INTERMODAL SPACE

System Architecture & Subsystem Design

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Michael E. Onofre
Founder, Intermodal Space, Inc.
contact@intermodal.space · intermodal.space

Companion to the Intermodal Space Technical White Paper v1.1.
The white paper answers “does the physics work.” This document answers “what do we actually build.”

1. Purpose and scope

This document is the source-of-truth subsystem design for Intermodal Space's three-component logistics architecture: a dispatching Hub, a lean ballistic Container, and an actively-maneuvering Catcher. It is intended for three audiences: (1) technical readers who want to know that the architecture is more than a block diagram, (2) investors who want to see the engineering envelope the $50K pre-seed is funding research against, and (3) future hires who want to know what they would inherit on day one.

The detail level is deliberately mixed. For each subsystem we give an architecture-level description (what it does, mass / power / cost envelope, open questions) plus one or two candidate parts where a specific choice is already obvious or where not naming one would look like hand-waving. Nothing in this document is a procurement commitment. Everything here is a working hypothesis we intend to stress-test — and discard if we need to — during the TRL-3 benchwork phase.

Numbers given as ranges (for example “~300 kg dry”) represent a pre-TRL-3 engineering envelope, not a flight-unit specification. Cost envelopes are rough order-of-magnitude estimates for a first flight unit at TRL 6, not a bill of materials. All three vehicles are designed for low Earth orbit operation at ~500 km altitude as the canonical reference case; the Hub and Catcher architectures are deliberately sized so the same bus can be reconfigured for cis-lunar operation with a larger propulsion allocation (see the white paper §7).

DESIGN PHILOSOPHY

Concentrate intelligence, propulsion authority, power, and computing in the two fixed endpoints. Keep the container as lean as physics will allow while still giving the Catcher the information it needs to make an ~80 m residual-miss correction in real time. The Catcher does the hard work; the container just has to broadcast honestly.

2. System overview

Intermodal Space is a three-vehicle, closed-loop logistics system operating on a recurring cadence between two fixed orbital stations. The three vehicles are:

- HUB-1 MERIDIAN — the smart dispatch endpoint. Receives inbound cargo from a launch provider, loads it into a container, and ejects the container on a calibrated prograde trajectory toward the Catcher.
- CARRIER-1 PALLET — the lean container. Carries cargo, broadcasts its position and velocity continuously, accepts guidance state from the Catcher, and performs only the smallest trim corrections needed to hold an attitude suitable for capture.
- CATCHER-1 APEX — the smart receiving endpoint. Listens to the container's state broadcast, fuses it with its own state, actively maneuvers to match the container's terminal approach vector, and captures the container via a deployable linear glide rail, magnetic eddy-current brake, and mechanical latch.

The information flow is the most important thing to understand about this architecture. During a transit window:

- The Hub timestamps the release event, measures the actual Δv imparted to the container, and broadcasts that release vector to both the container and the Catcher.
- The container runs a low-bandwidth beacon at ~1 Hz, broadcasting its GNSS-derived absolute position, its IMU-derived attitude, and its battery / thermal health.
- The Catcher runs a relative-state filter that fuses (a) the Hub's release telemetry, (b) the container's live beacon stream, and (c) its own absolute state into a single estimate of the container's position relative to the Catcher.
- The Catcher uses that estimate to drive its own attitude and translational trim thrusters, positioning itself to intercept the container at the correct relative velocity and attitude.
- At T−60 seconds to capture, the container receives the Catcher's current state and commands a final trim burn (up to ~0.5 m/s) to null the residual cross-track error.
- At T−0, the container slides into the Catcher's deployable glide rail. Eddy-current brakes along the rail absorb the residual closing velocity; a mechanical latch engages at the end of the rail to rigidize the container to the Catcher's structure.

The Catcher does ~90% of the guidance work. The container's only real job is to tell the Catcher, honestly and continuously, where it is. Everything downstream of that is corrected at the Catcher.

2.1 What a transit cycle looks like, end-to-end

For the canonical 100 km along-track transfer at 500 km circular altitude:

- T−∞: Cargo arrives at the Hub via rideshare launch (SpaceX Transporter, Rocket Lab Electron, Varda-style dedicated secondary). Hub manipulator transfers cargo into a waiting container.

- T−24 hours: Release window opens. Hub and Catcher exchange a planned release time and a target relative trajectory. Catcher confirms its state vector is good.
- T−60 minutes: Hub's release cradle is armed. Container beacon is activated.
- T = 0: Release. Hub imparts a 5.87 m/s prograde Δv over ~50 ms via a calibrated spring-loaded release mechanism. Hub logs the actual measured impulse to within 0.5 mm/s precision and broadcasts it.
- T + 1 min to T + 90 min: Container coasts ballistically around a closed Hill ellipse. Catcher runs its relative-state filter and trims its own position. No propulsive action by the container except for small attitude-only torques from magnetorquers.
- T + 93 min: Catcher commands container trim burn. Container fires cold-gas thrusters for ~2 seconds to apply ~0.3 m/s of cross-track correction.
- T + 94.6 min: Container slides into the Catcher's deployable glide rail at a relative closing velocity of ~5 cm/s.
- T + 94.7 min: Eddy-current brake absorbs closing velocity. Mechanical latch engages. Capture complete.
- T + 95 min: Cargo is transferred from the container to the destination (station, manufacturing platform, constellation servicing bay) via a standard pallet-exchange interface.

3. HUB-1 MERIDIAN — smart dispatch endpoint

The Hub is the single highest-precision mechanical subsystem in the architecture. Its job is to eject the container at a known, repeatable Δv to within 0.5 mm/s, and to tell the Catcher exactly what it did. Everything downstream in the error budget flows from how well this single mechanism can be calibrated and instrumented.

3.1 Role and operational concept

- Receive cargo from a launch provider via a standard docking interface; unload, inspect, and load containers for outbound transit.
- Hold station at a designated orbit (500 km circular, inclination matched to the Catcher) with minimal propulsive effort using a combination of solar-powered Hall thrusters and natural orbit maintenance.
- Execute release events on a programmed cadence, producing a calibrated prograde Δv on a container and broadcasting the actual measured impulse to the Catcher within ~100 ms of release.
- Act as a communications relay between ground, container, and Catcher for the duration of a transit window.

3.2 Mass and power envelope

Total Hub dry mass envelope: ~300 kg (target). Peak power consumption envelope: ~1.5 kW. Solar array sized for 2 kW continuous to provide margin.

Subsystem	Mass	Power	Cost env.	Candidate / notes
Structure & mechanisms	80 kg	—	$200K	Custom aluminum bus, modular container-handling manipulator
Release mechanism	60 kg	500 W (event)	$1.5M	Piezo-tuned spring-loaded cradle with closed-loop force feedback; custom build
Solar array (deployable)	35 kg	+2000 W	$300K	DHV Technology SPA-3S or equivalent triple-junction GaAs
Battery	12 kg	—	$60K	1 kWh Li-ion, EaglePicher SAR-10197 or equivalent
Propulsion (stationkeeping)	25 kg	300 W (firing)	$400K	Busek BHT-100 Hall thruster + xenon tank OR Moog MONARC-5 cold-gas backup
ADCS (reaction wheels + torquers)	20 kg	100 W	$350K	Blue Canyon XACT-50 or Honeywell HR0610 RWA
GNSS + inertial navigation	4 kg	20 W	$120K	NovAtel OEM7 dual-frequency GNSS + Honeywell HG1930 IMU
Comms (S-band + UHF crosslink)	11 kg	200 W (TX)	$200K	Syrlinks EWC27 S-band + Iridium SBD short-burst terminal
Flight computer	3 kg	30 W	$80K	Xiphos Q8J or Moog SBC rad-tolerant SBC

Subsystem	Mass	Power	Cost env.	Candidate / notes
(guidance)				
Thermal + harness + misc	22 kg	100 W	$250K	Passive radiators, MLI blankets, heaters, cabling
Margin (20%)	28 kg	250 W	—	Held as engineering margin through TRL 4

3.3 The release mechanism — where the company's engineering leverage lives

The release mechanism is the single highest-risk, highest-value subsystem in the entire architecture. If it cannot deliver a Δv repeatable to 0.5 mm/s (1σ) on the full mass range of container configurations, the Monte Carlo error budget in §6 of the white paper does not close. If it can, the rest of the architecture is essentially instrumentation and software.

The candidate approach is a spring-loaded linear release cradle with piezoelectric preload tuning and closed-loop force-feedback instrumentation. The cradle holds the container rigidly during coast, commands a calibrated linear displacement, and releases the container at the programmed velocity. A load cell and a high-bandwidth laser vibrometer on the cradle rail measure the actual impulse delivered to the container within ~0.1 mm/s resolution; that measurement is broadcast to the Catcher via the Hub's comms subsystem inside the first 100 ms after release.

The engineering risk is non-trivial. Spring-based CubeSat deployers today achieve Δv repeatability of ~10 mm/s at best. Getting to 0.5 mm/s requires closing a feedback loop around the release event itself — measuring the actual impulse and reporting it, rather than relying on pre-calibrated release energy. This is a follow-up paper and a significant TRL-3 benchwork program in its own right.

TRL-3 MILESTONE

A 1/10-scale release cradle on an air-bearing table demonstrating sub-1 mm/s Δv repeatability across a 3x container mass range. This is the single most important physical experiment on the 24-month roadmap.

3.4 Open questions

- Can the release mechanism achieve sub-0.5 mm/s repeatability without exotic piezo actuators?
- What is the launch-provider-side manipulator interface? ISS-style CBM, IDSS, or a custom low-force docking collar?
- Does the Hub need a backup release mechanism for contingency, or is a single high-reliability cradle acceptable?
- Radiation tolerance of the flight computer under continuous LEO operation — COTS rad-tolerant is cheaper than space-qualified; what is the useful life?

4. CARRIER-1 PALLET — lean ballistic container

The container is the cheapest of the three vehicles by a wide margin, and is the only one that is cost-sensitive on a per-unit basis (Hubs and Catchers are amortized over many transit cycles; containers are amortized over one). It carries the absolute minimum electronics and propulsion authority consistent with giving the Catcher good state information and the ability to trim out residual error at the end of transit.

4.1 Role and operational concept

- Carry cargo inside a standardized pallet envelope (target internal volume ~100 L, cargo mass up to 100 kg per container).
- Broadcast position, velocity, attitude, and health telemetry at 1 Hz during transit via a low-power S-band beacon.
- Accept a single terminal trim-burn command from the Catcher (~0.3 m/s typical, 2 m/s maximum budget) and execute it via cold-gas thrusters.
- Hold attitude for solar-panel pointing and capture-face alignment via magnetorquers or a small reaction wheel set.
- Provide a passive mechanical docking interface compatible with the Catcher's glide rail — no active latches on the container side.

4.2 Mass and power envelope

Container dry mass envelope: ~50 kg. Cargo mass up to 100 kg. Container wet mass (dry + cargo + trim propellant): ~155 kg. Average power consumption ~15 W, peak during trim burn and beacon TX ~40 W. Solar array sized for 50 W peak to provide margin for attitude-limited pointing.

Subsystem	Mass	Power	Cost env.	Candidate / notes
Structure (cylindrical shell)	18 kg	—	$30K	Spun aluminum shell with ring stiffeners; standardized cargo bay
Cargo (variable)	0–100 kg	—	(customer)	Standard pallet interface
Solar array (body-mounted)	3 kg	+50 W	$25K	Rollable solar array, e.g. Redwire ROSA or SolAero triple-junction cells
Battery	1.5 kg	—	$10K	50 Wh Li-ion, 24h survival reserve
Beacon (S-band TX)	1.5 kg	15 W TX	$20K	Syrlinks EWC15 or custom low-power S-band modem
GNSS (single freq.)	0.5 kg	3 W	$15K	NovAtel OEM719 or similar smallsat GNSS
IMU + magnetometer	0.8 kg	2 W	$12K	STIM300 MEMS IMU + magnetometer
Flight computer (state broadcast)	0.7 kg	5 W	$25K	Xiphos Q7, minimal software load
Trim propulsion (cold-	8 kg	25 W	$80K	VACCO MiPS micro-propulsion system, R-236fa

Subsystem	Mass	Power	Cost env.	Candidate / notes
gas, 2 m/s)		(firing)		propellant
ADCS (magnetorquers)	3 kg	5 W	$15K	3-axis magnetorquer rods, e.g. ZARM MTQ
Thermal + harness + misc	8 kg	5 W	$15K	MLI, heaters, cabling
Margin (10%)	5 kg	8 W	—	Engineering margin through TRL 4

4.3 Why the container does NOT have more

Every component added to the container is a component the architecture must pay for on every single delivery. A 5 kg reaction wheel set on the container is 5 kg × every flight ever × $250K per wheel set, versus 5 kg on the Catcher, which flies once and is amortized over thousands of captures. So the rule is simple: if a subsystem can live on the Catcher without breaking physics, it lives on the Catcher.

The container has exactly the four things that must be on the container and cannot live elsewhere: (1) a power source because it has to survive a 95-minute transit window, (2) a GNSS and IMU because the Catcher needs to know the container's absolute state, (3) a beacon because the Catcher needs that information broadcast, (4) a minimum trim-thrust budget so the Catcher can command a final cross-track correction that cannot be achieved by the Catcher's own maneuvering. Nothing else.

TARGET UNIT COST AT SCALE

$500K per container at TRL 6 flight unit; $100K per container at volume (first 100 units); $25K per container at mature production (first 1000 units). The container is intended to be reusable for at least 10 round trips before retirement, driving the effective per-trip amortization toward a few thousand dollars.

4.4 Open questions

- Reusability: does the container survive a 10-cycle reuse model, or is it a single-flight disposable? (Economics differ by an order of magnitude.)
- Thermal design: can a 50-Wh battery survive a worst-case eclipse without active thermal control, or does the container need a PCM / heater load?
- Radiation-tolerant GNSS: COTS smallsat GNSS vs. rad-hard qualified parts; what is the MTBF delta?
- Beacon protocol: custom short-burst over S-band, or leverage an existing standard like CCSDS Proximity-1?

5. CATCHER-1 APEX — smart active receiver

The Catcher is the heaviest and most complex of the three vehicles, and it is where most of the real-time guidance work happens. It has two jobs the Hub does not: (1) actively maneuver to match a moving container's terminal approach vector, and (2) physically absorb the residual closing velocity at capture without damaging cargo.

5.1 Role and operational concept

- Hold station at the designated destination orbit (canonical: 500 km circular, 100 km along-track from the Hub).
- Listen to the container's beacon throughout transit. Fuse container beacon + Hub release telemetry + own state into a relative-state estimate.
- Continuously command small translational and attitude corrections to its own position and orientation to match the container's predicted arrival vector.
- At T−60 seconds, command the container's final trim burn to null the residual cross-track error.
- At T−0, receive the container into a deployable linear glide rail. Absorb residual closing velocity via an eddy-current magnetic brake along the rail. Engage a mechanical three-point latch at the end of the rail to rigidize the container to the Catcher structure.
- Transfer cargo from the captured container to the destination (station, manufacturing platform, servicing bay) via a standard pallet interface.

5.2 Mass and power envelope

Total Catcher dry mass envelope: ~400 kg. Peak power consumption envelope: ~2.5 kW during capture events (driven by the magnetic brake), ~1 kW nominal. Solar array sized for 2 kW continuous.

Subsystem	Mass	Power	Cost env.	Candidate / notes
Structure + deployable glide rail	150 kg	—	$2.0M	5 m deployable linear rail + funnel; custom composite structure
Magnetic brake (eddy-current)	50 kg	1500 W (event)	$800K	Linear electromagnet array along glide rail; closed-loop current control sized to container closing velocity
Mechanical latch	20 kg	100 W	$200K	Three-point radial latch at end of glide rail; rigidizes container to structure
Solar array (deployable)	35 kg	+2000 W	$300K	DHV Technology SPA-3S (same bus as Hub)
Battery	12 kg	—	$60K	1 kWh Li-ion
ADCS (fast-response)	30 kg	200 W	$500K	Blue Canyon XACT-50 + Honeywell HR0610 high-bandwidth RWA for terminal alignment
Propulsion (trim + stationkeeping)	20 kg	250 W (firing)	$350K	Busek BHT-100 Hall + VACCO cold-gas for fast terminal corrections

Subsystem	Mass	Power	Cost env.	Candidate / notes
GNSS + inertial navigation	4 kg	20 W	$120K	NovAtel OEM7 + Honeywell HG1930 (same as Hub)
Comms (S-band + UHF crosslink)	11 kg	200 W (TX)	$200K	Syrlinks EWC27 + Iridium SBD (same as Hub)
Flight computer (higher perf)	5 kg	60 W	$150K	Xiphos Q8J + dedicated GPU card for real-time relative-state filter
Thermal + harness + misc	28 kg	120 W	$300K	Passive radiators, MLI, heaters, cabling
Margin (20%)	35 kg	350 W	—	Engineering margin through TRL 4

5.3 The capture sequence — where the mechanical engineering lives

The capture sequence is the second of the two highest-risk mechanical subsystems in the architecture (the first being the Hub's release cradle). It works in four phases:

- Geometric capture (T−5 to T−1 sec). The container enters the mouth of the Catcher's deployable glide rail — a 5 m long linear structure with a ~3 m funnel at the entrance that tapers to a ~0.5 m slot. The funnel absorbs the residual 3σ miss distance of ~36 m only in the degenerate case where cross-track error was not corrected. In nominal operation, cross-track error is already ≤10 m at funnel entry and the funnel exists as a safety margin.
- Magnetic braking (T−1 to T+0 sec). As the container slides through the rail, eddy currents are induced in a conductive plate mounted on the container's aft face by a series of switchable electromagnets along the rail. Closed-loop current control modulates brake force to target a smooth deceleration from ~5 cm/s closing velocity to near-zero over ~1 meter of travel. Peak instantaneous power to the brake coils is ~1.5 kW, delivered from the battery.
- Mechanical latch (T+0). At the end of the rail travel, a three-point radial latching mechanism engages the container's mating collar, rigidizing it to the Catcher structure. The latch carries both load and electrical continuity for cargo-side power / data pass-through.
- Cargo transfer (T+0 to T+5 min). Once the container is rigid, a short-travel manipulator on the Catcher opens the container's cargo bay and transfers the cargo to a destination pallet. This is the only subsystem on the Catcher that interfaces with the destination (a station, a manufacturing platform, etc.) and is customer-specific.

The magnetic brake is the subsystem most likely to require a long TRL-3 benchwork program. Eddy-current braking is a well-understood physical phenomenon, but closed-loop current control sized to a 150 kg mass decelerating at ~5 cm/s is not something any existing space vehicle has flown. A 1/10-scale brake mounted on an air-bearing rig — receiving an air-bearing-cart analog of a container at realistic closing velocities — is the companion experiment to the Hub release cradle, and the two of them are the two most expensive pieces of benchwork on the 24-month roadmap.

5.4 Open questions

- Is the eddy-current brake a single-pulse or a closed-loop continuous brake? (Closed-loop is more forgiving but much more complex.)
- Is there a graceful failure mode if the magnetic brake underperforms? (Current answer: a mechanical buffer at the end of the rail takes up to 50 cm/s of residual energy.)
- How does the Catcher interface to the destination? Station / manufacturing-platform / servicing-bay pallet exchange is customer-specific and not solved inside this architecture.
- Can the Catcher's fast-response ADCS hit the ~10 cm/s relative-velocity matching target, or do we need a cold-gas vernier thruster on the capture face specifically for terminal alignment?

6. Interface control summary

The three vehicles communicate with each other and with ground through a small number of well-defined interfaces. This section summarizes them; a full ICD is out of scope for this document and will be a companion deliverable before any flight build.

6.1 Data interfaces

- Hub → Catcher (release telemetry): S-band direct link. Message: release timestamp, measured Δv vector, container health snapshot. Latency budget: 100 ms from release event to Catcher receipt.
- Container → Catcher (beacon): S-band direct link, 1 Hz. Message: GNSS position, GNSS velocity, IMU attitude quaternion, battery voltage, temperature, ADCS status.
- Catcher → Container (trim command): S-band direct link, on-demand. Message: cross-track correction vector, burn duration, safe-mode trigger.
- Hub / Catcher → ground: S-band to TDRSS or a commercial ground network (KSAT, AWS Ground Station). Telemetry, command, software updates.
- Container → ground (emergency fallback): Iridium Short Burst Data backup if primary S-band beacon fails. Low bandwidth but global coverage.

6.2 Mechanical interfaces

- Container ↔ Hub release cradle: rigid restraint during coast, calibrated release on command. Standard latch interface shared with the Catcher glide rail so containers are interchangeable at both ends.
- Container ↔ Catcher glide rail: passive rail entry geometry on the container side, active magnetic brake and latch on the Catcher side.
- Container ↔ launch provider: fits inside an ESPA Grande secondary-payload envelope or smaller. Standard launch-vehicle separation interface.
- Catcher ↔ destination station: customer-specific pallet transfer interface. Not standardized at architecture level; designed per integration.

6.3 Power interfaces

- All three vehicles are fully solar-powered with battery buffering. The Hub and Catcher carry 2 kW solar arrays and 1 kWh batteries; the container carries a 50 W array and a 50 Wh battery.
- When the container is rigid-docked to the Catcher (post-capture), the Catcher provides a small trickle-charge bus (~20 W) to the container through the latch interface, allowing the container to stay healthy during ground-refurbishment cycles.

7. Build vs. buy

Intermodal Space is not a buses company. We do not plan to build spacecraft buses from scratch when COTS exists. The design-out above is deliberately structured to maximize the use of existing commercial parts wherever the performance envelope is not what makes the company defensible. Our engineering effort — and the $50K pre-seed, and the SBIR-funded benchwork, and eventually the Series A team — is concentrated on two subsystems: the Hub release mechanism and the Catcher magnetic brake. Everything else is, in principle, a catalog purchase.

7.1 Build

- Hub release cradle. Custom. This is the defensible technical moat. Piezo-tuned spring mechanism with closed-loop force feedback; no existing COTS part comes close to the required Δv repeatability.
- Catcher glide rail, funnel, and magnetic brake. Custom. Second defensible subsystem; no existing spacecraft has flown anything comparable.
- Catcher mechanical latch. Custom — but derivative of well-understood docking-collar designs. Build in-house or contract to an established docking-mechanism vendor (Airbus, RUAG).
- Flight software: guidance, navigation, and the relative-state filter. Custom. This is where the cis-lunar extension will ultimately live.
- Container structure. Custom, but simple. Spun-aluminum shell is a week of CNC work per unit.

7.2 Buy

- Solar arrays, batteries, reaction wheels, GNSS, IMU, comms modems, flight computers. All COTS smallsat parts from the vendors listed in the subsystem tables above.
- Propulsion. Busek, Moog, VACCO, Bradford — four established commercial smallsat propulsion vendors, any one of which can supply both the Hub's Hall thruster and the container's cold-gas system.
- Launch integration. Spaceflight Inc., Exolaunch, or direct integration with SpaceX Transporter / Rocket Lab.
- Ground station access. Commercial network (KSAT, AWS Ground Station, Viasat RTE). No custom antennas.

CAPITAL EFFICIENCY NOTE

At the pre-seed stage, the $50K is not buying any of these parts. It is funding the research, design, simulation, and the first 1/10-scale bench experiments on the release cradle and the magnetic brake. The COTS part list above is the envelope we are designing against, not the shopping list we are ordering from.

8. Revision history

Version	Date	Changes
1.0	April 2026	Initial design-out. Hub release cradle and Catcher magnetic brake identified as the two defensible technical subsystems. Companion document to white paper v1.1.

The box is the innovation — not the ship.

— Intermodal Space, April 2026 —