



TWO-VEHICLE SYSTEM · CONCEPT BRIEF · REV B

# SCAVENGER

## + SPARROW

A trash can in orbit. A drone that fills it.

A passive orbital storage bin served by a fleet of small, reusable retrieval drones. The dangerous work happens on the small, replaceable drone — the big, expensive asset never approaches a tumbling target.

12

SATELLITES PER MISSION

\$7.7M

COST PER OBJECT

25

SORTIES PER SPARROW

17x

CHEAPER THAN CLEARSPACE-1

01 · EXECUTIVE SUMMARY

# Separate the chasing from the hauling.

Existing Active Debris Removal architectures try to do everything in one bus — propulsion, rendezvous, capture, storage, and deorbit. Each subsystem drives up mass, complexity, and cost, and a failure in any one of them strands the entire \$130M asset. ClearSpace-1, ADRAS-J, and ELSA-d have all flown or are funded as single-target, single-bus missions.

Waypoint's second-generation architecture splits the job in two. SCAVENGER is a passive orbital trash can — a 9.4 m cylindrical bay with twelve self-latching dockports, station-keeping thrusters, and a one-shot chemical deorbit engine. It does not chase anything and does not grapple anything. SPARROW is the active half — a fridge-sized, reusable drone that runs down targets, captures them, and ferries them back to SCAVENGER's open bay. SPARROWS refuel at the depot and fly again, completing ~25 sorties per drone before retirement.

The result: 12 satellites removed per mission at approximately \$7.7M per object — a 17x reduction over single-target missions of the current generation.

12	\$7.7M	25	17x
SATELLITES / MISSION	COST / OBJECT	SORTIES / SPARROW	VS CLEARSPACE-1

02 · TWO VEHICLES, ONE JOB

## A depot and its workboats.

SCAVENGER and SPARROW are designed around each other. SCAVENGER's standardized dockports accept any SPARROW carrier cassette. SPARROW carries no propellant or storage beyond a single sortie. Neither vehicle makes sense without the other.

VEHICLE	ROLE	WHAT IT DOES	WHAT IT DOES NOT DO
<b>SCAVENGER</b>	Passive storage depot	Holds 12 captured satellites. Station-keeps. Single deorbit burn at EOM.	No chasing. No grappling. Never approaches a target.
<b>SPARROW</b>	Active retrieval drone	Departs depot, captures target, ferries it back, docks cassette. Refuels and repeats.	No deorbit. No interplane transfers. Returns home between sorties.

The key insight: the dangerous, complex work (proximity ops with uncooperative tumbling debris) happens on the small, cheap, reusable drone. The big, expensive asset stays in a stable orbit and only does two things well: hold satellites, and deorbit cleanly.

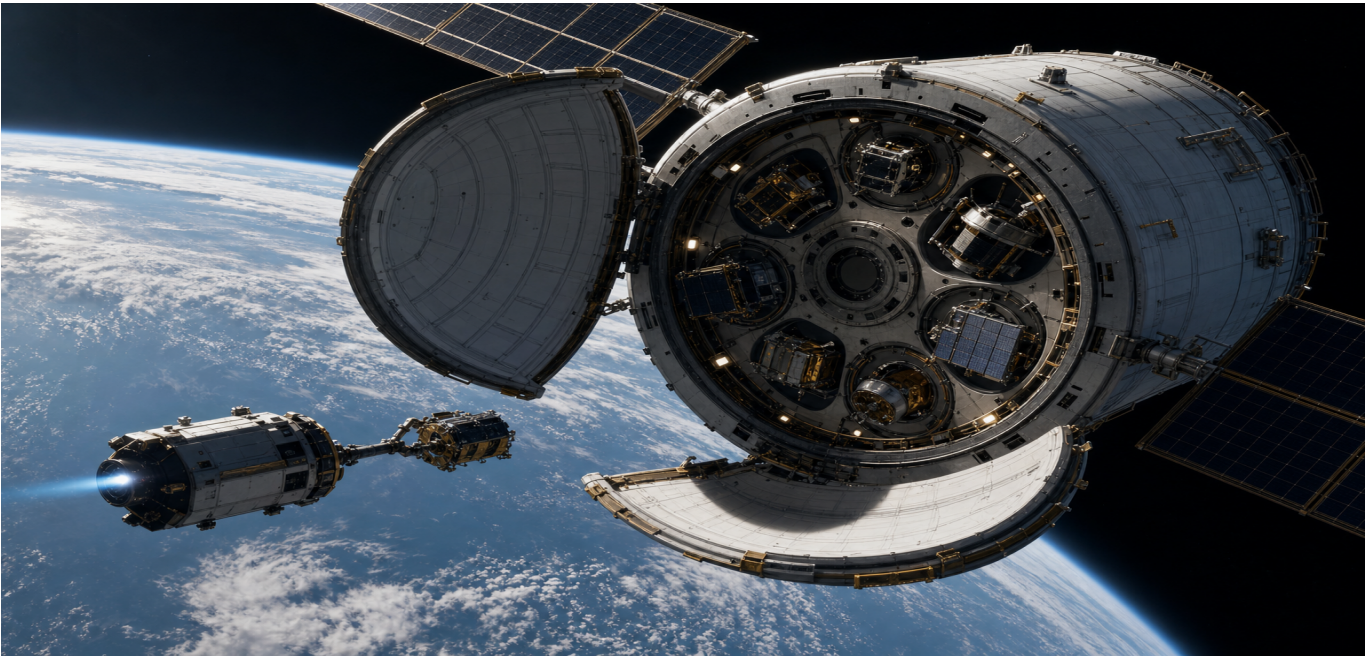


FIG. 01 SCAVENGER with its receiving bay open (right). SPARROW approaching with a captured satellite secured to its carrier cassette (foreground left). The carousel of 12 dockports rotates to present the next available slot.

## 03 · SCAVENGER – THE BIN

## Stripped down to its essence.

Removing every capture mechanism, every rendezvous sensor, every Hall thruster, and every kilogram of Xenon from SCAVENGER frees mass, volume, and budget for what it actually does well: holding things and deorbiting cleanly. The bus is simpler, the bay is larger, the dry mass is ~30% lower than an equivalent single-vehicle scow.

### Storage bay ("The Hold")

Open-front cylindrical bay, 8.5 m x 4.0 m diameter. Twelve standardized dockports arranged in a 3-ring carousel (4 ports per ring). Each port accepts a SPARROW Carrier Cassette pre-loaded with a captured satellite. Active CG-trim via propellant transfer between RCS tanks keeps the loaded stack balanced. Clamshell doors close between dockings to reduce drag.

### Propulsion (single-purpose)

Chemical only. 4x 220 N MMH/NTO bipropellant thrusters for primary maneuvers and the final deorbit kick. 16x 22 N RCS for attitude. No Hall thrusters, no Xenon tanks, no electric propulsion infrastructure. Total delta-v budget is ~700 m/s — enough for 36 months of station-keeping and drag makeup plus a single 300 m/s deorbit burn.

WET MASS	~5,200 kg
DRY MASS	~3,400 kg
LENGTH	9.4 m
BAY DIAMETER	4.0 m
SOLAR ARRAY SPAN	12 m
POWER BOL	~6 kW
DOCKPORT COUNT	12 (3-ring carousel)
PROPELLANT	~1,800 kg MMH/NTO
TOTAL DELTA-V	~700 m/s
DESIGN LIFE	36 months on-orbit



FIG. 02 Forward view into the SCAVENGER receiving bay – 12 standardized dockports in a 3-ring carousel around a central hub. Each port accepts a SPARROW Carrier Cassette pre-loaded with a captured satellite. Several ports are shown already loaded; remaining slots await delivery.

## 04 · SPARROW – THE FETCHER

## Small, agile, replaceable.

SPARROW is built around the assumption that catching tumbling debris is hard and sometimes a vehicle will be lost trying. That assumption changes everything: instead of putting your only avionics, your only Hall thruster, and your only capture suite on a \$130M bus, you put them on a 480 kg drone that costs \$7M to replace.

A SPARROW departs the SCAVENGER depot with an empty carrier cassette mounted on its forward face. The cassette is a standardized cradle that the captured satellite gets mechanically secured into during de-tumble. On return, SPARROW pushes the cassette into an open SCAVENGER dockport, the cassette latches, and SPARROW backs away clean — ready to receive a fresh cassette at its service port for the next sortie.

### Capture suite ("The Beak")

Tri-modal capture, mode selected per target. **3-DOF capture arm** with universal soft-jaw end effector (2.5 m reach) for cooperative targets. **Single-shot net cartridge** (5 m diameter, swapped at dock) for tumbling unprepared satellites. **Tethered electrostatic grapple** for cubesats and small fragments. Forward LiDAR and monocular vision package handles tumble characterization at close range.

### Propulsion (agile, modest range)

1x Busek BHT-1500 Hall thruster<sup>[1]</sup> for primary transfers between SCAVENGER and target (1.5 kW, 1,820 s Isp, 89 mN). 8x 22 N MMH/NTO RCS for proximity ops and capture maneuvers. Refuels at SCAVENGER's service port between sorties — ~40 kg Xenon and ~30 kg bipropellant per refuel. Per-sortie delta-v of ~280 m/s is sufficient for targets within  $\pm 50$  km altitude and  $\pm 2^\circ$  inclination of the depot orbit.

WET MASS	~480 kg
DRY MASS	~280 kg
LENGTH	2.1 m
HALL THRUSTER	Busek BHT-1500
ISP	1,820 s
THRUST	89 mN
RCS	8x 22 N MMH/NTO
PER-SORTIE DELTA-V	~280 m/s
REUSES	~25 sorties per drone
FLEET	2-3 SPARROWS per SCAVENGER



FIG. 03 SPARROW retrieval drone – gold MLI-wrapped bus, two deployable solar wings, single Hall thruster aft, 3-DOF capture arm forward holding a captured defunct cubesat. The arm grips standardized launch adapter rings on cooperative targets; net cartridge mounts on the forward face for tumbling debris.

## 05 · MISSION CONOPS

## One launch. Many sorties. One reentry.

A complete SCAVENGER + 2-SPARROW system fits one medium-lift co-manifest launch. The system fills the depot bay over ~6-8 months of parallel SPARROW operations, then deorbits as a complete stack.

T+0	<p><b>Launch &amp; commissioning</b> SCAVENGER + 2x SPARROW co-manifest to 750 km SSO depot orbit. Deploy arrays, verify dockport functionality, test SPARROW undock/redock autonomy. 30 days.</p>
T+30d	<p><b>First SPARROW sortie</b> SPARROW-1 undocks with empty carrier cassette, Hall-thrusts to first queued target (12 hours to 6 days). SPARROW-2 prepares parallel sortie to a second target.</p>
x12	<p><b>Sortie loop</b> Each sortie: rendezvous, characterize tumble, capture (arm / net / grapple), de-tumble, secure to cassette, return transfer, dock cassette into SCAVENGER, RTB for refuel and net-cartridge swap. 24-48 h of servicing between sorties.</p>
T+8mo	<p><b>Bin fills</b> All 12 SCAVENGER bays loaded. Mission planners may extend with a 13th nearby high-value target, or proceed to disposal. SPARROW fleet stows at service ports.</p>
T+9mo	<p><b>Optional SPARROW transfer</b> Surviving SPARROW drones may transfer to the next SCAVENGER on station (Program ADR-003) if one is in a nearby orbit. Drones reused across SCAVENGER missions.</p>
EOM	<p><b>Controlled deorbit</b> SCAVENGER fires 300 m/s chemical deorbit burn. Targeted reentry over the South Pacific Ocean Uninhabited Area. SCAVENGER and all 12 cassettes burn up together.</p>

## 06 · ECONOMICS

## Splitting the bus splits the cost.

PER-SYSTEM COST		PER-OBJECT ECONOMICS	
LAUNCH (3 VEHICLES CO-MANIFEST)	\$22M	TARGETS REMOVED PER MISSION	12
SCAVENGER BUS & INTEGRATION	\$32M	COST PER OBJECT – WAYPOINT	\$7.7M
SPARROW (X 2)	\$14M	COST PER OBJECT – CLEARSPACE-1 CLASS	\$130M+
PROPELLANT (SYSTEM)	\$5M	REDUCTION FACTOR	~17x
MISSION OPERATIONS (~9 MONTHS)	\$12M	TARGETS PER \$1B DEPLOYED	~130
RESERVES & CONTINGENCY	\$7M		
TOTAL PER SYSTEM	\$92M		

### Where the savings come from

**SCAVENGER simplification.** No capture hardware, no Hall thrusters, no Xenon. Dry mass drops ~30% versus a single-vehicle scow. Bay volume increases — fits 12 cassettes instead of 8 in-bus storage.

**SPARROW small-and-cheap.** All the expensive precision avionics live on a small, replaceable drone. Per-unit cost is a fraction of a full ADR vehicle.

**Drone reuse.** Each SPARROW completes ~25 sorties before retirement. The capture suite amortizes across hundreds of captures over its operational life.

**Risk asymmetry.** A lost SPARROW costs \$7M. A lost full ADR vehicle costs \$130M+. Two-drone redundancy lets missions complete through individual capture failures.

## 07 · KEY RISKS &amp; MITIGATIONS

## What we're worried about.

RISK	DESCRIPTION	MITIGATION
<b>SPARROW lost during capture</b>	Tumbling-debris capture is risky. A SPARROW may be damaged mid-sortie.	Two-drone redundancy. SCAVENGER can complete partial mission with single surviving SPARROW. Lost SPARROW costs \$7M, not \$130M.
<b>Cassette dock failure on return</b>	SPARROW pushing a cassette into a SCAVENGER dockport must align precisely.	Soft-capture dock with auto-realign tolerances of $\pm 5$ cm and $\pm 2^\circ$ . Backup berthing port for one-shot fallback dockings.
<b>SCAVENGER bay CG imbalance</b>	Mass distribution shifts as cassettes load — affects deorbit-burn vectoring.	Propellant transfer between RCS tanks for trim. Dock-assignment optimizer routes cassettes to slots based on real-time CG balance.
<b>Re-contact during deorbit burn</b>	The 300 m/s chemical deorbit burn could shift loosely-stowed cassettes.	All 12 cassettes mechanically latched and pinned to their dockports. Stack verified rigid via load-cell handshake before burn arming.

## 08 · PROGRAM STATUS

SCAVENGER + SPARROW is a concept-stage study developed by Waypoint Dynamics as the second-generation architecture of our active debris removal program (designation ADR-002). It builds on lessons from ClearSpace-1<sup>[2]</sup>, ADRAS-J<sup>[3]</sup>, and ELSA-d, and extends them with a two-vehicle division of labor that decouples the high-risk capture function from the high-value storage and disposal function. We are sharing it openly to invite technical review, partnership discussion, and customer interest from ESA Zero Debris Charter signatories, FCC-regulated operators subject to the 5-year deorbit rule, megaconstellation operators paying remediation fees, and insurance underwriters offsetting orbital collision liability.

## SOURCES

- [1] Busek BHT-1500 Hall thruster performance overview. <https://www.busek.com/bht1500>
- [2] ESA ClearSpace-1 mission overview, Space Safety Programme. [https://www.esa.int/Space\\_Safety/ClearSpace-1](https://www.esa.int/Space_Safety/ClearSpace-1)
- [3] Astroscale ADRAS-J debris inspection mission. <https://www.astroscale.com/en/missions/adras-j>

## 09 · SPARROW DEPOT

# A propellant station for the fleet.

Refueling is the third element of the architecture. SPARROW carries enough propellant for one sortie. SCAVENGER carries none for its visitors. The Sparrow Depot — a 1,200 kg co-orbiting propellant station — sits next to the SCAVENGER and refills every SPARROW that comes home empty. With the depot in the architecture, SPARROW's mission count is bound by avionics wear, not tank size.



FIG. 04 Sparrow Depot — cylindrical MLI-wrapped trunk with composite-overwrapped krypton tank and diaphragm-isolated green-mono tank. Four-panel solar array, RAFTI-class docking face forward.

WET MASS	PROPELLANT	INTERFACE	REFUELS / FILL
<b>~1,200 kg</b> 4.0 m overall length	<b>600 kg Kr</b> + 200 kg green-mono	<b>RAFTI-class</b> 1 Kr + 3 GM ports	<b>~5 sorties</b> per SPARROW

## Why a depot, and not just bigger SPARROWS.

A bigger SPARROW means a bigger Hall thruster, bigger tanks, more avionics mass — and a more expensive replacement when the inevitable capture failure happens. The depot pushes propellant mass off the disposable drone and into a shared, refillable, mostly-passive asset that several SPARROWS use over and over. Each SPARROW becomes smaller, cheaper, and faster to launch; the depot pays for itself across the captures it enables. It is also servicer-agnostic — the RAFTI fluid coupling is the emerging industry standard, and any third-party operator that builds to it can pay to refuel here.

## 10 · THE THREE-VEHICLE ARCHITECTURE

# Capture, store, refuel.

With the Sparrow Depot in place, the architecture resolves into three vehicles, each doing one thing well. The dangerous work stays on the small drone. The expensive disposal asset never moves. The propellant infrastructure is shared and refillable. Each can be launched, replaced, and operated independently — and each can serve more than one mission.

VEHICLE	ROLE	WHAT IT DOES	WHAT IT DOES NOT DO
<b>SPARROW</b>	Active retrieval drone	Departs depot, captures target with arm / net / grapple, ferries cassette home, docks at SCAVENGER, refuels at Sparrow Depot, sorties again.	No deorbit. No interplane transfers. Returns home between sorties.
<b>SCAVENGER</b>	Passive storage depot	Holds 12 captured satellites in standardized dockports. Station-keeps. Single chemical deorbit burn at EOM.	No chasing. No grappling. Never approaches a target. Does not carry propellant for SPARROW.
<b>SPARROW DEPOT</b>	Propellant station	Holds ~600 kg Kr + ~200 kg green-mono. RAFTI fluid coupling, four GaAs panels, self station-keeping. Refills every visiting SPARROW.	No capture, no rendezvous with debris. Vehicle-agnostic — accepts any RAFTI-compatible servicer.

## The SPARROW sortie loop, with depot integration.

- 01 DEPART** SPARROW undocks from Sparrow Depot service port with full Kr + green-mono tanks and an empty carrier cassette.
- 02 CHASE** Hall-thrusts to target (12 h to 6 days). Vision-based pose lock. Capture with arm, net, or electrostatic grapple.
- 03 RETURN** Hauls captured satellite secured in cassette back to SCAVENGER. Docks cassette into next available dockport. Cassette latches; SPARROW backs away clean.
- 04 REFUEL** SPARROW transfers to Sparrow Depot, mates the RAFTI port: 1 Kr line + 3 green-mono lines + electrical handshake. ~40 kg Xe and ~30 kg green-mono unloaded. Net-cartridge swap optional.
- 05 REPEAT** SPARROW undocks fully fueled. Next target queued. Loop repeats ~25 times per drone — 50–75 with depot reuse across SCAVENGER missions.

## 11 · DEPOT IMPACT ON ECONOMICS

# Why the depot pays for itself.

Adding the Sparrow Depot to the ADR-002 architecture is a one-time capital cost that improves the unit economics of every SPARROW sortie that follows. The depot is small relative to a SCAVENGER bus, shares its rideshare slot or co-manifests with the next SCAVENGER launch, and amortizes across every captured object the system enables over its 3–5 year life.

## DEPOT CAPITAL & LIFECYCLE COST

Depot bus build	\$55–80 M
First-fill propellant	\$8–12 M
Launch (rideshare)	\$10–18 M
Ground ops (3 yr)	\$6–9 M
Tanker refill / visit	\$12–18 M
<b>Program total, depot life</b>	<b>~\$80–120 M</b>

## FLEET-SCALE BENEFITS

### SORTIES PER SPARROW

**~25 » 50–75**

across design life

### SPARROW WET MASS

**~480 » ~350 kg**

smaller bus, cheaper ride

### PER-MISSION COST FLOOR

**\$15–20M » \$4–6M**

3–4× improvement

### RESPONSE TIME

**months » days**

no return-to-launch cycle

### FLEET LEVERAGE

**1 depot : N SPARROWS**

shared infrastructure

## What the numbers mean in practice.

A single Sparrow Depot supports roughly 25 SPARROW missions over its 3–5 year life. Spread across that traffic, the depot adds about \$3–5M to the cost of each sortie — but it lets SPARROW carry half the propellant onboard at launch, so SPARROW's own per-unit cost drops by a comparable amount. The net effect on captures-per-object is a 3–4× unit-economics improvement at fleet scale: the per-object cost falls from ~\$7.7M (ADR-002 v1) toward \$2–3M in the depot-coupled configuration.

Just as important: the depot decouples response time from launch cadence. Without it, a SPARROW that runs dry chasing a fragmenting object has to wait for the next SCAVENGER rideshare. With it, the SPARROW is back in the chase within days — the difference between catching a fragmenting object and chasing its cloud.

Phasing. Phase 1 (2026–2029): ship SCAVENGER + 2× SPARROW standalone. Demonstrate capture, dock, deorbit. Phase 2 (2030+): launch the Sparrow Depot once SPARROW service has demand and RAFTI is the industry standard. Open the RAFTI interface to other operators as infrastructure-as-a-service.

HERITAGE · Orbit Fab RAFTI · DARPA Orbital Express (2007) · Northrop MEV-1 / MEV-2 · Astroscale APS-R.