus checkout	1–3	Power, thermal and C&DH health over full orbits; battery charge and discharge profiles; heater and thermostat operation; onboard time and command schedule tested with no-op commands	All housekeeping within limits over 10 consecutive orbits; schedule executes within 1 s of tag (SR-4.2)
C2 Attitude sensors	3–5	Star tracker on; magnetometer and gyro calibration; attitude estimation compared across sensors	Estimated attitude consistent between sensors to within the star tracker accuracy
C3 Fine attitude control	5–8	Reaction wheels in closed loop; momentum unloading with magnetorquers; slew and settle tests; pointing stability measured	Pointing and stability within SR-2.1 and SR-2.2 on test targets; slew time recorded against SR-2.4 (TBR-03). T3 taken.

Step	Days after separation	Activity	Exit criterion
C4 Payload downlink	8–11	S-band Transmitter (Lite) or X-band Payload Radio (Flight) switched on over a station; test files of increasing size by CFDP; encryption keys verified (Flight)	Link margin and data rate confirmed over a 10° pass (SR-5.1 or SR-5.5); error-free file delivery
C5 Camera outgassing hold and first light	11–15	Camera electronics on, focal plane at operating temperature after the outgassing hold; dark frames; first strip over a bright, uniform desert site, then over a farm region	Dark noise and defective pixel map within the payload acceptance limits; image downlinked and displayed
C6 Calibration	15–25	Geometric calibration against ground control points; radiometric calibration over vicarious calibration sites; spectral band-to-band registration; star tracker to camera alignment updated	Ground sample distance, swath and band registration within SR-1.2 to SR-1.4; alignment table uploaded
C7 End-to-end pilot	25–30	Full planning cycle with customer targets: tasking through the portal, plan, capture, downlink, processing, delivery; operators run the day-shift timeline	Planning cycle within 100 min (SR-6.5); delivery within 6 h of downlink (SR-6.2); operations readiness review

Commissioning steps

The calibration in C6 sets the baseline that later calibration checks compare against (N6). C7 doubles as the first part of the customer alert pilot (VAL-01). Commissioning steps may overlap when a step's exit criterion is met early; a step that fails its criterion holds the steps that depend on it, not the whole sequence.

3.3.4 Nominal operations

Nominal operations run from the operations readiness review to the end-of-mission decision. The spacecraft spends almost all of its time in **Nominal Imaging**, executing the time-tagged command schedule loaded from the ground (SM.1). Inside that mode it moves between Sun-pointing standby, target imaging and momentum unloading; it enters **Downlink Contact** for each booked payload downlink pass and returns at the end of the pass (T4, T5).

The operations team works one day shift on working days. Passes outside the shift are flown unattended from the booked contact schedule: the spacecraft executes its stored commands, the stations record and forward the data, and the Mission Operations Center processes and delivers

products automatically. Telemetry limit violations and missed passes raise an alert to the on-call operator. A plan uplinked on a Friday covers the weekend, since each plan holds the next 24 h of targets and the schedule can hold up to 72 h of commands.

The growing season sets the tasking rhythm. In season, the customer's target list covers its farm regions in full and the plan is rebuilt every day. Out of season, the target list shrinks to calibration sites and selected regions, and the team uses the lower load for calibration checks, flight software updates and battery conditioning.

3.3.5 End of life and disposal

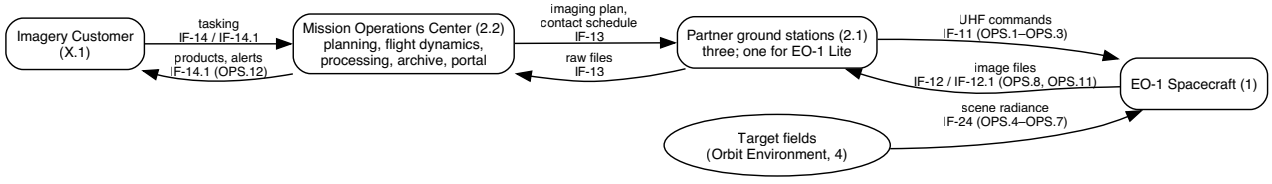
The mission ends after 730 days in orbit, or earlier if the spacecraft can no longer meet its minimum success criteria and the Imagery Customer agrees. The Systems Lead may propose an extension when the spacecraft is healthy; an extension does not change the disposal approach.

Disposal relies on natural orbital decay. Before decay begins in earnest, the spacecraft is passivated so that it cannot break up or interfere with other users (N9, N10). The end-of-mission sequence is described as a scenario below ("End of mission"); it ends in transition T9 End of Mission to **Decommissioned**, from which no return is possible. With the arrays deployed, the lifetime analysis predicts reentry between 4 and 6 years after the end of the mission, depending on solar activity. The upper end exceeds the 5-year limit of SR-13.4 [TBR-19], so the last commanded attitude before passivation holds the arrays broadside to the flow for maximum drag, and the limit stays under review until the decay analysis for the final orbit. The spacecraft is designed to demise completely on reentry; the camera's titanium and glass parts are the last to demise and are covered by the casualty risk analysis in the Space Debris Mitigation Plan (EO1-PLN-340).

3.4 Imaging concept

3.4.1 From tasking to delivery

An image product passes through six stages. The scenario "Run Nominal Imaging Pass" (OPS) breaks the space and ground part into twelve actions, OPS.1 to OPS.12; the stages, the actions and the functions that perform them line up as follows.



Operations concept: tasking, planning, capture, downlink, processing and delivery

Stage	Actions	Performed by	Function	Typical duration
Tasking	(before OPS) The customer enters areas of interest, deadlines and priorities on the portal (UC.1)	Imagery Customer, customer portal	—	Any time; plans close 2 h before the uplink

Stage	Actions	Performed by	Function	Typical duration
Planning	(before OPS) The planner selects targets for the next 24 h, computes off-nadir angles, checks power, data and thermal limits, books contacts (UC.2)	Mission Operations Center, Mission Operator	F11 (ground part)	Plan built and checked by an operator in at most 20 min (SR-6.4); contacts booked 48 h ahead (SR-6.1)
Plan uplink	OPS.1 Transmit Imaging Plan; OPS.2 Receive Imaging Plan; OPS.3 Load Command Schedule	Ground Station; UHF Transceiver; C&DH	F6 Receive Commands	4–9 min of a UHF pass (6 min typical); 1 min decode; 2 min validate and load
Capture	OPS.4 Rotate to Target; OPS.5 Prepare Camera; OPS.6 Capture Image Strip; OPS.7 Encode and Store Image	ADCS; Payload Camera; Payload Camera; C&DH	F4, F5; F7; F7; F8	about 3 min slew and settle; 5 min camera preparation; 40 s per strip (up to 54 s); 20–40 s compression per strip
Downlink	OPS.8 Transmit Image Data, or OPS.9 Hold Data Onboard when no contact is booked this orbit; OPS.11 Receive Downlink	Payload downlink radio; C&DH; Ground Station	F9; F8	8 min usable S-band pass (7 min X-band) inside a 9 min contact
Processing and delivery	OPS.12 Process Image Products: calibrate, orthorectify, compute vegetation indices and alerts, publish	Mission Operations Center	F11	45 min typical per pass's data, to the portal

Imaging chain, OPS actions and functions

Between captures and contacts, OPS.10 Recharge Battery in Sunlight returns the spacecraft to Sun-pointing so the arrays face the Sun (F3); in the design-case orbit it accounts for about 35 min of the sunlit arc.

3.4.2 Planning cycle

The planning cycle is the elapsed time from the start of the plan uplink (OPS.1) to the delivery of the first product from that plan on the portal (end of OPS.12). It is the measure behind MOE-7 and SR-6.5 (at most 100 min, objective 80 min). The cycle is short only when the plan uplink, the capture and a payload downlink fall on the same orbit or on consecutive orbits; planners schedule priority targets that way. A typical fast cycle:

Action	Start (min)	Duration (min)
OPS.1 Transmit Imaging Plan	0	6
OPS.2 Receive Imaging Plan	6	1

Action	Start (min)	Duration (min)
OPS.3 Load Command Schedule	7	2
Coast to the target	9	6
OPS.4 Rotate to Target	15	3
OPS.5 Prepare Camera (during the slew and coast)	13	5
OPS.6 Capture Image Strip (priority strip)	18	0.7
OPS.7 Encode and Store Image	19	0.5
Coast to the downlink station	20	9
OPS.8 Transmit Image Data and OPS.11 Receive Downlink (priority file first)	29	9
Transfer to the Mission Operations Center (IF-13)	38	2
OPS.12 Process Image Products	40	45
Product on the portal	**85**	

Example of a fast planning cycle

The example lands between the objective and the threshold. The largest single contributor is processing; the largest variable one is the coast to the downlink station, which the choice of station geometry controls.

3.4.3 Collection capacity and the downlink queue

Each 40 s strip covers about 282 km along track and produces 1.84 GB of raw data, or about 0.34 GB after compression. The design-case day collects 120 scenes of 22 × 22 km, equal to about 9.3 strips, and stores 3.22 GB (SR-1.5; data volume budget). Downlink capacity, not collection, limits what reaches the customer:

- **EO-1 Flight** downlinks 9.87 GB per day on two 7 min X-band passes, three times the daily collection. A single X-band pass clears the whole morning collection.
- **EO-1 Lite on the three-station service** downlinks 3.38 GB per day on six 8 min S-band passes, a 5 % margin over the collection. Each pass carries about 0.56 GB, so a heavy morning collection reaches the ground over the rest of the day.
- **EO-1 Lite on the one-station plan** downlinks 1.13 GB per day on two passes (at least 1 GB, SR-5.4 Lite value). The planner limits the target list to about 40 scenes a day, chosen by the customer's priorities.

The flight software keeps stored files in a downlink queue ordered by priority, then by age. Priority files (alert regions flagged by the customer) are sent first on the next pass, which is what makes same-day alerts possible on a service whose daily capacity is close to the daily collection. Files are deleted onboard only after the Mission Operations Center confirms receipt through the file delivery protocol; with 64 GB of storage the spacecraft can hold 20 days of compressed collection, so a missed pass delays data but does not lose it.

3.5 Day in the life

The table follows the design-case day for EO-1 Lite on the three-station service, during the growing season, with the customer's main farm region close to the longitude of the Mission Operations Center. Times are Mission Operations Center local time. The heaviest orbit of the day (orbit 7) is the power design case: two imaging windows, eight strips and one S-band pass. EO-1 Flight follows the same day with X-band passes at the times marked; EO-1 Lite on the one-station plan keeps only the passes over its single station.

Time	Orbit	Mode	Activity	OPS
00:40	1	Downlink Contact	Unattended S-band pass at Station C (in eclipse: battery worst case, 23 % depth of discharge); remaining data from the previous day	OPS.8, OPS.11
02:15	2	Nominal Imaging	Momentum unloading with magnetorquers over the high-latitude arc	—
04:05	3	Downlink Contact	Unattended S-band pass at Station A; UHF housekeeping dump	OPS.8, OPS.11
06:00	—	—	Automatic processing of the overnight passes complete; products on the portal	OPS.12
07:00	—	—	Day shift starts. Operator reviews overnight telemetry, alarms and the delivery report	UC.5
07:30	—	—	Contact schedule for the next 48 h confirmed with the partner network	UC.2
08:00	—	—	Tasking for today closes on the portal. Planner builds the next 24 h plan; operator checks power, data, thermal and slew constraints and approves it (under 20 min)	UC.1, UC.2

Time	Orbit	Mode	Activity	OPS
08:55	6	Nominal Imaging	UHF pass at Station A: plan uplink, schedule loaded, previous plan's execution report downlinked	OPS.1–OPS.3
09:05	6	Nominal Imaging	First imaging window over the eastern part of the region: one strip	OPS.4–OPS.7
10:30	7	Nominal Imaging	UHF pass at Station A: late plan update with two priority targets	OPS.1–OPS.3
10:39	7	Nominal Imaging	Imaging window 1 over the main region: four strips, off-nadir up to 20°	OPS.4–OPS.7
10:48	7	Nominal Imaging	Imaging window 2: four strips; camera to standby	OPS.4–OPS.7
10:58	7	Downlink Contact	S-band pass at Station B (X-band pass for EO-1 Flight): priority files first	OPS.8, OPS.11
11:10	7–8	Nominal Imaging	Sun-pointing; battery recharge for the rest of the sunlit arc	OPS.10
11:55	—	—	Products from the priority strips on the portal; customer's alert service picks them up	OPS.12
12:20	8	Nominal Imaging	Imaging window over the western part of the region: one short strip (about 15 s)	OPS.4–OPS.7
12:33	8	Downlink Contact	S-band pass at Station B	OPS.8, OPS.11
14:05	9	Downlink Contact	S-band pass at Station C	OPS.8, OPS.11
14:30	—	—	Operator reviews the day's image quality report and the downlink queue	UC.5
16:30	—	—	Shift handover note to the on-call operator; shift ends at 17:00	—

Time	Orbit	Mode	Activity	OPS
22:20	15	Downlink Contact	Unattended S-band pass at Station A (X-band pass for EO-1 Flight)	OPS.8, OPS.11
23:50	16	Nominal Imaging	No contact booked this orbit; data held onboard	OPS.9

Design-case day (EO-1 Lite, three-station service)

The day collects about 9.3 strip-equivalents (120 scenes, 3.22 GB stored), of which the eight strips of orbit 7 are the bulk. Orbits are counted from local midnight (15.22 orbits per day, so a 16th orbit starts shortly before the day ends). Every orbit has an eclipse of up to 35.8 min; the orbit 7 load profile, which the power budget treats as if it repeated every orbit, gives a bus load of 25.0 W against 33.0 W orbit-average generation at end of life. The worst battery case is the night pass at 00:40, with heaters on and the transmitter running in eclipse.

3.6 Ground contact concept

3.6.1 Partner station network

The ground segment buys station time from a partner network. Three stations are under contract for the program, chosen for geographic spread:

Station	Location type	Role
Station A	High northern latitude	Most passes per day; main UHF command station; LEOP and safe mode recovery
Station B	Mid-latitude, downrange of the customer's main farm region	Fast-cycle downlink after the morning imaging orbits
Station C	Southern hemisphere	Night passes; coverage of southern-hemisphere targets

Partner stations

Each station has a 3.7 m S/X-band dish and a UHF yagi antenna, so every station can command the spacecraft and receive either payload downlink. Data reach the Mission Operations Center over the ground network (IF-13) within minutes of the end of a pass.

3.6.2 Contacts

There are two kinds of contact:

- **Command and telemetry contacts** use the UHF link only (9.6 kbps both ways). They carry plan uplinks, command schedules, housekeeping telemetry, flight software patches and recovery commands. The UHF link closes from 5° elevation (11.2 dB uplink margin), so the usable UHF part of a pass is longer than the payload downlink part.
- **Payload downlink contacts** use the UHF link and the payload downlink radio together. At contact start (T4) the spacecraft enters Downlink Contact, points the downlink antenna at the station and switches the transmitter on as its entry action (SM.3). Files are sent by CFDP;

acknowledgments and retransmission requests return on UHF. At contact end (T5) the transmitter switches off and the spacecraft returns to Nominal Imaging. The X-band downlink is planned from 10° elevation and the S-band downlink from 7° (pass geometry in the Communications chapter); at 10° the budgets give 4.7 dB (S-band) and 7.7 dB (X-band) margin against the 3 dB requirement (SR-5.3, TBR-04).

Contacts are booked with the partner network 48 h ahead (SR-6.1). The flight dynamics function produces pass predictions from the latest orbit determination, the planner selects the passes, and the booked schedule goes into the plan uplinked to the spacecraft, so that the spacecraft knows when to expect each contact.

Service	UHF contacts per day	Payload downlink passes per day	Daily downlink capacity
EO-1 Flight, three stations	at least 4	2 X-band, 7 min each	9.87 GB
EO-1 Lite, three stations	at least 4	6 S-band, 8 min each	3.38 GB
EO-1 Lite, one-station plan	at least 2	2 S-band, 8 min each	1.13 GB

Contact plans

3.6.3 EO-1 Lite one-station plan

The one-station plan uses one of the three partner stations [TBD-05] for all contacts. With two booked downlink passes per day it carries about one third of the full daily collection. The concept adapts as follows:

- the planner caps the daily target list at what the two passes can carry (about 40 scenes), in the customer’s priority order;
- the plan uplink, both downlinks and any recovery commands go through the one station, so a station outage stops all contact; outages longer than 24 h are covered by booking ad hoc passes at another station of the network under the same agreement;
- revisit (SR-1.6) is a property of the orbit and is unchanged, but each field is collected only when it is on the capped list, so the effective revisit per field is longer; the customer chooses which fields keep the 72 h revisit.

3.7 Operational scenarios

The scenarios describe the step sequences the system must support. The steps refer to OPS actions, functions and mode transitions; the requirements that bound each step are cited in brackets.

3.7.1 Nominal imaging pass

1. The customer has entered targets and priorities on the portal (UC.1).
2. The planner builds the next 24 h imaging plan: targets, off-nadir angles (at most 25°, SR-1.6.2), strip lengths, slews, downlink passes and the file priority for each strip. It checks the plan against the power, data, slew and thermal constraints, and the operator approves it [SR-6.4].

3. At the next UHF contact the ground station transmits the plan (OPS.1). The UHF Transceiver receives the frames and passes the command packets to the C&DH (OPS.2).
4. The C&DH authenticates and validates the packets and loads the time-tagged command schedule (OPS.3). It acknowledges the load in telemetry; a rejected plan leaves the previous schedule in force.
5. Ahead of each target the schedule commands the ADCS to slew to the target attitude (OPS.4, F4) and to settle within the stability limit [SR-2.2, SR-2.4]. In parallel it powers the camera's detector and brings the focal plane to its operating temperature (OPS.5).
6. At the scheduled time, within 1 s of the tag [SR-4.2], the camera captures the strip in four bands (OPS.6, F7).
7. The C&DH compresses the strip and writes it to payload storage with its attitude, ephemeris and time data (OPS.7, F8). Steps 5 to 7 repeat for each target in the imaging window.
8. After the last strip of the window the camera returns to standby and the spacecraft returns to Sun-pointing to recharge the battery (OPS.10, F3).
9. If a payload downlink pass is booked on this orbit, the downlink contact scenario follows. Otherwise the data stay onboard (OPS.9) for the next pass.

3.7.2 Downlink contact

1. Before the pass the schedule slews the spacecraft so that the payload downlink antenna can track the station.
2. At acquisition the station locks on the UHF beacon and starts the contact (T4 Contact Start). The spacecraft enters Downlink Contact and switches on the payload downlink transmitter (SM.3).
3. The station locks on the payload downlink carrier. The C&DH sends files from the downlink queue, priority files first (OPS.8, F9); for EO-1 Flight the frames are encrypted [SR-4.4].
4. The station records the pass and reassembles the files (OPS.11). Acknowledgments and retransmission requests return over UHF; the C&DH marks acknowledged files for deletion.
5. At the end of the pass the station ends the contact (T5 Contact End). The transmitter switches off and the spacecraft returns to Nominal Imaging.
6. The station forwards the files to the Mission Operations Center (IF-13), which processes and publishes them (OPS.12, F11) within 6 h of the end of downlink [SR-6.2].
7. If the downlink carrier loses lock for more than 60 s during the contact, the spacecraft takes T8 Link Fault to Safe Mode (see "Safe mode entry and recovery"); unacknowledged files stay in the queue.

3.7.3 Safe mode entry and recovery

1. A fault is detected onboard: the battery falls below 6.4 V per cell pair (12.8 V pack), transition T6 Undervoltage; or the downlink link fault of the previous scenario, T8; or one of the further safe-mode triggers defined in the operational modes chapter.

2. Within 10 s of the undervoltage [SR-4.3; 15 s accepted by deviation until flight software 2.4] the flight software enters Safe Mode (F10): it suspends the command schedule, switches off the camera and the payload downlink radio, and sheds non-essential heaters.
3. The ADCS orients the arrays to the Sun (SM.2). The bus load falls to 15.6 W and the battery starts to recharge.
4. The UHF beacon continues with safe-mode telemetry: the entry cause, the fault log and the state of charge.
5. At the next UHF contact the operator sees the safe-mode flag (UC.5) and opens a recovery (UC.6). The fault log and the stored housekeeping around the entry time are downlinked.
6. The operator and the subsystem lead diagnose the cause and decide on the recovery: a parameter change, a load change or a flight software patch. The recovery commands and a new schedule are prepared and checked on the flatsat when the cause is not a known one.
7. The operator sends the recovery command (T7 Recovery Command). The spacecraft returns to Nominal Imaging and resumes the new schedule.
8. The spacecraft is back in Nominal Imaging within 24 h of the recovery command [SR-2.5], and imaging resumes with the next plan. The data stored before the entry are kept and downlinked normally.

3.7.4 Contact loss

1. A booked contact does not take place: the station has an outage, the ground network is down, or the spacecraft does not respond.
2. Onboard, the schedule continues. Data that were to be downlinked stay in the queue (OPS.9); imaging continues while storage allows (20 days of compressed collection).
3. The Mission Operations Center receives the station’s missed-pass report or detects the missing data and alerts the on-call operator.
4. The operator books replacement passes, at another partner station if needed, and checks the next contacts for a beacon.
5. If the spacecraft is heard but does not accept commands, the operator verifies the command counters, onboard time and authentication state from telemetry and resynchronizes them.
6. If the spacecraft is not heard on several consecutive passes, the operator requests passes on all three stations and widens the frequency search for oscillator drift.
7. If no valid command reaches the spacecraft for 72 h, the flight software enters Safe Mode on its own (the loss-of-contact trigger in the operational modes chapter) and keeps beaconing. Recovery then follows the safe mode scenario.

3.7.5 End of mission

1. The end-of-mission decision is made: 730 days in orbit reached without extension, or a failure that rules out the minimum success criteria. The Imagery Customer is informed, and the final products are delivered.
2. The operator downlinks the remaining payload data and the full housekeeping history for the archive (SR-6.3).

3. The operator commands the passivation steps in order, each confirmed in telemetry: camera and payload downlink radio off; reaction wheels spun down; for EO-1 Flight, encryption keys erased; battery disconnected from charging and discharged through the load to the passivation level set in EO1-PLN-340 (HAZ-004).
4. The operator sends the end-of-mission command (T9 End of Mission). The spacecraft enters Decommissioned and permanently inhibits all transmitters.
5. The ground segment notifies the frequency and space-operation authorities, updates the debris tracking information and archives the mission data. Reentry follows by natural decay [TBR-19].

3.8 Use cases

The use cases describe the system from the point of view of its two actors: the **Imagery Customer** (X.1, through its analysts and the portal) and the **Mission Operator** (2.3). The system boundary is the EO-1 Mission System.

Id	Use case	Actor	Goal	Relations	Functions and scenarios
UC.1	Request Imagery	Imagery Customer	Submit areas of interest, deadlines and priorities, and see when each will be collected	—	Portal (IF-14.1); input to UC.2
UC.2	Plan Imaging Campaign	Mission Operator	Build the collection plan from the customer's requests and book the contacts	Included by UC.3	F11 (ground planning), flight dynamics
UC.3	Collect Imagery	Mission Operator	Have the spacecraft image the planned targets and bring the data to the ground	Includes UC.2	F5–F9; scenarios "Nominal imaging pass" and "Downlink contact"
UC.4	Receive Image Products	Imagery Customer	Download calibrated, orthorectified products and alerts from the portal	—	F11; OPS.12
UC.5	Monitor Spacecraft Health	Mission Operator	Review telemetry after each pass and act on limit violations	Extended by UC.6	Telemetry archive (SR-6.3)

Id	Use case	Actor	Goal	Relations	Functions and scenarios
UC.6	Recover from Safe Mode	Mission Operator	Diagnose the fault and command the return to imaging	Extends UC.5 (when telemetry shows Safe Mode)	F10; T7; scenario “Safe mode entry and recovery”

Use cases

UC.1 Request Imagery. Trigger: the customer has fields to monitor. The customer draws or uploads areas of interest, sets a deadline and a priority, and marks alert regions. The portal checks each area against the accessible latitude band and the off-nadir limit, shows the predicted collection opportunities, and confirms the request. Requests received before the daily tasking cutoff enter the next plan. Outcome: the request appears in the customer’s list with its predicted collection time.

UC.2 Plan Imaging Campaign. Trigger: the daily planning slot, or a priority request. The planner proposes targets for the next 24 h from all open requests, weighted by priority, deadline and the time since each field was last collected; the operator reviews the proposal, resolves conflicts and approves it. Contacts are booked 48 h ahead. Outcome: an approved plan and a contact schedule, ready for uplink.

UC.3 Collect Imagery. Trigger: an approved plan (UC.2, included). The plan is uplinked, the spacecraft captures and stores the strips and downlinks them on the booked passes. Outcome: raw files for every planned strip at the Mission Operations Center, or an explanation in the execution report for each strip not collected (cloud forecast, conflict, fault).

UC.4 Receive Image Products. Trigger: products published. The customer receives a notice, downloads the products and the alert layer through the portal or its machine interface (IF-14). Outcome: products delivered within 6 h of downlink.

UC.5 Monitor Spacecraft Health. Trigger: the end of each contact, or an alert. The operator reviews housekeeping trends, limit violations, the downlink queue and the command execution report, and records any anomaly. Outcome: the spacecraft state is known and anomalies have an owner.

UC.6 Recover from Safe Mode. Trigger: telemetry shows Safe Mode (extends UC.5 at that point). The operator downlinks the fault log, diagnoses the cause with the subsystem lead, prepares and checks the recovery, and sends the recovery command. Outcome: the spacecraft back in Nominal Imaging within 24 h of the recovery command.

4 Stakeholders and Needs

This chapter records who has a stake in the EO-1 mission, what they need from it, how the program will judge whether the mission meets those needs, and which constraints it must respect. The needs N1 to N11 are the top of the requirement tree: every system requirement (SR) traces to at least one of them. Needs are written as need statements, in the stakeholders' terms; they are validated, not verified (see the verification chapter, validation activities VAL-01 to VAL-03).

4.1 Stakeholders

Stakeholder	Role in the program	Main interests
Imagery Customer	Agricultural analytics company that funds the mission, tasks it and receives its products (X.1)	Timely, consistent field-level imagery of its farm regions; secure handling of its data; predictable service through two seasons
Field Agronomists	The customer's staff and the growers they advise, who act on crop stress alerts	Alerts on the day of an overpass; maps that separate one field from the next; trust that a change in a map is a change in the crop
Customer Data Analysts	The customer's staff who ingest products into its analytics systems	Stable product formats and calibration; machine access through the customer interface
Program Manager	Leads the EO-1 program for the developing organization; owns cost, schedule and the agreement with the customer	Meeting the agreed needs within budget; a launch slot; low operations cost
Systems Lead	Technical authority for the system; owns this specification, the budgets and the open items	A consistent, verifiable baseline; margins held to CDR
Payload Lead, subsystem leads	Design and verify the Payload Camera and the bus subsystems	Clear, stable allocations and interface definitions
Mission Operations Team	Mission Operators (2.3) and the operations lead, who run the spacecraft from the Mission Operations Center	A system that one small day-shift team can run, with automation for nights and weekends and clear fault indications
Ground Station Network Provider	Partner network that sells station time and data delivery (2.1)	Passes booked ahead within its rules; spacecraft emissions within the agreed frequency and power
Rideshare Integrator and Launch Provider	Integrate the spacecraft into a 6U dispenser and launch it (3)	Compliance with the dispenser interface, inhibits and launch safety rules; delivery on time
Spectrum Authorities	National administration responsible for the radio filings under the ITU Radio Regulations	Lawful frequency use, coordination with other users, timely filings
Space Operations and Debris Authority	National authority that authorizes the space operation and its disposal plan	Debris mitigation, passivation and reentry within the applicable limits; tracking and notification

Stakeholder	Role in the program	Main interests
Security Officer	Owns the Security Plan and the key management for the program	Protection of the command link and, for EO-1 Flight, of the imagery in transit
Space Community	Other operators in nearby orbits (represented through tracking and coordination services)	No collision or interference risk; responsive conjunction coordination

Stakeholders

Stakeholders are identified by role only. The Imagery Customer speaks for the Field Agronomists and the Customer Data Analysts in the program's reviews; validation activities VAL-01 and VAL-03 involve them directly.

4.2 Needs

Each need states what a stakeholder needs, why, and who stated it. The need identifiers are fixed; system requirements cite them in their `Trace` field.

4.2.1 N1 Same-Day Crop Stress Alerts

Statement. Farm customers need to learn about crop stress on the day of an overpass.

Rationale. Water stress, nutrient deficiency, pests and disease spread within days in the growing season; irrigation and spraying decisions are made the same day or the next. An alert that arrives a day late often arrives after the window for an inexpensive fix has closed. Same-day alerts are the service that sets the customer's offering apart from free public imagery with a lower revisit and a longer delivery time.

Source. Imagery Customer, on behalf of the Field Agronomists.

Main requirements. Delivery within 6 h of downlink (SR-6.2); planning cycle (SR-6.5); daily data volume (SR-5.4).

4.2.2 N2 Twice-Weekly Revisit

Statement. Farm customers need fresh imagery of their fields at least twice a week in the growing season.

Rationale. Crop condition changes measurably over three to four days in the main growth stages. With cloud cover removing some collections, a 72 h revisit gives at least one usable image of most fields in most weeks and two in a clear week.

Source. Imagery Customer.

Main requirements. Revisit (SR-1.6), ground track repeat (SR-1.6.1), off-nadir pointing (SR-1.6.2).

4.2.3 N3 Field-Level Vegetation Maps

Statement. Farm customers need vegetation maps detailed enough to tell one field from the next.

Rationale. Management decisions are made per field and often per management zone within a field. Separating fields and their boundaries needs 5 m class resolution; the four bands give the vegetation indices that indicate plant vigor and stress.

Source. Imagery Customer, on behalf of the Field Agronomists.

Main requirements. Ground sample distance (SR-1.2), swath (SR-1.3), spectral bands (SR-1.4), pointing accuracy and stability (SR-2.1, SR-2.2).

4.2.4 N4 Two-Season Mission Life

Statement. The customer needs the service to run for at least two full growing seasons.

Rationale. The customer's business case depends on building a multi-season record of each field and on selling the service for more than one season. Two seasons from a single spacecraft also show that the follow-on EO-1 Lite units are worth buying. The 730-day life with a probability of 0.8 is the agreed balance between that need and the cost of a CubeSat-class reliability program.

Source. Imagery Customer and Program Manager.

Main requirements. Lifetime (SR-1.7), battery energy and depth of discharge (SR-3.2, SR-3.3), the reliability area (area 15).

4.2.5 N5 Secure Imagery

Statement. The customer needs its tasking and imagery protected from disclosure, and the spacecraft protected from unauthorized commands.

Rationale. The fields the customer tasks, and the products it buys, are commercially sensitive: they reveal which growers it serves. An unauthorized command could end the mission. Every configuration authenticates commands; EO-1 Flight, which carries the customer's full collection on a high-rate link, also encrypts the payload downlink.

Source. Imagery Customer and Security Officer.

Main requirements. Downlink encryption (SR-4.4, Flight), the security area (area 14), external interfaces (area 12) .

4.2.6 N6 Consistent Calibration

Statement. The customer needs products whose radiometric and geometric calibration stays consistent from one collection to the next and across spacecraft.

Rationale. Alerts are raised from changes in vegetation indices between collections. If the calibration drifts, the change appears in the map although the crop has not changed, and the agronomists lose trust in the alerts. The same holds when EO-1 Lite units join EO-1 Flight in the constellation: a field imaged by two spacecraft must give the same index.

Source. Imagery Customer and Customer Data Analysts.

Main requirements. Spectral bands (SR-1.4), the payload calibration requirements in the payload chapter, thermal stability of the optics (area 9).

4.2.7 N7 Responsive Tasking

Statement. The customer needs to add or change targets and see them collected within one planning cycle.

Rationale. Agronomists ask for images of fields after events they see on the ground (a storm, a suspected infestation). The customer sells a fast response to such requests. A planning cycle of at most 100 min from plan uplink to delivered product, with the tasking cutoff before the plan uplink, lets a request made in the morning reach the agronomist before midday.

Source. Imagery Customer.

Main requirements. Contact scheduling (SR-6.1), operator interface (SR-6.4), planning cycle (SR-6.5), command execution timing (SR-4.2), slew time (SR-2.4).

4.2.8 N8 Rideshare Compatibility

Statement. The program needs the spacecraft to fly on any standard 6U rideshare launch without changes.

Rationale. A dedicated launch is unaffordable. Rideshare slots change at short notice, and a design that fits only one launch vehicle turns a launch slip (RK-3) into a mission-level delay. The CubeSat Design Specification 6U form factor, the 12.0 kg dispenser mass limit, the inhibit rules and enveloping launch environments keep the choice of launch open.

Source. Program Manager and the Rideshare Integrator.

Main requirements. Mass (allocation 12.0 kg), structure and mechanisms (area 8), environments and launch compatibility (area 11), external interfaces (IF-15).

4.2.9 N9 Responsible Disposal

Statement. The space operation authority and the space community need the spacecraft to leave its orbit promptly after the mission and to release no debris before then.

Rationale. Authorization to operate depends on a credible disposal plan. Without propulsion, the plan relies on natural decay from 500 km and on passivating the battery and the wheels at the end of the mission, so that the spacecraft cannot break up while it decays (HAZ-004).

Source. Space Operations and Debris Authority; Space Community.

Main requirements. The safety, space debris and disposal area (area 13), end of mission (T9).

4.2.10 N10 Spectrum Compliance

Statement. The spectrum authorities and the station provider need every emission to stay within its license and coordination conditions.

Rationale. The program may transmit only on assigned frequencies, at licensed power and bandwidth, and only when permitted (no emission before 45 min after separation). Interference with other users can lead to the loss of the license. The S-band license timing is a program risk (RK-4).

Source. Spectrum Authorities; Ground Station Network Provider.

Main requirements. Communications (area 5), RF inhibit timing (area 11), external interfaces (IF-10 to IF-12.1).

4.2.11 N11 Small-Team Operations

Statement. The program needs the mission to be operable by a small team working one day shift, with unattended passes at night and on weekends.

Rationale. Operations cost over two seasons is the largest cost after the spacecraft itself. A staffed around-the-clock team is unaffordable for a single CubeSat. Unattended passes need a spacecraft that keeps itself safe (autonomous safe mode, stored schedules), and a ground segment that processes and delivers without an operator.

Source. Program Manager and Mission Operations Team.

Main requirements. Safe mode entry and recovery (SR-2.5, SR-4.3), operator interface (SR-6.4), telemetry archive (SR-6.3), flight software and autonomy (area 10).

4.2.12 Summary of needs

Id	Need	Source stakeholder	Measures of effectiveness
N1	Same-Day Crop Stress Alerts	Imagery Customer (Field Agronomists)	MOE-3, MOE-6, MOE-7
N2	Twice-Weekly Revisit	Imagery Customer	MOE-2, MOE-4
N3	Field-Level Vegetation Maps	Imagery Customer (Field Agronomists)	MOE-1, MOE-4
N4	Two-Season Mission Life	Imagery Customer, Program Manager	MOE-5
N5	Secure Imagery	Imagery Customer, Security Officer	— (verified through SR-4.4 and area 14)
N6	Consistent Calibration	Imagery Customer, Customer Data Analysts	MOE-1
N7	Responsive Tasking	Imagery Customer	MOE-7
N8	Rideshare Compatibility	Program Manager, Rideshare Integrator	— (verified through mass, area 8 and area 11)
N9	Responsible Disposal	Space Operations and Debris Authority, Space Community	— (verified through area 13)
N10	Spectrum Compliance	Spectrum Authorities, Ground Station Network Provider	MOE-6
N11	Small-Team Operations	Program Manager, Mission Operations Team	MOE-7

Needs, sources and measures of effectiveness

N5, N8, N9 and N10 are compliance needs: they are met or not met, and have no graded measure of effectiveness.

4.3 Measures of effectiveness

The measures of effectiveness (MOEs) express how well the operating mission meets the needs, as the customer would judge it. Each MOE is a score from 0 % to 100 %. The threshold is the lowest value the customer accepts; the objective is the value beyond which further improvement adds little. MOE-7 is stated directly in minutes. The scoring rule for each MOE, the data sources and the evaluation periods are set in the Systems Engineering Management Plan (EO1-PLN-300); the table gives the underlying measure.

Id	Measure	Underlying measure	Threshold	Objective	Needs
MOE-1	Image Quality	Share of delivered scenes that meet the product quality criteria (MTF at Nyquist at least 0.12, signal-to-noise ratio, band-to-band registration, geolocation), excluding cloud	70 %	95 %	N3, N6
MOE-2	Daily Coverage	Share of the day's planned targets collected, averaged over the growing season	60 %	90 %	N2
MOE-3	Data Latency	Share of priority products delivered on the day of the overpass	60 %	90 %	N1
MOE-4	Pointing Performance	Share of strips whose target lies within 0.1° of the commanded line of sight	75 %	95 %	N2, N3
MOE-5	Power Margin	Orbit-average generation margin over the bus load at end of life, scored linearly from 0 % margin (score 0) to 40 % margin (score 100)	65 %	90 %	N4

Id	Measure	Underlying measure	Threshold	Objective	Needs
MOE-6	Link Availability	Share of booked payload downlink passes that deliver their planned volume	60 %	85 %	N1, N10
MOE-7	Planning Cycle Time	Elapsed time from the start of the plan uplink to the first product on the portal (see Mission Overview and Concept of Operations, “Planning cycle”)	100 min	80 min	N1, N7, N11

Measures of effectiveness

Present predictions, for orientation: the power budget gives a 32 % end-of-life margin (MOE-5 score 80 %, between threshold and objective); the flatsat pointing test TC-04 had 17 of 20 targets within 0.1° (MOE-4 at 85 %), with the three misses attributed to wheel friction and tracked as risk RK-1; the example fast planning cycle lands at 85 min (MOE-7). The budgets chapter and the technical performance measures in EO1-PLN-300 track these values to launch.

4.4 Mission success criteria

Mission success is judged against the primary objectives MO-1 to MO-3 (see Mission Overview and Concept of Operations, “Mission objectives”) for each spacecraft.

Full mission success is achieved when, for one spacecraft:

1. it operates for 730 days in orbit, covering two growing seasons;
2. in each growing season, MOE-1, MOE-2 and MOE-3 meet their thresholds, averaged over the season;
3. the customer’s alert service runs on its products for both seasons, as shown in the customer alert pilot (VAL-01) and the agronomist map review (VAL-03);
4. the spacecraft is passivated and placed in Decommissioned at the end of the mission.

Minimum mission success is achieved when, for one spacecraft:

1. it completes commissioning and delivers calibrated products for at least one full growing season over the minimum target area [TBD-06];
2. over that season, MOE-1 and MOE-2 meet their thresholds, and products are delivered within 6 h of downlink (SR-6.2);
3. the spacecraft is passivated before the end of operations, or is shown to be passive (battery and wheels unable to store energy) if commanding is lost.

Each criterion is assessed per spacecraft; an EO-1 Lite unit is judged against its one-station service plan (see Mission Overview and Concept of Operations, “EO-1 Lite one-station plan”), so its daily coverage is measured against its capped target list.

4.5 Constraints

Constraints restrict the solution space. They are not traded against performance; the design meets them or the program changes its plan.

Id	Constraint	Origin	Consequence for the design
CON-1	6U CubeSat form factor per the CubeSat Design Specification (CDS), Rev. 14.1, including rails, envelope, deployment switches and remove-before-flight provisions	N8; rideshare dispenser	Volume and mass set the aperture (95 mm), array area and battery size
CON-2	Launch mass at most 12.0 kg, the dispenser limit	N8	System mass margin at least 10 % of the allocation at CDR; currently 13.3 % (Lite) and 12.1 % (Flight)
CON-3	Rideshare launch: launch date, orbit and environments set by the primary mission and the launch provider; the spacecraft is unpowered and cannot be charged in the dispenser	N8; launch provider	Environments enveloping several launch vehicles; battery sized for the storage period; designed for a 500 km sun-synchronous orbit with tolerance on the delivered altitude (TBR-01)
CON-4	No deployment before 30 min and no transmission before 45 min after separation	CDS; launch provider; N10	Separation timer and inhibit chain (LEOP timeline)
CON-5	No propulsion	Program decision after the propulsion study	No orbit maintenance; disposal by natural decay; ground-track repeat drifts and is absorbed in planning
CON-6	Emissions only on licensed frequencies: UHF 435 MHz, S-band 2.245 GHz (EO-1 Lite), X-band 8.2 GHz (EO-1 Flight), within the filed power, bandwidth and modulation	ITU Radio Regulations; national licenses; N10	Fixed radio designs; transmitters controlled by the schedule and the inhibits

Id	Constraint	Origin	Consequence for the design
CON-7	Debris mitigation per ISO 24113: no release of parts in normal operation, passivation at end of mission, post-mission orbital lifetime within the applicable limit	N9; space operations authority	Captive burn-wire hold-downs and covers; passivation sequence; reentry within 5 years after the mission [TBR-19]
CON-8	Ground stations are a contracted service with fixed antennas (3.7 m S/X-band dishes, UHF yagis) and booking rules	Ground Station Network Provider	Link budgets use the partner's G/T; contacts booked 48 h ahead
CON-9	Materials meet the outgassing limits of ASTM E595 and the program's materials rules (ECSS-Q-ST-70-71C, as tailored in STD-1)	Rideshare safety; N6 (optics contamination)	Materials list and bake-out under the Contamination Control Plan

Constraints

5 System Architecture

This chapter defines the EO-1 system as a set of elements, functions and connections. It fixes the product breakdown that all other chapters use, the functions the system performs and the element that performs each one, the logical elements that sit between the power and data handling functions and the parts that realize them, and the internal connections of the spacecraft. Interface characteristics (signal levels, data rates, connectors, protocols) are specified in the Interface Requirements chapter; this chapter names each interface by its id only. The operational modes that sequence these functions are defined in Operational Modes.

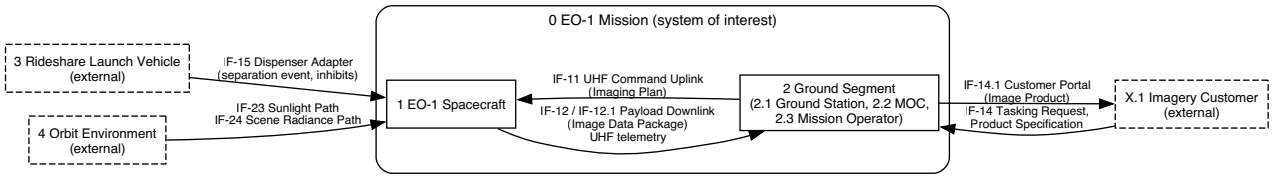
5.1 System Context

The system of interest is the **EO-1 Mission (0)**: the EO-1 Spacecraft (1) and the Ground Segment (2), operated together to turn tasking from the Imagery Customer into delivered image products. Three elements lie outside the system boundary. They are not designed by the EO-1 program, but the mission depends on them and the specification constrains how the system interacts with them:

- **Rideshare Launch Vehicle (3)** carries the spacecraft in a 6U dispenser, holds the deployment inhibits closed during ascent and releases the spacecraft into the reference orbit. The program controls only its side of the Dispenser Adapter Interface (IF-15): rails, separation switches and the inhibit circuit.
- **Orbit Environment (4)** supplies sunlight to the solar arrays (Sunlight Path, IF-23) and reflected scene radiance to the camera (Scene Radiance Path, IF-24). It also imposes the eclipse cycle, trapped and solar particle radiation, atomic oxygen, thermal extremes and the orbital debris flux, all quantified in the Environments chapter.
- **Imagery Customer (X.1)** submits tasking requests (areas of interest, priority, deadline, product specification) and receives image products through the Customer Interface (IF-14), implemented as the Customer Portal (IF-14.1).

The Launch Vehicle and the Orbit Environment carry product numbers 3 and 4 so that the mission model can hold their interfaces and the actions they perform (release of the spacecraft, illumination of the arrays and the scene). They remain external: no requirement in this specification is allocated to them, and their behavior is taken as given.

Inside the boundary, the Space-to-Ground Link (IF-10) joins the spacecraft and the ground segment. It decomposes into the UHF Command Uplink (IF-11) and the payload downlink, S-band (IF-12) on EO-1 Lite or X-band (IF-12.1) on EO-1 Flight. The Ground Network (IF-13) links the ground stations to the Mission Operations Center, and the Operations Console (IF-25) is the operator’s interface to the Mission Operations Center.



EO-1 system context: the mission, its two segments and the three external elements

5.2 Product Breakdown Structure

The product breakdown below is the configuration baseline for the EO-1 product line. Product numbers are fixed and are used for requirement allocation (`Alloc:`), mass and power budgets and the verification matrix. The configuration column states which configuration contains the element; elements marked “All” are identical in both, apart from software parameters stated in the requirements.

No.	Element	Description	Configuration
0	EO-1 Mission	Spacecraft, ground segment and operations, with the launch vehicle and orbit environment as context	All
1	EO-1 Spacecraft	6U CubeSat bus with a four-band push-broom imager; launch mass 10.40 kg (Lite), 10.55 kg (Flight) with contingency	All
1.1	Payload Camera	Four-band push-broom imager: 95 mm aperture, 611 mm focal length, f/6.4, 5.5 μm pixels, 4,889 active pixels across track, 12-bit quantization	All
1.2	ADCS	Attitude determination and control	All
1.2.1	Reaction Wheel Assembly	Four wheels in a pyramid, 10 mNms each, 40 mNms total	All
1.2.2	Star Tracker	Fine attitude sensor, 10 arcsec (1σ, cross-boresight)	All
1.2.3	Magnetorquers	Three torque rods for detumble and momentum unloading	All
1.2.4	ADCS Controller and Sensors	Controller board, six coarse sun sensors, three-axis magnetometer, MEMS rate gyro	All
1.3	EPS	Electrical power subsystem	All

No.	Element	Description	Configuration
1.3.1	Solar Arrays	Two deployable triple-junction panels, 0.2 m² of cells, 29.5 % BOL efficiency, 75.4 W peak	All
1.3.2	Battery Pack	8-cell lithium-ion (4S2P), 77 Wh BOL, 14.4 V nominal; undervoltage threshold 12.8 V pack (6.4 V per series cell pair)	All
1.3.3	Power Distribution Unit	Peak power tracking, 12 V regulated main bus (±2 %), 5 V always-on line to the C&DH, switched load outputs, I2C telemetry	All
1.4	C&DH	Command and data handling	All
1.4.1	Flight Computer	Processor board, hardware watchdog, real-time clock	All
1.4.2	Payload Data Storage	64 GB radiation-tolerant flash with error detection and correction (EDAC)	All
1.4.3	Flight Software	Executive, command and telemetry, schedule, fault management, payload data handling, image compression	All
1.5	Communications	Radios and antennas	All
1.5.1	UHF Transceiver	435 MHz half-duplex, 9.6 kbps GMSK, 2 W RF; command uplink and telemetry downlink	All
1.5.2	S-band Transmitter	2.245 GHz, 10 Mbps OQPSK, 1 W RF, 6 dBi patch antenna	Lite
1.5.3	X-band Payload Radio	8.2 GHz, 100 Mbps OQPSK, 2 W RF, 16 dBi patch array, frame encryption	Flight
1.5.4	UHF Antenna	Deployable turnstile/dipole with burn-wire release	All
1.6	Structure and Thermal	6U aluminum frame, deployment hinges, passive thermal control	All
1.6.1	Primary Structure	Frame, rails and panels	All
1.6.2	Deployment Mechanisms	Array hinges, burn-wire hold-downs, UHF antenna release, deployment and separation switches	All

No.	Element	Description	Configuration
1.6.3	Thermal Control Hardware	Coatings, multilayer insulation, heaters, thermostats, thermistors, payload radiator	All
1.7	Harness	Power and signal harness, connectors and RF cables between the spacecraft elements	All
2	Ground Segment	Ground stations, operations center and operations staff	All
2.1	Ground Station	Partner network: 3.7 m S/X-band dishes with UHF yagi antennas; three stations under contract, one used by the EO-1 Lite service plan	All
2.2	Mission Operations Center	Planning, commanding, flight dynamics, image processing, archive and customer portal	All
2.3	Mission Operator	Day-shift operations staff	All
3	Rideshare Launch Vehicle	External; rideshare launch with a 6U dispenser	External
4	Orbit Environment	External; sunlight, eclipse, radiation, atomic oxygen, debris	External
X.1	Imagery Customer	External; agricultural analytics company that tasks the mission and receives products	External

EO-1 product breakdown structure

The payload downlink radio is a configuration-dependent slot: where this specification says “payload downlink radio”, it means the S-band Transmitter (1.5.2) on EO-1 Lite and the X-band Payload Radio (1.5.3) on EO-1 Flight.

5.3 Functional Architecture

5.3.1 Top-Level Functions

The top-level function **F0 Perform EO-1 Mission** covers the mission from separation to image delivery. It decomposes into eleven functions.

No.	Function	Description
F1	Separate and Detumble	Separate from the dispenser, power up and null the tip-off rates with the magnetorquers.

No.	Function	Description
F2	Deploy Solar Arrays	Release the hinged arrays and the UHF antenna after the post-separation quiet period and confirm deployment.
F3	Generate and Store Power	Track the array peak power, charge the battery in sunlight, supply the bus in eclipse and regulate the 12 V bus.
F4	Determine and Control Attitude	Estimate attitude and point the spacecraft as each mode requires: Sun, target or ground station.
F5	Operate Imaging Orbits	Repeat the command, imaging, storage and downlink cycle each orbit for the mission life.
F6	Receive Commands	Receive, decode and validate ground commands over the UHF uplink.
F7	Capture Images	Point at each scheduled target and image its strip in four bands.
F8	Store Payload Data	Compress image strips and hold them in payload storage until they are downlinked and acknowledged.
F9	Transmit Payload Data	Transmit stored image data to a ground station during a scheduled contact.
F10	Enter Safe Mode	Detect a fault, shed loads, point the arrays at the Sun and wait for ground commands.
F11	Process and Deliver Images	Calibrate, orthorectify and deliver products to the customer, then archive data and telemetry.

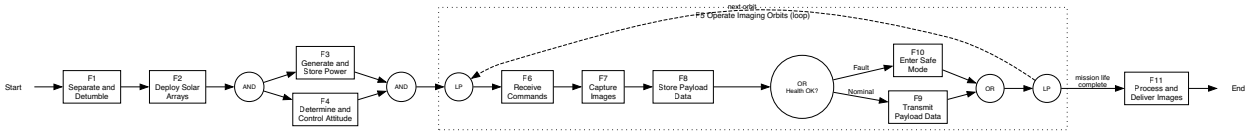
Top-level functions of F0 Perform EO-1 Mission

5.3.2 Top-Level Functional Flow

The functional flow block diagram below gives the order in which the top-level functions become active:

1. **F1 Separate and Detumble** starts when the launch vehicle releases the spacecraft (Separation Event). It ends when the body rates are below 0.5 deg/s.
2. **F2 Deploy Solar Arrays** follows F1 and ends when the deployment switches report the arrays and the UHF antenna deployed (Deployment Status). Whether the array release is started by a timer or by the rate condition is open (TBR-02, see Operational Modes).
3. **F3 Generate and Store Power** and **F4 Determine and Control Attitude** then run in parallel (an AND branch). Both are continuous functions that stay active for the rest of the mission. The branch joins when the spacecraft is power-positive with deployed arrays and attitude control is closed on the star tracker, which is the condition commissioning confirms before imaging starts.

4. **F5 Operate Imaging Orbits** is an iteration (loop) that repeats once per imaging orbit for the 730-day mission life. Each pass through the loop runs, in sequence:
   - **F6 Receive Commands**, which brings the Imaging Plan aboard and yields a loaded Command Schedule;
   - **F7 Capture Images**, which images the scheduled targets;
   - **F8 Store Payload Data**, which compresses and stores the strips;
   - an OR decision **"Health OK?"**, evaluated by fault management. On the **Nominal** branch the spacecraft performs **F9 Transmit Payload Data** when a contact is scheduled (on orbits without a contact, data stays in storage for the next pass). On the **Fault** branch it performs **F10 Enter Safe Mode**. Both branches rejoin before the loop returns for the next orbit; after F10 the loop resumes only once the ground has commanded recovery (Operational Modes, transition T7).
5. **F11 Process and Deliver Images** follows the loop. The diagram shows it after the loop to complete the end-to-end chain; in operation it runs on the ground after every downlink pass, concurrently with later orbits.



Top-level functional flow of F0 Perform EO-1 Mission

5.3.3 Subfunctions of F3 and F4

F3 Generate and Store Power repeats once per orbit (about 15 times a day): sunlight is converted, the bus is regulated and the battery stores the surplus for the eclipse.

No.	Function	Description
F3.1	Convert Sunlight to Power	Turn incident sunlight into array output at the peak power point.
F3.2	Store Battery Energy	Charge the cells in sunlight and supply the bus in eclipse.
F3.3	Regulate Bus Power	Track the array peak power, limit the depth of discharge, hold the bus at 12 V and switch loads on command.

Subfunctions of F3 Generate and Store Power

The F3 flow is a loop "each orbit" containing F3.1, then F3.3, then F3.2. F3.1 receives Solar Illumination and produces Array Power Output. F3.3 receives Array Power Output, Battery Discharge Power and Safe Mode Commands, and produces Battery Charge Power and Power Telemetry. F3.2 receives Battery Charge Power and produces Battery Discharge Power, which feeds F3.3 in the next eclipse.

F4 Determine and Control Attitude repeats once per control cycle.

No.	Function	Description
F4.1	Estimate Attitude	Compute the attitude quaternion from star tracker images, with the gyro and coarse sensors as backup.
F4.2	Compute Control Torques	Run the pointing control law against the attitude commanded by the schedule or the active mode.
F4.3	Drive Reaction Wheels	Apply the commanded wheel torques and report wheel speeds.
F4.4	Unload Wheel Momentum	Drive the torque rods to dump stored wheel momentum against the geomagnetic field.

Subfunctions of F4 Determine and Control Attitude

The F4 flow is a loop “each control cycle” containing F4.1, then F4.2, then an AND branch with F4.3 and F4.4 in parallel. F4.2 receives ADCS Sensor Data and the Command Schedule and produces ADCS Bus Commands; F4.1, F4.3 and F4.4 receive ADCS Bus Commands and return ADCS Sensor Data. F4.4 is active only when wheel momentum exceeds its unloading threshold and target imaging is not in progress (Operational Modes, sub-mode NI.3).

5.3.4 Subfunctions of F7 Capture Images

F7 runs once per target in the Command Schedule; the design-case orbit contains eight targets in two imaging windows. Its flow is F7.1 and F7.2 in parallel (AND), then F7.3, then F7.4.

No.	Function	Description
F7.1	Prepare Focal Plane	Power the detector, bring the focal plane to its operating temperature and report ready (Focal Plane Status).
F7.2	Slew to Target Attitude	Rotate the spacecraft to the target attitude, up to 25° off nadir, and settle within the stability limit.
F7.3	Acquire Image Strip	Clock the detector at the line rate (1,569 lines/s) for the strip duration (40 s nominal, 54 s maximum) in four bands.
F7.4	Tag Strip with Ancillary Data	Attach time tags, attitude, ephemeris and calibration parameters to the strip.

Subfunctions of F7 Capture Images

F7.3 runs only when F7.1 has reported ready and F7.2 has settled; if either is not achieved by the scheduled start time the target is skipped and logged in housekeeping, and the schedule continues with the next target.

5.3.5 Subfunctions of F8 Store Payload Data

F8 runs once per image strip. Its flow is the sequence F8.1, F8.2, F8.3, F8.4.

No.	Function	Description
F8.1	Receive Image Strip	Read the strip from the payload buffer over the Payload Interface into flight computer memory.
F8.2	Compress Image Data	Compress the strip with CCSDS 122.0-B image compression at 2.2 bits per pixel (5.45:1), or store it raw in calibration mode.
F8.3	Write to Payload Storage	Write the compressed file to payload storage with EDAC and verify the write.
F8.4	Manage Storage Catalog	Keep the file catalog with downlink priority, release files the ground has acknowledged and protect unacknowledged files from overwrite.

Subfunctions of F8 Store Payload Data

F8.4 also supplies Retained Image Data: files not downlinked on one orbit stay in the catalog for the next contact.

5.3.6 Subfunctions of F9 Transmit Payload Data

F9 runs once per scheduled payload contact. Its flow is F9.1 and F9.2 in parallel (AND), then F9.3 and F9.4 in parallel (AND, they run together for the duration of the pass), then F9.5.

No.	Function	Description
F9.1	Enable Payload Transmitter	Power the payload downlink radio at contact start (mode activity SM.3, Transmitter Enable Command).
F9.2	Track Ground Station	Point the downlink antenna boresight at the ground station for the duration of the pass.
F9.3	Frame and Encode Data	Packetize stored files into CCSDS TM transfer frames, apply LDPC coding and, on EO-1 Flight, encrypt the frames.
F9.4	Deliver Files to Ground	Transmit the files by CCSDS File Delivery Protocol (CFDP), with retransmission of missing segments on ground request.
F9.5	Close Contact	Record which files the ground acknowledged, pass the acknowledgements to F8.4 and power the transmitter off.

Subfunctions of F9 Transmit Payload Data

5.3.7 Subfunctions of F10 Enter Safe Mode

F10 runs when fault management detects one of the Safe Mode trigger conditions defined in Operational Modes. Its flow is F10.1, then F10.2, then F10.3 and F10.4 in parallel (AND), then F10.5.

No.	Function	Description
F10.1	Detect Fault Condition	Evaluate power telemetry, temperatures, attitude error, watchdog reset count and command-loss timer against the trigger limits.
F10.2	Shed Non-Essential Loads	Switch off the payload, the star tracker and the payload downlink radio and stop the command schedule (Safe Mode Commands).
F10.3	Acquire Sun-Pointing Attitude	Point the array normal at the Sun using the coarse sun sensors, magnetometer, gyro and wheels.
F10.4	Transmit Health Beacon	Transmit a periodic health beacon over UHF so the ground can assess the spacecraft at the next pass.
F10.5	Await Recovery Command	Hold the safe configuration and accept ground commands until a valid recovery command is executed.

Subfunctions of F10 Enter Safe Mode

5.3.8 Subfunctions of F11 Process and Deliver Images

F11 runs on the ground once per downlink pass. Its flow is F11.1, F11.2, F11.3, F11.4, then F11.5 and F11.6 in parallel (AND), then F11.7.

No.	Function	Description
F11.1	Receive and Reassemble Downlink	Record the pass, decode the frames, reassemble the files and forward them to the operations center (Raw Image Files).
F11.2	Calibrate Radiometrically	Convert detector counts to top-of-atmosphere radiance with the current calibration coefficients.
F11.3	Orthorectify and Register	Map the strip to ground coordinates with the elevation model and register the four bands to each other.
F11.4	Generate Crop Products	Compute vegetation index maps and crop stress alerts for the customer’s fields.
F11.5	Publish Products	Post the Image Product to the Customer Portal and notify the customer.

No.	Function	Description
F11.6	Archive Data and Telemetry	Archive raw files, products and housekeeping telemetry for the retention period.
F11.7	Report Collection Status	Report targets imaged, delivered and missed to the operator for replanning (Collection Status Report).

Subfunctions of F11 Process and Deliver Images

F11.4 follows Processing Priorities set by the operator, so that alert-critical scenes are processed first. Whether cloud screening of strips is done onboard (between F8.1 and F8.2) or on the ground in F11.4 is open [TBD-10]; the baseline does it on the ground.

5.3.9 Functional Allocation

Each function is performed by exactly one element. The table gives the performing element and the main items each function receives and produces; the items are listed by their names in the mission model. Subfunctions inherit their parent's allocation unless the table gives a different element. For F9, "payload downlink radio" means the S-band Transmitter (1.5.2) on EO-1 Lite and the X-band Payload Radio (1.5.3) on EO-1 Flight.

Function	Performed by	Main inputs	Main outputs
F1 Separate and Detumble	1.2 ADCS	Separation Event, ADCS Sensor Data	ADCS Bus Commands
F2 Deploy Solar Arrays	1.6 Structure and Thermal	Separation Event	Deployment Status
F3 Generate and Store Power	1.3 EPS	Solar Illumination, Safe Mode Commands	Power Telemetry
F3.1 Convert Sunlight to Power	1.3.1 Solar Arrays	Solar Illumination	Array Power Output
F3.2 Store Battery Energy	1.3.2 Battery Pack	Battery Charge Power	Battery Discharge Power
F3.3 Regulate Bus Power	1.3.3 Power Distribution Unit	Array Power Output, Battery Discharge Power, Safe Mode Commands	Battery Charge Power, Power Telemetry
F4 Determine and Control Attitude	1.2 ADCS	Command Schedule	ADCS Sensor Data
F4.1 Estimate Attitude	1.2.2 Star Tracker	ADCS Bus Commands	ADCS Sensor Data
F4.2 Compute Control Torques	1.2 ADCS (1.2.4 ADCS Controller)	ADCS Sensor Data, Command Schedule	ADCS Bus Commands
F4.3 Drive Reaction Wheels	1.2.1 Reaction Wheel Assembly	ADCS Bus Commands	ADCS Sensor Data
F4.4 Unload Wheel Momentum	1.2.3 Magnetorquers	ADCS Bus Commands	ADCS Sensor Data
F5 Operate Imaging Orbits	1 EO-1 Spacecraft	Collection Plan	Raw Image Data
F6 Receive Commands	1.5.1 UHF Transceiver	Imaging Plan	Command Packets
F7 Capture Images	1.1 Payload Camera	Command Schedule, Ground Scene Radiance	Image Strip

Function	Performed by	Main inputs	Main outputs
F7.1 Prepare Focal Plane	1.1 Payload Camera	Command Schedule	Focal Plane Status
F7.2 Slew to Target Attitude	1.2 ADCS	Command Schedule	ADCS Bus Commands
F7.3 Acquire Image Strip	1.1 Payload Camera	Focal Plane Status, Ground Scene Radiance	Image Strip
F7.4 Tag Strip with Ancillary Data	1.4.3 Flight Software	Image Strip, ADCS Sensor Data	Image Strip (tagged)
F8 Store Payload Data	1.4 C&DH	Image Strip	Downlink Frames
F8.1 Receive Image Strip	1.4.1 Flight Computer	Image Strip	Image Strip (in memory)
F8.2 Compress Image Data	1.4.3 Flight Software	Image Strip	Compressed image file
F8.3 Write to Payload Storage	1.4.2 Payload Data Storage	Compressed image file	Stored image file
F8.4 Manage Storage Catalog	1.4.3 Flight Software	Stored image file, file acknowledgements	Downlink Frames, Retained Image Data
F9 Transmit Payload Data	payload downlink radio	Downlink Frames, Retained Image Data, Transmitter Enable Command	Image Data Package
F9.1 Enable Payload Transmitter	1.4.3 Flight Software	Command Schedule	Transmitter Enable Command
F9.2 Track Ground Station	1.2 ADCS	Command Schedule	ADCS Bus Commands
F9.3 Frame and Encode Data	payload downlink radio	Downlink Frames	Encoded transfer frames
F9.4 Deliver Files to Ground	payload downlink radio	Encoded transfer frames	Image Data Package
F9.5 Close Contact	1.4.3 Flight Software	File acknowledgements	Housekeeping Telemetry
F10 Enter Safe Mode	1.4 C&DH	Power Telemetry, Deployment Status, Housekeeping Telemetry	Safe Mode Commands
F10.1 Detect Fault Condition	1.4.3 Flight Software	Power Telemetry, Housekeeping Telemetry, ADCS Sensor Data	Fault flag
F10.2 Shed Non-Essential Loads	1.3.3 Power Distribution Unit	Safe Mode Commands	Power Telemetry
F10.3 Acquire Sun-Pointing Attitude	1.2 ADCS	Safe Mode Commands, ADCS Sensor Data	ADCS Bus Commands
F10.4 Transmit Health Beacon	1.5.1 UHF Transceiver	Housekeeping Telemetry	Health beacon
F10.5 Await Recovery Command	1.4.3 Flight Software	Command Packets	Recovery command
F11 Process and Deliver Images	2.2 Mission Operations Center	Raw Image Files, Processing Priorities	Image Product, Collection Status Report
F11.1 Receive and Reassemble Downlink	2.1 Ground Station	Image Data Package	Raw Image Files

Function	Performed by	Main inputs	Main outputs
F11.2 – F11.7	2.2 Mission Operations Center	Raw Image Files, Processing Priorities, Product Specification	Image Product, Collection Status Report

Functional allocation with main input and output items

The Command Schedule is produced on board from the Command Packets of F6. Validating the packets and loading the time-tagged schedule (operations step OPS.3 Load Command Schedule) and executing it (mode activity SM.1) belong to the logical element L4 Onboard Command Processing, realized by the C&DH. Housekeeping Telemetry (voltages, temperatures and mode flags sampled every 10 s) is produced by the C&DH while it executes the schedule and is downlinked over UHF and with the payload data.

5.4 Logical Architecture

The logical architecture covers the power and data handling slices of the spacecraft. Its elements are solution-independent: they state what must be done without naming the hardware. Each logical element groups functions and is realized by one physical part. The power slice maps one-to-one onto the EPS parts; the three data handling elements share one physical part, the C&DH, and are separated inside it by flight software components and dedicated hardware (watchdog, storage).

No.	Logical element	Responsibility	Functions grouped	Realized by
L0	EO-1 Logical Architecture	Power and data handling slices of the spacecraft	—	1 EO-1 Spacecraft
L1	Power Generation	Turn an external energy source into electrical power.	F3.1	1.3.1 Solar Arrays
L2	Energy Storage	Hold energy for eclipse and peak loads.	F3.2	1.3.2 Battery Pack
L3	Power Conditioning and Distribution	Regulate the bus, manage charging and switch loads.	F3.3	1.3.3 Power Distribution Unit
L4	Onboard Command Processing	Validate, schedule and execute commands.	OPS.3 Load Command Schedule, SM.1 Execute Command Schedule, SM.3 Enable Downlink Transmitter	1.4 C&DH (Flight Computer 1.4.1 and the command, telemetry and schedule components of Flight Software 1.4.3)
L5	Payload Data Management	Compress, store and release payload data.	F8, OPS.7 Encode and Store Image	1.4 C&DH (Payload Data Storage 1.4.2 and the payload data handling and compression components of 1.4.3)

No.	Logical element	Responsibility	Functions grouped	Realized by
L6	Fault Management	Detect faults and put the spacecraft in a safe state.	F10	1.4 C&DH (fault management component of 1.4.3 and the hardware watchdog of 1.4.1)

Logical architecture and the parts that realize it

Keeping L4, L5 and L6 distinct even though they share a part has two purposes. It lets the flight software be partitioned so that a failure in payload data handling cannot block fault management, and it keeps open a later design in which payload data management moves to a separate payload processor without changing the functional allocation.

5.5 Internal Structure of the Spacecraft

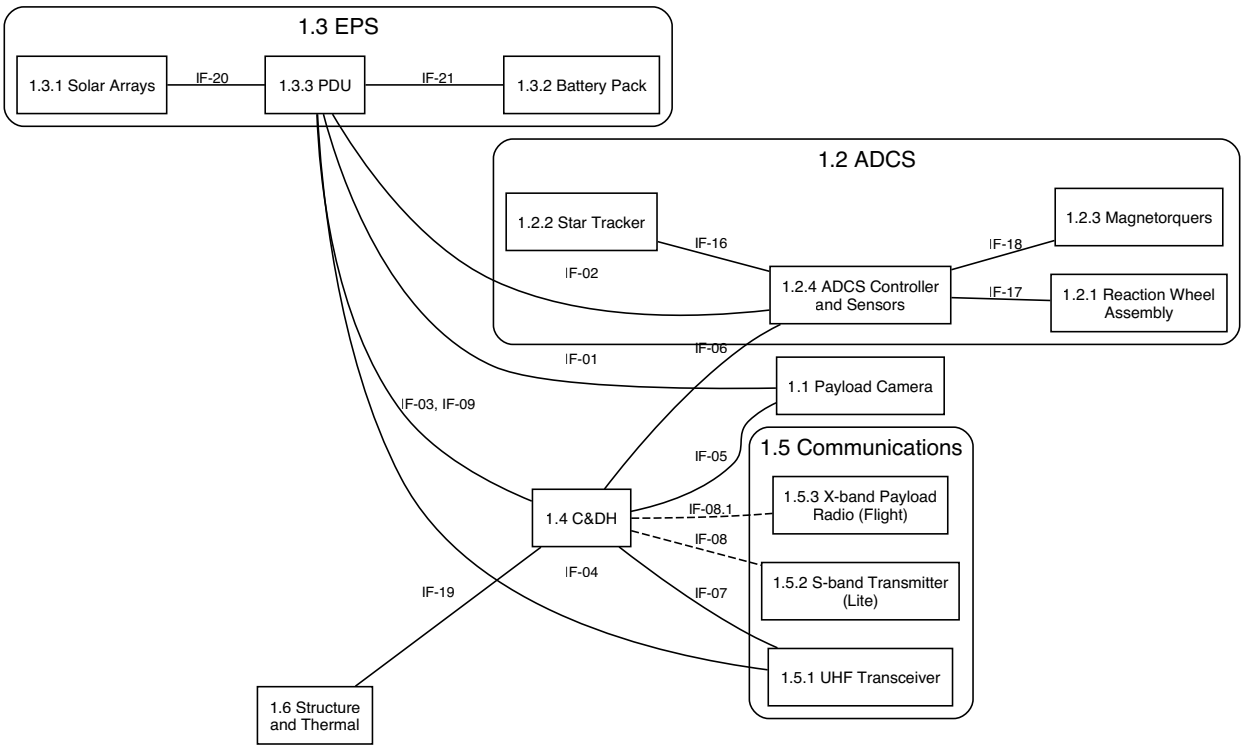
The spacecraft subsystems connect through the interfaces below. The table states what each connection carries in terms of the model's items; ratings, protocols and connectors are in the Interface Requirements chapter. All power lines originate at the EPS Power Distribution Unit.

Interface	From	To	Carries
IF-01 Payload Power Line	1.3 EPS	1.1 Payload Camera	Switched 12 V supply
IF-02 ADCS Power Line	1.3 EPS	1.2 ADCS	Switched 12 V supply
IF-03 C&DH Power Line	1.3 EPS	1.4 C&DH	Always-on 5 V supply
IF-04 Radio Power Line	1.3 EPS	1.5 Communications	Switched 12 V supply to the UHF Transceiver and the payload downlink radio
IF-05 Payload Interface	1.4 C&DH	1.1 Payload Camera	Command Schedule (control, SPI) to the camera; Image Strip (LVDS) and Focal Plane Status from it
IF-06 ADCS Data Bus	1.4 C&DH	1.2 ADCS	Command Schedule (attitude targets), Safe Mode Commands; ADCS telemetry back
IF-07 Radio Command Interface	1.5.1 UHF Transceiver	1.4 C&DH	Command Packets; telemetry frames back for UHF downlink
IF-08 Payload Data Interface	1.4 C&DH	1.5.2 S-band Transmitter (Lite)	Downlink Frames, Transmitter Enable Command
IF-08.1 X-band Data Interface	1.4 C&DH	1.5.3 X-band Payload Radio (Flight)	Downlink Frames, Transmitter Enable Command
IF-09 Power Telemetry Link	1.3.3 Power Distribution Unit	1.4 C&DH	Power Telemetry to the C&DH; Safe Mode Commands and load switch commands to the PDU

Interface	From	To	Carries
IF-16 Star Tracker Link	1.2.2 Star Tracker	1.2.4 ADCS Controller	ADCS Sensor Data; ADCS Bus Commands back
IF-17 Wheel Drive Link	1.2.4 ADCS Controller	1.2.1 Reaction Wheel Assembly	ADCS Bus Commands (wheel torque); wheel speeds back
IF-18 Torque Rod Link	1.2.4 ADCS Controller	1.2.3 Magnetorquers	ADCS Bus Commands (dipole); magnetometer readback
IF-19 Deployment Switch Harness	1.6 Structure and Thermal	1.4 C&DH	Deployment Status, separation switch states
IF-20 Array Power	1.3.1 Solar Arrays	1.3.3 Power Distribution Unit	Array Power Output
IF-21 Battery Power	1.3.3 Power Distribution Unit	1.3.2 Battery Pack	Battery Charge Power in; Battery Discharge Power out
IF-22 Regulated Bus	1.3.3 Power Distribution Unit	EPS 12 V bus port	Regulated 12 V bus feeding IF-01, IF-02 and IF-04

Internal connections of the EO-1 Spacecraft

The spacecraft also has three boundary connections: IF-15 to the launch vehicle (through the Primary Structure and the separation switches), IF-23 and IF-24 from the orbit environment (to the Solar Arrays and the Payload Camera aperture), and IF-10 to the ground segment through the UHF Antenna and the payload downlink antenna. The RF cables between the radios and their antennas, and the burn-wire release circuits of the Deployment Mechanisms, are part of the Harness (1.7) and carry no separate interface id.



Internal structure of the EO-1 Spacecraft (interface ids; Lite and Flight payload radio paths shown dashed)

5.6 Configuration Differences

EO-1 Flight and EO-1 Lite share every element except the payload downlink radio. The differences that follow from that choice are listed below; all other characteristics are common.

Characteristic	EO-1 Flight	EO-1 Lite
Serial numbers	1 and 2	3 onward
Payload downlink radio	1.5.3 X-band Payload Radio	1.5.2 S-band Transmitter
Downlink frequency, rate, modulation	8.2 GHz, 100 Mbps, OQPSK	2.245 GHz, 10 Mbps, OQPSK
Downlink antenna	16 dBi patch array	6 dBi patch
Data interface and RF link	IF-08.1, IF-12.1	IF-08, IF-12
Link margin at 10° elevation	7.7 dB	4.7 dB
Downlink encryption (SR-4.4)	Frame encryption, 256-bit keys	None; secure delivery from the ground station onward
Ground service	Three-station network, 2 passes of 7 min per day	One-station service plan, 2 passes of 8 min per day (three-station S-band service available)
Daily downlink capacity	9.87 GB (207 % margin over 3.22 GB stored)	1.13 GB one-station plan; 3.38 GB with the three-station service
Daily data volume requirement (SR-5.4)	≥ 3 GB	≥ 1 GB
Downlink transmit power (design case)	15.0 W, 7 min pass	11.5 W, 9 min pass

Characteristic	EO-1 Flight	EO-1 Lite
Bus load, Nominal Imaging, with contingency	25.0 W	25.0 W
Launch mass with contingency	10.55 kg (margin 12.1 %)	10.40 kg (margin 13.3 %)
Downlink pointing during a pass	Ground-station tracking required (narrow patch array beam)	Ground-station tracking used to hold the link margin

Configuration differences between EO-1 Flight and EO-1 Lite

Both configurations acquire the full 3.22 GB a day (SR-1.5). On the EO-1 Lite one-station plan the downlink carries about a third of that, so the Mission Operations Center limits tasking to about 40 scenes a day, or uses payload storage (20 days of compressed collection) to carry the backlog of a short campaign, unless the customer buys the three-station service.

5.7 Design Drivers and Key Trades

5.7.1 Design Drivers

- **Ground sample distance.** 4.5 m from 500 km with 5.5 μm pixels fixes the focal length at 611 mm. The folded telescope and focal plane take most of the 6U volume along the long axis and set the Payload Camera's 2.4 kg, the largest single mass item. This is the main reason for a 6U rather than a 3U bus.
- **Data volume.** 120 scenes a day produce 17.2 GB raw. Compression at 2.2 bits per pixel brings this to 3.22 GB, which sets both the 64 GB storage and the downlink design. With S-band the three-station service has only 5 % margin, which is what drove the X-band option.
- **Pointing.** The 0.1° accuracy and 0.01 deg/s stability during capture require a star tracker and reaction wheels. The pointing budget gives 0.045° (3σ), with control error (wheel jitter) the largest term; flatsat test TC-04 measured 0.14° on 3 of 20 targets, carried as risk RK-1.
- **Power.** The orbit-average bus load of 25.0 W in the Nominal Imaging design case, against 33.0 W orbit-average generation at end of life, requires deployable arrays. The 35.8 min longest eclipse with a pass in eclipse sets the battery depth of discharge at 23 % against the 30 % limit.
- **Small-team operations.** Operations run on a day shift. The spacecraft must therefore run a 24 h command schedule unattended, protect itself autonomously when a fault occurs and wait safely for the next shift. This drives the mode logic and fault management in Operational Modes.
- **Rideshare compatibility.** A 6U dispenser with a 12.0 kg limit, closed inhibits during ascent and the post-separation quiet periods (30 min for deployables, 45 min for RF) constrain the mass, the Launch mode and the deployment sequence.

5.7.2 TR-1 Downlink Band Selection

The trade compared S-band at 10 Mbps, X-band at 100 Mbps and Ka-band on capacity, mass, power, spectrum licensing, ground station availability and cost. Ka-band was eliminated early: few partner stations support it, and the pointing needed for a high-gain antenna was beyond the baseline ADCS. At PDR **S-band was chosen for the baseline**. It meets the 3 GB daily requirement with the three-station service, uses a simple 6 dBi patch, has the lowest transmit power, and its

frequency coordination path is the shorter of the two (license delay is nonetheless carried as risk RK-4). The 5 % daily margin left no room for growth in tasking or for missed passes. **X-band was therefore added for EO-1 Flight**: the 100 Mbps radio with its 16 dBi patch array costs 0.13 kg and about 3.5 W more transmit power than the S-band unit, but it delivers 9.87 GB a day from two 7 min passes and adds frame encryption for customers that require secure imagery. EO-1 Lite keeps S-band to serve customers on the lower-cost one-station plan.

5.7.3 Propulsion Studied and Excluded

A cold-gas thruster module for orbit maintenance was studied to hold the 3-day ground-track repeat (TBR-01) against drag and to lower the orbit at end of mission. It is **not included in either configuration**. The only free volume large enough for the module is the bay beside the X-band Payload Radio, which would have to give up the radio's radiator area; the module's estimated 0.8 kg with contingency would also take EO-1 Flight's mass margin below the 10 % required at CDR. The benefits are small at 500 km: the ground-track drift over a season is absorbed by replanning, and the natural orbital decay meets the disposal requirements (see Safety, Space Debris and Disposal) without a deorbit burn. Propulsion remains an option for a later configuration at a lower altitude.

6 Operational Modes

This chapter defines the operational modes of the EO-1 Spacecraft as a state machine: the modes, the transitions between them with their triggers, guards and actions, the sub-modes inside Nominal Imaging, Detumble and Safe Mode, the activities run on entry to, during and on exit from each mode, and the equipment and pointing configuration in each mode. The mode logic is implemented by the Flight Software (1.4.3), in the logical elements L4 Onboard Command Processing and L6 Fault Management (see System Architecture). The mode-logic requirements are given at the end of the chapter as SR-10.1 to SR-10.19.

The state machine belongs to the EO-1 Spacecraft (1) and is the same for EO-1 Flight and EO-1 Lite. Where this chapter says “payload downlink radio”, it means the S-band Transmitter (1.5.2) on EO-1 Lite and the X-band Payload Radio (1.5.3) on EO-1 Flight.

6.1 Mode Overview

The spacecraft has one initial pseudo-state, six modes and one final state. At any time after the initial transition the spacecraft is in exactly one mode.

State	Kind	Purpose
Initial	Initial pseudo-state	Start of the state machine at the end of integration
Launch	Mode	Survive ascent unpowered in the dispenser, then wait out the post-separation quiet period
Detumble	Mode	Null the tip-off rates, deploy the arrays and the UHF antenna, and commission the spacecraft
Nominal Imaging	Mode	Execute the command schedule: image targets, store data, keep power and attitude
Downlink Contact	Mode	Transmit stored payload data to a ground station during a scheduled contact
Safe Mode	Mode	Protect the spacecraft after a fault: minimum loads, arrays to the Sun, wait for the ground
Decommissioned	Final state	End of mission: spacecraft passivated, transmitters permanently off

Operational states of the EO-1 Spacecraft

6.2 ADCS Pointing Modes

Each spacecraft mode commands one ADCS pointing mode. The pointing modes are configurations of the ADCS, not states of the spacecraft state machine.

Id	Pointing mode	Sensors and actuators	Attitude held
AP-0	Off	None	None
AP-1	Rate Damping	Magnetometer, magnetorquers (B-dot control)	Body rates reduced toward zero; no attitude target
AP-2	Coarse Sun Pointing	Coarse sun sensors, magnetometer, rate gyro, reaction wheels, magnetorquers	Array normal toward the Sun within 15°; in eclipse, rates held on the gyro
AP-3	Fine Sun Pointing	Star tracker, rate gyro, reaction wheels, magnetorquers	Array normal toward the Sun, star tracker on a dark-sky attitude
AP-4	Target Pointing	Star tracker, rate gyro, reaction wheels	Camera boresight on the scheduled target, up to 25° off nadir, with the accuracy and stability of SR-2.1 and SR-2.2
AP-5	Ground Station Tracking	Star tracker, rate gyro, reaction wheels	Payload downlink antenna boresight on the ground station

ADCS pointing modes

6.3 Mode Definitions

6.3.1 Launch

Purpose. Carry the spacecraft safely through integration, ascent and dispenser release, and keep it inert for the first 30 min after separation so that it cannot affect the launch vehicle or other rideshare payloads.

Entry. Transition T1 Power On, when integration ends with the battery charged, the remove-before-flight pin removed and the spacecraft loaded in the dispenser with the separation switches depressed.

Behavior. While the separation switches are depressed the inhibits hold the battery off the bus and the spacecraft is unpowered. When the switches are released at separation, the 5 V always-on line powers the C&DH, the Flight Software boots and starts the separation timer, and the ADCS Controller and Sensors are powered to record the tip-off rates. Nothing is actuated, deployed or transmitted. The do-activity **SM.13 Monitor Separation** keeps the separation timer, debounces the separation switch states and records the rate history for the ground.

Exit. Transition T2 Separation, 30 min after separation.

Active functions. F1 Separate and Detumble (separation and power-up part only).

Pointing mode. AP-0 Off (rates measured, no control).

6.3.2 Detumble

Purpose. Reduce the body rates from up to 10 deg/s to below 0.5 deg/s, deploy the UHF Antenna and the Solar Arrays, establish contact with the ground, and complete commissioning of the bus and the payload.

Entry. Transition T2 Separation. The entry action enables the magnetorquers and the UHF receiver.

Sub-modes. Detumble has three sub-modes, entered in sequence:

- **DT.1 Rate Damping** (initial sub-mode). AP-1 Rate Damping runs through the do-activity **SM.9 Damp Body Rates**. SR-2.3 requires rates below 0.5 deg/s within 3 h from 10 deg/s.
- **DT.2 Deployment**, which overlaps DT.1. The do-activity **SM.10 Release Deployables** fires the UHF Antenna burn-wire at 30 min after separation and the Solar Array hold-downs so that the arrays are deployed within 45 min of separation (SR-3.6). Whether the array release is started by a timer at separation + 35 min or by the body rate falling below 0.5 deg/s is TBR-02. The UHF transmitter is enabled at 45 min after separation and starts the health beacon.
- **DT.3 Bus Commissioning**, entered when the rates are below 0.5 deg/s and the deployment switches report all deployables deployed. The ADCS changes to AP-2 Coarse Sun Pointing. The ground runs the bus and attitude commissioning steps C1 to C3 of the Mission Overview and Concept of Operations chapter by command: bus checkout, then the star tracker and attitude sensors, then the reaction wheels in closed loop with slew, settle and momentum unloading tests. When C3 meets its exit criterion the ground sets the commissioning-complete flag. The payload downlink and camera commissioning steps (C4 to C7) follow in Nominal Imaging and Downlink Contact under ground command.

Exit. Transition T3 Rates Nulled. Safe Mode triggers are not evaluated in Detumble: its load set is at or below the Safe Mode load set and its pointing is already the Safe Mode pointing. A battery undervoltage in Detumble suspends deployment and checkout activities and switches off any unit under checkout; the spacecraft stays in Detumble.

Active functions. F1 Separate and Detumble, F2 Deploy Solar Arrays, F3 Generate and Store Power, F4 Determine and Control Attitude (coarse determination, then F4.1 to F4.4 under test in DT.3), F6 Receive Commands.

Pointing mode. AP-1 in DT.1 and DT.2; AP-2 in DT.3, with AP-3 and AP-4 used briefly during checkout.

6.3.3 Nominal Imaging

Purpose. Run the planning, imaging and storage cycle of F5 Operate Imaging Orbits while keeping the battery charged and the wheel momentum in range. This is the mode the spacecraft spends most of its life in.

Entry. Transition T3 Rates Nulled (first entry), T5 Contact End, or T7 Recovery Command. On entry by T3 or T7 the entry activity **SM.11 Restore Imaging Configuration** powers the star tracker, the payload standby electronics and the payload thermal control heater, and clears the stored command schedule after T7 (the ground uploads a new one). Entry always starts in sub-mode NI.1.

Behavior. The do-activity **SM.1 Execute Command Schedule** runs the time-tagged commands from the loaded Command Schedule; each command executes within 1 s of its time tag (SR-4.2). The sub-modes are defined under Sub-Modes of Nominal Imaging.

Exit. Transition T4 Contact Start (to Downlink Contact), T6 Undervoltage with its guard alternatives (to Safe Mode) or T9 End of Mission (to Decommissioned).

Active functions. F3, F4, F5 with F6 Receive Commands, F7 Capture Images and F8 Store Payload Data, and F10.1 Detect Fault Condition (monitoring only).

Pointing mode. AP-3 in NI.1 and NI.3; AP-4 in NI.2.

6.3.4 Downlink Contact

Purpose. Transmit stored payload data to a ground station during a scheduled contact.

Entry. Transition T4 Contact Start. Before the contact window opens, the Command Schedule slews the spacecraft so that the downlink antenna can acquire the station. The entry activity **SM.3 Enable Downlink Transmitter** powers the payload downlink radio (Transmitter Enable Command) and commands AP-5 Ground Station Tracking toward the station named in the contact entry of the schedule.

Behavior. The do-activity **SM.7 Deliver Stored Files** transmits the files from the storage catalog in priority order by CFDP and records the ground acknowledgements (F9.3 to F9.5). The UHF link stays active for commanding and for the ground link acknowledgements that T8 monitors. Command schedules containing commands time-tagged inside a contact window, other than contact-control commands, are rejected at load (OPS.3), so SM.1 has nothing to execute during a contact. Target imaging and momentum unloading do not take place in this mode.

Exit. Transition T5 Contact End (to Nominal Imaging) or T8 Link Fault with its guard alternatives (to Safe Mode). The exit activity **SM.8 Disable Downlink Transmitter** powers the payload downlink radio off and returns the acknowledgement list to the storage catalog (F8.4).

Active functions. F3, F4 (F9.2 Track Ground Station), F6, F8.4 Manage Storage Catalog, F9 Transmit Payload Data, F10.1 Detect Fault Condition.

Pointing mode. AP-5 Ground Station Tracking.

6.3.5 Safe Mode

Purpose. Put the spacecraft in a configuration that survives indefinitely without ground commands after a fault, keeps the battery charged and lets the ground find and recover it.

Entry. Transition T6 (from Nominal Imaging) or T8 (from Downlink Contact), each with the guard alternatives listed under Safe Mode Triggers. The entry activity **SM.4 Shed Non-Essential Loads** sends the Safe Mode Commands: the Payload Camera, its heater, the star tracker and the payload downlink radio are switched off, the command schedule is suspended and the safe-entry cause is latched in telemetry. Safe Mode is reached within 10 s of an undervoltage (SR-4.3; Flight Software 2.3 measures 14 s and operates under a deviation that accepts 15 s until Flight Software 2.4).

Sub-modes.

- **SA.1 Sun Acquisition** (initial sub-mode). If any body rate exceeds 0.5 deg/s, AP-1 Rate Damping runs first; then AP-2 Coarse Sun Pointing turns the array normal toward the Sun. In eclipse the spacecraft holds its rates on the gyro and acquires the Sun at eclipse exit.
- **SA.2 Sun-Pointing Hold**, entered when the Sun is within 15° of the array normal for 60 s. The spacecraft stays here until recovery.

Behavior. The do-activities are **SM.2 Orient Arrays to Sun** (AP-2), **SM.5 Transmit Health Beacon** (a UHF beacon frame of at most 2 s every 30 s, about 6 % transmitter duty, with mode, safe-entry cause, battery voltage and temperature, and attitude state) and **SM.6 Cycle UHF Transceiver** (power-cycles the UHF Transceiver after each 24 h without a valid ground command, to clear a latched receiver fault). Stored payload files and the storage catalog are preserved. The ground can command telemetry dumps, diagnostics and individual unit power over UHF.

Exit. Transition T7 Recovery Command only. There is no autonomous exit. SR-2.5 requires the spacecraft to be back in Nominal Imaging, imaging-ready, within 24 h of the recovery command.

Active functions. F3, F4 (as F10.3), F6, F10 Enter Safe Mode (F10.2 to F10.5).

Pointing mode. AP-1 then AP-2.

The Safe Mode bus load is 15.6 W orbit average (power budget below). The 33.0 W end-of-life orbit-average generation assumes the 0.83 attitude factor of imaging and downlink pointing; in continuous Sun pointing the factor is close to one, so the arrays deliver more than twice the Safe Mode bus load and the spacecraft is power-positive in SA.2 for the whole mission life.

Load	On (W)	Duty	Orbit avg (W)	Basis	With cont. (W)
ADCS controller, sun sensors, magnetometer	1.0	100.0 %	1.00	Calculated	1.10
Reaction Wheels (four, average)	2.0	100.0 %	2.00	Measured	2.06
Magnetorquers	1.2	35.0 %	0.42	Calculated	0.46
PDU overhead	1.5	100.0 %	1.50	Calculated	1.65
C&DH flight computer and storage	4.0	100.0 %	4.00	Measured	4.12
UHF Transceiver - receive	1.0	100.0 %	1.00	Measured	1.03

Load	On (W)	Duty	Orbit avg (W)	Basis	With cont. (W)
UHF Transceiver - transmit	6.0	6.0 %	0.36	Measured	0.37
Battery and structure heaters	3.5	80.0 %	2.80	Estimated	3.22
Load total			**13.08**		**14.01**
Bus load at the array side (efficiency 0.90)			14.53		15.57

6.3.6 Decommissioned

Purpose. End the mission in a passive state that cannot interfere with other spacecraft or radio services.

Entry. Transition T9 End of Mission. Before sending it, the operators command the passivation steps one by one in Nominal Imaging, each confirmed in telemetry: camera and payload downlink radio off, reaction wheels spun down, encryption keys erased (EO-1 Flight), battery disconnected from charging and discharged through the loads to the passivation level. The entry activity **SM.12 Passivate Spacecraft** checks that these steps are complete and completes any that are not, sends a final telemetry record, and permanently inhibits all transmitters.

Exit. None (final state).

Active functions. None after passivation.

Pointing mode. AP-0 Off.

6.4 Sub-Modes of Nominal Imaging

Nominal Imaging contains three sub-modes. The seven top-level states are unchanged; the sub-modes are states nested inside Nominal Imaging, and only one is active at a time.

Sub-mode	Purpose	Pointing	Payload
NI.1 Sun-Pointing Standby (initial)	Charge the battery and wait for the next imaging window or contact	AP-3	Standby electronics on, detector off
NI.2 Target Imaging	Slew to each target in the imaging window, prepare the focal plane and capture the strip (F7, F8)	AP-4	Detector on, capture per schedule
NI.3 Momentum Unloading	Reduce stored wheel momentum with the torque rods (F4.4)	AP-3	Standby

Sub-modes of Nominal Imaging

Id	From	To	Trigger	Guard
n1 Window Start	NI.1 or NI.3	NI.2	Time event: scheduled start of an imaging window (Command Schedule)	None
n2 Window End	NI.2	NI.1	Time event: last target of the window captured or skipped	None
n3 Momentum High	NI.1	NI.3	Change event: total wheel momentum > 24 mNms (60 % of 40 mNms)	Not within 10 min of a scheduled imaging window start
n4 Momentum Low	NI.3	NI.1	Change event: total wheel momentum < 8 mNms (20 % of 40 mNms)	None

Sub-mode transitions inside Nominal Imaging

A design-case orbit has two imaging windows with four 40 s strips each. Each window starts with a slew of up to 30° (SR-2.4, 60 s, TBR-03) and the focal plane preparation in parallel (F7.1 and F7.2), then captures the four strips in turn. An imaging window that starts during unloading (n1 from NI.3) ends the unloading; the 40 mNms wheel capacity is enough to finish the window and unload afterwards.

6.5 Transitions

The nine transitions T1 to T9 are the only transitions between top-level states. Trigger types follow the usual state-machine terms: a **time event** fires at a time or after a duration, a **change event** fires when its condition becomes true, a **signal event** is an asynchronous signal generated on board, and a **call event** is a ground command.

Id	Name	From	To	Trigger type	Trigger and guard	Action
T1	Power On	Initial	Launch	Completion	Integration complete: battery charged, remove-before-flight pin removed, separation switches depressed in the dispenser	None
T2	Separation	Launch	Detumble	Time event	30 min after separation; guard: all separation switches released (debounced)	Enable magnetorquers and UHF receiver; start SM.9

Id	Name	From	To	Trigger type	Trigger and guard	Action
T3	Rates Nulled	Detumble	Nominal Imaging	Change event	Body rate < 0.5 deg/s on all axes for 600 s **and** all deployables reported deployed **and** commissioning-complete flag set by ground command	SM.11 on entry to Nominal Imaging
T4	Contact Start	Nominal Imaging	Downlink Contact	Signal event	Contact-start signal, raised on board when the first ground link acknowledgement arrives over UHF inside a payload contact window of the Command Schedule; guard: sub-mode is not NI.2	Stop unloading if NI.3 is active; SM.3 on entry
T5	Contact End	Downlink Contact	Nominal Imaging	Signal event	Contact-end signal, raised on board at the end of the scheduled contact window or on the station's end-of-contact command over UHF, whichever comes first	SM.8 on exit; enter NI.1
T6	Undervoltage	Nominal Imaging	Safe Mode	Change event	Guard G-UV: battery voltage < 12.8 V (6.4 V per series cell pair); guard alternatives G-WD, G-BT, G-AE, G-CL (see Safe Mode Triggers)	Latch safe-entry cause; SM.4 on entry
T7	Recovery Command	Safe Mode	Nominal Imaging	Call event	Authenticated "Exit Safe Mode" command; guard: G-UV, G-BT and G-WD all false	Clear reset counter and safe-entry cause; SM.11 on entry

Id	Name	From	To	Trigger type	Trigger and guard	Action
T8	Link Fault	Downlink Contact	Safe Mode	Change event	Guard G-LF: no link lock for more than 60 s within the contact window; guard alternatives G-UV, G-WD, G-BT, G-AE, G-CL	SM.8 on exit; latch cause; SM.4 on entry
T9	End of Mission	Nominal Imaging	Decommissioned	Call event	Authenticated “Decommission” command; guard: matching “Arm Decommission” command executed within the previous 600 s	SM.12 on entry

Mode transitions T1–T9

Notes on the transitions:

- **T2** is the end of the 30 min deployables quiet period. The 45 min RF quiet period ends inside Detumble (DT.2). The separation timer keeps counting through processor resets (SR-10.4), so a reset cannot shorten or extend either period.
- **T3** is a change event on a compound condition. In practice the body rate condition is met within a few hours of separation and the transition happens when the ground sets the commissioning-complete flag at the end of commissioning.
- **T4 and T5** are driven by the contact windows the ground places in the Command Schedule (contacts are scheduled 48 h ahead, SR-6.1) together with the station: the station starts the contact by locking on the UHF beacon and sending its first link acknowledgement, and ends it at the end of the pass. A window in which no acknowledgement arrives produces no T4; the data stay in storage (contact loss). The ground planner keeps imaging windows out of contact windows; the T4 guard protects a capture in progress if a plan error makes them overlap, in which case the contact-start signal is rejected and logged.
- **T6 and T8** both lead to Safe Mode. T6 keeps the name of its primary trigger, battery undervoltage; the other Safe Mode triggers are guard alternatives on T6 and T8, combined by OR.
- **“Link lock” for G-LF** means the ground link acknowledgement that the station sends over the UHF uplink every 10 s while it holds lock on the payload downlink, or the payload downlink radio’s own synthesizer lock indication. Loss of either for more than 60 s inside the contact window satisfies G-LF. Losing lock with the transmitter on indicates a pointing or radio fault; Safe Mode switches the transmitter off and points the arrays at the Sun.
- **T7** cannot be taken while the condition that caused Safe Mode still exists, except G-CL (the recovery command is itself a valid ground command) and G-AE (fine pointing is not commanded in Safe Mode).

6.6 Safe Mode Triggers

Safe Mode is entered when any trigger condition below is true in Nominal Imaging (T6) or Downlink Contact (T8). The conditions are evaluated by F10.1 Detect Fault Condition each second.

Guard	Condition	Persistence	Applies on	Rationale
G-UV Undervoltage	Battery voltage < 12.8 V (6.4 V per series cell pair)	2 s	T6, T8	Protects the battery from deep discharge; primary trigger of T6 (SR-4.3)
G-WD Watchdog Resets	Three or more watchdog resets of the Flight Computer within 24 h [TBR-11]	Counted in nonvolatile memory	T6, T8	Repeated resets indicate a software or hardware fault that restoring the last mode would repeat
G-BT Battery Temperature	Battery temperature below the minimum battery temperature [TBD-01] or above +45 °C [TBR-12]	60 s	T6, T8	Charging or high-rate discharge outside the cell temperature range damages the cells (HAZ-001)
G-AE Attitude Error	Attitude error > 2.0° [TBR-10] while AP-3, AP-4 or AP-5 is commanded	300 s	T6, T8	Persistent loss of fine pointing indicates a wheel, star tracker or controller fault (RK-1)
G-CL Command Loss	No valid authenticated ground command received for 72 h	Timer	T6, T8	Covers a failed receiver or a lost uplink beyond the longest planned gap between operations shifts
G-LF Link Fault	No link lock for more than 60 s within a contact window	60 s	T8 only	Transmitter on without a link indicates a pointing or radio fault

Safe Mode trigger conditions (guard alternatives on T6 and T8)

In the model, the T6 guard is the expression `G-UV or G-WD or G-BT or G-AE or G-CL`, and the T8 guard is `G-LF or G-UV or G-WD or G-BT or G-AE or G-CL`.

Processor resets. A watchdog reset reboots the Flight Software. On boot it reads the last mode and the reset count from nonvolatile memory. If the reset count satisfies G-WD it enters Safe Mode; otherwise it restores the last mode, except that Downlink Contact is restored as Nominal Imaging with the payload downlink radio off (SR-10.7).

6.7 Mode Activities

The activities below are run by the mode logic. SM.1 to SM.3 are the activities of the mission model; SM.4 to SM.13 complete the set.

Id	Activity	Kind	State	Performed by	Description
SM.1	Execute Command Schedule	Do	Nominal Imaging	1.4 C&DH	Execute the time-tagged commands within 1 s of their tags.
SM.2	Orient Arrays to Sun	Do	Safe Mode	1.2 ADCS	Hold the array normal toward the Sun in AP-2.
SM.3	Enable Downlink Transmitter	Entry	Downlink Contact	1.4 C&DH	Power the payload downlink radio and command AP-5 toward the contact's station.
SM.4	Shed Non-Essential Loads	Entry	Safe Mode	1.4 C&DH	Send the Safe Mode Commands to the PDU and the ADCS and suspend the command schedule.
SM.5	Transmit Health Beacon	Do	Safe Mode	1.5.1 UHF Transceiver	Transmit a beacon frame of at most 2 s every 30 s.
SM.6	Cycle UHF Transceiver	Do	Safe Mode	1.4 C&DH	Power-cycle the UHF Transceiver after each 24 h without a valid command.
SM.7	Deliver Stored Files	Do	Downlink Contact	payload downlink radio	Transmit catalog files by priority over CFDP and record acknowledgements.
SM.8	Disable Downlink Transmitter	Exit	Downlink Contact	1.4 C&DH	Power the payload downlink radio off and update the storage catalog.
SM.9	Damp Body Rates	Do	Detumble	1.2 ADCS	Run AP-1 B-dot control on the magnetorquers.
SM.10	Release Deployables	Do	Detumble	1.4 C&DH	Fire the UHF Antenna and Solar Array burn-wires at their times and confirm the deployment switches.

Id	Activity	Kind	State	Performed by	Description
SM.11	Restore Imaging Configuration	Entry	Nominal Imaging (by T3 or T7)	1.4 C&DH	Power the star tracker, payload standby electronics and payload heater; after T7, clear the schedule.
SM.12	Passivate Spacecraft	Entry	Decommissioned	1.4 C&DH	Check and complete the commanded passivation steps, send final telemetry, inhibit all transmitters permanently.
SM.13	Monitor Separation	Do	Launch	1.4 C&DH	Keep the separation timer, debounce the separation switches, record tip-off rates.

Mode activities

6.8 Equipment State per Mode

The table gives the power state of each major unit in each mode. “Duty” values are the orbit-average duty cycles of the power budgets (Technical Budgets and Margins chapter). “Thermostat” means the heater is enabled and switched by its thermostat or by flight software set points.

Unit	Launch	Detumble	Nominal Imaging	Downlink Contact	Safe Mode	Decommissioned
1.1 Payload Camera, standby electronics	Off	Off	On	On	Off	Off
1.1 Payload Camera, detector	Off	Off	On in NI.2 only	Off	Off	Off
1.6.3 Payload thermal control heater	Off	Off	Thermostat (60 %)	Thermostat	Off	Off
1.2.2 Star Tracker	Off	Off (on from DT.3, step C2)	On	On	Off	Off
1.2.1 Reaction Wheel Assembly	Off	Off (on from DT.3, step C3)	On	On	On	Spun down, off
1.2.3 Magnetorquers	Off	On (90 %)	On as needed (35 %)	Off	On as needed (35 %)	Off

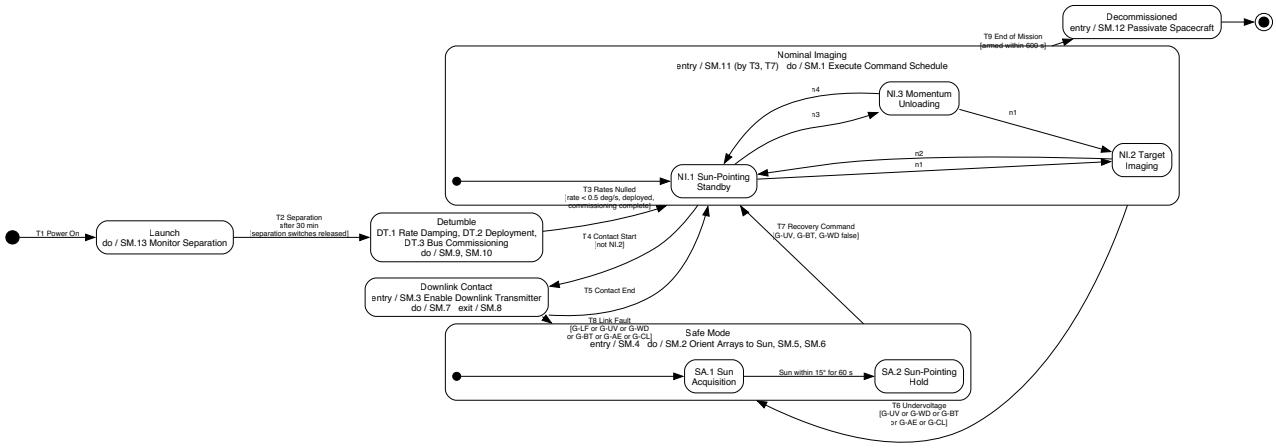
Unit	Launch	Detumble	Nominal Imaging	Downlink Contact	Safe Mode	Decommissioned
1.2.4 ADCS Controller and Sensors	On after separation, sensing only	On	On	On	On	Off
1.4.1 Flight Computer and 1.4.2 Payload Data Storage	On after separation	On	On (compression bursts in NI.2)	On	On (files kept)	Off after SM.12
1.5.1 UHF Transceiver, receiver	Off	On	On	On	On (cycled by SM.6)	Off
1.5.1 UHF Transceiver, transmitter	Off	Beacon from 45 min after separation	On during passes (6 %)	On (6 %); EO-1 Flight: off while the X-band Payload Radio transmits (ICD-008)	Beacon (6 %)	Inhibited
Payload downlink radio (1.5.2 or 1.5.3)	Off	Off	Off	On	Off	Inhibited
1.6.3 Battery and structure heaters	Off in dispenser; thermostat after separation	Thermostat (80 %)	Thermostat (60 %)	Thermostat	Thermostat (80 %)	Off
1.6.2 Deployment burn-wire circuits	Inhibited	Armed and fired by SM.10, then safed	Safed	Safed	Safed	Safed
1.3.3 Power Distribution Unit	Inhibited in dispenser; on after separation	On	On	On	On	Charge path open

Equipment state per mode

The resulting orbit-average bus loads with contingency are 14.1 W in Detumble (DT.1 and DT.2), 25.0 W in the Nominal Imaging design case (one downlink contact per orbit included) and 15.6 W in Safe Mode. In Safe Mode the payload is kept within its non-operating temperature range by the structure heaters and the payload radiator’s cover position; no payload operational heater runs.

6.9 State Machine

The figure shows the seven top-level states and the transitions T1 to T9 with their guards, and the sub-modes of Nominal Imaging and Safe Mode. The Detumble sub-modes are omitted from the figure for readability.



EO-1 Spacecraft state machine: modes, transitions T1–T9 and sub-modes

6.10 Mode Logic Requirements

The requirements below specify the mode logic. Related requirements stated elsewhere are not repeated: Safe Mode entry time after undervoltage (SR-4.3), Safe Mode recovery time (SR-2.5), command execution timing (SR-4.2), detumble time (SR-2.3) and array deployment time (SR-3.6).

SR-10.1 Operating Mode Set · Verify: Inspection, Test · Trace: N4, N11 · Applies: All

From the end of integration until decommissioning, the Flight Software shall hold the spacecraft in exactly one of the modes Launch, Detumble, Nominal Imaging, Downlink Contact, Safe Mode and Decommissioned at all times.

Rationale: A single, always-defined mode is the basis for the equipment configuration, the fault responses and the operators' understanding of the spacecraft at every pass.

SR-10.2 Permitted Mode Transitions · Verify: Test, Inspection · Trace: N4, N11 · Applies: All

The Flight Software shall change mode only by the transitions T1 to T9 of the transition table, and shall reject and report any command that requests another mode change.

Rationale: A closed transition set can be verified exhaustively on the flatsat and prevents an operator error from putting the spacecraft into an untested configuration.

SR-10.3 Post-Separation Quiet Period · Verify: Test · Trace: N8 · Applies: All

While in Launch mode, the spacecraft shall not command any actuator, fire any deployment mechanism or transmit any radio frequency.

Rationale: Rideshare compatibility: the spacecraft must stay inert in the dispenser and during the first 30 min after separation, while other payloads are still being released nearby.

SR-10.4 Separation Time Persistence · Verify: Test · Trace: N8 · Applies: All

The Flight Software shall preserve the time elapsed since separation across processor resets and power cycles with an error of no more than 10 s.

Rationale: The 30 min deployment and 45 min RF quiet periods are timed from separation; a reset during the quiet period must neither shorten them (launch safety) nor restart them indefinitely (mission loss).

SR-10.5 Detumble Exit Conditions · Verify: Test, Demonstration · Trace: N4 · Applies: All

The Flight Software shall leave Detumble for Nominal Imaging only when the body rate has been below 0.5 deg/s on all axes for 600 s, all deployment switches report deployed, and the ground has set the commissioning-complete flag.

Rationale: Imaging and fine pointing must not start on a spacecraft whose arrays are not deployed or whose bus and attitude control have not been checked out; the 600 s dwell filters out a momentary rate dip during rate damping.

SR-10.6 Payload Transmitter Mode Restriction · Verify: Test · Trace: N10 · Applies: All

The Flight Software shall power the payload downlink radio only in Downlink Contact.

Rationale: Transmitting only inside scheduled contacts keeps emissions within the coordinated station passes of the spectrum license and saves 11.5 W (Lite) or 15.0 W (Flight) outside contacts.

SR-10.7 Mode Restoration After Reset · Verify: Test · Trace: N4, N11 · Applies: All

After a processor reset that does not satisfy guard G-WD, the Flight Software shall restore the mode held before the reset within 60 s of boot, restoring Downlink Contact as Nominal Imaging with the payload downlink radio off.

Rationale: A single reset (for example from a radiation upset) should not interrupt imaging for a whole day by forcing Safe Mode; a contact interrupted by a reset is safer to resume at the next scheduled pass.

SR-10.8 Link Fault Response · Verify: Test · Trace: N4, N10 · Applies: All

The Flight Software shall enter Safe Mode by transition T8 when no link lock has been present for more than 60 s within a scheduled contact window.

Rationale: A transmitter radiating without a ground link indicates a pointing or radio fault; continuing wastes energy and may radiate outside the coordinated pass geometry.

SR-10.9 Watchdog Reset Safe Mode Trigger · Verify: Test · Trace: N4 · Applies: All · TBR: TBR-11

The Flight Software shall enter Safe Mode when three [TBR] or more watchdog resets of the Flight Computer occur within 24 h.

Rationale: Repeated resets show a fault that restoring the last mode would repeat; three in 24 h separates a persistent fault from the isolated upsets expected in the 500 km orbit. The count is TBR until the single-event upset rate of the flight computer is measured in radiation testing.

SR-10.10 Battery Temperature Safe Mode Trigger · Verify: Test · Trace: N4 · Applies: All · TBR: TBR-12

The Flight Software shall enter Safe Mode when the battery temperature has been below the minimum battery temperature of SR-3.5 or above +45 °C [TBR] for 60 s.

Rationale: Lithium-ion cells lose capacity or become hazardous when charged cold or operated hot (HAZ-001). The upper limit is TBR pending the cell supplier's qualification data; the lower limit is TBD-01 of SR-3.5.

SR-10.11 Attitude Error Safe Mode Trigger · Verify: Test, Analysis · Trace: N4 · Applies: All · TBR: TBR-10

The Flight Software shall enter Safe Mode when the attitude error has exceeded 2.0° [TBR] for 300 s while Fine Sun Pointing, Target Pointing or Ground Station Tracking is commanded.

Rationale: An error of twenty times the pointing requirement held for five minutes cannot come from a slew or a transient; it indicates a wheel, star tracker or controller fault (RK-1). The threshold is TBR until the flatsat slew and settling tests (TC-04, TC-17) give the largest transient error.

SR-10.12 Command Loss Safe Mode Trigger · Verify: Test · Trace: N4, N11 · Applies: All

The Flight Software shall enter Safe Mode when no valid authenticated ground command has been received for 72 h.

Rationale: The longest planned gap between operations shifts is a weekend of about 64 h; a longer silence indicates a receiver or uplink fault, and Safe Mode then starts the receiver power cycling of SM.6.

SR-10.13 Safe Mode Load Set · Verify: Test, Inspection · Trace: N4 · Applies: All

In Safe Mode, the spacecraft shall power only the units marked on for Safe Mode in the equipment-state-per-mode table.

Rationale: The Safe Mode load set gives a 15.6 W orbit-average bus load, which Sun-pointed arrays cover more than twice over at end of life, so the spacecraft can stay in Safe Mode indefinitely.

SR-10.14 Safe Mode Sun Acquisition · Verify: Test, Analysis · Trace: N4 · Applies: All · TBR: TBR-13

After entering Safe Mode in sunlight with body rates below 2 deg/s, the spacecraft shall point the array normal within 15° of the Sun within 30 min [TBR].

Rationale: 15° costs less than 4 % of array output; 30 min keeps the battery discharge from a fault in sunlight within the energy already budgeted for an eclipse. TBR until the coarse sun pointing simulation includes the measured sun sensor fields of view.

SR-10.15 Safe Mode Health Beacon · Verify: Test · Trace: N11, N4 · Applies: All

In Safe Mode, the spacecraft shall transmit a UHF health beacon frame of no more than 2 s duration every 30 s, with the mode, the safe-entry cause, battery voltage and temperature, and attitude state.

Rationale: The beacon lets the day-shift team diagnose the spacecraft from the first pass after a fault without first having to command it; the 2 s frame every 30 s matches the 6 % UHF transmit duty of the Safe Mode power budget.

SR-10.16 Safe Mode Exit by Ground Command · Verify: Test · Trace: N4, N11 · Applies: All

The Flight Software shall leave Safe Mode only by transition T7 on an authenticated recovery command, and shall reject that command while guard G-UV, G-BT or G-WD is true.

Rationale: Recovery is a ground decision taken after the fault has been understood; rejecting the command while the cause persists prevents an immediate re-entry cycle.

SR-10.17 Momentum Unloading Exclusion · Verify: Test · Trace: N3 · Applies: All

The spacecraft shall not drive the magnetorquers during target imaging (sub-mode NI.2) or within 10 min before a scheduled imaging window.

Rationale: Torque rod switching disturbs the attitude and the magnetometer; excluding it from capture protects the 0.01 deg/s stability of SR-2.2 needed for field-level image quality.

SR-10.18 Mode Status Telemetry · Verify: Test · Trace: N11 · Applies: All

The Flight Software shall include the current mode and sub-mode, the last transition id, its trigger cause and its time in every housekeeping telemetry record.

Rationale: Housekeeping is sampled every 10 s; recording the mode history lets the operators reconstruct events between passes without extra commanding.

SR-10.19 Decommissioning Command Protection · Verify: Test · Trace: N9, N5 · Applies: All

The Flight Software shall execute transition T9 End of Mission only when an authenticated decommission command follows an authenticated arm command within 600 s.

Rationale: Decommissioning is irreversible; a two-step, authenticated sequence prevents both an operator slip and an unauthorized command from ending the mission.

7 System Requirements

This chapter states the binding requirements on the EO-1 mission as a whole: the spacecraft, the ground segment and operations. The requirements are grouped in fifteen numbered areas that keep the section numbers of the System Requirements Specification SRS-001, so SR-*x.y* here is SRS-001 requirement *x.y* with the same value and intent; requirements added in this revision continue the numbering inside each area. Area 7 is not used (SRS-001 section 7 lists the applicable documents, which this specification carries in its own chapter). A number such as SR-1.6.1 refines the requirement above it. Each requirement names its verification method, the stakeholder needs it traces to (N1–N11, see Stakeholders and Needs), the configurations it applies to (EO-1 Flight, EO-1 Lite or both) and the product-tree elements it is allocated to. Open values carry a TBD or TBR id and are listed in the open-items index.

7.1 Mission Imaging

Area 1 sets the image collection performance that the Imagery Customer's crop monitoring depends on. The values follow from the payload design summary and the data volume budget.

The mission assumes a 500 km circular sun-synchronous reference orbit with a 10:30 local time of descending node (inclination 97.4°, period 94.6 min, longest eclipse 35.8 min). This is SRS-001 item 1.1, an assumption rather than a requirement; every performance value in this chapter is stated for this orbit, and the final altitude after launch is confirmed during commissioning.

SR-1.2 Ground Sample Distance · Verify: Test · Trace: N3 · Applies: All · Alloc: 1.1

The payload shall resolve ground features at 4.5 m ground sample distance at nadir from the 500 km reference orbit.

Rationale: Field-level crop monitoring needs 5 m class imagery; 4.5 m leaves margin for jitter and focus drift. The 611 mm focal length and 5.5 μm pixels give 4.5 m; the diffraction spot radius at 800 nm is 5.1 m, so the test criterion is a modulation transfer function at Nyquist of at least 0.12 on the 4 m bar target (TC-01).

SR-1.3 Swath Width · Verify: Test · Trace: N2, N3 · Applies: All · Alloc: 1.1

The payload shall image the ground across a swath of at least 22 km at nadir.

Rationale: The swath sets the daily area coverage with one strip per target and, with off-nadir access, the revisit of SR-1.6. It corresponds to a 2.52° field of view and 4,889 active pixels across track (TC-02).

SR-1.4 Spectral Bands · Verify: Test · Trace: N1, N3 · Applies: All · Alloc: 1.1

The payload shall capture four spectral bands (blue, green, red and near-infrared) within the 450 nm to 900 nm range.

Rationale: Blue, green, red and near-infrared bands support the vegetation indices behind the crop stress alerts. Each band edge is verified within 5 nm of its design value (TC-03).

SR-1.5 Daily Collection Volume · Verify: Analysis · Trace: N2, N3 · Applies: All · Alloc: 1.1, 1.4

The payload shall acquire at least 3.2 GB of image data per day, measured after onboard compression.

Rationale: Sized from the customer target list of 120 scenes per day: 17.2 GB raw, compressed at 2.2 bits per pixel and with 2 % ancillary data, gives 3.22 GB per day (data volume budget). Verified by simulating a 30-day plan. This is the acquisition capability of both configurations; EO-1 Lite delivery is limited by its one-station service (SR-5.4.1), so the mission operations center caps Lite tasking at about 40 scenes per day unless the three-station service is bought.

SR-1.6 Revisit Time · Verify: Analysis · Trace: N2 · Applies: All · Alloc: 1, 2.2

The mission shall revisit each target region within 72 h.

Rationale: Customers need imagery at least twice per week during the growing season. Verified by a coverage analysis showing a worst-case revisit of 72 h for the target regions (TC-13).

SR-1.6.1 Ground Track Repeat · Verify: Analysis · Trace: N2 · Applies: All · TBR: TBR-01 · Alloc: 0, 3

The reference orbit shall repeat its ground track every 3 days [TBR] within ±1 h.

Rationale: A 3-day repeat with off-nadir pointing gives the 72 h revisit of SR-1.6. The repeat period follows from the final altitude after launch, which the rideshare launch vehicle sets; TBR-01 closes when the injection orbit is known.

SR-1.6.2 Off-Nadir Imaging · Verify: Test · Trace: N2, N7 · Applies: All · Alloc: 1.2, 1.1

The spacecraft shall image targets up to 25° off nadir while meeting SR-2.1.

Rationale: Off-nadir access fills the gaps between repeat ground tracks. Beyond 25° the ground sample distance degrades past the 5 m class needed for field-level maps (TC-14).

SR-1.7 Mission Lifetime · Verify: Analysis · Trace: N4 · Applies: All · Alloc: 1

The spacecraft shall operate in orbit for at least 730 days.

Rationale: Two growing seasons are needed to close the Imagery Customer's business case. The probability of meeting this lifetime is set by SR-15.1 (TC-16).

SR-1.8 Signal-to-Noise Ratio · Verify: Test, Analysis · Trace: N3, N6 · Applies: All · TBR: TBR-15 · Alloc: 1.1

The payload shall achieve a signal-to-noise ratio of at least 100 [TBR] in each band for a Lambertian scene of 0.30 reflectance at a solar zenith angle of 45°.

Rationale: Vegetation index differences of a few percent separate stressed from healthy crops; an SNR of 100 keeps the index noise below that level. 45° is a representative solar zenith angle for a 10:30 orbit over mid-latitude farmland in spring and autumn. TBR-15 closes when the detector's measured read noise and full-well data are available.

SR-1.9 Absolute Radiometric Accuracy · Verify: Analysis, Test · Trace: N6 · Applies: All · Alloc: 1.1, 2.2

The mission shall deliver radiance products with an absolute radiometric accuracy of 5 % (1σ) or better in each band.

Rationale: Agronomists compare EO-1 products with other sources and across seasons; 5 % is a common accuracy for small-satellite multispectral imagers calibrated against a laboratory integrating sphere and checked against ground reference sites.

SR-1.10 Radiometric Stability · Verify: Analysis · Trace: N6, N4 · Applies: All · Alloc: 1.1, 2.2

The mission shall keep the calibrated response of each band stable within 2 % over the 730-day mission.

Rationale: Consistent calibration across two seasons (N6) matters more to trend analysis than absolute accuracy. Detector radiation damage (RK-5) and contamination change the response; lunar imaging (SR-1.14) and coefficient updates (SR-6.13) keep the trend within 2 %.

SR-1.11 Band-to-Band Registration · Verify: Test, Analysis · Trace: N3 · Applies: All · Alloc: 1.1, 2.2

The ground segment shall register the four bands of each product to each other within 0.3 pixel (90 % of points).

Rationale: The vegetation index is computed pixel by pixel; a band shift larger than about a third of a pixel creates false index values at field edges. The four bands are separate line arrays, so attitude stability (SR-2.2) and ground resampling both contribute.

SR-1.12 Product Geolocation Accuracy · Verify: Analysis, Demonstration · Trace: N3 · Applies: All · TBR: TBR-16 · Alloc: 2.2, 1.2

The ground segment shall geolocate each orthorectified product within 20 m [TBR] (CE90) of its true ground position.

Rationale: Customers overlay products on field boundaries; 20 m is about four pixels and keeps a product inside the right field. Attitude knowledge alone (the knowledge terms of the pointing budget, about 80 arcsec 3σ, or about 200 m at nadir) cannot meet this, so products are registered to a reference image base. TBR-16 closes when the accuracy of the reference image base is confirmed.

SR-1.13 Imaging Strips per Orbit · Verify: Analysis, Test · Trace: N2, N3 · Applies: All · Alloc: 1, 1.3, 1.4

The spacecraft shall capture at least eight 40 s imaging strips in a single orbit.

Rationale: The target regions cluster over the agricultural areas, so a few orbits per day carry most of the collection; the power budget's design-case orbit has eight 40 s strips. The daily average is lower: 120 scenes per day is about ten strips, since one 40 s strip (1.84 GB raw) holds about 13 scenes.

SR-1.14 Lunar Calibration Imaging · Verify: Demonstration, Analysis · Trace: N6 · Applies: All · Alloc: 1.2, 1.1, 2.2

The spacecraft shall image the Moon at least once per lunar cycle (29.5 days).

Rationale: The Moon's reflectance is stable over decades, so monthly lunar images give a trending reference that does not depend on ground site weather. The slew uses the capability of SR-2.4 outside imaging windows.

SR-1.15 Saturation Radiance · Verify: Test · Trace: N3, N6 · Applies: All · Alloc: 1.1

The payload shall not saturate in any band for a Lambertian scene of 0.90 reflectance at a solar zenith angle of 20°.

Rationale: Bright clouds, greenhouse roofs and snow appear in agricultural scenes; saturated pixels bleed into neighboring fields and corrupt cloud masking. 20° is the smallest solar zenith angle at the target latitudes in the 10:30 orbit.

7.2 Attitude Determination and Control

Area 2 covers pointing, stability, slewing and attitude recovery. Values come from the pointing budget and the imaging geometry.

SR-2.1 Pointing Accuracy · Verify: Test, Analysis · Trace: N3 · Applies: All · Alloc: 1.2

The ADCS shall point the payload boresight within 0.1° (3σ) of the commanded target.

Rationale: 0.1° is 0.87 km at 500 km, inside the 22 km swath margin. The pointing budget gives 0.045° (163 arcsec, 3σ RSS), a margin of 197 arcsec. The flatsat test TC-04 measured 0.14° on 3 of 20 targets; wheel friction is suspected (RK-1), and the requirement stays at 0.1° pending that investigation.

SR-2.2 Pointing Stability · Verify: Test · Trace: N3 · Applies: All · Alloc: 1.2

The ADCS shall limit boresight drift to 0.01 deg/s during each image capture.

Rationale: At this rate the image smear over one 0.64 ms line period is a small fraction of a pixel, and the shift between the four band arrays stays within what ground registration removes (SR-1.11). Verified over each 40 s capture.

SR-2.3 Detumble · Verify: Test, Analysis · Trace: N4, N8 · Applies: All · Alloc: 1.2.3, 1.2.4

The ADCS shall reduce the body rates from up to 10 deg/s per axis to below 0.5 deg/s within 3 h of separation.

Rationale: Separation tip-off rates can reach 10 deg/s, and the arrays must face the Sun before the battery drains. The Detumble bus load of 14.1 W would take 42 Wh in 3 h from a fully dark spacecraft, about half the 77 Wh battery (TC-05).

SR-2.4 Target Slew · Verify: Analysis · Trace: N2, N7 · Applies: All · TBR: TBR-03 · Alloc: 1.2.1, 1.2.4

The ADCS shall slew the spacecraft through 30° within 60 s [TBR].

Rationale: Allows two adjacent targets in one pass. TBR-03 stays open until the end-of-life wheel torque and the friction finding of RK-1 are known (TC-17).

SR-2.5 Safe Mode Recovery · Verify: Demonstration, Test · Trace: N4, N11 · Applies: All · Alloc: 1, 2.2

The spacecraft shall return from Safe Mode to Nominal Imaging within 24 h of receiving the recovery command.

Rationale: Replaces the unmeasurable SRS-001 wording. 24 h covers star tracker reacquisition, wheel spin-up, payload thermal stabilization and one planning cycle, and limits the loss to under one third of the 72 h revisit window. Verified in the operations rehearsal (TC-20); the transition itself is T7 in Operational Modes.

SR-2.6 Attitude Knowledge · Verify: Analysis, Test · Trace: N3 · Applies: All · Alloc: 1.2.2, 1.2.4

The ADCS shall determine the attitude of the payload boresight within 50 arcsec (3σ) about each cross-boresight axis during image capture.

Rationale: The pointing budget carries 30 arcsec for star tracker knowledge and 25 arcsec for the estimation filter (39 arcsec RSS); 50 arcsec bounds both and sets the starting accuracy for geolocation (SR-1.12).

SR-2.7 Safe Mode Sun Pointing · Verify: Test · Trace: N4 · Applies: All · Alloc: 1.2.4, 1.2.3, 1.2.1

In Safe Mode, the ADCS shall hold the solar array normal within 20° of the Sun direction using only the coarse sun sensors, magnetometer and rate gyro.

Rationale: The generation budget assumes 20° Sun incidence on the deployed arrays. Safe Mode must not depend on the star tracker, which may be the unit that caused the fault.

SR-2.8 Wheel Momentum Management · Verify: Analysis, Test · Trace: N2, N4 · Applies: All · Alloc: 1.2.3, 1.2.4

The ADCS shall keep the stored momentum of each reaction wheel at or below 8 mNms.

Rationale: 8 mNms is 80 % of each wheel's 10 mNms capacity and keeps the remaining capacity for slews. Unloading with the magnetorquers is scheduled outside imaging windows so it does not disturb captures.

SR-2.9 Single Wheel Failure Tolerance · Verify: Analysis, Test · Trace: N4 · Applies: All · Alloc: 1.2.1, 1.2.4

With any one reaction wheel failed, the ADCS shall meet SR-2.1 and SR-2.2.

Rationale: Reaction wheel failure is the leading attitude risk (RK-1). The four-wheel pyramid allows three-axis control on any three wheels; slew time may degrade, but imaging must continue for the two-season mission.

SR-2.10 Ground Station Pointing · Verify: Test, Analysis · Trace: N1 · Applies: All · Alloc: 1.2

During each payload downlink contact above 10° elevation, the ADCS shall point the downlink antenna boresight within 5° of the ground station direction.

Rationale: The link budgets allocate 1.0 dB (S-band patch) and 1.5 dB (X-band patch array) of spacecraft pointing loss; 5° stays inside both allocations with margin.

7.3 Electrical Power

Area 3 covers power generation, storage, distribution and protection. Values come from the generation, power and energy budgets.

SR-3.1 Orbit Average Power · Verify: Test, Analysis · Trace: N4 · Applies: All · Alloc: 1.3.1, 1.3.3

The solar arrays shall generate at least 30 W orbit-average power at end of life.

Rationale: Revised from 28 W after PDR, when the load estimate grew; 28 W is now the power allocation (SR-3.9). The design-case Nominal Imaging bus load is 25.0 W; the generation budget predicts 33.0 W at end of life (37.4 W at beginning of life). Verified by predicting end-of-life power from the measured peak power (TC-06).

SR-3.2 Battery Capacity · Verify: Test · Trace: N4 · Applies: All · Alloc: 1.3.2

The battery shall store at least 77 Wh at beginning of life, measured at C/2 and 20 °C.

Rationale: The worst-case eclipse (35.8 min, heaters on, one downlink pass in eclipse) takes 17.7 Wh, a 23 % depth of discharge; the remainder covers capacity fade over two years (SR-15.8) and the separation sequence (TC-07).

SR-3.3 Depth of Discharge · Verify: Test, Analysis · Trace: N4 · Applies: All · Alloc: 1.3.3, 1.3.2

The EPS shall limit battery depth of discharge to 30 % per orbit.

Rationale: The 730-day mission is about 11,100 charge cycles (15.22 orbits per day). Lithium-ion cells keep their capacity over that many cycles at 30 % depth of discharge. Verified by the charge controller trip in each test orbit.

SR-3.4 Bus Regulation · Verify: Inspection, Test · Trace: N4 · Applies: All · Alloc: 1.3.3

The EPS shall regulate the main power bus to 12 V within 2 % (11.76 V to 12.24 V) under all load steps.

Rationale: Payload and reaction wheel electronics are rated for 12 V within 3 %; 2 % leaves margin for harness drop (TC-18).

SR-3.5 Battery Minimum Temperature · Verify: Analysis, Test · Trace: N4 · Applies: All · TBD: TBD-01 · Alloc: 1.6.3, 1.3.2

The thermal control shall keep every battery cell at or above [TBD] °C in all modes.

Rationale: Replaces the SRS-001 wording “warm enough”. Lithium-ion capacity and charge acceptance drop sharply when cold. TBD-01 closes when the cell qualification data and the heater set point are chosen (Thermal Engineer).

SR-3.6 Array Deployment · Verify: Test · Trace: N4, N8 · Applies: All · Alloc: 1.6.2

The structure shall deploy both solar array panels within 45 min after release from the dispenser.

Rationale: The battery reserve after release covers 45 min before the arrays must produce power. No deployable may deploy before 30 min (SR-8.6), so the window is 15 min. The deployment trigger (timer or body rate) is TBR-02 in Operational Modes; a rate trigger alone could wait up to the 3 h of SR-2.3 (TC-19).

SR-3.7 Cold Charge Inhibit · Verify: Test · Trace: N4 · Applies: All · Alloc: 1.3.3

The EPS shall stop battery charging while any cell temperature is below 0 °C.

Rationale: Charging lithium-ion cells below 0 °C plates lithium on the anode, which permanently reduces capacity and can cause internal shorts (HAZ-001).

SR-3.8 Output Fault Isolation · Verify: Test · Trace: N4 · Applies: All · Alloc: 1.3.3

The EPS shall isolate an overcurrent on any switched output within 10 ms without resetting any unit on another output.

Rationale: A single failed load must not take down the bus or the flight computer. 10 ms is short enough for the bus capacitance to hold the other outputs inside their rated range.

SR-3.9 Power Allocation · Verify: Analysis · Trace: N4 · Applies: All · Alloc: 1

The design-case Nominal Imaging bus load, including contingency, shall not exceed the 28 W power allocation.

Rationale: The power budget gives 25.0 W (22.5 W load with contingency at 0.90 conversion efficiency), a 12 % margin (TPM-2). The allocation sits below the 30 W generation requirement so growth is caught before it eats generation margin.

SR-3.10 Safe Mode Power · Verify: Analysis · Trace: N4 · Applies: All · Alloc: 1.3.1, 1.2

In the Safe Mode attitude, the EPS shall provide at least 20 W orbit-average power at end of life.

Rationale: The Safe Mode bus load is 15.6 W; 20 W keeps a positive energy balance with 28 % margin. Sun pointing removes the attitude factor of the imaging budget, so about 40 W is predicted.

SR-3.11 Hardware Undervoltage Disconnect · Verify: Test · Trace: N4 · Applies: All · Alloc: 1.3.3

The EPS shall disconnect all switched outputs except the UHF receiver, without flight software action, when the battery pack voltage falls below 12.0 V.

Rationale: Backstop below the 12.8 V software threshold (6.4 V per cell pair, SR-4.3): if the software fails to shed load, the hardware does it at 3.0 V per cell, before cell damage. The C&DH always-on line and the UHF receiver stay powered so the ground can still command recovery.

SR-3.12 Autonomous Power Restart · Verify: Test · Trace: N4 · Applies: All · Alloc: 1.3.3

After a full loss of battery energy, the EPS shall restore power to the C&DH and the UHF receiver within 10 min of the arrays receiving sunlight, without ground command.

Rationale: A spacecraft that drains its battery (for example after a long tumble) must restart by itself; there is no other path to recover it.

7.4 Command and Data Handling

Area 4 covers onboard storage, commanding, timekeeping and data protection.

SR-4.1 Onboard Storage · Verify: Test · Trace: N3, N6 · Applies: All · Alloc: 1.4.2

The C&DH shall store at least 64 GB of payload data.

Rationale: Holds 3.7 days of raw calibration-mode collection, or 20 days of compressed collection, so a lost contact day or a calibration campaign never forces captures to stop. Verified by a 64 GB write and read-back with no bit errors (TC-08).

SR-4.2 Command Execution · Verify: Test · Trace: N3, N7 · Applies: All · Alloc: 1.4.1, 1.4.3

The C&DH shall execute each stored command within 1 s of its scheduled time.

Rationale: A 1 s error in imaging start shifts the strip by 7.1 km along track at the 7.06 km/s ground speed; the planners pad each strip for this. Verified with 500 time-tagged commands.

SR-4.3 Fault Detection · Verify: Test · Trace: N4 · Applies: All · Alloc: 1.4.3

The C&DH shall enter Safe Mode within 10 s of undervoltage detection.

Rationale: Prevents battery damage below 6.4 V per cell pair (transition T6 in Operational Modes). Flight software 2.3 measures 14 s; an approved deviation accepts 15 s until flight software 2.4 (TC-09).

SR-4.4 Downlink Encryption · Verify: Inspection, Test · Trace: N5 · Applies: Flight · Alloc: 1.4, 1.5.3

The spacecraft shall encrypt each payload downlink frame with a 256-bit key.

Rationale: The customer contract requires encrypted imagery in transit for EO-1 Flight. Frame encryption follows CCSDS 355.0-B Space Data Link Security Protocol. The X-band Payload Radio encrypts the frames; the C&DH holds the keys and loads them into the radio wrapped (ICD-036; key handling in area 14).

SR-4.5 Image Compression · Verify: Test · Trace: N1, N3 · Applies: All · Alloc: 1.4.3

The C&DH shall compress payload images to no more than 2.2 bits per pixel using CCSDS 122.0-B Image Data Compression.

Rationale: The data volume budget depends on 5.45:1 compression (3.16 GB of compressed image data per day). The standard algorithm is near-lossless at this rate for agricultural scenes and is decoded by the ground processor.

SR-4.6 Compression Throughput · Verify: Test · Trace: N1 · Applies: All · Alloc: 1.4.1, 1.4.3

The C&DH shall compress the raw data of one 40 s strip (1.84 GB) within 60 s.

Rationale: Eight strips per orbit (SR-1.13) must be compressed between captures; the power budget carries the compression burst at 8.5 % of the orbit, about 1 min per strip.

SR-4.7 Onboard Time Accuracy · Verify: Test · Trace: N3 · Applies: All · Alloc: 1.4.1, 2.2

The C&DH shall keep onboard time within 2 ms of UTC with one time correction per day.

Rationale: 2 ms is 14 m along track. Together with orbit determination (SR-6.8) it fits the 20 arcsec (48 m) ephemeris and time allocation of the pointing budget.

SR-4.8 Stored Command Capacity · Verify: Test · Trace: N7, N11 · Applies: All · Alloc: 1.4.3, 1.4.1

The C&DH shall store at least 2,000 time-tagged commands.

Rationale: Covers 72 h of autonomous operations at the design-case command rate of about 600 commands per day, so a weekend or a lost contact day does not interrupt imaging before the 72 h loss-of-contact safe mode trigger.

SR-4.9 Stored Data Integrity · Verify: Analysis, Test · Trace: N3 · Applies: All · Alloc: 1.4.2

The Payload Data Storage shall deliver stored data with an uncorrected bit error rate of at most 1×10^{-12} after 20 days of storage in orbit.

Rationale: A compressed image loses a whole segment to one bit error. At 3.22 GB per day this rate gives fewer than one damaged segment per month; 20 days is the longest storage time (SR-4.1).

7.5 Communications

Area 5 covers the UHF command and telemetry link, the payload downlinks and spectrum compliance. Values come from the link and data volume budgets.

SR-5.1 S-band Downlink Rate · Verify: Test · Trace: N1 · Applies: Lite · Alloc: 1.5.2

The S-band transmitter shall downlink payload data at 10 Mbps.

Rationale: On the three-station service, six 8 min passes carry 3.38 GB per day, one day of collection with 5 % margin; the EO-1 Lite one-station plan carries 1.13 GB (SR-5.4.1). Verified at a frame error rate of at most 1×10^{-6} through the RF suitcase (TC-10).

SR-5.2 UHF Command Uplink · Verify: Test · Trace: N7, N11 · Applies: All · Alloc: 1.5.1, 1.5.4

The UHF transceiver shall receive ground commands at 9.6 kbps.

Rationale: 9.6 kbps GMSK is supported by the UHF equipment of the partner ground network and carries a day's plan in one contact. Verified with 500 test commands (TC-11).

SR-5.3 Downlink Link Margin · Verify: Analysis, Test · Trace: N1 · Applies: Lite · TBR: TBR-04 · Alloc: 1.5.2

The S-band downlink shall close with at least 3 dB [TBR] link margin at 10° elevation.

Rationale: Covers rain fade and pointing loss at low elevation. The link budget gives 4.7 dB. TBR-04 closes when the partner stations' measured G/T and the flight antenna pattern are available.

SR-5.4 Daily Data Volume · Verify: Demonstration, Analysis · Trace: N1 · Applies: Flight · Alloc: 1.5.3, 2.1

The ground segment shall receive at least 3 GB of EO-1 Flight payload data each day.

Rationale: Matches the daily collection after compression (3.22 GB). Two 7 min X-band passes carry 9.87 GB per day (207 % margin). Verified by three consecutive days of at least 3 GB in the end-to-end test.

SR-5.4.1 Daily Data Volume, EO-1 Lite · Verify: Demonstration, Analysis · Trace: N1 · Applies: Lite · Alloc: 1.5.2, 2.1

The ground segment shall receive at least 1 GB of EO-1 Lite payload data each day.

Rationale: The EO-1 Lite service plan uses one station: two S-band contacts with 8 min usable above 7° elevation (see the Communications chapter for pass geometry) carry 1.13 GB per day, so Lite tasking is capped at about 40 scenes per day (SR-1.5).

SR-5.5 X-band Downlink Rate · Verify: Test · Trace: N1 · Applies: Flight · Alloc: 1.5.3

The X-band payload radio shall transmit payload data at 100 Mbps.

Rationale: Delivers a full day of scenes in one pass over the customer station (TC-21).

SR-5.6 X-band Link Margin · Verify: Analysis, Test · Trace: N1 · Applies: Flight · Alloc: 1.5.3

The X-band downlink shall close with at least 3 dB link margin at 10° elevation.

Rationale: Same basis as SR-5.3; X-band rain loss is higher. The link budget gives 7.7 dB.

SR-5.7 UHF Uplink Margin · Verify: Analysis, Test · Trace: N4, N11 · Applies: All · Alloc: 1.5.1, 1.5.4

The UHF command uplink shall close with at least 6 dB link margin at 5° elevation in any spacecraft attitude.

Rationale: Commanding must work during Detumble and Safe Mode, when the attitude is not controlled. The budget includes 6 dB of worst-attitude pattern loss and gives 11.2 dB.

SR-5.8 UHF Telemetry Downlink Margin · Verify: Analysis, Test · Trace: N11 · Applies: All · Alloc: 1.5.1, 1.5.4

The UHF telemetry downlink shall close with at least 3 dB link margin at 10° elevation in any spacecraft attitude.

Rationale: Health telemetry must reach the ground in any attitude. The budget gives 3.2 dB, only 0.2 dB above the requirement; it is a watch item for the antenna pattern measurement.

SR-5.9 Downlink Channel Coding · Verify: Test · Trace: N1 · Applies: All · Alloc: 1.5.2, 1.5.3

The payload downlinks shall encode each transfer frame with the rate 7/8 LDPC code of CCSDS 131.0-B Telemetry Synchronization and Channel Coding.

Rationale: Both link budgets assume this code (required Eb/N0 4.2 dB at a frame error rate of 1×10^{-6}), and the partner stations decode it.

SR-5.10 Spectrum Authorization · Verify: Test, Inspection · Trace: N10 · Applies: All · Alloc: 1.5

Each spacecraft transmitter shall emit only within the center frequency and occupied bandwidth assigned in the program's spectrum license.

Rationale: Operation under the ITU Radio Regulations and the national license is a condition of flight; the S-band license is an open risk (RK-4).

SR-5.11 Transmitter Shutoff · Verify: Test · Trace: N10 · Applies: All · Alloc: 1.4.3, 1.5

The spacecraft shall cease all RF transmission within 10 s of receiving a transmitter-off command.

Rationale: The ITU Radio Regulations require that space station emissions can be stopped by telecommand, for example to resolve harmful interference.

7.6 Ground Segment and Operations

Area 6 covers scheduling, tasking, product delivery, archiving and staffing. The values come from the customer needs and the planning cycle measure (MOE-7).

SR-6.1 Contact Scheduling · Verify: Demonstration · Trace: N11 · Applies: All · Alloc: 2.2

The mission operations center shall schedule ground station contacts at least 48 h ahead.

Rationale: Partner stations need two days' notice to book antenna time. Verified by booking contacts 48 h ahead for 14 consecutive days in rehearsal.

SR-6.2 Image Delivery · Verify: Demonstration · Trace: N1 · Applies: All · Alloc: 2.2, 2.1

The ground segment shall deliver processed image products to the customer portal within 6 h of downlink.

Rationale: Customers act on crop stress alerts the same day. Verified when products reach the portal within 6 h for 95 % of passes in rehearsal (TC-12).

SR-6.3 Telemetry Archive · Verify: Inspection · Trace: N4, N11 · Applies: All · Alloc: 2.2

The mission operations center shall archive each telemetry frame for 730 days.

Rationale: Supports anomaly investigation over the full mission.

SR-6.4 Operator Planning Time · Verify: Demonstration · Trace: N11, N7 · Applies: All · Alloc: 2.2, 2.3

A trained operator shall complete the plan for a nominal imaging pass in no more than 20 min using the operations console.

Rationale: Replaces the unmeasurable SRS-001 wording "user friendly". 20 min of planning fits inside the 100 min planning cycle (SR-6.5). Verified in the operations rehearsal (TC-20).

SR-6.5 Planning Cycle Time · Verify: Analysis · Trace: N1, N7 · Applies: All · Alloc: 0

The mission shall complete each planning cycle, from target list uplink to product delivery, within 100 min.

Rationale: Same-day crop stress alerts need the whole cycle inside one afternoon shift (MOE-7: threshold 100 min, objective 80 min). Verified by a Monte Carlo simulation of the imaging pass meeting 100 min with a probability of at least 90 %.

SR-6.6 Tasking Lead Time · Verify: Demonstration · Trace: N7 · Applies: All · Alloc: 2.2

The mission operations center shall include in the next uplinked plan every feasible tasking request received at least 2 h before that plan's uplink contact.

Rationale: Responsive tasking (N7) means a request made in the morning is imaged on the next suitable pass. 2 h covers feasibility checks and the 20 min plan build (SR-6.4).

SR-6.7 Downlink Contacts per Day · Verify: Analysis, Demonstration · Trace: N1 · Applies: All · Alloc: 2.1, 2.2

The ground segment shall provide each spacecraft at least two payload downlink contacts per day, each with a maximum elevation of at least 60°.

Rationale: From 500 km an overhead pass stays above 10° for about 7.4 min and above 7° for about 8.4 min. The data volume budget assumes two 7 min X-band passes above 10° (EO-1 Flight) and two 8 min S-band passes above 7° (EO-1 Lite plan), which only high passes provide; a 60° maximum elevation gives about 7.3 min above 10°.

SR-6.8 Orbit Determination · Verify: Analysis, Demonstration · Trace: N3 · Applies: All · TBR: TBR-22 · Alloc: 2.2

The mission operations center shall determine each spacecraft's position within 40 m [TBR] (3σ).

Rationale: With the 2 ms time error of SR-4.7 (14 m) this fits the 20 arcsec (48 m) ephemeris and time allocation of the pointing budget. The flight dynamics function uses partner station tracking data and image registration results. The spacecraft carries no navigation receiver, so the value is TBR-22 until the orbit determination analysis with the flight oscillator stability (COM-024) and the partner stations' ranging accuracy confirms it; a receiver is the fallback if it does not.

SR-6.9 Out-of-Limit Notification · Verify: Demonstration · Trace: N11 · Applies: All · Alloc: 2.2

Outside staffed hours, the mission operations center shall notify the on-call operator within 5 min of receiving telemetry outside its limits.

Rationale: A day-shift team (N11) leaves most contacts unattended; prompt notification keeps a fault from waiting until the next shift.

SR-6.10 Unattended Contacts · Verify: Demonstration · Trace: N11 · Applies: All · Alloc: 2.1, 2.2

The ground segment shall execute scheduled contacts, including command uplink and payload downlink, without an operator present.

Rationale: About 15 orbits per day per spacecraft cannot be staffed by a small day-shift team.

SR-6.11 Operations Staffing · Verify: Demonstration, Analysis · Trace: N11 · Applies: All · Alloc: 2.2, 2.3

Routine operations of three spacecraft shall need no more than two operators on duty at a time during staffed hours.

Rationale: The Imagery Customer's operating cost case assumes a small team (N11); three spacecraft is the product line in the first phase (two EO-1 Flight and one EO-1 Lite).

SR-6.12 Vegetation Index Product · Verify: Demonstration · Trace: N3, N1 · Applies: All · Alloc: 2.2

The ground segment shall produce a normalized difference vegetation index map at 4.5 m pixel spacing for each processed scene.

Rationale: The index map is the product agronomists use for field-level stress detection (N3) and the basis of the crop stress alerts (N1). Reviewed with agronomists in VAL-03.

SR-6.13 Calibration Traceability · Verify: Inspection, Demonstration · Trace: N6 · Applies: All · Alloc: 2.2

The ground segment shall record in each image product's metadata the version of the radiometric calibration coefficients applied.

Rationale: Customers comparing seasons must know which calibration each product used, and products can be reprocessed when the coefficients change (SR-1.10).

SR-6.14 Commissioning Duration · Verify: Demonstration · Trace: N4, N2 · Applies: All · Alloc: 0

The mission shall complete commissioning and start routine imaging within 30 days of separation.

Rationale: Each month of commissioning shortens the first growing season. 30 days covers checkout of each subsystem, payload focus and first calibration.

7.7 Structure and Mechanisms

Area 8 covers the stowed envelope, mass, stiffness and deployment mechanisms. Values come from the mass budget and the dispenser adapter interface (IF-15).

SR-8.1 Stowed Envelope · Verify: Inspection · Trace: N8 · Applies: All · Alloc: 1.6.1

In the stowed configuration, the spacecraft shall fit within the 6U envelope of the CubeSat Design Specification (CDS), Rev. 14.1, as adapted by the dispenser adapter interface (IF-15).

Rationale: Rideshare compatibility (N8) depends on fitting a standard 6U dispenser.

SR-8.2 Launch Mass · Verify: Test, Analysis · Trace: N8 · Applies: All · Alloc: 1

The spacecraft launch mass shall not exceed 12.0 kg.

Rationale: 12.0 kg is the dispenser limit. The mass budget gives 10.40 kg with contingency for EO-1 Lite and 10.55 kg for EO-1 Flight. Verified by weighing each flight model.

SR-8.3 Center of Mass · Verify: Test · Trace: N8 · Applies: All · Alloc: 1.6.1

The spacecraft center of mass shall lie within 4.0 cm of the geometric center along each transverse axis and within 7.0 cm along the deployment axis.

Rationale: Limits from the dispenser adapter interface (IF-15); an offset center of mass causes tip-off rates at separation.

SR-8.4 Mass Margin · Verify: Analysis · Trace: N8 · Applies: All · Alloc: 1

The system mass margin shall be at least 10 % of the 12.0 kg allocation at CDR.

Rationale: Program contingency policy. The budget gives 13.3 % (EO-1 Lite) and 12.1 % (EO-1 Flight).

SR-8.5 Stowed Natural Frequency · Verify: Test, Analysis · Trace: N8 · Applies: All · Alloc: 1.6.1

The stowed spacecraft shall have a first natural frequency of at least 100 Hz when constrained at its rails.

Rationale: Keeps the spacecraft modes clear of the dispenser and launch vehicle modes, a usual rideshare condition.

SR-8.6 Deployment Delay · Verify: Test · Trace: N8 · Applies: All · Alloc: 1.6.2, 1.4.3

The spacecraft shall not deploy any deployable earlier than 30 min after separation.

Rationale: The CubeSat Design Specification delays deployment so a deploying spacecraft cannot strike the dispenser or another payload.

SR-8.7 Redundant Release · Verify: Test · Trace: N4 · Applies: All · Alloc: 1.6.2

Each burn-wire hold-down shall release when either of its two independent heater circuits is energized.

Rationale: A stuck array or antenna ends the mission; two independent circuits remove the single-point failure in the release.

SR-8.8 Deployed Natural Frequency · Verify: Test, Analysis · Trace: N3 · Applies: All · Alloc: 1.6.2, 1.3.1

The spacecraft with deployed arrays shall have a first natural frequency of at least 2 Hz.

Rationale: Keeps panel modes well above the ADCS control bandwidth (about 0.1 Hz) so slews do not excite panel motion during captures (SR-2.2).

SR-8.9 Camera-to-Star-Tracker Alignment · Verify: Analysis, Test · Trace: N3 · Applies: All · Alloc: 1.6.1, 1.6.3

The structure shall keep the alignment between the Payload Camera boresight and the star tracker within 60 arcsec (3σ) of its ground-measured value over the on-orbit temperature range.

Rationale: The pointing budget allocates 60 arcsec to thermo-elastic drift; optical misalignment in thermal cycling is an open risk (RK-7).

7.8 Thermal Control

Area 9 covers unit temperatures, payload thermal stability and survival heating. Heater power values come from the power budget.

SR-9.1 Unit Temperature Margin · Verify: Analysis, Test · Trace: N4 · Applies: All · Alloc: 1.6.3

The thermal control shall keep each unit’s predicted temperature at least 10 °C inside its operating limits in the hot and cold operating cases.

Rationale: 10 °C covers thermal model uncertainty before correlation with the thermal vacuum test (SR-11.4).

SR-9.2 Focal Plane Temperature · Verify: Test · Trace: N6 · Applies: All · Alloc: 1.6.3, 1.1

The thermal control shall hold the payload focal plane at 20 °C ± 2 °C during image capture.

Rationale: Dark current and responsivity change with detector temperature; a fixed temperature keeps calibration consistent (N6). The power budget carries the 1.5 W payload heater at 60 % duty.

SR-9.3 Telescope Thermal Gradient · Verify: Analysis, Test · Trace: N3 · Applies: All · Alloc: 1.6.3, 1.1

The thermal control shall keep the axial temperature difference across the telescope structure below 2 °C during image capture.

Rationale: Axial gradients defocus the f/6.4 telescope; 2 °C keeps the focus shift inside the image quality budget (RK-7).

SR-9.4 Battery Maximum Temperature · Verify: Analysis, Test · Trace: N4 · Applies: All · Alloc: 1.6.3

The thermal control shall keep every battery cell at or below 30 °C in all modes.

Rationale: Capacity fade accelerates above 30 °C (RK-2); the lower limit is SR-3.5.

SR-9.5 Thermostatic Survival Heaters · Verify: Test, Inspection · Trace: N4 · Applies: All · Alloc: 1.6.3

The battery and structure heaters shall be controlled by thermostats that operate without flight software.

Rationale: Survival heating must work after a flight computer reset or failure, when software heater control is not available.

SR-9.6 Safe Mode Thermal Survival · Verify: Analysis · Trace: N4 · Applies: All · Alloc: 1.6.3

In the Safe Mode attitude, the thermal control shall keep every unit within its non-operating limits with no more than 3.5 W of heater power.

Rationale: 3.5 W is the battery and structure heater power in the Safe Mode power budget.

7.9 Flight Software and Autonomy

Area 10 covers the flight software functions that are not mode logic. Requirements SR-10.1 to SR-10.19 (mode logic and fault responses) are in the Operational Modes chapter; this area continues from SR-10.20.

SR-10.20 Software Image Activation · Verify: Test · Trace: N4 · Applies: All · Alloc: 1.4.3

The flight software shall activate an uploaded software image only after its checksum matches and a ground command selects it.

Rationale: Software updates in orbit are needed over 730 days, the first being flight software 2.4 to close the SR-4.3 deviation; a corrupt image must never run.

SR-10.21 Protected Boot Image · Verify: Test · Trace: N4 · Applies: All · Alloc: 1.4.1, 1.4.3

The flight computer shall boot from a write-protected software image after three consecutive failed boots of the selected image.

Rationale: A faulty update or a radiation-corrupted image must not make the spacecraft unrecoverable.

SR-10.22 Plan Constraint Check · Verify: Test · Trace: N7, N11 · Applies: All · Alloc: 1.4.3

The flight software shall reject each uplinked plan entry that violates the onboard constraint table (power, thermal, pointing keep-out and storage) and report it in telemetry.

Rationale: A planning error must not put the spacecraft at risk; an onboard check protects it when the plan is built fast (SR-6.4) by a small team.

SR-10.23 Downlink Priority · Verify: Test · Trace: N1 · Applies: All · Alloc: 1.4.3

The flight software shall downlink stored payload files in the priority order set by the ground.

Rationale: Alert targets must come down first on the next pass so same-day alerts (N1) do not wait behind routine collection.

SR-10.24 Event Log · Verify: Test · Trace: N11 · Applies: All · Alloc: 1.4.3, 1.4.2

The flight software shall keep a time-tagged log of at least 1,000 events (fault detections, mode changes and rejected commands) that survives processor resets.

Rationale: Unattended operations mean the ground often learns of an event hours later; the log lets operators reconstruct it.

SR-10.25 Command Validation · Verify: Test · Trace: N11 · Applies: All · Alloc: 1.4.3

The flight software shall reject each command whose parameters are outside their defined ranges and report the rejection in telemetry.

Rationale: Guards against operator and ground software errors.

SR-10.26 Processor Utilization · Verify: Test, Analysis · Trace: N4 · Applies: All · Alloc: 1.4.3, 1.4.1

The flight software shall use no more than 60 % of the processor’s capacity in any 1 s interval in the worst-case mode.

Rationale: Keeps margin for updates over the mission; flight software overrun is an open risk (RK-6).

SR-10.27 Memory Utilization · Verify: Inspection, Test · Trace: N4 · Applies: All · Alloc: 1.4.3, 1.4.1

The flight software shall use no more than 70 % of the flight computer's program and data memory.

Rationale: Same basis as SR-10.26; memory growth limited future updates on earlier small missions.

SR-10.28 Deletion After Ground Confirmation · Verify: Test · Trace: N1, N3 · Applies: All · Alloc: 1.4.3

The flight software shall delete a stored payload file only after the ground confirms its complete receipt or a ground command deletes it.

Rationale: Lost frames are retransmitted on a later pass (SR-12.3); no image is lost to an incomplete pass.

7.10 Environments and Launch Compatibility

Area 11 covers the launch, space and electromagnetic environments and the rules of a rideshare launch. The launch vehicle is not yet assigned (RK-3), so launch levels use an enveloping approach until it is.

SR-11.1 Random Vibration · Verify: Test · Trace: N8 · Applies: All · TBD: TBD-17 · Alloc: 1

The spacecraft shall operate within specification after random vibration at the qualification level [TBD] for 2 min in each of three axes.

Rationale: Qualification is the maximum predicted environment plus 3 dB, as in GSFC-STD-7000 General Environmental Verification Standard (GEVS); until the launch vehicle is assigned, the design uses the GEVS generalized random envelope. TBD-17 closes with the launch services agreement.

SR-11.2 Quasi-Static Loads · Verify: Analysis, Test · Trace: N8 · Applies: All · Alloc: 1.6.1

The spacecraft structure shall withstand a quasi-static limit load of 10 g along each axis with a factor of safety of 1.25 on yield.

Rationale: 10 g envelopes the quasi-static loads of the rideshare vehicles under consideration.

SR-11.3 Separation Shock · Verify: Test, Analysis · Trace: N8 · Applies: All · Alloc: 1

The spacecraft shall operate within specification after a shock of 1,000 g peak shock response between 1 kHz and 10 kHz.

Rationale: Envelopes the separation shock of a 6U dispenser and the launch vehicle stage events.

SR-11.4 Thermal Vacuum Operation · Verify: Test · Trace: N4 · Applies: All · Alloc: 1

The spacecraft shall operate within specification in vacuum at 10 °C beyond the predicted minimum and maximum unit temperatures.

Rationale: Protoflight practice in GEVS; the 10 °C matches the analysis margin of SR-9.1.

SR-11.5 Total Ionizing Dose · Verify: Analysis, Test · Trace: N4 · Applies: All · TBR: TBR-18 · Alloc: 1

The spacecraft shall meet its requirements after a total ionizing dose of 10 krad(Si) [TBR].

Rationale: The dose analysis predicts about 5 krad(Si) over 730 days behind the spacecraft shielding; 10 krad(Si) applies a radiation design margin of 2. Detector damage is an open risk (RK-5). TBR-18 closes with the dose analysis for the final orbit and shielding.

SR-11.6 Single-Event Recovery · Verify: Test, Analysis · Trace: N4, N11 · Applies: All · Alloc: 1.4, 1.3.3

The spacecraft shall return each unit affected by a non-destructive single-event effect to service within 60 s without ground command.

Rationale: Upsets and latch-ups are frequent in this orbit, especially in the South Atlantic Anomaly; a day-shift team cannot recover them by hand.

SR-11.7 Outgassing · Verify: Inspection · Trace: N8, N6 · Applies: All · Alloc: 1

Every nonmetallic material on the spacecraft shall have a total mass loss of at most 1.0 % and collected volatile condensable material of at most 0.1 % when tested to ASTM E595.

Rationale: Outgassed films darken the optics and change calibration (N6); rideshare providers also require these limits.

SR-11.8 EMC Self-Compatibility · Verify: Test, Analysis · Trace: N3, N4 · Applies: All · Alloc: 1

The spacecraft shall operate within specification with all units powered in every operating mode, with at least 6 dB margin between emissions and susceptibility levels.

Rationale: The UHF transmitter can operate during image capture. Emissions and susceptibility are tested with methods of MIL-STD-461G tailored to the spacecraft.

SR-11.9 RF Transmission Delay · Verify: Test · Trace: N8, N10 · Applies: All · Alloc: 1.4.3, 1.5

The spacecraft shall not transmit RF earlier than 45 min after separation.

Rationale: The CubeSat Design Specification delays transmission to protect the launch vehicle and other payloads.

SR-11.10 Dispenser Storage Duration · Verify: Test, Analysis · Trace: N8 · Applies: All · Alloc: 1.3.2, 1.3.3

After 180 days in the dispenser without charging, the battery shall hold at least 60 % state of charge.

Rationale: Rideshare integration can be months before launch, and slips are an open risk (RK-3). The separation sequence until the arrays deploy takes about 14 % of capacity (14.1 W for 45 min); 60 % leaves margin for a slow detumble.

7.11 External Interfaces

Area 12 sets system-level requirements on the external interfaces; the Interfaces chapter details each one. The space and ground data links follow STD-2 Space-Ground Data Exchange Standard.

SR-12.1 Telemetry Frame Format · Verify: Test · Trace: N11 · Applies: All · Alloc: 1.4.3, 1.5

The spacecraft shall format all downlinked telemetry and payload data in transfer frames of CCSDS 132.0-B TM Space Data Link Protocol.

Rationale: The partner ground network processes this standard frame format (IF-10, IF-12, IF-12.1), so no custom station equipment is needed.

SR-12.2 Telecommand Frame Format · Verify: Test · Trace: N11 · Applies: All · Alloc: 1.4.3, 1.5.1

The spacecraft shall accept telecommands in transfer frames of CCSDS 232.0-B TC Space Data Link Protocol.

Rationale: Same basis as SR-12.1 for the command uplink (IF-11).

SR-12.3 File Delivery Protocol · Verify: Test · Trace: N1, N3 · Applies: All · Alloc: 1.4.3, 2.2

The spacecraft shall transfer payload files using the acknowledged mode of CCSDS 727.0-B CCSDS File Delivery Protocol (CFDP).

Rationale: Acknowledged transfer retransmits frames lost at low elevation on a later pass, with the acknowledgments carried on the UHF uplink; it is the basis of SR-10.28.

SR-12.4 Station-to-MOC Transfer · Verify: Demonstration · Trace: N1 · Applies: All · Alloc: 2.1

Each ground station shall deliver the data of a contact to the mission operations center within 30 min of the end of the contact.

Rationale: The largest pass (7 min of X-band, about 4.9 GB) takes about 7 min over the 100 Mbps ground network (IF-13); 30 min leaves most of the 6 h of SR-6.2 for processing.

SR-12.5 Product Format · Verify: Inspection, Demonstration · Trace: N3 · Applies: All · Alloc: 2.2

The customer portal shall deliver image products as GeoTIFF files with band, calibration and acquisition metadata.

Rationale: GeoTIFF opens directly in the farm management and GIS tools the Imagery Customer uses (IF-14.1).

SR-12.6 Machine Tasking Interface · Verify: Demonstration · Trace: N7, N1 · Applies: All · Alloc: 2.2

The customer interface (IF-14) shall accept tasking requests and deliver products through a documented machine interface in addition to the portal.

Rationale: The Imagery Customer's analytics platform tasks and retrieves imagery automatically; manual portal use would slow responsive tasking (N7).

SR-12.7 No Dispenser Electrical Interface · Verify: Inspection · Trace: N8 · Applies: All · Alloc: 1.7, 1.6.1

The spacecraft shall have no electrical connection to the dispenser or the launch vehicle.

Rationale: Rideshare dispensers provide only a mechanical interface (IF-15); the separation switches sense release mechanically.

7.12 Safety, Space Debris and Disposal

Area 13 covers hazard controls for ground processing and launch, debris mitigation and end-of-mission disposal. The hazards are listed in the safety chapter (HAZ-001 to HAZ-004).

SR-13.1 Launch Inhibits · Verify: Inspection, Test · Trace: N8 · Applies: All · Alloc: 1.6.2, 1.3.3

While the spacecraft is in the dispenser, at least three independent inhibits shall interrupt the power path from the battery to each RF transmitter and each deployment actuator.

Rationale: An inadvertent transmission or deployment inside the dispenser is a hazard to the launch vehicle and other payloads; three independent inhibits is a usual rideshare condition. They are the three separation switches (two in the battery lines, one on the output enable; ICD-041); the remove-before-flight pin is a ground-only safeguard and is not counted (IF-15, IF-19).

SR-13.2 Battery Hazard Controls · Verify: Test, Inspection · Trace: N8 · Applies: All · Alloc: 1.3.2, 1.3.3

The battery pack shall provide two independent controls against each of overcharge, overdischarge and external short circuit.

Rationale: Battery thermal runaway (HAZ-001) is catastrophic in ground processing and on the launch vehicle, so it needs two-fault tolerance.

SR-13.3 Ground Transmitter Enable · Verify: Test · Trace: N8 · Applies: All · Alloc: 1.5.2, 1.5.3, 1.4.3

On the ground, the S-band and X-band transmitters shall radiate only after a test command from the ground support equipment.

Rationale: Controls RF exposure of personnel near the downlink antennas (HAZ-003).

SR-13.4 Post-Mission Orbital Lifetime · Verify: Analysis · Trace: N9 · Applies: All · TBR: TBR-19 · Alloc: 0, 1

The spacecraft shall reenter the atmosphere within 5 years [TBR] after the end of mission.

Rationale: ISO 24113 Space systems — Space debris mitigation requirements limits post-mission presence in low Earth orbit; 5 years follows current licensing practice. The decay estimate from 500 km depends on solar activity and the tumbling area of the deployed arrays; TBR-19 closes with the decay analysis for the final orbit.

SR-13.5 Battery Passivation · Verify: Test · Trace: N9 · Applies: All · Alloc: 1.3.3

At end of mission, the spacecraft shall permanently disconnect the battery from the solar arrays on ground command.

Rationale: A battery charged by the arrays for years after the mission can break up (HAZ-004).

SR-13.6 End-of-Mission RF Silence · Verify: Test · Trace: N9, N10 · Applies: All · Alloc: 1.5, 1.4.3

At end of mission, the spacecraft shall permanently disable all RF transmitters on ground command.

Rationale: With the battery disconnected, the arrays can still power units in sunlight; a disabled transmitter cannot interfere with other users after the license ends.

SR-13.7 No Released Objects · Verify: Inspection, Test · Trace: N9 · Applies: All · Alloc: 1.6.2

The spacecraft shall release no objects into orbit during deployment, operations or disposal.

Rationale: Debris mitigation; burn-wire releases must keep the cut line ends captured.

SR-13.8 Reentry Casualty Risk · Verify: Analysis · Trace: N9 · Applies: All · Alloc: 1

The reentry casualty risk of the spacecraft shall not exceed 1 in 10,000.

Rationale: 1 in 10,000 is the commonly applied limit. A small aluminum spacecraft is expected to burn up fully; the analysis checks the optics glass, the star tracker and any titanium parts.

SR-13.9 No Pressure Vessels or Pyrotechnics · Verify: Inspection · Trace: N8 · Applies: All · Alloc: 1

The spacecraft shall carry no pressure vessels, propellants or pyrotechnic devices.

Rationale: Keeps rideshare safety review simple, in line with the CubeSat Design Specification. The cold-gas thruster was studied and is not in either configuration.

7.13 Security

Area 14 protects commanding and imagery (N5). Space link security follows CCSDS 355.0-B Space Data Link Security Protocol; downlink encryption for EO-1 Flight is SR-4.4.

SR-14.1 Telecommand Authentication · Verify: Test · Trace: N5 · Applies: All · Alloc: 1.4.3

The spacecraft shall reject every telecommand that does not carry a valid authentication code under CCSDS 355.0-B Space Data Link Security Protocol.

Rationale: Only the mission operations center may command the spacecraft; an unauthorized command could end the mission.

SR-14.2 Replay Protection · Verify: Test · Trace: N5 · Applies: All · Alloc: 1.4.3

The spacecraft shall reject each authenticated telecommand whose security sequence number is not greater than that of the last accepted command.

Rationale: Authentication alone does not stop a recorded valid command from being sent again.

SR-14.3 Onboard Key Store · Verify: Test · Trace: N5 · Applies: All · Alloc: 1.4.3

The spacecraft shall hold at least eight cryptographic keys, from which an authenticated ground command selects the active key.

Rationale: Spare keys allow rotation (SR-14.4) and recovery from a compromised key without uploading key material.

SR-14.4 Key Rotation · Verify: Demonstration, Inspection · Trace: N5 · Applies: All · TBR: TBR-20 · Alloc: 2.2

The mission operations center shall replace each active key at intervals of no more than 90 days [TBR].

Rationale: Limits exposure if a key leaks. TBR-20 closes with the Imagery Customer’s security review.

SR-14.5 Ground Transfer Encryption · Verify: Inspection, Test · Trace: N5 · Applies: All · Alloc: 2.1, 2.2

The ground segment shall encrypt all payload data and commands carried over the ground network (IF-13) and the customer interface (IF-14) with authenticated encryption using keys of at least 256 bits.

Rationale: Imagery is protected on the ground for both configurations; EO-1 Lite's space link is not encrypted by its service plan, so its data is encrypted at the station.

SR-14.6 Customer Multi-Factor Sign-In · Verify: Test · Trace: N5 · Applies: All · Alloc: 2.2

The customer portal shall require multi-factor authentication for every customer sign-in.

Rationale: A stolen password must not expose a customer's imagery or tasking.

SR-14.7 Customer Data Isolation · Verify: Test · Trace: N5 · Applies: All · Alloc: 2.2

The customer portal shall give each customer account access only to the products and tasking requests of its own organization.

Rationale: Tasking requests and products reveal which farms a customer serves and are commercially sensitive.

SR-14.8 Security Audit Log · Verify: Inspection, Demonstration · Trace: N5 · Applies: All · Alloc: 2.2

The mission operations center shall record the user identity and time of every command uplink and every product download in an audit log kept for 730 days.

Rationale: Supports investigation of misuse over the mission; 730 days matches the telemetry archive (SR-6.3).

SR-14.9 Critical Command Arming · Verify: Test · Trace: N5, N9 · Applies: All · Alloc: 1.4.3

The spacecraft shall execute a critical command (software activation, key change, battery passivation or transmitter disable) only when a matching arm command was accepted within the preceding 60 s (600 s for the decommissioning sequence, SR-10.19).

Rationale: These commands are irreversible or mission-critical; a two-step sequence protects against a single operator error.

7.14 Reliability, Quality and Lifetime

Area 15 covers mission reliability, availability and the product assurance that supports the two-season life.

SR-15.1 Mission Reliability · Verify: Analysis · Trace: N4 · Applies: All · Alloc: 1

The probability that the spacecraft meets SR-1.7 shall be at least 0.8.

Rationale: 0.8 over 730 days is the value the Imagery Customer's business case uses and is achievable for a largely single-string 6U spacecraft with the protections in this chapter (TC-16).

SR-15.2 Failure Propagation · Verify: Analysis · Trace: N4 · Applies: All · Alloc: 1

No single failure in one unit shall cause a failure in another unit.

Rationale: The bus is largely single-string, so containing failures is the main reliability protection; verified by the failure modes, effects and criticality analysis.

SR-15.3 Imaging Availability · Verify: Analysis, Demonstration · Trace: N2, N1 · Applies: All · TBR: TBR-21 · Alloc: 1, 2

After commissioning, each spacecraft shall be available for imaging on at least 90 % [TBR] of days in each 30-day period.

Rationale: Revisit (N2) assumes the spacecraft is imaging; outages for safe mode, calibration and software updates must stay small. TBR-21 closes with the Imagery Customer's service-level agreement.

SR-15.4 Portal Availability · Verify: Analysis, Demonstration · Trace: N1, N7 · Applies: All · Alloc: 2.2

The customer portal shall be available at least 99.5 % of the time in each 30-day period.

Rationale: Alerts and tasking pass through the portal; 99.5 % allows about 3.6 h of outage per month, mostly planned maintenance.

SR-15.5 Prohibited Materials · Verify: Inspection · Trace: N4 · Applies: All · Alloc: 1

The spacecraft shall contain no pure tin, cadmium or zinc finishes.

Rationale: These finishes grow metal whiskers that short circuits; materials are selected per ECSS-Q-ST-70-71C.

SR-15.6 Optics Cleanliness · Verify: Inspection · Trace: N6 · Applies: All · Alloc: 1.1

The Payload Camera optics shall be assembled and integrated only in ISO 14644-1 Class 7 or cleaner environments.

Rationale: Particles on the optics scatter light and change calibration (N6).

SR-15.7 Unit Burn-In · Verify: Test, Inspection · Trace: N4 · Applies: All · Alloc: 1

Each flight unit shall complete at least 100 h of powered operation before spacecraft integration, the last 50 h without failure.

Rationale: Screens out early-life failures, which dominate small-satellite losses in the first weeks.

SR-15.8 End-of-Life Battery Capacity · Verify: Analysis, Test · Trace: N4 · Applies: All · Alloc: 1.3.2

The battery shall retain at least 59 Wh of capacity after 730 days in orbit.

Rationale: The worst-case eclipse energy (17.7 Wh) divided by the 30 % depth-of-discharge limit (SR-3.3) gives 59 Wh, so up to 23 % fade from 77 Wh is allowed over about 11,100 cycles (RK-2). Verified by cell cycle testing.

SR-15.9 Limited-Life Items · Verify: Analysis · Trace: N4 · Applies: All · Alloc: 1.2.1, 1.2.2, 1.4.2

Each limited-life item (reaction wheels, star tracker, payload storage write endurance) shall have a demonstrated or predicted life of at least twice its use over 730 days.

Rationale: A factor of two covers uncertainty in life data; the battery is covered separately by SR-15.8.

8 Payload Camera Specification

This chapter specifies the Payload Camera (product 1.1), the four-band push-broom imager that produces every image the mission delivers. It describes the camera's design, the functions and operating states it provides to the spacecraft, and its interfaces, and it states the camera requirements PAY-001 to PAY-030. Each requirement traces to the system requirements of areas 1, 2, 3, 8, 9, 11 and 15 (System Requirements chapter). The camera is identical in EO-1 Flight and EO-1 Lite.

The camera performs the imaging subfunctions F7.1 Prepare Focal Plane and F7.3 Acquire Image Strip. Pointing at the target (F7.2) belongs to the ADCS, and tagging, compression and storage of the strips (F7.4, F8) belong to the C&DH. The camera's thermal control hardware (radiator, heater, thermistors on the focal plane and telescope) is part of Thermal Control Hardware (1.6.3) and is specified in the Thermal Control Specification; this chapter states only what the camera needs from it.

8.1 Description

8.1.1 Optical Design

The telescope is a two-mirror Ritchey–Chrétien design with a two-element refractive field corrector ahead of the focal plane. Its 95 mm entrance aperture and 611 mm effective focal length give f/6.4. The optical axis runs along the spacecraft's long axis (X), and the aperture looks out through the −X end face, which points at nadir in target imaging (body frame in the Structure and Mechanisms Specification). The Cassegrain fold keeps the physical length of the telescope to about 250 mm, so the camera occupies roughly the −X third of the 6U volume.

The primary and secondary mirrors are low-expansion glass-ceramic with protected-silver coatings, chosen for their reflectance across 450–900 nm, which is higher in the near-infrared than that of aluminum coatings. The secondary is held on three vanes; its 30 mm baffle gives a linear central obscuration of 32 %. The metering structure is carbon fiber reinforced polymer (CFRP) tubes with titanium end fittings, which gives an effective axial expansion coefficient near 1 ppm/K. The camera has no focus mechanism: focus is set on the ground with shims, with an offset that allows for gravity release, moisture desorption of the CFRP in vacuum and the operating temperature (see PAY-008). A baffle tube with internal vanes and a black interior coating extends forward of the secondary to control stray light.

The cross-track field of view is 2.52°, which covers the 22 km swath at nadir. Along track, the field covers the four band sections of the focal plane, about 0.16° in all.

8.1.2 Focal Plane

The detector is a single monolithic CMOS line sensor with time delay and integration (TDI). It carries four band sections, one per spectral band, each 5,000 pixels long with 5.5 µm pitch and up to 16 selectable TDI stages. A four-stripe interference filter assembly is bonded above the sensor so that each section sees one band. The band sections are separated along track by 100 pixel rows

(0.55 mm), so a ground point crosses the four bands about 64 ms apart; the ground processor registers the bands to each other (SR-1.11), and yaw steering by the ADCS keeps the ground motion parallel to the TDI columns (see the ADCS Specification).

Of the 5,000 pixels in each line, 4,889 fall inside the field stop and image the swath; 32 pixels at each end are covered by an opaque mask and give a dark reference in every line. The remaining pixels are outside the field stop and are not read out. TDI accumulation and the 12-bit conversion take place on the sensor.

The detector is mounted on a titanium flexure carrier with a copper thermal strap to the payload radiator. A film heater and two thermistors on the carrier, part of 1.6.3, let the flight software hold the focal plane at 20 °C ± 2 °C during capture (SR-9.2). A relative response monitor of two light-emitting diodes, one broadband white and one at 850 nm, illuminates the focal plane through the field corrector when commanded, for trending the pixel response between lunar and vicarious calibrations.

8.1.3 Electronics

The camera electronics consist of a focal plane board directly behind the detector and a camera control unit in the same housing. The camera control unit contains:

- a field-programmable gate array (FPGA) that sequences the detector, applies the line rate, collects the four band lines and adds a header to each line;
- an image buffer of 4 GB of synchronous memory with error detection and correction, of which at least 2.48 GB is usable for image data;
- the LVDS image data transmitter and the SPI command and telemetry port of the Payload Interface (IF-05);
- secondary power converters fed from the switched 12 V Payload Power Line (IF-01), with current monitoring and latch-up protection on the detector and FPGA supplies;
- housekeeping: voltages, currents, detector and electronics temperatures, buffer status and error counters.

The camera does no image compression. It delivers raw 12-bit pixels to the C&DH, which compresses the strips with CCSDS 122.0-B Image Data Compression at 2.2 bits per pixel (SR-4.5). Keeping compression in the C&DH lets calibration-mode strips be stored raw and keeps the camera FPGA design small.

8.1.4 Design Parameters

Parameter	Value	Note
Telescope	Two-mirror Ritchey–Chrétien with two-element field corrector	Protected-silver mirrors, CFRP metering structure
Entrance aperture	95 mm	Central obscuration 32 % (linear)
Effective focal length	611 mm	pitch × altitude / GSD
Focal ratio	f/6.4	
Ground sample distance at nadir	4.5 m	SR-1.2, from 500 km

Parameter	Value	Note
Diffraction spot radius at 800 nm	5.1 m on the ground	Sets the MTF criterion of SR-1.2
Full field of view, cross-track	2.52°	Swath 22 km at nadir (SR-1.3)
Detector	CMOS TDI line sensor, four band sections	Up to 16 TDI stages per band
Pixel pitch	5.5 μm	
Pixels per band line	5,000, of which 4,889 active and 2 × 32 masked	Active pixels = swath / GSD
Band section spacing	100 rows (0.55 mm)	64 ms between bands at nadir
Spectral bands	Blue, green, red, near-infrared within 450–900 nm	Band edges in PAY-004
Quantization	12 bit	On-sensor conversion
Line rate	1,569 lines/s nominal; programmable 1,300–1,800 lines/s	Ground speed / GSD
Raw data rate while imaging	368 Mbps	Line rate × pixels × bands × bits
Raw scene size (22 × 22 km)	143 MB	
Nominal strip (40 s)	1.84 GB raw	
Longest strip (54 s)	2.48 GB raw	Usable image buffer
Image data output	LVDS, 400 Mbps (IF-05)	Band-interleaved lines with headers
Command and telemetry	SPI (IF-05)	
Power, standby / prepare / capture	2.5 W / 6.0 W / 14.0 W	From IF-01, 15 W line rating
Mass	2.40 kg (current best estimate)	2.64 kg allocation
Focal plane temperature in capture	20 °C ± 2 °C	SR-9.2

Payload Camera design parameters

8.2 Functions

The camera performs two subfunctions of F7 Capture Images and contributes data to two others.

Function	Camera role
F7.1 Prepare Focal Plane	Performed by the camera: power the detector, confirm the focal plane temperature, load the band settings for the target (line rate, TDI stages, gain) and report Focal Plane Status “ready”.
F7.3 Acquire Image Strip	Performed by the camera: clock the detector at the commanded line rate for the strip duration, write the four band lines with headers into the image buffer and stream them to the C&DH over IF-05.
F7.4 Tag Strip with Ancillary Data	Supplied by the camera: line counter, line time tag, band settings and focal plane temperature in each line header; the flight software adds attitude and ephemeris.
F8.1 Receive Image Strip	Supplied by the camera: buffer read-out to the C&DH on request.

Functions performed or supported by the Payload Camera

F7.1 runs in parallel with the slew to the first target of an imaging window (F7.2). If the camera has not reported ready by the scheduled start of a strip, the flight software skips the target (System Architecture, F7 flow).

8.3 Operating States

The camera has six operating states, commanded by the C&DH over IF-05. The spacecraft mode determines which states are permitted; the camera itself does not change state except to fall back to Standby after a latch-up or a buffer error.

State	Camera activity	Power from IF-01	Spacecraft modes in which it is used
Off	Unpowered; the focal plane heater may still be powered from its own PDU output	0 W	Launch, Detumble, Safe Mode, Decommissioned
Standby	Control unit and focal plane control electronics on, detector off; housekeeping reported	2.5 W	Nominal Imaging (NI.1, NI.3), Downlink Contact
Prepare	Detector powered and settling, band settings loaded	6.0 W	NI.2 before each strip
Capture	Detector clocked at the line rate, buffer written and read out	14.0 W	NI.2 during each strip
Calibration	Capture with the aperture on a calibration target (dark sky, Moon, calibration site) or with the response monitor on; strips flagged for raw storage	14.0 W	NI.2 (commanded calibration windows)
Decontamination	Detector off; the focal plane and telescope heaters held at the decontamination set point	2.5 W (plus heater power)	Nominal Imaging, commissioning step C5 and on ground command

Payload Camera operating states

The power values are those of the Nominal Imaging power budget (Budgets chapter). Safe Mode switches the camera off (SM.4); entry to Nominal Imaging by T3 or T7 returns it to Standby (SM.11).

8.4 Interfaces

The camera has the following interfaces. Their electrical, data, mechanical and thermal details are in EO1-ICD-200 and the Interface Requirements chapter; this chapter refers to them by id only.

- **IF-01 Payload Power Line** from the EPS: switched 12 V, rated 15 W.
- **IF-05 Payload Interface** with the C&DH: LVDS image data at 400 Mbps from the camera, SPI commands and telemetry, and the time synchronization pulse used for line time tags.

- **IF-24 Scene Radiance Path** from the orbit environment: reflected scene radiance through the −X aperture.
- **Mechanical mount** to the optical bench of the Primary Structure, shared with the star tracker, through three titanium bipod flexures (Structure and Mechanisms Specification).
- **Thermal interfaces** to the payload radiator and the heaters and thermistors of 1.6.3 (Thermal Control Specification).

8.5 Requirements

8.5.1 Optics and Geometry

PAY-001 Aperture and Focal Length · Verify: Inspection, Test · Trace: SR-1.2, SR-1.8 · Applies: All

The Payload Camera shall have an entrance aperture of 95 mm diameter and an effective focal length of 611 mm ± 3 mm.

Rationale: 5.5 µm pixels at 611 mm focal length from 500 km give the 4.5 m ground sample distance of SR-1.2; a focal length error of 0.5 % changes the GSD by 2 cm and the swath by 110 m. The aperture sets the collected signal behind the SNR of SR-1.8 and the 5.1 m diffraction spot at 800 nm.

PAY-002 Detector Format · Verify: Inspection, Test · Trace: SR-1.2, SR-1.3 · Applies: All

The detector shall provide, in each of the four band sections, at least 4,889 active pixels of 5.5 µm pitch inside the cross-track field of view of 2.52°.

Rationale: 4,889 pixels of 4.5 m cover the 22 km swath of SR-1.3 at nadir. The field stop and the detector position are set so that all active pixels see the scene with none vignetted; swath width on the ground is confirmed in TC-02.

PAY-003 Laboratory Modulation Transfer Function · Verify: Test · Trace: SR-1.2 · Applies: All

At best focus and at the Nyquist frequency of 90.9 cycles/mm, the Payload Camera shall have a modulation transfer function of at least 0.18 across track and at least 0.14 along track in each band over the full field.

Rationale: The system criterion of SR-1.2 is an MTF at Nyquist of at least 0.12 in orbit. The along-track value includes the TDI smear of one line; in orbit, attitude jitter (factor about 0.95) and residual defocus (about 0.90) reduce 0.14 to 0.12. The near-infrared band at the edge of the field is the limiting case because of diffraction.

PAY-004 Telescope Wavefront Error · Verify: Test, Analysis · Trace: SR-1.2 · Applies: All

The assembled telescope shall have a wavefront error of no more than 0.07 waves rms at 633 nm at every field point.

Rationale: 0.07 waves rms keeps the optics MTF at Nyquist within about 10 % of the diffraction limit, which PAY-003 needs. The allocation covers mirror figure, alignment and mounting distortion; it is measured by interferometry in the laboratory and checked after vibration.

PAY-005 Focus in Orbit · Verify: Analysis, Test · Trace: SR-1.2 · Applies: All · TBR: TBR-30

In orbit at the operating temperature, the best-focus position of the telescope shall lie within ± 20 μm [TBR] of the detector surface in every band.

Rationale: The camera has no focus mechanism, so the ground setting must anticipate the shifts in orbit. The focus budget is 8 μm for setting accuracy, 5 μm for gravity release, 10 μm for CFRP moisture desorption and 5 μm for temperature, about 14 μm root sum square; ± 20 μm keeps the MTF loss from defocus below 10 %. TBR-30 closes when the moisture desorption test of the metering structure coupons is complete.

PAY-006 Band Co-alignment · Verify: Test · Trace: SR-1.11 · Applies: All

The four band lines shall be parallel to each other within 0.2 pixel over the 4,889 active pixels, with their cross-track pixel positions coinciding within 0.3 pixel at every field point.

Rationale: The ground processor removes the along-track offset between bands from the known 100-row spacing and the attitude data, but a rotation or cross-track shift of one band section relative to another varies across the field and is harder to model. Keeping the as-built residual below about a third of a pixel lets the ground meet the 0.3-pixel registration of SR-1.11 with little resampling.

8.5.2 Spectral Response

PAY-007 Spectral Band Edges · Verify: Test · Trace: SR-1.4 · Applies: All

The 50 % relative response points of each band shall lie within 5 nm of the band edges in the table Payload Camera spectral bands.

Rationale: The edges are chosen for vegetation indices: the red band sits on the chlorophyll absorption and the near-infrared band on the leaf reflectance plateau, both clear of the strong water vapor absorption near 940 nm. 5 nm is the tolerance stated with SR-1.4; the edges are measured with a monochromator in TC-03.

Band	Name	Lower edge	Upper edge	Use
B1	Blue	450 nm	515 nm	Atmospheric correction, true color
B2	Green	525 nm	595 nm	Canopy vigor, true color

Band	Name	Lower edge	Upper edge	Use
B3	Red	630 nm	690 nm	Chlorophyll absorption, vegetation indices
B4	Near-infrared	780 nm	890 nm	Leaf structure, vegetation indices

Payload Camera spectral bands (50 % relative response points)

PAY-008 Out-of-Band Response · Verify: Test · Trace: SR-1.4, SR-1.9 · Applies: All

For each band, the response integrated outside the band edges over 400–1,000 nm shall be no more than 1.5 % of the total integrated response.

Rationale: Out-of-band light adds a scene-dependent error that calibration cannot remove; for a vegetation scene with high near-infrared reflectance, 1.5 % leakage into the red band is about a 1 % radiance error, which fits the 5 % absolute accuracy of SR-1.9. The silicon response ends near 1,000 nm, so that is the upper integration limit.

8.5.3 Radiometry

PAY-009 Signal-to-Noise Ratio · Verify: Test, Analysis · Trace: SR-1.8 · Applies: All · TBR: TBR-15

At end of life and with the nominal band settings, the Payload Camera shall achieve a signal-to-noise ratio of at least 100 [TBR] in each band for a Lambertian scene of 0.30 reflectance at a solar zenith angle of 45°.

Rationale: This is the camera share of SR-1.8, with the top-of-atmosphere radiance computed for that scene. The prediction (table Predicted signal-to-noise ratio) includes the measured read noise of the engineering-model detector, a dark current increase for 10 krad(Si) and the throughput loss of the contamination allowance. The near-infrared margin is the smallest, because silicon quantum efficiency falls off at 850 nm; this is part of risk RK-5. The value stays TBR with SR-1.8 (TBR-15).

Band	Nominal TDI stages	Predicted SNR, beginning of life	Predicted SNR, end of life
B1 Blue	8	128	112
B2 Green	8	150	134
B3 Red	8	138	121
B4 Near-infrared	16	121	104

Predicted signal-to-noise ratio, 0.30 reflectance at 45° solar zenith angle

PAY-010 Saturation Margin · Verify: Test · Trace: SR-1.15 · Applies: All

With the nominal band settings, the signal for a Lambertian scene of 0.90 reflectance at a solar zenith angle of 20° shall not exceed 90 % of the 12-bit output range in any band.

Rationale: SR-1.15 forbids saturation on bright clouds and roofs. The 10 % headroom covers pixel-to-pixel response spread and the response drift between calibrations. That scene is about four times brighter than the SNR reference scene, so the reference signal sits near 22 % of full scale, where quantization noise is negligible.

PAY-011 Band Settings · Verify: Test · Trace: SR-1.8, SR-1.15 · Applies: All

The Payload Camera shall accept, for each band and each strip, a commanded number of TDI stages from 1 to 16 and a commanded analog gain from at least two settings.

Rationale: Per-band settings let the operators trade SNR against saturation for the season and the latitude of the target (low sun in autumn, snow in early spring) without changing the flight software; the settings used are recorded in every line header.

PAY-012 Radiometric Linearity · Verify: Test · Trace: SR-1.9 · Applies: All

Between 5 % and 90 % of the output range, the response of each pixel shall deviate from a straight-line fit by no more than 1 % of the signal.

Rationale: The ground calibration (F11.2) applies a linear model with a dark offset per pixel. 1 % non-linearity uses a fifth of the 5 % absolute accuracy budget of SR-1.9; a larger non-linearity would need a per-pixel polynomial that is hard to maintain over the mission.

PAY-013 Defective Pixels · Verify: Test · Trace: SR-1.2, SR-1.8 · Applies: All

Each band section shall have no more than 0.05 % defective active pixels at delivery and no two adjacent defective pixels.

Rationale: 0.05 % is two pixels per band line. A single defective pixel is replaced by interpolation on the ground without visible artifacts in field maps; two adjacent ones leave a 9 m line along the whole strip. A pixel is defective when its dark signal, noise or response is more than 20 % from the band median.

8.5.4 Calibration

PAY-014 Dark Reference · Verify: Inspection, Test · Trace: SR-1.9, SR-1.10 · Applies: All

Every line read out by the Payload Camera shall include at least 32 optically masked pixels at each end of each band section.

Rationale: The masked pixels track the dark offset and its drift with temperature line by line, without a shutter. Full-field dark frames are taken by pointing the aperture at dark sky in a calibration window (SR-1.14 slews are used for the same purpose).

PAY-015 Relative Response Monitor · Verify: Test, Demonstration · Trace: SR-1.10 · Applies: All

The Payload Camera shall illuminate every active pixel of each band with its onboard response monitor at a signal of at least 20 % of the output range, with an illumination stability of 0.5 % over 10 min.

Rationale: Monthly lunar images (SR-1.14) give the absolute trend; the response monitor fills the gaps, detects pixel-level changes after radiation events (RK-5) and separates detector changes from optics contamination. The monitor's own aging is tracked against the lunar trend.

PAY-016 Pre-Launch Radiometric Calibration · Verify: Test · Trace: SR-1.9, SR-6.13 · Applies: All

The pre-launch calibration shall determine the absolute radiance response of each band with an uncertainty of no more than 3 % (1σ), traceable to a national radiometric standard.

Rationale: 3 % from the laboratory leaves room within the 5 % of SR-1.9 for on-orbit changes between calibration updates and for the atmospheric correction. The integrating sphere is calibrated with a transfer radiometer before and after the campaign; the traceability record feeds SR-6.13.

PAY-017 Focal Plane Temperature Knowledge · Verify: Test · Trace: SR-9.2, SR-1.10 · Applies: All

The Payload Camera shall report the detector temperature with an accuracy of ±0.2 °C in every line header and in housekeeping.

Rationale: The dark offset and responsivity are corrected for temperature on the ground; ±0.2 °C makes that correction error small compared with the ±2 °C control band of SR-9.2. The control loop itself uses the 1.6.3 thermistors (Thermal Control Specification).

8.5.5 Stray Light, Sun and Contamination

PAY-018 Stray Light · Verify: Test, Analysis · Trace: SR-1.9 · Applies: All

For an Earth scene of uniform 0.30 reflectance extending 10° beyond the field of view, the stray-light signal from outside the field and from internal ghosts shall not exceed 2 % of the in-field signal in any band.

Rationale: Stray light raises the signal over dark fields next to bright ones and biases vegetation indices. 2 % is held by the forward baffle, the secondary baffle and the field stop; it is set with the scatter model of the mirrors and checked with a collimated source scanned outside the field.

PAY-019 Sun Exposure Tolerance · Verify: Analysis, Test · Trace: SR-1.10, SR-1.7 · Applies: All

The Payload Camera, powered or unpowered, shall withstand the Sun inside its field of view for up to 60 s per event without a permanent change in response of more than 0.5 %.

Rationale: In nominal attitudes the aperture faces away from the Sun (Sun pointing puts the −X face anti-sun), but a tumble, a slew error or Detumble can sweep the Sun through the field. The focused Sun image on the field stop and the filter must not burn or bleach them. 60 s bounds a slow tumble at 0.5 deg/s across the 2.52° field many times over.

PAY-020 Optics Cleanliness at Delivery · Verify: Inspection · Trace: SR-15.6, SR-1.10 · Applies: All

At delivery to spacecraft integration, every optical surface of the Payload Camera shall have a particulate area coverage of no more than 0.2 % and a molecular deposit of no more than 0.5 $\mu g/cm^2$.

Rationale: The contamination budget of the Contamination Control Plan (EO1-PLN-370) allows 1 % throughput loss up to launch and 1 % in orbit; the delivery levels use under half of the first. Cleanliness is checked with witness plates kept beside the optics through assembly and test.

PAY-021 Decontamination Tolerance · Verify: Test · Trace: SR-1.10, SR-11.7 · Applies: All

The Payload Camera shall operate within specification after being held at +30 °C for a total of 200 h in vacuum.

Rationale: The camera optics and focal plane are warmed above their operating temperature during commissioning step C5 (outgassing hold) and on ground command if the response monitor shows a contamination trend (Thermal Control Specification, THM-015). 200 h covers the commissioning hold and several later decontamination periods.

8.5.6 Alignment and Stability

PAY-022 Alignment Reference · Verify: Test · Trace: SR-8.9, SR-2.6 · Applies: All

The Payload Camera shall carry an optical alignment cube whose orientation relative to the camera line of sight is known within 15 arcsec (3σ) in each axis.

Rationale: The pointing budget allocates 40 arcsec to the ground measurement of the star tracker to camera alignment. The cube lets that measurement be made with theodolites on the integrated spacecraft; 15 arcsec for the cube calibration leaves the rest for the star tracker reference and the measurement itself.

PAY-023 Line-of-Sight Stability · Verify: Analysis, Test · Trace: SR-8.9, SR-2.1 · Applies: All

Relative to its alignment cube, the Payload Camera line of sight shall move by no more than 30 arcsec (3σ) over the operating temperature range and after launch loads.

Rationale: SR-8.9 allows 60 arcsec of thermo-elastic drift between the camera and the star tracker. The camera's internal share is 30 arcsec and the optical bench's share is 50 arcsec (STR-011), 58 arcsec root sum square. Optical misalignment in thermal cycling is risk RK-7.

8.5.7 Data and Timing

PAY-024 Image Buffer · Verify: Test · Trace: SR-1.13, SR-1.5 · Applies: All

The Payload Camera shall hold at least 2.48 GB of image data, one 54 s strip at 368 Mbps, in its image buffer with error detection and correction.

Rationale: The buffer decouples capture from the C&DH: a strip is never cut short because the flight computer is still busy with the previous strip. 54 s is the longest strip planned (two adjacent scenes along track); a nominal 40 s strip uses 1.84 GB.

PAY-025 Image Data Output · Verify: Test · Trace: SR-4.5, SR-4.6 · Applies: All

The Payload Camera shall deliver each strip to the C&DH over IF-05 as raw 12-bit pixels, band-interleaved by line, with a header on every line, completing the transfer within 10 s after the end of the strip.

Rationale: Raw band-interleaved lines are the input format of the flight software's CCSDS 122.0-B compressor (SR-4.5); the 10 s limit leaves the 60 s of SR-4.6 almost entirely for compression. Read-out starts with the capture and runs at the 400 Mbps link rate, faster than the 368 Mbps raw rate, so the buffer drains as it fills unless the C&DH pauses it.

PAY-026 Line Time Tagging · Verify: Test · Trace: SR-1.12, SR-4.7 · Applies: All

The Payload Camera shall time-tag each line relative to the onboard time synchronization pulse with an error of no more than 50 μs.

Rationale: 50 μs is 0.35 m along track, small against the 2 ms (14 m) onboard time allocation of SR-4.7. Line time tags let the ground interpolate attitude and ephemeris for every line in geolocation (SR-1.12).

PAY-027 Line Rate Control · Verify: Test · Trace: SR-1.2, SR-1.6.2 · Applies: All

The Payload Camera shall run at a commanded line rate between 1,300 and 1,800 lines/s, set in steps of no more than 0.05 % and held within 0.01 % for the strip.

Rationale: The TDI line rate must match the motion of the ground image across the detector, which changes with altitude, latitude and off-nadir angle (1,569 lines/s at nadir from 500 km, about 1,400 lines/s at 25° off nadir). A 0.05 % mismatch over 16 TDI stages smears the image by less than 0.01 pixel.

8.5.8 Resources and Robustness

PAY-028 Payload Power · Verify: Test · Trace: SR-3.9 · Applies: All

The Payload Camera shall draw from IF-01 no more than 2.5 W in Standby, 6.0 W in Prepare and 14.0 W in Capture and Calibration.

Rationale: These are the values in the Nominal Imaging power budget (standby 100 %, prepare 10.6 %, capture 5.6 % of the orbit) and stay below the 15 W rating of IF-01. The focal plane heater is supplied separately from a PDU heater output and is not included.

PAY-029 Payload Mass · Verify: Test · Trace: SR-8.2, SR-8.4 · Applies: All

The Payload Camera mass, including its mounting flexures, harness pigtails and alignment cube, shall not exceed 2.64 kg.

Rationale: 2.64 kg is the camera line of the mass budget: 2.40 kg current best estimate with the 10 % contingency of a calculated item. The camera is the largest single mass item, so its growth is tracked at every review.

PAY-030 Latch-Up Protection · Verify: Test · Trace: SR-11.6, SR-15.2 · Applies: All

The Payload Camera shall remove power from its detector and FPGA supplies within 1 ms of a supply current above its latch-up threshold and then return to Standby without ground command.

Rationale: The CMOS sensor and the FPGA are the camera parts susceptible to single-event latch-up; fast removal prevents damage. Returning to Standby (rather than resuming the capture) lets the next scheduled strip run normally, which keeps the recovery inside the 60 s of SR-11.6. The PDU current limiter on IF-01 is a second, slower layer.

8.6 Verification Approach

The camera is verified at camera level before spacecraft integration and again at system level. At camera level, the Payload Lead runs the following tests on the engineering model and on each flight camera: **TC-30 Payload MTF and Focus Test** (collimator with slanted-edge and bar targets at several field points and through focus, in vacuum at the operating temperature; PAY-003,

PAY-004, PAY-005, PAY-006, PAY-027), **TC-31 Payload Radiometric Calibration** (integrating sphere at several radiance levels and band settings; PAY-009 to PAY-013, PAY-016), **TC-03 Spectral Response Calibration** (monochromator scan of every band; PAY-007, PAY-008), **TC-32 Payload Stray Light Test** (collimated source scanned outside the field, ghost survey; PAY-018) and **TC-33 Payload Thermal Vacuum and Line-of-Sight Test** (focal plane control, response monitor, line-of-sight drift against the cube over the temperature range, decontamination soak; PAY-015, PAY-017, PAY-021, PAY-023). The buffer, data output, line timing and latch-up response (PAY-024 to PAY-026, PAY-030) are tested on the flatsat with the flight computer engineering model. The camera ground sample distance and swath are verified at system level in TC-01 and TC-02, and the alignment cube calibration and mass in mechanical integration. Sun exposure (PAY-019) is verified by analysis of the focused solar flux on the field stop and filter, with a coupon exposure test of the filter material.

Commissioning steps C5 and C6 repeat the dark, response monitor, focus and calibration measurements in orbit; they are the first on-orbit confirmation of PAY-005 and PAY-009.

9 ADCS Specification

This chapter specifies the Attitude Determination and Control Subsystem (ADCS, product 1.2) with its four parts: the Reaction Wheel Assembly (1.2.1), the Star Tracker (1.2.2), the Magnetorquers (1.2.3) and the ADCS Controller and Sensors (1.2.4). It describes the hardware, the pointing modes, the estimation and control design and the momentum management, includes the pointing error budget, and states the ADCS requirements ADCS-001 to ADCS-029. The ADCS is identical in EO-1 Flight and EO-1 Lite; only the downlink antenna it points in Ground Station Tracking differs.

The ADCS performs F1 Separate and Detumble (rate damping), F4 Determine and Control Attitude with its subfunctions F4.1 to F4.4, F7.2 Slew to Target Attitude, F9.2 Track Ground Station and F10.3 Acquire Sun-Pointing Attitude (System Architecture, functional allocation). It receives attitude targets and pointing mode commands from the C&DH over the ADCS Data Bus (IF-06) and returns attitude, rate, wheel and sensor telemetry on the same bus.

9.1 Hardware

The ADCS runs its own software on the ADCS Controller, separate from the Flight Software of the C&DH. The controller executes the estimation filter and the control laws at 10 Hz and holds the active pointing mode even if the flight computer resets; the C&DH sends pointing mode changes, target and ground station coordinates and ephemeris updates.

Unit	Product	Qty	Main characteristics	Power (on)	Mass with contingency	Interface
Reaction wheel	1.2.1	4	10 mNms at 6,000 rpm, 1.0 mNm maximum torque; pyramid with spin axes at 54.7° from the pyramid axis	0.5 W each average; 4.0 W slew increment for the set	0.134 kg each (0.536 kg set)	IF-17
Star tracker	1.2.2	1	10 arcsec (1σ) cross-boresight, 60 arcsec (1σ) about boresight; 5 Hz; Sun exclusion 40°, Earth limb exclusion 25°; valid to 1.0 deg/s	1.8 W	0.360 kg	IF-16 (RS-422, 0.5 Mbps)
Magnetorquer	1.2.3	3	Torque rods, 0.4 A·m² each, one per body axis	1.2 W for the set at full dipole	0.231 kg (set)	IF-18

Unit	Product	Qty	Main characteristics	Power (on)	Mass with contingency	Interface
ADCS controller	1.2.4	1	Processor board, 10 Hz control cycle, CAN to the C&DH, power switching of the star tracker and wheels	Included in the 1.0 W below	0.127 kg (controller and sensors)	IF-06, IF-02
Coarse sun sensor	1.2.4	6	Cosine photodiodes, one per face, ±60° field	Included	Included	Controller
Magnetometer	1.2.4	1	Three-axis, ±80 μT range, noise 50 nT rms	Included	Included	Controller
Rate gyro	1.2.4	1	Three-axis MEMS, ±20 deg/s range, angle random walk 0.15 deg/√h, bias instability 1 deg/h	Included	Included	Controller

ADCS sensors and actuators

The controller, sun sensors and magnetometer together draw 1.0 W (power budget). The whole ADCS draws its power from the switched 12 V ADCS Power Line (IF-02), rated 10 W. The controller switches the star tracker and the wheels on command, so that Safe Mode can switch the star tracker off (SM.4) without removing power from the rest of the ADCS.

The star tracker is mounted on the optical bench next to the Payload Camera (Structure and Mechanisms Specification), with its boresight toward +Y canted 30° toward +X. In target imaging with the −X face at nadir, this puts the boresight 52° above the Earth limb, and still 27° above it at 25° off nadir rolled toward the tracker; in Sun pointing, with the array normal (+X) on the Sun, the boresight is 60° from the Sun.

The spacecraft moment of inertia with the arrays deployed is about 0.27 kg·m² about the largest axis (Y), 0.17 kg·m² about Z and 0.14 kg·m² about X (mass properties estimate; measured values replace it after TC-43). The four-wheel pyramid gives about 23 mNms of momentum capacity about each body axis, and about 11 mNms about the weakest axis with any one wheel failed.

9.2 Pointing Modes and Spacecraft Modes

The ADCS pointing modes AP-0 to AP-5 and the pointing mode used in each spacecraft mode and sub-mode are defined in Operational Modes (“ADCS Pointing Modes” and the mode definitions). This section adds what each pointing mode means inside the ADCS.

- **AP-0 Off.** The controller is powered after separation and records magnetometer, sun sensor and gyro data for the tip-off rate history, but it drives no actuator. The torque rod and wheel drivers stay disabled until the C&DH enables them at transition T2.
- **AP-1 Rate Damping.** B-dot control: the torque rod dipole opposes the measured rate of change of the magnetic field. It uses only the magnetometer and the torque rods, so it works with the wheels and the star tracker off and with any sun sensor or gyro failed. Magnetometer samples are taken in a 100 ms window each cycle with the rods switched off, so the rods do not corrupt their own measurement.
- **AP-2 Coarse Sun Pointing.** The coarse filter combines the sun sensors, magnetometer and gyro; the wheels point the array normal at the Sun and the rods unload momentum continuously. In eclipse the gyro holds the rates and the controller reacquires the Sun at eclipse exit.
- **AP-3 Fine Sun Pointing.** Star tracker attitude with the array normal on the Sun and the rotation about the Sun line chosen to keep the star tracker on dark sky. Used in NI.1 and NI.3.
- **AP-4 Target Pointing.** Star tracker attitude; the controller computes the attitude profile that holds the camera boresight on the target’s ground track, including yaw steering, from the onboard orbit propagator and the target coordinates in the Command Schedule. Used in NI.2.
- **AP-5 Ground Station Tracking.** Star tracker attitude; the downlink antenna boresight (−X) follows the station named in the contact entry. Used in Downlink Contact.

Yaw steering. The Earth’s rotation moves the ground image sideways across the detector at up to about 3.8° from the along-track direction at the equator. In AP-4 the controller rotates the spacecraft about the boresight by the crab angle for the target latitude, so that the ground motion stays along the TDI columns and the four band lines see the same ground track. Of the two yaw orientations 180° apart that satisfy this, the planner selects the one that keeps the +Y face, with the star tracker and the payload radiator, on the side away from the Sun (Thermal Control Specification).

Slews. Slews between attitudes are eigenaxis rotations with a rate limit of 1.5 deg/s and an acceleration profile that keeps the commanded wheel torque under 70 % of the 1.0 mNm wheel limit. A 30° slew about the largest axis takes about 45 s plus a settling period of up to 15 s, the basis of SR-2.4 (TBR-03).

9.3 Estimation and Control

Estimation (F4.1). A multiplicative extended Kalman filter propagates the attitude with the gyro at 10 Hz and updates it with star tracker quaternions at 5 Hz, estimating the gyro biases. Without the star tracker, a coarse filter uses the sun sensors and the magnetometer against onboard Sun and geomagnetic field models; its accuracy (a few degrees) is enough for AP-2. The filter's estimate and covariance are reported in telemetry.

Orbit and time. The ADCS has no navigation receiver. The C&DH passes the orbit state from the ground orbit determination (SR-6.8) to the controller once a day; the controller propagates it with a model that includes the Earth's oblateness and drag, and takes time from the C&DH time distribution (SR-4.7).

Control (F4.2, F4.3). A quaternion feedback law with integral action and feedforward of the commanded attitude profile drives the wheels. Its bandwidth is about 0.1 Hz, well below the deployed array mode of at least 2 Hz (SR-8.8). The wheel torques are distributed over the four wheels with a null-space term that keeps the wheel speeds near their bias values.

Reaction wheel friction finding. Flatsat test TC-04 measured 0.14° on 3 of 20 targets against the 0.1° of SR-2.1. In the three cases a wheel crossed zero speed during the capture, where dry friction changes sign and gives a torque step the controller cannot follow at its bandwidth. The suspected cause is carried as risk RK-1; the design response is ADCS-007, which keeps every wheel away from zero speed during captures, and the flatsat test is repeated with the updated null-space logic before CDR.

9.4 Momentum Management

The secular disturbance torques are the gravity gradient, the aerodynamic torque from the offset between the deployed arrays' center of pressure and the center of mass, and the residual magnetic dipole of the spacecraft (at most 0.05 A·m², ENV-019). They accumulate wheel momentum at a rate that depends on the attitude profile; the design-case orbit with two imaging windows and one contact accumulates up to about 15 mNms.

Momentum is managed in three ways:

1. **Null-space biasing.** The four wheels have one degree of freedom that produces no body torque. It is used to hold the wheels at bias speeds of ±1,500 rpm in alternating directions, so that no wheel nears zero speed in normal operation.
2. **Unloading in NI.3 (F4.4).** When the total wheel momentum exceeds 24 mNms (60 % of 40 mNms) outside the imaging exclusion period, Nominal Imaging enters NI.3 and the torque rods reduce the momentum to below 8 mNms (sub-mode transitions n3 and n4 in Operational Modes). The rods are never driven during target imaging or within 10 min before an imaging window (SR-10.17).
3. **Continuous unloading in AP-2.** In Coarse Sun Pointing, as used in Safe Mode, the rods unload continuously because there is no capture to protect.

Each wheel is kept at or below 8 mNms (SR-2.8), which keeps at least 2 mNms on every wheel for slews.

9.5 Pointing Error Budget

The pointing budget combines the knowledge and control errors that move the camera boresight away from the commanded target. Each contributor is a 3σ value, combined by root sum square.

Contributor (3 sigma)	arcsec
Star tracker attitude knowledge	30
Star tracker to camera alignment (ground measurement)	40
Thermo-elastic alignment drift on orbit	60
Attitude estimation filter error	25
Control error (wheel jitter, controller residual)	140
Ephemeris and time-tag error, as angle	20
Root sum square	**163** (0.045 deg)
Requirement SR-2.1	360 (0.100 deg)
Margin	197 arcsec

Pointing error budget for target imaging (3σ)

Control error is the largest term and is allocated to the ADCS control loop in ADCS-001. Star tracker knowledge and the estimation filter error make up the 39 arcsec knowledge allocation of SR-2.6 (ADCS-002, ADCS-003). Alignment measurement and thermo-elastic drift are allocated to the structure and the camera (SR-8.9, PAY-022, PAY-023, STR-011), and the ephemeris and time term to the onboard orbit propagator (ADCS-015) and onboard time (SR-4.7).

9.6 Interfaces

- **IF-02 ADCS Power Line** from the EPS: switched 12 V, rated 10 W.
- **IF-06 ADCS Data Bus** with the C&DH: CAN at 1 Mbps; pointing mode commands, targets, ephemeris, Safe Mode Commands in; attitude, rate, wheel and sensor telemetry and the ancillary attitude stream out.
- **IF-16 Star Tracker Link**, **IF-17 Wheel Drive Link** and **IF-18 Torque Rod Link**: internal links between the ADCS Controller and the star tracker, wheels and torque rods.
- **Mechanical**: the star tracker on the optical bench; the wheels, rods and controller on the Primary Structure.

9.7 Requirements

9.7.1 Pointing and Knowledge

ADCS-001 Control Error · Verify: Analysis, Test · Trace: SR-2.1 · Applies: All

In Target Pointing, the ADCS control error between the estimated and the commanded boresight direction shall not exceed 140 arcsec (3σ) about each cross-boresight axis.

Rationale: 140 arcsec is the control term of the pointing budget, which then totals 163 arcsec (0.045°) against the 360 arcsec of SR-2.1. It covers wheel jitter, friction torques and the controller residual; the TC-04 finding (RK-1) is within this term once zero-speed crossings are avoided (ADCS-007).

ADCS-002 Attitude Estimation Error · Verify: Analysis, Test · Trace: SR-2.6 · Applies: All

In Fine Sun Pointing, Target Pointing and Ground Station Tracking, the attitude estimation filter shall add no more than 25 arcsec (3σ) to the star tracker error about each cross-boresight axis of the camera.

Rationale: 25 arcsec is the filter term of the pointing budget. With the 30 arcsec of star tracker knowledge it gives 39 arcsec, inside the 50 arcsec of SR-2.6. The filter error includes gyro noise between star tracker updates, bias estimation error and the transformation from the star tracker frame to the camera frame.

ADCS-003 Star Tracker Accuracy · Verify: Test · Trace: SR-2.6 · Applies: All

The star tracker shall determine its attitude with an error of no more than 10 arcsec (1σ) about each cross-boresight axis and 60 arcsec (1σ) about its boresight.

Rationale: 10 arcsec 1σ is the 30 arcsec 3σ knowledge term of the pointing budget. The boresight axis error is larger, as for every single-head tracker; with the tracker canted relative to the camera, its boresight error maps only partly onto the camera axes, and the analysis of ADCS-002 includes that mapping.

ADCS-004 Star Tracker Rate Capability · Verify: Test · Trace: SR-2.10, SR-2.6 · Applies: All

The star tracker shall output valid attitude solutions at body rates up to 1.0 deg/s about any axis.

Rationale: The highest rate in a fine pointing mode is in Ground Station Tracking near zenith on an overhead pass, about 0.87 deg/s at 500 km (7.61 km/s over 500 km). Target Pointing rates are lower. During slews above 1.0 deg/s the filter propagates on the gyro and reacquires within the settling period.

ADCS-005 Star Tracker Field Clearance · Verify: Analysis · Trace: SR-2.6, SR-1.6.2 · Applies: All

In Fine Sun Pointing and in Target Pointing up to 25° off nadir, the star tracker boresight shall stay at least 40° from the Sun and at least 25° from the Earth limb.

Rationale: These are the tracker's exclusion angles; inside them it loses its solution. The 30° cant toward +X keeps 27° from the Earth limb in the worst off-nadir roll. Ground Station Tracking is excluded because a pass at low elevation can bring the limb inside 25°; the filter then propagates on the gyro, which is enough for the 5° of SR-2.10 for the few minutes involved.

ADCS-006 Rate Stability During Capture · Verify: Test, Analysis · Trace: SR-2.2 · Applies: All

During each image capture, the ADCS shall hold the boresight angular rate error to no more than 0.007 deg/s (3σ) about each axis.

Rationale: SR-2.2 allows 0.01 deg/s of boresight drift. 0.007 deg/s leaves 0.003 deg/s for deployed array motion and structural modes, which the ADCS does not sense. At 0.007 deg/s the smear across 16 TDI stages (10 ms) is 0.25 arcsec, a small fraction of the 1.9 arcsec pixel.

ADCS-007 Wheel Zero-Speed Avoidance · Verify: Test · Trace: SR-2.1, SR-2.2 · Applies: All

During image capture, the ADCS shall keep the speed of every reaction wheel outside the band from −300 rpm to +300 rpm.

Rationale: The TC-04 errors of 0.14° coincided with wheels crossing zero speed, where friction changes sign (RK-1). Null-space biasing at ±1,500 rpm keeps the wheels clear of the band in normal operation; the requirement makes the protection testable and lets the schedule check reject a capture that would violate it.

9.7.2 Actuators and Slewing

ADCS-008 Wheel Capacity · Verify: Test · Trace: SR-2.4, SR-2.8 · Applies: All

Each reaction wheel shall store at least 10 mNms of angular momentum and deliver at least 1.0 mNm of torque over its speed range at the minimum bus voltage.

Rationale: 10 mNms per wheel gives the 40 mNms total and the 8 mNms per-wheel limit of SR-2.8 at 80 % capacity. A 30° slew in 45 s about the largest axis needs about 0.3 mNm and 6 mNms, so 1.0 mNm per wheel leaves margin for end-of- life torque loss, which is part of TBR-03.

ADCS-009 Wheel Imbalance · Verify: Test · Trace: SR-2.2 · Applies: All

Each reaction wheel shall have a static imbalance of no more than 0.1 g·mm and a dynamic imbalance of no more than 1.0 g·mm².

Rationale: Wheel imbalance forces at the wheel speed are the main source of microvibration at the camera. These limits keep the jitter at the bias speeds below 1 arcsec at the camera in the structural model, a small part of the control error term and of ADCS-006.

ADCS-010 Slew Settling · Verify: Test, Analysis · Trace: SR-2.4, SR-2.2 · Applies: All

After each slew of up to 30°, the ADCS shall settle to within 0.05° of the commanded attitude and to rate errors below 0.007 deg/s within 15 s of the end of the slew profile.

Rationale: SR-2.4 (TBR-03) counts the 60 s from start of slew to the start of the capture, so it includes settling. 45 s of profile plus 15 s of settling meets it; the 0.05° settling band is half the pointing requirement, and the remaining error decays during the capture lead-in.

ADCS-011 Slew With One Wheel Failed · Verify: Analysis, Test · Trace: SR-2.9, SR-2.4 · Applies: All · TBR: TBR-31

With any one reaction wheel failed, the ADCS shall slew 30° about any axis and settle as in ADCS-010 within 90 s [TBR].

Rationale: SR-2.9 requires pointing accuracy and stability with three wheels but accepts a slower slew. With about 11 mNms on the weakest axis the rate limit falls to about 1.0 deg/s; 90 s keeps two targets per imaging window possible. TBR-31 closes with the three-wheel flatsat runs after the friction investigation of RK-1.

ADCS-012 Wheel Failure Reconfiguration · Verify: Test · Trace: SR-2.9, SR-11.6 · Applies: All

The ADCS shall detect a reaction wheel failure from the mismatch between commanded and measured wheel speed and reconfigure to three-wheel control within 60 s without ground command.

Rationale: A wheel that stops or runs away during a capture would otherwise drive the attitude error past the 2.0° Safe Mode trigger (G-AE). Autonomous reconfiguration keeps imaging going until the ground decides whether to keep the wheel off; a wheel shut down by a single-event effect is retried by the ground, not automatically.

ADCS-013 Magnetic Dipole · Verify: Test · Trace: SR-2.3, SR-2.8 · Applies: All

Each magnetorquer shall produce a magnetic dipole of at least 0.4 A·m² at the minimum bus voltage.

Rationale: With an average field of about 30 μT at 500 km, 0.4 A·m² per axis damps 10 deg/s on all three axes in about 2 h in the sizing estimate, inside the 3 h of SR-2.3, and unloads 16 mNms in well under one NI.3 period.

9.7.3 Target Pointing

ADCS-014 Off-Nadir Range · Verify: Test, Analysis · Trace: SR-1.6.2 · Applies: All

In Target Pointing, the ADCS shall point the camera boresight at targets up to 25° off nadir in any direction.

Rationale: SR-1.6.2 requires off-nadir imaging to 25° to fill the gaps between repeat ground tracks. Pointing in any direction, not only cross-track, also lets two targets on adjacent tracks be imaged in one window with a pitch offset.

ADCS-015 Yaw Steering · Verify: Test, Analysis · Trace: SR-1.11, SR-1.2 · Applies: All

In Target Pointing, the ADCS shall align the detector columns with the ground image motion within 0.1° by rotating the spacecraft about the boresight.

Rationale: Without yaw steering the Earth's rotation moves the image across the detector at up to 3.8° from the columns, smearing the TDI image and shifting the four band lines sideways against each other. 0.1° over 16 TDI stages is a sideways smear of 0.03 pixel, and over the 100-row band spacing it is 0.17 pixel, which the ground registration of SR-1.11 removes.

ADCS-016 Onboard Orbit Propagation · Verify: Analysis, Test · Trace: SR-2.1, SR-1.12 · Applies: All

The ADCS orbit propagator shall add no more than 30 m (3σ) to the position error of the uploaded orbit state over 26 h of propagation.

Rationale: The pointing budget allocates 20 arcsec, 48 m at 500 km, to ephemeris and time. 30 m from propagation, the ground orbit determination error and the 14 m of onboard time (SR-4.7) fit inside 48 m root sum square. 26 h covers one daily update plus a missed update window.

ADCS-017 Ancillary Attitude Data · Verify: Test · Trace: SR-1.12, SR-2.6 · Applies: All

During each image capture, the ADCS shall provide the estimated attitude quaternion and body rates to the C&DH at 10 Hz, each sample time-tagged within 1 ms of onboard time.

Rationale: The flight software attaches these samples to the strip (F7.4); the ground interpolates them to each line for geolocation and band registration. 10 Hz resolves attitude motion well above the 0.1 Hz control bandwidth, and 1 ms keeps the timing error at the 7 m along-track level or below.

ADCS-018 Lunar Calibration Scan · Verify: Test · Trace: SR-1.14 · Applies: All

The ADCS shall perform a commanded constant-rate inertial scan about a commanded axis at rates from 0.05 deg/s to 0.8 deg/s with a rate error of no more than 1 %.

Rationale: Lunar images (SR-1.14) are taken by sweeping the camera across the Moon, which does not move with the ground; the scan rate relative to the line rate sets the along-track sampling of the lunar disk. 1 % rate error keeps the lunar irradiance integral within 1 %, the level needed for the 2 % stability trend of SR-1.10.

9.7.4 Detumble and Safe Mode

ADCS-019 Actuator Enable After Separation · Verify: Test · Trace: SR-10.3, SR-8.6 · Applies: All

The ADCS Controller shall drive no torque rod or reaction wheel until the C&DH has sent the actuator enable command after transition T2.

Rationale: The quiet period of SR-10.3 covers actuators as well as deployables and transmitters. Holding the drivers disabled in the controller itself means a controller boot after separation cannot start actuation early, whatever the state of the flight software.

ADCS-020 Rate Damping Independence · Verify: Test, Analysis · Trace: SR-2.3 · Applies: All

Rate Damping shall reduce the body rates from 10 deg/s on each axis to below 0.5 deg/s using only the magnetometer and the torque rods.

Rationale: After separation the wheels and star tracker are off and the power budget is the Detumble load of 14.1 W. B-dot control on the magnetometer alone needs no attitude solution and works at any rate, so it cannot be blocked by a sensor that is saturated or not yet commissioned.

ADCS-021 Rate Sensing Range · Verify: Test · Trace: SR-2.3, SR-2.7 · Applies: All

The rate gyro shall measure body rates up to 20 deg/s about each axis.

Rationale: Tip-off rates can reach 10 deg/s per axis (SR-2.3); 20 deg/s covers the combined rate in any single axis of the gyro with margin, so the tip-off history recorded in Launch mode and the rate condition of T3 are never taken from a saturated sensor.

ADCS-022 Coarse Sun Sensing · Verify: Test, Analysis · Trace: SR-2.7 · Applies: All

Whenever the spacecraft is sunlit, the coarse sun sensors shall determine the Sun direction within 5° (3σ) in any attitude, excluding Earth albedo effects.

Rationale: Six cosine sensors, one per face, cover the full sphere. 5° plus the albedo error (up to about 10° at low Sun angle on the sunlit Earth) stays inside the 20° of SR-2.7 for most of the orbit; in the worst geometry the gyro and magnetometer in the coarse filter carry the attitude until the albedo error falls.

ADCS-023 Safe Mode Sun Acquisition · Verify: Test, Analysis · Trace: SR-10.14, SR-2.7 · Applies: All · TBR: TBR-13

Starting in sunlight with body rates below 2 deg/s, Coarse Sun Pointing shall bring the array normal within 15° of the Sun within 30 min [TBR].

Rationale: This is the ADCS share of SR-10.14 and carries its open item TBR-13. The coarse filter needs about one minute to converge; the rest of the period covers a slew of up to 180° at the reduced rate limit of AP-2 (0.5 deg/s) and settling.

ADCS-024 Eclipse Attitude Hold · Verify: Test, Analysis · Trace: SR-2.7 · Applies: All

In Coarse Sun Pointing during an eclipse of up to 35.8 min, the ADCS shall hold the inertial attitude reached at eclipse entry closely enough that the array normal is within 20° of the Sun at eclipse exit.

Rationale: The Sun direction is fixed in inertial space, so holding the attitude on the gyro through the eclipse keeps the arrays on the Sun at exit without a reacquisition slew. A 1 deg/h gyro bias drifts about 0.6° over the longest eclipse; most of the 20° is the attitude error at entry from the coarse sun sensors. Holding the attitude also prevents a slow tumble from building up over many eclipses.

ADCS-025 Autonomous Pointing Mode Hold · Verify: Test · Trace: SR-2.7, SR-15.2 · Applies: All

The ADCS Controller shall continue the active pointing mode when the C&DH stops communicating, changing to Coarse Sun Pointing after 60 s without a valid message on IF-06.

Rationale: A flight computer reset takes up to 60 s to restore the mode (SR-10.7); continuing the active mode over a short gap avoids an unnecessary slew. A longer silence means the flight computer cannot command, and the Sun-pointing attitude is the safe one for power and for the camera.

9.7.5 Ground Station Tracking

ADCS-026 Ground Station Tracking Error · Verify: Test, Analysis · Trace: SR-2.10 · Applies: All

In Ground Station Tracking above 10° elevation, the ADCS shall keep the downlink antenna boresight within 2° (3σ) of the commanded station direction.

Rationale: SR-2.10 allows 5°; the antenna mounting and alignment take up to 1°, and the remaining margin covers star tracker outages near the Earth limb at low elevation, where the filter propagates on the gyro (ADCS-005).

9.7.6 Resources and Life

ADCS-027 ADCS Power · Verify: Test · Trace: SR-3.9 · Applies: All

The ADCS shall draw no more than 10.0 W from IF-02 in any pointing mode, and no more than 6.0 W averaged over any orbit without slews.

Rationale: The power budget carries 1.0 W for the controller and sensors, 1.8 W for the star tracker, 2.0 W for the wheels and 1.2 W for the rods at full dipole, 6.0 W in all; the 4.0 W slew increment brings the peak to 10.0 W, the rating of IF-02. Rods and slews do not run at the same time in NI.2, so the peak is not reached in imaging.

ADCS-028 ADCS Mass · Verify: Test · Trace: SR-8.2, SR-8.4 · Applies: All

The ADCS mass, comprising the four reaction wheels, the star tracker, the three magnetorquers and the controller and sensors, shall not exceed 1.254 kg.

Rationale: 1.254 kg is the sum of the ADCS lines of the mass budget with contingency: wheels 0.536 kg, star tracker 0.360 kg, magnetorquers 0.231 kg and controller with sensors 0.127 kg.

ADCS-029 Wheel and Star Tracker Life · Verify: Analysis, Test · Trace: SR-15.9, SR-1.7 · Applies: All

Each reaction wheel and the star tracker shall have a predicted or demonstrated life of at least 1,460 days of continuous operation in the orbit environment.

Rationale: SR-15.9 requires twice the 730-day use. The wheels run continuously from commissioning, so their bearing life is the critical item; the star tracker's limiting item is the detector's radiation degradation. The prediction uses the supplier's life test data at the bias speeds.

9.8 Verification Approach

ADCS verification relies on the flatsat (FS-1, FS-3) with the ADCS engineering model in the loop, on unit tests of the sensors and actuators, and on analysis with the spacecraft dynamics simulation. The existing system test cases apply as follows: **TC-04 Pointing Accuracy Test** (ADCS-001, ADCS-002, ADCS-006, ADCS-007, ADCS-015), **TC-05 Detumble Simulation** (ADCS-013, ADCS-020, ADCS-021) and **TC-17 Slew Time Analysis** (ADCS-008, ADCS-010, ADCS-011). Four ADCS test cases are added: **TC-34 Reaction Wheel Microvibration and Friction Test** measures imbalance forces, torque capability and friction torque at low speed for each flight wheel (ADCS-008, ADCS-009, ADCS-007, ADCS-029); **TC-35 Star Tracker Night-Sky and Stimulator Test** measures accuracy on the night sky and rate capability with a star field stimulator (ADCS-003, ADCS-004); **TC-36 ADCS Hardware-in-the-Loop Mode Test** runs every pointing mode and mode change on the flatsat, including Safe Mode Sun acquisition, eclipse attitude hold, loss of the C&DH link, wheel failure reconfiguration, yaw steering, lunar scans and ground station tracking (ADCS-010 to ADCS-012, ADCS-014 to ADCS-019, ADCS-022 to ADCS-026); and **TC-37 Magnetic Dipole and Magnetometer Calibration Test** measures the rod dipoles and the magnetometer

response in a field coil facility (ADCS-013, ADCS-020). Star tracker field clearance (ADCS-005) is verified by analysis of the attitude profiles over a year of targets; power and mass (ADCS-027, ADCS-028) by measurement in TC-36 and at integration.

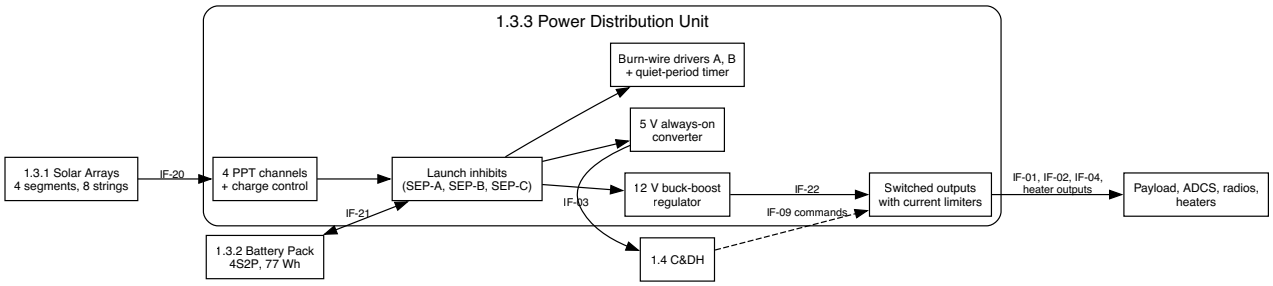
10 EPS Specification

This chapter specifies the Electrical Power Subsystem (EPS, product 1.3): the Solar Arrays (1.3.1), the Battery Pack (1.3.2) and the Power Distribution Unit (1.3.3). It describes how power is generated, stored, regulated, distributed and protected, includes the generation and energy budgets, and states the EPS requirements EPS-001 to EPS-028. The power consumed in each mode is given in the power budget tables of the Budgets chapter and is not repeated here. The EPS is identical in EO-1 Flight and EO-1 Lite.

The EPS performs F3 Generate and Store Power: F3.1 Convert Sunlight to Power (Solar Arrays), F3.2 Store Battery Energy (Battery Pack) and F3.3 Regulate Bus Power (Power Distribution Unit). The PDU also performs F10.2 Shed Non-Essential Loads on the Safe Mode Commands from the C&DH. In the logical architecture the three parts realize L1 Power Generation, L2 Energy Storage and L3 Power Conditioning and Distribution.

10.1 Architecture

The EPS is a peak-power-tracking system with a regulated 12 V main bus. The arrays feed four independent peak power tracking (PPT) channels in the PDU (IF-20). The PPT channels charge the battery directly (IF-21); the battery voltage, between 12.0 V and 16.8 V, is the input of two converters: a buck-boost converter that makes the regulated 12 V main bus (IF-22), and a 5 V converter for the always-on line to the C&DH (IF-03). The buck-boost topology keeps the bus in regulation over the whole battery range, including the region below 12.24 V where a buck converter would drop out of regulation.



EPS power flow: arrays, PPT channels, battery, converters and outputs

10.2 Power Generation

10.2.1 Solar Arrays

The two deployable array panels carry 72 triple-junction cells of 27.8 cm² each, 0.20 m² in total, with a beginning- of-life efficiency of 29.5 % at 28 °C. Each panel is a hinged pair of segments (inner and outer, Structure and Mechanisms Specification); each segment carries two strings of nine cells, so the arrays have eight strings in all. Each string has a blocking diode, and each cell a

bypass diode, so a shadowed or open cell costs only its own string's output. The two strings of a segment feed one PPT channel; the four channels are independent, so a failed channel loses a quarter of the array power and nothing more.

The string maximum power voltage is about 21 V at 28 °C and stays above 17 V at the hot operating limit, above the 16.8 V maximum battery voltage, so each PPT channel is a buck converter. The open-circuit voltage at eclipse exit, with the arrays at their coldest, reaches about 31 V; the PPT inputs are rated for 35 V.

Array power is delivered over IF-20 (Array Power). The deployed arrays face +X, the zenith direction in target imaging and the Sun direction in Sun pointing (IF-23 Sunlight Path).

10.2.2 Generation Budget

The generation budget derives the orbit-average power from the cell area and efficiency, the sunlit fraction of the bounding orbit and the attitude profile of the Nominal Imaging design case.

Parameter	Value
Cell area	0.2 m ^ 2
Cell efficiency (BOL, 28 C)	0.295
Solar constant	1361 W/m ^ 2
Sun incidence angle on the deployed arrays	0.35 rad (20 deg)
Peak array power, BOL	75.4 W
End-of-life factor (radiation 0.95, temperature 0.93)	0.883
Peak power tracking efficiency	0.96
Sunlit fraction (bounding case)	0.622
Attitude factor (imaging and downlink pointing)	0.83
Orbit-average power, BOL	**37.4 W**
Orbit-average power, EOL	**33.0 W**

Solar array generation budget

The 33.0 W end-of-life orbit average meets the 30 W of SR-3.1 with 10 % margin. In the Sun-pointing attitude of Safe Mode the attitude factor is close to one, which gives about 40 W at end of life against the 20 W of SR-3.10.

10.3 Energy Storage

10.3.1 Battery Pack

The Battery Pack has eight cylindrical 18650-format lithium-ion cells in a 4S2P arrangement: four series groups of two parallel cells. Each cell holds at least 2.68 Ah, so the pack stores at least 77 Wh at 14.4 V nominal. The pack voltage ranges from 12.0 V (3.0 V per cell, the hardware undervoltage disconnect of SR-3.11) to 16.8 V (4.2 V per cell); the PDU charges to 16.4 V (4.10 V per cell) [TBR-33] to extend cycle life. The flight software undervoltage threshold for Safe Mode is 12.8 V (6.4 V per series cell pair, 3.2 V per cell).

The cells come from one manufacturing lot, are screened by capacity, internal resistance and self-discharge, and are matched within 2 % in each parallel pair. A protection board on the pack carries the cell group voltage sensing, passive balancing of the four series groups, two cell temperature sensors, an overvoltage and undervoltage cut-off independent of the PDU, a current trip and the pack fuse. The battery heaters and their thermostats are part of Thermal Control Hardware (1.6.3); the battery temperature limits are in the Thermal Control Specification (minimum battery temperature TBD-01, SR-3.5).

10.3.2 Energy Budget

The energy budget gives the battery energy used in the worst-case eclipse: the 35.8 min longest eclipse of the reference orbit, with the battery and structure heaters on and one downlink pass in eclipse.

Configuration	Load with cont.	Bus load	Generation EOL	Margin	Eclipse energy from battery	Depth of discharge
EO-1 Lite	22.5 W	25.0 W	33.0 W	32.1 %	17.7 Wh	23 %
EO-1 Flight	22.5 W	25.0 W	33.0 W	32.0 %	17.7 Wh	23 %

Eclipse energy and depth of discharge, Nominal Imaging design case

The 17.7 Wh eclipse energy is a 23 % depth of discharge of the 77 Wh beginning-of-life capacity, against the 30 % limit of SR-3.3. At the 59 Wh end-of-life capacity of SR-15.8 the same eclipse is a 30 % depth of discharge; the battery is therefore sized by end of life, and capacity fade beyond 23 % would force the operators to reduce the eclipse load (RK-2).

10.4 Power Distribution

10.4.1 Regulated Bus and Always-On Line

The 12 V main bus is regulated within 2 % (11.76 V to 12.24 V) at the PDU output terminals. It feeds every switched output except the 5 V always-on line, which supplies the C&DH from its own converter at 5 V ± 3 % and has no switch: the C&DH is powered whenever the battery or the arrays can supply the PDU and the launch inhibits are released. The always-on line is rated for the IF-03 rating of 7 W, which covers the C&DH compression burst of up to 6.5 W.

10.4.2 Switched Outputs

The PDU switches each load on command from the C&DH over the Power Telemetry Link (IF-09). The outputs are listed below. Each switched output has a latching current limiter; its trip level is about 125–150 % of the output rating.

Output	Load	Interface	Rating	Trip level	Safe Mode	Hardware undervoltage disconnect
AO-1	C&DH, 5 V always-on	IF-03	7 W	1.8 A	On	On

Output	Load	Interface	Rating	Trip level	Safe Mode	Hardware undervoltage disconnect
SW-1	Payload Camera	IF-01	15 W	1.6 A	Off	Off
SW-2	ADCS (controller, wheels, rods, star tracker)	IF-02	10 W	1.1 A	On	Off
SW-3	UHF Transceiver	IF-04	7 W	0.75 A	On	On (receiver only)
SW-4	Payload downlink radio	IF-04	15 W	1.6 A	Off	Off
SW-5	Payload thermal control heater	Heater output	2 W	0.25 A	Off	Off
SW-6	Battery heaters, thermostat-controlled	Heater output	2 W	0.25 A	On	Off
SW-7	Structure heaters, thermostat-controlled	Heater output	3 W	0.35 A	On	Off
BW-A, BW-B	Burn-wire circuits A and B, three channels each (two array hold-downs, UHF antenna)	Deployment harness	10 W per channel for up to 15 s	1.2 A	Safed	Off

PDU outputs

SW-3 and SW-4 are the two branches of the IF-04 Radio Power Line, whose combined rating is 18 W [TBR-70] (Interface Requirements chapter); on EO-1 Flight the UHF transmitter is not used while the X-band radio transmits, so the branches never draw more than that together. The UHF Transceiver output (SW-3) is the one load that the hardware undervoltage disconnect keeps powered, in receive-only mode, so the ground can still command recovery (SR-3.11); the flight software can still power-cycle it (SM.6). The heater outputs SW-6 and SW-7 are enabled at separation and stay enabled unless the ground disables them; their thermostats switch the heaters (SR-9.5). The burn-wire drivers are powered only through the launch inhibits and the PDU's hardware quiet-period timer, in addition to the flight software's arm and fire commands.

10.4.3 Power Telemetry and Control

The C&DH polls the PDU once per second over IF-09 (I2C, 400 kbps). Each poll returns the battery voltage and current, the four cell group voltages, the two battery temperatures, the array current of each PPT channel, the bus voltage, the current and state of each output, the limiter trip flags and

the estimated state of charge. The PDU computes the state of charge by counting charge, reset to full at each end of charge, and sets a depth-of-discharge flag when the estimate passes 30 %. The flight software's undervoltage test (guard G-UV) uses the battery voltage of these polls.

10.5 Protection

The EPS protects the battery, the bus and the loads at several levels, from fast hardware action to flight software response:

Condition	First response	Second response
Overcurrent on a switched output	PDU current limiter opens the output within 10 ms; automatic retry (latch-up recovery)	Flight software reports the trip and keeps the output off after the retries
Battery undervoltage, 12.8 V	Flight software enters Safe Mode within 10 s (SR-4.3; 15 s under deviation until FSW 2.4)	—
Battery undervoltage, 12.0 V	PDU disconnects all switched outputs except the UHF receiver, without software (SR-3.11)	Battery protection board cut-off at 11.2 V
Overcharge	PDU charge regulator limits the voltage to the end-of-charge set point	Battery protection board cut-off at 17.0 V; cell internal current interrupt device
External short circuit at the pack	Battery protection board current trip	Pack fuse; cell internal positive temperature coefficient device
Charging below 0 °C	PDU charge inhibit from the battery temperature sensors, in hardware (SR-3.7)	Flight software Safe Mode on G-BT
Total loss of battery energy	PDU restarts from array power and restores the C&DH and UHF receiver (SR-3.12)	—

EPS protection levels

Launch inhibits. Three separation switches give the three independent inhibits of SR-13.1 while the spacecraft is in the dispenser (ICD-041): SEP-A and SEP-B break the battery's positive and return lines to the PDU, so the PDU, the C&DH and every load are unpowered, and SEP-C breaks the enable line of the transmitter outputs and the burn-wire drivers inside the PDU, a third break that does not depend on the other two. The remove-before-flight pin opens the battery line during ground handling and is removed before loading. The switches' mechanical design is in the Structure and Mechanisms Specification.

Quiet-period timer. A hardware timer in the PDU, started when the inhibits release, holds the burn-wire drivers disabled for 30 min and the transmitter outputs (SW-3 transmit enable and SW-4) disabled for 45 min, independently of the flight software's separation timer. A software fault therefore cannot deploy or transmit early.

Passivation. At end of mission the PDU opens the battery charge path permanently on an armed ground command (SR-14.9), by blowing a fusible link between the PPT channels and the battery. The battery is then discharged through the loads to the passivation level (Operational Modes, Decommissioned).

Grounding. The power return is connected to the structure at a single point in the PDU. All loads have isolated secondary converters or return their current through the harness, not through the structure.

10.6 Interfaces

- **IF-20 Array Power**, **IF-21 Battery Power** and **IF-22 Regulated Bus** inside the EPS.
- **IF-01, IF-02, IF-04** (switched 12 V) and **IF-03** (5 V always-on) to the loads; heater and burn-wire outputs through the harness (EO1-ICD-200).
- **IF-09 Power Telemetry Link** with the C&DH: telemetry, load switch commands and Safe Mode Commands.
- **IF-23 Sunlight Path** from the orbit environment to the arrays.
- **IF-15 / IF-19**: the separation switches SEP-A, SEP-B and SEP-C are in the inhibit path, and the remove-before-flight switch in the battery line (Structure and Mechanisms Specification).
- A ground support connector, reachable before dispenser loading only, for battery charging and bus monitoring; there is no electrical connection to the dispenser (SR-12.7).

10.7 Requirements

10.7.1 Generation

EPS-001 Solar Cell Efficiency · Verify: Test · Trace: SR-3.1 · Applies: All

Each solar cell, assembled with its cover glass and interconnects, shall have a conversion efficiency of at least 29.5 % at beginning of life, at 28 °C under the air mass zero spectrum at 1,361 W/m².

Rationale: 29.5 % is the efficiency in the generation budget. Stating it for the assembled cell puts the cover glass and interconnect losses in the cell, so that only harness and conversion losses remain for the 0.90 efficiency of the power budget. Verified on lot acceptance samples with a calibrated solar simulator.

EPS-002 Array Cell Area · Verify: Inspection · Trace: SR-3.1 · Applies: All

The two array panels shall carry at least 0.20 m² of active solar cell area in total.

Rationale: 72 cells of 27.8 cm² give 0.2002 m², the cell area of the generation budget. Together with EPS-001 it fixes the 75.4 W peak and the 33.0 W end-of-life orbit average.

EPS-003 Panel Peak Power · Verify: Test · Trace: SR-3.1 · Applies: All

At beginning of life, each array panel shall deliver at least 40.1 W at its connector under normal incidence at 1,361 W/m² and 28 °C.

Rationale: 0.1 m² × 1,361 W/m² × 0.295 gives 40.15 W per panel; at the budget's 20° incidence the two panels give the 75.4 W peak. The measured value is the starting point of the end-of-life prediction of SR-3.1 (TC-06).

EPS-004 Peak Power Tracking Efficiency · Verify: Test · Trace: SR-3.1 · Applies: All

Each PPT channel shall transfer at least 96 % of the available array maximum power to the battery and bus over the array operating voltage range.

Rationale: 96 % is the peak power tracking efficiency of the generation budget. The figure combines tracking accuracy (finding the maximum power point as temperature and illumination change) and converter efficiency; it is measured with a solar array simulator in TC-40.

EPS-005 Array Failure Containment · Verify: Analysis, Test · Trace: SR-3.1, SR-15.2 · Applies: All

A short or open circuit in any one cell, string or PPT channel shall reduce the array output by no more than 25 %, with no effect on the other channels.

Rationale: With four independent channels the worst single failure loses one segment. 25 % below the 33.0 W end-of- life average leaves 24.8 W, just under the 25.0 W design-case bus load: the operators then reduce the number of strips or passes per orbit, but the spacecraft stays power-positive in every mode with the Safe Mode load.

10.7.2 Storage

EPS-006 Battery Cell Capacity · Verify: Test · Trace: SR-3.2 · Applies: All

Each of the eight battery cells shall have a capacity of at least 2.68 Ah at C/2 discharge and 20 °C, with the two cells of each parallel pair matched within 2 %.

Rationale: Four series groups of two 2.68 Ah cells at 14.4 V nominal give the 77 Wh of SR-3.2. Matching keeps the current shared evenly in each pair, so neither cell ages faster than the other (RK-2).

EPS-007 End-of-Charge Voltage · Verify: Test · Trace: SR-15.8, SR-3.2 · Applies: All · TBR: TBR-33

The PDU shall end constant-voltage charging at a pack voltage of 16.4 V [TBR], adjustable by command between 16.0 V and 16.8 V in steps of no more than 0.1 V.

Rationale: Charging to 4.10 V per cell instead of 4.20 V gives up about 7 % of capacity but slows the capacity fade over about 11,100 cycles. 77 Wh is stated at full charge (SR-3.2); early in the mission the worst-case eclipse is about 25 % depth of discharge at 16.4 V. As the capacity fades, the operators raise the set point toward 16.8 V so that the full end-of-life capacity of SR-15.8 is available. TBR-33 closes with the cell cycle test (TC-41).

EPS-008 Charge Current Limit · Verify: Test · Trace: SR-15.8, SR-13.2 · Applies: All

The PDU shall limit the battery charge current to 2.7 A (C/2).

Rationale: At peak array power the surplus over the loads could charge at more than 3 A; C/2 is the cell maker's recommended maximum for cycle life and keeps the cell heating small. The PPT channels move off the maximum power point when the limit is reached.

EPS-009 Cell Cycle Life · Verify: Test, Analysis · Trace: SR-15.8, SR-3.3 · Applies: All

Cells of the flight lot shall retain enough capacity for the pack to store at least 59 Wh after 11,100 charge and discharge cycles at 30 % depth of discharge and 20 °C.

Rationale: 11,100 cycles is the 730-day mission at 15.22 orbits per day; 59 Wh is the end-of-life capacity of SR-15.8. The test runs on cells from the flight lot at an accelerated cycle rate with the flight end-of-charge voltage (TC-41).

EPS-010 State of Charge Estimation · Verify: Test · Trace: SR-3.3 · Applies: All

The PDU shall estimate the battery state of charge within ±3 % of capacity and set a depth-of-discharge flag in its telemetry whenever the estimated depth of discharge exceeds 30 %.

Rationale: The battery voltage alone does not show depth of discharge in the flat middle of the lithium-ion discharge curve. The estimate lets the planners check each plan against the 30 % limit of SR-3.3 (SR-10.22), and the flag gives the verification criterion of SR-3.3: no flag in any test orbit.

EPS-011 Hardware Cold Charge Inhibit · Verify: Test · Trace: SR-3.7, SR-13.2 · Applies: All

The PDU shall inhibit battery charging, without flight software action, whenever either of the two battery temperature sensors reads below 0 °C.

Rationale: Charging below 0 °C plates lithium (SR-3.7, HAZ-001). A hardware inhibit works after a flight computer reset and in the first orbits after separation, when the battery is coldest. Using either sensor makes the inhibit fail safe if one sensor fails warm.

EPS-012 Battery Hazard Controls · Verify: Test, Inspection · Trace: SR-13.2 · Applies: All

The EPS shall provide two independent hardware controls against each of battery overcharge, overdischarge and external short circuit, as listed in the table EPS protection levels.

Rationale: HAZ-001 battery thermal runaway is a catastrophic hazard in ground processing and on the launch vehicle, so each cause needs two controls that do not share a failure. The flight software undervoltage test is not counted as one of them, and the cells' internal devices are an additional layer.

EPS-013 Storage Drain · Verify: Test · Trace: SR-11.10 · Applies: All

While the launch inhibits are active, the total current drawn from the battery shall not exceed 50 μA.

Rationale: 50 μA over 180 days is 0.22 Ah, 4 % of the pack capacity; with cell self-discharge of about 2 % per month the pack keeps more than 60 % state of charge after 180 days if loaded at 80 % or more (SR-11.10). The drain is the protection board's quiescent current; nothing else is connected.

10.7.3 Distribution

EPS-014 Bus Regulation Range · Verify: Test · Trace: SR-3.4 · Applies: All

The PDU shall hold the main bus between 11.76 V and 12.24 V for any battery voltage from 12.0 V to 16.8 V and any total load up to 50 W, including load steps of up to 15 W.

Rationale: This is SR-3.4 stated over the PDU's input and load range. 50 W is the IF-22 rating; the design-case peak demand at the load terminals is 33.8 W (an X-band pass in eclipse, Interface Requirements chapter). The 15 W step is the camera switching to Capture or the X-band radio starting to transmit (TC-18, TC-38).

EPS-015 Always-On Line · Verify: Test, Inspection · Trace: SR-3.12, SR-4.3 · Applies: All

The PDU shall supply the C&DH at 5 V ± 3 % up to 7 W on the always-on line, with no means of switching it off by command.

Rationale: The C&DH runs fault management and the separation timer; it must stay powered whenever the PDU is. 7 W is the IF-03 rating, which covers the 6.5 W compression burst. Only the launch inhibits, a total loss of battery energy and passivation remove this supply.

EPS-016 Switched Output Set · Verify: Test, Inspection · Trace: SR-10.13, SR-3.8 · Applies: All

The PDU shall provide the switched outputs listed in the table PDU outputs, each with its rating and switched on and off individually by command over IF-09.

Rationale: Individual switching is what makes the Safe Mode load set of SR-10.13 possible and lets the ground isolate a faulty unit. The ratings are the interface ratings of IF-01, IF-02 and IF-04 and the heater and burn-wire loads.

EPS-017 Conversion Efficiency · Verify: Test · Trace: SR-3.9 · Applies: All

From the PPT channel inputs to the output terminals, the EPS shall have an efficiency of at least 90 % at the design-case Nominal Imaging load, including the PDU's own consumption of no more than 1.5 W.

Rationale: The power budget converts the 22.5 W load with contingency to the 25.0 W bus load with an efficiency of 0.90 and carries 1.5 W of PDU overhead. A lower efficiency would consume the 12 % margin against the 28 W allocation of SR-3.9.

EPS-018 Single-Point Ground · Verify: Inspection, Test · Trace: SR-11.8 · Applies: All

The EPS shall connect the primary power return to the spacecraft structure at a single point in the PDU.

Rationale: A single reference point keeps the PPT and converter switching currents out of the structure, where they would couple into the camera's analog electronics and the magnetometer; it supports the 6 dB EMC margin of SR-11.8.

10.7.4 Protection

EPS-019 Output Current Limiting · Verify: Test · Trace: SR-3.8, SR-15.2 · Applies: All

Each switched output shall open within 10 ms when its current exceeds its trip level, while the bus stays within 11.76 V to 12.24 V at the other outputs.

Rationale: This is the PDU's share of SR-3.8. A trip level of 125 % to 150 % of rating avoids nuisance trips on inrush; 10 ms is short enough that the bus capacitance holds the other outputs in regulation through the fault.

EPS-020 Latch-Up Recovery · Verify: Test · Trace: SR-11.6 · Applies: All

After a current limiter trip, the PDU shall re-enable the output after 1 s, up to three times within 60 s, and then hold it off until commanded.

Rationale: Most trips in orbit are single-event latch-ups that clear when power is removed; automatic retry brings the unit back within the 60 s of SR-11.6 without the ground. A hard short trips three times and stays off, so it cannot load the bus repeatedly.

EPS-021 Hardware Undervoltage Disconnect · Verify: Test · Trace: SR-3.11 · Applies: All

The PDU shall disconnect the switched outputs listed for disconnection in the table PDU outputs when the battery voltage falls below 12.0 V ± 0.1 V, reconnecting them only on command with the battery above 13.6 V.

Rationale: This implements SR-3.11 in the PDU hardware. Requiring a command and a recharged battery for reconnection prevents the outputs from cycling on and off at the threshold as the battery recovers under load.

EPS-022 Autonomous Restart · Verify: Test · Trace: SR-3.12 · Applies: All

With the battery fully discharged, the PDU shall start from array power alone and restore the always-on line and the UHF receiver within 10 min of the arrays receiving at least 30 % of full illumination.

Rationale: A spacecraft whose battery drained after a long tumble must restart itself (SR-3.12). 30 % covers a partly sun-facing tumbling attitude. Battery charging resumes only when the cold charge inhibit allows it (EPS-011), so a frozen battery is not charged.

EPS-023 Launch Inhibit Chain · Verify: Inspection, Test · Trace: SR-13.1 · Applies: All

The PDU shall route the battery positive line through separation switch SEP-A, the battery return line through SEP-B and the enable line of every transmitter output and burn-wire driver through SEP-C.

Rationale: This is the EPS side of SR-13.1 and ICD-041: three series breaks, each able on its own to keep every transmitter and deployment actuator unpowered in the dispenser. Breaking the return as well as the positive line keeps a single short to structure from bypassing the inhibits. The storage drain of EPS-013 is on the battery side of them.

EPS-024 Hardware Quiet-Period Timer · Verify: Test · Trace: SR-8.6, SR-11.9 · Applies: All

From the release of the launch inhibits, a PDU hardware timer shall hold the burn-wire drivers disabled for at least 30 min and the transmitter outputs disabled for at least 45 min, independently of the flight software.

Rationale: The flight software's separation timer already enforces both quiet periods (SR-10.3, SR-10.4); the hardware timer makes a software fault unable to deploy or transmit early, a protection rideshare providers commonly ask for. Its tolerance is set so the periods are never shorter than 30 min and 45 min.

EPS-025 Permanent Charge Path Disconnect · Verify: Test · Trace: SR-13.5 · Applies: All

On an armed ground command, the PDU shall permanently open the charge path between the PPT channels and the battery.

Rationale: SR-13.5 requires the battery to be disconnected from the arrays for good at end of mission (HAZ-004). A fusible link cannot close again; the arm and fire sequence of SR-14.9 protects it from an inadvertent command. The link and its driver are tested on qualification units; flight units are inspected and their driver tested into a dummy load.

10.7.5 Telemetry and Resources

EPS-026 Power Telemetry · Verify: Test · Trace: SR-4.3, SR-3.3 · Applies: All

The PDU shall report over IF-09 at least once per second the battery voltage within ±50 mV, the battery and output currents within ±2 % of reading or ±10 mA, and the battery temperatures within ±1 °C.

Rationale: The undervoltage guard G-UV compares the battery voltage with 12.8 V; ±50 mV keeps the threshold error small against the 0.8 V between the software and hardware thresholds. Once per second leaves most of the 10 s of SR-4.3 for persistence (2 s) and the Safe Mode entry.

EPS-027 EPS Mass · Verify: Test · Trace: SR-8.2, SR-8.4 · Applies: All

The EPS mass, comprising the two array panels, the Battery Pack and the PDU, shall not exceed 1.411 kg.

Rationale: 1.411 kg is the sum of the EPS lines of the mass budget with contingency: Solar Arrays 0.464 kg, Battery Pack 0.639 kg and PDU 0.308 kg. The array hinges and hold-downs are counted under 1.6 Structure and Thermal.

EPS-028 Battery Pack Mass · Verify: Test · Trace: SR-8.2 · Applies: All

The Battery Pack, including its protection board, housing and harness pigtail, shall not exceed 0.639 kg.

Rationale: The pack is a measured item in the mass budget (0.62 kg with 3 % contingency); a separate limit keeps a change of cell type or housing, a likely response to RK-2, from going unnoticed inside the EPS total.

10.8 Verification Approach

EPS verification uses the existing tests **TC-06 Solar Array Power Test** (flash test of each panel and the end-of- life prediction; EPS-001 to EPS-003), **TC-07 Battery Capacity Test** (EPS-006, EPS-028) and **TC-18 Bus Regulation Inspection** (EPS-014, EPS-015), and four new test cases. **TC-38 PDU Protection and Load Step Test** applies load steps, overcurrents and shorts on every output,

sweeps the battery voltage through both undervoltage thresholds and checks the restart from array power (EPS-014, EPS-016, EPS-019 to EPS-022, EPS-026). **TC-39 Battery Hazard Control Test** demonstrates each hazard control independently on a qualification pack, including cold charge inhibit and storage drain (EPS-008, EPS-011 to EPS-013). **TC-40 Power System Orbit Simulation Test** runs the EPS on the flatsat with a solar array simulator through 50 design-case orbits, including the worst-case eclipse, and measures tracking efficiency, conversion efficiency, state of charge accuracy and depth of discharge (EPS-004, EPS-010, EPS-017). **TC-41 Battery Cell Cycle Life Test** cycles flight-lot cells at 30 % depth of discharge to the equivalent of the mission (EPS-007, EPS-009). The inhibit chain and the quiet-period timer (EPS-023, EPS-024) are verified in TC-45 with the separation switches. Array failure containment (EPS-005) and grounding (EPS-018) are verified by analysis and inspection, the passivation link (EPS-025) on the qualification PDU.

11 Structure and Mechanisms Specification

This chapter specifies the Primary Structure (product 1.6.1) and the Deployment Mechanisms (1.6.2) of the EO-1 Spacecraft. It defines the spacecraft body frame used by all subsystem chapters, describes the 6U frame, the optical bench, the materials, the deployable array panels and UHF antenna with their hold-downs and hinges, and the separation and inhibit switches, and states the requirements STR-001 to STR-024. The third part of 1.6, Thermal Control Hardware (1.6.3), is specified in the Thermal Control Specification.

The structure performs F2 Deploy Solar Arrays (with the UHF antenna release) and carries the mechanical side of the Dispenser Adapter Interface (IF-15) and the Deployment Switch Harness (IF-19). It is identical in EO-1 Flight and EO-1 Lite, except for the mounting plate of the payload downlink radio, which differs in its hole pattern and radiator cut-out.

11.1 Body Frame and Layout

The spacecraft body frame is fixed to the Primary Structure, with its origin at the geometric center of the stowed envelope:

- **+X** along the long axis (366 mm), the direction of ejection from the dispenser. The deployed array panels face +X. In target imaging +X points to the zenith; in Sun pointing it points at the Sun.
- **−X** end face (226.3 × 100 mm): the Payload Camera aperture, the payload downlink antenna (S-band patch on EO-1 Lite, X-band patch array on EO-1 Flight) and the UHF antenna module. In target imaging −X points at nadir.
- **+Y** completes the right-handed frame with **+Z** normal to the large face that carries the stowed panel on its outside. The star tracker looks out through a cut-out in the +Y side panel.

The Payload Camera fills the −X third of the volume, mounted with the star tracker on a common optical bench. The middle third holds the C&DH, the PDU, the ADCS Controller, the reaction wheels and the radios; the +X third holds the Battery Pack, the magnetorquers and the deployment mechanisms. The mass is distributed so that the center of mass stays near the geometric center with the dense camera at one end (SR-8.3).

11.2 Primary Structure

The Primary Structure is a machined aluminum frame of four rails joined by two end frames and a mid-frame, with bolted side panels:

- **Rails.** Four rails of 7075-T7351 aluminum along X, hard anodized on the dispenser contact surfaces. The rails are the only contact with the dispenser (IF-15). The three separation switches sit in the −X rail ends, where the dispenser pusher plate holds them depressed.
- **Frames and panels.** End frames and mid-frame of 6061-T6 aluminum; side panels of 6061-T6, 1.5 mm thick with machined stiffening ribs. The ±Z panels carry the stowed array panels on standoffs; their outer surfaces carry the thermal coatings (Thermal Control Specification).

- **Optical bench.** A titanium alloy (Ti-6Al-4V) plate in the −X third, carried on three flexures that isolate it from frame distortion. The Payload Camera sits on three titanium bipods on the bench, and the star tracker on a titanium bracket on the same bench, so that their relative alignment depends on the bench alone (SR-8.9).
- **Radio mounting plate.** An aluminum plate in the middle third, conducting the radio's heat to its radiator area on the −Z panel. The bay beside it is the volume studied for propulsion (Propulsion Specification).
- **Fasteners.** A286 stainless steel or titanium fasteners in stainless steel helical inserts, all with a secondary locking feature.

The structure is grounded to the PDU single-point ground through the bonding of its parts (STR-012).

11.3 Deployment Mechanisms

11.3.1 Array Panels

Each of the two array panels is a hinged pair of segments of 340 × 220 mm, an inner and an outer segment, with the cells of the Solar Arrays (1.3.1) on one face. A panel is stowed on its ±Z face, inner segment against the side panel with its cells facing outward and the outer segment folded over it with its cells facing inward, separated by snubbers. The substrates are aluminum honeycomb with CFRP face sheets.

On release, the inner segment swings 90° about the **root hinge** at the +X edge of its face, and the outer segment unfolds 180° about the **segment hinge** at the far edge of the inner segment. The deployed panels form a flat array normal to +X beyond the +X end of the body, about 226 mm wide and 1.5 m long along Z. Each hinge has stainless steel torsion springs, a spring-loaded latch pin that locks the deployed position, and a deployment switch. The root hinges have viscous rotary dampers that keep the latching shock low.

11.3.2 Hold-Downs

Each array panel is held stowed by one burn-wire hold-down at its −X end, which clamps both segments to the side panel through a tensioned cord of ultra-high-molecular-weight polyethylene. The UHF antenna has a third hold-down of the same design. In each hold-down the cord crosses two nichrome resistor elements, one on burn-wire circuit A and one on circuit B; energizing either element melts the cord (SR-8.7). Both cut ends stay held in captive fittings, so the release frees no object (SR-13.7).

The PDU drives the hold-downs (burn-wire outputs BW-A and BW-B, EPS Specification) on commands from the flight software, through the launch inhibits and the PDU quiet-period timer. The UHF antenna is released at 30 min after separation and the arrays at 35 min, the timer option of TBR-02 (Operational Modes, DT.2).

11.3.3 UHF Antenna

The UHF antenna (1.5.4) is a turnstile of four spring-steel tape elements stowed wound in a holder on the −X end face. Releasing its hold-down lets the elements unroll to their deployed length; a switch at the root of each element reports it deployed. Its RF design is in the Communications Specification; this chapter covers its stowage and release.

11.3.4 Separation and Inhibit Switches

Three separation switches (SEP-A, SEP-B, SEP-C) in the −X rail ends are held depressed by the dispenser pusher plate while the spacecraft is loaded and are released at separation. They are the three launch inhibits of SR-13.1: SEP-A and SEP-B break the battery's positive and return lines, SEP-C the enable line of the transmitter and burn-wire outputs (EPS-023, ICD-041). Each switch has a second pole that reports its state to the C&DH over IF-19, so the flight software can debounce the separation event (SM.13). A remove-before-flight switch, actuated by a flagged pin through the ground support access port, opens the battery line during ground handling; the pin is removed as the last step before dispenser loading, so it is not counted as a flight inhibit.

Mechanism or switch	Quantity	Actuation	Status sensing	Interface
Array root hinge	2	Torsion springs, latch pin, rotary damper	Deployment switch at latch	IF-19
Array segment hinge	2	Torsion springs, latch pin	Deployment switch at latch	IF-19
Array hold-down	2	Burn-wire, two resistor elements (circuits A and B)	Through the hinge switches	Burn-wire outputs
UHF antenna hold-down	1	Burn-wire, two resistor elements	Deployment switch on each of the four elements	IF-19
Separation switch (SEP-A, SEP-B, SEP-C)	3	Plunger, depressed by the dispenser pusher plate	Second switch pole	IF-15, IF-19
Remove-before-flight switch	1	Ground-removed pin	Ground check through the umbilical	Ground support connector

Deployment mechanisms and switches

11.4 Mass of Structure and Mechanisms

The mass budget carries one line for product 1.6, 3.60 kg current best estimate and 3.96 kg with the 10 % contingency of a calculated item. This specification splits that line into allocations for its three parts:

Part	Current best estimate	Allocation with contingency
1.6.1 Primary Structure (frame, rails, panels, optical bench, fasteners)	2.950 kg	3.245 kg
1.6.2 Deployment Mechanisms (hinges, hold-downs, switches)	0.350 kg	0.385 kg

Part	Current best estimate	Allocation with contingency
1.6.3 Thermal Control Hardware (coatings, MLI, heaters, thermostats, thermistors, radiator)	0.300 kg	0.330 kg
1.6 Structure and Thermal	**3.600 kg**	**3.960 kg**

Mass allocation within product 1.6

11.5 Interfaces

- **IF-15 Dispenser Adapter Interface** with the rideshare dispenser: rails, rail ends, separation switches, the stowed envelope and the mass properties (EO1-ICD-230).
- **IF-19 Deployment Switch Harness** to the C&DH: deployment and separation switch states.
- Burn-wire circuits A and B from the PDU, part of the Harness (1.7).
- Mechanical mounting of every unit, and the optical bench interface to the Payload Camera and star tracker (EO1-ICD-200).

11.6 Requirements

11.6.1 Envelope and Dispenser Interface

STR-001 Stowed Envelope Dimensions · Verify: Inspection · Trace: SR-8.1 · Applies: All

In the stowed configuration, the spacecraft, excluding the permitted protrusions, shall fit within 226.3 mm (Y) by 100.0 mm (Z) by 366.0 mm (X).

Rationale: These are the 6U envelope dimensions of SR-8.1 as stated in EO1-ICD-230. They include the stowed array panels, which lie within the envelope on standoffs.

STR-002 Rail Interface · Verify: Inspection · Trace: SR-8.1, SR-12.7 · Applies: All

The four rails shall be hard anodized on all dispenser contact surfaces, with a surface roughness of no more than 1.6 μm Ra, and be the only parts of the spacecraft that touch the dispenser.

Rationale: The rails slide along the dispenser guides at ejection; a hard, smooth surface prevents galling and cold welding, and an insulating anodize keeps the spacecraft electrically isolated from the dispenser (SR-12.7).

STR-003 Protrusions · Verify: Inspection · Trace: SR-8.1 · Applies: All · TBR: TBR-40

No part of the stowed spacecraft other than the rails shall extend more than 6.5 mm [TBR] beyond the rail contact planes, and only within the protrusion zones of EO1-ICD-230.

Rationale: The stowed array panels, hold-downs and UHF antenna holder are the protrusions. 6.5 mm is the allowance of the dispensers under consideration; TBR-40 closes when the launch vehicle and dispenser are assigned (RK-3).

11.6.2 Stiffness and Strength

STR-004 Stowed Frequency Design Margin · Verify: Analysis, Test · Trace: SR-8.5 · Applies: All

The finite element model of the stowed spacecraft, constrained at its rails, shall predict a first natural frequency of at least 120 Hz.

Rationale: SR-8.5 requires 100 Hz by test. 20 % over the requirement covers the usual difference between an uncorrelated model and the first sine survey, so the test meets 100 Hz without redesign. The lowest predicted mode is the stowed panel stack against its standoffs.

STR-005 Bonded and Composite Joint Strength · Verify: Analysis, Test · Trace: SR-11.2 · Applies: All

Bonded joints and composite parts of the structure and the array substrates shall show a positive margin of safety under the limit loads with a factor of safety of at least 1.5 on ultimate.

Rationale: ENV-001 sets the factors of safety for the structure as a whole (1.25 on yield and 1.4 on ultimate when verified by test). Bonds and composites have a wider strength scatter and no yield point, so they carry a higher ultimate factor; the optical bench flexure bonds, the CFRP face sheets of the array substrates and the hinge inserts are the parts concerned.

STR-006 Mass Properties Determination · Verify: Test · Trace: SR-8.3, SR-2.4 · Applies: All

The center of mass of each flight spacecraft shall be measured within ±1 mm in each axis, and its moments of inertia within ±5 %, in the stowed and the deployed configuration.

Rationale: The center of mass is checked against the dispenser limits of SR-8.3 (4.0 cm transverse, 7.0 cm along X); the inertia sets the ADCS control gains and the slew time of SR-2.4. The deployed values are computed from the stowed measurement and the measured panel masses and hinge positions.

STR-007 Primary Structure Mass · Verify: Test · Trace: SR-8.2, SR-8.4 · Applies: All

The Primary Structure, including the optical bench, the radio mounting plate and all fasteners, shall not exceed 3.245 kg.

Rationale: 3.245 kg is the 1.6.1 allocation within the 3.96 kg line for product 1.6 (table Mass allocation within product 1.6), 2.950 kg current best estimate with 10 % contingency.

STR-008 Deployment Mechanisms Mass · Verify: Test · Trace: SR-8.2, SR-8.4 · Applies: All

The Deployment Mechanisms, comprising the hinges, hold-downs and switches, shall not exceed 0.385 kg.

Rationale: 0.385 kg is the 1.6.2 allocation within the 3.96 kg line for product 1.6, 0.350 kg current best estimate with 10 % contingency. The array substrates are counted with the Solar Arrays (1.3.1).

11.6.3 Materials and Construction

STR-009 Structural Materials · Verify: Inspection · Trace: SR-15.5, SR-11.7 · Applies: All

Structural parts shall be made only of materials on the program's approved materials list, with no pure tin, cadmium or zinc finishes and with every nonmetallic material meeting the outgassing limits of SR-11.7.

Rationale: SR-15.5 and SR-11.7 apply to the whole spacecraft; the structure carries most of its finishes, adhesives, lubricants and the hold-down cord, so the materials list is checked here part by part (ECSS-Q-ST-70-71C is the selection basis).

STR-010 Fastener Locking · Verify: Inspection · Trace: SR-11.1, SR-13.7 · Applies: All

Every fastener shall have a secondary locking feature (locking insert, locking nut, safety wire or staking compound) in addition to its installation torque.

Rationale: Random vibration (SR-11.1) loosens preloaded joints; a lost fastener inside the dispenser or in orbit is also a released object (SR-13.7).

STR-011 Optical Bench Stability · Verify: Analysis, Test · Trace: SR-8.9 · Applies: All

The optical bench shall keep the orientation between the Payload Camera mounting interface and the star tracker mounting interface within 50 arcsec (3σ) of its ground-measured value over the on-orbit temperature range and after launch loads.

Rationale: The 60 arcsec thermo-elastic allocation of SR-8.9 is shared between the camera's internal line-of-sight drift (30 arcsec, PAY-023) and the bench (50 arcsec), 58 arcsec root sum square. The titanium bench, its isolating flexures and its thermal control (THM-007) carry this; optical misalignment in thermal cycling is risk RK-7.

STR-012 Bonding Provisions · Verify: Inspection · Trace: SR-11.8 · Applies: All

Every unit mounting face and every structural joint shall have a bare, conductive-finish contact area, masked from anodizing and paint, of at least 1 cm² per fastener.

Rationale: ENV-020 requires at most 10 mΩ per bond and per joint. Anodized aluminum is an insulator, so the structure must provide the conductive contact areas by design; the masking is specified on each part drawing and inspected before assembly. The rail contact surfaces stay fully anodized to isolate the spacecraft from the dispenser (STR-002).

STR-013 Vent Direction · Verify: Inspection, Analysis · Trace: SR-11.7, SR-1.10 · Applies: All

No vent of an enclosed volume shall exhaust within 45° of the Payload Camera boresight or the star tracker boresight or toward the −X end face.

Rationale: ENV-006 sets the vent areas. Gas vented during ascent and outgassing in orbit carries molecular contaminants that condense on the coldest surfaces in their path; directing every vent away from the aperture and the star tracker baffle protects the calibration (SR-1.10) beyond the material limits of SR-11.7.

11.6.4 Deployment Mechanisms

STR-014 Hold-Down Release · Verify: Test · Trace: SR-8.7, SR-3.6 · Applies: All

Each hold-down shall release within 15 s of either of its two resistor elements being energized at the minimum burn-wire supply voltage of 11.0 V, over the temperature range from −20 °C to +50 °C.

Rationale: SR-8.7 requires release by either circuit. The flight software fires circuit A first and circuit B if the deployment switches do not confirm within 30 s, so a release time of 15 s per circuit keeps the whole sequence well inside the 10 min between the 35 min array release and the 45 min limit of SR-3.6.

STR-015 Stowed Restraint · Verify: Test, Analysis · Trace: SR-8.5, SR-11.1 · Applies: All

Each hold-down shall hold its stowed panel or antenna without gapping or slipping at the snubbers under the qualification loads, with a cord preload of at least twice the highest predicted separating load.

Rationale: A panel that rattles on its snubbers under vibration lowers the stowed frequency (SR-8.5) and wears the cells and the cord. The factor of two covers cord creep over months in the dispenser (SR-11.10).

STR-016 Captured Release Line · Verify: Inspection, Test · Trace: SR-13.7 · Applies: All

After release, both ends of every cut hold-down cord shall remain held by the spacecraft.

Rationale: SR-13.7 forbids released objects. Each cord is terminated in captive fittings on both sides of the resistor elements; the deployment tests check that no fragment leaves the spacecraft.

STR-017 Deployment Torque Margin · Verify: Test, Analysis · Trace: SR-3.6 · Applies: All

The spring torque of each hinge shall be at least twice the worst-case resistive torque over its whole travel, at the temperature extremes of deployment.

Rationale: A factor of two over friction, damper drag, harness bending and latch forces at the coldest predicted deployment temperature is common practice for spring-driven deployments. A hinge that stalls part-way would leave the arrays at an angle the ADCS and the power budget do not support.

STR-018 Deployed Geometry · Verify: Test, Inspection · Trace: SR-3.1, SR-2.7 · Applies: All

Once latched, each deployed array segment shall have its cell normal within 2° of +X.

Rationale: The generation budget and the Sun pointing of SR-2.7 assume the panel normal is the spacecraft +X axis. 2° costs less than 0.1 % of array power and is inside the 15° acquisition band of Safe Mode.

STR-019 Deployed Stiffness · Verify: Test, Analysis · Trace: SR-8.8, SR-2.2 · Applies: All · TBR: TBR-41

The latched hinges shall give each deployed array panel a first natural frequency of at least 2.5 Hz [TBR] about each hinge axis.

Rationale: SR-8.8 requires 2 Hz for the deployed spacecraft; 2.5 Hz for the panel on its hinges leaves margin for the coupling with the body. The value is TBR until the latched stiffness of the engineering-model hinges is measured.

STR-020 Deployment Status Sensing · Verify: Test · Trace: SR-10.5, SR-3.6 · Applies: All

Each array hinge and each UHF antenna element shall report its deployed state to the C&DH by a switch that changes state only when the hinge is latched or the element fully deployed.

Rationale: The Detumble exit condition (SR-10.5) and the redundant firing logic need a positive indication of each deployable. Sensing the latch, not the start of motion, distinguishes a fully deployed panel from one that stopped part-way.

11.6.5 Switches and Ground Handling

STR-021 Separation Switches · Verify: Test, Inspection · Trace: SR-13.1, SR-8.6 · Applies: All

The three separation switches shall be held in their inhibiting state while the rails are seated in the dispenser and change state within 50 ms of the spacecraft leaving the dispenser.

Rationale: The separation switches are the three launch inhibits (SR-13.1) and start the separation timer that times the 30 min and 45 min quiet periods. Their plunger travel and force are defined in EO1-ICD-230; a clean change of state within 50 ms lets the flight software debounce the event without delaying it.

STR-022 Remove-Before-Flight Switch · Verify: Test, Inspection · Trace: SR-13.2, SR-13.1 · Applies: All

The remove-before-flight switch shall hold its inhibiting state while its pin is inserted and be reachable for pin removal with the spacecraft fully integrated and ready for dispenser loading.

Rationale: The pin keeps the battery disconnected during integration and ground handling, when the separation switches are not depressed (HAZ-001, HAZ-002). It is removed only as the last step before loading, after the inhibit check (Mission Overview and Concept of Operations, pre-launch); access through the ground support port allows this without touching the stowed panels.

STR-023 Ground-Handling Restraint · Verify: Inspection, Test · Trace: SR-13.1, SR-3.6 · Applies: All

The structure shall accept a removable ground-support restraint on each array panel and on the UHF antenna that prevents deployment even if the hold-down releases.

Rationale: An inadvertent release during integration and test can injure personnel and damage the panels (HAZ-002). The flagged restraints are fitted whenever the spacecraft is handled outside a deployment test and removed with the remove-before-flight pin.

STR-024 Ground Support Access · Verify: Inspection · Trace: SR-12.7 · Applies: All

The structure shall give access to the ground support connector for battery charging and bus monitoring through a covered port that is inaccessible once the spacecraft is in the dispenser.

Rationale: The spacecraft has no electrical interface to the dispenser (SR-12.7), so charging and checkout end at loading. A covered port that the dispenser walls block prevents any connection being made or left in place after loading.

11.7 Verification Approach

The structure is qualified on FM-1 under the protoflight approach. **TC-42 Structural Qualification Test** performs sine surveys before and after each test axis, sine burst or static loading to the quasi-static level, random vibration (levels per SR-11.1, TBD-17) and the separation shock test; the first mode is confirmed at or above 100 Hz and its shift between surveys stays within 5 % (STR-004, STR-005, STR-015, with the factors of ENV-001). **TC-43 Mass Properties Measurement** weighs each flight spacecraft and measures its center of mass and inertia (STR-006 to STR-008). **TC-19 Array Deployment Test** deploys the panels and the UHF antenna on a zero-gravity fixture at ambient and, as **TC-44 Deployment Mechanism Thermal and Redundancy Test**, at the cold and hot deployment temperatures in a thermal chamber, firing each resistor element alone at the minimum supply voltage and measuring torque margin, latch geometry and latched stiffness (STR-014, STR-016 to STR-020). **TC-45 Inhibit and Separation Switch Test** verifies with a dispenser fit-check fixture that each separation switch alone keeps the transmitter and burn-wire outputs unpowered, that the switches change state at release and that the PDU quiet-period timer holds deployment and transmission (STR-021, STR-022, EPS-023, EPS-024). The optical bench

stability (STR-011) is verified by thermo-elastic analysis and by the camera-to-star-tracker alignment measurements before and after TC-42 and in thermal vacuum. The remaining requirements are verified by inspection and analysis.

12 Thermal Control Specification

This chapter specifies the thermal control of the EO-1 Spacecraft and its hardware, Thermal Control Hardware (product 1.6.3): coatings, multilayer insulation, heaters, thermostats, thermistors and the payload radiator. It describes the thermal design approach, gives the temperature limits of every unit and the design cases, and states the requirements THM-001 to THM-017. The system thermal requirements it refines are SR-9.1 to SR-9.6 and SR-3.5. The minimum battery temperature remains open as TBD-01 (SR-3.5).

Thermal control has no function of its own in the functional architecture; it supports F3.2 Store Battery Energy and F7.1 Prepare Focal Plane and keeps every unit within its limits while the other functions run.

12.1 Approach

The thermal design is passive, with heaters for the battery, the structure and the payload focal plane:

- **Radiators and coatings.** The outer surfaces of the side panels are anodized aluminum with areas of white paint that act as radiators. Three radiators serve units with high or time-varying dissipation: the **payload radiator** on the +Y side panel of the −X third, next to the star tracker cut-out, which takes the heat of the detector through a copper strap and the camera electronics through their mounting; the **radio radiator** on the −Z panel, which takes the heat of the payload downlink radio and is uncovered when the −Z array panel deploys; and the **avionics radiator** on the −Y panel for the C&DH and the PDU. Attitude planning keeps the +Y face on the side away from the Sun in imaging and contact attitudes (the planner chooses the yaw orientation accordingly), so the payload radiator and the star tracker look at cold space.
- **Insulation.** Multilayer insulation wraps the telescope tube and baffle and covers the inside of the −X end face around the aperture. The Battery Pack sits on titanium standoffs with a multilayer insulation wrap, so that its temperature is set by its heaters and a small conductive path to the frame rather than by the external panels.
- **Heaters.** Film heaters on the Battery Pack (1.5 W) and on the optical bench and the wheel and avionics mounting areas of the frame (2.0 W, the “structure heaters”) are switched by bimetallic thermostats and enabled from the PDU outputs SW-6 and SW-7 at separation. Together they are the 3.5 W “battery and structure heaters” of the power budget, at 60 % duty in Nominal Imaging and 80 % in Detumble and Safe Mode. The 1.5 W **payload thermal control heater** on the detector carrier and the telescope metering structure is controlled by the flight software from thermistor readings (PDU output SW-5), at 60 % duty in Nominal Imaging.
- **Sensing.** Thermistors on every unit and on the panels, read by the C&DH and the PDU, give the temperature telemetry and the inputs for the software-controlled heater and the Safe Mode trigger G-BT.

The spacecraft has no louvers, heat pipes or other active thermal hardware. The thermal design is analyzed with a thermal network model of the spacecraft and its orbit; the environment parameters (solar flux, albedo, Earth infrared, β-angle range of the reference orbit) are those of the Environments chapter.

12.2 Temperature Limits

The table gives the operating and non-operating limits of each unit. “Operating” applies while the unit is powered and performing its function; “non-operating” applies while it is unpowered, including Launch mode and the units switched off in Safe Mode. The design keeps predictions 10 °C inside the operating limits (SR-9.1).

Unit	Operating min	Operating max	Non-operating min	Non-operating max	Notes
Payload Camera detector (focal plane)	+18 °C	+22 °C	−20 °C	+40 °C	Capture limits (SR-9.2); +15 °C to +25 °C in Standby
Telescope (mirrors, metering structure)	+15 °C	+25 °C	−20 °C	+40 °C	Axial gradient below 2 °C in capture (SR-9.3)
Camera electronics	−10 °C	+40 °C	−30 °C	+60 °C	
Optical bench	+10 °C	+30 °C	−20 °C	+40 °C	Alignment measured at +20 °C
Star Tracker	−20 °C	+50 °C	−30 °C	+60 °C	
Reaction wheels	−20 °C	+50 °C	−30 °C	+60 °C	
Magnetorquers	−30 °C	+70 °C	−40 °C	+80 °C	
ADCS Controller and Sensors	−20 °C	+60 °C	−30 °C	+70 °C	
Coarse sun sensors	−40 °C	+85 °C	−50 °C	+100 °C	
Solar array panels	−90 °C	+100 °C	−100 °C	+110 °C	Deployment between −20 °C and +50 °C (STR-014)
Battery Pack, discharge	[TBD-01]	+30 °C	−10 °C	+30 °C	Charging only at or above 0 °C (SR-3.7); maximum 30 °C in all modes (SR-9.4)
Power Distribution Unit	−20 °C	+60 °C	−40 °C	+85 °C	

Unit	Operating min	Operating max	Non-operating min	Non-operating max	Notes
Flight Computer and Payload Data Storage	−20 °C	+60 °C	−40 °C	+85 °C	
UHF Transceiver	−20 °C	+60 °C	−30 °C	+70 °C	
S-band Transmitter (Lite)	−20 °C	+50 °C	−30 °C	+70 °C	
X-band Payload Radio (Flight)	−10 °C	+45 °C	−30 °C	+65 °C	
UHF Antenna and Deployment Mechanisms	−20 °C	+50 °C	−40 °C	+80 °C	Operating range applies to release and deployment

Unit temperature limits

12.3 Design Cases

The environment of the cold and hot cases (solar flux, albedo, Earth infrared, beta angle, surface properties) is defined in the Environments chapter (table Thermal design cases, ENV-007). The thermal analysis applies it to the spacecraft states below; the cold and hot survival and operational cases bound every mode that lasts longer than an orbit, and the Detumble and Launch cases cover the transients after separation.

Case	Mode and dissipation	Environment	Surface properties	Main purpose
Hot operational	Nominal Imaging design case: eight 40 s strips, one payload downlink pass, heaters as needed	Hot case	End of life	Radio, avionics and battery maximum temperatures
Cold operational	Nominal Imaging with one imaging window, no pass	Cold case	Beginning of life	Battery minimum, focal plane and telescope heater capacity
Cold survival	Safe Mode, Sun-pointing hold (SA.2), heaters on thermostats	Cold case	Beginning of life	Non-operating limits with 3.5 W of heater power (SR-9.6)
Detumble	Detumble load, tumbling at up to 10 deg/s, arrays stowed then deployed	Cold and hot cases	Beginning and end of life	First hours after separation, before Sun pointing
Launch	Unpowered in the dispenser, then the first 30 min after separation	Dispenser environment of EO1-ICD-230	Beginning of life	Battery and camera non-operating limits at separation

Thermal design cases

12.4 Interfaces

Thermal Control Hardware has no interface ids of its own. Its heaters are supplied from the PDU outputs SW-5, SW-6 and SW-7 and its thermistors are read by the C&DH and the PDU through the Harness (EO1-ICD-200); its radiators and insulation are mounted on the Primary Structure and the Payload Camera.

12.5 Requirements

12.5.1 Unit Temperatures

THM-001 Operating Temperature Limits · Verify: Analysis, Test · Trace: SR-9.1 · Applies: All

In the hot and cold operating cases, the thermal design shall keep each powered unit within the operating limits of the table Unit temperature limits.

Rationale: The table is the set of limits that SR-9.1 applies its 10 °C analysis margin to. The limits come from each unit's specification; for the battery the lower operating limit is the open minimum battery temperature of SR-3.5 (TBD-01).

THM-002 Non-Operating Temperature Limits · Verify: Analysis · Trace: SR-9.6, SR-11.10 · Applies: All

In the cold survival, Detumble and Launch cases, the thermal design shall keep each unpowered unit within the non-operating limits of the table Unit temperature limits.

Rationale: The camera, star tracker and payload downlink radio are off in Safe Mode; in the dispenser and the first 30 min after separation nothing is heated except by the thermostats after the inhibits release. These cases set the heater capacity and the insulation of the camera and battery (SR-9.6).

THM-003 Thermal Model Resolution · Verify: Inspection · Trace: SR-9.1, SR-9.3 · Applies: All

The spacecraft thermal model shall represent each unit of the table Unit temperature limits by at least one node, the telescope metering structure by at least ten axial nodes and the Battery Pack by at least one node per cell.

Rationale: The model is correlated to the thermal balance test within 3 °C (ENV-008), but correlation can only confirm what the model resolves. The telescope gradient of SR-9.3 and the cell-to-cell difference of THM-009 are differences of a few degrees and need nodes along the tube and in the pack to be predicted at all.

12.5.2 Payload Thermal Control

THM-004 Focal Plane Temperature Control · Verify: Test, Analysis · Trace: SR-9.2 · Applies: All

The payload radiator, the detector thermal strap and the payload thermal control heater shall hold the detector at 20 °C ± 2 °C during capture in both the hot and the cold operating cases.

Rationale: The radiator is sized so that, in the hot case with the heater off, the detector would settle near 16 °C; the heater then controls it up to 20 °C at about 60 % duty, the value in the power budget. In the cold case the 1.5 W heater has enough capacity to reach 20 °C before the first strip of an imaging window.

THM-005 Focal Plane Stability During a Strip · Verify: Test · Trace: SR-9.2, SR-1.10 · Applies: All

During any strip of up to 54 s, the detector temperature shall change by no more than 0.3 °C.

Rationale: The detector dissipates more in Capture than in Prepare, so its temperature tends to rise during a strip. The ground corrects dark offset with the temperature in the line headers (PAY-017), but a slow change keeps the dark offset tracking the masked reference pixels within a line and keeps calibration consistent (N6).

THM-006 Telescope Temperature and Gradient · Verify: Analysis, Test · Trace: SR-9.3, SR-1.2 · Applies: All

During capture, the thermal design shall keep the telescope metering structure at 20 °C ± 3 °C with an axial temperature difference below 2 °C.

Rationale: The gradient limit is SR-9.3. The bulk temperature range keeps the focus shift from temperature within the 5 μm term of the payload focus budget (PAY-005). Multilayer insulation with an effective emittance of about 0.03 around the tube and baffle, and the heater share on the metering structure, hold both.

THM-007 Optical Bench Temperature · Verify: Analysis, Test · Trace: SR-8.9 · Applies: All

In all operating modes, the thermal design shall keep the optical bench within 20 °C ± 5 °C and the temperature difference across it below 3 °C.

Rationale: The camera-to-star-tracker alignment is measured with the bench at 20 °C. The bench's thermo-elastic drift allocation of 50 arcsec (STR-011) is calculated for these limits; the structure heaters on the bench keep it from cooling in Safe Mode and long Sun-pointing periods.

12.5.3 Battery

THM-008 Battery Heater Set Points · Verify: Test · Trace: SR-3.5 · Applies: All · TBD: TBD-01

The battery heater thermostats shall close at 3 °C above the minimum battery temperature [TBD] and open at 8 °C above it.

Rationale: The heater set point is what keeps the battery at or above the minimum battery temperature of SR-3.5. A closing point 3 °C above the limit covers thermostat tolerance and the temperature difference between the thermostat and the coldest cell; the 5 °C dead band limits heater cycling. Both values follow TBD-01.

THM-009 Battery Temperature Uniformity · Verify: Test, Analysis · Trace: SR-15.8, SR-3.2 · Applies: All

The temperature difference between any two battery cells shall not exceed 3 °C in any mode.

Rationale: Cells at different temperatures age at different rates and drift apart in capacity, which the passive balancing of the protection board can only partly correct (RK-2). An aluminum cell holder that conducts heat between the cells and heaters spread over both sides of the pack keep the difference small.

THM-010 Battery Maximum Temperature · Verify: Analysis, Test · Trace: SR-9.4 · Applies: All

In the hot operational case with charging at the 2.7 A limit, the thermal design shall keep every battery cell at or below 30 °C.

Rationale: SR-9.4 sets 30 °C in all modes; the highest cell temperatures occur at the end of a sunlit period with full charge current after a downlink pass in eclipse. The conductive path from the battery to the frame is sized for this case and for the cold case together, which is why its standoffs are titanium rather than aluminum.

12.5.4 Heaters

THM-011 Survival Heater Thermostats · Verify: Test, Inspection · Trace: SR-9.5, SR-15.2 · Applies: All

Each battery and structure heater circuit shall be switched by two thermostats in series and have a second, independently switched heater element on the same surface.

Rationale: SR-9.5 requires survival heating without flight software. Two thermostats in series protect against one thermostat failing closed, which would overheat the battery; the second element covers a thermostat or heater failing open. The two elements are on separate thermostat pairs.

THM-012 Heater Power · Verify: Analysis, Test · Trace: SR-9.6, SR-3.9 · Applies: All

The thermal design shall need no more than 3.5 W of battery and structure heater power in any case and no more than 1.5 W of payload heater power in the operating cases.

Rationale: 3.5 W and 1.5 W are the heater powers of the power budgets, at the duty cycles shown there (battery and structure 60 % in Nominal Imaging, 80 % in Detumble and Safe Mode; payload 60 %); SR-9.6 limits Safe Mode survival to the same 3.5 W.

12.5.5 Payload Downlink Radio

THM-013 X-band Radio Pass Temperature · Verify: Analysis, Test · Trace: SR-9.1, SR-5.5 · Applies: Flight

In the hot operational case, the X-band Payload Radio shall stay at or below +35 °C at the end of two 7 min passes separated by one orbit.

Rationale: The radio dissipates about 13 W while transmitting (15.0 W input, 2 W RF) on a small mounting plate. +35 °C is the +45 °C operating limit less the 10 °C margin of SR-9.1. Two consecutive passes are the worst case of the three-station network; the radio radiator on the −Z panel cools the unit between them.

THM-014 S-band Transmitter Pass Temperature · Verify: Analysis, Test · Trace: SR-9.1, SR-5.1 · Applies: Lite

In the hot operational case, the S-band Transmitter shall stay at or below +40 °C at the end of two 9 min passes separated by one orbit.

Rationale: The transmitter dissipates about 10.5 W while transmitting (11.5 W input, 1 W RF) for the longer S-band pass. +40 °C is the +50 °C operating limit less 10 °C. The same radio radiator serves both configurations.

12.5.6 Contamination, Telemetry and Surfaces

THM-015 Decontamination Heating · Verify: Test, Demonstration · Trace: SR-1.10, SR-11.7 · Applies: All

On ground command, the thermal design shall hold the telescope and the detector at +30 °C ± 2 °C with the camera in its Decontamination state, the payload heater at full duty and the payload radiator turned toward the Earth.

Rationale: Warming the optics and focal plane above the surrounding structure drives off molecular contamination that would otherwise condense on the coldest optical surface and reduce the response (SR-1.10). The radiator is sized to cool the detector, so the 1.5 W heater alone cannot reach +30 °C; turning the radiator toward the Earth's infrared (the opposite yaw orientation, with no imaging) removes most of its heat loss. It is used in commissioning step C5 (outgassing hold) and when the response monitor shows a contamination trend; the camera tolerates 200 h at this temperature (PAY-021).

THM-016 Temperature Telemetry · Verify: Inspection, Test · Trace: SR-9.1, SR-6.9 · Applies: All

The spacecraft shall carry at least 24 thermistors, including at least one on each unit of the table Unit temperature limits, two on the Battery Pack and two on the detector carrier, each read with an accuracy of ±1 °C between −40 °C and +85 °C.

Rationale: Every limit in the table needs a measurement for the ground's out-of-limit checks (SR-6.9) and for the correlation of the flight model. The detector carrier thermistors used by the heater control are calibrated more closely (±0.2 °C, PAY-017).

THM-017 Radiator Surface Properties · Verify: Test, Inspection · Trace: SR-9.1, SR-1.7 · Applies: All

At beginning of life, the radiator coatings shall have a hemispherical emittance of at least 0.85 and a solar absorptance of no more than 0.20.

Rationale: With the end-of-life increase of at most 0.05 allowed by ENV-015, the hot case uses an absorptance of 0.25 on the radiators. The values are measured on witness samples painted with each flight panel.

12.6 Verification Approach

The thermal design is verified by analysis with the thermal network model, correlated by test. **TC-46 Thermal Balance Test** places FM-1 in a thermal vacuum chamber with heater plates simulating the external fluxes of the hot and cold operating cases and the cold survival case, measures the steady-state temperatures for model correlation (THM-001, THM-002, THM-006, THM-007, THM-010; correlation per ENV-008) and runs simulated imaging windows and downlink passes for the transients (THM-004, THM-005, THM-013, THM-014). It is followed by the thermal vacuum cycling of SR-11.4. **TC-47 Heater and Thermostat Functional Test** checks the polarity, resistance, thermostat set points and redundancy of every heater circuit and the software control of the payload heater, at ambient and in thermal vacuum (THM-008, THM-011, THM-012, THM-015). Battery uniformity (THM-009) is measured during TC-46 and TC-07. The decontamination state is also run in the camera-level test TC-33. Thermistor coverage and accuracy (THM-016) and the model resolution (THM-003) are verified by inspection and calibration records, and the radiator properties (THM-017) by measurements on witness samples.

13 Propulsion Specification

Neither EO-1 Flight nor EO-1 Lite carries propulsion. This chapter records the result of the propulsion study (EO1-RPT-440, Propulsion Study) so that the reasons for the exclusion stay with the specification, and lists what a later configuration would have to change to add it. **This chapter contains no binding requirements.** The PROP requirement prefix is reserved; no PROP requirements are issued in this revision, and no product number is assigned to a propulsion element. SR-13.9 (no pressure vessels, propellants or pyrotechnic devices) applies to both configurations.

13.1 Study Summary

The study examined a cold-gas thruster module for two purposes:

- **Orbit maintenance.** Holding the altitude, and with it the 3-day ground-track repeat of SR-1.6.1 (TBR-01), against atmospheric drag over the 730-day mission.
- **End-of-mission lowering.** A retrograde burn before passivation to shorten the time to reentry (SR-13.4).

The module considered stores a liquefied propellant at its vapor pressure and expels it through a heated valve and a nozzle. Its main characteristics, as estimated in the study, are:

Characteristic	Estimate
Mass with contingency, including propellant	0.80 kg
Propellant mass	0.12 kg
Specific impulse	about 65 s
Thrust	about 10 mN
Total impulse	about 75 N·s
Velocity change for the EO-1 Flight spacecraft	about 6.8 m/s
Power	about 2 W while firing; propellant heater about 0.5 W orbit average
Volume	about 0.4 U, with the nozzle on an external face

Cold-gas module characteristics assumed in the propulsion study

13.2 Why It Is Not Included

Accommodation. The only free volume large enough for the module is the bay beside the X-band Payload Radio (Structure and Mechanisms Specification, radio mounting plate). Fitting the module there would take the part of the −Z panel that serves as the radio radiator, and the radio's pass temperature limits (THM-013) could no longer be met without a new radiator location. The same bay exists in EO-1 Lite beside the S-band Transmitter, with the same conflict.

Mass. Adding 0.80 kg takes both configurations below the system margin of SR-8.4 (10 % of the 12.0 kg allocation, 1.20 kg):

Configuration	Launch mass with contingency	With propulsion	Margin against 12.0 kg
EO-1 Flight	10.55 kg	11.35 kg	0.65 kg (5.4 %)
EO-1 Lite	10.40 kg	11.20 kg	0.80 kg (6.7 %)

Effect of the propulsion module on the mass margin

Benefit. At 500 km the benefit is small. The ground-track drift from drag over a growing season is absorbed by replanning the imaging windows, so the revisit of SR-1.6 does not depend on holding the repeat exactly. The 6.8 m/s available would lower the perigee by about 25 km, a modest reduction of the time to reentry, and the natural decay from 500 km already meets the disposal requirements of the Safety, Space Debris and Disposal area without a burn.

Safety and launch. A propellant tank is a pressure vessel. Carrying it would change SR-13.9 and add a pressure system to the rideshare safety review, against the simple safety case that rideshare compatibility (N8) relies on.

Propulsion remains an option for a later configuration at a lower altitude, where drag is higher and a ground-track repeat cannot be held by replanning alone.

13.3 What Adding Propulsion Would Require

The list below is not binding. It records the changes the study identified, so that a later configuration starts from them.

1. **Requirements baseline.** Change SR-13.9 to permit the propulsion module; add a PROP requirement area covering total impulse, thrust, minimum impulse bit, thrust vector alignment, propellant leak rate, maximum expected operating pressure with proof and burst factors from the rideshare user's guide, and propellant temperature limits; add an orbit maintenance requirement in area 1 and a disposal maneuver option in area 13.
2. **Mass.** Recover at least 0.55 kg on EO-1 Flight (0.40 kg on EO-1 Lite) elsewhere to restore the 10 % margin of SR-8.4, or accept a waiver under EO1-PLN-350.
3. **Accommodation and thermal.** Move the payload downlink radio's radiator to another panel or reduce the radio duty per pass, and add heater control to keep the propellant within its temperature limits.
4. **Safety.** Three independent inhibits on the valve drive while in the dispenser, as for the transmitters and deployables (SR-13.1); firing permitted only after commissioning and only as an armed critical command (SR-14.9); a pressure system hazard added to the System Hazard Analysis (EO1-RPT-420).
5. **ADCS.** Firing attitudes and a disturbance torque budget for thrust misalignment within the reaction wheel capacity; momentum unloading after each burn.
6. **Operations and ground.** Orbit maintenance planning in flight dynamics (2.2), burn commanding procedures and post-burn orbit determination.
7. **Verification.** Proof pressure and leak tests at module and spacecraft level, a functional firing test, and materials compatibility with the propellant.

14 Command and Data Handling Specification

This chapter specifies the Command and Data Handling element (1.4) as hardware: the Flight Computer (1.4.1) and the Payload Data Storage (1.4.2). The Flight Software (1.4.3) that runs on it is specified in the next chapter. The C&DH realizes three logical elements of the System Architecture chapter: L4 Onboard Command Processing, L5 Payload Data Management and L6 Fault Management. It performs F8 Store Payload Data and F10 Enter Safe Mode, and it carries out the mode activities SM.1, SM.3, SM.4, SM.6, SM.8 and SM.10 to SM.13 of Operational Modes.

The C&DH is identical in EO-1 Flight and EO-1 Lite. The only configuration difference at the C&DH is which payload data port is connected: IF-08 to the S-band Transmitter (Lite) or IF-08.1 to the X-band Payload Radio (Flight). Both ports are present on every unit, so one C&DH design and one spares pool serve the product line.

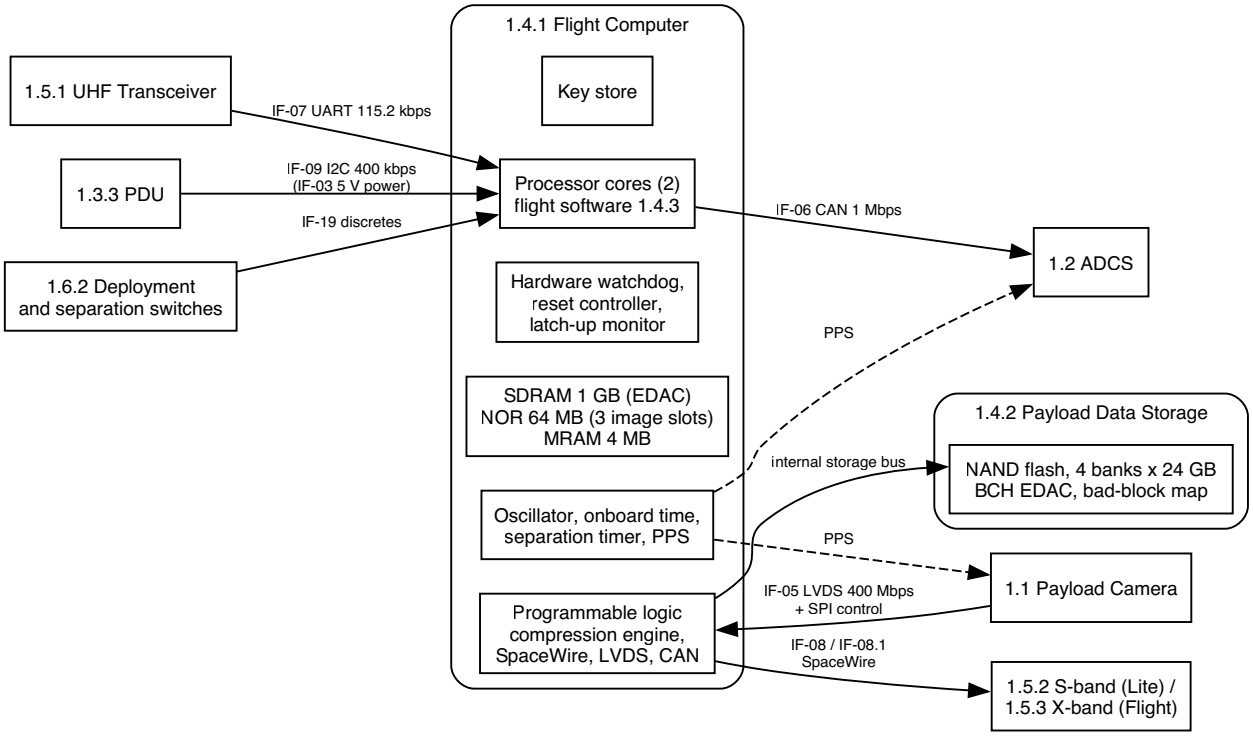
14.1 Overview

The C&DH is a two-board stack: a processor board (the Flight Computer) and a storage board (the Payload Data Storage), joined by a board-to-board connector and housed in one aluminum enclosure mounted on the spacecraft's internal deck next to the Power Distribution Unit. It is powered from the 5 V always-on line (IF-03), so it stays on in every mode after separation, including Safe Mode, and goes off only after SM.12 Passivate Spacecraft.

Characteristic	Value	Basis
Mass (both boards and enclosure)	0.34 kg	Measured (mass budget, 0.35 kg with 3 % contingency)
Orbit-average power	4.0 W	Measured (power budget, 4.12 W with contingency)
Peak power during a compression burst	6.5 W (4.0 W plus 2.5 W)	Measured; IF-03 rated 7 W
Supply	5 V always-on line from the PDU (IF-03)	
Processor	Radiation-tolerant system-on-chip: two 32-bit processor cores at 400 MHz with floating point, and integrated programmable logic	
Data memory	1 GB SDRAM with single-error-correct, double-error-detect (SECDED) EDAC	
Program memory	64 MB NOR flash holding three software image slots and the boot table	
Nonvolatile memory	4 MB magnetoresistive RAM (MRAM): event log, counters, timers, last mode, key store index	

Characteristic	Value	Basis
Payload storage	96 GB raw NAND flash in four banks; at least 64 GB for payload files after EDAC and spare blocks	SR-4.1
Timekeeping	Temperature-compensated crystal oscillator with onboard rate correction; one pulse-per-second output to the ADCS and the payload	SR-4.7
Operating temperature range	−20 °C to +50 °C (unit qualification −30 °C to +60 °C)	STD-1

C&DH summary characteristics



C&DH block diagram: Flight Computer, Payload Data Storage and their spacecraft interfaces

14.2 Flight Computer

14.2.1 Processor and Memory

The processor is a radiation-tolerant system-on-chip with two 32-bit cores and a block of programmable logic. Core 0 runs the real-time executive, command and telemetry, the command schedule, fault management and the subsystem interface applications. Core 1 runs payload data handling, file delivery and the compression control. The split lets the flight software keep fault management on a core that the payload data path cannot load (see Flight Software Specification, “Architecture”), which is the hardware side of keeping L5 and L6 separate. The programmable logic

holds the CCSDS 122.0-B compression engine and the interface controllers that need hardware rate (LVDS, SpaceWire, CAN); its configuration is loaded at boot from the selected software image and checked by readback every 10 s.

Memory	Size	Technology	Protection	Contents
Boot memory	64 kB	One-time-programmable, inside the processor	Fixed	First-stage boot loader: selects an image slot from the boot table and verifies its checksum
Program memory	64 MB	NOR flash	Per-slot CRC-32 and SHA-256 digest; slot 0 hardware write-protected	Slot 0: protected image (the qualified flight software); slots 1 and 2: updatable images, 8 MB each reserved; boot table
Data memory	1 GB	SDRAM	SECDED EDAC on every 64-bit word, hardware scrubber	Running software, data structures, 256 MB ring buffer for strip intake and compression
Nonvolatile memory	4 MB	MRAM	CRC on each record; two copies of the critical records	Event log (SR-10.24), reset counter and causes, separation timer copy, last mode and sub-mode, anti-replay counter, storage catalog index, key store index
Processor on-chip memory	512 kB	SRAM	Parity; tasks with hard deadlines use it	Interrupt vectors, executive kernel, fault management tables

Flight Computer memory map

The boot table in program memory names the selected slot and counts consecutive failed boots. A boot counts as failed when the flight software does not report “boot complete” to the reset controller within 60 s of reset release. After three consecutive failed boots the boot loader selects slot 0 regardless of the boot table (SR-10.21). Slot 0 is write-protected by a hardware strap that is set at final integration and is not reachable by any command; slot 0 can therefore never be corrupted by an update, only by a radiation-induced bit error, which its digest check detects at boot.

14.2.2 Error Detection and Correction

Every memory that holds code or state is protected against single-event upsets:

- **SDRAM.** SECDED corrects any single-bit error per 64-bit word on read and reports double-bit errors. A hardware scrubber reads and rewrites the whole 1 GB in the background so that single-bit errors are removed before a second error accumulates in the same word. At the

predicted upset rate in the 500 km orbit (fewer than 20 single-bit upsets per day in 1 GB, including passes through the South Atlantic Anomaly) a 10 min scrub period makes a double error in one word improbable over the mission. A double-bit error in code or kernel data causes a controlled reset; in a data buffer it marks the affected strip segment as damaged.

- **NOR flash and MRAM** are not susceptible to upset of stored data at the levels of concern; their contents are checked by CRC and digest when read.
- **Programmable logic.** Configuration memory is read back every 10 s and compared with the stored image; a mismatch reloads the configuration, which takes about 200 ms and interrupts only the compression engine and the interface controllers, not the processor cores.
- **Payload storage.** See “Payload Data Storage” below.

Corrected-error counts for each memory are reported in housekeeping so that the ground can trend the upset rate and compare it with the radiation analysis.

14.2.3 Watchdog, Reset and Boot

The hardware watchdog is a counter clocked from its own oscillator, separate from the processor clock. The flight software must service it at least every 4 s; the executive services it only after every category 1 task has reported its heartbeat (see Flight Software Specification, “Software Criticality”). A missed service resets the processor. The reset controller records the reset cause (watchdog, latch-up, power-on, commanded, double-bit error) and its onboard time in MRAM and increments the reset counter that guard G-WD evaluates (three resets in 24 h, TBR-11, Operational Modes).

From reset release, the boot loader verifies and loads the selected image (about 6 s for an 8 MB image), the programmable logic is configured (about 2 s), and the executive starts the mode logic, which reads the last mode from MRAM. The total is under 15 s, well inside the 60 s mode restoration time of SR-10.7. A short boot also keeps a reset during a Safe Mode entry from pushing the entry past its 10 s limit by more than the boot time.

14.2.4 Timekeeping

Onboard time is a 48-bit counter of seconds and sub-seconds (resolution about 15 μs) driven by a temperature- compensated crystal oscillator. Raw oscillator stability over the operating temperature range is about ±1 ppm, which on its own would drift about 86 ms per day. The ground therefore estimates the oscillator’s frequency offset and its slow change from the daily time correlation, and uploads a rate correction that the timekeeping logic applies continuously. What remains is the residual drift, set by the orbital temperature cycle and aging.

Contributor	Value	Notes
Time correlation on the ground (station time stamp, light time from orbit determination)	0.1 ms	Station clocks disciplined to UTC; see Ground Segment Specification
Residual drift after rate correction, 24 h	1.7 ms	20 ppb [TBR-50] over 86,400 s
Correction quantization and application delay	0.05 ms	

Contributor	Value	Notes
Distribution to the users (PPS edge alignment)	0.05 ms	ADCS controller and payload time stamps
Total, worst case one day after correction	**1.9 ms**	SR-4.7 limit 2 ms

Onboard time error budget (one correction per day)

The 20 ppb residual is the value the time budget can afford, not yet a measured one: it depends on how well the temperature compensation holds over the orbital cycle in thermal vacuum, and is TBR-50 until TC-50 measures it.

A pulse-per-second output, aligned with the onboard second, goes to the ADCS controller (on a discrete line of the IF-06 harness) and to the payload (on IF-05). Both time-stamp their measurements and image lines against it, so the time tags on attitude data and on image lines share one time base.

The **separation timer** is a separate hardware counter started by the release of the separation switches (IF-19). It counts from the oscillator even while the processor is held in reset, and the flight software copies its value to MRAM every second. On boot the software takes the hardware counter when it is valid and the MRAM copy plus the reset duration when the counter itself was disturbed by a power loss, which bounds the error to well under the 10 s of SR-10.4.

14.2.5 Single-Event Effects and Latch-Up

The C&DH protects itself against single-event latch-up with a current monitor on each internal supply rail (core, memory, programmable logic, storage banks). An overcurrent above the latch-up threshold for more than 1 ms removes power from the affected rail group within 10 ms, holds it off for 1 s, and restores it; the processor then boots as after a watchdog reset. The always-on input from IF-03 is never interrupted by this protection, so the separation timer, the MRAM and the reset controller keep their state. Single-event functional interrupts of a storage bank are cleared by power-cycling that bank alone (see below).

14.2.6 Spacecraft Interfaces

The C&DH terminates the data interfaces listed below. Electrical levels, connectors and pin assignments are in the Interface Requirements chapter and EO1-ICD-200.

Interface	Partner	Protocol and rate	Use
IF-03 C&DH Power Line	1.3.3 PDU	5 V always-on, 7 W rating	C&DH power in all modes after separation
IF-05 Payload Interface	1.1 Payload Camera	LVDS 400 Mbps (data), SPI (control), PPS	Strip intake from the payload buffer; camera commands and status
IF-06 ADCS Data Bus	1.2.4 ADCS Controller	CAN 1 Mbps, PPS discrete	Attitude targets, pointing mode commands, ADCS telemetry

Interface	Partner	Protocol and rate	Use
IF-07 Radio Command Interface	1.5.1 UHF Transceiver	UART 115.2 kbps	Received telecommand frames in; UHF telemetry frames out; radio control
IF-08 Payload Data Interface	1.5.2 S-band Transmitter (Lite)	SpaceWire 100 Mbps	Encoded-ready transfer frames, transmitter enable and status
IF-08.1 X-band Data Interface	1.5.3 X-band Payload Radio (Flight)	SpaceWire 200 Mbps, connector J5 (Micro-D 9)	Transfer frames, transmitter enable, key selection and status
IF-09 Power Telemetry Link	1.3.3 PDU	I2C 400 kbps	Power telemetry; load switch, Safe Mode load-shed and burn-wire commands
IF-19 Deployment Switch Harness	1.6.2 Deployment Mechanisms	Discrete inputs	Separation switch states (starts the separation timer); deployment switch states

C&DH data interfaces

A ground test connector on the enclosure, reached through the spacecraft access port, gives the ground support equipment a debug and software load path during integration. It has no connection to the dispenser (SR-12.7) and is covered before flight.

14.2.7 Cryptographic Key Store

The key store holds the cryptographic keys of SR-14.3 in a dedicated region of the processor's secure memory, separate from the MRAM and not mapped into the address space that memory dump commands can read. It holds eight telecommand authentication key slots and, on EO-1 Flight, eight downlink encryption key slots; an authenticated command selects the active key of each kind. For each X-band pass the C&DH wraps the active downlink key under the key-encryption key installed in the X-band Payload Radio before flight and sends it over IF-08.1 (ICD-036), so no key crosses an interface in clear text. A zeroize command, a critical command under SR-14.9, overwrites every slot.

14.3 Payload Data Storage

14.3.1 Organization

The Payload Data Storage is a NAND flash array of four independent banks of 24 GB each (96 GB raw), on the storage board with its own controller in the programmable logic. Each bank has its own power switch, so a bank that suffers a single-event functional interrupt or fails can be power-cycled or removed from service without affecting the others.

Item	Capacity	Notes
Raw flash	96 GB	Four banks of 24 GB
Error correction parity (BCH, about 7 %)	6.7 GB	Per 1,024-byte codeword

Item	Capacity	Notes
Spare-block reserve for factory and in-orbit bad blocks (15 %)	13.4 GB	Covers growth of bad blocks over 730 days
Usable capacity	**75.9 GB**	
Payload file partition	64.0 GB	SR-4.1: 20 days of compressed or 3.7 days of raw collection
Stored housekeeping and event log copies	2.0 GB	About 100 days of housekeeping at 0.02 GB per day
Upload staging (software images, tables)	1.0 GB	
Unallocated margin	8.9 GB	Absorbs a bank failure in part (see below)

Payload Data Storage capacity allocation

Files are written in a log-structured layout: new data are always appended to erased blocks, a file's blocks are released only when the flight software deletes the file (after ground acknowledgment, SR-10.28), and wear leveling spreads erase cycles over all blocks. The storage catalog (file names, priorities, sizes, acknowledgment state) is kept in payload storage with an index in MRAM, so it survives resets and power loss.

Loss of one whole bank removes 19 GB of usable capacity; after the unallocated margin is used up the payload partition shrinks to about 54 GB, still 16 days of compressed collection. This is a graceful degradation, not a requirement case: SR-4.1 is verified with all four banks.

14.3.2 Data Integrity

Each 1,024-byte codeword carries a BCH code that corrects up to 40 bit errors. Flash bit errors grow with storage time, erase cycles and ionizing dose. To keep the delivered error rate below 1×10^{-12} after 20 days (SR-4.9), the controller scrubs the stored files: it reads every page of every retained file at least once every 72 h, and rewrites to fresh blocks any page whose corrected-error count exceeds 20 bits per codeword, half the correction capability. A codeword that cannot be corrected marks the segment of the image it holds as damaged in the file's segment map; the file is still delivered, and the ground processor fills the damaged segment from the next collection of the same field.

14.3.3 Rates

The storage must accept the output of the compression engine and, in calibration mode, raw strips at the full payload interface rate. It must also feed the payload downlink radio during a contact while a compression burst from a capture just before the contact is still being written.

Flow	Rate needed	Source
Compressed strip write	about 9 MB/s	0.34 GB compressed per 40 s strip, written in under 40 s
Raw calibration strip write	50 MB/s	Strip read out from the payload buffer at the IF-05 rate (400 Mbps)
X-band downlink read (Flight)	12.5 MB/s	100 Mbps

Flow	Rate needed	Source
S-band downlink read (Lite)	1.25 MB/s	10 Mbps
Scrub read	about 0.3 MB/s average	64 GB in 72 h

Payload Data Storage throughput needs

14.3.4 Write Endurance

Over 730 days the predicted data written are about 3.2 TB: 2.35 TB of compressed collection (3.22 GB per day), about 0.4 TB of raw calibration campaigns (one three-day campaign per quarter at 17.2 GB per day), 0.02 TB of housekeeping files, about 0.1 TB of scrub rewrites, and a write amplification of 1.1 from the log-structured layout. On 96 GB of raw flash this is fewer than 40 program/erase cycles per block, far below the rating of the flash type. Endurance is therefore not the limiting factor; data retention after radiation dose is, which the scrubbing above covers.

14.4 Requirements

CDH-001 Data Memory · Verify: Inspection, Test · Trace: SR-10.27 · Applies: All · Alloc: 1.4.1

The Flight Computer shall provide at least 1 GB of data memory protected by single-error-correct, double-error-detect EDAC on every 64-bit word.

Rationale: The flight software needs about 400 MB for code, data and tables plus a 256 MB ring buffer for strip intake; 1 GB keeps the 70 % memory limit of SR-10.27 with room for updates. EDAC is needed because SDRAM upsets are frequent in this orbit.

CDH-002 Software Image Slots · Verify: Inspection, Test · Trace: SR-10.20, SR-10.21 · Applies: All · Alloc: 1.4.1

The Flight Computer shall hold three software images of at least 8 MB each in nonvolatile program memory, one of which is write-protected by hardware that no command can change.

Rationale: Two updatable slots let an uploaded image be stored without overwriting the running one (SR-10.20); the protected slot is the fallback of SR-10.21. The current image is about 5 MB, so 8 MB leaves room for growth.

CDH-003 Data Memory Scrubbing · Verify: Test, Analysis · Trace: SR-11.6 · Applies: All · Alloc: 1.4.1

The Flight Computer shall read and correct every word of its data memory at least once every 10 min without flight software action.

Rationale: SECDED corrects only one error per word; scrubbing removes single errors before a second one accumulates. At fewer than 20 upsets per day in 1 GB, a 10 min period makes an uncorrectable double error negligible over the mission (TC-52).

CDH-004 Hardware Watchdog · Verify: Test · Trace: SR-10.9, SR-11.6 · Applies: All · Alloc: 1.4.1

The Flight Computer shall reset the processor when the flight software has not serviced the watchdog for 4 s, using a watchdog clock independent of the processor clock.

Rationale: A hung processor must recover without the ground (SR-11.6). 4 s is longer than any legitimate non-preemptible operation (a flash erase of 2 ms is the longest) and short enough that a hang during a Safe Mode entry still completes the entry soon after boot. An independent clock means a stopped processor clock cannot stop the watchdog.

CDH-005 Reset Record · Verify: Test · Trace: SR-10.9, SR-10.24 · Applies: All · Alloc: 1.4.1

The Flight Computer shall record the cause and onboard time of every processor reset in nonvolatile memory before the flight software restarts.

Rationale: Guard G-WD counts watchdog resets over 24 h across the resets themselves, so the count cannot live in volatile memory; the cause lets the ground tell a radiation upset from a software fault.

CDH-006 Boot Time · Verify: Test · Trace: SR-10.7, SR-4.3 · Applies: All · Alloc: 1.4.1

The Flight Computer shall start the flight software mode logic within 20 s of reset release.

Rationale: SR-10.7 restores the mode within 60 s of boot, which needs a short hardware boot; a reset during a Safe Mode entry also delays the entry by the boot time. The design boots in under 15 s.

CDH-007 Nonvolatile State Memory · Verify: Inspection, Test · Trace: SR-10.24, SR-10.4 · Applies: All · Alloc: 1.4.1

The Flight Computer shall provide at least 4 MB of nonvolatile memory that accepts a write at any time and retains its data for at least 730 days without power.

Rationale: The event log of 1,000 events, the separation timer copy, the reset record, the last mode and the anti-replay counter must survive resets and power cycles; MRAM accepts byte writes every second without wear-out. A 1,000-event log at 64 bytes per event needs 64 kB, so 4 MB holds two copies of every record with large margin.

CDH-008 Latch-Up Protection · Verify: Test · Trace: SR-11.6 · Applies: All · Alloc: 1.4.1, 1.4.2

The C&DH shall remove power from any internal supply rail group drawing more than its latch-up threshold within 10 ms and restore it automatically, with the affected function back in service within 60 s.

Rationale: Latch-up destroys parts if the current persists; recovery must happen without ground command (SR-11.6). The always-on input stays connected so the timers and nonvolatile records are kept (TC-52).

CDH-009 Radiation Tolerance · Verify: Analysis, Test · Trace: SR-11.5, SR-11.6 · Applies: All · Alloc: 1.4.1, 1.4.2

Each electronic part of the C&DH shall tolerate a total ionizing dose of at least 10 krad(Si) and shall either be immune to latch-up up to a linear energy transfer of 37 MeV·cm²/mg or be protected by CDH-008.

Rationale: 10 krad(Si) is the system dose requirement of SR-11.5 with its design margin of 2. 37 MeV·cm²/mg is a common threshold above which the latch-up rate in low Earth orbit is negligible; below it, CDH-008 is the protection.

CDH-010 Oscillator Residual Drift · Verify: Test, Analysis · Trace: SR-4.7 · Applies: All · TBR: TBR-50 · Alloc: 1.4.1

After the ground-supplied rate correction is applied, the onboard time shall drift by no more than 20 ppb [TBR] from UTC over any 24 h period under the orbital temperature cycle.

Rationale: 20 ppb is 1.7 ms per day, the largest term of the onboard time error budget that keeps SR-4.7 at 2 ms with one correction per day. TBR-50 closes when TC-50 has measured the drift of the flight oscillator over orbital thermal cycles in thermal vacuum.

CDH-011 Time Correction Resolution · Verify: Test · Trace: SR-4.7 · Applies: All · Alloc: 1.4.1

The Flight Computer shall apply commanded onboard time offsets with a resolution of 20 μs or better and commanded rate corrections with a resolution of 0.1 ppb or better.

Rationale: Quantization of the corrections must stay small against the 2 ms budget: 20 μs is about one counter tick, and 0.1 ppb accumulates only 9 μs per day.

CDH-012 Time Distribution · Verify: Test · Trace: SR-4.7, SR-2.6 · Applies: All · Alloc: 1.4.1

The Flight Computer shall provide a pulse-per-second signal to the ADCS controller and the Payload Camera whose edge is within 50 μs of the onboard second.

Rationale: Attitude samples and image line time tags must share one time base; 50 μs is 0.4 m along track and a negligible attitude error at the 0.01 deg/s stability of SR-2.2.

CDH-013 Separation Timer · Verify: Test · Trace: SR-10.4, SR-8.6 · Applies: All · Alloc: 1.4.1

The Flight Computer shall count the time since separation in a hardware counter that starts when the separation switches are released and keeps counting while the processor is reset.

Rationale: The 30 min deployment and 45 min RF quiet periods are timed from separation (SR-8.6, SR-11.9); a hardware counter that runs through resets is the basis of the 10 s persistence of SR-10.4.

CDH-014 Key Store · Verify: Test, Inspection · Trace: SR-14.3, SR-4.4 · Applies: All · Alloc: 1.4.1

The C&DH shall hold at least eight telecommand authentication keys, and on EO-1 Flight at least eight downlink encryption keys, in memory that no telemetry or memory dump command can read, and shall overwrite all of them within 1 s of an executed zeroize command.

Rationale: Eight slots of each kind support rotation and recovery from a compromised key (SR-14.3, SR-14.4). Keys must never be readable on the downlink; zeroizing is part of passivation at end of mission (TC-54).

CDH-015 Compression Engine Throughput · Verify: Test · Trace: SR-4.6, SR-4.5 · Applies: All · Alloc: 1.4.1

The Flight Computer shall compress image data with CCSDS 122.0-B Image Data Compression in hardware at an input rate of at least 400 Mbps.

Rationale: The camera streams each strip at the 400 Mbps IF-05 rate from the start of the capture and completes the read-out within 10 s of the strip's end (PAY-025); compressing at that rate keeps pace with the read-out, so a 40 s strip is compressed about 10 s after it ends, well inside the 60 s of SR-4.6. Software compression on the processor cores would take several minutes per strip (TC-65).

CDH-016 Payload Storage Capacity · Verify: Test, Analysis · Trace: SR-4.1 · Applies: All · Alloc: 1.4.2

The Payload Data Storage shall provide at least 64 GB for payload files at end of life, after error correction parity and the spare-block reserve.

Rationale: SR-4.1 states the capacity for payload data; housekeeping and upload staging have their own partitions (capacity allocation table). The end-of-life condition is covered by the 15 % spare-block reserve; verified with TC-08 and by analysis of bad-block growth.

CDH-017 Storage Error Correction · Verify: Analysis, Test · Trace: SR-4.9 · Applies: All · Alloc: 1.4.2

The Payload Data Storage shall encode stored data with an error-correcting code that corrects at least 40 bit errors in each 1,024-byte codeword.

Rationale: With scrubbing every 72 h (CDH-018), a 40-bit correction capability keeps the uncorrected bit error rate well below 1×10^{-12} at the raw error rates expected after the mission dose and 20 days of retention (TC-51).

CDH-018 Storage Scrubbing · Verify: Test · Trace: SR-4.9 · Applies: All · Alloc: 1.4.2, 1.4.3

The Payload Data Storage shall read every page of every retained file at least once every 72 h and rewrite each page whose corrected error count exceeds 20 bits per codeword.

Rationale: Rewriting at half the correction capability removes accumulated errors before they exceed the code; 72 h needs an average read of only 0.3 MB/s, which costs no measurable power.

CDH-019 Storage Write Rate · Verify: Test · Trace: SR-4.6, SR-4.1 · Applies: All · Alloc: 1.4.2

The Payload Data Storage shall accept a sustained write of at least 50 MB/s.

Rationale: In calibration mode raw strips are read out from the payload buffer at the 400 Mbps IF-05 rate without compression; storage must keep up so that calibration strips can be captured at the same spacing as normal strips.

CDH-020 Storage Read Rate · Verify: Test · Trace: SR-5.5, SR-5.4 · Applies: All · Alloc: 1.4.2

The Payload Data Storage shall deliver a sustained read of at least 20 MB/s while writing at 50 MB/s.

Rationale: The X-band downlink needs 12.5 MB/s; a contact can start while a compression burst from the last imaging window is still writing. 20 MB/s leaves margin for CFDP retransmissions and scrub reads.

CDH-021 Storage Write Endurance · Verify: Analysis, Test · Trace: SR-15.9 · Applies: All · Alloc: 1.4.2

The Payload Data Storage shall accept at least 6.4 TB of written data over its life without loss of the capacity of CDH-016.

Rationale: Twice the predicted 3.2 TB written over 730 days (SR-15.9 factor of two). Verified by the flash qualification data and an accelerated cycling test on samples of the flight lot (TC-51).

CDH-022 Storage Bank Isolation · Verify: Test, Analysis · Trace: SR-15.2, SR-11.6 · Applies: All · Alloc: 1.4.2

A fault or functional interrupt in one Payload Data Storage bank shall not prevent reading or writing the other three banks.

Rationale: Independent bank power and bus isolation contain a flash failure (SR-15.2); a functional interrupt is cleared by power-cycling the one bank within 60 s (SR-11.6).

CDH-023 Average Power · Verify: Test · Trace: SR-3.9 · Applies: All · Alloc: 1.4

The C&DH shall draw no more than 4.12 W from IF-03 averaged over any orbit, excluding compression bursts.

Rationale: 4.0 W measured plus the 3 % contingency for a measured item is the value carried in all three power budgets; growth beyond it reduces the 12 % allocation margin of SR-3.9.

CDH-024 Peak Power · Verify: Test · Trace: SR-3.9 · Applies: All · Alloc: 1.4

The C&DH shall draw no more than 6.5 W from IF-03 at any time.

Rationale: The compression burst adds 2.5 W to the 4.0 W baseline. IF-03 is rated 7 W (an interface change from the earlier 4 W rating, see Interface Requirements), so 6.5 W keeps 0.5 W of headroom.

CDH-025 C&DH Mass · Verify: Inspection · Trace: SR-8.2 · Applies: All · Alloc: 1.4

The C&DH, including its enclosure and both boards, shall have a mass of no more than 0.35 kg.

Rationale: 0.34 kg measured plus 3 % contingency is the mass budget entry; verified by weighing the flight unit.

14.5 Verification Approach

The C&DH is verified at unit level before spacecraft integration and again in the spacecraft tests. Capacity, rate and error correction are verified on the flight unit in the Onboard Storage Test (TC-08), extended by the storage retention and endurance test TC-51 on flash samples from the flight lot, irradiated to the mission dose and held for 20 days before readout. Reset, watchdog, boot and latch-up behavior is verified by fault injection on the flight unit in TC-52 (forced watchdog expiry, injected double-bit errors, simulated latch-up currents on each rail group, power interruption during separation timer counting). Oscillator drift is measured in thermal vacuum over at least three days of simulated orbital cycles in TC-50, which also closes TBR-50. Compression throughput and power are measured with flight-representative strips from the payload engineering model in TC-65. Radiation tolerance is verified by analysis of the parts' test data, with heavy-ion test data for the processor and the flash. Mass and the inspection items are closed at the unit acceptance review.

15 Flight Software Specification

This chapter specifies the Flight Software (1.4.3) that runs on the Flight Computer (1.4.1): its architecture, command and telemetry, the time-tagged command schedule, fault management, payload data handling and compression, file delivery, software update and the software criticality categories. The mode logic (the six modes, transitions T1 to T9, sub-modes and mode activities) is specified in Operational Modes, with its requirements SR-10.1 to SR-10.19; this chapter refers to it and does not repeat it. The other flight software requirements of area 10 (SR-10.20 to SR-10.28) and the command, security and data requirements of areas 4, 12 and 14 are the parents of the requirements below.

The Flight Software is one build for both configurations. A configuration table loaded at integration selects the payload data port (IF-08 for EO-1 Lite, IF-08.1 for EO-1 Flight), the downlink rate and whether frame encryption key selection commands are accepted (EO-1 Flight only). The ADCS controller (1.2.4) runs its own attitude control software, which is specified with the ADCS; the Flight Software commands it through the ADCS Data Bus (IF-06).

The software flying at launch is version 2.3. Version 2.4, which closes the SR-4.3 deviation (Safe Mode entry measured at 14 s against 10 s), is uploaded in orbit by the procedure of “Software Update” below. Requirements that 2.3 does not meet are noted in their rationale.

15.1 Architecture

15.1.1 Structure

The software is a set of applications on a preemptive real-time executive. Applications communicate only through the executive’s message queues, never through shared memory, so that a fault in one application cannot corrupt another’s data. The two processor cores are used asymmetrically: core 0 runs everything that keeps the spacecraft safe and commandable, core 1 runs the payload data path, which is the largest and most variable load.

Id	Application	Responsibility	Core	Rate or trigger	Category
EXEC	Executive	Task scheduling, message queues, task heartbeats, watchdog service	0	100 Hz tick	1
BOOT	Boot and Image Manager	Image verification at boot, boot table, image copy and activation	0	Boot; on command	1

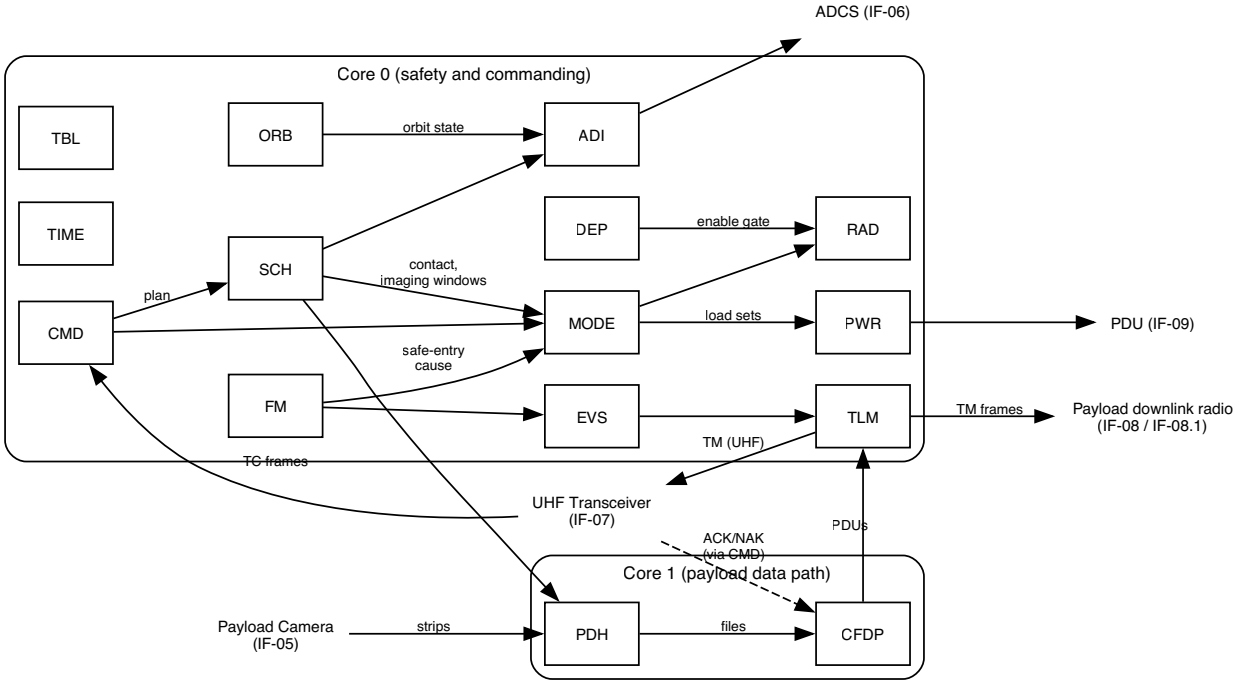
Id	Application	Responsibility	Core	Rate or trigger	Category
MODE	Mode Manager	State machine of Operational Modes: modes, sub-modes, transitions T1–T9, mode activities SM.1–SM.13	0	1 Hz and on event	1
FM	Fault Management	Monitors and responses of the fault management table	0	1 Hz	1
CMD	Command Ingest	Telecommand frame acceptance, authentication, anti-replay, validation, routing, critical command arming	0	On frame arrival	1
TIME	Time Manager	Onboard time, offset and rate corrections, time correlation, separation timer	0	1 Hz	1
DEP	Deployment and RF Inhibit	Release sequence (SM.10), deployables and RF quiet periods, transmitter enable gate	0	1 Hz in Launch and Detumble; on enable requests	1
PWR	Power Interface	PDU telemetry over I2C, load switching, Safe Mode load-shed group command	0	1 Hz	1
SCH	Command Schedule	Stored time-tagged commands and sequences, plan load, constraint check, execution report	0	10 Hz	2
TLM	Telemetry	Housekeeping collection, packet generation, frame building, virtual channel multiplexing	0	0.1 Hz housekeeping; 10 Hz high-rate	2

Id	Application	Responsibility	Core	Rate or trigger	Category
EVS	Event Service	Event reports and the nonvolatile event log (SR-10.24)	0	On event	2
ADI	ADCS Interface	Pointing mode commands, attitude targets, ADCS telemetry over CAN	0	10 Hz	2
ORB	Orbit State Service	Passes the uplinked orbit state to the ADCS controller; records the ADCS-propagated position and velocity for the ancillary data	0	Daily update; 1 Hz recording	2
RAD	Radio Interface	UHF Transceiver control, payload downlink radio enable and status, downlink key wrapping and loading (Flight), UHF transmit interlock during X-band passes (ICD-008)	0	1 Hz	2
TBL	Table Manager	Load, verify and activate parameter tables (limits, constraints, fault management, configuration)	0	On command	2
PDH	Payload Data Handling	Strip intake, compression control, file building, ancillary tagging, storage catalog	1	Per strip	2
CFDP	File Delivery	CFDP entity, acknowledged mode, for downlink and uplink files	1	Per frame	2
MEM	Memory Service	Memory load, dump and checksum	0	On command	2

Id	Application	Responsibility	Core	Rate or trigger	Category
DIAG	Diagnostics	Integration test utilities; removed from the flight configuration table	1	On command	3

Flight Software applications

Priorities follow the categories: category 1 applications run above category 2, and nothing on core 1 can block a core 0 task. The 1 Hz fault management cycle is the shortest deadline that matters to the spacecraft; it runs at the second highest priority, after the executive.



Flight Software applications and their main data flows

15.1.2 Resource Budgets

Resource	Limit	Measured, version 2.3	Target, version 2.4
Core 0 load, worst 1 s interval	60 % (SR-10.26)	41 % (plan load during a contact)	40 %
Core 1 load, worst 1 s interval	60 % (SR-10.26)	54 % (X-band contact at 100 Mbps with a compression burst)	50 %
Program memory, largest image	70 % of the 8 MB slot (SR-10.27)	5.0 MB (62 %)	5.3 MB (66 %)
Data memory	70 % of 1 GB (SR-10.27)	655 MB (64 %), of which 256 MB is the strip ring buffer	665 MB (65 %)
Nonvolatile memory (MRAM)	70 % of 4 MB	1.1 MB (27 %)	1.1 MB (27 %)

Flight Software resource budgets

The core 1 figure of version 2.3 is close to its limit and is the main contributor to risk RK-6 (Flight Software Overrun). Version 2.4 moves the CFDP frame checksum to the programmable logic, which brings the worst case to about 50 %.

15.2 Command and Telemetry

15.2.1 Protocol Stack

The space-ground protocols follow the profile of STD-2 Space-Ground Data Exchange Standard:

- **Uplink (UHF, IF-11).** Telecommand transfer frames of CCSDS 232.0-B TC Space Data Link Protocol (SR-12.2), at most 256 octets, carrying space packets of CCSDS 133.0-B Space Packet Protocol. Frames are delivered with the COP-1 sequence-controlled service on virtual channels 0 and 1; the expedited service is accepted only on virtual channel 0 and only for the command set listed under “Command Handling”. Every frame carries a CCSDS 355.0-B Space Data Link Security Protocol security header and trailer in authentication mode (SR-14.1), on both configurations.
- **Downlink (UHF and payload radio, IF-11 return, IF-12, IF-12.1).** Telemetry transfer frames of CCSDS 132.0-B TM Space Data Link Protocol (SR-12.1). UHF frames are 256 octets with a frame error control field. Payload downlink frames are 892 octets, one frame per rate 7/8 LDPC codeword of CCSDS 131.0-B Telemetry Synchronization and Channel Coding (SR-5.9). On EO-1 Flight the X-band Payload Radio encrypts the frame data field under CCSDS 355.0-B (SR-4.4); the frame header stays in clear so that the station can sort frames without keys.
- **Files.** Payload files, stored housekeeping files and uploads use CCSDS 727.0-B CCSDS File Delivery Protocol in acknowledged mode (SR-12.3).

Virtual channel	Direction	Link	Content
TM VC0	Downlink	UHF and payload downlink	Real-time telemetry: beacon, housekeeping, events, command verification, time correlation
TM VC1	Downlink	UHF	Event log playback and memory or table dumps on request
TM VC2	Downlink	Payload downlink	CFDP file data: payload files and stored housekeeping files
TM VC7	Downlink	Payload downlink	Idle frames (only when no file data is queued)
TC VC0	Uplink	UHF	Real-time commands (sequence-controlled), and the expedited command set

Virtual channel	Direction	Link	Content
TC VC1	Uplink	UHF	Plan loads, table loads and CFDP PDUs (file uplink, acknowledgments, retransmission requests)

Virtual channel allocation

15.2.2 Application Process Identifiers

APID	Direction	Packet	Rate or trigger
0x001	TM	Health beacon (essential housekeeping)	Every 30 s in Detumble and Safe Mode; first packet of every UHF contact
0x010	TM	Full housekeeping, all subsystems, with mode status (SR-10.18)	Every 10 s, stored and real time
0x011	TM	ADCS high-rate (quaternion, body rates, wheel speeds, attitude error)	10 Hz during captures and contacts
0x012	TM	Power detail (each PDU channel, battery cells)	Every 10 s
0x013	TM	Payload status (focal plane temperature, buffer state, detector settings)	Every 10 s while the payload is on
0x014	TM	Radio status (UHF, payload downlink radio, active key slot)	Every 10 s
0x020	TM	Event report	On event
0x021	TM	Command verification (acceptance, execution completion or failure)	Per command
0x022	TM	Schedule status and execution report	On change; on request
0x023	TM	Storage catalog report	Start of each contact; on request
0x024	TM	Time correlation	Every 60 s during a UHF contact
0x025	TM	Memory and table dump	On request
0x030	TM	CFDP protocol data units (downlink)	During a contact
0x080	TC	Executive and mode commands	
0x081	TC	Schedule loads and edits	
0x082	TC	Subsystem commands (power, ADCS, radios)	

APID	Direction	Packet	Rate or trigger
0x083	TC	Payload and payload data handling commands	
0x084	TC	Table, memory and image manager commands	
0x085	TC	Security commands (key selection, zeroize, arm)	
0x086	TC	Time commands (offset, rate correction)	
0x090	TC	CFDP protocol data units (uplink)	

Application process identifiers

Housekeeping volume is about 20 MB per day (0.02 GB in the data volume budget): the full housekeeping packet is about 1,100 octets every 10 s (9.5 MB per day), the high-rate ADCS packets during captures and contacts add about 6 MB, and events, verification and catalog reports the rest. The UHF link cannot carry this volume, so the stored housekeeping goes down as daily files on the payload downlink; the UHF contact carries the real-time packets, events and command verification.

15.2.3 Command Handling

CMD processes each received frame in a fixed order: frame header check, security trailer check (authentication and anti-replay, SR-14.1, SR-14.2), COP-1 frame acceptance, then packet extraction. Nothing in a frame is interpreted before its authentication code has been verified. Each packet is checked against the command database compiled into the image (APID, function code, length, each parameter's type and range, SR-10.25) and against the current mode's permitted command set, then routed to its application. Acceptance or rejection is reported in a verification packet, and execution completion or failure when the command has run.

Critical commands (software activation, key change and zeroize, battery passivation, transmitter permanent disable, and the commands listed in SR-14.9) are named in a critical command table. A critical command runs only if the matching arm command was accepted within the preceding 60 s (SR-14.9). The end-of-mission command uses the longer 600 s arming window of SR-10.19, because the passivation steps that precede it are confirmed in telemetry one by one.

The expedited service on TC VC0 accepts only the transmitter-off command (SR-5.11), the COP-1 unlock directive and the telemetry request for the health beacon. These must work when the sequence-controlled service is out of step, for example after a reset that the ground has not yet noticed. They are still authenticated.

15.3 Command Schedule

The command schedule (SM.1 Execute Command Schedule) holds the time-tagged commands that run the spacecraft between contacts. An uplinked plan contains:

- schedule entries: an absolute onboard time tag (10 ms resolution) and one command packet or a call to a stored sequence with its parameters;
- the target table: for each strip, target coordinates, start time, duration, off-nadir angle and downlink priority;
- contact windows: start and end time, station, link type (UHF only or payload downlink);
- the orbit state from the latest orbit determination, which ORB passes to the ADCS controller; the ADCS propagates it (ADCS-016) and its propagated position and velocity are also what the ancillary data record.

Stored sequences are relative-time command lists kept onboard (up to 64 sequences of up to 50 commands each), so that a plan carries one entry per strip (“capture strip n of the target table”) instead of the dozen commands each capture needs. The schedule holds at least 2,000 entries (SR-4.8), which is 72 h at the design-case rate of about 600 entries per day.

Plan load. A plan arrives over TC VC1 as a set of packets. SCH assembles it in an inactive buffer and checks its completeness and CRC, then runs the constraint check of SR-10.22 on every entry against the onboard constraint table:

Constraint	Check	Source of limits
Power	Predicted battery state of charge at the start of each imaging window and contact stays above the imaging inhibit level of FSW-029	Power budget, EPS Specification
Thermal	Camera detector on-time per orbit and payload downlink radio on-time per contact within their limits	Thermal Control Specification
Pointing keep-out	No commanded attitude puts the Sun inside the camera or star tracker keep-out cones	Payload and ADCS Specifications
Storage	Predicted free space before each capture is at least one maximum strip (2.48 GB raw, the payload buffer limit)	This chapter
Contact windows	No entry other than contact control is time-tagged inside a contact window (OPS.3)	Operational Modes
Mode	Each command is permitted in the mode the spacecraft will be in at its time tag	Command database

Onboard plan constraint check

Entries that fail are removed and reported; the rest of the plan is kept. A plan that fails the completeness or CRC check is rejected as a whole and the previous schedule stays in force. The new schedule replaces the active one at the activation time given in the plan. Individual entries can also be inserted or deleted in the active schedule, which is how a late plan update with priority targets is uplinked without a full plan (SR-6.6).

Execution report. SCH records the outcome of every entry (executed, skipped with reason, rejected) and every target (captured, skipped because the focal plane or the slew was not ready, skipped by a fault management response). The report is downlinked at the start of each UHF contact and is the onboard part of the collection status report of F11.7.

15.4 Fault Management

Fault management detects faults and responds to them at the lowest level that contains them. The Safe Mode trigger conditions (guards G-UV, G-WD, G-BT, G-AE, G-CL and G-LF) and the Safe Mode behavior are specified in Operational Modes; the table below shows them together with the lower-level responses that keep a single unit fault from reaching Safe Mode. Thresholds and persistence values are parameters in the fault management table, changeable by a table load.

Level	Meaning
0	Handled in hardware without software: PDU overcurrent trip (SR-3.8), C&DH latch-up protection, watchdog reset, hardware undervoltage disconnect (SR-3.11)
1	Unit recovery by the Flight Software: retry, reset or power-cycle the unit; mode unchanged
2	Activity inhibit: skip a capture or an imaging window, stop a function; mode unchanged
3	Safe Mode (transition T6 or T8)

Fault response levels

Id	Monitor	Condition and persistence	Response	Level
FM-01	Battery voltage	G-UV (Operational Modes)	Safe Mode by T6 or T8; SM.4 load shed as one PDU group command (FSW-004)	3
FM-02	Battery state of charge before an imaging window	Below 75 % [TBR-51] at window start	Skip the window; report; contacts continue	2
FM-03	Battery temperature	G-BT	Safe Mode	3
FM-04	Processor resets	G-WD at boot	Safe Mode at boot; a single reset restores the last mode (SR-10.7)	3
FM-05	Attitude error	G-AE	Safe Mode	3
FM-06	Ground command reception	G-CL	Safe Mode	3

Id	Monitor	Condition and persistence	Response	Level
FM-07	Payload downlink link lock	G-LF (in a contact window)	Safe Mode by T8	3
FM-08	Star tracker solution	Invalid for 120 s while AP-3 or AP-4 is commanded	Power-cycle the star tracker once; skip captures until the solution is valid; G-AE covers a lasting loss	1, 2
FM-09	ADCS controller response on IF-06	No response for 5 s	Reset the CAN controller; after 15 s more, power-cycle the ADCS through the PDU; back in service within 60 s (SR-11.6)	1
FM-10	Reaction wheel health (reported by the ADCS controller)	Speed or current outside limits for 10 s	ADCS continues on three wheels (SR-2.9); Flight Software reports and sets the degraded slew rate in the constraint table	1
FM-11	PDU output trip	Any switched output tripped (SR-3.8)	Log; one retry after 60 s; a second trip leaves the output off and reports; if the output feeds the payload, skip captures	1
FM-12	Payload focal plane temperature	Outside 20 °C ± 2 °C at capture start (SR-9.2)	Skip the capture; camera to standby at the end of the window	2
FM-13	Payload storage uncorrectable codeword	Any	Mark the segment damaged in the file's segment map; retire the block; continue	1
FM-14	Payload storage free space	Below 2.48 GB in the payload partition	Skip new captures; report; never overwrite unacknowledged files	2
FM-15	Storage bank	Bank not responding for 1 s	Power-cycle the bank; after a second failure in 24 h, retire it and report	1
FM-16	Task heartbeat, category 1	Missed for 2 s	Stop servicing the watchdog; hardware reset follows (4 s)	0

Id	Monitor	Condition and persistence	Response	Level
FM-17	Task heartbeat, category 2	Missed for 5 s	Restart the task; after three restarts in 24 h, leave it stopped and report	1
FM-18	Deployment switch after firing	Not confirmed 60 s after the primary circuit was energized	Fire the redundant circuit (SR-8.7); report	1
FM-19	UHF receiver in Safe Mode	No valid command for 24 h	SM.6 Cycle UHF Transceiver	1
FM-20	Plan entry	Fails the onboard constraint check	Remove the entry, report (SR-10.22)	2

Fault management monitors and responses

Every detection and every response is written to the event log with its time, so the day-shift team can reconstruct events that happened between contacts (SR-10.24). Responses at levels 1 and 2 never change the mode; only the Mode Manager changes modes, and only by T1 to T9 (SR-10.2).

Safe Mode entry timing. In version 2.3, SM.4 sends the load-shed commands one unit at a time, each waiting for its I2C acknowledgment from the PDU with a 1 s time-out, and then waits for the ADCS to report Coarse Sun Pointing before declaring entry complete. That sequence measured 14 s after a G-UV detection (2 s persistence included). Version 2.4 sends one group load-shed command, which the PDU executes in one step, and no longer waits for the ADCS pointing mode before the load shed is complete. The predicted entry time is 5 s plus the 2 s persistence, inside the 10 s of SR-4.3.

15.5 Payload Data Handling

15.5.1 Strip Intake and Compression

PDH runs one pipeline per strip (F8.1 to F8.4). The payload writes each strip into its image buffer and streams it over IF-05 at 400 Mbps from the start of the capture, slightly faster than the 368 Mbps raw rate, so the read-out ends within 10 s of the strip's end (PAY-025). The compression engine in the programmable logic compresses the data as they arrive and the compressed segments are written to payload storage; PDH can pause the read-out, and the payload buffer then holds the rest of the strip, when storage is busy. The compression engine's parameters are set per strip by PDH:

Parameter	Value
Algorithm	CCSDS 122.0-B Image Data Compression, floating-point wavelet transform for rate-limited compression
Rate	2.2 bits per pixel per band (5.45:1 for 12-bit pixels), rate-controlled per segment (SR-4.5)
Segment	16 image lines across the full width: 612 blocks of 8 × 8 pixels per block row, two block rows; width padded from 4,889 to 4,896 pixels

Parameter	Value
Band handling	Each band compressed separately and stored as its own section of the strip file
Lossless option	Integer wavelet transform, selectable per strip for calibration sites
Raw mode	Compression bypassed; strip stored as received (calibration mode, SR-4.1 sizing of 3.7 days)

Onboard compression parameters

Segments are decoded independently, so an uncorrectable storage error or a lost frame costs one segment of one band (16 lines, about 72 m along track), not the whole strip.

A strip file holds a header, the four band sections, an ancillary section and a segment map. The ancillary section, about 2 % of the file (data volume budget), carries attitude quaternions and body rates at 10 Hz from the ADCS high-rate data, spacecraft position and velocity at 1 Hz from the ADCS orbit propagator, line time tags every 128 lines from the payload (time-stamped against the C&DH pulse per second), focal plane temperature, detector gain and integration settings, and the strip and target identifiers. A 40 s strip makes a file of about 0.34 GB.

Cloud screening is done on the ground in the baseline (F11.4); onboard screening between F8.1 and F8.2 is the open alternative TBD-10 of the System Architecture chapter. PDH reserves a hook for it in the pipeline but has no screening code in version 2.4.

15.5.2 Storage Catalog and Downlink Queue

The storage catalog lists every retained file with its priority (0 to 7, 0 highest, set per strip in the plan's target table; alert regions are priority 0), creation time, size, segment map and delivery state (queued, in transfer, delivered and awaiting acknowledgment, acknowledged). The downlink queue is ordered by priority, then by age (SR-10.23). Stored housekeeping files are queued at priority 1, so a day's housekeeping is never held back behind routine imagery. The ground can change any file's priority or delete a file by command.

A file is deleted only when the ground's CFDP entity has confirmed its complete receipt or a ground command deletes it (SR-10.28). When free space in the payload partition falls below one maximum strip, PDH skips new captures (FM-14) instead of overwriting data.

15.6 File Delivery

The CFDP entity runs in acknowledged mode. During a payload downlink contact (SM.7) it sends file data from the queue on TM VC2. The ground receiving entity returns retransmission requests for missing segments over the UHF uplink on TC VC1 during the pass (Ground Segment Specification, "File reception"). The confirmation that a file is complete, which lets the spacecraft delete it (SR-10.28), is released only after the Mission Operations Center holds the file intact, and normally reaches the spacecraft at a later UHF contact (IF-13, Interface Requirements). Up to 64 transactions can be open at once.

At the end of a contact window (T5) or on T8 every open transaction is suspended, with its state (segments sent, segments acknowledged, outstanding retransmission requests) saved in nonvolatile memory. At the next contact the transactions resume with the outstanding segments; acknowledged segments are not sent again. A transaction ends only when its file is acknowledged or the ground cancels it; no inactivity timer abandons a file on its own.

Uplink files (software images, parameter tables, ephemeris and target tables larger than one plan load) use the same entity in the other direction over the UHF uplink, into the upload staging partition of payload storage.

15.7 Software Update

A new image is uploaded as a CFDP file over the UHF uplink into the upload staging partition. The uplink's effective throughput is about 5 kbps (9.6 kbps less frame, security and protocol overhead and the half-duplex share used for verification and telemetry), so a full 5 MB image takes about 15 UHF contacts of 10 min, spread over several days of normal operations; a patch that replaces single applications is usually under 1 MB and fits in three contacts. The update sequence is:

1. Upload the image file; CFDP confirms complete receipt.
2. BOOT verifies the image's SHA-256 digest against the value in the signed image header and copies the image into the inactive updatable slot (slot 1 or 2), then verifies the copy.
3. The ground arms and then sends the activation command (a critical command, SR-14.9), which selects the slot in the boot table (SR-10.20).
4. The ground commands a reset at a time chosen outside imaging windows and contacts. The new image boots and reports "boot complete"; the mode is restored as after any single reset (SR-10.7).
5. If the new image fails to boot three times in a row, the boot loader falls back to the protected slot 0 (SR-10.21); the ground then reselects the previous image or uploads a corrected one.

Parameter tables (limits, constraints, fault management thresholds, configuration) are updated without a reset: TBL loads the new table into a second buffer, verifies its CRC and range checks, and swaps it in on command.

15.8 Software Criticality

Each application belongs to one of three criticality categories. The category sets the development and verification rigor.

Category	Definition	Applications	Development and verification rigor
1	A failure can lose the spacecraft, violate launch safety (deployment or RF before the quiet periods) or the spectrum license, or let an unauthorized command run	EXEC, BOOT, MODE, FM, CMD, TIME, DEP, PWR	Independent design review; static analysis with no open findings; 100 % statement and decision coverage in unit test; every requirement tested on the flatsat; independent test witness

Category	Definition	Applications	Development and verification rigor
2	A failure degrades or interrupts the mission (images, files, schedule) but leaves the spacecraft safe	SCH, TLM, EVS, ADI, ORB, RAD, TBL, PDH, CFDP, MEM	Peer design review; static analysis; 100 % statement coverage in unit test; every requirement tested on the flatsat
3	No effect on the flight mission	DIAG	Peer review; not loaded in the flight configuration

Software criticality categories

The categories also set the fault containment rules above: category 1 heartbeats gate the watchdog, category 2 tasks are restarted individually.

15.9 Requirements

FSW-001 Fault Monitor Rate · Verify: Test, Inspection · Trace: SR-4.3 · Applies: All · Alloc: 1.4.3

The Flight Software shall evaluate every monitor of the fault management table at least once per second in every mode after Launch.

Rationale: Operational Modes evaluates the Safe Mode triggers each second; the 10 s Safe Mode entry of SR-4.3 assumes a detection delay of no more than 1 s plus the 2 s G-UV persistence (TC-53).

FSW-002 Fault Management Isolation · Verify: Test, Analysis · Trace: SR-15.2 · Applies: All · Alloc: 1.4.3, 1.4.1

The Flight Software shall complete each 1 s fault management cycle within 100 ms of its scheduled start with the payload data handling and file delivery applications at their maximum load.

Rationale: Keeps L6 Fault Management independent of L5 Payload Data Management, as the logical architecture requires; the payload data path runs on the other core and cannot delay a core 0 task (TC-58).

FSW-003 Watchdog Service Condition · Verify: Test · Trace: SR-11.6, SR-10.9 · Applies: All · Alloc: 1.4.3

The Flight Software shall service the hardware watchdog only when every category 1 application has reported its heartbeat within the preceding 2 s.

Rationale: Servicing the watchdog from a timer alone would hide a hung safety task; tying it to the heartbeats turns any category 1 hang into a hardware reset within 6 s (TC-53).

FSW-004 Grouped Load Shed · Verify: Test · Trace: SR-4.3 · Applies: All · Alloc: 1.4.3

The Flight Software shall complete the SM.4 load shed within 5 s of the G-UV condition being confirmed, by sending the Safe Mode load set to the PDU as one command.

Rationale: 5 s plus the 2 s persistence and 1 s detection meets the 10 s of SR-4.3 with 2 s margin. Version 2.3 sends unit commands one at a time and waits for the ADCS mode (14 s measured, accepted to 15 s by deviation); version 2.4 implements this requirement (TC-09, TC-53).

FSW-005 Authentication Before Processing · Verify: Test · Trace: SR-14.1 · Applies: All · Alloc: 1.4.3

The Flight Software shall verify the authentication code of each telecommand frame before interpreting any part of the frame other than its transfer frame header and security header.

Rationale: Parsing unauthenticated content is the usual path for an attacker to reach software flaws; nothing past the security header is read until the frame is proven to come from the operations center (TC-54).

FSW-006 Anti-Replay Counter Persistence · Verify: Test · Trace: SR-14.2 · Applies: All · Alloc: 1.4.3

The Flight Software shall store the security sequence number of each accepted telecommand in nonvolatile memory before executing the command.

Rationale: If the counter were lost at a reset, a recorded command could be replayed after the reset; writing it first means a reset during execution cannot roll it back (TC-54).

FSW-007 Command Verification Reports · Verify: Test · Trace: SR-10.25 · Applies: All · Alloc: 1.4.3

The Flight Software shall report the acceptance or rejection of each received command packet in telemetry within 2 s of its receipt.

Rationale: Operators confirm each step of a procedure before sending the next; a 2 s report fits inside the UHF round trip so a contact is not spent waiting. Execution completion is reported separately when the command finishes.

FSW-008 Transmitter-Off Precedence · Verify: Test · Trace: SR-5.11 · Applies: All · Alloc: 1.4.3

The Flight Software shall execute an authenticated transmitter-off command within 1 s of receipt, ahead of every queued command, whether it arrives on the sequence-controlled or the expedited service.

Rationale: SR-5.11 allows 10 s for all RF to stop; executing in 1 s leaves the rest for the radios' own turn-off. Accepting it on the expedited service means it works even when the COP-1 sequence is out of step (TC-54).

FSW-009 Critical Command Table · Verify: Test, Inspection · Trace: SR-14.9 · Applies: All · Alloc: 1.4.3

The Flight Software shall identify critical commands from a table that can be changed only by a critical command.

Rationale: If an ordinary table load could remove a command from the critical list, the arming protection of SR-14.9 could be bypassed by one operator error.

FSW-010 Schedule Timing · Verify: Test · Trace: SR-4.2 · Applies: All · Alloc: 1.4.3

The Flight Software shall accept schedule time tags with a resolution of 10 ms and dispatch each scheduled command within 100 ms of its time tag.

Rationale: SR-4.2 allows 1 s; 100 ms dispatch leaves the rest for the receiving unit to act, and 10 ms resolution keeps strip timing errors under 0.1 km along track (TC-56).

FSW-011 Stored Sequences · Verify: Test · Trace: SR-4.8 · Applies: All · Alloc: 1.4.3

The Flight Software shall hold at least 64 stored command sequences of up to 50 relative-time commands each, in addition to the 2,000 schedule entries of SR-4.8.

Rationale: One schedule entry per capture keeps a 72 h plan inside 2,000 entries; without stored sequences each capture would need about a dozen entries.

FSW-012 Plan Load Integrity · Verify: Test · Trace: SR-10.22 · Applies: All · Alloc: 1.4.3

The Flight Software shall replace the active schedule with an uplinked plan only after the complete plan has been received, its CRC has been verified and its constraint check has been completed.

Rationale: A plan cut short by the end of a contact must never run half-loaded; the previous schedule stays in force until a complete, checked plan replaces it (TC-56).

FSW-013 Contact Window Exclusion · Verify: Test · Trace: SR-10.22 · Applies: All · Alloc: 1.4.3

The Flight Software shall reject at load each schedule entry, other than a contact-control command, whose time tag falls inside a contact window of the same plan.

Rationale: Downlink Contact executes no schedule entries (Operational Modes); rejecting them at load reports the planning error at once instead of silently skipping the commands during the pass.

FSW-014 Schedule Editing · Verify: Test · Trace: SR-6.6 · Applies: All · Alloc: 1.4.3

The Flight Software shall insert and delete individual entries in the active schedule by ground command, applying the constraint check to each inserted entry.

Rationale: Priority targets received after the daily plan are added by a short late update (design-case day, 10:30 contact), which keeps responsive tasking within one UHF contact (TC-56).

FSW-015 Execution Report · Verify: Test · Trace: SR-10.24 · Applies: All · Alloc: 1.4.3

The Flight Software shall record, for each schedule entry and each target, whether it was executed, skipped or rejected, and the reason, and shall keep the record until the ground has received it.

Rationale: The execution report feeds the collection status report (F11.7) and lets the planner retask missed targets the next day.

FSW-016 Housekeeping Collection · Verify: Test · Trace: SR-10.18 · Applies: All · Alloc: 1.4.3

The Flight Software shall collect a full housekeeping record every 10 s in every mode after Launch.

Rationale: SR-10.18 puts the mode status in every housekeeping record; a 10 s rate resolves the fastest events the ground needs to reconstruct, such as a Safe Mode entry sequence, at about 20 MB per day (TC-56).

FSW-017 Stored Housekeeping · Verify: Test · Trace: SR-6.3 · Applies: All · Alloc: 1.4.3, 1.4.2

The Flight Software shall store every housekeeping record onboard until the ground has acknowledged the file that contains it.

Rationale: The 730-day telemetry archive (SR-6.3) must be complete, but contacts cover only part of each day; stored records reach the ground as daily files on the payload downlink.

FSW-018 Virtual Channel Allocation · Verify: Test, Inspection · Trace: SR-12.1, SR-12.2 · Applies: All · Alloc: 1.4.3

The Flight Software shall assign telemetry and telecommand data to virtual channels as given in the virtual channel allocation table.

Rationale: The partner stations and the operations center sort frames by virtual channel; a fixed allocation lets real-time telemetry bypass file data on the same link.

FSW-019 Time Correlation Packets · Verify: Test · Trace: SR-4.7 · Applies: All · Alloc: 1.4.3

During each UHF contact, the Flight Software shall send a time correlation packet at least every 60 s giving the onboard time at which the leading edge of a named telemetry frame left the transmitter, within 20 μs.

Rationale: The ground compares this time with the station's UTC time stamp of the same frame, corrected for light time, to compute the clock offset and rate (onboard time error budget, Command and Data Handling Specification).

FSW-020 Strip Ancillary Data · Verify: Test · Trace: SR-1.12, SR-2.6 · Applies: All · Alloc: 1.4.3

The Flight Software shall attach to each strip file the attitude quaternions at 10 Hz or faster, the spacecraft position and velocity at 1 Hz or faster, and line time tags at least every 128 lines.

Rationale: Geolocation and band registration on the ground interpolate attitude and position to each line; at the 0.01 deg/s stability of SR-2.2, 10 Hz attitude samples keep the interpolation error below 1 arcsec (TC-57).

FSW-021 Compression Segmentation · Verify: Test · Trace: SR-4.5, SR-4.9 · Applies: All · Alloc: 1.4.3

The Flight Software shall compress each band of each strip to no more than 2.2 bits per pixel in independently decodable segments of no more than 16 image lines.

Rationale: 2.2 bits per pixel is the data volume budget's rate (SR-4.5); 16-line segments limit the loss from one uncorrectable error or lost frame to about 72 m of one band (TC-57, TC-65).

FSW-022 Raw Calibration Mode · Verify: Test · Trace: SR-1.9, SR-4.1 · Applies: All · Alloc: 1.4.3

The Flight Software shall store a strip without compression when the schedule entry for that strip selects raw mode.

Rationale: Radiometric calibration over vicarious sites and the Moon uses uncompressed data so compression error does not enter the 5 % accuracy budget of SR-1.9; storage is sized for 3.7 days of raw collection.

FSW-023 Downlink Queue Order · Verify: Test · Trace: SR-10.23 · Applies: All · Alloc: 1.4.3

The Flight Software shall downlink queued files in order of their priority level, from 0 (highest) to 7, and by age within each level.

Rationale: Eight levels let the planner separate alert regions, housekeeping, routine collection and calibration data; ordering by age within a level keeps old files from waiting indefinitely (TC-57).

FSW-024 Storage Full Protection · Verify: Test · Trace: SR-10.28, SR-4.1 · Applies: All · Alloc: 1.4.3

When the free space in the payload partition is less than 2.48 GB, the Flight Software shall skip new captures and report each skipped capture.

Rationale: 2.48 GB is the longest strip the payload buffer holds; skipping captures, rather than overwriting old files, keeps unacknowledged data safe (SR-10.28).

FSW-025 File Transfer Persistence · Verify: Test · Trace: SR-12.3 · Applies: All · Alloc: 1.4.3

The Flight Software shall suspend each open file transaction at the end of a contact and resume it at a later contact, including after a processor reset, without resending segments the ground has acknowledged.

Rationale: A 0.34 GB strip file and the backlog of a missed pass span several passes on EO-1 Lite; resuming instead of restarting is what makes the acknowledged mode of SR-12.3 efficient (TC-55, TC-57).

FSW-026 Downlink Frame Supply · Verify: Test · Trace: SR-5.4, SR-5.4.1 · Applies: All · Alloc: 1.4.3

While files are queued during a payload downlink contact, the Flight Software shall supply transfer frames to the payload downlink radio with no more than 2 % idle frames.

Rationale: The data volume budget's 0.94 framing factor covers headers and protocol overhead with about 2 % idle; starving the radio would cut the daily capacity below the 3 GB (Flight) and 1 GB (Lite) requirements (TC-57).

FSW-027 Software Image Upload · Verify: Test · Trace: SR-10.20 · Applies: All · Alloc: 1.4.3

The Flight Software shall copy an uploaded software image into an updatable image slot only after its SHA-256 digest matches the digest in its signed image header.

Rationale: The checksum check of SR-10.20 is done before the image touches a slot, so a corrupt upload never replaces the standby image (TC-55).

FSW-028 Table Update Without Reset · Verify: Test · Trace: SR-10.22 · Applies: All · Alloc: 1.4.3

The Flight Software shall activate a loaded parameter table on ground command without a processor reset, after verifying its CRC and the range of each value.

Rationale: Constraint, limit and fault management thresholds change over the mission (for example the degraded slew rate after a wheel failure); a reset for each change would interrupt imaging (TC-55).

FSW-029 Low-Energy Imaging Inhibit · Verify: Test, Analysis · Trace: SR-3.3 · Applies: All · TBR: TBR-51 · Alloc: 1.4.3

The Flight Software shall skip an imaging window when the battery state of charge at the window's start is below 75 % [TBR].

Rationale: The design-case orbit reaches 23 % depth of discharge; starting a window below 75 % could take the following eclipse past the 30 % limit of SR-3.3. The threshold is TBR until the EPS state-of-charge estimator accuracy is measured on the engineering model battery (TC-53).

FSW-030 RF Inhibit Gate · Verify: Test · Trace: SR-11.9 · Applies: All · Alloc: 1.4.3

The Flight Software shall refuse every transmitter enable, whether scheduled, commanded or from a mode activity, until the separation timer has reached 45 min.

Rationale: The CubeSat Design Specification quiet period (SR-11.9) must hold even if an integration test schedule or a corrupted table were left in memory; the gate checks the hardware separation timer, not the schedule (TC-53).

FSW-031 Deployment Retry · Verify: Test · Trace: SR-8.7, SR-3.6 · Applies: All · Alloc: 1.4.3

When a deployment switch does not report deployed within 60 s of its primary release circuit being energized, the Flight Software shall energize the redundant release circuit.

Rationale: Uses the two independent circuits of SR-8.7 automatically; with the array release at separation + 35 min the retry still completes inside the 45 min of SR-3.6 (TC-19, TC-53).

FSW-032 ADCS Unit Recovery · Verify: Test · Trace: SR-11.6 · Applies: All · Alloc: 1.4.3

When the ADCS controller does not respond on the ADCS Data Bus for 5 s, the Flight Software shall reset the bus interface and, if the controller still does not respond 15 s later, power-cycle the ADCS through the PDU.

Rationale: An upset ADCS controller is the most likely single-event effect with an attitude consequence; the sequence returns it to service within the 60 s of SR-11.6, before G-AE could trigger Safe Mode (TC-53).

FSW-033 Processor Margin at Release · Verify: Test, Analysis · Trace: SR-10.26 · Applies: All · Alloc: 1.4.3

Each released Flight Software version shall use no more than 50 % of either processor core in any 1 s interval of the worst-case test scenario.

Rationale: SR-10.26 limits use to 60 % over the mission; 50 % at release keeps a 10-point reserve for in-orbit updates. Version 2.3 measures 54 % on core 1 (RK-6), so this applies from version 2.4 (TC-58).

FSW-034 Category 1 Test Coverage · Verify: Inspection · Trace: SR-15.2, SR-15.1 · Applies: All · Alloc: 1.4.3

Every category 1 application shall reach 100 % statement and decision coverage in unit test before each release.

Rationale: Category 1 software can lose the spacecraft or breach launch safety; full decision coverage is the practical evidence that every branch of the fault logic has been exercised. Verified at the software release review.

15.10 Verification Approach

The Flight Software is verified on the flatsat (FS-1 for EO-1 Flight, FS-3 for EO-1 Lite), which carries an engineering-model Flight Computer and storage board, the payload and radio engineering models or their simulators, and a dynamic simulator for attitude, power and orbit. Every release runs the full requirement test set before it is loaded on a flight unit. The fault management table and the Safe Mode responses are verified by fault injection in TC-53 (each monitor driven past its threshold in each mode where it applies, including the RF and deployment gates with the separation timer forced), and the Safe Mode entry time by TC-09. Command security is verified in TC-54 (invalid authentication codes, replayed frames, unarmed critical commands, expedited transmitter-off with COP-1 out of step). Commanding, telemetry and the schedule are verified in TC-56, which runs a 72 h plan of 2,000 entries with deliberate constraint violations and a late update. The payload data path is verified end to end in TC-57 (strip intake to CFDP delivery over several simulated passes, with dropped frames and a reset in mid-transfer). Software update and boot fallback are verified in TC-55, processor and memory use in TC-58, and compression performance in TC-65. FSW-034 is verified by inspection of the coverage reports at each release review.

16 Communications Specification

This chapter specifies the Communications element (1.5): the UHF Transceiver (1.5.1), the S-band Transmitter (1.5.2, EO-1 Lite), the X-band Payload Radio (1.5.3, EO-1 Flight) and the UHF Antenna (1.5.4). It covers frequencies, modulation and coding, data rates, antennas, the link budgets, the protocols as they concern the radios, link security and spectrum coordination. The signal-level interface requirements of the space-to-ground links (channel, Doppler tolerance, downlink signal, occupied bandwidth, X-band power flux density and frame encryption, ICD-030 to ICD-036) are in the Interface Requirements chapter and are not repeated here; the requirements below are the unit requirements that make those interfaces work.

The communications element performs F6 Receive Commands (UHF Transceiver), F9 Transmit Payload Data and its subfunctions F9.3 and F9.4 (payload downlink radio) and F10.4 Transmit Health Beacon (UHF Transceiver). The radios are controlled by the C&DH; the decisions about when they transmit belong to the mode logic (SR-10.6, SR-10.15) and the RF inhibit gate of the Flight Software (FSW-030).

16.1 Overview

Link	Unit	Frequency	Modulation and coding	Rate	RF power	Spacecraft antenna	Configuration	Use
UHF uplink (IF-11)	1.5.1 UHF Transceiver	435.5 MHz [TBR-71]	GMSK, BT 0.5; TC frames in CLTUs, no coding gain claimed	9.6 kbps	— (ground 50 W)	1.5.4 turnstile, about 0 dBi	All	Commands, plans, file uplink, CFDP and link acknowledgments
UHF downlink (IF-11)	1.5.1 UHF Transceiver	435.5 MHz, same channel, half duplex	GMSK, BT 0.5; TM frames with CRC, uncoded	9.6 kbps	2 W	1.5.4 turnstile	All	Real-time telemetry, health beacon, event playback
S-band downlink (IF-12)	1.5.2 S-band Transmitter	2,245.0 MHz	OQPSK, root-raised-cosine; LDPC rate 7/8	10 Mbps	1 W	6 dBi patch, RHCP	Lite	Payload files, stored housekeeping
X-band downlink (IF-12.1)	1.5.3 X-band Payload Radio	8,200.0 MHz	OQPSK, root-raised-cosine; LDPC rate 7/8; frame encryption	100 Mbps	2 W	16 dBi patch array, RHCP	Flight	Payload files, stored housekeeping, real-time telemetry during the pass

Communications links

Unit	Mass with contingency	DC power	Notes
1.5.1 UHF Transceiver	0.093 kg	1.0 W receiving; 6.0 W transmitting (total)	Measured
1.5.4 UHF Antenna	0.046 kg	—	Estimated; burn-wire power drawn from the PDU release outputs
1.5.2 S-band Transmitter with patch antenna	0.352 kg	11.5 W transmitting; off otherwise	Calculated; EO-1 Lite only
1.5.3 X-band Payload Radio with patch array	0.495 kg	15.0 W transmitting; off otherwise	Calculated; EO-1 Flight only

Communications unit mass and power (mass and power budgets)

All four units draw from the Radio Power Line (IF-04), rated 18 W [TBR-70]. On EO-1 Flight the X-band radio and the UHF transmitter together would draw 21.0 W, so the C&DH holds the UHF transmitter off while the X-band radio transmits (ICD-008); real-time telemetry then travels in the X-band frames and the UHF receiver stays on for commands and link acknowledgments. On EO-1 Lite both transmitters together draw 17.5 W, inside the rating.

16.2 UHF Transceiver

The UHF Transceiver is a half-duplex radio on one channel for both directions. Its receiver is powered from the start of Detumble (T2, 30 min after separation) until Decommissioned, from the same supply branch that the hardware undervoltage disconnect leaves on (SR-3.11), so the ground can always command the spacecraft. Its transmitter is enabled only after the 45 min RF quiet period (SR-11.9) and is used for the health beacon in Detumble and Safe Mode (a frame of at most 2 s every 30 s, SR-10.15) and for telemetry during UHF contacts in the other modes.

The receiver demodulates GMSK, finds the CLTU start sequence, removes the CLTU coding (whose BCH code is used for error detection only; the link budget claims no coding gain) and forwards each decoded TC frame to the C&DH over IF-07 within 100 ms (ICD-018). It does not interpret frames: authentication and validation are done in the C&DH, so the radio holds no keys. The station pre-compensates the uplink Doppler; the receiver tolerates the full ±11 kHz Doppler when the station's orbit data are stale (ICD-031).

Receiver sensitivity. The uplink budget assumes a spacecraft G/T of −29.0 dB/K with an antenna of about 0 dBi, which corresponds to a system noise temperature of about 790 K (29 dBK). At the required Eb/N0 of 12.5 dB plus 2.0 dB implementation loss, 9.6 kbps needs a C/N0 of 54.3 dBHz, a carrier of about −115 dBm at the receiver input. COM-001 sets the sensitivity 2 dB better than this, so the receiver is not the element that uses up the margin.

Transmitter. 2 W RF from 6.0 W of DC input (total unit draw while transmitting). The carrier frequency is held within ±1.5 kHz over temperature and life so that the ground receiver's acquisition range covers the residual Doppler and the oscillator offset together.

16.3 UHF Antenna

The UHF Antenna is a deployable turnstile: four tape-spring monopoles of 17.2 cm (a quarter wavelength at 435.5 MHz) mounted at the corners of one end panel, stowed wrapped around a low-profile base and held by one burn-wire release with two independent heater circuits (SR-8.7). A phasing network feeds the elements in quadrature, which gives near-circular polarization along the antenna axis and near-linear polarization toward the horizon of the antenna. At T+30 min the Flight Software energizes the primary circuit (SM.10); a deployment switch on each element pair confirms deployment, and if confirmation is missing after 60 s the redundant circuit is fired (FSW-031). The cut line is held in a capture channel so that no fragment is released (SR-13.7).

The link budgets carry the antenna as about 0 dBi with a worst-attitude pattern loss of 6.0 dB on the uplink and 3.0 dB on the telemetry downlink, plus 3 dB of polarization loss in both. The two pattern loss values come from different definitions: the uplink must close in any attitude, including the deepest null of the stowed-element pattern and the tumbling attitudes of Detumble (SR-5.7), while the downlink value was taken as the level exceeded over 95 % of the sphere, the share of attitudes in which telemetry is collected in practice. A turnstile on a 6U body has nulls deeper than −3 dBi on a few percent of the sphere, so SR-5.8's "any attitude" with 3 dB is met only if the measured pattern confirms that the deep nulls are confined to that share. COM-007 states both values; the 95 % coverage figure is TBR-52 until the pattern is measured on the flight-representative structure (TC-60). If the measurement shows −6 dBi in the worst attitude also applies to the downlink, the telemetry margin at 10° falls to 0.2 dB below the 3 dB of SR-5.8, which is why SR-5.8 is carried as a watch item.

16.4 S-band Transmitter (EO-1 Lite)

The S-band Transmitter is a single-board transmitter with an integrated 6 dBi right-hand circular patch on the nadir-facing panel. It takes 892-octet transfer frames from the C&DH over IF-08 (SpaceWire, 100 Mbps), randomizes them, adds the LDPC rate 7/8 parity and the 32-bit attached sync marker, and modulates OQPSK at 5.74 Msymbol/s with root-raised-cosine filtering (0.35 roll-off, about 7.8 MHz occupied bandwidth). When no frame is waiting it sends idle frames (ICD-021) so that the station stays locked. It radiates only while its IF-04 branch is powered and a Transmitter Enable Command is active (ICD-019).

The 1 W RF output is produced from 11.5 W of DC input; most of the difference is the power amplifier and the modulator's digital section. Thermal design sizes the unit for 12 min of continuous transmission, which covers the 9 min contact of the power budget with margin; the transmitter is off outside contacts (SR-10.6).

The S-band link has no space-link encryption: the EO-1 Lite service protects its data from the station onward (SR-14.5). Commands to EO-1 Lite are authenticated like those to EO-1 Flight (SR-14.1).

16.5 X-band Payload Radio (EO-1 Flight)

The X-band Payload Radio is a two-board unit, a baseband and encryption board and an RF board with a solid-state power amplifier, with a 16 dBi right-hand circular patch array (four by four elements) on the nadir-facing panel. Its half power beamwidth is about 25°, so it must be pointed at the station during the pass (AP-5 Ground Station Tracking, SR-2.10). It takes frames from the C&DH over IF-08.1 (SpaceWire, 200 Mbps), encrypts each frame's data field, applies randomization, LDPC rate 7/8 coding and the attached sync marker, and modulates OQPSK at 57.4 Msymbol/s (about 78 MHz occupied bandwidth). 2 W RF output is produced from 15.0 W of DC input. The thermal design covers 12 min of continuous transmission, against 7 min usable passes inside a 9 min contact.

Frame encryption. The radio applies CCSDS 355.0-B authenticated encryption to the data field of each frame with a 256-bit session key (SR-4.4, ICD-036). The transfer frame primary header, which carries the spacecraft identifier, virtual channel and frame count, stays in clear so that the station can sort and count frames without keys. The security header carries the key identifier and the initialization vector; the trailer carries the 128-bit message authentication code, which the Mission Operations Center checks before it accepts the frame. The security fields take 30 octets of each 892-octet frame (3.4 %); with the frame, packet and file protocol headers this uses about the 6 % overhead that the data volume budget's 0.94 framing factor allows.

Keys. The radio holds one key-encryption key, installed at integration in its protected memory, and the current session key. For each pass the C&DH sends the active downlink key from its key store wrapped under the key-encryption key (CDH-014), and the radio unwraps it internally. The radio's key memory cannot be read over IF-08.1 or in telemetry, and a zeroize command erases both keys; the end-of-mission passivation erases the keys in the radio and in the C&DH.

16.6 Link Budgets

The link budgets below are computed for the design elevations: 10° for the payload downlinks and the UHF telemetry downlink, 5° for the UHF command uplink, which must close earlier in the pass and in any attitude.

S-band payload downlink (EO-1 Lite)

Item	Value
Frequency	2,245.0 MHz
Transmitter RF power	1 W (0.0 dBW)
Transmit antenna gain	6.0 dBi
Transmit line and connector loss	1.5 dB
EIRP	4.5 dBW
Elevation / slant range	10 deg / 1,695 km
Free-space path loss	164.0 dB
Spacecraft antenna pointing loss	1.0 dB
Atmospheric and rain loss	0.4 dB

Item	Value
Polarization loss	0.3 dB
Ground antenna pointing loss	0.5 dB
Receive G/T	14.0 dB/K
Boltzmann constant	-228.6 dBW/K/Hz
C/N0	80.9 dBHz
Information rate	10 Mbps
Eb/N0 received	10.9 dB
Eb/N0 required	4.2 dB (OQPSK, LDPC rate 7/8, FER 1e-6)
Implementation loss	2.0 dB
Margin	**4.7 dB**

X-band payload downlink (EO-1 Flight)

Item	Value
Frequency	8,200.0 MHz
Transmitter RF power	2 W (3.0 dBW)
Transmit antenna gain	16.0 dBi
Transmit line and connector loss	1.2 dB
EIRP	17.8 dBW
Elevation / slant range	10 deg / 1,695 km
Free-space path loss	175.3 dB
Spacecraft antenna pointing loss	1.5 dB
Atmospheric and rain loss	1.2 dB
Polarization loss	0.3 dB
Ground antenna pointing loss	0.6 dB
Receive G/T	26.4 dB/K
Boltzmann constant	-228.6 dBW/K/Hz
C/N0	93.9 dBHz
Information rate	100 Mbps
Eb/N0 received	13.9 dB
Eb/N0 required	4.2 dB (OQPSK, LDPC rate 7/8, FER 1e-6)
Implementation loss	2.0 dB
Margin	**7.7 dB**

UHF command uplink

Item	Value
Frequency	435.5 MHz
Transmitter RF power	50 W (17.0 dBW)
Transmit antenna gain	14.0 dBi

Item	Value
Transmit line and connector loss	2.0 dB
EIRP	29.0 dBW
Elevation / slant range	5 deg / 2,078 km
Free-space path loss	151.6 dB
Spacecraft antenna pattern loss (worst attitude)	6.0 dB
Atmospheric and ionospheric loss	1.5 dB
Polarization loss	3.0 dB
Spacecraft line loss	1.0 dB
Receive G/T	-29.0 dB/K
Boltzmann constant	-228.6 dBW/K/Hz
C/N0	65.5 dBHz
Information rate	9.6 kbps
Eb/N0 received	25.7 dB
Eb/N0 required	12.5 dB (GMSK, uncoded, BER 1e-6)
Implementation loss	2.0 dB
Margin	**11.2 dB**

UHF telemetry downlink

Item	Value
Frequency	435.5 MHz
Transmitter RF power	2 W (3.0 dBW)
Transmit antenna gain	0.0 dBi
Transmit line and connector loss	1.0 dB
EIRP	2.0 dBW
Elevation / slant range	10 deg / 1,695 km
Free-space path loss	149.8 dB
Spacecraft antenna pattern loss (worst attitude)	3.0 dB
Atmospheric and ionospheric loss	1.5 dB
Polarization loss	3.0 dB
Receive G/T	-15.8 dB/K
Boltzmann constant	-228.6 dBW/K/Hz
C/N0	57.5 dBHz
Information rate	9.6 kbps
Eb/N0 received	17.7 dB
Eb/N0 required	12.5 dB (GMSK, uncoded, BER 1e-6)
Implementation loss	2.0 dB
Margin	**3.2 dB**

Link budgets at the design elevations

Link	Margin	Required	Requirement	Comment
S-band downlink, 10°	4.7 dB	3 dB [TBR-04]	SR-5.3	TBR-04 closes with the partner stations' measured G/T and the flight antenna pattern
X-band downlink, 10°	7.7 dB	3 dB	SR-5.6	Rain loss at X-band is taken as 1.2 dB; margin allows heavy rain at the mid-latitude station
UHF command uplink, 5°, any attitude	11.2 dB	6 dB	SR-5.7	Includes the 6 dB worst-attitude pattern loss
UHF telemetry downlink, 10°, any attitude	3.2 dB	3 dB	SR-5.8	Watch item: depends on the antenna pattern measurement (TBR-52)

Link margin summary

The usable part of a pass is set by the elevation mask. From 500 km an overhead pass stays above 5° for about 9.2 min, above 7° for about 8.4 min and above 10° for about 7.4 min; lower passes are shorter. The 9 min contact of the power budget is therefore the 5°-to-5° part of a near-overhead pass, which the UHF link (closing from 5°) uses in full. The data volume budget's 8 min of S-band transfer extends below 10° at both ends of the pass, down to about 7°, where the slant range of about 1,910 km costs about 1.1 dB and the S-band margin is still about 3.5 dB. The 7 min of X-band transfer above 10° is reached only on passes within a few degrees of the zenith. Contact selection therefore favors high passes, and the daily capacity on a day with only low passes is lower than the budget value (see Ground Segment Specification, "Contact Planning").

16.7 Protocols

The protocol profile is that of STD-2 and is detailed in the Flight Software Specification ("Command and Telemetry") and the Interface Requirements chapter (IF-07, IF-08, IF-08.1, IF-11, IF-12, IF-12.1). From the radios' point of view:

- the UHF Transceiver is transparent to the TC and TM frames: it removes and adds the CLTU and frame synchronization only;
- the payload downlink radios add randomization, LDPC coding and the attached sync marker (CCSDS 131.0-B), and the X-band radio adds the frame security processing (CCSDS 355.0-B); frame building, virtual channel multiplexing and CFDP are done in the C&DH;
- the ground link acknowledgment that guard G-LF monitors (Operational Modes) arrives on the UHF uplink every 10 s while the station holds lock on the payload downlink, and the payload downlink radio reports its own synthesizer lock to the C&DH; either indication lost for 60 s in a contact window satisfies G-LF.

16.8 Link Security

Protection	Link	Configuration	Mechanism	Requirement
Command authentication	UHF uplink	All	CCSDS 355.0-B authentication of every TC frame, checked in the C&DH	SR-14.1, FSW-005
Replay protection	UHF uplink	All	Security sequence number, stored before execution	SR-14.2, FSW-006
Critical command arming	UHF uplink	All	Arm command within 60 s (600 s for decommissioning)	SR-14.9, SR-10.19
Downlink confidentiality and integrity	X-band downlink	Flight	CCSDS 355.0-B authenticated encryption per frame, 256-bit session key	SR-4.4, ICD-036
Downlink protection from the station onward	IF-13	Lite (and Flight, as a second layer)	Authenticated encryption on the ground network	SR-14.5
Telemetry on UHF	UHF downlink	All	Not encrypted; housekeeping only, no imagery	—

Link security measures

UHF telemetry is not encrypted: it carries housekeeping and the beacon, which the ground must be able to read in any condition, including after a key loss. No image data ever travels on UHF.

16.9 Spectrum Coordination

Each transmitter operates under the program's frequency assignments, which the Frequency Management Plan (EO1-PLN-380) tracks from filing to license. The steps for each band are: an advance publication and coordination filing with the ITU through the national administration, coordination with the administrations of the partner stations' countries, the national space station license for each frequency, and the license conditions recorded as transmitter parameters (center frequency, occupied bandwidth, maximum EIRP, permitted pass geometry). The S-band license is the longest lead item and is carried as risk RK-4 (S-band License Delay).

Band	Assigned frequency	Allocation used	Bandwidth	Configuration	Status
UHF	435.5 MHz [TBR-71]	Space operation (telecommand and telemetry), as filed	25 kHz channel	All	Coordination in progress
S-band	2,245.0 MHz	Space-to-Earth allocation in 2,200–2,290 MHz	8 MHz	Lite	License pending (RK-4)

Band	Assigned frequency	Allocation used	Bandwidth	Configuration	Status
X-band	8,200.0 MHz	Earth exploration-satellite (space-to-Earth) in 8,025–8,400 MHz	80 MHz	Flight	Coordinated

Frequency assignments

The power flux density at the Earth's surface stays below the ITU Radio Regulations limits for both payload downlinks. With the antenna pointed at a station at the zenith (500 km), the S-band downlink gives about −153 dB(W/m²) in 4 kHz against a limit of −144, and the X-band downlink about −150 against −140 (ICD-035). At low arrival angles the longer range lowers the flux by more than the limit falls, so the margin is at least 9 dB for S-band and 10 dB for X-band at every angle. The transmitters radiate only inside scheduled contacts (SR-10.6), stop within 10 s of a transmitter-off command (SR-5.11) and are permanently disabled at end of mission (SR-13.6).

16.10 Requirements

COM-001 UHF Receiver Sensitivity · Verify: Test · Trace: SR-5.7 · Applies: All · Alloc: 1.5.1

The UHF Transceiver shall demodulate the uplink with a bit error rate of at most 1×10^{-6} at a received signal level of −117 dBm or lower.

Rationale: The uplink budget's G/T of −29.0 dB/K and its required Eb/N0 with implementation loss correspond to about −115 dBm; −117 dBm keeps 2 dB in the receiver so the budget's 11.2 dB margin is not consumed by the unit (TC-11, TC-59).

COM-002 UHF Transmit Power · Verify: Test · Trace: SR-5.8 · Applies: All · Alloc: 1.5.1

The UHF Transceiver shall deliver 2 W ± 0.5 dB of RF power at its antenna port over its operating temperature range.

Rationale: The telemetry downlink budget assumes 2 W and closes with only 3.2 dB margin; a power shortfall of more than 0.5 dB would breach the 3 dB of SR-5.8 (TC-59).

COM-003 UHF Transceiver Power Draw · Verify: Test · Trace: SR-3.9 · Applies: All · Alloc: 1.5.1

The UHF Transceiver shall draw no more than 1.0 W while receiving and no more than 6.0 W in total while transmitting.

Rationale: The values of all three power budgets; the receiver runs continuously, so its draw is the largest communications term in Safe Mode.

COM-004 UHF Receiver Always Available · Verify: Test, Inspection · Trace: SR-3.11, SR-5.7 · Applies: All · Alloc: 1.5.1

The UHF Transceiver receiver shall be powered in every mode from separation + 30 min to Decommissioned, including after a hardware undervoltage disconnect.

Rationale: The receiver is the only command path; SR-3.11 keeps it powered through a load shed so the ground can command recovery in any condition.

COM-005 UHF Turnaround Time · Verify: Test · Trace: SR-5.2, SR-12.3 · Applies: All · Alloc: 1.5.1

The UHF Transceiver shall switch between transmitting and receiving within 20 ms.

Rationale: The half-duplex channel alternates telemetry and the station's acknowledgments during a pass; at 9.6 kbps 20 ms is 24 octets, so frequent turnarounds cost little channel time.

COM-006 UHF Transmit Frequency Stability · Verify: Test · Trace: SR-5.10 · Applies: All · Alloc: 1.5.1

The UHF Transceiver shall hold its transmitted carrier within ±1.5 kHz of the assigned frequency over its operating temperature range and the 730-day life.

Rationale: Keeps the emission inside the 25 kHz assigned channel together with the ±11 kHz Doppler and the GMSK occupied bandwidth of about 10 kHz (TC-59).

COM-007 UHF Antenna Coverage · Verify: Test, Analysis · Trace: SR-5.7, SR-5.8 · Applies: All · TBR: TBR-52 · Alloc: 1.5.4

The deployed UHF Antenna shall have a gain of at least −6 dBi over the whole sphere and at least −3 dBi over at least 95 % [TBR] of the sphere, in any polarization sense, when mounted on the spacecraft.

Rationale: −6 dBi everywhere is the 6 dB worst-attitude loss of the uplink budget (SR-5.7); −3 dBi is the 3 dB assumed for the telemetry downlink (SR-5.8). TBR-52 closes when the pattern is measured on a flight-representative structure model with deployed arrays (TC-60).

COM-008 UHF Antenna Deployment · Verify: Test · Trace: SR-8.7, SR-3.6 · Applies: All · Alloc: 1.5.4

The UHF Antenna shall deploy all four elements within 60 s of either of its two burn-wire heater circuits being energized.

Rationale: Either circuit alone must release the antenna (SR-8.7); 60 s is the confirmation wait after which the Flight Software fires the redundant circuit (FSW-031) (TC-60).

COM-009 UHF Antenna Deployment Indication · Verify: Test · Trace: SR-10.5 · Applies: All · Alloc: 1.5.4

The UHF Antenna shall report the deployed state of each of its four elements through a deployment switch on IF-19.

Rationale: T3 requires every deployable to report deployed (SR-10.5); a switch per element also tells the ground whether a partial deployment explains a weak signal.

COM-010 UHF Antenna Match · Verify: Test · Trace: SR-5.7, SR-5.8 · Applies: All · Alloc: 1.5.4

The deployed UHF Antenna with its phasing network shall present a voltage standing wave ratio of at most 1.5:1 over 435.5 MHz ± 0.5 MHz.

Rationale: 1.5:1 reflects 4 % of the power (0.2 dB), inside the 1.0 dB line and connector loss of the budgets; the ± 0.5 MHz band covers the frequency still under coordination (TBR-71) and deployed-element tolerances.

COM-011 UHF Release Debris Containment · Verify: Inspection, Test · Trace: SR-13.7 · Applies: All · Alloc: 1.5.4

The UHF Antenna release shall retain both ends of the cut burn-wire line on the spacecraft.

Rationale: A loose line end is a released object (SR-13.7); the capture channel is inspected after each deployment test (TC-60).

COM-012 S-band Transmitter Power Draw · Verify: Test · Trace: SR-3.9 · Applies: Lite · Alloc: 1.5.2

The S-band Transmitter shall draw no more than 11.5 W while transmitting.

Rationale: The value of the EO-1 Lite Nominal Imaging power budget (9 min contact, 1.09 W orbit average); it also keeps IF-04 within 18 W with the UHF transmitter on.

COM-013 S-band Antenna Gain · Verify: Test · Trace: SR-5.3, SR-2.10 · Applies: Lite · Alloc: 1.5.2

The S-band patch antenna shall have a right-hand circular gain of at least 5.0 dBi and an axial ratio of at most 3 dB within 5° of its boresight.

Rationale: The budget's 6 dBi gain less the 1.0 dB pointing loss allocated at the 5° of SR-2.10; 3 dB axial ratio keeps the polarization loss at the budgeted 0.3 dB or less against a circular ground feed (TC-10).

COM-014 S-band Frequency Stability · Verify: Test · Trace: SR-5.10 · Applies: Lite · Alloc: 1.5.2

The S-band Transmitter shall hold its carrier within ±2 ppm of 2,245.0 MHz over its operating temperature range and the 730-day life.

Rationale: ±4.5 kHz is negligible against the 8 MHz assigned bandwidth and the ±56 kHz Doppler the station tracks (TC-59).

COM-015 S-band Power Flux Density · Verify: Analysis · Trace: SR-5.10 · Applies: Lite · Alloc: 1.5.2

The power flux density of the S-band downlink at the Earth's surface shall stay at least 3 dB below the limits of the ITU Radio Regulations for the band at every arrival angle.

Rationale: The analysis gives at least 9 dB below the limit; 3 dB covers antenna pattern and power uncertainty, as for X-band (ICD-035).

COM-016 X-band Radio Power Draw · Verify: Test · Trace: SR-3.9 · Applies: Flight · Alloc: 1.5.3

The X-band Payload Radio shall draw no more than 15.0 W while transmitting.

Rationale: The value of the EO-1 Flight Nominal Imaging power budget (7 min pass, 1.11 W orbit average) and of the IF-04 interlock analysis (ICD-008).

COM-017 X-band Antenna Gain · Verify: Test · Trace: SR-5.6, SR-2.10 · Applies: Flight · Alloc: 1.5.3

The X-band patch array shall have a right-hand circular gain of at least 14.5 dBi and an axial ratio of at most 3 dB within 5° of its boresight.

Rationale: The budget's 16 dBi less the 1.5 dB pointing loss allocated at the 5° of SR-2.10 (TC-21).

COM-018 X-band Frequency Stability · Verify: Test · Trace: SR-5.10 · Applies: Flight · Alloc: 1.5.3

The X-band Payload Radio shall hold its carrier within ±2 ppm of 8,200.0 MHz over its operating temperature range and the 730-day life.

Rationale: ±16.4 kHz is small against the 80 MHz assigned bandwidth and the ±205 kHz Doppler the station tracks (TC-59).

COM-019 X-band Encryption Throughput · Verify: Test · Trace: SR-4.4, SR-5.5 · Applies: Flight · Alloc: 1.5.3

The X-band Payload Radio shall encrypt frames at the full 100 Mbps information rate without dropping or delaying any frame by more than 1 ms.

Rationale: Encryption must not reduce the downlink capacity of 9.87 GB per day that SR-5.4 relies on; a fixed small delay keeps the frame stream continuous for the station (TC-61).

COM-020 X-band Key Protection · Verify: Test, Inspection · Trace: SR-14.3, SR-4.4 · Applies: Flight · Alloc: 1.5.3

The X-band Payload Radio shall accept session keys only wrapped under its key-encryption key, shall make no key readable over IF-08.1 or in telemetry, and shall erase all keys within 1 s of a zeroize command.

Rationale: Keys never cross an interface in clear text (ICD-036); the zeroize command is part of passivation (TC-61).

COM-021 Downlink Implementation Loss · Verify: Test · Trace: SR-5.3, SR-5.6 · Applies: All · Alloc: 1.5.2, 1.5.3

The payload downlink radio shall contribute no more than 1.0 dB of implementation loss at a frame error rate of 1×10^{-6}, measured against an ideal reference receiver.

Rationale: The link budgets carry 2.0 dB of implementation loss for transmitter and ground receiver together; half is allocated to the radio (modulator distortion, phase noise, filtering) (TC-59, TC-62).

COM-022 Continuous Transmission Time · Verify: Test · Trace: SR-6.7, SR-5.4 · Applies: All · Alloc: 1.5.2, 1.5.3

The payload downlink radio shall transmit continuously for at least 12 min, starting from its maximum predicted pre-contact temperature, without exceeding its operating temperature limit.

Rationale: The power budget's contact is 9 min (S-band) or 7 min usable within a 9 min contact (X-band); 12 min allows a long high pass and the start-up time (TC-59).

COM-023 Transmitter Ready Time · Verify: Test · Trace: SR-6.7 · Applies: All · Alloc: 1.5.2, 1.5.3

The payload downlink radio shall transmit valid frames within 10 s of receiving the Transmitter Enable Command with its IF-04 branch powered.

Rationale: Contact time is short; 10 s of start-up keeps the 7 min or 8 min of transfer counted in the data volume budget after the station's acquisition (TC-10, TC-21).

COM-024 Oscillator Short-Term Stability · Verify: Test · Trace: SR-6.8 · Applies: All · TBR: TBR-53 · Alloc: 1.5.2, 1.5.3

The payload downlink radio's reference oscillator shall have an Allan deviation of at most 1×10^{-10} [TBR] at averaging times from 1 s to 100 s.

Rationale: Without a navigation receiver, orbit determination uses one-way Doppler of the payload downlink carrier (SR-6.8); 1×10^{-10} corresponds to about 3 cm/s of range-rate noise. TBR-53 closes with the flight dynamics covariance analysis that sets the Doppler precision the 40 m requirement needs (TC-59).

COM-025 Spurious Emissions · Verify: Test · Trace: SR-5.10 · Applies: All · Alloc: 1.5

Each spacecraft transmitter shall keep its spurious emissions within the limits of the ITU Radio Regulations for space services.

Rationale: A condition of every license; measured at each transmitter's antenna port across the harmonics and the receive band of the UHF Transceiver (TC-59).

COM-026 UHF Receiver Desensitization · Verify: Test · Trace: SR-11.8, SR-5.7 · Applies: All · Alloc: 1.5

The UHF Transceiver sensitivity shall degrade by no more than 1 dB while the payload downlink radio transmits.

Rationale: Commands, CFDP retransmission requests and the link acknowledgments that G-LF monitors arrive on UHF during the payload downlink; 1 dB is within the 6 dB EMC margin of SR-11.8 and costs little of the 11.2 dB uplink margin.

COM-027 Transmitter Permanent Disable · Verify: Test, Inspection · Trace: SR-13.6 · Applies: All · Alloc: 1.5

Each spacecraft transmitter shall provide a disable that, once commanded, no later command or power cycle can reverse.

Rationale: After passivation the arrays still power units in sunlight; a reversible inhibit could be undone by a latent fault for years after the license ends (SR-13.6). Implemented by a one-time fuse in each radio's enable path.

COM-028 RF Exposure · Verify: Analysis · Trace: SR-13.3 · Applies: All · Alloc: 1.5.2, 1.5.3

The power density radiated by the payload downlink antenna shall not exceed 10 W/m^2 at 1 m from the antenna aperture.

Rationale: Controls HAZ-003 during ground tests that radiate: the X-band array gives about 5 W/m^2 at 1 m and the S-band patch about 0.2 W/m^2, so personnel outside 1 m need no further control.

COM-029 Communications Mass · Verify: Inspection · Trace: SR-8.2 · Applies: All · Alloc: 1.5

The communications units of each configuration, including antennas, shall have a total mass of no more than 0.49 kg for EO-1 Lite and 0.64 kg for EO-1 Flight.

Rationale: The mass budget values with contingency (UHF Transceiver 0.093 kg, UHF Antenna 0.046 kg, and 0.352 kg S-band or 0.495 kg X-band); verified by weighing each unit.

16.11 Verification Approach

Each radio is tested at unit level for frequency, power, spectrum, stability, power draw and continuous transmission in thermal vacuum in the RF Characterization Test TC-59 (COM-001 to COM-006, COM-012, COM-014, COM-016, COM-018, COM-021 to COM-025). The UHF Antenna is deployed on a flight-representative structure and its pattern is measured in an anechoic range in the UHF Antenna Pattern and Deployment Test TC-60, which closes TBR-52 (COM-007 to COM-011). X-band frame encryption, throughput and key handling are tested with the Mission Operations Center's decryption software in TC-61 (COM-019, COM-020). Compatibility with the partner stations, from the radios through a station's demodulator, decoder and front-end processor,

is tested in TC-62 with a portable RF test set at the station and with the spacecraft radiating into the station antenna from a test site (COM-021). The system link tests TC-10 (S-band), TC-11 (UHF) and TC-21 (X-band) verify the end-to-end links at the spacecraft level, including the antenna gains COM-013 and COM-017 measured on the integrated spacecraft. COM-015 and COM-028 are closed by analysis from the measured EIRP and pattern; COM-026 by the spacecraft EMC test; COM-027 and COM-029 by inspection and test at the unit acceptance review.

17 Ground Segment Specification

This chapter specifies the Ground Segment (2) as two elements: the Ground Station service (2.1), bought from a partner network, and the Mission Operations Center (2.2), which the program builds and runs. The people who operate it, the Mission Operator (2.3), and their procedures are in the Mission Operations Specification. The ground segment performs F11 Process and Deliver Images (F11.1 at the stations, F11.2 to F11.7 at the operations center) and the ground parts of UC.1 to UC.6; it realizes the ground ends of IF-10 to IF-14.1 and IF-25, whose characteristics are in the Interface Requirements chapter (ICD-037 to ICD-040 among them).

The ground segment is shared by the whole product line: the same stations and the same operations center serve the two EO-1 Flight spacecraft and every EO-1 Lite spacecraft. Configuration differences are in the station service (three stations for EO-1 Flight and the EO-1 Lite three-station option, one station for the EO-1 Lite one-station plan) and in the handling of encrypted X-band data.

17.1 Ground Station Service

17.1.1 Stations and Service Plans

The program buys pass time from a partner ground station network under a service agreement. Three stations are under contract (Mission Overview and Concept of Operations, “Partner station network”): Station A at high northern latitude, the main command station with the most passes per day; Station B at mid latitude, downrange of the customer’s main farm region, for fast-cycle downlinks after the morning imaging orbits; and Station C in the southern hemisphere, for night passes and southern targets. Each has a 3.7 m S/X-band dish and a UHF yagi antenna, so every station can command either configuration and receive either payload downlink.

Characteristic	Value	Link budget use
Dish	3.7 m, S-band and X-band feeds, right-hand circular	—
S-band receive G/T at 10° elevation	14.0 dB/K	S-band downlink
X-band receive G/T at 10° elevation	26.4 dB/K	X-band downlink
Dish beamwidth (3 dB)	about 2.5° at S-band, 0.7° at X-band	Ground antenna pointing loss 0.5 dB (S), 0.6 dB (X)
Tracking	Program track from predictions, with monopulse autotrack on the downlink carrier	—
UHF antenna	Crossed yagi, 14.0 dBi, switchable circular polarization	UHF uplink and telemetry
UHF transmitter	50 W, uplink EIRP 29.0 dBW	UHF command uplink
UHF receive G/T	−15.8 dB/K	UHF telemetry downlink
Demodulation and decoding	GMSK (UHF); OQPSK with LDPC rate 7/8 decoding and frame synchronization (S, X)	—

Characteristic	Value	Link budget use
Time reference	Station clock disciplined to UTC by satellite navigation	Time correlation, tracking data

Partner station characteristics

Service plan	Stations	Payload downlink passes per day	UHF contacts per day	Daily downlink capacity
EO-1 Flight	A, B, C	2 X-band, 7 min	at least 4	9.87 GB
EO-1 Lite, three-station option	A, B, C	6 S-band, 8 min	at least 4	3.38 GB
EO-1 Lite, one-station plan	one of A, B, C [TBD-05]	2 S-band, 8 min	at least 2	1.13 GB

Ground station service plans (contact plans of the concept of operations)

17.1.2 Pass Execution

Every pass is flown unattended from the contact schedule that the Mission Operations Center sends to the network 48 h ahead (SR-6.1, SR-6.10). For each pass the station:

1. points the dish and the yagi from the pass prediction, acquires the UHF beacon or telemetry and, for a payload downlink contact, the downlink carrier, then changes to autotrack;
2. uplinks the authenticated command files received from the operations center (the station holds no command keys, ICD-038) and relays the station's link acknowledgment every 10 s while it holds lock on the payload downlink (the acknowledgment that guard G-LF monitors);
3. demodulates and decodes the payload downlink, synchronizes the frames, records the frame stream and the raw baseband, and forwards the frames to the operations center over IF-13 as they arrive;
4. collects tracking data: antenna angles, one-way Doppler of the payload downlink and UHF carriers, and the UTC time stamps of named telemetry frames for time correlation;
5. at the end of the pass, sends a pass report (acquisition and loss times, frames received, frame error count, link quality) and completes the transfer of the pass data within 30 min of the end of the contact (SR-12.4).

A pass that fails (station fault, no acquisition) is reported by the station as a missed pass within 5 min of its scheduled end, which starts the contact loss procedure at the operations center.

17.1.3 File Reception

Files arrive by CFDP in acknowledged mode (SR-12.3). Retransmission requests for missing segments are sent during the pass, so that most gaps are filled before the pass ends; the confirmation that lets the spacecraft delete a file (SR-10.28) is released only after the operations center holds the file intact and reaches the spacecraft on a later UHF contact (IF-13, Interface Requirements).

Where the in-pass retransmission requests are generated depends on the configuration. On EO-1 Lite the frames are not encrypted on the space link, and the station's CFDP entity detects gaps and sends the requests directly. On EO-1 Flight the frame data fields are encrypted and the station

holds no downlink keys, so the station cannot read the file segments; it forwards the frames to the operations center as they arrive, and the operations center's CFDP entity, after decryption, sends the retransmission requests back through the station's UHF uplink. The 100 Mbps ground network (ICD-037) matches the X-band rate, so the forwarding delay stays at a few seconds during the pass.

17.1.4 Contact Planning

Pass length depends on the pass geometry: an overhead pass at 500 km gives about 7.4 min above 10° and 9.2 min above 5°, a low pass much less. The data volume budget's 7 min X-band and 8 min S-band transfers assume near-overhead passes (the S-band transfer extending to about 7° elevation at each end, Communications Specification, "Link Budgets"). Flight dynamics ranks the predicted passes of each station by their usable transfer time, and the planner books the highest passes for payload downlinks and the remaining passes for UHF contacts. Over a three-day repeat cycle each station sees a different set of passes, so the daily downlink capacity varies; the planner tracks the predicted storage backlog and sets the daily target list so that the backlog does not grow over a cycle.

17.2 Mission Operations Center

17.2.1 Functions

The Mission Operations Center runs the planning, commanding, telemetry, flight dynamics, image processing, archive and customer portal functions. It is built as separate services on two hosting sites, a primary and a backup, with the archive replicated between them.

Function	Main tasks	Model function	Main requirements
Tasking and portal	Receive tasking requests and product specifications through the portal and the machine interface; show predicted collection; publish products and alerts; notify customers	UC.1, UC.4, F11.5	SR-12.5, SR-12.6, SR-14.6, SR-14.7, SR-15.4
Mission planning	Build the 24 h imaging plan from open requests, check it against the constraint model, book contacts, produce command files	UC.2, OPS.1 preparation	SR-6.1, SR-6.4, SR-6.6
Flight dynamics	Orbit determination, pass prediction, orbit state for uplink, attitude target computation, conjunction screening	Supports UC.2, F11.3	SR-6.8
Commanding	Command database, procedure execution, authentication of command frames, critical command release	OPS.1	SR-14.1, SR-14.9

Function	Main tasks	Model function	Main requirements
Telemetry and monitoring	Frame processing, decommutation, limit checking, trending, alarms, on-call notification	UC.5	SR-6.3, SR-6.9
Image processing	Levels L0 to L2 (below), calibration, quality assessment	F11.1 (ground part) to F11.4	SR-1.9 to SR-1.12, SR-6.2, SR-6.12, SR-6.13
Archive	Telemetry, raw data, products, audit records	F11.6	SR-6.3, SR-14.8
Collection reporting	Targets imaged, delivered and missed, for replanning	F11.7	SR-6.5

Mission Operations Center functions

17.2.2 Planning

The planner proposes the next 24 h of targets from all open requests, weighted by priority, deadline and the time since each field was last collected. It computes each target's start time, strip length and off-nadir angle from the latest orbit, checks the plan against the same constraint model the spacecraft applies onboard (power, thermal, pointing keep-out, storage, contact windows, mode), and produces the schedule entries, the target table, the contact windows and the orbit state for uplink (Flight Software Specification, "Command Schedule"). The operator reviews, adjusts and approves the plan within the 20 min of SR-6.4. Tasking requests that arrive after the daily plan and at least 2 h before an uplink contact go up as a late update of individual entries (SR-6.6).

For EO-1 Lite on the one-station plan, the planner caps the daily list at what two passes can carry (about 40 scenes) in the customer's priority order (SR-1.5).

17.2.3 Flight Dynamics

The spacecraft carries no navigation receiver. Orbit determination uses the stations' tracking data (one-way Doppler of the payload downlink and UHF carriers, antenna angles) and the along-track and cross-track offsets found when products are registered to the reference image base, which tie the orbit to known ground positions. A new orbit solution is produced every day and its orbit state is uplinked in the plan, which the ADCS propagates for up to 26 h (ADCS-016). Flight dynamics also predicts passes for 72 h, produces the contact windows, and screens the orbit daily against the public catalog of tracked objects; the spacecraft cannot maneuver, so a close approach is reported to the other operator and the coordination service.

17.2.4 Image Processing Chain

Level	Product	Processing	Function
L0	Reconstructed instrument data	Frames decrypted (EO-1 Flight) and checked; files reassembled; strips decompressed; lines in time order with ancillary data; segment quality map	F11.1

Level	Product	Processing	Function
L1A	Calibrated radiance, sensor geometry	Dark offset and flat-field correction, defective pixel replacement, conversion to top-of-atmosphere radiance with the current calibration coefficients, coefficient version recorded (SR-6.13)	F11.2
L1B	Orthorectified radiance	Line-by-line geometric model from attitude, orbit and time; registration to the reference image base; orthorectification with the elevation model; band-to-band registration (SR-1.11); resampling to 4.5 m in the local map projection; cloud mask	F11.3
L2A	Surface reflectance	Atmospheric correction with aerosol and water vapor from the scene and from weather analyses	F11.4
L2B	Crop products	Normalized difference vegetation index map at 4.5 m (SR-6.12); field-level stress indicators; crop stress alerts for the customer's alert regions	F11.4

Image processing levels

Products are delivered as GeoTIFF files with band, calibration and acquisition metadata (SR-12.5); about 240 MB per scene for the delivered L1B, L2A and L2B set. Alert-region files (downlink priority 0) are processed first; for them the chain runs in about 45 min from receipt at the operations center: L0 about 3 min, L1A 5 min, L1B 20 min (the registration is the longest step), L2 12 min, publication and quality check 5 min. This is the processing time of the 85 min fast planning cycle in the concept of operations.

Calibration. The calibration function keeps the radiometric coefficients of each band. It uses the prelaunch laboratory calibration as the starting point, the commissioning calibration (step C6) as the in-orbit baseline, monthly lunar images (SR-1.14) for trending, and vicarious calibration sites for absolute checks. When a band's trend departs by more than 0.5 % from the coefficients in use, a new coefficient set is issued with a new version number; products made with the old version are reprocessed on customer request or in the quarterly reprocessing.

17.2.5 Archive

The archive holds every telemetry frame for 730 days (SR-6.3), every L0 file and every delivered product for the mission, the command history and the security audit log (SR-14.8). Sizing for the first phase (two EO-1 Flight spacecraft at full collection and one EO-1 Lite on the one-station plan): about 7.6 GB of compressed downlink data and about 68 GB of products per day, or about 55 TB over 730 days, held in two copies on the two hosting sites.

17.2.6 Security

The operations center is divided into three zones. The command zone (commanding, key management, the flight software and table build environment) has no direct internet connection; it reaches the stations only over IF-13 and the rest of the operations center only through a gateway that passes approved file types. The processing zone holds the image processing chain and the archive. The customer zone holds the portal and the machine interface. Command frames are authenticated in the command zone with keys held in a hardware security module, which also holds the downlink decryption keys of EO-1 Flight (SR-4.4) and generates new keys for rotation (SR-14.4, TBR-20). Every operator and customer sign-in uses multi-factor authentication (SR-14.6 for customers), and every command uplink and product download is recorded with the user's identity (SR-14.8).

17.2.7 Availability

Service	Target	Basis
Customer portal and machine interface	99.5 % per 30 days	SR-15.4
Command and telemetry functions	Restored at the backup site within 4 h of a primary site failure	SR-15.3: a lost day of commanding costs a day of imaging
Image processing	Full day's collection processed within 4 h of receipt	SR-6.2 with margin for backlogs
Station pass success	98 % [TBR-55] of booked passes per 30 days	Service agreement

Ground segment availability targets

The spacecraft stores 20 days of compressed collection and holds a 72 h schedule, so a ground outage of hours costs latency, not data. An operations center outage longer than 72 h without any command would let G-CL put the spacecraft in Safe Mode; the 4 h restoration target keeps that far away.

17.3 Requirements

> **GND-001 S-band Receive G/T** · Verify: Test · Trace: SR-5.3 · Applies: Lite · Alloc: 2.1
>
> Each station used for S-band downlinks shall provide a receive G/T of at least 14.0 dB/K at 10° elevation.
>
> *Rationale:* The value assumed in the S-band link budget (4.7 dB margin). TBR-04 of SR-5.3 closes with the partner's measured values, which TC-62 confirms at each station.

GND-002 X-band Receive G/T · Verify: Test · Trace: SR-5.6 · Applies: Flight · Alloc: 2.1

Each station used for X-band downlinks shall provide a receive G/T of at least 26.4 dB/K at 10° elevation.

Rationale: The value assumed in the X-band link budget (7.7 dB margin), confirmed at each station in TC-62.

GND-003 UHF Uplink EIRP · Verify: Test · Trace: SR-5.7 · Applies: All · Alloc: 2.1

Each station shall radiate the UHF command uplink with an EIRP of at least 29.0 dBW.

Rationale: 50 W into a 14.0 dBi yagi with 2.0 dB of line loss, as in the uplink budget that gives 11.2 dB margin at 5° elevation in any attitude.

GND-004 UHF Receive G/T · Verify: Test · Trace: SR-5.8 · Applies: All · Alloc: 2.1

Each station shall provide a UHF receive G/T of at least −15.8 dB/K at 10° elevation.

Rationale: The telemetry downlink closes with only 3.2 dB margin; the station value cannot be lower than budgeted.

GND-005 Dish Tracking Error · Verify: Test · Trace: SR-5.6, SR-5.3 · Applies: All · Alloc: 2.1

Each station shall keep its dish pointed within 0.15° of the spacecraft during every pass above 10° elevation, including passes through the zenith.

Rationale: 0.15° is about a fifth of the 0.7° X-band beamwidth and gives the 0.6 dB ground pointing loss of the X-band budget; the S-band beam is wider, so its 0.5 dB is met with margin. Zenith passes need a mount or tracking mode that avoids the azimuth keyhole.

GND-006 Three-Station Service · Verify: Inspection, Demonstration · Trace: SR-6.7, SR-5.4 · Applies: Flight · Alloc: 2.1

The ground station service shall provide EO-1 Flight with passes at three stations, one at high northern latitude, one at mid latitude and one in the southern hemisphere.

Rationale: Spread stations give at least two high passes per day for the 7 min X-band transfers and keep night and southern-hemisphere coverage (TC-12).

GND-007 One-Station Service · Verify: Demonstration, Analysis · Trace: SR-5.4.1 · Applies: Lite · Alloc: 2.1

On the EO-1 Lite one-station plan, the designated station shall provide at least two S-band passes per day with at least 8 min of transfer time each.

Rationale: Two 8 min passes carry 1.13 GB per day against the 1 GB of SR-5.4.1. The station is still to be chosen (TBD-05); the choice must give two near-overhead passes on most days, which favors a high-latitude site.

GND-008 Pass Success Rate · Verify: Analysis, Demonstration · Trace: SR-6.7 · Applies: All · TBR: TBR-55 · Alloc: 2.1

The ground station service shall execute at least 98 % [TBR] of booked passes in each 30-day period.

Rationale: With two downlink passes per day, a lower success rate would delay deliveries on several days a month. TBR-55 closes when the service agreement's availability figures are final.

GND-009 Unattended Pass Execution · Verify: Demonstration · Trace: SR-6.10, SR-6.9 · Applies: All · Alloc: 2.1

Each station shall start every booked pass from the contact schedule without operator action and report the pass result to the Mission Operations Center within 5 min of the end of the pass.

Rationale: Most passes fall outside the day shift (SR-6.10); a prompt pass report lets the operations center alert the on-call operator within the 5 min of SR-6.9 when a pass fails (TC-12, TC-20).

GND-010 Ground Link Acknowledgment · Verify: Test · Trace: SR-10.8 · Applies: All · Alloc: 2.1

While it holds lock on a payload downlink, each station shall transmit a ground link acknowledgment to the spacecraft over the UHF uplink every 10 s.

Rationale: The spacecraft starts Downlink Contact on the first acknowledgment (T4) and enters Safe Mode when they stop for 60 s (G-LF, SR-10.8); a missed acknowledgment cadence on the ground would cause a false Safe Mode entry (TC-62).

GND-011 In-Pass Retransmission · Verify: Test · Trace: SR-12.3 · Applies: All · Alloc: 2.1, 2.2

During a payload downlink pass, the ground segment shall send a retransmission request for each detected gap in a file within 60 s of detecting it.

Rationale: Gaps from low-elevation fades are filled in the same pass when the request goes up quickly; on EO-1 Flight the request comes from the operations center through the station, which the forwarding delay of a few seconds allows.

GND-012 Pass Recording Retention · Verify: Inspection, Demonstration · Trace: SR-12.4, SR-6.2 · Applies: All · Alloc: 2.1

Each station shall keep the frame recording of every pass for at least 7 days.

Rationale: If an IF-13 transfer fails or a file is found damaged in processing, the station can resend it without waiting for a retransmission from the spacecraft; 7 days covers a long weekend and a slow investigation.

GND-013 Station Time Reference · Verify: Test · Trace: SR-4.7 · Applies: All · Alloc: 2.1

Each station shall time-stamp received telemetry frames within 10 μs of UTC.

Rationale: The time correlation contributes 0.1 ms to the 2 ms onboard time budget; 10 μs at the station leaves the rest for the light-time correction from the orbit.

GND-014 Planning Constraint Model · Verify: Test, Inspection · Trace: SR-10.22, SR-6.4 · Applies: All · Alloc: 2.2

The mission planning function shall check each plan against a constraint model generated from the same constraint table version that is loaded on the spacecraft.

Rationale: If the ground and onboard checks differ, plans built in the 20 min of SR-6.4 would have entries rejected onboard and targets lost; one source table keeps them identical (TC-56).

GND-015 Candidate Plan Generation · Verify: Demonstration · Trace: SR-6.4, SR-6.5 · Applies: All · Alloc: 2.2

The mission planning function shall produce a constraint-checked candidate 24 h plan for each spacecraft within 5 min of the daily tasking cutoff.

Rationale: The operator's 20 min (SR-6.4) is for review and adjustment, not for building the plan by hand (TC-20).

GND-016 Pass Prediction Accuracy · Verify: Analysis, Demonstration · Trace: SR-6.1 · Applies: All · Alloc: 2.2

Flight dynamics shall predict acquisition and loss times for each station within 5 s for passes up to 72 h ahead.

Rationale: Contacts are booked 48 h ahead (SR-6.1) and the contact windows go into a 72 h schedule; 5 s keeps the window guards short and the transfer time near the budget value.

GND-017 Daily Orbit Solution · Verify: Demonstration · Trace: SR-6.8, SR-2.1 · Applies: All · Alloc: 2.2

Flight dynamics shall produce a new orbit solution and an orbit state for uplink for each spacecraft at least once every 24 h.

Rationale: The ADCS propagates the uplinked state for up to 26 h within its error allocation (ADCS-016); a daily solution keeps every target inside the propagation interval (TC-20).

GND-018 Limit Checking Latency · Verify: Demonstration · Trace: SR-6.9 · Applies: All · Alloc: 2.2

The Mission Operations Center shall check each received housekeeping parameter against its limits within 30 s of receiving it.

Rationale: Leaves most of the 5 min of SR-6.9 for the notification path to reach the on-call operator.

GND-019 Priority Product Latency · Verify: Demonstration · Trace: SR-6.5, SR-6.2 · Applies: All · TBR: TBR-54 · Alloc: 2.2

The Mission Operations Center shall publish the L2B products of each priority 0 file within 60 min [TBR] of receiving the file.

Rationale: The 85 min fast planning cycle counts 45 min of processing; 60 min keeps the cycle inside the 100 min of SR-6.5 when the transfer and coast steps run long. TBR-54 closes when the atmospheric correction step has been timed on the production processing system (TC-63).

GND-020 Processing Capacity · Verify: Test, Demonstration · Trace: SR-6.2 · Applies: All · Alloc: 2.2

The Mission Operations Center shall process one day's collection of all operating spacecraft from L0 to L2B within 4 h of receiving it.

Rationale: About 280 scenes a day in the first phase; 4 h keeps a backlog after a missed pass within the 6 h of SR-6.2 (TC-12, TC-63).

GND-021 Elevation Model Accuracy · Verify: Inspection, Analysis · Trace: SR-1.12 · Applies: All · Alloc: 2.2

The image processing chain shall orthorectify products with an elevation model of 10 m (LE90) vertical accuracy or better over the customer's target regions.

Rationale: At 25° off nadir a 10 m height error displaces a ground point by about 5 m, a small share of the 20 m geolocation requirement.

GND-022 Reference Image Registration · Verify: Test, Analysis · Trace: SR-1.12, SR-1.11 · Applies: All · Alloc: 2.2

The image processing chain shall register each L1B product to the reference image base with at least 20 matched control points per scene, and shall flag any product registered with fewer.

Rationale: Attitude knowledge alone gives about 200 m (SR-1.12 rationale); registration is what meets 20 m. Cloudy scenes may lack control points, and a flagged product tells the customer its geolocation is the unregistered one. The accuracy of the reference image base itself is TBR-16 (TC-63).

GND-023 Calibration Trending · Verify: Demonstration, Analysis · Trace: SR-1.10 · Applies: All · Alloc: 2.2

The calibration function shall compute each band's response trend from lunar and vicarious calibration data at least once per lunar cycle, and shall issue new coefficients when the trend departs from the coefficients in use by more than 0.5 %.

Rationale: Updating at 0.5 % keeps the calibrated response within the 2 % stability of SR-1.10 with room for the trend uncertainty.

GND-024 Reprocessing · Verify: Demonstration · Trace: SR-6.13, SR-1.10 · Applies: All · Alloc: 2.2

The image processing chain shall reprocess archived L0 data with a new coefficient version at a rate of at least 500 scenes per day alongside routine processing.

Rationale: A coefficient change after a season would otherwise leave earlier products on the old calibration; 500 scenes a day reprocesses a month of one spacecraft's collection in about a week.

GND-025 Archive Retention · Verify: Inspection, Demonstration · Trace: SR-6.3, SR-14.8 · Applies: All · Alloc: 2.2

The Mission Operations Center shall keep every telemetry frame, L0 file, delivered product and audit record for at least 730 days in two copies at separate sites.

Rationale: SR-6.3 and SR-14.8 require 730 days; the second copy protects against a site loss. About 55 TB per copy for the first phase.

GND-026 Key Protection · Verify: Inspection, Test · Trace: SR-14.1, SR-14.4, SR-4.4 · Applies: All · Alloc: 2.2

The Mission Operations Center shall hold every command authentication and downlink decryption key in a hardware security module, from which no key is exported in clear text.

Rationale: The keys protect commanding (SR-14.1) and EO-1 Flight imagery (SR-4.4); generating, rotating (SR-14.4) and using them inside the module limits exposure to the module itself (TC-64).

GND-027 Two-Person Critical Command Release · Verify: Demonstration · Trace: SR-14.9 · Applies: All · Alloc: 2.2

The commanding function shall release a critical command for uplink only after a second certified operator has approved it on the operations console.

Rationale: The onboard arm-and-execute sequence (SR-14.9) protects against a single error in the uplink; a second person on the ground protects against a single wrong decision.

GND-028 Operator Sign-In · Verify: Test · Trace: SR-14.8, SR-14.1 · Applies: All · Alloc: 2.2

The operations console shall require multi-factor authentication for every operator sign-in.

Rationale: The audit log of SR-14.8 records the user identity of each command; a stolen password must not let someone command the spacecraft under another operator's name (TC-64).

GND-029 Backup Operations Site · Verify: Demonstration · Trace: SR-15.3, SR-6.10 · Applies: All · Alloc: 2.2

The Mission Operations Center shall restore planning, commanding and telemetry functions at its backup site within 4 h of a primary site failure.

Rationale: An outage beyond a day costs imaging availability (SR-15.3) and, beyond 72 h without a command, a Safe Mode entry (G-CL); 4 h keeps both away. Demonstrated in the operations rehearsal (TC-20).

17.4 Verification Approach

Station performance (GND-001 to GND-005, GND-010, GND-013) is verified at each partner station in the Ground Station Compatibility Test TC-62, which uses a portable RF test set carrying flight-equivalent radios to measure G/T, EIRP, tracking and the end-to-end decode chain, and repeats the measurement on the commissioning passes. The service plans and unattended operation (GND-006 to GND-009, GND-012) are demonstrated in the End-to-End Image Delivery test TC-12 and the Operations Rehearsal TC-20, which runs 14 days of booked contacts with the flight dynamics, planning and processing systems in their operational configuration. The planning and flight dynamics functions (GND-014 to GND-017) are tested against the flatsat schedule loads in TC-56 and in TC-20. The processing chain (GND-019 to GND-024) is verified in the Image Processing Chain Test TC-63, first with simulated strips from the payload model and then with commissioning imagery (step C6 and the C7 pilot), which also closes TBR-54. Security (GND-026 to GND-028) is verified in the Ground Security Test TC-64, and archive retention (GND-025) and the backup site switchover (GND-029) are demonstrated in TC-20 and inspected at the operations readiness review.

18 Mission Operations Specification

This chapter specifies the Mission Operator element (2.3): the operations team, its shifts, the planning cycle, the contact plan, the procedures, the anomaly response and the training of the operators. The concept of operations (Mission Overview and Concept of Operations) describes how the mission is flown and gives the design-case day; this chapter sets the rules the team works to. The procedures themselves are kept in the Mission Operations Plan (EO1-PLN-320); the list below fixes their scope and identifiers.

The operations concept rests on three properties of the system that the team relies on and must not work around: the spacecraft runs a 72 h schedule and protects itself (Operational Modes), the ground segment flies passes and processes data without an operator (SR-6.10), and the operations center notifies the on-call operator of anything out of limits within 5 min (SR-6.9). The team plans, checks, decides and recovers; it does not fly passes by hand.

18.1 Organization and Staffing

Role	Number	Hours	Responsibilities
Mission Operator, shift lead	1 per staffed shift (rotating among the certified operators)	Day shift	Approves plans, releases commands, owns the shift log and any anomaly opened during the shift
Mission Operator	1 per staffed shift	Day shift	Builds and checks plans, monitors passes and housekeeping, manages the downlink queue, second approver for critical commands
On-call operator	1 (weekly rotation among the certified operators)	Outside staffed hours	Responds to notifications; recovers or holds the spacecraft until the next shift
Operations lead	1, part time	Working days, on call for class A1 anomalies	Owns the procedures, training and certification, contact booking agreements; chairs the anomaly review
Flight dynamics analyst	1, part time, shared with the ground systems team	Working days	Orbit determination review, pass predictions, conjunction screening review
Image quality analyst	1, part time	Working days	Daily image quality report, calibration trending, coefficient releases
Subsystem leads	From the spacecraft team	On call	Engineering support for anomalies and recovery decisions

Operations roles

Routine operations of the first-phase fleet (two EO-1 Flight and one EO-1 Lite spacecraft) need two operators on the day shift (SR-6.11). The staffed hours run from 07:00 to 17:00 local time on working days, covered by two staggered 8 h shifts: the first operator works 07:00 to 15:30 and the second 08:30 to 17:00, each with a 30 min break. Both are present for the daily plan release and the late update contact, and the shift handover to the on-call operator is at 16:30. Five or six certified operators are needed for the shifts, the on-call rotation, leave and training.

18.2 Planning Cycle

18.2.1 Daily Cycle

The daily cycle follows the design-case day of the concept of operations. In outline:

1. **07:00 Review.** Overnight telemetry, alarms, the pass reports, the delivery report and the execution reports of the previous plan (UC.5).
2. **07:30 Contacts.** Confirm the booked contacts for the next 48 h with the partner network and book replacements for any the network has dropped (SR-6.1).
3. **08:00 Tasking cutoff and plan build.** The planning system produces a candidate plan for each spacecraft within 5 min (GND-015); the operator reviews it against the customer's priorities, resolves conflicts and approves it, in at most 20 min per spacecraft (SR-6.4).
4. **08:55 Plan uplink** at the morning UHF contact (Station A in the design-case day), with load verification from the command verification and schedule status packets.
5. **10:30 Late update** with priority targets received since the cutoff (SR-6.6), as individual schedule entries.
6. **Afternoon.** Image quality report, downlink queue and storage review, calibration and maintenance activities, the next day's special requests (lunar imaging, raw-mode campaigns, software or table loads).
7. **16:30 Handover** to the on-call operator.

18.2.2 The 100 min Planning Cycle

The planning cycle, from the start of a plan uplink to the first product of that plan on the portal, is the measure behind MOE-7 and SR-6.5 (threshold 100 min, objective 80 min). It is short only when the uplink, the capture and a payload downlink fall on the same or consecutive orbits; the concept of operations shows an 85 min example. The team controls it in three ways: it schedules priority targets on the orbit of the uplink or the next one; it picks the downlink station whose pass follows the capture most closely; and it sets the file priority of alert targets to 0 so that they are downlinked and processed first. In operations the cycle is measured for every priority target, from the uplink start in the station's pass report to the publication time in the portal log, and the 90th percentile is reported each month as the MOE-7 value.

18.2.3 Weekly, Monthly and Seasonal Cycles

Cycle	Activities
Weekly	Friday plan covering the weekend (up to 72 h, within the 2,000-entry schedule); unattended weekend uplinks of the time correction; weekly contact confirmation; review of open anomalies
Lunar cycle (29.5 days)	Lunar calibration imaging (SR-1.14); calibration trend review and coefficient release decision (GND-023)
90 days [TBR-20]	Rotation of the active command authentication key and, on EO-1 Flight, the downlink key (SR-14.4)
Quarterly	Raw-mode vicarious calibration campaign; reprocessing decision; procedure review
Season	In season: daily plan rebuilt over the full target regions. Out of season: reduced target list, flight software and table updates, battery conditioning, operator recertification

Operations cycles

18.3 Contact Plan

The contact plan for each spacecraft follows its service plan (Ground Segment Specification, “Ground station service plans”). Within it, each UHF contact has a fixed role:

Contact role	Per day	Station (design case)	Content
Plan uplink	1	Station A, morning	Daily plan, orbit state, time and rate correction, execution report and catalog downlink
Late update	1 on working days	Station A, mid-morning	Priority targets as schedule edits
Housekeeping and file acknowledgment	1 or more	Any	CFDP confirmations for files received earlier, event log playback, queue changes
Recovery reserve	1 booked, released 12 h ahead if not needed	A different station from the plan uplink	Backup plan uplink, anomaly response

UHF contact roles

The three spacecraft share the stations. When two spacecraft compete for one pass, the planner gives it by this order: Safe Mode recovery or LEOP, then plan uplinks, then priority downlinks, then routine downlinks and housekeeping contacts. On the EO-1 Lite one-station plan all contacts are at one station, so the recovery reserve is the next pass at the same station and an outage longer than 24 h is covered by ad hoc passes at another station of the network.

18.4 Procedures

Id	Procedure	Trigger	Main requirements
NP-01	Daily Planning and Plan Release	Tasking cutoff	SR-6.4, SR-6.6, GND-015
NP-02	Plan Uplink and Load Verification	Plan uplink contact	SR-10.22, FSW-012
NP-03	Late Plan Update	Priority request after the cutoff	SR-6.6, FSW-014
NP-04	Pass Monitoring and Housekeeping Review	Each staffed contact; daily review	SR-6.9, SR-10.18
NP-05	Downlink Queue and Storage Management	Daily; storage backlog above the action level	SR-10.23, SR-10.28, SR-4.1
NP-06	Time Correlation and Correction	Daily	SR-4.7
NP-07	Orbit State Update	Daily	SR-6.8, GND-017
NP-08	Lunar Calibration Imaging	Once per lunar cycle	SR-1.14
NP-09	Vicarious Calibration Campaign (raw mode)	Quarterly	SR-1.9, FSW-022
NP-10	Key Rotation	90 days [TBR-20]	SR-14.3, SR-14.4
NP-11	Flight Software and Table Update	Approved change	SR-10.20, SR-10.21, FSW-027, FSW-028
NP-12	Weekend Plan and Unattended Uplinks	Friday	SR-4.8, SR-10.12
NP-13	Shift Handover	End of each staffed shift	SR-6.9, SR-6.11
LP-01	First Acquisition and State of Health	First beacon after separation	SR-11.9, SR-2.3
LP-02	Bus Checkout (commissioning step C1)	Two-way contact established	SR-4.2, SR-3.3
LP-03	Attitude Sensor Commissioning (C2)	C1 complete	SR-2.6
LP-04	Fine Attitude Control Commissioning (C3)	C2 complete	SR-2.1, SR-2.2, SR-2.4
LP-05	Payload Downlink Commissioning (C4)	C3 complete; T3 taken	SR-5.1 or SR-5.5, SR-4.4
LP-06	First Light (C5)	C4 complete; outgassing hold over	SR-1.2 to SR-1.4
LP-07	In-Orbit Calibration (C6)	C5 complete	SR-1.9, SR-1.11, SR-1.12
LP-08	End-to-End Pilot (C7)	C6 complete	SR-6.2, SR-6.5, SR-6.14
CP-01	Safe Mode Recovery	Safe Mode seen in telemetry	SR-2.5, SR-10.16
CP-02	Contact Loss	Missed pass report or missing data	SR-10.12, SR-6.9

Id	Procedure	Trigger	Main requirements
CP-03	Unit Reset or Latch-Up Investigation	Reset or latch-up event in the log	SR-11.6, SR-10.9
CP-04	Reaction Wheel Failure Reconfiguration	Wheel removed by the ADCS	SR-2.9
CP-05	Storage Bank Fault	Bank retired by fault management	SR-4.1, CDH-022
CP-06	Interference Report and Transmitter Off	Notice from a spectrum authority or another operator	SR-5.11, SR-5.10
CP-07	Ground Station Outage and Rebooking	Station outage notice	SR-6.7
CP-08	Operations Center Failover	Primary site failure	GND-029
CP-09	Suspected Key Compromise	Security alert	SR-14.3, SR-14.4
CP-10	Conjunction Notification	Close approach predicted	— (coordination with the other operator)
EP-01	Final Data Recovery	End-of-mission decision	SR-6.3
EP-02	Passivation	Final data recovered	SR-13.5, SR-13.6
EP-03	Decommissioning and Notifications	Passivation confirmed	SR-10.19, SR-13.4

Operations procedures

Every procedure is a step list with the expected telemetry response of each step and the go/no-go criteria between steps. A procedure is validated on the flatsat before its first use in flight, and again after any change to the flight software or the command database that it uses.

18.5 Anomaly Response

Class	Definition	Response
A1 Spacecraft safety	Safe Mode entry; no contact for more than 24 h; battery or thermal limit violation; an uncommanded mode change	On-call operator responds (OPS-002) and informs the operations lead and the subsystem lead; recovery plan prepared, checked on the flatsat when the cause is not a known one, and executed (CP-01)
A2 Mission degradation	A fault management response at level 1 or 2 that recurs; repeated skipped captures; loss of a storage bank or a wheel; missed deliveries	Handled by the next staffed shift; anomaly report within 24 h; review at the weekly anomaly review
A3 Minor	A single upset or reset that cleared; one missed pass; a single limit excursion that returned to normal	Logged and trended; no report unless it recurs

Anomaly classes

Every Safe Mode entry is class A1. The recovery follows the scenario “Safe mode entry and recovery” of the concept of operations: downlink the event log and the stored housekeeping around the entry, diagnose with the subsystem lead, prepare the recovery commands and a new

schedule, send the recovery command (T7), and have the spacecraft back in Nominal Imaging within 24 h of that command (SR-2.5). For the causes listed in CP-01 (an isolated undervoltage after a planning error, a G-CL entry after a ground outage, a G-LF entry with a known station fault) the recovery command goes up within 24 h of the first contact that shows the entry; an unknown cause waits for the flatsat check.

The monthly anomaly review board (operations lead, Systems Lead, subsystem leads) closes reports, decides on parameter or software changes and tracks recurring anomalies against the risk register.

18.6 Training and Certification

Operators are certified before they command a spacecraft or take the on-call rotation:

1. **Classroom**, 40 h: mission and system overview, each subsystem, the modes and fault management, the ground segment, security rules, the procedures.
2. **Console training** on the operations center's test instance connected to the flatsat, with real plan builds and uplinks.
3. **Simulations**: six scenarios run on the flatsat with injected faults: nominal day with a late update, Safe Mode recovery after undervoltage, contact loss over a weekend, reaction wheel failure, storage bank fault, and an interference notice with transmitter off.
4. **Supervised shifts**: one week of shifts under a certified operator, including one critical command sequence.

The operations lead certifies each operator. Certification lapses after 180 days unless the operator has run one simulation in that period. The pre-launch Operations Rehearsal (TC-20) and a LEOP rehearsal with the full team are run after the first operators are certified.

18.7 Requirements

OPS-001 Shift Staffing · Verify: Demonstration · Trace: SR-6.11 · Applies: All · Alloc: 2.3

Each staffed shift shall have two certified Mission Operators on duty, one of them designated shift lead.

Rationale: Two operators are the SR-6.11 limit for three spacecraft and the minimum for the two-person release of critical commands (GND-027); one named lead avoids split decisions during a pass (TC-20).

OPS-002 On-Call Response · Verify: Demonstration · Trace: SR-6.9 · Applies: All · TBR: TBR-56 · Alloc: 2.3

Outside staffed hours, the on-call operator shall acknowledge each notification within 15 min and be working at an operations console within 30 min [TBR].

Rationale: The operations center notifies within 5 min (SR-6.9); 30 min to a console still reaches most next contacts, which are about 95 min apart. TBR-56 closes with the staffing agreement for remote console access (TC-66).

OPS-003 Command Interval · Verify: Analysis, Demonstration · Trace: SR-10.12 · Applies: All · Alloc: 2.3

The operations team shall plan uplinks so that no spacecraft goes more than 48 h without a valid authenticated command.

Rationale: A gap of 72 h triggers Safe Mode (G-CL); a weekend from Friday afternoon to Monday morning is about 66 h, so the Friday plan schedules unattended weekend uplinks of the time correction, which also serve NP-06.

OPS-004 Backup Uplink Contact · Verify: Demonstration · Trace: SR-6.6, SR-6.1 · Applies: All · Alloc: 2.3

For each plan uplink, the operations team shall book a backup UHF contact within the following 3 h at a station other than the plan uplink station, or at the same station on the EO-1 Lite one-station plan.

Rationale: A missed plan uplink otherwise costs a day of the new targets and of responsive tasking (SR-6.6); the backup pass is released 12 h ahead when not needed.

OPS-005 Priority Target Scheduling · Verify: Demonstration, Analysis · Trace: SR-6.5 · Applies: All · Alloc: 2.3

The operations team shall schedule each priority 0 target so that its capture and its payload downlink fall within the two orbits that follow the plan uplink containing it, whenever the target’s access geometry allows.

Rationale: The 100 min cycle of SR-6.5 holds only when uplink, capture and downlink are on the same or consecutive orbits (concept of operations, “Planning cycle”).

OPS-006 Planning Cycle Reporting · Verify: Demonstration · Trace: SR-6.5 · Applies: All · Alloc: 2.3

The operations team shall measure the planning cycle time of every priority 0 target and report its 90th percentile for each calendar month.

Rationale: SR-6.5 is verified before launch by simulation; in operations MOE-7 needs the measured value, and the 90th percentile matches the 90 % probability of the SR-6.5 verification.

OPS-007 Commanding from Approved Procedures · Verify: Inspection, Demonstration · Trace: SR-10.25, SR-14.9 · Applies: All · Alloc: 2.3

Operators shall uplink commands only from an approved plan or an approved procedure, except under a deviation authorized by the operations lead and recorded in the shift log.

Rationale: Onboard range checks (SR-10.25) catch out-of-range values, not wrong but valid commands; approved procedures are the protection against those.

OPS-008 Procedure Validation · Verify: Inspection · Trace: SR-2.5, SR-10.2 · Applies: All · Alloc: 2.3

Each procedure shall be validated on the flatsat before its first use in flight and after each change to the flight software or command database items it uses.

Rationale: A recovery procedure that fails in flight extends Safe Mode beyond the 24 h of SR-2.5; the flatsat runs the flight software and command database of the flight units.

OPS-009 Known-Cause Safe Mode Recovery · Verify: Demonstration · Trace: SR-15.3, SR-2.5 · Applies: All · Alloc: 2.3

For a Safe Mode entry whose cause is one listed in CP-01, the operations team shall send the recovery command within 24 h of the first contact that shows the entry.

Rationale: Together with the 24 h of SR-2.5 this bounds a known-cause outage to about two days, which keeps the 90 % imaging availability of SR-15.3 (TC-20, TC-66).

OPS-010 Anomaly Reporting · Verify: Inspection · Trace: SR-15.1, SR-15.3 · Applies: All · Alloc: 2.3

The operations team shall open an anomaly report within 24 h of detecting each class A1 or A2 anomaly.

Rationale: Recurring anomalies are the early sign of a wear-out or design problem that threatens the 0.8 mission reliability (SR-15.1); reports feed the anomaly review and the risk register.

OPS-011 Operator Certification · Verify: Inspection · Trace: SR-6.4, SR-6.11 · Applies: All · Alloc: 2.3

No person shall command a spacecraft or take the on-call rotation without a current certification from the operations lead.

Rationale: SR-6.4 assumes a trained operator; certification (classroom, console training, six simulations and a supervised week) is the evidence of that training (TC-66).

OPS-012 Recertification · Verify: Inspection · Trace: SR-6.4 · Applies: All · Alloc: 2.3

Each operator's certification shall lapse after 180 days unless the operator has completed at least one flatsat simulation in that period.

Rationale: Contingency skills fade when contingencies are rare; one simulation per 180 days keeps every operator able to run CP-01 at night without help.

OPS-013 Daily Time Correction · Verify: Demonstration · Trace: SR-4.7 · Applies: All · Alloc: 2.3, 2.2

The operations team shall uplink a time offset and rate correction to each spacecraft at least once per day.

Rationale: SR-4.7 is met with one correction per day; on weekends the correction goes up on the unattended uplinks of OPS-003.

OPS-014 Storage Backlog Action · Verify: Demonstration · Trace: SR-4.1, SR-10.28 · Applies: All · Alloc: 2.3

When a spacecraft's unacknowledged payload data exceed 32 GB, the operations team shall reduce its next daily target list or book additional downlink passes until the backlog falls below 32 GB.

Rationale: Half of the 64 GB storage is 10 days of compressed collection; acting at half full keeps room for a calibration campaign or a lost station without reaching the storage-full skip of FSW-024.

OPS-015 Interference Response · Verify: Demonstration · Trace: SR-5.11, SR-5.10 · Applies: All · Alloc: 2.3

On a harmful interference notice that names an EO-1 transmitter, the operations team shall send the transmitter-off command at the first UHF contact after the notice and within 2 h of receiving it.

Rationale: Stopping emissions on request is a license condition; the onboard part takes 10 s (SR-5.11), so the response time is set by the ground.

OPS-016 Lunar Calibration Scheduling · Verify: Demonstration · Trace: SR-1.14 · Applies: All · Alloc: 2.3

The operations team shall schedule one lunar calibration imaging sequence per lunar cycle, at a lunar phase angle between 5° and 10°.

Rationale: A narrow phase angle range makes the monthly lunar images comparable for trending (SR-1.10); near-full phases also give the largest illuminated disk.

OPS-017 Shift Handover Log · Verify: Inspection · Trace: SR-6.11, SR-6.9 · Applies: All · Alloc: 2.3

At the end of each staffed shift, the shift lead shall record in the shift log the open anomalies, pending commands and critical events of the next 24 h.

Rationale: The on-call operator usually acts alone and at night; the handover log is the context that makes the 5 min notification of SR-6.9 actionable.

18.8 Verification Approach

Operations requirements are verified by demonstration and inspection. The Operations Rehearsal TC-20 runs 14 days of operations with the certified team, the operations center in its operational configuration, the partner stations and the flatsat standing in for the spacecraft; it demonstrates OPS-001, OPS-003 to OPS-006, OPS-009 and OPS-013 to OPS-016, including a weekend with unattended uplinks and a Safe Mode recovery. The Operator Certification and Anomaly Drill TC-66 checks the certification records and runs unannounced night drills of the on-call response (OPS-002, OPS-009, OPS-011, OPS-012). The procedure validation records and the shift and anomaly logs are inspected at the operations readiness review (OPS-007, OPS-008, OPS-010, OPS-017). OPS-005 and OPS-006 are demonstrated again with customer targets in the C7 end-to-end pilot, which is also the first part of VAL-01.

19 Interface Requirements

This chapter specifies the interfaces named in System Architecture: what each one connects, in which direction, what it carries and at what rate or rating, and the standard or connector it uses. The interface ids are fixed; the items carried use the item names of the functional architecture (Command Schedule, Image Strip, Downlink Frames and so on), so each interface can be modeled as a connection between two ports that carry those items.

The detailed definitions (pin assignments, message dictionaries, timing diagrams, mechanical drawings) are in the interface control documents: EO1-ICD-200 for the spacecraft internal interfaces, EO1-ICD-210 for the RF links, EO1-ICD-220 for the ground interfaces and EO1-ICD-230 for the dispenser. This chapter states the characteristics that the system design depends on and the requirements that bind both sides. Where an interface control document and this chapter disagree, this chapter governs (Applicable and Reference Documents, Order of precedence).

Conventions used in the interface tables:

- **Endpoints** name the product-tree elements at each end. The first element is the source of the main item flow; the direction row states what flows the other way.
- **Rating** for a power line is the continuous power the source must deliver within its regulation limits; the loads' maximum draw must stay at or below it.
- **Rate** for a data interface is the line or link rate; the information carried is stated separately.
- Connector types are generic (Micro-D, nanoD, SMA). Each connector's designator and pinout are in the interface control document. Harness and connector derating follow STD-1.

19.1 Interface Overview

The two N² tables below show which element pairs connect and through which interface. A row is the source of a flow, a column its destination; a cell names the interface that carries it. An interface that carries items both ways appears in both cells of the pair.

From To	SA	BAT	PDU	CDH	PAY	ACS	STT	RWA	MTQ	UHF	SBT	XBR	STR
SA	1.3.1		IF-20										
BAT		1.3.2	IF-21										
PDU		IF-21	1.3.3	IF-03, IF-09	IF-01	IF-02				IF-04	IF-04	IF-04	
CDH			IF-09	1.4	IF-05	IF-06				IF-07	IF-08	IF-08.1	
PAY				IF-05	1.1								
ACS				IF-06		1.2.4	IF-16	IF-17	IF-18				
STT						IF-16	1.2.2						
RWA						IF-17		1.2.1					
MTQ						IF-18			1.2.3				
UHF				IF-07						1.5.1			

From To	SA	BAT	PDU	CDH	PAY	ACS	STT	RWA	MTQ	UHF	SBT	XBR	STR
SBT				IF-08							1.5.2		
XBR				IF-08.1								1.5.3	
STR				IF-19									1.6

N² diagram of the spacecraft internal interfaces (SA Solar Arrays, BAT Battery Pack, PDU Power Distribution Unit, CDH C&DH, PAY Payload Camera, ACS ADCS Controller and Sensors, STT Star Tracker, RWA Reaction Wheel Assembly, MTQ Magnetorquers, UHF UHF Transceiver, SBT S-band Transmitter, XBR X-band Payload Radio, STR Structure and Thermal)

IF-22 Regulated Bus is internal to the PDU: it is the 12 V converter output that feeds the switched outputs IF-01, IF-02 and IF-04, and it is specified here because the regulation of SR-3.4 is defined at that port. The Star Tracker, Reaction Wheel Assembly and Magnetorquers receive their power from the ADCS Controller over the IF-16, IF-17 and IF-18 harnesses; the ADCS as a whole draws from IF-02. The SBT and XBR columns are exclusive: EO-1 Lite carries the S-band Transmitter, EO-1 Flight the X-band Payload Radio.

From To	SC	GS	MOC	OPR	CUST	LV	ENV
SC	1	IF-11, IF-12 / IF-12.1				IF-15	
GS	IF-11	2.1	IF-13				
MOC		IF-13	2.2	IF-25	IF-14, IF-14.1		
OPR			IF-25	2.3			
CUST			IF-14, IF-14.1		X.1		
LV	IF-15					3	
ENV	IF-23, IF-24						4

N² diagram of the mission-level interfaces (SC EO-1 Spacecraft, GS Ground Station, MOC Mission Operations Center, OPR Mission Operator, CUST Imagery Customer, LV Rideshare Launch Vehicle, ENV Orbit Environment)

IF-10 Space-to-Ground Link is the parent of IF-11, IF-12 and IF-12.1 and appears in the table through its children. The Mission Operations Center has no direct link to the spacecraft: every command and every downlinked file passes through a ground station.

19.2 Power Interfaces

All power originates at the Power Distribution Unit (1.3.3). The PDU tracks the array peak power into an unregulated battery bus (12.0 V to 16.8 V, set by the battery), converts the battery bus to the regulated 12 V main bus (IF-22) and to the 5 V always-on line (IF-03), and switches the 12 V bus to the loads through latching current limiters. The conversion efficiency of 0.90 used in the power budget is the combined efficiency from the array input to the load terminals.

The heater outputs to the Thermal Control Hardware (1.6.3) and the burn-wire release circuits of the Deployment Mechanisms (1.6.2) are PDU outputs routed in the Harness (1.7). Like the RF cables, they carry no separate interface id; their ratings are in EO1-ICD-200.

19.2.1 IF-01, IF-02, IF-04 Switched Load Lines

Property	IF-01 Payload Power Line	IF-02 ADCS Power Line	IF-04 Radio Power Line
Endpoints	1.3.3 PDU → 1.1 Payload Camera	1.3.3 PDU → 1.2 ADCS (1.2.4 ADCS Controller)	1.3.3 PDU → 1.5.1 UHF Transceiver and the payload downlink radio (1.5.2 or 1.5.3), two switched branches
Direction	Power to the load; current telemetry stays in the PDU	Power to the load	Power to the load
Voltage	12 V ± 2 % (from IF-22)	12 V ± 2 %	12 V ± 2 %
Rating	15 W (1.25 A)	10 W (0.83 A)	18 W (1.50 A) [TBR]
Maximum load draw	14.0 W during capture; 6.0 W prepare; 2.5 W standby	8.8 W in a slew (controller 1.0 W, star tracker 1.8 W, four wheels 6.0 W)	EO-1 Lite 17.5 W (S-band 11.5 W with UHF transmit 6.0 W); EO-1 Flight 16.0 W (X-band 15.0 W with UHF receive 1.0 W)
Switching	Commanded on/off over IF-09; off in Safe Mode	Commanded; on from separation (controller), units under controller control	UHF branch on after separation, kept on by the hardware undervoltage disconnect (SR-3.11); radio branch commanded per contact
Protection	Latching current limiter, trip at 125 % of rated current	Same	Same, one limiter per branch
Connector	Micro-D 9, two pins per polarity	Micro-D 9, two pins per polarity	Micro-D 9 per branch, two pins per polarity
Items	Switched 12 V supply	Switched 12 V supply	Switched 12 V supply

Switched 12 V load lines IF-01, IF-02 and IF-04

The power budget books the UHF receiver at full duty and the camera standby electronics at full duty even while the transmitter or the detector is on. The “maximum load draw” row uses the actual simultaneous draw: the half-duplex UHF Transceiver draws 6.0 W in total while transmitting, and the 14.0 W capture power includes the camera’s standby electronics. The budget is therefore conservative by about 0.2 W orbit-average.

IF-04 on EO-1 Flight. The X-band Payload Radio draws 15.0 W while transmitting. With the UHF transmitter on at the same time the radio line would carry 21.0 W, more than its 18 W rating. The baseline therefore inhibits UHF transmission while the X-band transmitter is on (ICD-008); housekeeping telemetry is carried in the X-band frames during the pass, and the UHF receiver stays on for commands and ground link acknowledgements. A change request to raise the IF-04 rating to 22 W on EO-1 Flight, which would allow UHF telemetry during X-band passes, is under evaluation; the rating is TBR-70 until it is decided.

19.2.2 IF-03 C&DH Power Line

Property	Value
Endpoints	1.3.3 PDU → 1.4 C&DH (Flight Computer 1.4.1 and Payload Data Storage 1.4.2)
Direction	Power to the C&DH
Voltage	5.0 V ± 3 %, derived from the battery bus
Rating	7 W (1.4 A); changed from 4 W in this revision
Load draw	4.0 W continuous; 6.5 W during an image compression burst (4.0 W plus 2.5 W)
Switching	Always on after separation. Not switchable by command; not opened by the hardware undervoltage disconnect (SR-3.11)
Protection	Hardware current limiter with automatic restart (ICD-006)
Connector	Micro-D 9, two pins per polarity
Items	Always-on 5 V supply

IF-03 C&DH Power Line

ICD change: IF-03 rating 4 W to 7 W. The previous issue of EO1-ICD-200 rated IF-03 at 4 W, the C&DH's continuous draw. The flatsat measurements on FS-1 showed that the flight computer draws a further 2.5 W while it compresses an image strip (the "C&DH compression burst" line of the power budget), so the line carries 6.5 W for up to 60 s per strip, eight times in the design-case orbit. A 4 W line would have tripped its limiter on the first strip. The rating is now 7 W, which keeps 0.5 W (7.7 %) above the measured peak, and the PDU's 5 V converter is sized for it. The change is recorded against EO1-ICD-200 under the Configuration Management Plan; the orbit-average effect (0.21 W) is already in the power budget.

19.2.3 IF-20, IF-21, IF-22 EPS Internal Power

Property	IF-20 Array Power	IF-21 Battery Power	IF-22 Regulated Bus
Endpoints	1.3.1 Solar Arrays (four segments, two per panel) → 1.3.3 PDU	1.3.3 PDU ⍰ 1.3.2 Battery Pack	1.3.3 PDU converter → PDU switched outputs (IF-01, IF-02, IF-04)
Direction	Power from each segment to its own PDU peak power tracking channel; panel thermistor signals to the PDU	Battery Charge Power in; Battery Discharge Power out; cell-pair voltages and cell temperatures to the PDU	Power to the switched outputs
Voltage	String maximum power point about 21 V at 28 °C and above 17 V at the hot limit; open circuit up to about 31 V at eclipse exit	12.0 V to 16.8 V (4S2P lithium-ion); 14.4 V nominal; 12.8 V software undervoltage (G-UV); 12.0 V hardware disconnect (SR-3.11)	12 V ± 2 % (11.76 V to 12.24 V)

Property	IF-20 Array Power	IF-21 Battery Power	IF-22 Regulated Bus
Rating	18.9 W per segment at the beginning-of-life peak (75.4 W for all four); PPT inputs rated for 35 V	Charge up to 2.7 A (C/2, EPS chapter); end of charge 16.4 V by default (TBR-33); discharge 5.0 A continuous, 3.0 A design-case peak	50 W continuous; design-case peak demand 33.8 W at the load terminals (X-band pass in eclipse)
Protection	Blocking diode on each string and bypass diode on each cell; reverse-current protection at each PDU input	Fuse in the positive line at the pack; pack protection circuit (SR-13.2); cold-charge inhibit (SR-3.7)	Output overvoltage clamp at 13.2 V; each switched output has its own limiter
Connector	Micro-D 15 per panel (both segments) through the hinge harness	nanoD 15 (power on paired pins; voltage taps and thermistors)	Internal to the PDU (test point on the ground support connector)
Items	Array Power Output	Battery Charge Power, Battery Discharge Power	Regulated 12 V bus

EPS internal power interfaces IF-20, IF-21 and IF-22

Both separation-switch inhibits of the battery (ICD-041) are in the IF-21 power path, so the battery is isolated from the PDU whenever the spacecraft is in the dispenser.

19.2.4 Power Interface Requirements

ICD-001 Switched Load Line Ratings · Verify: Test · Trace: SR-3.4, SR-3.9 · Applies: All

The PDU shall deliver at least the rated power of each switched load line (IF-01 15 W, IF-02 10 W, IF-04 18 W [TBR]) while holding the line voltage within 11.76 V to 12.24 V at the PDU connector.

Rationale: The ratings sit above each load's maximum simultaneous draw (14.0 W, 8.8 W and 17.5 W), so a unit at its peak never sees a sagging supply. Verified on the flatsat with electronic loads at the rated current.

ICD-002 Switched Output Overcurrent Trip · Verify: Test · Trace: SR-3.8, SR-15.2 · Applies: All

Each switched load output of the PDU shall open when its current exceeds 125 % of the line's rated current for more than 5 ms, and shall stay open until commanded on.

Rationale: 125 % clears normal inrush and load transients but catches a shorted unit; latching off keeps a faulty unit from cycling the bus. The 5 ms filter plus the switch opening time stays inside the 10 ms isolation of SR-3.8, so a load failure is contained to its own line.

ICD-003 Load Inrush Current · Verify: Test · Trace: SR-3.4, SR-3.8 · Applies: All

Each unit powered from a switched 12 V line shall limit its turn-on inrush current to at most 150 % of the line's rated current, falling below 125 % of the rated current within 2 ms of turn-on.

Rationale: An inrush that falls below the trip level within 2 ms never outlasts the 5 ms filter of ICD-002, and load steps on IF-22 stay small enough for the converter to hold SR-3.4.

ICD-004 C&DH Power Line Rating · Verify: Test · Trace: SR-3.12, SR-4.3, SR-4.6 · Applies: All

The PDU shall deliver at least 7 W on the IF-03 always-on line at 5.0 V ± 3 % from separation onward, for any battery bus voltage from 12.0 V to 16.8 V.

Rationale: The C&DH draws 6.5 W during a compression burst; the 4 W rating of the previous ICD issue was changed to 7 W (ICD change above). The line must keep the C&DH running down to the 12.0 V hardware disconnect, where all other loads are already shed; below it the C&DH is restarted from the arrays alone (SR-3.12).

ICD-005 C&DH Power Line Not Commandable · Verify: Inspection, Test · Trace: SR-3.11, SR-4.3 · Applies: All

The IF-03 always-on line shall have no switch that can be opened by command, by flight software or by the hardware undervoltage disconnect.

Rationale: The C&DH runs fault management and the only path for ground recovery; a commanded or automatic turn-off of its supply would leave nothing to turn it back on.

ICD-006 C&DH Power Line Latch-Up Recovery · Verify: Test · Trace: SR-11.6, SR-3.11 · Applies: All

The PDU shall remove power from IF-03 for 1 s and then restore it, without command, whenever the line current exceeds 1.8 A for more than 50 ms.

Rationale: A single-event latch-up in the flight computer shows as a sustained overcurrent; a timed power cycle clears it well inside the 60 s of SR-11.6. 1.8 A is about 130 % of the 7 W rating, above the compression burst.

ICD-007 Radio Power Line Rating · Verify: Test, Analysis · Trace: SR-3.4, SR-3.9 · Applies: All · TBR: TBR-70

The IF-04 Radio Power Line shall be rated for 18 W [TBR] in total across its UHF and payload downlink radio branches.

Rationale: 18 W covers EO-1 Lite with both transmitters on (17.5 W) and EO-1 Flight with the X-band radio and the UHF receiver on (16.0 W). TBR-70 closes when the change request to raise the EO-1 Flight rating to 22 W, which would allow UHF transmission during X-band passes, is decided (Systems Lead, before the FM-2 pre-shipment review).

ICD-008 UHF Transmit Interlock During X-band Passes · Verify: Test · Trace: SR-3.9, SR-5.8 · Applies: Flight

While the X-band Payload Radio transmits, the C&DH shall not command the UHF Transceiver to transmit.

Rationale: Keeps IF-04 within its 18 W rating on EO-1 Flight (15.0 W plus 6.0 W would be 21.0 W). Housekeeping telemetry is carried in the X-band frames during the pass; the UHF receiver stays on, so commanding and the T8 link-lock acknowledgements are not affected.

ICD-009 Array Input Range · Verify: Test · Trace: SR-3.1, SR-3.12 · Applies: All

Each PDU array input shall track the maximum power point for string voltages from 17 V to 24 V and withstand without damage an input voltage of 35 V.

Rationale: The maximum power point moves with panel temperature from hot sunlit conditions (above 17 V) to the cold exit from eclipse, when the open-circuit voltage reaches about 31 V; 35 V leaves margin above it. The tracker must work over the whole range to deliver the generation budget's 0.96 tracking efficiency, and must start from the arrays alone for SR-3.12.

ICD-010 Battery Line Voltage Drop · Verify: Test · Trace: SR-3.3, SR-3.11 · Applies: All

The IF-21 power path, including both separation switch contacts in it, shall drop no more than 100 mV between the battery pack terminals and the PDU at a discharge current of 5.0 A.

Rationale: The PDU measures the battery voltage for the 12.8 V Safe Mode threshold and the 12.0 V hardware disconnect at its own input; a larger drop would make both trip early at high load. The charge current and voltage limits themselves are EPS requirements (EPS chapter).

ICD-011 Battery Line Fuse · Verify: Inspection, Test · Trace: SR-13.2 · Applies: All

The battery pack shall carry a fuse rated at 7.5 A in its positive line, located inside the pack ahead of the IF-21 connector.

Rationale: An external short between the pack and the PDU, for example a damaged harness during integration, must be cleared at the source. 7.5 A is 1.5 times the 5.0 A continuous rating, in line with STD-1 fuse derating.

ICD-012 Regulated Bus Ripple · Verify: Test · Trace: SR-3.4, SR-11.8 · Applies: All

The ripple and noise on IF-22 shall not exceed 50 mV peak-to-peak in a 20 MHz bandwidth at any load from 5 W to 50 W.

Rationale: The camera's analog front end and the star tracker detector are the most sensitive loads; 50 mV is within their supply rejection and leaves the static regulation band of SR-3.4 intact.

19.3 Data Interfaces

The C&DH is the hub of the onboard data architecture: every unit with a data interface talks to it, except the ADCS units, which talk to the ADCS Controller. All data interfaces use differential signaling except IF-09 (a short I2C bus inside the avionics stack) and IF-19 (switch contacts). Onboard time is distributed by the C&DH: a time message on each bus once per second and a hardware pulse on IF-05.

19.3.1 IF-05 Payload Interface

Property	Value
Endpoints	1.4 C&DH ⍰ 1.1 Payload Camera
Direction	C&DH → camera: control and time. Camera → C&DH: image data and status
Type	Image data: four LVDS lanes plus clock and frame-valid. Control: SPI, C&DH as master. Time: one-pulse-per-second discrete
Rate	Image data 400 Mbps aggregate (100 Mbps per lane); SPI 4 MHz clock; time pulse 1 Hz
Items	Command Schedule (imaging commands: configure bands and gains, prepare focal plane, capture start at time tag, stop); Image Strip; Focal Plane Status
Volume	1.84 GB per 40 s strip, 2.48 GB for the longest strip (54 s), read from the camera buffer
Connector	Micro-D 25 at each end, shielded twisted pairs for the LVDS lanes
Standard	LVDS signaling; message definitions in EO1-ICD-200

IF-05 Payload Interface

The camera writes each strip into its image buffer at the raw rate of 368 Mbps and streams it to the C&DH over IF-05 from the start of the capture. Because the 400 Mbps link is faster than the raw rate, the buffer drains as it fills and the read-out ends within 10 s of the end of the strip (PAY-025); the buffer, sized for the longest strip, lets the C&DH pause the read-out without cutting a strip short.

19.3.2 IF-06 ADCS Data Bus

Property	Value
Endpoints	1.4 C&DH ⍰ 1.2 ADCS (1.2.4 ADCS Controller)
Direction	C&DH → ADCS: commands and time. ADCS → C&DH: telemetry
Type	CAN 2.0B, extended identifiers, 120 Ω termination at both ends; one-pulse-per-second time discrete
Rate	1 Mbps; attitude telemetry at 10 Hz, housekeeping at 1 Hz, time message at 1 Hz

Property	Value
Items	Command Schedule (attitude targets as quaternion and rate with time tag, pointing mode AP-0 to AP-5, ephemeris); Safe Mode Commands; ADCS Sensor Data (attitude and rate estimate, pointing mode, wheel speeds, sensor and actuator health, ancillary attitude stream)
Bus load	Below 5 % in the design case
Connector	Micro-D 9
Standard	CAN 2.0B; message dictionary in EO1-ICD-200

IF-06 ADCS Data Bus

The 10 Hz attitude telemetry is what the flight software uses to tag each image strip with attitude (F7.4).

19.3.3 IF-07 Radio Command Interface

Property	Value
Endpoints	1.5.1 UHF Transceiver ? 1.4 C&DH
Direction	UHF → C&DH: received frames and radio status. C&DH → UHF: telemetry frames for transmission, radio commands
Type	Asynchronous serial (UART, 8 data bits, no parity, 1 stop bit) on RS-422 differential lines, full duplex
Rate	115.2 kbps, 12 times the 9.6 kbps RF rate
Items	Command Packets (TC transfer frames after CLTU decoding: Imaging Plan, recovery commands, file acknowledgements and the station's link acknowledgements); Housekeeping Telemetry (TM transfer frames for UHF downlink, including the health beacon); radio status (receiver lock, signal strength, temperature)
Framing	Each frame wrapped with a sync word, length and CRC-16
Connector	Micro-D 15
Standard	Frame formats CCSDS 232.0-B TC Space Data Link Protocol and CCSDS 132.0-B TM Space Data Link Protocol, as profiled in STD-2

IF-07 Radio Command Interface

The UHF Transceiver demodulates and decodes the uplink but does not interpret commands: authentication, replay checks and validation are done in the C&DH (SR-14.1, SR-14.2, SR-10.25), so the radio holds no keys.

19.3.4 IF-08 Payload Data Interface and IF-08.1 X-band Data Interface

Property	IF-08 Payload Data Interface (EO-1 Lite)	IF-08.1 X-band Data Interface (EO-1 Flight)
Endpoints	1.4 C&DH → 1.5.2 S-band Transmitter	1.4 C&DH → 1.5.3 X-band Payload Radio

Property	IF-08 Payload Data Interface (EO-1 Lite)	IF-08.1 X-band Data Interface (EO-1 Flight)
Direction	Frames and commands to the radio; radio status back	Frames, commands and session keys to the radio; radio status back
Type	SpaceWire, point to point	SpaceWire, point to point
Rate	100 Mbps link rate (about 80 Mbps of data, 8 times the 10 Mbps downlink)	200 Mbps link rate (about 160 Mbps of data, 1.6 times the 100 Mbps downlink)
Items	Downlink Frames; Transmitter Enable Command; radio status (frame buffer level, RF output power, power amplifier temperature, synthesizer lock)	Downlink Frames; Transmitter Enable Command; wrapped session key for frame encryption; radio status as IF-08 plus encryption status
Frame format	TM transfer frames of 892 octets, one LDPC codeblock each	Same, with security header and trailer fields reserved in each frame
Connector	C&DH J4, Micro-D 9	C&DH J5, Micro-D 9
Standard	SpaceWire; CCSDS 132.0-B TM Space Data Link Protocol	SpaceWire; CCSDS 132.0-B; CCSDS 355.0-B Space Data Link Security Protocol

IF-08 and IF-08.1 payload downlink data interfaces

The C&DH builds the transfer frames from the stored files (CFDP file data in space packets) and sends them in the priority order of SR-10.23. The radio applies the security processing (EO-1 Flight), randomization, LDPC coding and the attached sync marker, then modulates. The 892-octet frame length matches the 7,136-bit information block of the rate 7/8 LDPC code, so each frame is one codeblock. The 0.94 framing factor of the data volume budget is the share of each frame left for file data after the frame, packet and file protocol headers.

The Transmitter Enable Command reaches the radio over this interface only after the PDU has powered the radio branch of IF-04; turning the radio's RF output on therefore takes two separate actions (ICD-019).

19.3.5 IF-09 Power Telemetry Link

Property	Value
Endpoints	1.3.3 PDU ⍰ 1.4 C&DH
Direction	PDU → C&DH: Power Telemetry. C&DH → PDU: Safe Mode Commands, load switch and burn-wire commands
Type	I2C, C&DH as the only master, PDU as slave
Rate	400 kbps; full power telemetry set polled every 1 s
Items	Power Telemetry (battery voltage, four cell-pair voltages, battery current and temperatures, array voltage and current per panel, bus voltages, current and state of each switched output, charge state); Safe Mode Commands (shed list); load switch and burn-wire firing commands
Connector	Micro-D 9 (shared avionics stack connector)
Standard	I2C fast mode; register map in EO1-ICD-200

IF-09 Power Telemetry Link

The 1 s polling period supports the G-UV guard (2 s persistence) and the 10 s Safe Mode entry of SR-4.3.

19.3.6 IF-16, IF-17, IF-18 ADCS Internal Links

Property	IF-16 Star Tracker Link	IF-17 Wheel Drive Link	IF-18 Torque Rod Link
Endpoints	1.2.2 Star Tracker ⍰ 1.2.4 ADCS Controller	1.2.4 ADCS Controller ⍰ 1.2.1 Reaction Wheel Assembly (four wheels)	1.2.4 ADCS Controller → 1.2.3 Magnetorquers (three rods)
Direction	Tracker → controller: attitude. Controller → tracker: commands, time, power	Controller → wheels: commands, power. Wheels → controller: telemetry	Controller → rods: drive current. Rods → controller: current sense
Type	RS-422, full duplex	Four point-to-point RS-422 links, one per wheel	Bipolar pulse-width-modulated current drive, one channel per rod
Rate	0.5 Mbps; attitude quaternion at 5 Hz	115.2 kbps per wheel; command and telemetry at 10 Hz	20 kHz drive frequency; dipole command at 10 Hz; up to 0.4 A·m² per rod
Items	ADCS Sensor Data (quaternion, covariance, time tag, star count, status); ADCS Bus Commands (mode, exposure settings, time)	ADCS Bus Commands (torque or speed command); ADCS Sensor Data (wheel speed, motor current, temperature)	ADCS Bus Commands (dipole); ADCS Sensor Data (rod current readback)
Power carried	5 V, 1.8 W from the controller	12 V motor supply per wheel, limited to 0.15 A (1.75 W) per wheel	12 V drive, up to 0.4 W per rod
Connector	Micro-D 15	Micro-D 9 per wheel	Micro-D 9
Standard	EO1-ICD-200 message definitions	EO1-ICD-200 message definitions	EO1-ICD-200

ADCS internal links IF-16, IF-17 and IF-18

Each wheel has its own link and its own current-limited supply, so a failed wheel cannot take down the other three (SR-2.9, SR-15.2). The torque rods are switched off for a 20 ms window in every 100 ms control cycle while the magnetometer is sampled; the rod current readback lets the controller confirm the rods are off during that window.

19.3.7 IF-19 Deployment Switch Harness

Property	Value
Endpoints	1.6 Structure and Thermal (1.6.2 Deployment Mechanisms and separation switches) → 1.4 C&DH
Direction	Switch states to the C&DH
Type	Dry contact closures to signal return; 3.3 V pull-up and 50 ms debounce in the C&DH
Rate	Sampled at 10 Hz from separation

Property	Value
Signals	Three separation switch monitor contacts (SEP-A, SEP-B, SEP-C); two deployment switches per solar array panel; one deployment switch per UHF antenna element (four)
Items	Deployment Status; separation switch states
Connector	Micro-D 15

IF-19 Deployment Switch Harness

Each separation switch has two poles: one in the inhibit path (ICD-041) and one that reports its state on IF-19. The monitor contacts are what the separation timer and the T2 guard read.

19.3.8 Data Interface Requirements

ICD-013 Payload Data Throughput · Verify: Test · Trace: SR-4.6, SR-1.13 · Applies: All

The IF-05 image data link shall transfer image data from the Payload Camera to the C&DH at 400 Mbps sustained for at least 60 s with a bit error rate of at most 1×10^{-12}.

Rationale: 60 s covers the longest strip (54 s) streamed as it is captured, plus the end of its read-out. At 1×10^{-12} a 40 s strip (1.5×10^{10} bits) has about a 1.5 % chance of a single bit error, which the line CRC detects.

ICD-014 Capture Time Synchronization · Verify: Test · Trace: SR-4.2, SR-4.7 · Applies: All

The Payload Camera shall time-tag each image line within 100 μs of onboard time, using the IF-05 time pulse and the time message that follows it.

Rationale: 100 μs is 0.7 m along track at 7.06 km/s, negligible against the 14 m of onboard time error (SR-4.7); the strip start itself only needs the 1 s of SR-4.2.

ICD-015 ADCS Bus Telemetry Rate · Verify: Test · Trace: SR-2.6, SR-1.12 · Applies: All

The ADCS shall transmit its attitude and rate estimate on IF-06 at 10 Hz, each message time-tagged within 1 ms of onboard time.

Rationale: Image strips are tagged with attitude for geolocation (F7.4); at 10 Hz and 1 ms the interpolation error is well below the 50 arcsec knowledge requirement.

ICD-016 Safe Mode Command Response · Verify: Test · Trace: SR-4.3, SR-2.7 · Applies: All

The ADCS shall begin AP-2 Coarse Sun Pointing within 1 s of receiving a Safe Mode Command on IF-06.

Rationale: Safe Mode must be complete within 10 s of undervoltage (SR-4.3); the ADCS response must not consume that time.

ICD-017 ADCS Data Bus Load · Verify: Test, Analysis · Trace: SR-2.2, SR-4.3 · Applies: All

The traffic on IF-06 shall use no more than 30 % of the 1 Mbps bus capacity in any mode, with Safe Mode Commands on the highest-priority message identifiers.

Rationale: A lightly loaded bus bounds the delay of the 10 Hz attitude messages and leaves room for added telemetry over the mission; giving Safe Mode Commands the highest priority means they win arbitration against any other traffic. The ADCS response to a silent bus is ADCS-025 (ADCS chapter).

ICD-018 Command Frame Forwarding · Verify: Test · Trace: SR-5.2, SR-12.2, SR-4.2 · Applies: All

The UHF Transceiver shall forward each correctly decoded TC transfer frame to the C&DH on IF-07 within 100 ms of the end of its reception.

Rationale: Time-critical commands (contact start acknowledgements, CFDP acknowledgements during a pass) depend on short forwarding delay; 100 ms is about one frame time at 9.6 kbps.

ICD-019 Two-Step Transmitter Enable · Verify: Test · Trace: SR-5.11, SR-13.3, SR-11.9 · Applies: All

The payload downlink radio shall radiate only while its IF-04 branch is powered and a Transmitter Enable Command received on IF-08 or IF-08.1 is active, and shall stop radiating within 1 s of either condition ending.

Rationale: Two independent actions (PDU power and radio enable) are needed for the radio to transmit, which protects the 45 min RF delay and ground personnel (HAZ-003); 1 s keeps the 10 s shutoff of SR-5.11 with margin.

ICD-020 Downlink Frame Format · Verify: Test · Trace: SR-12.1, SR-5.9, SR-12.3 · Applies: All

The C&DH shall deliver Downlink Frames to the payload downlink radio as CCSDS 132.0-B TM transfer frames of 892 octets carrying CFDP protocol data units in space packets.

Rationale: One frame per 7,136-bit LDPC codeblock; the partner stations decode this format directly (SR-12.1), and CFDP in acknowledged mode is the file transfer protocol of SR-12.3.

ICD-021 Idle Frame Insertion · Verify: Test · Trace: SR-12.1, SR-5.3 · Applies: All

The payload downlink radio shall insert idle transfer frames whenever no Downlink Frame is available, so that the downlink is continuous from transmitter enable to disable.

Rationale: A continuous frame stream keeps the station’s demodulator and decoder locked; gaps would cost reacquisition time in a short pass.

ICD-022 S-band Data Interface · Verify: Test · Trace: SR-5.1, SR-12.1 · Applies: Lite

The IF-08 SpaceWire link between the C&DH and the S-band Transmitter shall operate at 100 Mbps.

Rationale: 100 Mbps gives about 80 Mbps of data throughput, eight times the 10 Mbps downlink, so the C&DH can refill the radio's frame buffer in bursts between compression tasks.

ICD-023 X-band Data Interface · Verify: Test, Inspection · Trace: SR-5.5, SR-12.1 · Applies: Flight

The IF-08.1 SpaceWire link between the C&DH and the X-band Payload Radio shall operate at 200 Mbps through connector J5 (Micro-D 9) of the C&DH.

Rationale: 200 Mbps gives about 160 Mbps of data throughput, 1.6 times the 100 Mbps downlink plus frame overhead; J5 keeps the X-band link separate from J4, so the same C&DH board serves both configurations.

ICD-024 Power Telemetry Update · Verify: Test · Trace: SR-4.3, SR-3.3 · Applies: All

The PDU shall provide its complete Power Telemetry set on IF-09, with battery voltage measured to within 50 mV, at least once per second.

Rationale: The G-UV guard compares the battery voltage with 12.8 V and needs 2 s of persistence; 1 s updates and 50 mV accuracy keep the Safe Mode decision inside the 10 s of SR-4.3.

ICD-025 Power Telemetry Bus Fault Tolerance · Verify: Test · Trace: SR-15.2, SR-11.6 · Applies: All

The PDU shall keep every switched output in its last commanded state when IF-09 communication fails, and the C&DH shall clear a held I2C bus within 100 ms.

Rationale: An I2C bus held low by an upset device must not switch loads or stop telemetry for long; the C&DH clocks the bus free and resumes polling.

ICD-026 Star Tracker Data Latency · Verify: Test · Trace: SR-2.2, SR-2.6 · Applies: All

The Star Tracker shall deliver each attitude quaternion on IF-16 within 50 ms of its exposure midpoint, with the exposure midpoint time-tagged in onboard time.

Rationale: The control loop holds 0.01 deg/s stability during capture (SR-2.2); a known, short latency lets the estimator propagate the measurement without adding to the 25 arcsec filter error allocation.

ICD-027 Wheel Supply Isolation · Verify: Test · Trace: SR-2.9, SR-15.2 · Applies: All

The ADCS Controller shall supply each reaction wheel through its own current limiter set at 0.15 A, so that a short in one wheel leaves the other three wheels powered and commanded.

Rationale: Three-wheel operation after a wheel failure (SR-2.9) requires that the failure stay inside the failed wheel; four limiters at 1.75 W each keep IF-02 within its 10 W rating with the controller and star tracker.

ICD-028 Torque Rod Dipole and Blanking · Verify: Test · Trace: SR-2.3, SR-2.8 · Applies: All

Each torque rod drive on IF-18 shall be able to drive its rod to the full 0.4 A·m² dipole in either polarity and shall be off during the magnetometer sampling window of each control cycle.

Rationale: 0.4 A·m² per axis is the rod capacity the ADCS chapter sizes for the 3 h detumble of SR-2.3; blanking keeps the rods' own field out of the magnetometer measurement that the B-dot law uses.

ICD-029 Deployment Switch Status · Verify: Test · Trace: SR-3.6, SR-8.6, SR-13.1 · Applies: All

The C&DH shall read the state of every separation and deployment switch on IF-19 at 10 Hz from the moment it powers up after separation.

Rationale: The separation timer, the T2 guard and the deployment confirmation (Deployment Status) all depend on these contacts; reading from power-up ensures the timer starts at release.

19.4 RF Interfaces

19.4.1 IF-10 Space-to-Ground Link

IF-10 is the radio link between the EO-1 Spacecraft and the partner ground stations. It has three children, one per radio channel. The link budgets that close each channel are in the Communications chapter; their margins are summarized in Technical Budgets and Margins.

Child	Band	Direction	Information rate	Configuration	Carries
IF-11 UHF Command Uplink	UHF, 435.5 MHz	Ground → spacecraft (commands); spacecraft → ground (telemetry, beacon)	9.6 kbps each way, half duplex	All	Command Packets; Housekeeping Telemetry
IF-12 S-band Downlink	S-band, 2,245.0 MHz	Spacecraft → ground	10 Mbps	Lite	Image Data Package
IF-12.1 X-band Downlink	X-band, 8,200.0 MHz	Spacecraft → ground	100 Mbps	Flight	Image Data Package (encrypted)

Children of IF-10 Space-to-Ground Link

IF-11 carries both directions of the UHF channel; its name follows its main use. The UHF uplink also carries the return path of the payload downlink: the station's link acknowledgements (every 10 s while it holds lock) and the CFDP acknowledgements and retransmission requests.

19.4.2 IF-11 UHF Command Uplink

Property	Value
Endpoints	2.1 Ground Station (UHF yagi) ⍰ 1.5.1 UHF Transceiver through 1.5.4 UHF Antenna
Frequency	435.5 MHz [TBR], one channel for both directions, 25 kHz channel width
Modulation	GMSK, BT 0.5
Rate	9.6 kbps uplink and downlink
Coding and framing	Uplink: TC transfer frames in CLTUs, authenticated (SR-14.1). Downlink: TM transfer frames with CRC, no forward error correction
Ground side	50 W transmitter, 14.0 dBi yagi, EIRP 29.0 dBW; receive G/T −15.8 dB/K
Spacecraft side	2 W RF transmitter; deployable turnstile, about 0 dBi; receive G/T −29.0 dB/K
Polarization	Ground: circular, switchable sense. Spacecraft: near-circular on axis, linear off axis; 3 dB polarization loss in both budgets
Doppler	±11 kHz at 5° elevation; the station pre-compensates the uplink
Link margin	Uplink 11.2 dB at 5° elevation in any attitude; telemetry downlink 3.2 dB at 10°
Items	Command Packets (Imaging Plan, recovery and contact-control commands, acknowledgements); Housekeeping Telemetry; health beacon
Standard	CCSDS 232.0-B TC and CCSDS 132.0-B TM Space Data Link Protocols, CCSDS 355.0-B authentication, as profiled in STD-2

IF-11 UHF Command Uplink

The center frequency is the one filed for the program; it stays TBR-71 until the frequency coordination under the Frequency Management Plan (EO1-PLN-380) is complete.

19.4.3 IF-12 S-band Downlink and IF-12.1 X-band Downlink

Property	IF-12 S-band Downlink (EO-1 Lite)	IF-12.1 X-band Downlink (EO-1 Flight)
Endpoints	1.5.2 S-band Transmitter → 2.1 Ground Station (3.7 m dish)	1.5.3 X-band Payload Radio → 2.1 Ground Station (3.7 m dish)
Frequency	2,245.0 MHz	8,200.0 MHz
Modulation	OQPSK, root-raised-cosine filtered	OQPSK, root-raised-cosine filtered
Information rate	10 Mbps	100 Mbps

Property	IF-12 S-band Downlink (EO-1 Lite)	IF-12.1 X-band Downlink (EO-1 Flight)
Coding	LDPC rate 7/8 (8160, 7136), randomizer, 32-bit attached sync marker	Same
Channel symbol rate	5.74 Msymbol/s	57.4 Msymbol/s
Occupied bandwidth (99 % power)	At most 8 MHz	At most 80 MHz
Polarization	Right-hand circular	Right-hand circular
Transmitter power, antenna	1 W RF; 6 dBi patch	2 W RF; 16 dBi patch array
EIRP	4.5 dBW	17.8 dBW
Ground receive G/T	14.0 dB/K	26.4 dB/K
Doppler	±56 kHz	±205 kHz
Link margin at 10° elevation	4.7 dB (requirement 3 dB, SR-5.3)	7.7 dB (requirement 3 dB, SR-5.6)
Security	None on the space link; data encrypted at the station (SR-14.5)	Authenticated encryption of each frame, 256-bit keys (SR-4.4)
Items	Image Data Package (CFDP files with Housekeeping Telemetry)	Image Data Package (encrypted), with Housekeeping Telemetry
Standard	CCSDS 131.0-B, CCSDS 132.0-B, CCSDS 727.0-B, as profiled in STD-2	Same, plus CCSDS 355.0-B

Payload downlinks IF-12 and IF-12.1

The channel symbol rate follows from the information rate: 8,192 channel bits (codeblock and sync marker) carry 7,136 information bits, so 10 Mbps becomes 11.48 Mbps on the channel, or 5.74 Msymbol/s at two bits per OQPSK symbol; the occupied bandwidth with 0.35 roll-off is about 7.8 MHz. The X-band values scale by ten.

On EO-1 Flight the X-band Payload Radio performs the frame encryption. The C&DH holds the key store (SR-14.3) and loads the session key for each pass into the radio over IF-08.1, wrapped under a key-encryption key that is installed in the radio before flight; no key crosses an interface in clear text. The Decommissioned entry erases the keys in both units.

19.4.4 RF Interface Requirements

> **ICD-030 UHF Channel** · Verify: Test · Trace: SR-5.2, SR-5.10 · Applies: All · TBR: TBR-71
>
> The UHF Transceiver shall transmit and receive GMSK at 9.6 kbps on a center frequency of 435.5 MHz [TBR] within a 25 kHz channel.
>
> *Rationale:* The frequency and channel width are those filed for the program; the partner stations' UHF equipment supports 9.6 kbps GMSK. TBR-71 closes when frequency coordination is complete (Communications Lead, before the FM-1 pre-shipment review).

ICD-031 UHF Receiver Doppler Tolerance · Verify: Test · Trace: SR-5.2, SR-5.7 · Applies: All

The UHF Transceiver shall acquire and hold an uplink carrier offset by up to ±12 kHz from its nominal frequency.

Rationale: The station pre-compensates the ±11 kHz Doppler, but before the first orbit determination and when the station uses old orbit data the residual can approach the full Doppler; ±12 kHz also covers oscillator aging.

ICD-032 S-band Downlink Signal · Verify: Test · Trace: SR-5.1, SR-5.3, SR-5.9 · Applies: Lite

The S-band Transmitter shall transmit OQPSK at 2,245.0 MHz with right-hand circular polarization and an EIRP of at least 4.5 dBW on the antenna boresight.

Rationale: These are the inputs of the S-band link budget that gives 4.7 dB margin at 10° elevation; a lower EIRP would erode the margin carried under TBR-04.

ICD-033 X-band Downlink Signal · Verify: Test · Trace: SR-5.5, SR-5.6, SR-5.9 · Applies: Flight

The X-band Payload Radio shall transmit OQPSK at 8,200.0 MHz with right-hand circular polarization and an EIRP of at least 17.8 dBW on the antenna boresight.

Rationale: Inputs of the X-band link budget that gives 7.7 dB margin at 10° elevation.

ICD-034 Downlink Occupied Bandwidth · Verify: Test · Trace: SR-5.10 · Applies: All

The occupied bandwidth (99 % power) of the payload downlink shall not exceed 8 MHz for the S-band Transmitter and 80 MHz for the X-band Payload Radio.

Rationale: The filed bandwidths; the coded signals occupy about 7.8 MHz and 78 MHz with 0.35 roll-off filtering.

ICD-035 X-band Power Flux Density · Verify: Analysis · Trace: SR-5.10 · Applies: Flight

The power flux density of the X-band downlink at the Earth's surface shall stay at least 3 dB below the limits of the ITU Radio Regulations for the band at every arrival angle.

Rationale: The worst case is the station at zenith (500 km range), where the analysis gives about −150 dB(W/m²) in 4 kHz; 3 dB covers antenna pattern and power uncertainty.

ICD-036 X-band Frame Encryption · Verify: Test, Inspection · Trace: SR-4.4, SR-14.3 · Applies: Flight

The X-band Payload Radio shall apply CCSDS 355.0-B authenticated encryption with a 256-bit session key to the data field of each Downlink Frame, using only keys received wrapped over IF-08.1.

Rationale: Implements SR-4.4 in the unit that performs F9.3 Frame and Encode Data; keys are managed in the C&DH key store (SR-14.3) and never cross IF-08.1 in clear text.

19.5 Ground Interfaces

19.5.1 IF-13 Ground Network

Property	Value
Endpoints	2.1 Ground Station ? 2.2 Mission Operations Center (three partner stations)
Direction	Station → MOC: Raw Image Files, Housekeeping Telemetry, pass reports, tracking data. MOC → station: contact schedule, authenticated command files (Imaging Plan, recovery commands), file receipt confirmations
Type	Secure file transfer over a wide-area network, mutual authentication, authenticated encryption
Rate	100 Mbps sustained per station
Volume	Largest pass about 4.9 GB (7 min X-band), transferred in about 7 min; priority file (one compressed strip, about 0.34 GB) in under 30 s
Standard	STD-2 ground profile; delivery time per SR-12.4

IF-13 Ground Network

Commands are authenticated at the Mission Operations Center before they leave it; a station forwards them without holding the command keys. On EO-1 Lite the station's CFDP entity requests retransmission of missing segments during the pass; on EO-1 Flight the station holds no keys and cannot read the encrypted file data, so the Mission Operations Center's CFDP entity forms the requests and the station relays them on the UHF uplink; the confirmation that lets the spacecraft delete a file (SR-10.28) is released only after the Mission Operations Center has received the file intact over IF-13, and reaches the spacecraft on a later UHF contact.

19.5.2 IF-14 Customer Interface and IF-14.1 Customer Portal

Property	IF-14 Customer Interface	IF-14.1 Customer Portal
Endpoints	2.2 Mission Operations Center ? X.1 Imagery Customer (machine interface)	2.2 Mission Operations Center ? X.1 Imagery Customer (people, through a web browser)
Direction	Customer → MOC: Tasking Request, Product Specification. MOC → customer: Image Product, crop stress alerts, collection status	Same items, through interactive pages; notifications to the customer
Type	Documented machine interface over encrypted web transport, token-based authentication per organization	Web portal over encrypted web transport, multi-factor sign-in (SR-14.6)
Rate	1 Gbps at the MOC's internet connection, shared by both	Shared with IF-14
Volume	About 29 GB of products per spacecraft per day at full collection (about 240 MB per scene)	Same products

Property	IF-14 Customer Interface	IF-14.1 Customer Portal
Formats	Products as GeoTIFF with metadata (SR-12.5); tasking and status as structured text	Same
Availability	99.5 % in each 30-day period (SR-15.4)	Same

IF-14 Customer Interface and IF-14.1 Customer Portal

19.5.3 IF-25 Operations Console

Property	Value
Endpoints	2.3 Mission Operator ⍰ 2.2 Mission Operations Center
Direction	Operator → MOC: plans, Processing Priorities, commands, approvals. MOC → operator: telemetry displays, alarms, Collection Status Report, plan checks
Type	Operator workstation application, on site or over the secure ground network; per-operator sign-in with multi-factor authentication
Items	Processing Priorities; Imaging Plan (for review and release); Collection Status Report; Housekeeping Telemetry displays; out-of-limit notifications (SR-6.9)
Standard	EO1-ICD-220

IF-25 Operations Console

19.5.4 Ground Interface Requirements

ICD-037 Ground Network Throughput · Verify: Test, Demonstration · Trace: SR-12.4, SR-6.5 · Applies: All

Each IF-13 connection between a ground station and the Mission Operations Center shall sustain at least 100 Mbps of file transfer throughput.

Rationale: Moves the largest pass (4.9 GB) in about 7 min against the 30 min of SR-12.4, and the priority file in under 30 s, which the 100 min planning cycle budget assumes (2 min transfer step).

ICD-038 Command Keys Stay at the MOC · Verify: Inspection, Demonstration · Trace: SR-14.1, SR-14.5 · Applies: All

The Mission Operations Center shall send commands to the ground stations over IF-13 only as already-authenticated TC frames, and no ground station shall hold a spacecraft command key.

Rationale: The stations are a partner's facilities; keeping the keys at the MOC limits the people and systems that could forge a command.

ICD-039 Product Notification · Verify: Demonstration · Trace: SR-6.2, SR-12.6 · Applies: All

The customer interface shall notify the Imagery Customer, through IF-14 and IF-14.1, within 1 min of each product or crop stress alert being published.

Rationale: Same-day alerts (N1) only help if the customer's systems learn of them at once; polling for new products would add delay and load.

ICD-040 Operations Console Telemetry Latency · Verify: Demonstration · Trace: SR-6.9, SR-6.4 · Applies: All

The operations console shall display each housekeeping telemetry value within 10 s of the frame's reception at the ground station.

Rationale: Operators judge commanding decisions during a pass from live telemetry; 10 s keeps them inside one UHF pass, and it is also the basis of the 5 min out-of-limit notification.

19.6 Mechanical Interface

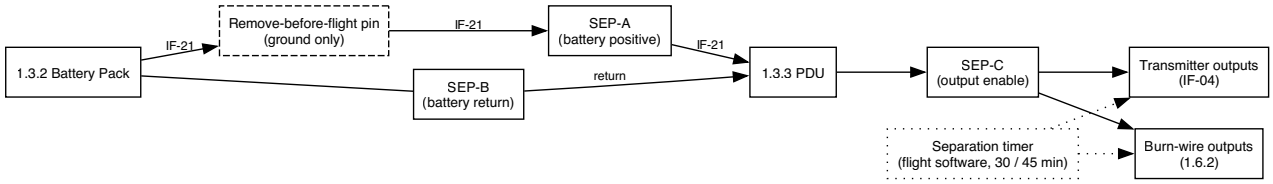
19.6.1 IF-15 Dispenser Adapter Interface

Property	Value
Endpoints	3 Rideshare Launch Vehicle (6U dispenser) ? 1.6.1 Primary Structure (rails) and 1.6.2 separation switches
Direction	Dispenser → spacecraft: launch loads, constraint, release (Separation Event). Spacecraft → dispenser: mass, center of mass, stiffness
Type	Mechanical only; no electrical connection (SR-12.7)
Envelope	6U envelope of the CubeSat Design Specification (CDS), Rev. 14.1: 100.0 mm × 226.3 mm × 366.0 mm, stowed
Rails	Four rails along the deployment axis, dimensions, finish and hard anodizing to the CDS 6U definition
Mass properties	Mass at most 12.0 kg (SR-8.2); center of mass within 4.0 cm (transverse) and 7.0 cm (deployment axis) of the geometric center (SR-8.3)
Stiffness	First natural frequency at least 100 Hz, constrained at the rails (SR-8.5)
Separation switches	Three rail-end switches (SEP-A, SEP-B, SEP-C), held depressed by the dispenser pusher plate; actuation stroke and force [TBD] for the assigned dispenser
Ground inhibit	Remove-before-flight pin, removed as the last step before loading
Ground support access	Access port with the umbilical (ground test) connector and the remove-before-flight pin, reachable with the deployables stowed; covered for flight
Items	Separation Event; launch loads (Environmental Requirements)

Property	Value
Standard	CDS Rev. 14.1; EO1-ICD-230; rideshare payload user's guide

IF-15 Dispenser Adapter Interface

The figure shows the inhibit arrangement that SR-13.1 requires. SEP-A and SEP-B interrupt the battery's positive and return lines (IF-21), so the whole spacecraft is unpowered in the dispenser. SEP-C interrupts the enable line of the PDU outputs that feed the transmitters and the burn-wire circuits, a third hardware break that is independent of the other two. After release, the flight software's separation timer adds the 30 min and 45 min delays (SR-8.6, SR-11.9) before the burn-wire and transmitter outputs can be enabled; the timer is not counted as one of the three inhibits. The remove-before-flight pin opens the battery line during ground handling and is removed before loading.



Launch inhibit arrangement: three separation switches and the ground remove-before-flight pin

19.6.2 Mechanical Interface Requirements

ICD-041 Separation Switch Inhibits · Verify: Inspection, Test · Trace: SR-13.1, SR-12.7 · Applies: All

The spacecraft shall carry three separation switches, each of which, while depressed by the dispenser, opens a different series break in the power path from the battery to every RF transmitter and every deployment actuator.

Rationale: Three independent hardware inhibits that act while the spacecraft is in the dispenser meet SR-13.1. The remove-before-flight pin is removed before loading, so it protects ground handling but is not counted in flight; this replaces the reading of the SR-13.1 rationale that counted it.

ICD-042 Separation Switch Actuation · Verify: Test · Trace: SR-13.1, SR-8.1 · Applies: All · TBD: TBD-70

Each separation switch shall change state within the plunger stroke of [TBD] mm and at the actuation force set by the assigned dispenser.

Rationale: Stroke and force differ between 6U dispensers; the switches must be fully actuated by the pusher plate when loaded and fully released at separation. TBD-70 closes with the launch services agreement (RK-3), the same event that closes TBD-17.

ICD-043 Deployables Restrained by the Spacecraft · Verify: Inspection, Test · Trace: SR-8.1, SR-8.6, SR-13.7 · Applies: All

Every deployable shall be held stowed by its own hold-down, independently of the dispenser walls, and shall stay within the 6U envelope when stowed.

Rationale: A deployable that relies on the dispenser wall to stay stowed would release as the spacecraft leaves the dispenser, before the 30 min delay, and could strike the dispenser.

ICD-044 Ground Support Access · Verify: Inspection, Demonstration · Trace: SR-13.1, SR-12.7, SR-11.10 · Applies: All

The umbilical connector and the remove-before-flight pin shall be reachable with the spacecraft fully integrated and the deployables stowed, and the umbilical connector shall be covered and electrically isolated for flight.

Rationale: Final charging, functional checks and the inhibit check before loading are done through this access; covering it for flight keeps SR-12.7 (no electrical connection to the dispenser).

19.7 Physical Paths

IF-23 and IF-24 are not built; they are the paths by which the Orbit Environment reaches the spacecraft. They are specified so that the design keeps them clear and the budgets use consistent inputs.

Property	IF-23 Sunlight Path	IF-24 Scene Radiance Path
Endpoints	4 Orbit Environment (the Sun) → 1.3.1 Solar Arrays	4 Orbit Environment (the target scene, the Moon for SR-1.14) → 1.1 Payload Camera aperture
Items	Solar Illumination	Ground Scene Radiance
Intensity	1,361 W/m² mean (1,322 W/m² to 1,414 W/m² over the year), air-mass-zero spectrum	Reflected sunlight from 0.30 reflectance at 45° solar zenith (SNR case, SR-1.8) to 0.90 reflectance at 20° (saturation case, SR-1.15)
Spectral range	Cell response, about 300 nm to 1,800 nm	450 nm to 900 nm, four bands (SR-1.4)
Geometry	20° design incidence on the deployed arrays; sunlit fraction 0.622 and longest eclipse 35.8 min in the bounding case	2.52° full cross-track field of view; boresight up to 25° off nadir
Clear field	Cell area free of shadow from the spacecraft's own appendages in Sun-pointing attitudes	Field of view plus 2° free of spacecraft structure; Sun outside 30° [TBR] of the boresight

Physical paths IF-23 and IF-24

ICD-045 Array Self-Shadowing · Verify: Analysis, Inspection · Trace: SR-3.1, SR-3.10 · Applies: All

In the AP-2 and AP-3 Sun-pointing attitudes, the spacecraft's own structure and appendages shall shadow no more than 1 % of the deployed solar cell area.

Rationale: The generation budget has no shadowing term; a shadowed cell in a series string also drags down the rest of the string, so even small shadows matter.

ICD-046 Camera Clear Field of View · Verify: Inspection, Analysis · Trace: SR-1.3, SR-1.15 · Applies: All

No part of the spacecraft shall lie within 2° of the edge of the Payload Camera's 2.52° field of view.

Rationale: Structure or deployed antennas near the field edge would vignette the swath edges (SR-1.3) or scatter sunlit light into the telescope.

ICD-047 Camera Sun Exclusion · Verify: Analysis, Test · Trace: SR-1.10, SR-1.15, SR-15.2 · Applies: All · TBR: TBR-72

The spacecraft shall keep the Sun more than 30° [TBR] from the Payload Camera boresight at all times, except for transits of less than 10 s during slews.

Rationale: The Sun near the field of view floods the telescope with stray light and heats the filters, which shifts the response that calibration relies on (SR-1.10). The camera itself tolerates the Sun in its field for up to 60 s (PAY-019); the 10 s transit limit keeps slews well inside that. TBR-72 closes when the stray light and focal plane damage analysis for the final baffle design is complete (Payload Lead, before the FM-1 thermal vacuum test).

20 Technical Budgets and Margins

This chapter states the program's margin policy and the current technical budgets: mass, power by mode, data volume, link margins, pointing and the timing of the planning cycle. It closes with the technical performance measures (TPMs) that track the budgets from CDR to launch. The budget tables are generated from the program's budget model (EO1-RPT-400 Budget Report) and are included unchanged; the text explains the cases and assumptions behind them. The generation and energy balance budgets are in the EPS chapter, the full link budgets in the Communications chapter and the pointing budget in the ADCS chapter; this chapter quotes their results.

Budget values are design predictions. The requirements they support are the system requirements (SR-1.5, SR-3.1, SR-3.3, SR-3.9, SR-5.3, SR-5.6, SR-6.5, SR-8.2, SR-8.4 and others); this chapter adds only the rules for how budgets are kept (VER-001 to VER-005).

20.1 Margin Policy

20.1.1 Terms

- **Current best estimate (CBE):** the present value of a quantity, from the best available source.
- **Contingency:** an allowance added to the CBE for the growth expected as the design matures. Its size depends on the basis of the CBE.
- **Allocation:** the value assigned to an element by the level above it, for example the 12.0 kg launch mass limit or the 28 W power allocation.
- **System margin:** the allocation minus the CBE with contingency. It is held by the Systems Lead, not by the subsystems, and is stated as a percentage of the allocation.

20.1.2 Contingency by Basis

Basis	Contingency	Meaning
Estimated	15 %	Value from a sketch, a similar unit or a supplier's preliminary figure
Calculated	10 %	Value calculated from the detailed design (drawings, CAD mass properties, circuit-level power analysis)
Measured	3 %	Value measured on the flight unit or on an identical qualification or engineering unit

Contingency applied to each budget line by the basis of its CBE

The same contingency percentages apply to mass and to power. A line moves to a lower contingency only when the evidence for the new basis is recorded in the budget report.

20.1.3 Margin Targets

Milestone	Minimum system margin (mass and power allocation)
PDR	15 %

Milestone	Minimum system margin (mass and power allocation)
CDR (this revision)	10 % (SR-8.4 for mass)
Pre-shipment review	5 %

Minimum system margin by milestone

The targets fall as the contingency on each line falls with maturity; at pre-shipment almost every line is measured, so a smaller margin carries the same risk. Link budgets keep their own 3 dB margin requirements (SR-5.3, SR-5.6, SR-5.8) and the 6 dB UHF uplink requirement (SR-5.7); the energy budget is held by the 30 % depth of discharge limit (SR-3.3).

20.1.4 Budget Management Requirements

VER-001 Contingency by Basis · Verify: Inspection · Trace: SR-8.4, SR-3.9 · Applies: All

Each line of the mass and power budgets shall carry a contingency of 15 % (Estimated), 10 % (Calculated) or 3 % (Measured) of its CBE, according to the recorded basis of that CBE.

Rationale: A uniform rule keeps subsystems from holding hidden reserves and makes the system margin a true measure of the remaining room. The percentages follow the growth seen between design maturity levels on comparable small spacecraft.

VER-002 Measured Basis Evidence · Verify: Inspection · Trace: SR-8.2, SR-3.9 · Applies: All

A budget line shall be given the Measured basis only when its value comes from a calibrated measurement of the flight unit or of a unit built to the same drawings and parts list.

Rationale: The 3 % contingency covers measurement error and small late changes only; a measurement of a different build standard does not justify it.

VER-003 Margin Threshold Action · Verify: Inspection · Trace: SR-8.4, SR-3.9 · Applies: All

When a TPM’s current value crosses its threshold, the Systems Lead shall open a corrective action and record it in the open-item list within 10 working days.

Rationale: Crossing a threshold means the system can no longer absorb normal growth; the action (design change, reallocation or requirement change) must be started before the next design decision consumes more margin.

VER-004 Budget Reporting · Verify: Inspection · Trace: SR-8.4, SR-3.9, SR-5.3 · Applies: All

The Systems Lead shall report the mass, power, energy, data, link and pointing budgets and the TPMs of this chapter at each milestone review and at least once a month between reviews.

Rationale: Monthly reporting catches growth trends early; the milestone reports are the evidence for the margin targets.

VER-005 Flight Unit Weighing · Verify: Inspection, Test · Trace: SR-8.2, SR-8.3 · Applies: All

Each flight unit shall be weighed to within 1 g before spacecraft integration, and each integrated spacecraft shall have its mass and center of mass measured before shipment.

Rationale: Unit weights move the budget lines to the Measured basis; the integrated measurement verifies SR-8.2 and SR-8.3 directly and catches harness and fastener mass that unit weights miss.

20.2 Mass Budget

The mass budget covers the spacecraft at launch, stowed, with the battery charged. Both configurations share every line except the payload downlink radio.

No.	Item	Qty	Unit (kg)	CBE (kg)	Basis	Cont.	With cont. (kg)
1.1	Payload Camera (optics, focal plane, electronics)	1	2.40	2.400	Calculated	10 %	2.640
1.2.1	Reaction Wheel Assembly (per wheel)	4	0.13	0.520	Measured	3 %	0.536
1.2.2	Star Tracker	1	0.35	0.350	Measured	3 %	0.360
1.2.3	Magnetorquers (set of three)	1	0.21	0.210	Calculated	10 %	0.231
1.2.4	ADCS Controller, sun sensors, magnetometer	1	0.11	0.110	Estimated	15 %	0.127
1.3.1	Solar Arrays (two deployable panels)	1	0.45	0.450	Measured	3 %	0.464
1.3.2	Battery Pack	1	0.62	0.620	Measured	3 %	0.639
1.3.3	Power Distribution Unit	1	0.28	0.280	Calculated	10 %	0.308
1.4	C&DH flight computer and storage	1	0.34	0.340	Measured	3 %	0.350
1.5.1	UHF Transceiver	1	0.09	0.090	Measured	3 %	0.093
1.5.4	UHF deployable antenna	1	0.04	0.040	Estimated	15 %	0.046

No.	Item	Qty	Unit (kg)	CBE (kg)	Basis	Cont.	With cont. (kg)
1.5.2	S-band Transmitter with patch antenna	1	0.32	0.320	Calculated	10 %	0.352
1.6	Structure, hinges, thermal hardware	1	3.60	3.600	Calculated	10 %	3.960
1.7	Harness and connectors	1	0.26	0.260	Estimated	15 %	0.299
	Total			**9.590**			**10.404**

Mass budget, EO-1 Lite

Allocation 12.0 kg; system margin 1.60 kg (13.3 % of the allocation).

No.	Item	Qty	Unit (kg)	CBE (kg)	Basis	Cont.	With cont. (kg)
1.1	Payload Camera (optics, focal plane, electronics)	1	2.40	2.400	Calculated	10 %	2.640
1.2.1	Reaction Wheel Assembly (per wheel)	4	0.13	0.520	Measured	3 %	0.536
1.2.2	Star Tracker	1	0.35	0.350	Measured	3 %	0.360
1.2.3	Magnetorquers (set of three)	1	0.21	0.210	Calculated	10 %	0.231
1.2.4	ADCS Controller, sun sensors, magnetometer	1	0.11	0.110	Estimated	15 %	0.127
1.3.1	Solar Arrays (two deployable panels)	1	0.45	0.450	Measured	3 %	0.464
1.3.2	Battery Pack	1	0.62	0.620	Measured	3 %	0.639
1.3.3	Power Distribution Unit	1	0.28	0.280	Calculated	10 %	0.308
1.4	C&DH flight computer and storage	1	0.34	0.340	Measured	3 %	0.350
1.5.1	UHF Transceiver	1	0.09	0.090	Measured	3 %	0.093

No.	Item	Qty	Unit (kg)	CBE (kg)	Basis	Cont.	With cont. (kg)
1.5.4	UHF deployable antenna	1	0.04	0.040	Estimated	15 %	0.046
1.5.3	X-band Payload Radio with patch array	1	0.45	0.450	Calculated	10 %	0.495
1.6	Structure, hinges, thermal hardware	1	3.60	3.600	Calculated	10 %	3.960
1.7	Harness and connectors	1	0.26	0.260	Estimated	15 %	0.299
	Total			**9.720**			**10.547**

Mass budget, EO-1 Flight

Allocation 12.0 kg; system margin 1.45 kg (12.1 % of the allocation).

Notes on the mass budget:

- The structure, hinges and thermal hardware (3.96 kg with contingency) and the Payload Camera (2.64 kg) make up 63 % of the EO-1 Lite mass. Both are Calculated from the detailed design; their weighing on FM-1 is the largest single step in retiring contingency.
- By basis, the EO-1 Lite CBE is 2.37 kg Measured, 6.81 kg Calculated and 0.41 kg Estimated. The contingency is 0.81 kg, an average of 8.5 % of the CBE.
- The X-band Payload Radio with its patch array is 0.13 kg heavier than the S-band Transmitter with its patch (0.14 kg with contingency), which is the whole difference between the configurations.
- Both configurations meet the CDR target of SR-8.4: 13.3 % (EO-1 Lite) and 12.1 % (EO-1 Flight) against 10 %. The propulsion module studied for orbit maintenance (0.8 kg with contingency) would have taken EO-1 Flight to about 5.4 %, one reason it is not included (System Architecture, Propulsion Studied and Excluded).

20.3 Power Budget

20.3.1 Design Case

The power budget is computed for each mode as an orbit average over one 94.6 min orbit. The Nominal Imaging design case is a demanding but routine orbit: two imaging windows with four 40 s strips each (eight strips, SR-1.13), the payload prepared for 5 min before each window, one compression burst of up to 60 s per strip, the slews for both windows, and one payload downlink pass: 9 min of S-band (EO-1 Lite) or 7 min of X-band (EO-1 Flight). The duty column of each table follows from these times; for example the eight strips are 320 s, or 5.6 % of the orbit. The bus load at the array side divides the load by the 0.90 combined conversion efficiency of the PDU.

Load	On (W)	Duty	Orbit avg (W)	Basis	With cont. (W)
Payload electronics standby and focal plane control	2.5	100.0 %	2.50	Estimated	2.88
Payload Camera - prepare (two imaging windows)	6.0	10.6 %	0.63	Estimated	0.73
Payload Camera - capture (eight 40 s strips)	14.0	5.6 %	0.79	Calculated	0.87
Payload thermal control heater	1.5	60.0 %	0.90	Estimated	1.03
ADCS controller, sun sensors, magnetometer	1.0	100.0 %	1.00	Calculated	1.10
Star Tracker	1.8	100.0 %	1.80	Measured	1.85
Reaction Wheels (four, average)	2.0	100.0 %	2.00	Measured	2.06
Reaction Wheels (slew increment)	4.0	12.7 %	0.51	Measured	0.52
Magnetorquers	1.2	35.0 %	0.42	Calculated	0.46
PDU overhead	1.5	100.0 %	1.50	Calculated	1.65
C&DH flight computer and storage	4.0	100.0 %	4.00	Measured	4.12
C&DH compression burst	2.5	8.5 %	0.21	Measured	0.22
UHF Transceiver - receive	1.0	100.0 %	1.00	Measured	1.03
UHF Transceiver - transmit	6.0	6.0 %	0.36	Measured	0.37
Payload downlink radio - transmit (S-band, Lite)	11.5	9.5 %	1.09	Calculated	1.20
Battery and structure heaters	3.5	60.0 %	2.10	Estimated	2.42
Load total			**20.82**		**22.51**
Bus load at the array side (efficiency 0.90)			23.13		25.01

Power budget, Nominal Imaging design case, EO-1 Lite

Load	On (W)	Duty	Orbit avg (W)	Basis	With cont. (W)
Payload electronics standby and focal plane control	2.5	100.0 %	2.50	Estimated	2.88
Payload Camera - prepare (two imaging windows)	6.0	10.6 %	0.63	Estimated	0.73
Payload Camera - capture (eight 40 s strips)	14.0	5.6 %	0.79	Calculated	0.87
Payload thermal control heater	1.5	60.0 %	0.90	Estimated	1.03
ADCS controller, sun sensors, magnetometer	1.0	100.0 %	1.00	Calculated	1.10
Star Tracker	1.8	100.0 %	1.80	Measured	1.85
Reaction Wheels (four, average)	2.0	100.0 %	2.00	Measured	2.06
Reaction Wheels (slew increment)	4.0	12.7 %	0.51	Measured	0.52
Magnetorquers	1.2	35.0 %	0.42	Calculated	0.46
PDU overhead	1.5	100.0 %	1.50	Calculated	1.65
C&DH flight computer and storage	4.0	100.0 %	4.00	Measured	4.12
C&DH compression burst	2.5	8.5 %	0.21	Measured	0.22
UHF Transceiver - receive	1.0	100.0 %	1.00	Measured	1.03
UHF Transceiver - transmit	6.0	6.0 %	0.36	Measured	0.37
Payload downlink radio - transmit (X-band, Flight)	15.0	7.4 %	1.11	Calculated	1.22
Battery and structure heaters	3.5	60.0 %	2.10	Estimated	2.42
Load total			**20.83**		**22.53**
Bus load at the array side (efficiency 0.90)			23.15		25.03

Power budget, Nominal Imaging design case, EO-1 Flight

The two configurations differ only in the downlink line: the X-band radio draws more (15.0 W against 11.5 W) for a shorter pass (7 min against 9 min), so the orbit averages are almost equal, 25.0 W with contingency in both cases. Against the 28 W allocation of SR-3.9 the margin is 12 % (TPM-2).

20.3.2 Safe Mode and Detumble

In Safe Mode the payload, the star tracker, the payload heater and the payload downlink radio are off, the wheels hold Sun pointing and the UHF Transceiver sends the health beacon. The survival heaters run at a higher duty than in Nominal Imaging because the payload is cold. Detumble differs from Safe Mode in that the wheels are off and the magnetorquers run the rate damping law at 90 % duty. The EO-1 Flight tables for these two modes are identical to the EO-1 Lite tables shown, since the payload downlink radio is off in both.

Load	On (W)	Duty	Orbit avg (W)	Basis	With cont. (W)
ADCS controller, sun sensors, magnetometer	1.0	100.0 %	1.00	Calculated	1.10
Reaction Wheels (four, average)	2.0	100.0 %	2.00	Measured	2.06
Magnetorquers	1.2	35.0 %	0.42	Calculated	0.46
PDU overhead	1.5	100.0 %	1.50	Calculated	1.65
C&DH flight computer and storage	4.0	100.0 %	4.00	Measured	4.12
UHF Transceiver - receive	1.0	100.0 %	1.00	Measured	1.03
UHF Transceiver - transmit	6.0	6.0 %	0.36	Measured	0.37
Battery and structure heaters	3.5	80.0 %	2.80	Estimated	3.22
Load total			**13.08**		**14.01**
Bus load at the array side (efficiency 0.90)			14.53		15.57

Power budget, Safe Mode (EO-1 Lite; EO-1 Flight identical)

Load	On (W)	Duty	Orbit avg (W)	Basis	With cont. (W)
ADCS controller, sun sensors, magnetometer	1.0	100.0 %	1.00	Calculated	1.10
Magnetorquers	1.2	90.0 %	1.08	Calculated	1.19
PDU overhead	1.5	100.0 %	1.50	Calculated	1.65
C&DH flight computer and storage	4.0	100.0 %	4.00	Measured	4.12

Load	On (W)	Duty	Orbit avg (W)	Basis	With cont. (W)
UHF Transceiver - receive	1.0	100.0 %	1.00	Measured	1.03
UHF Transceiver - transmit	6.0	6.0 %	0.36	Measured	0.37
Battery and structure heaters	3.5	80.0 %	2.80	Estimated	3.22
Load total			**11.74**		**12.68**
Bus load at the array side (efficiency 0.90)			13.04		14.09

Power budget, Detumble (EO-1 Lite; EO-1 Flight identical)

Mode	Bus load with contingency	Available power	Margin	Source of the available power
Detumble	14.1 W	Battery until the arrays deploy; then array output in tumbling attitude	Energy-limited before deployment: about 14 % of capacity for 45 min (SR-11.10)	Generation budget, battery capacity
Nominal Imaging, design case	25.0 W	33.0 W EOL orbit average	32 % over the bus load; 12 % allocation margin (28 W)	Generation budget, SR-3.9
Downlink Contact	Included in the Nominal Imaging design case	—	—	—
Safe Mode	15.6 W	At least 20 W required (SR-3.10); about 40 W predicted in Sun pointing	28 % against the 20 W requirement	SR-3.10

Bus load and available power by mode

20.4 Orbit-Average Generation and Energy Balance

The generation budget and the energy balance are in the EPS chapter. Their results, used here and in the TPMs:

- Orbit-average generation is **37.4 W at beginning of life and 33.0 W at end of life** in the imaging attitude profile, which meets the 30 W of SR-3.1. The end-of-life value includes radiation and temperature losses (factor 0.883), peak power tracking (0.96), the bounding sunlit fraction (0.622) and the 0.83 attitude factor of imaging and downlink pointing.
- Against the 25.0 W design-case bus load, the end-of-life generation margin is 32.1 % (EO-1 Lite) and 32.0 % (EO-1 Flight). On the MOE-5 Power Margin scale (0 % margin scores 0, 40 % scores 100) this scores 80, between the 65 threshold and the 90 objective.
- In the worst-case eclipse (35.8 min, survival heaters on, one downlink pass in eclipse) the battery supplies **17.7 Wh, a depth of discharge of 23 %** of the 77 Wh beginning-of-life capacity, against the 30 % limit of SR-3.3. At the 59 Wh end-of-life capacity of SR-15.8 the same eclipse is a 30 % discharge, exactly the limit; that is how SR-15.8 was derived.

20.5 Data Volume

The data volume budget follows one design-case day of collection, 120 scenes, from the camera to the ground.

Step	Value	Note
Scenes per day (design case)	120	Customer target list
Raw data per day	17.2 GB	120 x 143 MB
Compression	2.2 bits per pixel (5.45:1)	CCSDS 122.0 image compression, near-lossless
Compressed image data per day	3.16 GB	
Ancillary data and metadata	2 %	Attitude, ephemeris, time tags, calibration
Stored payload data per day	**3.22 GB**	Meets SR-1.5 (at least 3.2 GB)
Housekeeping telemetry per day	0.02 GB	Over UHF and the payload downlink
S-band capacity per day, three-station service	3.38 GB	6 passes x 8 min x 10 Mbps x 0.94 framing
S-band daily margin	5 %	Three-station service
S-band capacity per day, EO-1 Lite service plan	1.13 GB	One station: 2 passes x 8 min (SR-5.4 Lite value, at least 1 GB)
X-band capacity per day (EO-1 Flight)	9.87 GB	2 passes x 7 min x 100 Mbps x 0.94 framing
X-band daily margin	207 %	
Onboard storage	64 GB	SR-4.1
Days of compressed collection held	20 days	
Days of raw (calibration mode) collection held	3.7 days	Basis of the 3-day sizing in SR-4.1

Data volume budget, design-case day

The budget shows the two constraints that shape operations. First, collection is not the limit: compression brings 17.2 GB of raw data to 3.22 GB, which meets SR-1.5. Second, on S-band the downlink is the limit. The three-station service clears a full day with only 5 % margin, so a missed pass carries over into the next day's queue; the EO-1 Lite one-station plan carries 1.13 GB, which is why its tasking is capped at about 40 scenes a day. X-band clears the full day three times over. The 64 GB storage holds 20 days of compressed collection, which is what makes a missed pass a delay rather than a loss.

20.6 Link Margins

The full link budgets are in the Communications chapter. Their margins at the planning elevations:

Link	Configuration	Elevation	Margin	Required	Excess over requirement
S-band payload downlink (IF-12)	Lite	10°	4.7 dB	3 dB [TBR] (SR-5.3)	1.7 dB

Link	Configuration	Elevation	Margin	Required	Excess over requirement
X-band payload downlink (IF-12.1)	Flight	10°	7.7 dB	3 dB (SR-5.6)	4.7 dB
UHF command uplink (IF-11)	All	5°, any attitude	11.2 dB	6 dB (SR-5.7)	5.2 dB
UHF telemetry downlink (IF-11)	All	10°, any attitude	3.2 dB	3 dB (SR-5.8)	0.2 dB

Link margin summary

The UHF telemetry downlink is the watch item: its 0.2 dB excess depends on the 3 dB worst-attitude pattern loss assumed for the deployed turnstile, which the antenna pattern measurement on FM-1 will confirm or replace. If the measured pattern is worse, the remedy is operational (plan telemetry dumps above 15° elevation) and does not affect commanding, which has 5.2 dB in hand.

20.7 Pointing

The pointing budget is in the ADCS chapter. It combines six 3σ contributors by root sum square to **163 arcsec (0.045°)** against the 360 arcsec (0.1°) of SR-2.1, a margin of 197 arcsec. The largest contributor is control error from wheel jitter and controller residual (140 arcsec). The flatsat test TC-04 measured 0.14° on 3 of 20 targets, above the requirement; wheel friction is suspected and the case is carried as risk RK-1 until the investigation closes. The budget value is not changed for the test result until the cause is confirmed, but the TC-04 repeat with the flight wheels is a CDR action.

20.8 Timing Budget for the Planning Cycle

SR-6.5 requires each planning cycle, from the start of the plan uplink to the first product on the portal, to take at most 100 min (MOE-7 threshold 100 min, objective 80 min). The cycle runs on the fastest geometry the planner can book: plan uplink, capture and payload downlink on consecutive parts of one or two orbits (Mission Overview and Concept of Operations, Planning cycle).

20.8.1 Imaging Window Timing

Within an imaging window the strips follow each other at a cadence set by the retargeting slew between targets. Each strip streams to the C&DH over IF-05 as it is captured and is compressed in hardware at the same rate, so the data handling keeps pace with the capture.

Step	Start (s)	Duration (s)	Notes
OPS.5 Prepare Camera	−300	300	Focal plane powered and brought to 20 °C ± 2 °C (SR-9.2)
OPS.4 Rotate to Target	−180	180	Slew of up to 30° (60 s, SR-2.4 [TBR-03]) plus settling to 0.01 deg/s

Step	Start (s)	Duration (s)	Notes
OPS.6 Capture Image Strip, strip 1	0	40	1.84 GB raw at 368 Mbps
Strip 1 read-out over IF-05	0	50	Streams from the start of capture at 400 Mbps; ends within 10 s of the strip end (PAY-025)
OPS.7 Encode and Store Image, strip 1	0	50	Hardware compression at the read-out rate (CDH-015); SR-4.6 allows 60 s
Retarget to strip 2	40	40	Small slew and settle to 0.01 deg/s
Strips 2 to 4	80, 160, 240	40 each	80 s cadence: 40 s capture, 40 s retargeting
End of window (last compression complete)	—	—	About 290 s after the first strip starts; at most 340 s at the SR-4.6 limit

Timing of one imaging window with four 40 s strips

Two windows of this length give the design-case orbit's eight strips. The power budget books 60 s of compression burst per strip, 8 min in all (8.5 % of the orbit), which is the SR-4.6 limit and slightly more than the hardware needs.

20.8.2 Planning Cycle

The steps up to the end of the downlink are tied to orbital geometry: the uplink pass, the target and the downlink station are fixed times on the orbit, so a longer step on board uses up slack rather than delaying the steps after it, as long as the plan is loaded before the camera preparation must start. The ground steps after the downlink add directly.

Step	Start (min)	Nominal (min)	Worst case (min)	Notes
OPS.1 Transmit Imaging Plan	0	6	9	Part of a UHF pass (SR-5.2)
OPS.2 Receive Imaging Plan	6	1	1	Frames forwarded within 100 ms each (ICD-018)
OPS.3 Load Command Schedule	7	2	2	Validation and constraint check (SR-10.22); must end by 13 min, when OPS.5 starts
Coast to the target	9	6	1	Absorbs a longer uplink
OPS.5 Prepare Camera	13	5	5	In parallel with the coast and the slew
OPS.4 Rotate to Target	15	3	3	

Step	Start (min)	Nominal (min)	Worst case (min)	Notes
OPS.6 Capture Image Strip (priority strip)	18	0.7	0.7	40 s strip
OPS.7 Encode and Store Image	19	0.5	1.0	Up to 60 s (SR-4.6)
Coast to the downlink station	20	9	9	Starts at a fixed orbit time; the 0.5 min before it absorbs a longer compression
OPS.8 Transmit Image Data and OPS.11 Receive Downlink	29	9	9	Priority file first (SR-10.23)
Transfer to the Mission Operations Center (IF-13)	38	2	3	Priority file at 100 Mbps (ICD-037)
OPS.12 Process Image Products	40	45	55	45 ± 10 min processing to the portal
Product on the portal		**85**	**96**	Requirement 100 min (SR-6.5)

Timing budget of the planning cycle

The cycle closes under 100 min in both columns: 15 min of margin nominally and 4 min in the worst case. Two observations follow from the budget:

- **Processing dominates.** Of the 85 min, 47 min are on the ground after the downlink, and the 10 min processing uncertainty is the only one that reaches the end of the cycle. The MOE-7 objective of 80 min needs processing of at most 40 min; the Mission Operations Center's alert-first processing path (Processing Priorities) is the candidate for it.
- **The onboard slack is small.** A 9 min uplink leaves 1 min between the end of the schedule load and the start of camera preparation. A plan that cannot be uplinked in 9 min of a pass is split, with the time-critical part first.

20.9 Technical Performance Measures

Three TPMs are tracked from CDR to launch. The threshold is the value at which corrective action is required (VER-003); the objective is the value the program aims for.

TPM	Measure	Parent	Threshold	Objective	Current value	Status
TPM-1 Spacecraft Mass	Launch mass with contingency	SR-8.2, SR-8.4	At most 10.80 kg (10 % margin)	At most 10.20 kg (15 % margin)	EO-1 Lite 10.40 kg (13.3 %); EO-1 Flight 10.55 kg (12.1 %)	Within threshold; objective not met

TPM	Measure	Parent	Threshold	Objective	Current value	Status
TPM-2 Orbit-Average Power Margin	Margin of the 28 W allocation over the design-case bus load	SR-3.9, SR-3.1	At least 10 %	At least 15 %	12 % (bus load 25.0 W), both configurations; end-of-life generation margin 32 %	Within threshold; objective not met
TPM-3 Payload Downlink Rate	Information rate that closes at 10° elevation, with its link margin	SR-5.1, SR-5.3, SR-5.5, SR-5.6	Required rate with at least 3 dB margin	Required rate with at least 6 dB margin	EO-1 Lite 10 Mbps at 4.7 dB; EO-1 Flight 100 Mbps at 7.7 dB	Lite within threshold; Flight meets objective

Technical performance measures at CDR

TPM-3 is stated as a rate together with its margin because the two trade against each other: at a 3 dB margin the S-band link would carry about 14.8 Mbps and the X-band link about 295 Mbps. The program keeps the rates fixed and tracks the margin, since the rates are set by the radios and the ground stations.

21 Environmental Requirements

This chapter defines the environments the EO-1 Spacecraft must survive and operate in, from storage and transport through launch and two years in orbit, and the test levels and margins that demonstrate it. The system-level environment requirements are SR-11.1 to SR-11.10 (Environments and Launch Compatibility) and the related safety and debris requirements of area 13; this chapter gives the environment definitions behind them and the ENV requirements that apply them to the design and to testing. Program test levels, durations and tolerances not stated here are in STD-1, which tailors GSFC-STD-7000 General Environmental Verification Standard (GEVS) and ECSS-E-ST-10-03C, Testing.

The launch vehicle is not yet assigned (RK-3). Launch environments are therefore enveloping values that cover the rideshare vehicles under consideration; they are replaced by the assigned vehicle's levels from the rideshare payload user's guide when the launch services agreement is signed, if those are lower, or the design is reassessed if they are higher.

21.1 Environment Phases

Phase	Duration	Spacecraft state	Main environments	Section
Integration and test	About 6 months per flight model	Powered for tests, otherwise off	Clean room, test environments	Ground Environments; Test Levels
Storage and transport	Up to 12 months storage; days per shipment	Off, battery at storage charge	Temperature, humidity, handling and transport loads	Ground Environments
Dispenser	Up to 180 days (SR-11.10)	Off, inhibits closed	Integrator and launch site conditions	Ground Environments
Launch	About 1 h to separation	Off, inhibits closed	Quasi-static, sine, random, shock, depressurization	Launch Environment
Orbit	730 days (SR-1.7)	Operating	Thermal, vacuum, radiation, atomic oxygen, UV, debris	Orbital Environment
Post-mission	Until reentry (SR-13.4)	Passivated	Orbital environment, no operating requirements	—

Environment phases of an EO-1 spacecraft

21.2 Launch Environment

The spacecraft rides inside a 6U dispenser. The dispenser, not the spacecraft, is attached to the launch vehicle, so the launch environments here are defined at the dispenser rail interface (IF-15). The spacecraft is unpowered for the whole launch phase.

21.2.1 Quasi-Static Loads

The quasi-static limit load is 10 g along each axis (SR-11.2), applied one axis at a time and combined as the launch provider's load factors require. It envelopes the steady acceleration and the low-frequency transients of the rideshare vehicles under consideration.

ENV-001 Structural Factors of Safety · Verify: Analysis · Trace: SR-11.2, SR-8.5 · Applies: All

The primary structure shall show positive margins at the 10 g limit load with factors of safety of at least 1.25 on yield and 1.4 on ultimate when the strength is verified by test, and 1.6 on yield and 2.0 on ultimate when it is verified by analysis alone.

Rationale: SR-11.2 sets the yield factor for the tested structure; the ultimate factor and the higher factors for analysis-only parts (brackets, inserts not covered by the protoflight test) follow STD-1 and common rideshare practice.

21.2.2 Sine Vibration

Sine vibration covers the low-frequency transients of the launch vehicle transmitted through the dispenser.

Frequency	Acceptance level	Qualification and protoflight level
5 Hz to 100 Hz	2.0 g (0 to peak)	2.5 g [TBR] (0 to peak)
Sweep rate	4 octaves/min	2 octaves/min (qualification), 4 octaves/min (protoflight)

Sine vibration levels at the dispenser rail interface, each axis

ENV-002 Sine Vibration · Verify: Test · Trace: SR-11.2, SR-8.5 · Applies: All · TBR: TBR-73

The spacecraft shall operate within specification after sine vibration from 5 Hz to 100 Hz at 2.5 g [TBR] in each of three axes.

Rationale: 2.5 g is 1.25 times the 2.0 g enveloping flight level. The stowed first mode above 100 Hz (SR-8.5) keeps the spacecraft out of resonance in this band, so the test is mainly a check of the dispenser-to-rail load path. Notching at the rails to the quasi-static load is allowed with the launch provider's agreement. TBR-73 closes with the launch services agreement (Systems Lead).

21.2.3 Random Vibration

Random vibration is the dominant launch environment for a CubeSat in a dispenser. Until the launch vehicle is assigned, the design uses the GEVS generalized random envelope for components; the qualification level in SR-11.1 stays TBD-17 until the vehicle's level is known.

Frequency (Hz)	Design envelope, qualification (g^2/Hz)	Design envelope, acceptance (g^2/Hz)	Flight qualification level
20	0.026	0.013	[TBD]
20 to 50	+6 dB/octave	+6 dB/octave	[TBD]
50 to 800	0.16	0.08	[TBD]

Frequency (Hz)	Design envelope, qualification (g^2/Hz)	Design envelope, acceptance (g^2/Hz)	Flight qualification level
800 to 2,000	−6 dB/octave	−6 dB/octave	[TBD]
2,000	0.026	0.013	[TBD]
Overall	14.1 g rms	10.0 g rms	[TBD] (TBD-17)
Duration per axis	2 min (qualification), 1 min (protoflight)	1 min	—

Random vibration acceleration spectral density at the dispenser rail interface, each axis

ENV-003 Unit Random Vibration · Verify: Test · Trace: SR-11.1, SR-15.7 · Applies: All

Each flight unit without a prior qualification to these levels shall be tested at unit level to the design envelope of the random vibration table, at the qualification level for qualification units and at the acceptance level for flight units.

Rationale: Testing units to the GEVS envelope now, while the vehicle level is TBD-17, protects the schedule: unit failures are found before integration, and the envelope is expected to cover the final vehicle level.

ENV-004 Vibration Signature Criteria · Verify: Test · Trace: SR-11.1, SR-8.5 · Applies: All

A low-level sine sweep from 5 Hz to 2,000 Hz shall be run before and after each spacecraft random and sine vibration run, and the spacecraft shall show no shift of more than 5 % in the frequency of any mode above 100 Hz and no change of more than 20 % in its amplitude.

Rationale: A frequency or amplitude change shows that a joint has loosened or a part has cracked, which a functional test alone may not reveal.

21.2.4 Shock

The shock environment is set by the dispenser door release and separation and by the launch vehicle stage events (SR-11.3).

Frequency (Hz)	Maximum predicted (g, Q = 10)	Qualification (g, Q = 10)
100	35	50
100 to 1,000	Straight line on log-log axes	Straight line on log-log axes
1,000 to 10,000	707	1,000

Shock response spectrum at the dispenser rail interface

ENV-005 Separation Shock Test · Verify: Test · Trace: SR-11.3, SR-13.7 · Applies: All

Each flight spacecraft shall be released at least once from a flight-equivalent 6U dispenser before shipment, and the protoflight model at least twice, with a functional test after each release.

Rationale: Release from a real dispenser is the most representative shock source and checks the rail interface, the separation switches and the captive hold-downs (SR-13.7) at the same time.

21.2.5 Acoustic Noise

The acoustic environment inside the fairing does not act directly on the spacecraft: the closed dispenser shields it, and the acoustic energy that reaches it arrives as vibration through the rails, which the random vibration levels already include. No acoustic test is required. If the assigned vehicle's user's guide requires one for dispensed payloads, it is added to the protoflight campaign.

21.2.6 Depressurization

The fairing vents during ascent. The bounding depressurization rate for the vehicles under consideration is 3.5 kPa/s.

> **ENV-006 Venting** · Verify: Analysis, Inspection · Trace: SR-11.2, SR-13.9 · Applies: All
>
> Every enclosed volume of the spacecraft shall have a vent path whose area keeps the pressure difference across its walls below 1 kPa at a depressurization rate of 3.5 kPa/s.
>
> *Rationale:* Unvented boxes, blind fastener holes and multilayer insulation blankets can burst or billow during ascent. The spacecraft carries no sealed volume by design (SR-13.9), so venting is a design rule for every unit.

21.3 Orbital Environment

The orbital environment is that of the 500 km sun-synchronous reference orbit with a 10:30 local time of the descending node, for 730 days.

21.3.1 Thermal Environment

Parameter	Cold case	Hot case
Solar flux	1,322 W/m²	1,414 W/m²
Earth albedo (orbit average)	0.20	0.35
Earth infrared emission	220 W/m²	260 W/m²
Beta angle	0° (longest eclipse, 35.8 min)	Highest beta of the 10:30 orbit over the year
Surface properties	Beginning of life	End of life (UV and atomic oxygen degraded)
Spacecraft state	Safe Mode loads, survival heaters only	Nominal Imaging design case with downlink

Thermal design cases

For the 10:30 orbit the beta angle stays between about 15° and 35° over the year; the cold case uses 0° so that the longest possible eclipse is covered if the delivered orbit drifts in local time.

ENV-007 Thermal Design Cases · Verify: Analysis · Trace: SR-11.4, SR-9.1, SR-9.6 · Applies: All

The thermal design shall be analyzed in at least the cold and hot cases of the thermal design case table, in each operational mode that can last more than one orbit.

Rationale: The cases combine the bounding environment with the bounding spacecraft state; Safe Mode is the cold operating case (SR-9.6) and Nominal Imaging with a downlink is the hot one. Modes shorter than an orbit are covered inside these cases.

ENV-008 Thermal Model Correlation · Verify: Test, Analysis · Trace: SR-11.4, SR-9.1 · Applies: All

The spacecraft thermal model shall be correlated to the FM-1 thermal balance test so that predicted unit temperatures agree with the measured ones within 3 °C.

Rationale: The 10 °C analysis margin of SR-9.1 covers model uncertainty before correlation; after correlation within 3 °C the flight predictions for all models rest on test data.

21.3.2 Vacuum and Contamination

In orbit the pressure is below 10^{-5} Pa. Vacuum causes outgassing of nonmetallic materials (screened to ASTM E595, SR-11.7), cold welding of unlubricated metal contacts, and loss of convective cooling, which the thermal design already assumes.

ENV-009 Spacecraft Bake-Out · Verify: Test, Inspection · Trace: SR-11.7, SR-15.6 · Applies: All

Each spacecraft shall be baked out in vacuum at its maximum acceptance temperature for at least 24 h and until the outgassing rate measured by a quartz crystal microbalance falls below the limit of the Contamination Control Plan (EO1-PLN-370).

Rationale: Material screening alone does not remove the residues of integration (adhesives, cleaning agents, handling). A bake-out at the end of the thermal vacuum test protects the optics and the star tracker baffle (N6).

21.3.3 Radiation

The radiation environment combines trapped protons (concentrated in the South Atlantic Anomaly), trapped electrons (mainly in the auroral zones crossed by the polar orbit), solar particle events and galactic cosmic rays. Total ionizing dose is computed behind 2.5 mm of aluminum, the representative shielding of a unit inside the 6U structure.

Effect	Environment over 730 days	Design value
Total ionizing dose, behind 2.5 mm aluminum	About 5 krad(Si) [TBR], including solar particle events	10 krad(Si) [TBR] (radiation design margin 2, SR-11.5)
Displacement damage, behind 2.5 mm aluminum	About 5×10^9 protons/cm², 10 MeV equivalent	1×10^{10} protons/cm² (margin 2)
Single-event effects	Trapped protons in the South Atlantic Anomaly; heavy ions from cosmic rays and solar particle events	Parts screened by linear energy transfer threshold (ENV-012)

Radiation environment of the 500 km sun-synchronous orbit

The dose values stay under TBR-18 until the dose analysis is repeated for the final orbit and the as-built shielding (SR-11.5). Units that sit near the spacecraft skin with less than 2.5 mm of shielding (the coarse sun sensors, the solar cells under their cover glass) use a location-specific dose.

ENV-010 Part Dose Tolerance · Verify: Analysis, Inspection · Trace: SR-11.5 · Applies: All · TBR: TBR-18

Each electronic part shall have a demonstrated total ionizing dose tolerance of at least twice the dose predicted at its location, or at least 10 krad(Si) [TBR] where no location analysis has been made.

Rationale: Applies the radiation design margin of 2 of SR-11.5 part by part, so that parts with better local shielding can use the location analysis instead of the general value.

ENV-011 Detector Displacement Damage · Verify: Test, Analysis · Trace: SR-11.5, SR-1.8 · Applies: All

The Payload Camera detector shall meet the signal-to-noise ratio of SR-1.8 after a displacement damage dose equivalent to 1×10^{10} protons/cm^2 at 10 MeV.

Rationale: Displacement damage raises dark current and creates hot pixels, which lowers the signal-to-noise ratio over the mission (RK-5). The detector is tested by proton irradiation of sample parts from the flight lot.

ENV-012 Single-Event Latch-Up · Verify: Analysis, Inspection · Trace: SR-11.6, SR-15.2 · Applies: All

A part with a single-event latch-up threshold below 37 MeV·cm^2/mg shall be used only on a supply that limits its current and removes and restores power without ground action, and only with analysis or test showing that the part survives the latched current until it is removed.

Rationale: Latch-up susceptible commercial parts are common in small-satellite avionics; a protected supply (for example ICD-006 for the C&DH) turns a destructive event into a recoverable one within the 60 s of SR-11.6.

ENV-013 Single-Event Upset Mitigation · Verify: Analysis, Test · Trace: SR-11.6, SR-4.9 · Applies: All

All program, data and payload memories of the C&DH shall be protected by error detection and correction and scrubbed completely at least once every 24 h.

Rationale: Scrubbing corrects single-bit upsets before a second upset in the same word makes them uncorrectable; with the upset rate of the worst solar particle event week, a 24 h scrub keeps the stored-data error rate inside SR-4.9.

21.3.4 Atomic Oxygen

At 500 km atomic oxygen is the main constituent of the residual atmosphere. Surfaces facing the direction of flight (ram) erode at a rate that depends on solar activity. The design fluence for a ram-facing surface over 730 days, taken at solar maximum density, is 5×10^{21} atoms/cm^2 [TBR].

ENV-014 Atomic Oxygen Resistance · Verify: Analysis, Inspection · Trace: SR-1.7, SR-11.7 · Applies: All · TBR: TBR-74

Each externally exposed material shall keep its function after an atomic oxygen fluence of 5×10^{21} atoms/cm^2 [TBR].

Rationale: Unprotected polyimide and other polymers lose thickness and change their optical properties; the multilayer insulation outer layer, the array substrate edges and the harness jacketing must be resistant or coated. TBR-74 closes when the fluence is recomputed for the final attitude profile and the solar cycle forecast for the launch period (Thermal Engineer, before CDR close-out).

21.3.5 Ultraviolet Radiation

Sun-facing surfaces receive about 10,900 equivalent sun hours over 730 days (730 days × 24 h × the 0.622 sunlit fraction of the bounding case). Ultraviolet exposure raises the solar absorptance of coatings and darkens adhesives and cover glass.

ENV-015 Coating Ultraviolet Stability · Verify: Analysis, Inspection · Trace: SR-1.7, SR-9.1 · Applies: All

Each external thermal control coating shall increase in solar absorptance by no more than 0.05 after 10,900 equivalent sun hours and the atomic oxygen fluence of ENV-014.

Rationale: The end-of-life hot case uses degraded absorptance; a coating that degrades further than 0.05 would push the payload radiator and the battery above their limits (SR-9.4) in the second season.

21.3.6 Micrometeoroids and Orbital Debris

At 500 km the flux of particles large enough to penetrate a CubeSat panel is dominated by orbital debris. The spacecraft is not shielded beyond its structure; the requirement limits the probability that an impact ends the mission.

ENV-016 Impact Survival Probability · Verify: Analysis · Trace: SR-15.1, SR-13.7 · Applies: All

The probability that a micrometeoroid or debris impact causes the loss of a function needed for the mission shall be below 1 % over 730 days.

Rationale: 1 % is a small share of the 20 % failure allowance of SR-15.1. The analysis uses a current debris and meteoroid flux model for the reference orbit and the penetration limits of the panels and units.

21.4 Electromagnetic Compatibility

EMC covers emissions and susceptibility between the units of the spacecraft (SR-11.8), compatibility with the spacecraft's own receivers, and the spacecraft's magnetic and electrostatic properties. The spacecraft is off in the dispenser, so it has no EMC interface with the launch vehicle beyond the inhibits of SR-13.1.

Test method of MIL-STD-461G	Applies to	Tailoring
CE102, conducted emissions, power leads	Each unit on the 12 V and 5 V lines	Limit set to keep IF-22 ripple below 50 mV (ICD-012)
CS101, conducted susceptibility, power leads	Each unit	Level set by the PDU converter ripple, plus 6 dB
CS114, conducted susceptibility, bulk cable injection	Each unit	Reduced level for a spacecraft environment
CS116, damped sinusoidal transients	Each unit	Applied to power and signal cables
RE102, radiated emissions, electric field	Each unit; the integrated spacecraft	Notched limits in the UHF, S-band and X-band receive and transmit bands of the program
RS103, radiated susceptibility, electric field	Each unit; the integrated spacecraft	Level from the spacecraft's own transmitters at each unit location, plus 6 dB

EMC test methods and their tailoring

ENV-017 Unit EMC Tests · Verify: Test · Trace: SR-11.8 · Applies: All

Each electronic unit shall pass the MIL-STD-461G test methods of the EMC table with the program tailoring of STD-1 before spacecraft integration.

Rationale: Unit tests catch emission or susceptibility problems while the unit can still be modified; the spacecraft-level test then confirms the margins of SR-11.8 with all units together.

ENV-018 UHF Receiver Band Emissions · Verify: Test · Trace: SR-11.8, SR-5.7 · Applies: All

Emissions of the spacecraft, in every operating mode, within ±1 MHz of the UHF center frequency and measured at the UHF Antenna port shall be at least 6 dB below the receiver's noise floor.

Rationale: The 11.2 dB uplink margin assumes the receiver is limited by thermal noise; broadband noise from the flight computer, the wheel drives or the PDU converters falling in the receive band would erode it.

ENV-019 Residual Magnetic Dipole · Verify: Test · Trace: SR-11.8, SR-2.8 · Applies: All

The residual magnetic dipole of the spacecraft, with the torque rods off, shall not exceed 0.05 $A \cdot m^2$ in any operating mode.

Rationale: A residual dipole interacts with the geomagnetic field as a disturbance torque that the wheels must store, and biases the magnetometer used by detumble and Safe Mode. 0.05 $A \cdot m^2$ is an eighth of one torque rod's 0.4 $A \cdot m^2$ capacity.

ENV-020 Electrical Bonding · Verify: Test, Inspection · Trace: SR-11.8, SR-11.6 · Applies: All

Each unit housing shall be bonded to the primary structure with a resistance of at most 10 mΩ, and the primary structure joints shall have a resistance of at most 10 mΩ across each joint.

Rationale: A low-resistance structure is the reference for shields and the single-point power return, and gives charge on unit housings a path to the structure.

ENV-021 Surface Charging · Verify: Analysis, Inspection · Trace: SR-11.6, SR-11.8 · Applies: All

Every external surface larger than 1 cm² shall be conductive or dissipative and connected to the structure, except for the solar cell cover glass and the optical surfaces.

Rationale: The polar orbit crosses the auroral zones, where surface charging can lead to discharges that upset or damage electronics. Exceptions are limited to surfaces whose function needs an insulator.

21.5 Ground Environments

Environment	Integration and test	Storage	Transport	In the dispenser
Temperature	20 °C ± 3 °C	15 °C to 25 °C	5 °C to 35 °C inside the container	10 °C to 30 °C
Relative humidity	30 % to 60 %, non-condensing	30 % to 60 %	Container sealed and purged with dry nitrogen	Integrator's facility conditions
Cleanliness	ISO 14644-1 Class 8; Class 7 with the optics open (SR-15.6)	Sealed bag, purged	Sealed container	Dispenser closed
Mechanical	Handling with lifting fixtures; electrostatic discharge controls	—	Shock and vibration below acceptance levels, recorded	Launch site handling of the dispenser
Battery	Charged as needed for tests	30 % to 50 % state of charge	30 % to 50 % state of charge	Storage charge of the user's guide; at least 60 % after 180 days (SR-11.10)

Ground environments

ENV-022 Clean Room Class · Verify: Inspection · Trace: SR-15.6, SR-11.7 · Applies: All

The spacecraft shall be integrated and tested only in ISO 14644-1 Class 8 or cleaner areas, with the camera aperture and the star tracker baffle covered whenever the area is worse than Class 7.

Rationale: Class 8 keeps particle levels on the bus acceptable; the optics need Class 7 when exposed (SR-15.6), so covers allow the spacecraft to leave the optics area for environmental tests.

ENV-023 Ground Temperature and Humidity · Verify: Inspection · Trace: SR-11.10, SR-15.6 · Applies: All

Outside thermal tests, the spacecraft shall be kept between 15 °C and 25 °C and between 30 % and 60 % relative humidity, except during transport in a sealed, nitrogen-purged container.

Rationale: Limits battery self-discharge and capacity loss in storage, keeps moisture out of the optics and composite parts, and avoids the dry conditions that raise electrostatic discharge risk.

ENV-024 Transport Loads · Verify: Inspection, Test · Trace: SR-11.1, SR-11.3 · Applies: All

The transport container shall keep the shock and vibration reaching the spacecraft below the acceptance levels of this chapter, and shall carry a recorder that logs every acceleration above 3 g.

Rationale: Transport must not use up the spacecraft's qualification margin; the recorder shows after each shipment whether a retest is needed.

ENV-025 Battery Storage Charge · Verify: Inspection, Test · Trace: SR-11.10, SR-13.2 · Applies: All

During storage and transport the battery shall be kept between 30 % and 50 % state of charge and its voltage checked at least every 30 days.

Rationale: A partly charged lithium-ion battery ages least and carries less stored energy if it is damaged (HAZ-001); the 30-day check detects a failing cell before it reaches a hazardous state. The battery is charged to the dispenser storage level only before loading.

21.6 Test Levels and Margins

The test program uses one qualification approach for the product line: FM-1 (EO-1 Flight serial number 1) is tested at protoflight levels, that is qualification levels for acceptance durations, and the later flight models at acceptance levels. The terms follow GSFC-STD-7000 General Environmental Verification Standard (GEVS) and ECSS-E-ST-10-03C, Testing.

Test	Qualification (qualification units)	Protoflight (FM-1)	Acceptance (FM-2, serial number 3 on)
Random vibration	Maximum predicted level + 3 dB, 2 min per axis	Maximum predicted level + 3 dB, 1 min per axis	Maximum predicted level, 1 min per axis
Sine vibration	1.25 × maximum predicted level, 2 octaves/min	1.25 × maximum predicted level, 4 octaves/min	Maximum predicted level, 4 octaves/min
Shock	Maximum predicted level + 3 dB, three times per axis (unit level)	Two dispenser releases (ENV-005)	One dispenser release
Thermal vacuum	10 °C beyond the predicted extremes, 8 cycles	10 °C beyond the predicted extremes, 4 cycles (SR-11.4)	5 °C beyond the predicted extremes, 4 cycles
Thermal balance	—	One hot and one cold balance (ENV-008)	—

Test	Qualification (qualification units)	Protoflight (FM-1)	Acceptance (FM-2, serial number 3 on)
EMC	Full unit tests	Full spacecraft test	Spacecraft self-compatibility and RE102 in the radio bands
Magnetic dipole	—	Measured (ENV-019)	Measured

Test levels and durations by test class

Thermal vacuum dwells are at least 4 h at each extreme of the first and last cycles and at least 1 h at the others, with functional tests at the hot and cold operating plateaus and a cold start and a hot start of the spacecraft. The test pressure is at most 1.3×10^{-3} Pa.

ENV-026 Protoflight Testing of FM-1 · Verify: Test · Trace: SR-11.1, SR-11.3, SR-11.4 · Applies: Flight

FM-1 shall complete the protoflight levels and durations of the test level table, in the order sine and random vibration, shock, thermal vacuum with thermal balance, and EMC, with a full functional test before and after each environment.

Rationale: One protoflight model qualifies the design and is flown, which suits a small production run. The order puts mechanical tests first, so that damage they cause shows up in the thermal vacuum functional tests.

ENV-027 Acceptance Testing of Later Models · Verify: Test · Trace: SR-11.1, SR-11.4, SR-15.7 · Applies: All

Every flight model after FM-1 shall complete the acceptance levels and durations of the test level table with a full functional test before and after each environment.

Rationale: Acceptance testing screens workmanship on each unit built to the qualified design without consuming its life.

ENV-028 S-band Transmitter Qualification · Verify: Test · Trace: SR-11.1, SR-11.4, SR-11.8 · Applies: Lite

The S-band Transmitter design shall be qualified at unit level to the qualification levels of the test level table before the first EO-1 Lite spacecraft (serial number 3) starts acceptance testing.

Rationale: FM-1 carries the X-band Payload Radio, so the protoflight campaign does not qualify the S-band Transmitter, the only unit that differs in EO-1 Lite. A unit qualification closes that gap without a second protoflight campaign.

22 Verification and Validation

This chapter defines how the program shows that each EO-1 spacecraft and the ground segment meet this specification (verification) and that the delivered system meets the stakeholder needs N1 to N11 (validation). It sets out the verification levels and methods, the models that carry the tests, the order of the test campaigns, the three test suites, every verification event that closes a requirement, and the requirements on the verification programme itself (VER-006 to VER-020; VER-001 to VER-005, on the budgets, are in Budgets and Margins). The allocation of each requirement to its events is the Verification Cross-Reference Matrix in Appendix A. Procedures and reports are controlled in the Verification and Validation Plan EO1-PLN-310.

Environmental test levels, durations and tolerances are in Environmental Requirements, “Test Levels and Margins”, which tailors GSFC-STD-7000 General Environmental Verification Standard (GEVS) and ECSS-E-ST-10-03C, Testing. EMC test methods follow MIL-STD-461G, Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment, as tailored there.

22.1 Approach

22.1.1 Verification levels

Requirements are verified at the lowest level where the result is meaningful and confirmed at the level above only where integration could change it. Four levels are used.

Level	Item verified	Typical events	Where
Unit	A single unit or component: camera, wheel, radio, battery pack, Flight Computer, cell or flash sample	Performance, calibration, unit environmental and EMC tests	Supplier or program laboratory
Subsystem	A function spread over several units, with the rest simulated: ADCS, EPS, flight software, deployment chain	Flatsat and hardware-in-the-loop tests, subsystem analyses	Flatsat laboratory
System	The integrated spacecraft	Functional, environmental, mass properties, deployment and link tests	Integration and test facility
Mission	Spacecraft, or flatsat standing in for it, with the ground segment and operations team	End-to-end, compatibility, rehearsal and validation events	Operations center, partner stations

Verification levels

A requirement is closed at the level stated in its events in Appendix A. Where a unit-level test closes a system requirement, the system-level functional test confirms that the unit still performs after integration, but the measurement is not repeated unless integration can change it (for example antenna gain on the structure, or the camera’s line of sight relative to the star tracker).

22.1.2 Verification methods

The four methods are Test (T), Analysis (A), Inspection (I) and Demonstration (D), defined in the Introduction, “Verification methods”. In short: a test measures values against criteria set in advance; an analysis shows compliance by calculation, simulation or similarity; an inspection examines the item or its documents; a demonstration shows that a function works, pass or fail. The first method in a requirement’s Verify field closes it; the others supply supporting evidence. An event listed in Appendix A for a requirement provides at least one of that requirement’s methods, and every method of the requirement is provided by one of its events.

22.1.3 Success criteria

Each event’s procedure states, before the event is run, the requirements it closes, the measured quantities, the pass/fail criterion for each and the configuration of the article. The criterion is the requirement’s value. Where the event measures a quantity that the requirement constrains only after combination with other terms (for example the 0.1° pointing accuracy, of which the flatsat measures the control and estimation parts), the procedure states the allocation used and the analysis that combines the results.

22.2 Model Philosophy

The program builds few models, so each model carries several purposes. Qualification is by the protoflight approach on the first flight spacecraft: FM-1 is tested to protoflight levels and durations and then flown, which qualifies the design without a dedicated qualification spacecraft. Later spacecraft are tested to acceptance levels.

Model	Article id	What it is	Used for	Flies
Engineering models	EM	Form-and-function units built to the flight design with commercial-grade parts where needed: camera, ADCS units, PDU and qualification battery pack, Flight Computer and storage board, radios, a flight-representative structure model; also cell, flash and detector samples from the flight lots	Unit performance and calibration development, destructive and hazard tests, life tests, simulator validation, flatsat units	No

Model	Article id	What it is	Used for	Flies
Flatsat, EO-1 Flight	FS-1	Bench layout of engineering-model avionics with the Flight Computer, payload and radio models or their simulators, and a dynamic simulator for attitude, power and orbit; flight harness lengths on the data lines	Flight software and subsystem tests, fault injection, interface tests, operations rehearsals before launch and in operations	No
Flatsat, EO-1 Lite	FS-3	As FS-1 with the S-band Transmitter model in place of the X-band Payload Radio	EO-1 Lite flight software variant, S-band data path, operations support for SN 3	No
Protoflight	FM-1	EO-1 Flight serial number 1	Protoflight levels (ENV-026), system performance, thermal balance, full EMC, deployment, links	Yes
First EO-1 Lite	SN-3	EO-1 Lite serial number 3, built to the qualified design	Acceptance levels (ENV-027), system performance, links	Yes
Ground segment	ground	Mission Operations Center, partner stations, processing system and customer portal in their operational configuration	Compatibility, security, processing, end-to-end and rehearsal events	—

Verification models and articles

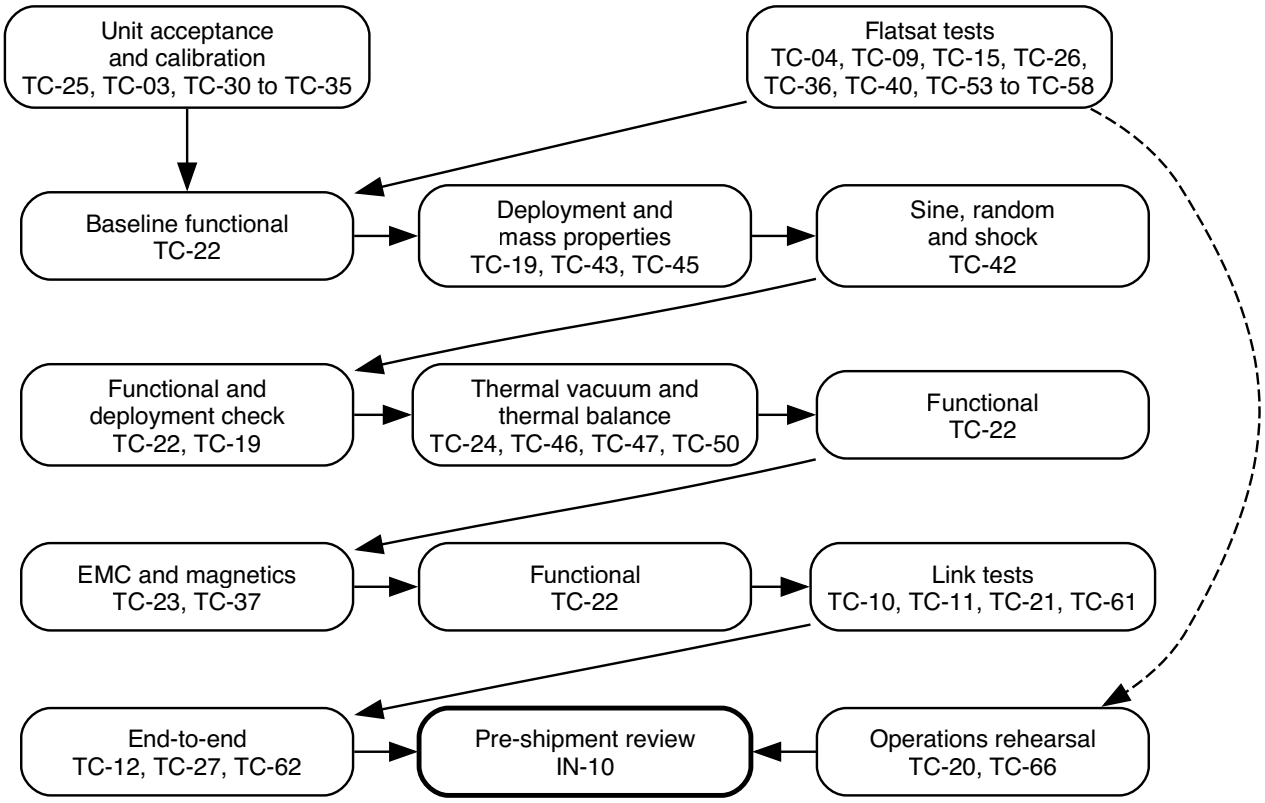
The S-band Transmitter is the only unit of EO-1 Lite that FM-1 does not carry; it is qualified at unit level on an engineering model before SN 3 starts acceptance testing (ENV-028). Flight model FM-2 and later EO-1 Flight spacecraft follow the SN 3 acceptance campaign and the same events, so they are not listed separately in the event table.

Tests that could consume life or damage the article are run only on engineering models: the battery hazard controls (TC-39), the cell cycle life test (TC-41), detector displacement damage (TC-48) and the storage retention and endurance test (TC-51). The flatsats stay in service through operations so that procedures, plans and flight software updates can be checked before they are sent to a spacecraft.

22.3 Test Campaigns

22.3.1 Sequence

Unit and flatsat campaigns run in parallel with spacecraft assembly. A unit enters spacecraft integration only after its unit acceptance test (TC-25) and, for units with flight software interfaces, its flatsat interface test (TC-15). The spacecraft campaign follows the order of ENV-026: a full functional test, mechanical tests, thermal vacuum with thermal balance, then EMC, with a full functional test before and after each environment. The link and end-to-end tests come last because they need the spacecraft in its final configuration. The operations rehearsal runs with the flatsat standing in for the spacecraft, so it can run while the spacecraft is still in environmental testing.



FM-1 verification campaign sequence; SN 3 follows the same order at acceptance levels without thermal balance

22.3.2 Campaigns

Functional. The Spacecraft Functional Test TC-22 is the reference against which the article is compared after each environment. The full version exercises every unit in every operating mode, all redundant paths and the deployment and inhibit status; a short aliveness version runs during the environments. Results are compared with the baseline run, not only with the requirement limits, so that a shift inside the limits is noticed.

Deployment. The arrays and the UHF Antenna are deployed at ambient before and after vibration (TC-19) and at the cold and hot deployment temperatures (TC-44); the separation switches and the quiet-period timer are checked on the dispenser fit-check fixture (TC-45). The ground-handling restraints stay fitted at all other times.

EMC. Units are tested to the tailored MIL-STD-461G methods before delivery; the integrated spacecraft is tested for self-compatibility, receiver desensitization and radiated emissions in the band of the launch vehicle's receivers (TC-23). The residual magnetic dipole is measured in the same period (TC-37).

Vibration. TC-42 runs sine surveys, sine and random vibration on three axes and the separation shock test on FM-1 at protoflight levels and on SN 3 at acceptance levels, with the signature criteria of ENV-004.

Thermal vacuum. TC-24 starts with the bake-out (ENV-009), runs the thermal cycles with functional tests at each plateau and, on FM-1, includes the Thermal Balance Test TC-46 for model correlation. The heater tests (TC-47) and the oscillator drift measurement (TC-50) use the same chamber run.

End to end. TC-12 runs tasking through the portal, planning, capture of a scene projector image, downlink through an RF link to a partner station, processing and delivery; TC-27 and TC-62 prove the space link protocols and the station chain.

Operations rehearsals. TC-20 runs 14 days of operations with the certified team, the flatsat and the ground segment in its operational configuration; TC-66 certifies the operators and drills the on-call response. A shorter rehearsal is repeated before each launch.

22.4 Test Suites

The events are grouped into three suites, each with its own test readiness and post-test reviews.

Suite	Name	Scope	Events	Closes before
TS-1	Spacecraft Qualification Tests	Unit, subsystem and spacecraft tests of performance, environments, mass properties, deployment, power, attitude, data handling and flight software	TC-01 to TC-09, TC-14, TC-15, TC-17 to TC-19, TC-22 to TC-26, TC-28, TC-30 to TC-48, TC-50 to TC-58, TC-65	Pre-shipment review
TS-2	Communications and Ground Tests	Radios, antennas, links, space link protocols, encryption, partner stations, processing chain, ground and portal security	TC-10, TC-11, TC-21, TC-27, TC-29, TC-59 to TC-64	Operations readiness review
TS-3	Mission Validation	End-to-end delivery, operations rehearsals and certification, mission analyses and the validation events	TC-12, TC-13, TC-16, TC-20, TC-66, VAL-01 to VAL-03	Flight readiness review (VAL events: end of commissioning and first season)

Test suites

Analyses (AN) and inspections (IN) are not part of a suite; their reports are reviewed with the suite whose review they feed, as stated in the event table.

22.5 Verification Events

The table lists every event that closes a requirement. Method is the method or methods the event provides; Level is the verification level of the table above; Article names the models of the model table (EM, FS-1, FS-3, FM-1, SN-3, ground), or "—" for analyses that use no article. TC-15 and TC-22 to TC-29 are defined in this chapter, TC-30 to TC-48 and TC-50 to TC-66 in the subsystem chapters that introduce them (TC-48 for the detector, here). TC-49 and TC-67 to TC-69 are not used.

Id	Name	Method	Level	Article	Suite	Purpose
TC-01	Ground Sample Distance Test	T	System	FM-1, SN-3	TS-1	Image the 4 m bar target through a collimator with the integrated camera; ground sample distance and MTF at Nyquist (SR-1.2)
TC-02	Swath Width Measurement	T	System	FM-1, SN-3	TS-1	Measure the field of view and the active pixels across track; swath on the ground at the design altitude
TC-03	Spectral Response Calibration	T	Unit	EM, FM-1, SN-3	TS-1	Monochromator scan of every band; band edges and out-of-band response
TC-04	Pointing Accuracy Test	T	Subsystem	FS-1, FS-3	TS-1	Point at 20 simulated targets with the ADCS engineering model in the loop; control and estimation error, rate stability, yaw steering
TC-05	Detumble Simulation	T, A	Subsystem	FS-1	TS-1	Run detumble from 10 deg/s with the magnetometer, rods and Flight Computer in the loop, extended by simulation to 3 h; rate sensing range
TC-06	Solar Array Power Test	T, A	Unit	FM-1, SN-3	TS-1	Flash test of each panel; cell efficiency, panel peak power, end-of-life orbit-average prediction
TC-07	Battery Capacity Test	T	Unit	FM-1, SN-3	TS-1	Capacity of each flight pack at 20 °C, charge and discharge profiles, separation sequence energy, pack mass, cell temperature spread
TC-08	Onboard Storage Test	T	Unit	FM-1, SN-3	TS-1	64 GB write and read-back without bit errors; write and read rates, error correction, scrubbing, bank isolation
TC-09	Safe Mode Entry Test	T	Subsystem	FS-1, FS-3	TS-1	Drive each Safe Mode trigger; entry time, load set, command response over the ADCS bus
TC-10	S-band Link Test	T	System	SN-3	TS-2	Link through the RF suitcase at the budget's received power; frame error rate, rate, antenna gain, transmitter ready time
TC-11	UHF Command Test	T	System	FM-1, SN-3	TS-2	500 commands and telemetry through the UHF link at threshold power; receiver sensitivity, Doppler offsets
TC-12	End-to-End Image Delivery	T, D	Mission	FM-1, SN-3, ground	TS-3	Tasking through the portal to product delivery over an RF link and a partner station; delivery time, service plans, product format

Id	Name	Method	Level	Article	Suite	Purpose
TC-13	Ground Track Repeat Analysis	A	Mission	—	TS-3	Orbit propagation over the mission; ground track repeat and worst-case revisit of the target regions
TC-14	Off-Nadir Imaging Test	T	Subsystem	FS-1, FS-3	TS-1	Slew to targets up to 25° off nadir and capture with the payload simulator; pointing at the off-nadir limit
TC-15	Flatsat Interface Test	T	Subsystem	FS-1, FS-3	TS-1	Power and data interfaces of each unit on the flatsat: line ratings, inrush, voltage drop, data throughput, time synchronization, unit power draw
TC-16	Lifetime Reliability Analysis	A	System	—	TS-3	Reliability model of the single-string spacecraft over 730 days; probability of mission lifetime
TC-17	Slew Time Analysis	A, T	Subsystem	FS-1	TS-1	Slew and settle times from the dynamics model, calibrated by flatsat slews; wheel capacity, settling, one-wheel-failed case
TC-18	Bus Regulation Inspection	I, T	Unit	FM-1, SN-3	TS-1	Inspection of the PDU regulation test records and a check of bus voltage and ripple at load steps; always-on line
TC-19	Array Deployment Test	T	System	FM-1, SN-3	TS-1	Deploy arrays and UHF Antenna on the zero-gravity fixture at ambient, before and after vibration; deployment status, released-object containment
TC-20	Operations Rehearsal	D	Mission	FS-1, FS-3, ground	TS-3	14 days of operations with the certified team, partner stations and flatsat; planning, contacts, unattended passes, Safe Mode recovery, backup site
TC-21	X-band Link Test	T	System	FM-1	TS-2	Link through the RF suitcase with encryption on; rate, frame error rate, antenna gain, ready time
TC-22	Spacecraft Functional Test	T	System	FM-1, SN-3	TS-1	Full functional test before and after each environment, short aliveness test during them; failure-free operating hours
TC-23	EMC Test	T	Unit, System	EM, FM-1, SN-3	TS-1	Tailored MIL-STD-461G unit tests; spacecraft self-compatibility, UHF receiver desensitization, launch vehicle band emissions, bonding resistance
TC-24	Spacecraft Thermal Vacuum Test	T	System	FM-1, SN-3	TS-1	Bake-out, then thermal cycles at protoflight or acceptance levels with functional tests at each plateau
TC-25	Unit Acceptance and Qualification Test	T	Unit	EM, FM-1, SN-3	TS-1	Unit random vibration, thermal cycling and burn-in; unit weighing, alignment cube calibration, witness samples; S-band Transmitter qualification on an engineering model
TC-26	Mode Management Test	T, D	Subsystem	FS-1, FS-3	TS-1	Every mode transition and its conditions, quiet period, mode restoration after reset, Safe Mode beacon and exit

Id	Name	Method	Level	Article	Suite	Purpose
TC-27	Space Link Protocol Test	T	Subsystem	FS-1, FS-3, ground	TS-2	Telemetry and telecommand frame formats, coding, idle frames, CFDP delivery and retransmission between flatsat and ground software
TC-28	Passivation and End-of-Mission Test	T	Unit, Subsystem	EM, FS-1	TS-1	Permanent battery disconnect on the qualification PDU, transmitter disable, decommissioning command protection on the flatsat
TC-29	Customer Portal Security and Availability Test	T, D	Mission	ground	TS-2	Multi-factor sign-in, customer data isolation and portal availability monitoring over 30 days
TC-30	Payload MTF and Focus Test	T	Unit	EM, FM-1, SN-3	TS-1	Collimator with slanted-edge and bar targets through focus in vacuum; MTF, wavefront, focus, co-alignment, line rate
TC-31	Payload Radiometric Calibration	T	Unit	EM, FM-1, SN-3	TS-1	Integrating sphere at several radiance levels; signal-to-noise, saturation, linearity, defective pixels, calibration coefficients
TC-32	Payload Stray Light Test	T	Unit	EM, FM-1	TS-1	Collimated source scanned outside the field; ghost survey; sun exclusion angle
TC-33	Payload Thermal Vacuum and Line-of-Sight Test	T	Unit	EM, FM-1, SN-3	TS-1	Focal plane control, response monitor, line-of-sight drift, decontamination soak; filter coupon sun exposure
TC-34	Reaction Wheel Microvibration and Friction Test	T	Unit	FM-1, SN-3	TS-1	Imbalance forces, torque, friction at low speed and capacity of each flight wheel
TC-35	Star Tracker Night-Sky and Stimulator Test	T	Unit	EM, FM-1	TS-1	Accuracy on the night sky and rate capability with a star field stimulator; data latency
TC-36	ADCS Hardware-in-the-Loop Mode Test	T	Subsystem	FS-1, FS-3	TS-1	Every pointing mode and mode change on the flatsat: Safe Mode Sun acquisition, eclipse hold, wheel failure, lunar scan, station tracking
TC-37	Magnetic Dipole and Magnetometer Calibration Test	T	Unit, System	FM-1, SN-3	TS-1	Rod dipoles and magnetometer response in a field coil facility; residual dipole of the integrated spacecraft
TC-38	PDU Protection and Load Step Test	T	Unit	EM, FM-1, SN-3	TS-1	Load steps, overcurrent and shorts on every output; undervoltage thresholds; restart from array power
TC-39	Battery Hazard Control Test	T	Unit	EM	TS-1	Each battery hazard control alone on the qualification pack; cold charge inhibit, storage drain
TC-40	Power System Orbit Simulation Test	T	Subsystem	FS-1, FS-3	TS-1	50 design-case orbits with a solar array simulator; tracking and conversion efficiency, state of charge, depth of discharge
TC-41	Battery Cell Cycle Life Test	T	Unit	EM	TS-1	Flight-lot cells cycled at 30 % depth of discharge to the mission equivalent; capacity fade

Id	Name	Method	Level	Article	Suite	Purpose
TC-42	Structural Qualification Test	T	System	FM-1, SN-3	TS-1	Sine surveys, sine, random and separation shock on three axes; first mode and its shift; alignment before and after
TC-43	Mass Properties Measurement	T	System	FM-1, SN-3	TS-1	Mass, center of mass and inertia of each flight spacecraft
TC-44	Deployment Mechanism Thermal and Redundancy Test	T	Subsystem	FM-1	TS-1	Deployments at cold and hot temperatures, each resistor element alone at minimum voltage; torque margin, geometry, stiffness
TC-45	Inhibit and Separation Switch Test	T, D	System	FM-1, SN-3	TS-1	Dispenser fit-check fixture: each switch alone keeps transmitters and burn wires unpowered; release; quiet-period timer; ground support access
TC-46	Thermal Balance Test	T	System	FM-1	TS-1	Hot, cold and survival cases with heater plates; steady-state temperatures for correlation; imaging and pass transients
TC-47	Heater and Thermostat Functional Test	T, D	Subsystem	FM-1, SN-3	TS-1	Heater polarity, resistance, thermostat set points, redundancy and software control at ambient and in thermal vacuum
TC-48	Detector Displacement Damage Test	T	Unit	EM	TS-1	Proton irradiation of detector samples to the mission fluence; dark current and response change
TC-50	Oscillator Drift Test	T	Unit	FM-1, SN-3	TS-1	Flight oscillator drift over three days of simulated orbital cycles in thermal vacuum; time correction and distribution
TC-51	Storage Retention and Endurance Test	T	Unit	EM	TS-1	Flash samples irradiated to the mission dose, cycled and held 20 days; error rates, endurance
TC-52	C&DH Fault Injection Test	T	Unit	FM-1, SN-3	TS-1	Forced watchdog expiry, double-bit errors, simulated latch-up on each rail group, power interruption during the separation timer
TC-53	Fault Management Test	T	Subsystem	FS-1, FS-3	TS-1	Each fault monitor driven past its threshold in each mode, including the RF and deployment gates
TC-54	Command Security Test	T	Subsystem	FS-1, FS-3	TS-1	Invalid authentication, replayed frames, unarmed critical commands, expedited transmitter-off, key store
TC-55	Software Update and Boot Fallback Test	T	Subsystem	FS-1, FS-3	TS-1	Image upload, activation, table update and fallback to the protected boot image
TC-56	Commanding, Telemetry and Schedule Test	T	Subsystem	FS-1, FS-3, ground	TS-1	72 h plan of 2,000 entries with constraint violations and a late update; housekeeping, event log, verification reports
TC-57	Payload Data Path Test	T	Subsystem	FS-1, FS-3	TS-1	Strip intake to CFDP delivery over several passes, with dropped frames and a reset mid-transfer; downlink priority, storage full

Id	Name	Method	Level	Article	Suite	Purpose
TC-58	Processor and Memory Utilization Test	T	Subsystem	FS-1, FS-3	TS-1	Processor load and memory use in the worst-case mode timeline; core isolation
TC-59	RF Characterization Test	T	Unit	EM, FM-1, SN-3	TS-2	Frequency, power, spectrum, stability, power draw and continuous transmission of each radio in thermal vacuum
TC-60	UHF Antenna Pattern and Deployment Test	T	Unit	EM	TS-2	Pattern of the deployed UHF Antenna on a flight-representative structure in an anechoic range; deployment and match
TC-61	X-band Encryption Test	T	Subsystem	FM-1, ground	TS-2	Frame encryption, throughput and key handling with the operations center's decryption software
TC-62	Ground Station Compatibility Test	T	Mission	FM-1, SN-3, ground	TS-2	Portable RF test set at each partner station and spacecraft radiating into the station antenna; G/T, EIRP, tracking, decode chain
TC-63	Image Processing Chain Test	T, D	Mission	ground	TS-2	Simulated strips, then commissioning imagery through the processing chain; latency, capacity, registration, calibration trending
TC-64	Ground Security Test	T, D	Mission	ground	TS-2	Key protection, operator sign-in, two-person release, archive access
TC-65	Compression Performance Test	T	Unit	EM	TS-1	Compression throughput and power with flight-representative strips from the payload engineering model
TC-66	Operator Certification and Anomaly Drill	I, D	Mission	ground	TS-3	Certification records and unannounced night drills of the on-call response
AN-01	Mass Budget Analysis	A	System	—	TS-1 review	Mass and contingency by basis; margin against 12.0 kg
AN-02	Power and Energy Budget Analysis	A	System	—	TS-1 review	Generation, loads by mode, eclipse energy, depth of discharge, Safe Mode power
AN-03	Data Budget Analysis	A	System	—	TS-2 review	Daily collection, compressed volume, downlink capacity per service plan, storage days
AN-04	Link Budget Analysis	A	System	—	TS-2 review	S-band, X-band and UHF margins at the budget elevations
AN-05	Pointing and Attitude Analysis	A	Subsystem	—	TS-1 review	Pointing error budget, dynamics simulation of modes, momentum, one-wheel failure, star tracker exclusion
AN-06	Structural Analysis	A	System	—	TS-1 review	Finite element model correlated with TC-42; factors of safety, quasi-static loads, frequencies, thermo-elastic alignment
AN-07	Thermal Analysis	A	System	—	TS-1 review	Thermal network model of the design cases correlated with TC-46; margins, gradients, heater power
AN-08	Radiation Analysis	A	System	—	TS-1 review	Dose-depth, part dose margins, displacement damage, single-event rates and mitigation

Id	Name	Method	Level	Article	Suite	Purpose
AN-09	Orbital Lifetime and Debris Analysis	A	Mission	—	TS-3 review	Orbital decay, post-mission lifetime, debris impact probability, reentry casualty risk
AN-10	Failure Modes and Effects Analysis	A	System	—	TS-1 review	Failure propagation across interfaces and the protections that contain it
AN-11	Coverage and Collection Analysis	A	Mission	—	TS-3 review	Strips per orbit, daily collection volume, downlink contacts per day
AN-12	Radiometric Performance Analysis	A	Unit	—	TS-1 review	Signal-to-noise, absolute accuracy and stability budgets from TC-31 data
AN-13	Geometric Accuracy Analysis	A	Mission	—	TS-2 review	Geolocation, band registration, orbit determination and elevation model error budgets
AN-14	Materials and Contamination Analysis	A	System	—	TS-1 review	Venting, outgassing, atomic oxygen and UV effects on surfaces and optics
AN-15	Spectrum and EMC Analysis	A	System	—	TS-2 review	Power flux density, RF exposure, intra-system compatibility margins
AN-16	Operations Timeline Analysis	A	Mission	—	TS-3 review	Planning cycle, command intervals and priority target scheduling against contact times
AN-17	Availability Analysis	A	Mission	—	TS-3 review	Imaging and portal availability, pass success rate, one-station service, staffing
AN-18	Software Resource and Timing Analysis	A	Subsystem	—	TS-1 review	Schedulability, processor margin, bus loading and fault isolation between tasks
AN-19	Electrical Design Analysis	A	System	—	TS-1 review	Array failure containment, grounding, surface charging and discharge paths
AN-20	Limited-Life Items Analysis	A	System	—	TS-1 review	Wear-out of wheels, star tracker, battery and flash; dispenser storage drain
AN-21	Field of View and Shadowing Analysis	A	System	—	TS-1 review	Camera and star tracker clear fields of view, sun exclusion, array self-shadowing over the attitude profiles
IN-01	Design Inspection	I	System	FM-1, SN-3	TS-1 review	Released drawings and interface control drawings against envelope, materials, layout and inhibit design
IN-02	Unit Acceptance Data Package Review	I	Unit	FM-1, SN-3	TS-1 review	Unit test records, mass, workmanship, burn-in logs and certificates at each unit acceptance review
IN-03	Parts, Materials and Processes Review	I	Unit	FM-1, SN-3	TS-1 review	Parts lists, radiation data, materials lists, outgassing and prohibited-material records
IN-04	Cleanliness Inspection	I	System	FM-1, SN-3	TS-1 review	Optics and clean room cleanliness, bake-out records

Id	Name	Method	Level	Article	Suite	Purpose
IN-05	Ground Handling and Storage Records Inspection	I	System	FM-1, SN-3	TS-1 review	Temperature, humidity, shock logger and battery charge records in storage and transport
IN-06	Flight Software Release Review	I	Subsystem	FS-1, FS-3	TS-1 review	Release records, test coverage, configuration tables, memory map at each release review
IN-07	Operations Readiness Inspection	I	Mission	ground	TS-3 review	Procedures, logs, archive, plans and records at the operations readiness review
IN-08	Security Audit	I	Mission	FM-1, SN-3, ground	TS-2 review	Key management records, key rotation, audit logs, encryption configuration
IN-09	Spectrum Authorization Review	I	Mission	ground	TS-2 review	Frequency assignments and filings against the radio configurations
IN-10	Verification Records Audit	I	System	FM-1, SN-3	TS-1 review	Procedures, as-run records, calibration, nonconformances, budgets and closure status at the pre-shipment review
IN-11	Interface Records Inspection	I	System	FM-1, SN-3	TS-1 review	Connector, pin-out, fuse and harness records against the interface tables
IN-12	Commissioning Results Review	I, D	Mission	FM-1, SN-3, ground	TS-3 review	In-orbit confirmation of focus, calibration, pointing and links against ground results
VAL-01	Customer Alert Pilot	D	Mission	FM-1, SN-3, ground	TS-3	Customer agronomists run crop stress alerts on delivered products from C7 through the first season; N1, N7
VAL-02	Growing Season Revisit Simulation	A	Mission	—	TS-3	Simulated season of tasking over the target regions with planning, orbit and cloud statistics; N2
VAL-03	Agronomist Map Review	D, I	Mission	FM-1, SN-3, ground	TS-3	Agronomists compare vegetation maps with field observations; N3, N6

Verification events

22.5.1 Analyses

The analyses are living reports: each is issued at the preliminary and critical design reviews and closed at the pre-shipment review with the measured values that replace estimates. An analysis that closes a requirement states its inputs, assumptions and uncertainty, and uses models correlated with test where a test exists (VER-017). The budget analyses AN-01 to AN-05 are the budgets of Budgets and Margins; the radiation analysis AN-08 uses the environment of Environmental Requirements, “Radiation”.

22.5.2 Inspections

Inspections examine the article or its records against the requirement. The design inspection IN-01 checks released drawings and the interface control drawings; IN-02 the unit acceptance data packages; IN-03 the parts, materials and processes records; IN-04 cleanliness; IN-05 ground handling and storage records; IN-06 the flight software release records; IN-07 the operations and ground records at the operations readiness review; IN-08 security and key management; IN-09 the spectrum authorizations; IN-10 the verification records themselves; IN-11 the interface connector and pin-out records; IN-12 the commissioning results.

22.5.3 Validation

Validation asks whether the system meets the needs, not whether it meets the requirements derived from them. The three validation events involve the imagery customer and are judged against the MOEs of Stakeholders and Needs.

- **VAL-01 Customer Alert Pilot** starts as commissioning step C7: the customer's agronomists task the spacecraft through the portal and run their crop stress alerts on the delivered products, first over the 5 days of C7 and then through the first growing season. It validates N1 and N7 against MOE-3 and MOE-7.
- **VAL-02 Growing Season Revisit Simulation** simulates a full growing season of tasking over the customer's target regions with the planning system, the orbit, cloud statistics and the operations calendar, before the critical design review and again with the as-flown orbit. It validates N2 against MOE-2 and MOE-4.
- **VAL-03 Agronomist Map Review** gives field agronomists vegetation maps from commissioning and first-season imagery side by side with field observations, and records whether the maps support field-level decisions. It validates N3 and N6 against MOE-1.

22.6 Verification Programme Requirements

VER-006 Verification Before Flight · Verify: Inspection · Trace: SR-15.1, SR-15.2 · Applies: All

Every requirement that applies to a spacecraft shall be closed by its events in Appendix A, or by an approved waiver or deviation, before that spacecraft's pre-shipment review.

Rationale: There is no repair after launch. A requirement left open at shipment is a risk accepted without the evidence the matrix was built to provide.

VER-007 Criteria Set Before the Event · Verify: Inspection · Trace: SR-15.1 · Applies: All

Each test and demonstration shall run from a released procedure that states, before the event, the requirements it closes, the quantities measured and the pass/fail criterion for each.

Rationale: Criteria chosen after the data are seen are not evidence. A released procedure also lets the test be repeated the same way on SN 3 and later models.

VER-008 As-Run Records · Verify: Inspection · Trace: SR-15.1, SR-6.13 · Applies: All

Each event record shall contain the measured values, the article's serial numbers and software versions, the test equipment used with its calibration status, the deviations from the procedure and the pass/fail result for each criterion.

Rationale: The record must show which hardware and software passed, so that a later change can be judged against it and calibration results can be traced (SR-6.13).

VER-009 Calibrated Test Equipment · Verify: Inspection · Trace: SR-6.13, SR-1.9 · Applies: All

Measuring equipment used to close a requirement shall be calibrated against a traceable standard, within its calibration interval, with an uncertainty no larger than one quarter of the tolerance being verified.

Rationale: The 4:1 ratio keeps measurement error from deciding pass or fail. It matters most for the radiometric calibration of SR-1.9, which inherits the uncertainty of the integrating sphere.

VER-010 Nonconformance Reporting · Verify: Inspection · Trace: SR-15.1, SR-15.2 · Applies: All

Any result outside a pass/fail criterion, unexpected behavior or damage to an article during an event shall be recorded as a nonconformance report within one working day, and the event shall not resume on that article until the report has a disposition from the Systems Lead and quality assurance.

Rationale: Continuing a test on a damaged or misbehaving article can turn one failure into several and hides the cause. The disposition (use as is, repair, rework, retest or scrap) is the decision point.

VER-011 Failure-Free Operating Time · Verify: Test, Inspection · Trace: SR-15.7, SR-15.1 · Applies: All · TBR: TBR-75

Each flight spacecraft shall accumulate at least 200 h [TBR-75] of powered operation during integration and test before shipment, the last 50 h without a failure.

Rationale: Unit burn-in (SR-15.7) screens infant failures in the units; the system hours do the same for the harness, connectors and interactions. The value is under review against the length of the FM-1 campaign.

VER-012 Re-Verification After Change · Verify: Inspection, Test · Trace: SR-15.1, SR-15.2 · Applies: All

After a hardware change, rework, unit replacement or connector demate on a verified article, the events affected by the change shall be repeated and the full functional test (TC-22) run before the article continues its campaign.

Rationale: A change after an event invalidates that event's evidence for the changed item. The impact assessment names the events to repeat; the functional test confirms nothing else was disturbed.

VER-013 Software Regression Before Upload · Verify: Test, Inspection · Trace: SR-10.20, SR-10.21 · Applies: All

Every flight software release and every table load shall pass the full requirement test set on the flatsat of the spacecraft variant (FS-1 or FS-3) before it is loaded on a flight spacecraft, on the ground or in orbit.

Rationale: The flatsat is the only place where a defective release can fail safely. The protected boot image (SR-10.21) is a recovery, not a substitute for testing.

VER-014 Test-as-You-Fly Exceptions · Verify: Inspection, Analysis · Trace: SR-15.2, SR-11.4 · Applies: All

Every difference between the configuration of a test article during an event and the flight configuration (ground support connections, simulated sources, removed or substituted units, software version) shall be listed in the event record with an analysis showing that the difference does not change the result.

Rationale: Ground tests always differ from flight in some way. Listing each difference and its effect is what lets a result on the bench stand for the result in orbit.

VER-015 Flight Hardware Exposure Limits · Verify: Inspection · Trace: SR-13.2, SR-15.1 · Applies: All

Flight hardware shall not be exposed to levels or durations above protoflight levels, to destructive tests or to hazard tests; such tests shall be run on engineering models only.

Rationale: Battery hazard, life and radiation tests consume or damage the article. Keeping them off flight hardware protects the flight battery from abuse (SR-13.2) and its life from being spent on the ground.

VER-016 Analysis Model Correlation · Verify: Analysis, Inspection · Trace: SR-9.1, SR-11.2, SR-2.1 · Applies: All

An analysis that closes a requirement shall use a model correlated with test data where a test of the item exists, and shall state the correlation criteria met and the remaining uncertainty.

Rationale: The thermal, structural and attitude models close requirements that cannot be tested in full on the ground (the orbital thermal cases, the launch loads, the 0.1° pointing). Their results are only as good as their correlation.

VER-017 Simulator Validation · Verify: Test, Inspection · Trace: SR-2.1, SR-3.1, SR-10.22 · Applies: All

Each simulator used to close a requirement (the flatsat dynamic simulator, solar array simulator, payload and radio simulators) shall be validated against engineering-model or flight-unit data before use, with the validation recorded in the event record.

Rationale: Flatsat tests close many attitude, power and software requirements. An unvalidated simulator can pass software that fails on the real unit.

VER-018 In-Orbit Confirmation · Verify: Inspection, Demonstration · Trace: SR-6.14, SR-1.2, SR-5.3 · Applies: All

Requirements whose ground verification depends on predicted orbit conditions (focus, radiometric calibration, geolocation, pointing, link margins) shall be confirmed in commissioning, with the results recorded in the commissioning report and compared against the ground results.

Rationale: The ground closes these requirements, but the comparison shows whether ground methods can be trusted for later spacecraft and feeds the calibration baseline of N6.

VER-019 Verification Status Reporting · Verify: Inspection · Trace: SR-15.1 · Applies: All

The Systems Lead shall report the closure status of every requirement in Appendix A, with open nonconformances, waivers and deviations, at each milestone review and at least monthly during integration and test.

Rationale: The matrix is the program's measure of readiness. Regular reporting shows a slipping verification campaign before it reaches the pre-shipment review.

VER-020 Validation Before Mission Success Claim · Verify: Inspection · Trace: SR-6.12, SR-15.3 · Applies: All

Full or minimum mission success shall be claimed only after the validation events VAL-01 and VAL-03 are complete for the season concerned and their reports accepted by the imagery customer.

Rationale: The success criteria of Stakeholders and Needs are about the customer's use of the products. Only the validation events show that use; requirement closure alone does not.

Appendix A. Verification Cross-Reference Matrix

Generated from the requirement blocks of this specification. Methods: T test, A analysis, I inspection, D demonstration (primary method first). Events name the test cases and analyses of the verification chapter that close each requirement.

Operational Modes

Id	Title	Method	Applies	Verification events
SR-10.1	Operating Mode Set	I, T	All	TC-26, IN-06
SR-10.2	Permitted Mode Transitions	T, I	All	TC-26, IN-06
SR-10.3	Post-Separation Quiet Period	T	All	TC-26, TC-45
SR-10.4	Separation Time Persistence	T	All	TC-52
SR-10.5	Detumble Exit Conditions	T, D	All	TC-05, TC-26
SR-10.6	Payload Transmitter Mode Restriction	T	All	TC-53
SR-10.7	Mode Restoration After Reset	T	All	TC-26
SR-10.8	Link Fault Response	T	All	TC-53
SR-10.9	Watchdog Reset Safe Mode Trigger	T	All	TC-52, TC-53
SR-10.10	Battery Temperature Safe Mode Trigger	T	All	TC-53
SR-10.11	Attitude Error Safe Mode Trigger	T, A	All	TC-53, TC-04, TC-17
SR-10.12	Command Loss Safe Mode Trigger	T	All	TC-53
SR-10.13	Safe Mode Load Set	T, I	All	TC-09, IN-06
SR-10.14	Safe Mode Sun Acquisition	T, A	All	TC-36, AN-05
SR-10.15	Safe Mode Health Beacon	T	All	TC-26
SR-10.16	Safe Mode Exit by Ground Command	T	All	TC-26
SR-10.17	Momentum Unloading Exclusion	T	All	TC-36
SR-10.18	Mode Status Telemetry	T	All	TC-56
SR-10.19	Decommissioning Command Protection	T	All	TC-28, TC-54

Verification matrix, Operational Modes

System Requirements

Id	Title	Method	Applies	Verification events
SR-1.2	Ground Sample Distance	T	All	TC-01, IN-12
SR-1.3	Swath Width	T	All	TC-02
SR-1.4	Spectral Bands	T	All	TC-03
SR-1.5	Daily Collection Volume	A	All	AN-11
SR-1.6	Revisit Time	A	All	TC-13, VAL-02
SR-1.6.1	Ground Track Repeat	A	All	TC-13
SR-1.6.2	Off-Nadir Imaging	T	All	TC-14
SR-1.7	Mission Lifetime	A	All	TC-16, AN-09
SR-1.8	Signal-to-Noise Ratio	T, A	All	TC-31, AN-12
SR-1.9	Absolute Radiometric Accuracy	A, T	All	AN-12, TC-31
SR-1.10	Radiometric Stability	A	All	AN-12
SR-1.11	Band-to-Band Registration	T, A	All	TC-30, AN-13
SR-1.12	Product Geolocation Accuracy	A, D	All	AN-13, TC-63
SR-1.13	Imaging Strips per Orbit	A, T	All	AN-11, TC-57
SR-1.14	Lunar Calibration Imaging	D, A	All	TC-20, TC-36, AN-05
SR-1.15	Saturation Radiance	T	All	TC-31
SR-2.1	Pointing Accuracy	T, A	All	TC-04, AN-05
SR-2.2	Pointing Stability	T	All	TC-04, TC-34
SR-2.3	Detumble	T, A	All	TC-05
SR-2.4	Target Slew	A	All	TC-17
SR-2.5	Safe Mode Recovery	D, T	All	TC-20, TC-36
SR-2.6	Attitude Knowledge	A, T	All	AN-05, TC-35
SR-2.7	Safe Mode Sun Pointing	T	All	TC-36
SR-2.8	Wheel Momentum Management	A, T	All	AN-05, TC-36
SR-2.9	Single Wheel Failure Tolerance	A, T	All	AN-05, TC-36
SR-2.10	Ground Station Pointing	T, A	All	TC-36, AN-05

Id	Title	Method	Applies	Verification events
SR-3.1	Orbit Average Power	T, A	All	TC-06, AN-02
SR-3.2	Battery Capacity	T	All	TC-07
SR-3.3	Depth of Discharge	T, A	All	TC-40, AN-02
SR-3.4	Bus Regulation	I, T	All	TC-18, IN-02
SR-3.5	Battery Minimum Temperature	A, T	All	AN-07, TC-47
SR-3.6	Array Deployment	T	All	TC-19
SR-3.7	Cold Charge Inhibit	T	All	TC-39
SR-3.8	Output Fault Isolation	T	All	TC-38
SR-3.9	Power Allocation	A	All	AN-02
SR-3.10	Safe Mode Power	A	All	AN-02
SR-3.11	Hardware Undervoltage Disconnect	T	All	TC-38
SR-3.12	Autonomous Power Restart	T	All	TC-38
SR-4.1	Onboard Storage	T	All	TC-08
SR-4.2	Command Execution	T	All	TC-56, TC-27
SR-4.3	Fault Detection	T	All	TC-09, TC-53
SR-4.4	Downlink Encryption	I, T	Flight	TC-61, IN-08
SR-4.5	Image Compression	T	All	TC-65
SR-4.6	Compression Throughput	T	All	TC-65
SR-4.7	Onboard Time Accuracy	T	All	TC-50
SR-4.8	Stored Command Capacity	T	All	TC-56
SR-4.9	Stored Data Integrity	A, T	All	AN-08, TC-51
SR-5.1	S-band Downlink Rate	T	Lite	TC-10
SR-5.2	UHF Command Uplink	T	All	TC-11
SR-5.3	Downlink Link Margin	A, T	Lite	AN-04, TC-10, TC-21
SR-5.4	Daily Data Volume	D, A	Flight	TC-12, AN-03
SR-5.4.1	Daily Data Volume, EO-1 Lite	D, A	Lite	TC-12, AN-03
SR-5.5	X-band Downlink Rate	T	Flight	TC-21
SR-5.6	X-band Link Margin	A, T	Flight	AN-04, TC-21
SR-5.7	UHF Uplink Margin	A, T	All	AN-04, TC-11

Id	Title	Method	Applies	Verification events
SR-5.8	UHF Telemetry Downlink Margin	A, T	All	AN-04, TC-59
SR-5.9	Downlink Channel Coding	T	All	TC-27, TC-62
SR-5.10	Spectrum Authorization	T, I	All	TC-59, IN-09
SR-5.11	Transmitter Shutoff	T	All	TC-54, TC-26
SR-6.1	Contact Scheduling	D	All	TC-20
SR-6.2	Image Delivery	D	All	TC-12, VAL-01
SR-6.3	Telemetry Archive	I	All	IN-07
SR-6.4	Operator Planning Time	D	All	TC-20
SR-6.5	Planning Cycle Time	A	All	AN-16
SR-6.6	Tasking Lead Time	D	All	TC-20
SR-6.7	Downlink Contacts per Day	A, D	All	AN-11, TC-20
SR-6.8	Orbit Determination	A, D	All	AN-13, TC-20
SR-6.9	Out-of-Limit Notification	D	All	TC-20
SR-6.10	Unattended Contacts	D	All	TC-20
SR-6.11	Operations Staffing	D, A	All	TC-20, AN-17
SR-6.12	Vegetation Index Product	D	All	VAL-03, TC-63
SR-6.13	Calibration Traceability	I, D	All	IN-07, TC-63
SR-6.14	Commissioning Duration	D	All	TC-20, IN-12
SR-8.1	Stowed Envelope	I	All	IN-01
SR-8.2	Launch Mass	T, A	All	TC-43, AN-01
SR-8.3	Center of Mass	T	All	TC-43
SR-8.4	Mass Margin	A	All	AN-01
SR-8.5	Stowed Natural Frequency	T, A	All	TC-42, AN-06
SR-8.6	Deployment Delay	T	All	TC-45
SR-8.7	Redundant Release	T	All	TC-44
SR-8.8	Deployed Natural Frequency	T, A	All	TC-44, AN-06
SR-8.9	Camera-to-Star-Tracker Alignment	A, T	All	AN-06, TC-42, TC-25
SR-9.1	Unit Temperature Margin	A, T	All	AN-07, TC-46

Id	Title	Method	Applies	Verification events
SR-9.2	Focal Plane Temperature	T	All	TC-33, TC-46
SR-9.3	Telescope Thermal Gradient	A, T	All	AN-07, TC-46
SR-9.4	Battery Maximum Temperature	A, T	All	AN-07, TC-46
SR-9.5	Thermostatic Survival Heaters	T, I	All	TC-47, IN-01
SR-9.6	Safe Mode Thermal Survival	A	All	AN-07
SR-10.20	Software Image Activation	T	All	TC-55
SR-10.21	Protected Boot Image	T	All	TC-55
SR-10.22	Plan Constraint Check	T	All	TC-56
SR-10.23	Downlink Priority	T	All	TC-57
SR-10.24	Event Log	T	All	TC-56
SR-10.25	Command Validation	T	All	TC-54, TC-27
SR-10.26	Processor Utilization	T, A	All	TC-58, AN-18
SR-10.27	Memory Utilization	I, T	All	IN-06, TC-58
SR-10.28	Deletion After Ground Confirmation	T	All	TC-57
SR-11.1	Random Vibration	T	All	TC-42
SR-11.2	Quasi-Static Loads	A, T	All	AN-06, TC-42
SR-11.3	Separation Shock	T, A	All	TC-42, AN-06
SR-11.4	Thermal Vacuum Operation	T	All	TC-24
SR-11.5	Total Ionizing Dose	A, T	All	AN-08, TC-51, TC-48
SR-11.6	Single-Event Recovery	T, A	All	TC-52, AN-08
SR-11.7	Outgassing	I	All	IN-03
SR-11.8	EMC Self-Compatibility	T, A	All	TC-23, AN-15
SR-11.9	RF Transmission Delay	T	All	TC-45
SR-11.10	Dispenser Storage Duration	T, A	All	TC-39, AN-20
SR-12.1	Telemetry Frame Format	T	All	TC-27
SR-12.2	Telecommand Frame Format	T	All	TC-27
SR-12.3	File Delivery Protocol	T	All	TC-27, TC-57

Id	Title	Method	Applies	Verification events
SR-12.4	Station-to-MOC Transfer	D	All	TC-12
SR-12.5	Product Format	I, D	All	IN-07, TC-12
SR-12.6	Machine Tasking Interface	D	All	TC-12
SR-12.7	No Dispenser Electrical Interface	I	All	IN-01
SR-13.1	Launch Inhibits	I, T	All	IN-01, TC-45
SR-13.2	Battery Hazard Controls	T, I	All	TC-39, IN-01
SR-13.3	Ground Transmitter Enable	T	All	TC-45
SR-13.4	Post-Mission Orbital Lifetime	A	All	AN-09
SR-13.5	Battery Passivation	T	All	TC-28
SR-13.6	End-of-Mission RF Silence	T	All	TC-28
SR-13.7	No Released Objects	I, T	All	IN-01, TC-19
SR-13.8	Reentry Casualty Risk	A	All	AN-09
SR-13.9	No Pressure Vessels or Pyrotechnics	I	All	IN-01
SR-14.1	Telecommand Authentication	T	All	TC-54
SR-14.2	Replay Protection	T	All	TC-54
SR-14.3	Onboard Key Store	T	All	TC-54
SR-14.4	Key Rotation	D, I	All	TC-20, IN-08
SR-14.5	Ground Transfer Encryption	I, T	All	IN-08, TC-64
SR-14.6	Customer Multi-Factor Sign-In	T	All	TC-29
SR-14.7	Customer Data Isolation	T	All	TC-29
SR-14.8	Security Audit Log	I, D	All	IN-08, TC-64
SR-14.9	Critical Command Arming	T	All	TC-54
SR-15.1	Mission Reliability	A	All	TC-16
SR-15.2	Failure Propagation	A	All	AN-10
SR-15.3	Imaging Availability	A, D	All	AN-17, TC-20
SR-15.4	Portal Availability	A, D	All	AN-17, TC-29
SR-15.5	Prohibited Materials	I	All	IN-03
SR-15.6	Optics Cleanliness	I	All	IN-04

Id	Title	Method	Applies	Verification events
SR-15.7	Unit Burn-In	T, I	All	TC-25, IN-02
SR-15.8	End-of-Life Battery Capacity	A, T	All	AN-20, TC-41
SR-15.9	Limited-Life Items	A	All	AN-20

Verification matrix, System Requirements

Payload Camera Specification

Id	Title	Method	Applies	Verification events
PAY-001	Aperture and Focal Length	I, T	All	IN-01, TC-30
PAY-002	Detector Format	I, T	All	IN-02, TC-02
PAY-003	Laboratory Modulation Transfer Function	T	All	TC-30
PAY-004	Telescope Wavefront Error	T, A	All	TC-30, AN-12
PAY-005	Focus in Orbit	A, T	All	AN-12, TC-30, IN-12
PAY-006	Band Co-alignment	T	All	TC-30
PAY-007	Spectral Band Edges	T	All	TC-03
PAY-008	Out-of-Band Response	T	All	TC-03
PAY-009	Signal-to-Noise Ratio	T, A	All	TC-31, AN-12, IN-12
PAY-010	Saturation Margin	T	All	TC-31
PAY-011	Band Settings	T	All	TC-31
PAY-012	Radiometric Linearity	T	All	TC-31
PAY-013	Defective Pixels	T	All	TC-31
PAY-014	Dark Reference	I, T	All	IN-02, TC-31
PAY-015	Relative Response Monitor	T, D	All	TC-33, TC-20
PAY-016	Pre-Launch Radiometric Calibration	T	All	TC-31
PAY-017	Focal Plane Temperature Knowledge	T	All	TC-33
PAY-018	Stray Light	T, A	All	TC-32, AN-21
PAY-019	Sun Exposure Tolerance	A, T	All	AN-07, TC-33
PAY-020	Optics Cleanliness at Delivery	I	All	IN-04
PAY-021	Decontamination Tolerance	T	All	TC-33
PAY-022	Alignment Reference	T	All	TC-25
PAY-023	Line-of-Sight Stability	A, T	All	AN-06, TC-33
PAY-024	Image Buffer	T	All	TC-57, TC-15
PAY-025	Image Data Output	T	All	TC-57, TC-15
PAY-026	Line Time Tagging	T	All	TC-57, TC-15
PAY-027	Line Rate Control	T	All	TC-30
PAY-028	Payload Power	T	All	TC-15
PAY-029	Payload Mass	T	All	TC-25

Id	Title	Method	Applies	Verification events
PAY-030	Latch-Up Protection	T	All	TC-15, TC-52

Verification matrix, Payload Camera Specification

ADCS Specification

Id	Title	Method	Applies	Verification events
ADCS-001	Control Error	A, T	All	TC-04, AN-05
ADCS-002	Attitude Estimation Error	A, T	All	TC-04, AN-05
ADCS-003	Star Tracker Accuracy	T	All	TC-35
ADCS-004	Star Tracker Rate Capability	T	All	TC-35
ADCS-005	Star Tracker Field Clearance	A	All	AN-21, AN-05
ADCS-006	Rate Stability During Capture	T, A	All	TC-04, AN-05
ADCS-007	Wheel Zero-Speed Avoidance	T	All	TC-04, TC-34
ADCS-008	Wheel Capacity	T	All	TC-34, TC-17
ADCS-009	Wheel Imbalance	T	All	TC-34
ADCS-010	Slew Settling	T, A	All	TC-17, TC-36
ADCS-011	Slew With One Wheel Failed	A, T	All	TC-17, TC-36
ADCS-012	Wheel Failure Reconfiguration	T	All	TC-36
ADCS-013	Magnetic Dipole	T	All	TC-37, TC-05
ADCS-014	Off-Nadir Range	T, A	All	TC-36, AN-05
ADCS-015	Yaw Steering	T, A	All	TC-04, TC-36, AN-05
ADCS-016	Onboard Orbit Propagation	A, T	All	AN-05, TC-36
ADCS-017	Ancillary Attitude Data	T	All	TC-36
ADCS-018	Lunar Calibration Scan	T	All	TC-36
ADCS-019	Actuator Enable After Separation	T	All	TC-36
ADCS-020	Rate Damping Independence	T, A	All	TC-37, TC-05
ADCS-021	Rate Sensing Range	T	All	TC-05
ADCS-022	Coarse Sun Sensing	T, A	All	TC-36, AN-05
ADCS-023	Safe Mode Sun Acquisition	T, A	All	TC-36, AN-05
ADCS-024	Eclipse Attitude Hold	T, A	All	TC-36, AN-05
ADCS-025	Autonomous Pointing Mode Hold	T	All	TC-36
ADCS-026	Ground Station Tracking Error	T, A	All	TC-36, AN-05
ADCS-027	ADCS Power	T	All	TC-36
ADCS-028	ADCS Mass	T	All	TC-43, TC-25
ADCS-029	Wheel and Star Tracker Life	A, T	All	AN-20, TC-34

Verification matrix, ADCS Specification

EPS Specification

Id	Title	Method	Applies	Verification events
EPS-001	Solar Cell Efficiency	T	All	TC-06
EPS-002	Array Cell Area	I	All	IN-01, TC-06
EPS-003	Panel Peak Power	T	All	TC-06
EPS-004	Peak Power Tracking Efficiency	T	All	TC-40
EPS-005	Array Failure Containment	A, T	All	AN-19, TC-38
EPS-006	Battery Cell Capacity	T	All	TC-07
EPS-007	End-of-Charge Voltage	T	All	TC-41
EPS-008	Charge Current Limit	T	All	TC-39
EPS-009	Cell Cycle Life	T, A	All	TC-41, AN-20
EPS-010	State of Charge Estimation	T	All	TC-40
EPS-011	Hardware Cold Charge Inhibit	T	All	TC-39
EPS-012	Battery Hazard Controls	T, I	All	TC-39, IN-01
EPS-013	Storage Drain	T	All	TC-39
EPS-014	Bus Regulation Range	T	All	TC-18, TC-38
EPS-015	Always-On Line	T, I	All	TC-18, IN-01
EPS-016	Switched Output Set	T, I	All	TC-38, IN-01
EPS-017	Conversion Efficiency	T	All	TC-40
EPS-018	Single-Point Ground	I, T	All	IN-01, TC-23
EPS-019	Output Current Limiting	T	All	TC-38
EPS-020	Latch-Up Recovery	T	All	TC-38
EPS-021	Hardware Undervoltage Disconnect	T	All	TC-38
EPS-022	Autonomous Restart	T	All	TC-38
EPS-023	Launch Inhibit Chain	I, T	All	IN-01, TC-45
EPS-024	Hardware Quiet-Period Timer	T	All	TC-45
EPS-025	Permanent Charge Path Disconnect	T	All	TC-28
EPS-026	Power Telemetry	T	All	TC-38
EPS-027	EPS Mass	T	All	TC-25
EPS-028	Battery Pack Mass	T	All	TC-07

Verification matrix, EPS Specification

Structure and Mechanisms Specification

Id	Title	Method	Applies	Verification events
STR-001	Stowed Envelope Dimensions	I	All	IN-01
STR-002	Rail Interface	I	All	IN-01
STR-003	Protrusions	I	All	IN-01

Id	Title	Method	Applies	Verification events
STR-004	Stowed Frequency Design Margin	A, T	All	AN-06, TC-42
STR-005	Bonded and Composite Joint Strength	A, T	All	AN-06, TC-42
STR-006	Mass Properties Determination	T	All	TC-43
STR-007	Primary Structure Mass	T	All	TC-43
STR-008	Deployment Mechanisms Mass	T	All	TC-43
STR-009	Structural Materials	I	All	IN-03
STR-010	Fastener Locking	I	All	IN-02
STR-011	Optical Bench Stability	A, T	All	AN-06, TC-42, TC-24
STR-012	Bonding Provisions	I	All	IN-01
STR-013	Vent Direction	I, A	All	IN-01, AN-14
STR-014	Hold-Down Release	T	All	TC-44, TC-19
STR-015	Stowed Restraint	T, A	All	TC-42, AN-06
STR-016	Captured Release Line	I, T	All	IN-01, TC-44
STR-017	Deployment Torque Margin	T, A	All	TC-44, AN-06
STR-018	Deployed Geometry	T, I	All	TC-44, TC-19, IN-01
STR-019	Deployed Stiffness	T, A	All	TC-44, AN-06
STR-020	Deployment Status Sensing	T	All	TC-44, TC-19
STR-021	Separation Switches	T, I	All	TC-45, IN-01
STR-022	Remove-Before-Flight Switch	T, I	All	TC-45, IN-01
STR-023	Ground-Handling Restraint	I, T	All	IN-01, TC-19
STR-024	Ground Support Access	I	All	IN-01

Verification matrix, Structure and Mechanisms Specification

Thermal Control Specification

Id	Title	Method	Applies	Verification events
THM-001	Operating Temperature Limits	A, T	All	AN-07, TC-46
THM-002	Non-Operating Temperature Limits	A	All	AN-07, TC-46

Id	Title	Method	Applies	Verification events
THM-003	Thermal Model Resolution	I	All	IN-01
THM-004	Focal Plane Temperature Control	T, A	All	TC-46, AN-07
THM-005	Focal Plane Stability During a Strip	T	All	TC-46
THM-006	Telescope Temperature and Gradient	A, T	All	AN-07, TC-46
THM-007	Optical Bench Temperature	A, T	All	AN-07, TC-46
THM-008	Battery Heater Set Points	T	All	TC-47
THM-009	Battery Temperature Uniformity	T, A	All	TC-46, TC-07, AN-07
THM-010	Battery Maximum Temperature	A, T	All	AN-07, TC-46
THM-011	Survival Heater Thermostats	T, I	All	TC-47, IN-01
THM-012	Heater Power	A, T	All	AN-07, TC-47
THM-013	X-band Radio Pass Temperature	A, T	Flight	AN-07, TC-46
THM-014	S-band Transmitter Pass Temperature	A, T	Lite	AN-07, TC-46
THM-015	Decontamination Heating	T, D	All	TC-47, TC-33
THM-016	Temperature Telemetry	I, T	All	IN-02, TC-22
THM-017	Radiator Surface Properties	T, I	All	TC-25, IN-03

Verification matrix, Thermal Control Specification

Command and Data Handling Specification

Id	Title	Method	Applies	Verification events
CDH-001	Data Memory	I, T	All	IN-02, TC-08
CDH-002	Software Image Slots	I, T	All	IN-02, TC-55
CDH-003	Data Memory Scrubbing	T, A	All	TC-52, AN-08
CDH-004	Hardware Watchdog	T	All	TC-52
CDH-005	Reset Record	T	All	TC-52
CDH-006	Boot Time	T	All	TC-52

Id	Title	Method	Applies	Verification events
CDH-007	Nonvolatile State Memory	I, T	All	IN-02, TC-52
CDH-008	Latch-Up Protection	T	All	TC-52
CDH-009	Radiation Tolerance	A, T	All	AN-08, TC-52
CDH-010	Oscillator Residual Drift	T, A	All	TC-50, AN-18
CDH-011	Time Correction Resolution	T	All	TC-50
CDH-012	Time Distribution	T	All	TC-50
CDH-013	Separation Timer	T	All	TC-52
CDH-014	Key Store	T, I	All	TC-54, IN-08
CDH-015	Compression Engine Throughput	T	All	TC-65
CDH-016	Payload Storage Capacity	T, A	All	TC-08, AN-03
CDH-017	Storage Error Correction	A, T	All	AN-08, TC-08, TC-51
CDH-018	Storage Scrubbing	T	All	TC-08, TC-51
CDH-019	Storage Write Rate	T	All	TC-08
CDH-020	Storage Read Rate	T	All	TC-08
CDH-021	Storage Write Endurance	A, T	All	AN-20, TC-51
CDH-022	Storage Bank Isolation	T, A	All	TC-08, AN-10
CDH-023	Average Power	T	All	TC-15, TC-65
CDH-024	Peak Power	T	All	TC-15, TC-65
CDH-025	C&DH Mass	I	All	IN-02

Verification matrix, Command and Data Handling Specification

Flight Software Specification

Id	Title	Method	Applies	Verification events
FSW-001	Fault Monitor Rate	T, I	All	TC-53, IN-06
FSW-002	Fault Management Isolation	T, A	All	TC-53, TC-58, AN-18
FSW-003	Watchdog Service Condition	T	All	TC-53
FSW-004	Grouped Load Shed	T	All	TC-09, TC-53
FSW-005	Authentication Before Processing	T	All	TC-54
FSW-006	Anti-Replay Counter Persistence	T	All	TC-54

Id	Title	Method	Applies	Verification events
FSW-007	Command Verification Reports	T	All	TC-56
FSW-008	Transmitter-Off Precedence	T	All	TC-54
FSW-009	Critical Command Table	T, I	All	TC-54, IN-06
FSW-010	Schedule Timing	T	All	TC-56
FSW-011	Stored Sequences	T	All	TC-56
FSW-012	Plan Load Integrity	T	All	TC-56
FSW-013	Contact Window Exclusion	T	All	TC-56
FSW-014	Schedule Editing	T	All	TC-56
FSW-015	Execution Report	T	All	TC-56
FSW-016	Housekeeping Collection	T	All	TC-56
FSW-017	Stored Housekeeping	T	All	TC-56
FSW-018	Virtual Channel Allocation	T, I	All	TC-57, IN-06
FSW-019	Time Correlation Packets	T	All	TC-56
FSW-020	Strip Ancillary Data	T	All	TC-57
FSW-021	Compression Segmentation	T	All	TC-57, TC-65
FSW-022	Raw Calibration Mode	T	All	TC-57
FSW-023	Downlink Queue Order	T	All	TC-57
FSW-024	Storage Full Protection	T	All	TC-57
FSW-025	File Transfer Persistence	T	All	TC-57, TC-55
FSW-026	Downlink Frame Supply	T	All	TC-57
FSW-027	Software Image Upload	T	All	TC-55
FSW-028	Table Update Without Reset	T	All	TC-55
FSW-029	Low-Energy Imaging Inhibit	T, A	All	TC-53, AN-02
FSW-030	RF Inhibit Gate	T	All	TC-53
FSW-031	Deployment Retry	T	All	TC-53, TC-19
FSW-032	ADCS Unit Recovery	T	All	TC-53

Id	Title	Method	Applies	Verification events
FSW-033	Processor Margin at Release	T, A	All	TC-58, AN-18
FSW-034	Category 1 Test Coverage	I	All	IN-06

Verification matrix, Flight Software Specification

Communications Specification

Id	Title	Method	Applies	Verification events
COM-001	UHF Receiver Sensitivity	T	All	TC-59, TC-11
COM-002	UHF Transmit Power	T	All	TC-59
COM-003	UHF Transceiver Power Draw	T	All	TC-59
COM-004	UHF Receiver Always Available	T, I	All	TC-59, IN-01
COM-005	UHF Turnaround Time	T	All	TC-59
COM-006	UHF Transmit Frequency Stability	T	All	TC-59
COM-007	UHF Antenna Coverage	T, A	All	TC-60, AN-04
COM-008	UHF Antenna Deployment	T	All	TC-60
COM-009	UHF Antenna Deployment Indication	T	All	TC-60
COM-010	UHF Antenna Match	T	All	TC-60
COM-011	UHF Release Debris Containment	I, T	All	IN-01, TC-60
COM-012	S-band Transmitter Power Draw	T	Lite	TC-59
COM-013	S-band Antenna Gain	T	Lite	TC-10
COM-014	S-band Frequency Stability	T	Lite	TC-59
COM-015	S-band Power Flux Density	A	Lite	AN-15
COM-016	X-band Radio Power Draw	T	Flight	TC-59
COM-017	X-band Antenna Gain	T	Flight	TC-21
COM-018	X-band Frequency Stability	T	Flight	TC-59
COM-019	X-band Encryption Throughput	T	Flight	TC-61
COM-020	X-band Key Protection	T, I	Flight	TC-61, IN-08
COM-021	Downlink Implementation Loss	T	All	TC-59, TC-62
COM-022	Continuous Transmission Time	T	All	TC-59
COM-023	Transmitter Ready Time	T	All	TC-59, TC-10, TC-21
COM-024	Oscillator Short-Term Stability	T	All	TC-59
COM-025	Spurious Emissions	T	All	TC-59
COM-026	UHF Receiver Desensitization	T	All	TC-23
COM-027	Transmitter Permanent Disable	T, I	All	TC-28, IN-02
COM-028	RF Exposure	A	All	AN-15
COM-029	Communications Mass	I	All	IN-02

Verification matrix, Communications Specification

Ground Segment Specification

Id	Title	Method	Applies	Verification events
GND-001	S-band Receive G/T	T	Lite	TC-62
GND-002	X-band Receive G/T	T	Flight	TC-62
GND-003	UHF Uplink EIRP	T	All	TC-62
GND-004	UHF Receive G/T	T	All	TC-62
GND-005	Dish Tracking Error	T	All	TC-62
GND-006	Three-Station Service	I, D	Flight	IN-07, TC-12
GND-007	One-Station Service	D, A	Lite	TC-12, AN-17
GND-008	Pass Success Rate	A, D	All	AN-17, TC-12
GND-009	Unattended Pass Execution	D	All	TC-12, TC-20
GND-010	Ground Link Acknowledgment	T	All	TC-62
GND-011	In-Pass Retransmission	T	All	TC-27, TC-62
GND-012	Pass Recording Retention	I, D	All	IN-07, TC-12
GND-013	Station Time Reference	T	All	TC-62
GND-014	Planning Constraint Model	T, I	All	TC-56, IN-07
GND-015	Candidate Plan Generation	D	All	TC-20, TC-56
GND-016	Pass Prediction Accuracy	A, D	All	AN-13, TC-56, TC-20
GND-017	Daily Orbit Solution	D	All	TC-20, TC-56
GND-018	Limit Checking Latency	D	All	TC-20
GND-019	Priority Product Latency	D	All	TC-63
GND-020	Processing Capacity	T, D	All	TC-63, TC-12
GND-021	Elevation Model Accuracy	I, A	All	IN-07, AN-13
GND-022	Reference Image Registration	T, A	All	TC-63, AN-13
GND-023	Calibration Trending	D, A	All	TC-63, AN-12
GND-024	Reprocessing	D	All	TC-63
GND-025	Archive Retention	I, D	All	IN-07, TC-20
GND-026	Key Protection	I, T	All	IN-08, TC-64
GND-027	Two-Person Critical Command Release	D	All	TC-64

Id	Title	Method	Applies	Verification events
GND-028	Operator Sign-In	T	All	TC-64
GND-029	Backup Operations Site	D	All	TC-20, IN-07

Verification matrix, Ground Segment Specification

Mission Operations Specification

Id	Title	Method	Applies	Verification events
OPS-001	Shift Staffing	D	All	TC-20
OPS-002	On-Call Response	D	All	TC-66
OPS-003	Command Interval	A, D	All	AN-16, TC-20
OPS-004	Backup Uplink Contact	D	All	TC-20
OPS-005	Priority Target Scheduling	D, A	All	TC-20, VAL-01, AN-16
OPS-006	Planning Cycle Reporting	D	All	TC-20, VAL-01
OPS-007	Commanding from Approved Procedures	I, D	All	IN-07, TC-20
OPS-008	Procedure Validation	I	All	IN-07
OPS-009	Known-Cause Safe Mode Recovery	D	All	TC-20, TC-66
OPS-010	Anomaly Reporting	I	All	IN-07
OPS-011	Operator Certification	I	All	TC-66, IN-07
OPS-012	Recertification	I	All	TC-66, IN-07
OPS-013	Daily Time Correction	D	All	TC-20
OPS-014	Storage Backlog Action	D	All	TC-20
OPS-015	Interference Response	D	All	TC-20
OPS-016	Lunar Calibration Scheduling	D	All	TC-20
OPS-017	Shift Handover Log	I	All	IN-07

Verification matrix, Mission Operations Specification

Interface Requirements

Id	Title	Method	Applies	Verification events
ICD-001	Switched Load Line Ratings	T	All	TC-15, TC-38
ICD-002	Switched Output Overcurrent Trip	T	All	TC-38
ICD-003	Load Inrush Current	T	All	TC-15

Id	Title	Method	Applies	Verification events
ICD-004	C&DH Power Line Rating	T	All	TC-15
ICD-005	C&DH Power Line Not Commandable	I, T	All	IN-11, TC-38
ICD-006	C&DH Power Line Latch-Up Recovery	T	All	TC-38, TC-52
ICD-007	Radio Power Line Rating	T, A	All	TC-15, AN-02
ICD-008	UHF Transmit Interlock During X-band Passes	T	Flight	TC-15, TC-21
ICD-009	Array Input Range	T	All	TC-40
ICD-010	Battery Line Voltage Drop	T	All	TC-15
ICD-011	Battery Line Fuse	I, T	All	IN-11, TC-39
ICD-012	Regulated Bus Ripple	T	All	TC-18, TC-23
ICD-013	Payload Data Throughput	T	All	TC-57, TC-15
ICD-014	Capture Time Synchronization	T	All	TC-15, TC-50
ICD-015	ADCS Bus Telemetry Rate	T	All	TC-15, TC-36
ICD-016	Safe Mode Command Response	T	All	TC-09
ICD-017	ADCS Data Bus Load	T, A	All	TC-36, AN-18
ICD-018	Command Frame Forwarding	T	All	TC-27
ICD-019	Two-Step Transmitter Enable	T	All	TC-45, TC-54
ICD-020	Downlink Frame Format	T	All	TC-27
ICD-021	Idle Frame Insertion	T	All	TC-27
ICD-022	S-band Data Interface	T	Lite	TC-15, TC-10
ICD-023	X-band Data Interface	T, I	Flight	TC-15, TC-21, IN-11
ICD-024	Power Telemetry Update	T	All	TC-40
ICD-025	Power Telemetry Bus Fault Tolerance	T	All	TC-53
ICD-026	Star Tracker Data Latency	T	All	TC-35, TC-36
ICD-027	Wheel Supply Isolation	T	All	TC-36

Id	Title	Method	Applies	Verification events
ICD-028	Torque Rod Dipole and Blanking	T	All	TC-37
ICD-029	Deployment Switch Status	T	All	TC-19, TC-44
ICD-030	UHF Channel	T	All	TC-59, TC-11
ICD-031	UHF Receiver Doppler Tolerance	T	All	TC-59
ICD-032	S-band Downlink Signal	T	Lite	TC-59, TC-10
ICD-033	X-band Downlink Signal	T	Flight	TC-59, TC-21
ICD-034	Downlink Occupied Bandwidth	T	All	TC-59
ICD-035	X-band Power Flux Density	A	Flight	AN-15
ICD-036	X-band Frame Encryption	T, I	Flight	TC-61, IN-08
ICD-037	Ground Network Throughput	T, D	All	TC-62, TC-12
ICD-038	Command Keys Stay at the MOC	I, D	All	IN-08, TC-20
ICD-039	Product Notification	D	All	TC-12
ICD-040	Operations Console Telemetry Latency	D	All	TC-20
ICD-041	Separation Switch Inhibits	I, T	All	IN-11, TC-45
ICD-042	Separation Switch Actuation	T	All	TC-45
ICD-043	Deployables Restrained by the Spacecraft	I, T	All	IN-01, TC-19
ICD-044	Ground Support Access	I, D	All	IN-01, TC-45
ICD-045	Array Self-Shadowing	A, I	All	AN-21, IN-01
ICD-046	Camera Clear Field of View	I, A	All	IN-01, AN-21
ICD-047	Camera Sun Exclusion	A, T	All	AN-21, TC-32

Verification matrix, Interface Requirements

Technical Budgets and Margins

Id	Title	Method	Applies	Verification events
VER-001	Contingency by Basis	I	All	IN-10

Id	Title	Method	Applies	Verification events
VER-002	Measured Basis Evidence	I	All	IN-10
VER-003	Margin Threshold Action	I	All	IN-10
VER-004	Budget Reporting	I	All	IN-10
VER-005	Flight Unit Weighing	I, T	All	IN-10, TC-43

Verification matrix, Technical Budgets and Margins

Environmental Requirements

Id	Title	Method	Applies	Verification events
ENV-001	Structural Factors of Safety	A	All	AN-06
ENV-002	Sine Vibration	T	All	TC-42
ENV-003	Unit Random Vibration	T	All	TC-25
ENV-004	Vibration Signature Criteria	T	All	TC-42
ENV-005	Separation Shock Test	T	All	TC-42
ENV-006	Venting	A, I	All	AN-14, IN-01
ENV-007	Thermal Design Cases	A	All	AN-07
ENV-008	Thermal Model Correlation	T, A	All	TC-46, AN-07
ENV-009	Spacecraft Bake-Out	T, I	All	TC-24, IN-04
ENV-010	Part Dose Tolerance	A, I	All	AN-08, IN-03
ENV-011	Detector Displacement Damage	T, A	All	TC-48, AN-08
ENV-012	Single-Event Latch-Up	A, I	All	AN-08, IN-03
ENV-013	Single-Event Upset Mitigation	A, T	All	AN-08, TC-52
ENV-014	Atomic Oxygen Resistance	A, I	All	AN-14, IN-03
ENV-015	Coating Ultraviolet Stability	A, I	All	AN-14, IN-03
ENV-016	Impact Survival Probability	A	All	AN-09
ENV-017	Unit EMC Tests	T	All	TC-23
ENV-018	UHF Receiver Band Emissions	T	All	TC-23
ENV-019	Residual Magnetic Dipole	T	All	TC-37
ENV-020	Electrical Bonding	T, I	All	TC-23, IN-02

Id	Title	Method	Applies	Verification events
ENV-021	Surface Charging	A, I	All	AN-19, IN-01
ENV-022	Clean Room Class	I	All	IN-04
ENV-023	Ground Temperature and Humidity	I	All	IN-05
ENV-024	Transport Loads	I, T	All	IN-05, TC-42
ENV-025	Battery Storage Charge	I, T	All	IN-05, TC-39
ENV-026	Protoflight Testing of FM-1	T	Flight	TC-22, TC-42, TC-24, TC-46, TC-23
ENV-027	Acceptance Testing of Later Models	T	All	TC-22, TC-42, TC-24, TC-23
ENV-028	S-band Transmitter Qualification	T	Lite	TC-25

Verification matrix, Environmental Requirements

Verification and Validation

Id	Title	Method	Applies	Verification events
VER-006	Verification Before Flight	I	All	IN-10
VER-007	Criteria Set Before the Event	I	All	IN-10
VER-008	As-Run Records	I	All	IN-10
VER-009	Calibrated Test Equipment	I	All	IN-10
VER-010	Nonconformance Reporting	I	All	IN-10
VER-011	Failure-Free Operating Time	T, I	All	TC-22, IN-10
VER-012	Re-Verification After Change	I, T	All	IN-10, TC-22
VER-013	Software Regression Before Upload	T, I	All	TC-56, TC-53, IN-06
VER-014	Test-as-You-Fly Exceptions	I, A	All	IN-10, AN-10
VER-015	Flight Hardware Exposure Limits	I	All	IN-10
VER-016	Analysis Model Correlation	A, I	All	AN-06, AN-07, AN-05, IN-10
VER-017	Simulator Validation	T, I	All	TC-36, TC-40, IN-10
VER-018	In-Orbit Confirmation	I, D	All	IN-12
VER-019	Verification Status Reporting	I	All	IN-10

Id	Title	Method	Applies	Verification events
VER-020	Validation Before Mission Success Claim	I	All	IN-10, VAL-01, VAL-03

Verification matrix, Verification and Validation

Appendix B. Open Items

Every TBD (value to be determined) and TBR (value to be reviewed) in this specification, with the requirements that carry it.

Item	Kind	Requirements	Where
TBD-01	To be determined	SR-3.5, THM-008	EPS Specification; Introduction; Operational Modes; System Requirements; Thermal Control Specification
TBR-01	To be reviewed	SR-1.6.1	Mission Overview and Concept of Operations; Propulsion Specification; Stakeholders and Needs; System Architecture; System Requirements
TBR-02	To be reviewed	—	Mission Overview and Concept of Operations; Operational Modes; Structure and Mechanisms Specification; System Architecture; System Requirements
TBR-03	To be reviewed	SR-2.4	ADCS Specification; Introduction; Mission Overview and Concept of Operations; Operational Modes; System Requirements; Technical Budgets and Margins
TBR-04	To be reviewed	SR-5.3	Communications Specification; Ground Segment Specification; Interface Requirements; Mission Overview and Concept of Operations; System Requirements
TBD-05	To be determined	—	Ground Segment Specification; Introduction; Mission Overview and Concept of Operations
TBD-06	To be determined	—	Introduction; Stakeholders and Needs
TBR-06	To be reviewed	—	Introduction; Mission Overview and Concept of Operations
TBD-10	To be determined	—	Flight Software Specification; System Architecture

Item	Kind	Requirements	Where
TBR-10	To be reviewed	SR-10.11	Operational Modes
TBR-11	To be reviewed	SR-10.9	Command and Data Handling Specification; Operational Modes
TBR-12	To be reviewed	SR-10.10	Operational Modes
TBR-13	To be reviewed	ADCS-023, SR-10.14	ADCS Specification; Operational Modes
TBR-15	To be reviewed	PAY-009, SR-1.8	Payload Camera Specification; System Requirements
TBR-16	To be reviewed	SR-1.12	Ground Segment Specification; System Requirements
TBD-17	To be determined	SR-11.1	Environmental Requirements; Interface Requirements; Structure and Mechanisms Specification; System Requirements
TBR-18	To be reviewed	ENV-010, SR-11.5	Environmental Requirements; System Requirements
TBR-19	To be reviewed	SR-13.4	Introduction; Mission Overview and Concept of Operations; Stakeholders and Needs; System Requirements
TBR-20	To be reviewed	SR-14.4	Ground Segment Specification; Mission Operations Specification; System Requirements
TBR-21	To be reviewed	SR-15.3	System Requirements
TBR-22	To be reviewed	SR-6.8	System Requirements
TBR-30	To be reviewed	PAY-005	Payload Camera Specification
TBR-31	To be reviewed	ADCS-011	ADCS Specification
TBR-33	To be reviewed	EPS-007	EPS Specification; Interface Requirements
TBR-40	To be reviewed	STR-003	Structure and Mechanisms Specification
TBR-41	To be reviewed	STR-019	Structure and Mechanisms Specification
TBR-50	To be reviewed	CDH-010	Command and Data Handling Specification
TBR-51	To be reviewed	FSW-029	Flight Software Specification

Item	Kind	Requirements	Where
TBR-52	To be reviewed	COM-007	Communications Specification
TBR-53	To be reviewed	COM-024	Communications Specification
TBR-54	To be reviewed	GND-019	Ground Segment Specification
TBR-55	To be reviewed	GND-008	Ground Segment Specification
TBR-56	To be reviewed	OPS-002	Mission Operations Specification
TBD-70	To be determined	ICD-042	Interface Requirements
TBR-70	To be reviewed	ICD-007	Communications Specification; EPS Specification; Interface Requirements
TBR-71	To be reviewed	ICD-030	Communications Specification; Interface Requirements
TBR-72	To be reviewed	ICD-047	Interface Requirements
TBR-73	To be reviewed	ENV-002	Environmental Requirements
TBR-74	To be reviewed	ENV-014	Environmental Requirements
TBR-75	To be reviewed	VER-011	Verification and Validation

Open items

Appendix C. Traceability Index

Each need and parent requirement with the requirements that trace to it (from the Trace field of each requirement block).

Parent	Traced requirements
N1	SR-1.4, SR-2.10, SR-4.5, SR-4.6, SR-5.1, SR-5.3, SR-5.4, SR-5.4.1, SR-5.5, SR-5.6, SR-5.9, SR-6.2, SR-6.5, SR-6.7, SR-6.12, SR-10.23, SR-10.28, SR-12.3, SR-12.4, SR-12.6, SR-15.3, SR-15.4
N2	SR-1.3, SR-1.5, SR-1.6, SR-1.6.1, SR-1.6.2, SR-1.13, SR-2.4, SR-2.8, SR-6.14, SR-15.3
N3	SR-10.17, SR-1.2, SR-1.3, SR-1.4, SR-1.5, SR-1.8, SR-1.11, SR-1.12, SR-1.13, SR-1.15, SR-2.1, SR-2.2, SR-2.6, SR-4.1, SR-4.2, SR-4.5, SR-4.7, SR-4.9, SR-6.8, SR-6.12, SR-8.8, SR-8.9, SR-9.3, SR-10.28, SR-11.8, SR-12.3, SR-12.5
N4	SR-10.1, SR-10.2, SR-10.5, SR-10.7, SR-10.8, SR-10.9, SR-10.10, SR-10.11, SR-10.12, SR-10.13, SR-10.14, SR-10.15, SR-10.16, SR-1.7, SR-1.10, SR-2.3, SR-2.5, SR-2.7, SR-2.8, SR-2.9, SR-3.1, SR-3.2, SR-3.3, SR-3.4, SR-3.5, SR-3.6, SR-3.7, SR-3.8, SR-3.9, SR-3.10, SR-3.11, SR-3.12, SR-4.3, SR-5.7, SR-6.3, SR-6.14, SR-8.7, SR-9.1, SR-9.4, SR-9.5, SR-9.6, SR-10.20, SR-10.21, SR-10.26, SR-10.27, SR-11.4, SR-11.5, SR-11.6, SR-11.8, SR-15.1, SR-15.2, SR-15.5, SR-15.7, SR-15.8, SR-15.9
N5	SR-10.19, SR-4.4, SR-14.1, SR-14.2, SR-14.3, SR-14.4, SR-14.5, SR-14.6, SR-14.7, SR-14.8, SR-14.9
N6	SR-1.8, SR-1.9, SR-1.10, SR-1.14, SR-1.15, SR-4.1, SR-6.13, SR-9.2, SR-11.7, SR-15.6
N7	SR-1.6.2, SR-2.4, SR-4.2, SR-4.8, SR-5.2, SR-6.4, SR-6.5, SR-6.6, SR-10.22, SR-12.6, SR-15.4
N8	SR-10.3, SR-10.4, SR-2.3, SR-3.6, SR-8.1, SR-8.2, SR-8.3, SR-8.4, SR-8.5, SR-8.6, SR-11.1, SR-11.2, SR-11.3, SR-11.7, SR-11.9, SR-11.10, SR-12.7, SR-13.1, SR-13.2, SR-13.3, SR-13.9
N9	SR-10.19, SR-13.4, SR-13.5, SR-13.6, SR-13.7, SR-13.8, SR-14.9
N10	SR-10.6, SR-10.8, SR-5.10, SR-5.11, SR-11.9, SR-13.6
N11	SR-10.1, SR-10.2, SR-10.7, SR-10.12, SR-10.15, SR-10.16, SR-10.18, SR-2.5, SR-4.8, SR-5.2, SR-5.7, SR-5.8, SR-6.1, SR-6.3, SR-6.4, SR-6.9, SR-6.10, SR-6.11, SR-10.22, SR-10.24, SR-10.25, SR-11.6, SR-12.1, SR-12.2
SR-1.2	PAY-001, PAY-002, PAY-003, PAY-004, PAY-005, PAY-013, PAY-027, ADCS-015, THM-006, VER-018
SR-1.3	PAY-002, ICD-046
SR-1.4	PAY-007, PAY-008

Parent	Traced requirements
SR-1.5	PAY-024
SR-1.6.2	PAY-027, ADCS-005, ADCS-014
SR-1.7	PAY-019, ADCS-029, THM-017, ENV-014, ENV-015
SR-1.8	PAY-001, PAY-009, PAY-011, PAY-013, ENV-011
SR-1.9	PAY-008, PAY-012, PAY-014, PAY-016, PAY-018, FSW-022, VER-009
SR-1.10	PAY-014, PAY-015, PAY-017, PAY-019, PAY-020, PAY-021, STR-013, THM-005, THM-015, GND-023, GND-024, ICD-047
SR-1.11	PAY-006, ADCS-015, GND-022
SR-1.12	PAY-026, ADCS-016, ADCS-017, FSW-020, GND-021, GND-022, ICD-015
SR-1.13	PAY-024, ICD-013
SR-1.14	ADCS-018, OPS-016
SR-1.15	PAY-010, PAY-011, ICD-046, ICD-047
SR-2.1	PAY-023, ADCS-001, ADCS-007, ADCS-016, GND-017, VER-016, VER-017
SR-2.2	ADCS-006, ADCS-007, ADCS-009, ADCS-010, STR-019, ICD-017, ICD-026
SR-2.3	ADCS-013, ADCS-020, ADCS-021, ICD-028
SR-2.4	ADCS-008, ADCS-010, ADCS-011, STR-006
SR-2.5	OPS-008, OPS-009
SR-2.6	PAY-022, ADCS-002, ADCS-003, ADCS-004, ADCS-005, ADCS-017, CDH-012, FSW-020, ICD-015, ICD-026
SR-2.7	ADCS-021, ADCS-022, ADCS-023, ADCS-024, ADCS-025, STR-018, ICD-016
SR-2.8	ADCS-008, ADCS-013, ICD-028, ENV-019
SR-2.9	ADCS-011, ADCS-012, ICD-027
SR-2.10	ADCS-004, ADCS-026, COM-013, COM-017
SR-3.1	EPS-001, EPS-002, EPS-003, EPS-004, EPS-005, STR-018, ICD-009, ICD-045, VER-017
SR-3.2	EPS-006, EPS-007, THM-009
SR-3.3	EPS-009, EPS-010, EPS-026, FSW-029, ICD-010, ICD-024
SR-3.4	EPS-014, ICD-001, ICD-003, ICD-007, ICD-012
SR-3.5	THM-008
SR-3.6	STR-014, STR-017, STR-020, STR-023, FSW-031, COM-008, ICD-029
SR-3.7	EPS-011
SR-3.8	EPS-016, EPS-019, ICD-002, ICD-003

Parent	Traced requirements
SR-3.9	PAY-028, ADCS-027, EPS-017, THM-012, CDH-023, CDH-024, COM-003, COM-012, COM-016, ICD-001, ICD-007, ICD-008, VER-001, VER-002, VER-003, VER-004
SR-3.10	ICD-045
SR-3.11	EPS-021, COM-004, ICD-005, ICD-006, ICD-010
SR-3.12	EPS-015, EPS-022, ICD-004, ICD-009
SR-4.1	CDH-016, CDH-019, FSW-022, FSW-024, OPS-014
SR-4.2	FSW-010, ICD-014, ICD-018
SR-4.3	EPS-015, EPS-026, CDH-006, FSW-001, FSW-004, ICD-004, ICD-005, ICD-016, ICD-017, ICD-024
SR-4.4	CDH-014, COM-019, COM-020, GND-026, ICD-036
SR-4.5	PAY-025, CDH-015, FSW-021
SR-4.6	PAY-025, CDH-015, CDH-019, ICD-004, ICD-013
SR-4.7	PAY-026, CDH-010, CDH-011, CDH-012, FSW-019, GND-013, OPS-013, ICD-014
SR-4.8	FSW-011
SR-4.9	CDH-017, CDH-018, FSW-021, ENV-013
SR-5.1	THM-014, ICD-022, ICD-032
SR-5.2	COM-005, ICD-018, ICD-030, ICD-031
SR-5.3	COM-013, COM-021, GND-001, GND-005, ICD-021, ICD-032, VER-004, VER-018
SR-5.4	CDH-020, FSW-026, COM-022, GND-006
SR-5.4.1	FSW-026, GND-007
SR-5.5	THM-013, CDH-020, COM-019, ICD-023, ICD-033
SR-5.6	COM-017, COM-021, GND-002, GND-005, ICD-033
SR-5.7	COM-001, COM-004, COM-007, COM-010, COM-026, GND-003, ICD-031, ENV-018
SR-5.8	COM-002, COM-007, COM-010, GND-004, ICD-008
SR-5.9	ICD-020, ICD-032, ICD-033
SR-5.10	COM-006, COM-014, COM-015, COM-018, COM-025, OPS-015, ICD-030, ICD-034, ICD-035
SR-5.11	FSW-008, OPS-015, ICD-019
SR-6.1	GND-016, OPS-004
SR-6.2	GND-012, GND-019, GND-020, ICD-039
SR-6.3	FSW-017, GND-025
SR-6.4	GND-014, GND-015, OPS-011, OPS-012, ICD-040
SR-6.5	GND-015, GND-019, OPS-005, OPS-006, ICD-037
SR-6.6	FSW-014, OPS-004
SR-6.7	COM-022, COM-023, GND-006, GND-008

Parent	Traced requirements
SR-6.8	COM-024, GND-017
SR-6.9	THM-016, GND-009, GND-018, OPS-002, OPS-017, ICD-040
SR-6.10	GND-009, GND-029
SR-6.11	OPS-001, OPS-011, OPS-017
SR-6.12	VER-020
SR-6.13	PAY-016, GND-024, VER-008, VER-009
SR-6.14	VER-018
SR-8.1	STR-001, STR-002, STR-003, ICD-042, ICD-043
SR-8.2	PAY-029, ADCS-028, EPS-027, EPS-028, STR-007, STR-008, CDH-025, COM-029, VER-002, VER-005
SR-8.3	STR-006, VER-005
SR-8.4	PAY-029, ADCS-028, EPS-027, STR-007, STR-008, VER-001, VER-003, VER-004
SR-8.5	STR-004, STR-015, ENV-001, ENV-002, ENV-004
SR-8.6	ADCS-019, EPS-024, STR-021, CDH-013, ICD-029, ICD-043
SR-8.7	STR-014, FSW-031, COM-008
SR-8.8	STR-019
SR-8.9	PAY-022, PAY-023, STR-011, THM-007
SR-9.1	THM-001, THM-003, THM-013, THM-014, THM-016, THM-017, ENV-007, ENV-008, ENV-015, VER-016
SR-9.2	PAY-017, THM-004, THM-005
SR-9.3	THM-003, THM-006
SR-9.4	THM-010
SR-9.5	THM-011
SR-9.6	THM-002, THM-012, ENV-007
SR-10.2	OPS-008
SR-10.3	ADCS-019
SR-10.4	CDH-007, CDH-013
SR-10.5	STR-020, COM-009
SR-10.7	CDH-006
SR-10.8	GND-010
SR-10.9	CDH-004, CDH-005, FSW-003
SR-10.12	OPS-003
SR-10.13	EPS-016
SR-10.14	ADCS-023
SR-10.18	FSW-016
SR-10.20	CDH-002, FSW-027, VER-013

Parent	Traced requirements
SR-10.21	CDH-002, VER-013
SR-10.22	FSW-012, FSW-013, FSW-028, GND-014, VER-017
SR-10.23	FSW-023
SR-10.24	CDH-005, CDH-007, FSW-015
SR-10.25	FSW-007, OPS-007
SR-10.26	FSW-033
SR-10.27	CDH-001
SR-10.28	FSW-024, OPS-014
SR-11.1	STR-010, STR-015, ENV-003, ENV-004, ENV-024, ENV-026, ENV-027, ENV-028
SR-11.2	STR-005, ENV-001, ENV-002, ENV-006, VER-016
SR-11.3	ENV-005, ENV-024, ENV-026
SR-11.4	ENV-007, ENV-008, ENV-026, ENV-027, ENV-028, VER-014
SR-11.5	CDH-009, ENV-010, ENV-011
SR-11.6	PAY-030, ADCS-012, EPS-020, CDH-003, CDH-004, CDH-008, CDH-009, CDH-022, FSW-003, FSW-032, ICD-006, ICD-025, ENV-012, ENV-013, ENV-020, ENV-021
SR-11.7	PAY-021, STR-009, STR-013, THM-015, ENV-009, ENV-014, ENV-022
SR-11.8	EPS-018, STR-012, COM-026, ICD-012, ENV-017, ENV-018, ENV-019, ENV-020, ENV-021, ENV-028
SR-11.9	EPS-024, FSW-030, ICD-019
SR-11.10	EPS-013, THM-002, ICD-044, ENV-023, ENV-025
SR-12.1	FSW-018, ICD-020, ICD-021, ICD-022, ICD-023
SR-12.2	FSW-018, ICD-018
SR-12.3	FSW-025, COM-005, GND-011, ICD-020
SR-12.4	GND-012, ICD-037
SR-12.6	ICD-039
SR-12.7	STR-002, STR-024, ICD-041, ICD-044
SR-13.1	EPS-023, STR-021, STR-022, STR-023, ICD-029, ICD-041, ICD-042, ICD-044
SR-13.2	EPS-008, EPS-011, EPS-012, STR-022, ICD-011, ENV-025, VER-015
SR-13.3	COM-028, ICD-019
SR-13.5	EPS-025
SR-13.6	COM-027
SR-13.7	STR-010, STR-016, COM-011, ICD-043, ENV-005, ENV-016
SR-13.9	ENV-006

Parent	Traced requirements
SR-14.1	FSW-005, GND-026, GND-028, ICD-038
SR-14.2	FSW-006
SR-14.3	CDH-014, COM-020, ICD-036
SR-14.4	GND-026
SR-14.5	ICD-038
SR-14.8	GND-025, GND-028
SR-14.9	FSW-009, GND-027, OPS-007
SR-15.1	FSW-034, OPS-010, ENV-016, VER-006, VER-007, VER-008, VER-010, VER-011, VER-012, VER-015, VER-019
SR-15.2	PAY-030, ADCS-025, EPS-005, EPS-019, THM-011, CDH-022, FSW-002, FSW-034, ICD-002, ICD-025, ICD-027, ICD-047, ENV-012, VER-006, VER-010, VER-012, VER-014
SR-15.3	GND-029, OPS-009, OPS-010, VER-020
SR-15.5	STR-009
SR-15.6	PAY-020, ENV-009, ENV-022, ENV-023
SR-15.7	ENV-003, ENV-027, VER-011
SR-15.8	EPS-007, EPS-008, EPS-009, THM-009
SR-15.9	ADCS-029, CDH-021

Traceability index

Appendix D. Glossary and Acronyms

Glossary

Term	Definition
Acceptance test	A test of a flight unit or spacecraft built to a qualified design, at levels equal to the maximum expected environment, to find workmanship defects.
Allocation	The share of a resource (mass, power, data, time, error) assigned to an element by the level above it.
Attitude factor	In the generation budget, the ratio of the array output averaged over the attitude profile of an orbit to the output with the arrays at the design Sun incidence.
Battery bus	The unregulated PDU node at battery voltage (12.0 V to 16.8 V) from which the regulated bus and the always-on line are derived.
Beta angle	The angle between the Sun direction and the orbit plane. It sets the length of eclipse: the smaller the angle, the longer the eclipse.
Burn-wire hold-down	A restraint for a deployable whose tie is cut by a heated resistor; the cut ends stay captive.
Calibration mode	A payload operating mode in which strips are stored without compression for radiometric calibration.
Codeblock	The unit of the LDPC channel code: 7,136 information bits encoded into 8,160 channel bits.
Command Schedule	The time-tagged list of commands loaded on board from an Imaging Plan and executed by mode activity SM.1.
Configuration	One of the two products of the EO-1 line: EO-1 Flight (X-band, serial numbers 1 and 2) or EO-1 Lite (S-band, serial number 3 on).
Contact	A period in which a ground station and the spacecraft exchange signals. A payload downlink contact uses the payload downlink radio as well as UHF.
Contingency	An allowance added to a current best estimate for the growth expected as the design matures, set by the basis of the estimate.
Current best estimate	The present value of a budget quantity from the best available source: estimate, calculation or measurement.
Deployable	Any part that moves from its stowed to its deployed position after separation: the solar array panels and the UHF antenna elements.
Depth of discharge	The energy drawn from the battery in one discharge, as a fraction of its capacity.
Design case	The Nominal Imaging orbit used for the power budget: eight 40 s strips in two imaging windows and one payload downlink pass.

Term	Definition
Detumble	The mode after separation in which the magnetorquers reduce the tip-off rates and the deployables are released.
Dispenser	The container on the launch vehicle that holds the spacecraft during launch and pushes it out along its rails at release.
Downlink Frames	The transfer frames the C&DH sends to the payload downlink radio, carrying stored files for transmission.
Eclipse	The part of an orbit in which the Earth blocks the Sun.
Equivalent sun hours	Ultraviolet exposure expressed as the hours of normal-incidence sunlight that would give the same dose.
Flatsat	A bench assembly of engineering or flight-representative units connected by flight-like harnesses, used to test interfaces and software before integration.
Ground sample distance	The distance on the ground between the centers of two adjacent pixels at nadir.
Ground-track repeat	The time after which the spacecraft's ground track passes over the same points again.
Health beacon	A short telemetry frame the UHF Transceiver sends periodically without a ground request, so that any station can assess the spacecraft.
Image Data Package	The set of files and frames received by a ground station from one payload downlink contact.
Image Strip	The continuous four-band image collected in one capture, nominally 40 s and at most 54 s long.
Imaging Plan	The plan built by the Mission Operations Center for the next period of operations and uplinked as command packets.
Imaging window	A period of Nominal Imaging, sub-mode NI.2, in which the spacecraft captures a group of strips over one region.
Inhibit	A physical break in a power or control path that prevents a hazardous function (deployment, transmission) until it is removed.
Interface	A defined connection between two elements, through which items (power, data, signals, loads, light) pass.
Item	Something that flows between functions or across an interface, such as Command Schedule, Image Strip or Power Telemetry.
Latch-up	A single-event effect in which a parasitic path in a part draws a high current until power is removed.
Link margin	The amount by which the received signal quality exceeds what is needed for the required error rate, in decibels.
Margin (system margin)	The allocation minus the current best estimate with contingency, held at system level.
Measure of effectiveness	A measure of how well the mission meets a stakeholder need, with a threshold and an objective value.

Term	Definition
Mode	A state of the spacecraft state machine (Launch, Detumble, Nominal Imaging, Downlink Contact, Safe Mode, Decommissioned).
Orbit-average power	Power averaged over one orbit of the stated case, including the eclipse.
Passivation	Removal of stored energy at the end of the mission: battery disconnected and discharged, wheels spun down, transmitters disabled.
Payload downlink radio	The S-band Transmitter on EO-1 Lite or the X-band Payload Radio on EO-1 Flight.
Planning cycle	The time from the start of a plan uplink to the first product from that plan on the customer portal.
Pointing mode	A configuration of the ADCS (AP-0 to AP-5) commanded by the spacecraft mode.
Power Telemetry	The voltages, currents, temperatures and switch states the PDU reports to the C&DH.
Protoflight	A test approach in which the first flight model is tested at qualification levels for acceptance durations and then flown.
Push-broom imager	A camera with line detectors across the ground track that builds an image as the spacecraft moves along it.
Qualification test	A test at levels above the maximum expected environment that shows a design has margin.
Radiation design margin	The ratio of a part's demonstrated radiation tolerance to the radiation predicted at its location.
Remove-before-flight pin	A ground-handling inhibit that opens the battery line until it is removed before the spacecraft is loaded into the dispenser.
Revisit time	The longest time between two opportunities to image the same point.
Safe Mode	The mode entered after a fault: non-essential loads off, arrays pointed at the Sun, waiting for ground commands.
Separation switch	A switch at a rail end held depressed by the dispenser; its release at separation ends the launch inhibits and starts the separation timer.
Shock response spectrum	The peak response of a set of single-degree-of-freedom oscillators to a shock, plotted against their natural frequency.
Single-event effect	A malfunction caused by one energetic particle passing through a part: an upset, a functional interrupt or a latch-up.
Sun-synchronous orbit	A near-polar orbit whose plane turns once a year, so that the spacecraft crosses each latitude at the same local time.
Swath	The width of the strip of ground imaged in one pass, at nadir.

Term	Definition
Technical performance measure	A budget quantity tracked over the design life with a threshold and an objective to show whether the design is converging.
Total ionizing dose	The accumulated ionizing radiation energy absorbed by a material, in rad(Si).
Transfer frame	The fixed-length data unit of the CCSDS space data link protocols.

Glossary

Acronyms

Acronym	Meaning
ACK	Acknowledgement
ADCS	Attitude determination and control subsystem
AO	Atomic oxygen
APID	Application process identifier
BCH	Family of cyclic error-correcting block codes used in telecommand coding
BER	Bit error rate
BOL	Beginning of life
BT	Bandwidth-time product (of the GMSK filter)
C&DH	Command and data handling
CAN	Controller area network
CBE	Current best estimate
CCSDS	Consultative Committee for Space Data Systems
CDR	Critical design review
CDS	CubeSat Design Specification
CE90	Circular error, 90 % probability
CFDP	CCSDS File Delivery Protocol
CFRP	Carbon-fiber-reinforced polymer
CLTU	Communications link transmission unit
CMOS	Complementary metal-oxide-semiconductor
COP-1	Communications Operation Procedure 1
CRC	Cyclic redundancy check
DC	Direct current
Eb/N0	Energy per bit to noise power spectral density ratio
ECSS	European Cooperation for Space Standardization
EDAC	Error detection and correction
EIRP	Equivalent isotropically radiated power
EMC	Electromagnetic compatibility

Acronym	Meaning
EOL	End of life
EPS	Electrical power subsystem
FER	Frame error rate
FM	Flight model
FPGA	Field-programmable gate array
FS	Flatsat
G/T	Antenna gain to system noise temperature ratio
GB	Gigabyte (10^9 bytes)
GEVS	General Environmental Verification Standard
GIS	Geographic information system
GMSK	Gaussian minimum shift keying
GSD	Ground sample distance
GSFC	Goddard Space Flight Center (issuer of GEVS)
I2C	Inter-integrated circuit (two-wire serial bus)
ICD	Interface control document; also the prefix of interface requirements
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
ITU	International Telecommunication Union
LDPC	Low-density parity-check (code)
LEOP	Launch and early orbit phase
LVDS	Low-voltage differential signaling
MB	Megabyte (10^6 bytes)
MEMS	Microelectromechanical system
MLI	Multilayer insulation
MOC	Mission Operations Center
MOE	Measure of effectiveness
MRAM	Magnetoresistive random-access memory
MTF	Modulation transfer function
NAK	Negative acknowledgement
NASA	National Aeronautics and Space Administration (issuer of the cited handbook)
OQPSK	Offset quadrature phase-shift keying
PDR	Preliminary design review
PDU	Power Distribution Unit
PPS	Pulse per second
PPT	Peak power tracking

Acronym	Meaning
RBF	Remove before flight
RF	Radio frequency
RHCP	Right-hand circular polarization
RS-422	Differential serial signaling standard
RSS	Root sum square
SDRAM	Synchronous dynamic random-access memory
SHA	Secure hash algorithm
SNR	Signal-to-noise ratio
SPI	Serial peripheral interface
SRAM	Static random-access memory
SRR	System requirements review
SRS	System Requirements Specification
TBD	To be determined
TBR	To be reviewed
TC	Telecommand; also the prefix of test cases
TDI	Time delay integration
TM	Telemetry
TPM	Technical performance measure
UART	Universal asynchronous receiver-transmitter
UHF	Ultra high frequency
UTC	Coordinated Universal Time
UV	Ultraviolet

Acronyms