Ground Data System Design

This document defines the HuskySat-2 Ground Data System (GDS): the hardware, software, networks, data stores, and operator interfaces used to command the spacecraft, monitor its state, archive mission data, and deliver science products.

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Acronyms and Terms

Acronym or term	Definition
ADCS	Attitude Determination and Control Subsystem
APID	Application Process Identifier
BMS	Battery Management System
CCSDS	Consultative Committee for Space Data Systems
CDH	Command and Data Handling
CTL	Command and Telemetry List
EM	Engineering Model
EGSE	Electrical Ground Support Equipment
EPS	Electrical Power Subsystem
F'	F Prime flight-software framework
FEC	Forward Error Correction
FM	Flight Model
GDS	Ground Data System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSE	Ground Support Equipment
HDLC	High-Level Data Link Control
IBF	Install Before Flight
ICD	Interface Control Document
MDB	Mission Database
MGSE	Mechanical Ground Support Equipment
MQTT	Message Queuing Telemetry Transport
OVP	Overvoltage Protection
PC/104	Embedded computer-bus form factor and interface
RF	Radio Frequency
REST	Representational State Transfer
RBF	Remove Before Flight
SDLS	Space Data Link Security
SDR	Software-Defined Radio
SOH	State of Health

Acronym or term	Definition
SPI	Security Parameter Index
TC	Telecommand
TBC	To Be Confirmed
TBD	To Be Determined
TBR	To Be Resolved
TM	Telemetry
TTL	Transistor-Transistor Logic
UART	Universal Asynchronous Receiver-Transmitter
XTCE	XML Telemetric and Command Exchange

1. System Responsibilities

1.1 Purpose and Scope

HuskySat-2 will use Leaf Space for provider-operated RF ground stations and network service. Leaf Space operates the antennas, RF chain, station equipment, local computing, scheduling, and backhaul. HuskySat-2 operates the mission-control and data-processing system that receives telemetry from Leaf Space and submits approved commands.

Yamcs is the operational system of record. It decodes and archives telemetry, commands, and events; provides the operator interface and API; and supplies decoded parameters to Grafana for read-only state-of-health, log, and other telemetry/state views. Mission processing reads authenticated Yamcs data and delivers products to the science team.

The following ownership boundary is used throughout this document: Leaf Space owns the provider ground-station service; HuskySat-2 owns the mission-control, archive, and science-processing functions; Yamcs is the production operational interface; and F' GDS is retained for development and wired integration diagnostics.

Element	Responsible party	Primary interface	Acceptance evidence
Spacecraft and flight software	HuskySat-2	S-band RF and wired test path	End-to-end command, telemetry, and response test
Leaf Space service	Leaf Space	Station scheduling, REST, MQTT, RF delivery	Approved service profile and compatibility test
Mission-control system	HuskySat-2	Yamcs, MDB, CTL, archive, command history	Released configuration and flatsat test
Engineering and science views	HuskySat-2	Grafana and science-processing exports	Representative trend and science-package test

1.2 Leaf Space Ground-Station Service

Leaf Space operates the provider ground segment: antennas, RF front ends, radios, station control, pass scheduling, signal processing, networking, and the contracted customer interface. For HuskySat-2, Leaf Space uses the same demodulation, forward-error correction (FEC), and framing as the EnduroSat S-Rx/S-Tx profile. HuskySat-2 will use the Leaf Line shared network, with the GAIA100 3.7 m station [TBR].

Leaf Space strictly only transports telemetry and command records but does not interpret mission parameters, calibrations, limits, or command semantics. Yamcs and the HuskySat-2 mission database (MDB) provide that interpretation.

1.3 HuskySat-2 Ground Data System

HuskySat-2 owns the mission-control layer and authoritative mission record: the Yamcs server and web interface, Grafana dashboards, MDB, Leaf adapter, archive, command history, configuration, backups, science processing, and mission-team interfaces.

The F' deployment JSON is the source for F'-defined commands, telemetry, events, and packet layouts. The build produces the F' dictionary; fprime-xtce converts it to the XTCE format, which is loaded by Yamcs. The Command and Telemetry List (CTL) reflects the same dictionary. Version-controlled Yamcs overlays add calibrations, displays, limits, and operational constraints without redefining F' metadata.

1.4 Spacecraft and Communications Boundary

The spacecraft runs F' flight software to execute commands and generate telemetry, events, and files. The communications subsystem frames and transmits this data over S-band. Flight software does not depend on the Yamcs web interface or Leaf Space implementation details.

F' applies CCSDS Space Data Link Security (SDLS) to form CCSDS TM and TC transfer frames on both links. On uplink, the GDS forms and protects TC frames; the spacecraft verifies and decrypts them before TC and Space Packet deframing. On downlink, the GDS retains the protected Leaf Space delivery, verifies and decrypts SDLS, and then deframes TM and Space Packets. Leaf Space handles RF and FEC processing, not mission SDLS.

2. System Architecture and Data Flows

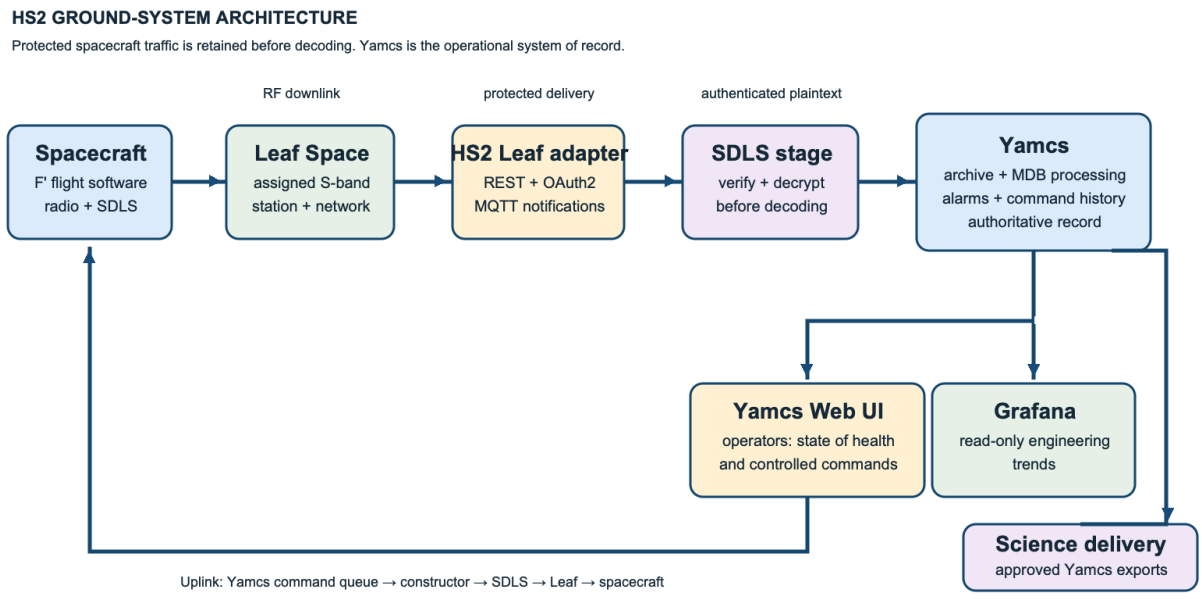


Figure 1. HuskySat-2 ground-system architecture and controlled data paths.

The Leaf adapter uses OAuth2-authenticated REST for scheduling, command handoff, and status, while MQTT carries asynchronous delivery and status notifications. Version-controlled configuration records the REST endpoint and version, OAuth2 identity and scopes, MQTT broker and topics, quality of service, replay settings, and certificate requirements from the approved Leaf Space customer documentation.

2.1 Telemetry Flow

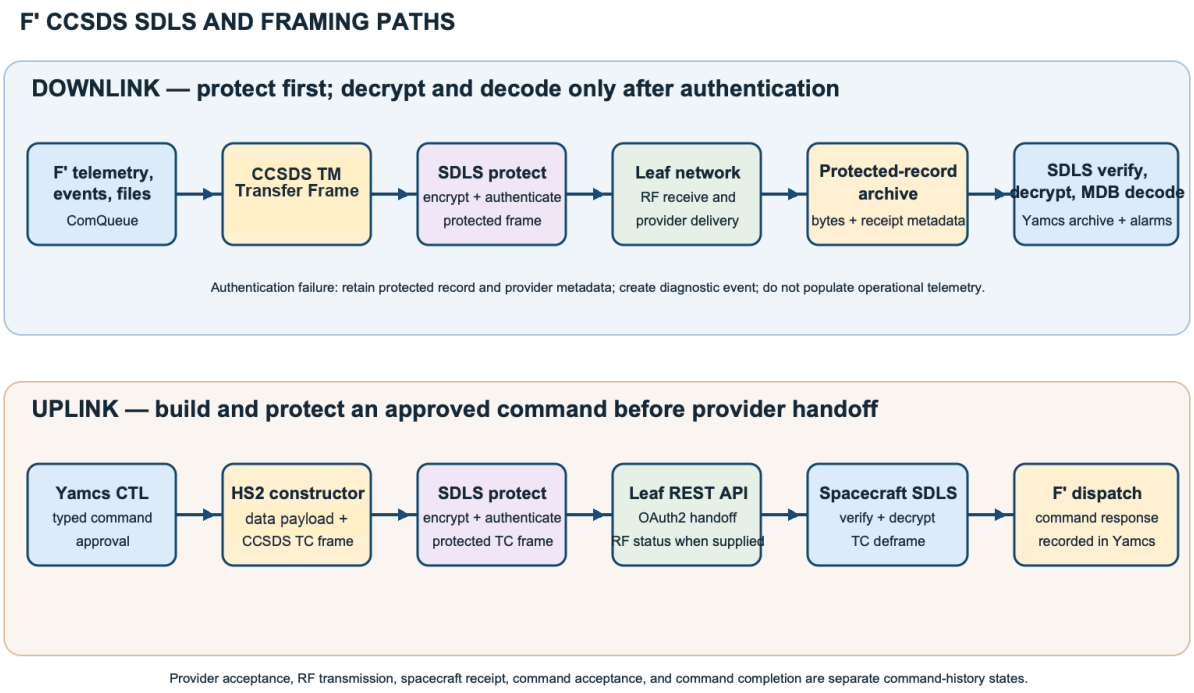


Figure 2. F' CCSDS SDLS and framing paths for downlink and uplink.

During a pass, Leaf Space demodulates the downlink and applies the mission's EnduroSat-compatible synchronization, FEC, and framing. The FEC profile, as defined by EnduroSat, is a rate-1/2 convolutional code with constraint length K = 5, generator polynomials g0 = 25_8 and g1 = 23_8, zero-padding to a 16-bit multiple, g0-branch inversion through every-other-bit XOR, and a 4 x 4 interleaver.

The Leaf adapter authenticates to the provider, preserves each protected record and its receipt metadata, and records gaps, duplicates, malformed messages, and reconnects. The GDS archives the protected record, verifies and decrypts SDLS, and then deframes CCSDS TM and Space Packets.

Yamcs validates packet formats, reorganizes data into telemetry, event logs, and errors, and archives decoded data. Authentication failures remain in the diagnostic archive and never populate operational telemetry. Sequence counters, timestamps, pass identifiers, and station identifiers are retained when supplied so records can be reprocessed after an MDB correction.

2.2 Command Flow

An authorized operator selects a CTL command in the Yamcs web interface, enters typed arguments, and reviews constraints along with spacecraft state. The MDB supplies the command definition. Critical commands remain queued until the approval required by the Mission Operations Document is complete.

After the command is approved, the command constructor builds the F' command payload and CCSDS TC frame. F' SDLS (with AES256 as the protocol) encrypts and authenticates the frame, and the Leaf adapter submits it through the REST API. Leaf Space applies the validated EnduroSat FEC and radio configuration before transmission. Yamcs records provider handoff, RF transmission when reported, spacecraft receipt and acceptance, command response, and completion as separate states. Provider acknowledgement does not prove spacecraft execution; the spacecraft will send down a response packet signaling whether it approved or denied the command, identified by its ID.

2.3 Build-Time Mission Metadata

Each ground release preserves a hierarchy: F' deployment metadata, generated dictionary, generated XTCE base, version-controlled Yamcs overlay, CTL, and release manifest. The manifest records the flight-software commit, dictionary and XTCE hashes, fprime-xtce version, overlay and CTL revisions, SDLS profile identifier, and test-vector result.

HuskySat-2 will maintain a mission-specific Yamcs deployment. fprime-yamcs may support development after integration testing but is not a production dependency [TBR].

3. Leaf Space Ground Segment

3.1 Ground-Station Network and Scheduling

HuskySat-2 will use Leaf Line S-band stations within the assigned mission frequency. Leaf Space assigns stations and contacts through the service plan. HuskySat-2 imports each approved contact and schedule change into the mission contact plan.

Each assigned station must support the approved frequency, polarization, modulation, coding, and CCSDS frame configuration and satisfy the link budget at a 10-degree elevation mask. The baseline uses GAIA100 3.7 m values: 50.0 dBW uplink EIRP, 140.92 K S-band receive-system noise temperature, and 12.93 dB/K S-band G/T at 10 degrees [TBR].

Section 11 lists the Leaf Space service-plan, interface, station-assignment, and readiness-test deliverables required before operational acceptance.

3.2 RF Compatibility and Link Performance

The data budgets currently a minimum usable downlink rate of 20.8 kbps and a planned usable uplink rate of 25 kbps. Both rates are measured on the CCSDS transfer-frame presented to

SDLS, and account for FEC, since the EnduroSat S-Band Transceiver has a raw data uplink and downlink rate of 50 kbps, which is effectively halved with the FEC code used.

The uplink budget estimates the peak planning case as 40 commands: error handling, component configuration, safe-mode exit, and experiment initiation, but this is TBR with the Mission Operations Plan. At 25 kbps, this command set requires approximately 15.7 seconds of transmission. This is a capacity-planning edge case, not a routine command quota.

The link budget demonstrates at least 6 dB uplink and downlink margin at a 10-degree elevation mask under UNP12-90. The link-budget sheet retains the current radio, antenna, waveform, coding, rate, station, loss, pointing, polarization, and atmospheric inputs.

HuskySat-2 will operate only under its approved S-band frequency authorization [TBD]. Leaf Space will verify station compatibility before booking passes and requires an ITU filing before it begins station licensing [TBD].

3.3 Provider Data Interface

The version-controlled Leaf integration configuration defines REST and MQTT endpoints, OAuth2 authentication, payload framing, topics and quality of service, ordering and acknowledgements, replay, rate limits, timing, errors, maintenance behavior, and the governing Leaf documentation revision.

The Leaf adapter provides lossless, idempotent transfer into the Yamcs archive and detects duplicate deliveries. Any Leaf Space replay service supplements, but does not replace, the HuskySat-2 archive; its retention and retrieval procedure will be recorded in the service configuration.

4. YAMCS Mission-Control System

4.1 Deployment and Hosting

The production server is a Lenovo ThinkCentre M70q Gen 6 Tiny with an Intel Core Ultra 7 265T processor, 32 GB RAM, Ubuntu Server 24.04 LTS, and two 1 TB M.2 NVMe SSDs in a mirrored array [TBR]. It uses wired Ethernet and UPS-backed power. Operators reach Yamcs through an authenticated connection; the server is not an operator laptop.

Production includes Yamcs, the Leaf adapter, MDB, SDLS configuration, archive, monitoring, logging, and backup. Development, flatsat, and production use separate instances. An automated encrypted (encryption method TBD) backup runs daily to an external USB SSD, and a weekly encrypted copy is stored offline at a separate location. USB flash drives are not approved backup media.

The GDS lead administers the server, operating-system patches, accounts, backups, and restore tests. The mission operations lead controls production command access.

4.2 Mission Database and Packet Processing

The Yamcs MDB defines telemetry containers and parameters, conversions, limits, error logs, command arguments and verifiers, and packet encodings. Generated XTCE supplies F' metadata; the version-controlled overlay contains only approved ground additions and identifies their sources.

Yamcs stores every Leaf delivery before decoding. Records that fail transport, SDLS, frame, or packet checks remain in the diagnostic archive. Only authenticated, format-valid packets populate parameters, error logs, plots, and science inputs.

4.3 Commanding and Command Verification

Yamcs allows for operators to select CTL commands, enter typed arguments, review and release them through command queues, and inspect the identifier, issue time, operator, binary encoding, queue state, provider acknowledgements, and spacecraft verification.

Roles, queues, transmission constraints, and the critical-command approvals defined in the Mission Operations Document limit unintended commanding. Command results distinguish success, failure, timeout, and unknown status.

The controlled SDLS profile identifies the security association, security parameter index, cryptographic suite, key identifier, initialization-vector construction, authentication tag, anti-replay policy, and key-loading procedure [TBD]. Provider transport security is separate and does not authorize commands on the spacecraft.

4.4 Telemetry, State of Health, and Logs

Yamcs displays real-time telemetry, events, error logs, packet contents, and plots during each pass and retains state-of-health data for the operational mission. Views are organized by subsystem, mode, mission objective, and pass, and support retrieval beyond the 48-hour requirement in GCDH-3. Operators can acknowledge errors, add notes, and inspect history.

4.5 Archive and Data Retention

Yamcs is the authoritative archive for protected records, decrypted packets, decoded parameters, commands and responses, command history, events, error logs, files, images, and provider metadata. GCDH-1 requires 7.5 GB of non-volatile storage. The data budget estimates 6.06 MB/day transmitted and 7.27 MB/day with 20 percent margin, or about 7.96 GB over three years before indexes, duplicate representations, logs, and backups. HuskySat-2 therefore allocates 1 TB [TBR] of mirrored primary storage, significantly more than what is required.

The archive retains all downlink records and ground-issued commands throughout operations. A daily backup covers Yamcs data, configuration, and audits; the weekly offline copy covers host loss, corruption, and operator error. Restore tests occur before acceptance and at least every six months during operations.

Archive exports include protected records, decoded packets and parameters, command history, provider metadata, release manifests, and science provenance. The project will set post-mission retention before decommissioning.

4.6 Ground Software Development and Integration

The GDS is developed as a layered system. Yamcs provides the operational services, mission database, command and telemetry processing, operator interface, and archive. Mission-specific software around Yamcs uses Python as the primary language for the Leaf Space adapter, provider-interface utilities, replay and export tools, data-quality checks, and science-processing services. The exact package and service boundaries remain a TBR implementation detail, but all components shall use documented Yamcs, Leaf Space, CCSDS, and project ICD interfaces rather than writing directly to the Yamcs database.

The development flow is requirements and ICD review, interface-contract definition, local unit and integration testing, flatsat testing, provider-compatibility testing, and end-to-end acceptance. Python dependencies shall be pinned in an approved environment or lock/requirements manifest. Source code, configuration, MDB/XTCE overlays, test vectors, and procedures are version controlled; credentials, certificates, and SDLS key material remain outside the source tree. Continuous or pre-release checks shall cover packet and command encoding, valid and invalid data, authentication failures, gaps and duplicates, replay behavior, archive ingestion, and representative science-package generation.

Component	**Current development baseline**	**Verification evidence**
Leaf adapter	Python client/service for REST scheduling and handoff plus MQTT delivery/status; idempotent transfer and protected-record retention.	Mocked interface tests and Leaf Space compatibility test.
Operations and replay tools	Python utilities using approved Yamcs APIs/exports to inspect, replay, diagnose, and package records; no direct database writes.	Gap, duplicate, malformed-record, replay, and archive-reconstruction tests.
Science processing	Versioned Python processing service that consumes authenticated Yamcs exports and emits provenance-bearing products.	Representative LOST/FOUND and quality-flag package test.

Component	Current development baseline	Verification evidence
Yamcs mission configuration	Version-controlled MDB/XTCE, overlays, CTL, SDLS profile, and deployment configuration integrated with the released server image.	Flatsat command/telemetry vectors and reproducible release-manifest build.

5. Science Data Processing and Delivery

Yamcs retains the raw mission record. The science-processing service reads authenticated exports and produces a package for each run containing a provenance manifest, LOST and FOUND comparison CSV, related images, quality flags, calibration identifier, software revision, acquisition time, and raw-record references.

Only the processing service can write to the science-delivery directory. Each versioned package has a unique run identifier and can be reproduced from immutable raw records and recorded software and calibration versions.

LOST records pair each result with the Arcsec Sagitta Star Tracker truth measure; FOUND records pair each result with the GNSS truth measure (when it is not jammed). Each record includes acquisition time, image identifier, quality flags, and calibration and processing revisions.

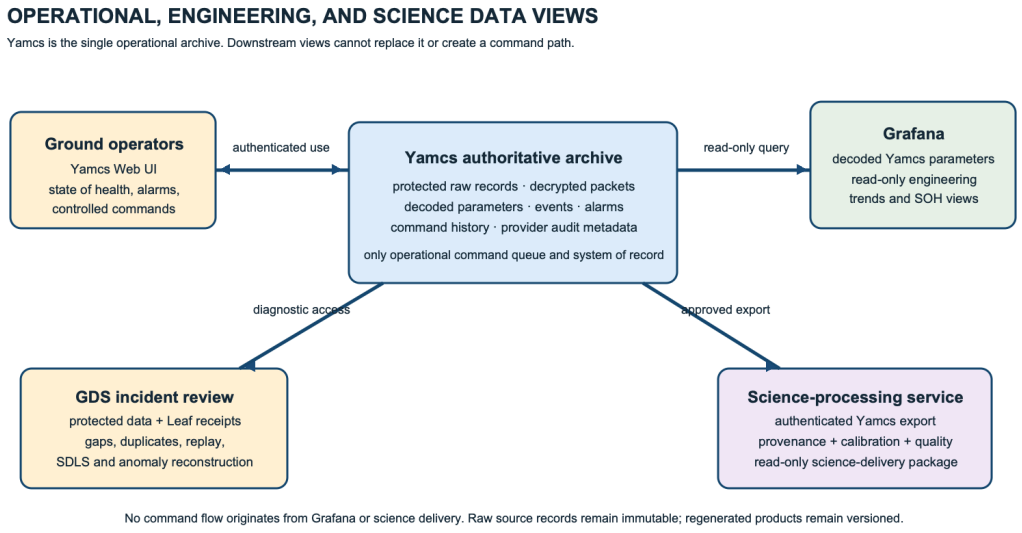


Figure 3. Operational, engineering, and science data responsibilities.

Grafana queries decoded Yamcs parameters for read-only engineering trends. It cannot send commands or replace the Yamcs operational or science archives.

6. Networking, Cybersecurity, and Regulatory Compliance

External connections use authenticated transport where supported. Secrets, provider credentials, certificates, and SDLS keys [TBD] will remain outside source code and follow an approved rotation process. Individual, role-based accounts limit access to administration, pass planning, commanding, monitoring, or science functions.

The production network record defines Leaf Space endpoints, firewall rules, ports, certificate trust, DNS, time synchronization, remote access, logging, and failure behavior. Monitoring covers the provider link, Yamcs links, archive, storage capacity, and scheduled passes.

F' CCSDS SDLS satisfies UNP12-92, GCDH-5, and GCDH-6 through protected uplink and downlink processing. UNP12-93 is not claimed as closed in this baseline; the selected downlink approach and supporting test results will be submitted to UNP for review and agreement before operational acceptance [TBD].

6.1 CCSDS SDLS Architecture and Key Lifecycle

Figure 2 defines SDLS placement in both uplink and downlink. HuskySat-2 controls encryption-related information; Leaf Space neither receives mission keys nor terminates SDLS. The GDS rejects unauthenticated frames from operational processing but retains their protected bytes and receipt metadata for diagnosis. EnduroSat FEC is separate from SDLS and is validated through the Leaf Space radio-integration process.

Leaf Space is responsible for licenses and authorizations for its stations, RF equipment, and network service. The HuskySat-2 communications and regulation is responsible for spacecraft frequency coordination, transmit authority, and applicable launch-provider and UNP approvals [TBD]. Flight records must identify the assigned frequencies, emission designator and bandwidth, power limits, operating restrictions, and license holder [TBD].

7. Operating Instructions

These instructions cover GDS operation and interface checks. The Mission Operations Document defines staffing, pass priorities, mission decisions, and detailed contingency responses.

7.1 System Startup and Health Check

1. Start the production Yamcs instance and confirm the expected software and MDB versions.

2. Verify server time synchronization, storage capacity, archive availability, backup status, and operator authentication.

3. Confirm that YAMCS telemetry and telecommand links are in the expected state.

4. Verify connectivity and authentication to the Leaf Space interface.

5. Load the approved pass schedule and compare it with the current orbit/contact plan.

6. Confirm that the current CTL, flight-software version, and station allocation are compatible.

7.2 Pre-Pass Preparation

1. Review the pass station, acquisition time, duration, maximum elevation, frequency configuration, and expected link margin.

2. Review spacecraft state, outstanding errors, last contact, expected telemetry, and planned commands.

3. Load the approved command stack and do not release it before the authorized window.

4. Confirm the Leaf Space route and provider link status.

5. Start pass-specific logging and record the responsible operators.

7.3 Contact Execution

1. Monitor provider acquisition and link-status indications.

2. Confirm receipt of valid spacecraft telemetry before sending nonessential commands.

3. Monitor real-time telemetry processing, packet sequence, timestamps, signal-quality and provider-quality indicators, decryption status, and archive ingestion.

4. Release only approved commands and observe provider and spacecraft verification stages.

5. Stop commanding when the link status, spacecraft state, command verification, or configuration identity is uncertain.

6. Record anomalies, manual actions, and operator decisions.

7.4 Post-Pass Processing

1. Confirm lossless ingestion. Investigate each packet gap, duplicate, and provider error.

2. Verify that raw packets, processed telemetry, events, errors (if applicable), and command history are archived.

3. Queue payload data for the science-processing pipeline.

4. Update contact status and record unresolved anomalies.

5. Retrieve provider-held data through the contracted replay process when expected telemetry is missing.

6. Confirm the next scheduled pass and return telemetry and command links to their normal state.

7.5 Interface Failure or Degraded Operation

If the Leaf Space interface disconnects, the adapter reconnects with the approved backoff and authentication settings without duplicating commands. A command with uncertain provider acceptance is not re-sent automatically unless both the command and provider interface are proven idempotent. Missing telemetry is recovered through the contracted replay process.

If Yamcs cannot decode a delivery, operators preserve the protected record and compare the flight manifest, MDB release, SDLS profile, framing configuration, and provider metadata. F' GDS remains a development diagnostic tool, not the operational mission-control system.

7.6 Command Authority, Anomaly Escalation, and Pass Handoff

The Mission Operations Document assigns the mission director, commanding operator, critical-command approver, science-data contact, and Leaf Space support contact for each phase. Operators do not release commands when authority, release identity, link state, or required approval is unknown. That document also defines pass handoff, lost-contact recovery, anomaly severity, and Leaf Space escalation times.

8. Requirements Compliance and Verification

GND-1 and GSTAT-1 are verified by the finalized link budget, GAIA100 3.7 m data, signed service profile, and end-to-end acceptance at a 20.8 kbps usable downlink rate, including authenticated receipt, SDLS decryption, and Yamcs ingestion.

GND-2, GSTAT-3, and GCDH-1 are verified by inspection of the 1 TB mirrored archive and tests of capacity, provider interruption, gap and duplicate detection, record retention, backup, and restore.

GND-3, GSTAT-2, and GCDH-2 are verified at a 25 kbps usable uplink rate by demonstrating CTL command entry, approval, SDLS protection, Leaf handoff, spacecraft execution, and command-history states. The test includes the 40-command, 15.7-second planning case from the uplink budget.

GND-4, GCDH-3, and GCDH-4 are verified by real-time pass processing, retrieval of state-of-health data older than 48 hours, generation of LOST and FOUND comparison packages, and delivery of representative science packages.

GCDH-5, GCDH-6, UNP12-92, and UNP12-93 are verified with F' SDLS vectors and end-to-end tests covering uplink and downlink protection, command acceptance, key loading, anti-replay behavior, authentication failure, and ground decryption. HuskySat-2 will submit the downlink approach and test results to UNP [TBD] for approval.

The GSTAT compatibility requirement, GSTAT-4, CAL2.4.1, and LIC-01 are verified by Leaf Space station data, spacecraft spectrum authorizations, released frequency settings, and required regulatory records. Licensed frequencies control operations.

UNP12-90 is verified by link analysis showing at least 6 dB uplink and downlink margin at a 10-degree elevation mask.

9. Development and Acceptance Plan

GDS acceptance has four stages:

1. Local verification: install the Linux server image, Yamcs, and MDB; generate XTCE; exercise telemetry, command, and SDLS vectors; and verify archive, backup, and replay.

2. Integrated flatsat test: connect Yamcs to the communications test article and verify CTL coverage, command encoding, SDLS, telemetry, events, error logs, files, and command responses.

3. Leaf Space compatibility test: use the issued mission account and approved REST and MQTT configuration to verify scheduling, acknowledgements, replay, duplicates, pass metadata, telemetry delivery, command handoff, and recovery.

4. End-to-end acceptance: use flight-equivalent hardware and released software to verify the 20.8 kbps downlink and 25 kbps uplink rates, SDLS, pass processing, retention, science delivery, links, backup, restore, and contingency recovery.

Flight operations begin only after the production hardware, software and metadata releases, Leaf interface, link budget, frequency authorization, accounts, backups, and operating procedures are under configuration control.

10. Configuration Management

The Working RVM is the authoritative requirements and verification matrix. Each GDS release contains the server image, Yamcs configuration, Leaf adapter, MDB overlay, generated XTCE, CTL, SDLS profile identifier, test vectors, and release manifest. The release manifest records the source revisions or hashes, deployment date, test result, backup/restore result, and approval status so an operator can reproduce or roll back the operational baseline.

Appendix A. Packetization, Commanding, and Data Views

The appendix summarizes the verified framing paths and identifies configuration inputs controlled by the F' topology, SDLS profile, communications ICD, Leaf Space documentation, Network Datasheet, and link budget. It does not define a separate packet specification.

Table A1. F′ / CCSDS telemetry and command data budget

Layer	Verified HuskySat-2 behavior	Configuration input	Ground handling
F' telemetry, events, and files	TlmPacketizer, EventManager, and FileDownlink send data to ComQueue.	Packet grouping, APIDs, rates, and file protocol.	Retain the protected record and decode released packets through XTCE/MDB.
CCSDS Space Packet	SpacePacketFramer encapsulates downlink data; SpacePacketDeframer extracts validated uplink data.	APIDs, sequence handling, packet length, and identifiers.	Validate only after SDLS verification and use released MDB definitions.
CCSDS TM and TC frames	ComAggregator and TmFramer form downlink TM frames; FrameAccumulator and TcDeframer process uplink TC frames. SDLS protects formed transfer frames before radio FEC.	SCID, VCID, frame length, FECF, idle pattern, and frame options.	Archive the protected frame, verify and decrypt SDLS, then deframe.
F' SDLS and Leaf delivery	HuskySat-2 applies SDLS. Leaf Space transports protected records and applies the validated radio and FEC configuration; it does not terminate mission SDLS.	Security association, SPI, cryptographic suite, key and anti-replay settings, EnduroSat profile, REST version and scopes, MQTT topics, and receipt metadata.	Archive provider metadata and protected bytes; block operational decoding after authentication failure.

Table A2. Yamcs command construction and verification path

Stage	Verified transformation	Configuration input	Evidence and operator state
Yamcs command UI	The operator selects a CTL command and enters MDB-typed arguments.	Arguments, constraints, and approvals.	Draft, queued, approved, current.

Stage	Verified transformation	Configuration input	Evidence and operator state
Command constructor	Builds the F' command payload and CCSDS TC representation.	Encoding, APID, sequence handling, and frame settings.	Encoding vector and flatsat test.
F' SDLS stage	Encrypts and authenticates the CCSDS TC frame before Leaf handoff.	Security association, SPI, key, IV, tag, and anti-replay settings.	Protected-frame vector and key-loading record.
Leaf handoff and spacecraft verification	The adapter submits the protected frame. Leaf applies radio and FEC settings; the spacecraft verifies SDLS, deframes, routes, and executes the command.	REST version, OAuth2 scopes, request format, acknowledgements, response, and completion signature.	Provider handoff; RF status when supplied; received, accepted, completed, failed, or unknown.

Table A3. Operational, engineering, and science data views

Audience or tool	Primary data	View or product	Authority and retention
Ground operators - Yamcs	Authenticated telemetry, events, alarms, packets, command history, and provider metadata.	State of health, pass status, alarms, and command verification.	Authoritative operational archive.
Engineering - Grafana	Decoded Yamcs parameters.	Read-only trends and state-of-health views beyond 48 hours.	No command or archival authority.
Science team	Authenticated exports, images, calibration records, and quality metadata.	Manifest, comparison CSV, images, and quality flags.	Raw sources are immutable; derived packages are versioned.
GDS incident review	Leaf audit data, protected records, SDLS results, and Yamcs history.	Gap, duplicate, replay, decryption, and anomaly reconstruction.	Retained with the mission archive.

11. References

YAMCS Mission Database: https://docs.yamcs.org/yamcs-server-manual/mdb/

YAMCS Data Links: https://docs.yamcs.org/yamcs-server-manual/links/

YAMCS Commanding: https://docs.yamcs.org/yamcs-server-manual/web-interface/commanding/

Evidence on file includes the Leaf Space Network Datasheet 2026 dated 22 April 2026, HuskySat-2 Link Budget downlink and uplink worksheets, and Leaf customer-portal integration and testing documentation. The portal lists EnduroSat S-Rx and S-Tx as integrated S-band radios, but requires confirmation with our EnduroSat Transceiver configuration for the GAIA100 3.7m station [TBR].