

# The Griffiths Free-Flying EVA Logistics Sled (NGLS)

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**Abstract:** As deep-space habitats, propulsion modules, and distributed construction platforms grow in scale and operational complexity, existing EVA mobility systems are no longer adequate to meet the increasing logistical demands on human crews. Conventional astronaut maneuvering units, such as SAFER and the historical MMU, were primarily designed for personal mobility and emergency self-rescue, rather than for transporting heavy equipment, structural components, or modular payloads across expansive spacecraft and habitat exteriors. The Griffiths Free-Flying EVA Logistics Sled (NGLS) addresses this critical gap by introducing a dedicated logistics-focused EVA architecture. It features dual high-pressure cold-gas propellant tanks, vectorable thruster assemblies, full six-degree-of-freedom control, autonomous stabilization, and modular cargo interfaces integrated into a lightweight composite frame. Designed for both piloted and autonomous operation, the system incorporates multiple redundant safety mechanisms, including fail-closed valves, dead-man stabilization, collision-avoidance sensors, and autonomous return-to-base capability, ensuring safe operation in proximity to complex, rotating, or thermally active structures. Performance modelling indicates that the NGLS can achieve an operational  $\Delta v$  of 50–150 m/s, transport payloads of 50–200 kg, and sustain sortie durations of 10–45 minutes, enabling logistics operations that extend well beyond the physiological limits of a suited astronaut. Furthermore, the architecture integrates seamlessly within the broader Griffiths ecosystem, supporting external maintenance of the Dual-Ring Habitat, inspection of propulsion modules such as the GNMT-Drive and MSH-Drive, and last-mile delivery of DIMDCP-fabricated components. Overall, the NGLS represents a practical, manufacturable, near-term solution that formalizes EVA logistics as a distinct and essential operational domain.

## Table of Contents

1. Introduction.....	1
2. Executive Summary .....	2
3. Key Metrics.....	3
4. System Architecture .....	3
5. Evalogistics Doctrine and Canon Integration .....	4
6. Propulsive Dynamics, Control Laws and Stability Envelope .....	5
7. Governing Equations .....	6
8. Comparative Analysis.....	7
9. Mission Integration and Operational Doctrine.....	8
10. Failure Modes, Predictive Diagnostics and Contingency Protocols .....	9
11. Narrative Signals, Canonical Resonance and Symbolics Motifs.....	10
12. Future Research Pathways and Expansion Opportunities .....	11
13. Conclusion .....	11
14. References.....	12
15. Conflict of Interest.....	12
16. Funding .....	12

## 1. Introduction

Human spaceflight beyond low Earth orbit demands more than capable habitats and propulsion systems, it demands the logistical infrastructure to operate and maintain them. As deep-space vessels and habitats grow in scale, their exterior surfaces become vast, complex, and operationally critical environments: radiator arrays require periodic inspection, propulsion modules demand access during cooldown phases, and fabricated structural components must be delivered and installed across geometries that no robotic arm can fully reach. Meeting this demand requires a dedicated logistics capability that existing EVA systems were never designed to provide. Traditional astronaut maneuvering units, the Manned Maneuvering Unit (MMU) and its successor SAFER were designed around a single operational premise: keeping the astronaut alive and returning them to the vehicle. They are personal mobility devices, optimized for body transport and self-rescue, not for the sustained, precision movement of heavy equipment across large structures. The mass-handling limits of a suited astronaut in microgravity, the absence of autonomous stabilization, and the lack of modular cargo interfaces mean that complex external logistics tasks either require multiple EVA sorties, tethering operations of impractical complexity, or robotic arm intervention that is itself constrained by reach and mounting location. The Griffiths Free-Flying EVA Logistics Sled (NGLS) is the answer to this structural gap. Conceived as a formal logistics-layer architecture within the Griffiths Canon, the NGLS is purpose-built to move mass, not just astronauts through the exterior environments of

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deep-space habitats and vessels. It combines dual high-pressure cold-gas propulsion, full six-degree-of-freedom control authority, autonomous stabilization, and modular cargo interfaces in a lightweight composite frame engineered for both piloted and unmanned operation. This document presents the complete system architecture of the NGLS: its propulsion and control subsystems, governing dynamics, safety and redundancy framework, integration with the broader Griffiths Canon, and forward research pathways. The work is positioned not as speculative design but as a practical, manufacturable, near-term architecture grounded in proven technologies and structured for incremental development and eventual deployment.

## 2. Executive Summary

Large deep-space habitats, propulsion modules, and distributed construction platforms demand a new class of EVA mobility system one capable of transporting heavy tools, modular components, and structural elements across complex external geometries. Traditional astronaut maneuvering units such as SAFER and the historical MMU were never designed for logistics; they support personal mobility and self-rescue, not the sustained movement of mass around large rotating or thermally active spacecraft. The Griffiths Free-Flying EVA Logistics Sled (NGLS) fills this gap by establishing a dedicated logistics-layer EVA architecture within the Griffiths Canon. The sled combines dual high-pressure cold-gas propellant tanks, vectorable thruster assemblies, six-degree-of-freedom control authority, autonomous stabilization, and modular cargo interfaces into a lightweight composite frame engineered for both piloted and unmanned operation. Its safety envelope includes fail-closed valves, redundant thruster pathways, dead-man stabilization, collision-avoidance sensors, and autonomous return-to-base capability, enabling safe operation even in cluttered or dynamic environments.

With an operational  $\Delta v$  of 50–150 m/s, payload capacity of 50–200 kg, and sortie durations of 10–45 minutes, the NGLS dramatically expands what EVA crews can accomplish. It reduces astronaut fatigue, shortens maintenance timelines, and enables logistics tasks that would otherwise require robotic arms, multiple EVA sorties, or complex tethering operations. The sled integrates seamlessly with the broader Griffiths Canon, servicing the Dual-Ring Habitat exterior, supporting GNMT-Drive and MSH-Drive inspection and maintenance, acting as the last-mile carrier for DIMDCP-fabricated components, and enabling distributed maintenance across multi-module deep-space vessels.





### 3. Key Metrics

#### 3.1 Mass and Structural Metrics

- Total wet mass: 55–65 kg
- Total dry mass: 25–35 kg
- Propellant mass: 30 kg (compressed nitrogen)
- Structural materials: carbon-fiber composite frame, titanium joints, Al-Li secondary brackets
- Payload capacity: 50–200 kg
- Cargo interface standards: ISS-style handrails, EVA latches, modular racks, quick-release clamps

#### 3.2 Propulsive Performance

- Specific impulse: 65–75 s
- Exhaust velocity: ~700 m/s
- Total impulse: ~21,000 N·s
- Operational  $\Delta v$ : 50–150 m/s
- Theoretical  $\Delta v$ : ~350 m/s
- Thrust (per nozzle): 0.2–1.2 N
- Total thrust: 2–6 N
- Rotational authority: 0.1–0.5 N·m

#### 3.3 Control and Stabilization Metrics

- Degrees of freedom: full 6-DOF translation and rotation
- Control modes: manual, assisted, autonomous, teleoperation
- Stabilization: triple-redundant IMUs, PID loops, drift correction, vibration damping
- Autonomous functions: position hold, collision avoidance, return-to-base, assisted docking
- Sensor suite: LIDAR, stereo cameras, ultrasonic proximity sensors

#### 3.4 Power and Endurance

- Battery capacity: 150–300 Wh
- Avionics: radiation-tolerant controllers, redundant buses, hot-swappable sensors
- Sortie duration: 10–45 minutes (mission-dependent)
- Thermal management: passive radiators, insulated tank jackets, heat-spreading composites

#### 3.5 Safety and Redundancy Metrics

- Valve architecture: fast-response solenoids, redundant pairs, fail-closed default
- Thruster redundancy: multi-pathway micro-thruster clusters
- Autonomous safety: dead-man stabilization, collision avoidance, emergency return
- Structural safety: reinforced hardpoints, shock-isolated cargo mounts, EVA-safe edges
- Emergency interfaces: tether points, manual override, safe-mode stabilization

### 4. System Architecture

The Griffiths Free-Flying EVA Logistics Sled (NGLS) is engineered around six tightly integrated domains that together form a coherent logistics-layer EVA architecture. Each domain is optimized for heavy-payload handling, precision manoeuvring, and safe operation around large, complex deep-space structures. The architecture supports both piloted and unmanned modes, enabling flexible deployment across diverse mission profiles. The six domains are: Structural and Materials Engineering; Propulsion Subsystem Architecture; Control Systems and Autonomy Stack; Power and Avionics Architecture; Thermal Management Pathways; and Safety, Redundancy and Fail-Safe Logic.

#### 4.1 Structural and Materials Engineering

##### 4.1.1 Frame Materials

- Carbon-fiber composite primary structure
- Titanium alloy load-bearing joints
- Aluminum-lithium secondary brackets
- EVA-safe edge treatments and integrated handholds

#### **4.1.2 Structural Load Paths**

The frame is designed to support 50–200 kg payloads, dynamic maneuvering loads, EVA handling forces, and docking and undocking impulses. Features include distributed load rails, shock-isolated cargo mounts, reinforced thruster hardpoints, and modular attachment points for mission-specific payloads.

#### **4.1.3 Cargo Interface Standards**

The NGLS is compatible with ISS-style handrails, EVA tool latches, modular payload racks, quick-release clamps, and standard mounting plates, ensuring interoperability with existing EVA tools and future canon architectures.

### **4.2 Propulsion Subsystem Architecture**

#### **4.2.1 Propellant Selection**

Compressed nitrogen is selected for its non-reactivity, EVA safety, thermal stability, and extensive flight heritage.

#### **4.2.2 Tank Design**

Two COPVs each carrying 15 kg nitrogen at 200–300 bar operating pressure with a 2× burst-pressure margin, integrated regulators, and isolation valves.

#### **4.2.3 Thruster Assemblies**

Two configurations are available. Gimballed nozzles provide mechanical gimbal actuation, high control authority, and are ideal for piloted precision work. Micro-thruster clusters use multiple fixed nozzles with PWM control, redundant pathways, and are ideal for autonomous modes.

#### **4.2.4 Valve Technology**

Fast-response solenoids with redundant paired valves and fail-closed default state ensure safe propellant management under all operating conditions.

### **4.1 Control Systems and Autonomy Stack**

The control architecture is structured in three layers. Manual control is provided via a rod-based controller enabling translation, rotation, and throttle modulation. The stabilization layer uses triple-redundant IMUs with PID control loops, drift correction, and vibration damping. Autonomous modes include position hold, return-to-base, collision avoidance, assisted docking, and teleoperation. The sensor suite comprising LIDAR, stereo cameras, and ultrasonic proximity sensors, feeds the autonomy stack for safe operation around complex structures.

### **4.2 Power and Avionics Architecture**

The power system uses Li-ion or Li-polymer batteries with 150–300 Wh capacity and redundant power buses. Avionics consist of radiation-tolerant controllers, triple-redundant IMUs, hot-swappable sensors, and a modular electronics bay.

### **4.3 Thermal Management Pathways**

Cold-gas propulsion introduces unique thermal behaviors including tank cooling via the Joule–Thomson effect, regulator heating, and electronics heat concentration. Thermal solutions include passive radiators, insulated tank jackets, and heat-spreading composite panels.

### **4.4 Safety, Redundancy and Fail-Safe Logic**

Primary failure modes addressed include thruster failure, tank leak, valve stuck open, controller dropout, sensor failure, and pilot incapacitation. Mitigations include redundant thrusters, fail-closed valves, autonomous stabilization, dead-man return, collision avoidance, and emergency tether points.

## **5. Evalogistics Doctrine and Canon Integration**

This section elevates the NGLS from a standalone EVA vehicle to a formal logistics-layer architecture within the Griffiths Canon. Just as the Dual-Ring Habitat defines habitation, GNMT-Drive defines propulsion, and DIMDCP defines fabrication, the NGLS defines the movement of mass across the exterior of deep-space systems. It becomes

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the operational bridge between human crews, large structures, and the distributed maintenance workflows that keep a deep-space civilization functioning.

### **5.1 The NGLS as a Logistics-Layer Architecture**

The NGLS establishes EVA logistics as a first-class operational domain, characterized by heavy-payload handling beyond astronaut physiological limits, precision maneuvering around complex and rotating structures, free-flying mobility unconstrained by rails or tether systems, autonomous stabilization for safety and fatigue reduction, and modular cargo interfaces compatible with habitat, propulsion, and fabrication systems. Within the canon, the sled is not a tool, it is the logistical backbone that enables construction, maintenance, and expansion of large-scale architectures.

### **5.2 Integration with the Dual-Ring Habitat**

The NGLS is the primary EVA interface for the Dual-Ring Habitat's exterior systems, covering radiator panel installation and replacement, flux-coil inspection and maintenance, thermal-manifold access, docking-port servicing, hull inspection during rotation, and cargo transfer between habitat modules. The habitat's spine-mounted docking ports and magnetic capture rings are intentionally designed for NGLS compatibility, enabling seamless EVA workflows. The Dual-Ring Habitat now includes six NGLS-compatible EVA logistics ports, enabling direct cargo transfer, radiator replacement, coil maintenance, and DIMDCP component delivery during full-rotation operation.

### **5.3 Integration with GNMT-Drive and MSH-Drive**

The sled supports propulsion-module maintenance across both major drive architectures. For GNMT-Drive, this covers nozzle and radiator inspection, microwave-thermal aperture servicing, thrust-phase cooldown access, and structural panel replacement. For MSH-Drive, it covers steam-cycle manifold inspection, thermal-loop access, radiator segment replacement, and external sensor servicing. Cold-gas propulsion ensures safe operation near reactor housings, thermal exchangers, and high-energy systems.

### **5.4 Integration with DIMDCP**

The NGLS is the last-mile carrier for DIMDCP-fabricated components including truss elements, replacement coils, radiator segments, modular payloads, repair kits, and structural reinforcements. DIMDCP builds; NGLS delivers. This pairing forms the core of distributed construction and repair across deep-space vessels and habitats.

### **5.5 EVA Workflow Standardization**

The sled formalizes EVA logistics into a repeatable, safe, and efficient three-phase workflow. The pre-sortie phase covers payload mounting, system checks, autonomy calibration, and habitat-to-sled interface verification. The operational phase covers free-flying transit, precision positioning, assisted docking, and payload installation or retrieval. The return phase covers dead-man stabilization, autonomous return-to-base if required, payload handoff, and post-sortie diagnostics. This standardization reduces EVA fatigue, shortens maintenance timelines, and increases mission throughput.

### **5.6 Canon-Wide Role**

The NGLS completes the four-pillar operational chain of the Griffiths Canon: GNMT-Drive and MSH-Drive for movement of vessels; the Dual-Ring Habitat for sustaining human life; DIMDCP for fabrication and repair; and the NGLS for logistics, installation, and external maintenance. Together, these architectures form a closed-loop deep-space civilization system where every component supports the others.

## **6. Propulsive Dynamics, Control Laws and Stability Envelope**

The NGLS operates as a free-flying, six-degree-of-freedom EVA logistics architecture driven by cold-gas propulsion, rigid-body dynamics, and a layered autonomy stack. This section formalizes the physical behaviour of the sled, the control-law philosophy, and the stability envelope that governs safe operation around large deep-space structures.

### **6.1 Cold-Gas Propulsion Fundamentals**

The sled's propulsion system is built around two high-pressure nitrogen tanks feeding either gimbaled nozzles for high-authority piloted control or micro-thruster clusters for redundant, PWM-driven autonomous control. Cold-gas propulsion provides predictable thrust curves, rapid response, thermal stability, zero ignition hazard, and

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compatibility with EVA environments. The system is optimized for precision manoeuvring in the 0.2–1.2 N thrust range per nozzle.

## 6.2 Thruster Configuration and Vectoring

Gimbaled nozzles provide continuous vector control and high rotational authority, ideal for human-in-the-loop operations. Micro-thruster clusters use pulse-width modulation with redundant pathways, ideal for autonomous stabilization. Both configurations support full 6-DOF translation and rotation, fine-grained impulse control, rapid thrust modulation, and safe operation near delicate structures.

## 6.3 Rigid-Body Dynamics

The sled behaves as a compact rigid body with low moment of inertia, high rotational responsiveness, predictable translational coupling, and minimal structural flex. Payload mass distribution affects centre-of-mass location, rotational inertia, control-loop tuning, and the stability envelope. The autonomy stack compensates for these shifts in real time.

## 6.4 PID Control Laws and Stabilization

The NGLS uses a layered control architecture. The inner loop handles high-frequency IMU-driven attitude control via micro-thruster or gimbal actuation. The outer loop handles lower-frequency position control using LIDAR and stereo vision fusion with drift correction and collision-avoidance integration. The supervisory layer handles dead-man stabilization, return-to-base logic, safe-mode damping, and DI-HCL-compatible telemetry. This architecture ensures stability even with asymmetric payloads, thruster failures, sensor dropout, or pilot incapacitation.

## 6.5 Autonomous Modes and Sensor Fusion

The sled supports position hold, assisted docking, collision avoidance, return-to-base, and teleoperation autonomy levels. Sensor fusion integrates triple-redundant IMUs, LIDAR point clouds, stereo-vision depth maps, and ultrasonic proximity envelopes, enabling safe operation in cluttered, rotating, or thermally dynamic environments.

## 6.6 Stability Envelope

The stability envelope defines maximum translational acceleration, maximum rotational rate, minimum safe distance to structures, maximum payload mass and offset, thermal limits for regulators and tanks, and thrust-vector saturation thresholds. The autonomy stack continuously evaluates these parameters and intervenes when necessary.

## 7. Governing Equations

This section presents the mathematical foundations that govern the NGLS's propulsion, rigid-body behaviour, control-loop dynamics, and stability envelope.

### 7.1 Thrust and Specific Impulse

Thrust is given by:

$$F = \dot{m} \cdot v_e$$

where  $F$  is thrust,  $\dot{m}$  is mass flow rate, and  $v_e$  is exhaust velocity ( $\sim 700$  m/s for  $N_2$ ). Specific impulse is:

$$I_{sp} = v_e / g_0$$

where  $I_{sp} \approx 65\text{--}75$  s and  $g_0 = 9.81$  m/s<sup>2</sup>.

### 7.2 Total Impulse and $\Delta v$ Budget

Total impulse is: The Tsiolkovsky  $\Delta v$  equation is:

$$I_{tot} = F \cdot t = \dot{m} \cdot v_e \cdot t \approx 21,000 \text{ N} \cdot \text{s} \Delta v = v_e \cdot \ln(m_0 / m^f)$$

where  $m_0$  is initial (wet) mass and  $m^f$  is final (dry) mass. Operational  $\Delta v$ : 50–150 m/s; theoretical  $\Delta v$ :  $\sim 350$  m/s.

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### 7.3 Rotational Authority and Torque

Torque from thrusters:

$$\tau = r \times F$$

where  $\tau$  is torque,  $r$  is moment arm, and  $F$  is thruster force. NGLS rotational authority: 0.1–0.5 N·m. Angular acceleration:

$$\alpha = \tau / I$$

where  $\alpha$  is angular acceleration and  $I$  is moment of inertia (payload-dependent).

### 7.4 Rigid-Body Motion

Translational motion:  $\Sigma F = m \cdot a$ . Rotational motion:  $\Sigma \tau = I \cdot \alpha$ . Payload offset introduces coupled dynamics where  $\vec{a}_{c_m} = \Sigma F / m$  and  $\vec{\alpha} = I^{-1} \Sigma \tau$ . The autonomy stack compensates for these shifts in real time.

### 7.5 Control-Loop Dynamics

The PID controller output is:

$$u(t) = K_p e(t) + K_i \int e(t) dt + K_d de(t)/dt$$

where  $u(t)$  is the control output (thruster command),  $e(t)$  is the error signal, and  $K_p$ ,  $K_i$ ,  $K_d$  are tuned gains. The inner loop uses high-frequency IMU-driven PID for attitude control. The outer loop uses lower-frequency PID with LIDAR and vision fusion for position control. The supervisory layer applies non-PID logic for dead-man stabilization, return-to-base, and safe-mode damping.

### 7.6 Collision-Avoidance Envelope

Minimum safe distance:

$$d_{sa}^f = d_{sensor} + v \cdot t$$

where  $d_{sensor}$  is sensor detection range,  $v$  is relative velocity, and  $t$  is controller reaction time. Braking distance:

$$d_{rk}^b = v^2 / (2a_{max})$$

where  $a_{max}$  is limited by available thrust.

### 7.7 Thermal Dynamics

Tank cooling via the Joule–Thomson effect:

$$\Delta T = \mu_{JT} \cdot \Delta P$$

where  $\mu_{JT}$  is the Joule–Thomson coefficient and  $\Delta P$  is the pressure drop across the regulator. Electronics heat balance:

$$Q_{elek} = mc\Delta T + \epsilon\sigma AT^4$$

where  $Q_{elek}$  is heat generated,  $mc\Delta T$  is absorbed heat, and  $\epsilon\sigma AT^4$  is radiated heat.

### 7.8 Stability Envelope Constraints

Maximum translational acceleration:  $a_{max} = F_{tot} / m$ . Maximum rotational rate:  $\omega_{max} = \sqrt{(T_{max} / I)}$ . Thrust saturation constraint:  $F_{c_m}^d \leq F_{max}$ . Thermal limit:  $T_{re}^g < T_{cr}^0$ . Payload offset constraint:  $r \leq r_{max}$ .

## 8. Comparative Analysis

This section positions the NGLS within the broader landscape of EVA mobility systems, logistics platforms, and external-maintenance architectures, articulating the sled's operational niche and advantages over legacy systems.

### 8.1 Comparison to SAFER

SAFER (Simplified Aid for EVA Rescue) is a personal-mobility, self-rescue device designed for contingency use. Its strengths include extreme lightness, simple operation, and low propellant mass. However, it was not designed

for logistics, has minimal  $\Delta v$ , no heavy-payload capability, no autonomous stabilization, and no precision maneuvering capability around large structures. The NGLS offers 50–200 kg payload capacity, 50–150 m/s operational  $\Delta v$ , full 6-DOF control, autonomous stabilization and return-to-base, modular cargo interfaces, and safe operation near rotating or thermally active structures. SAFER is a personal safety device; the NGLS is a logistics architecture.

## **8.2 Comparison to the MMU**

The MMU (Manned Maneuvering Unit) was a high-mobility EVA backpack used on a limited number of Shuttle missions. While it offered high  $\Delta v$  for its era and proven free-flight capability, it was extremely large and heavy, not optimized for logistics, lacked autonomous modes and safety redundancy, and is unsuitable for modern deep-space structures. The NGLS is far lighter and more compact, designed specifically for logistics, incorporates autonomous stabilization and collision avoidance, and is safer around delicate structures. The MMU was a mobility experiment; the NGLS is a purpose-built logistics platform.

## **8.3 Comparison to Robotic Arms**

Robotic arms such as Canadarm2 and ERA offer high precision and large payload capacity for fixed-path operations, but suffer from fixed mounting locations, limited reach, slow repositioning, high mass and complexity, and inability to serve distributed structures. The NGLS offers free-flying mobility, rapid repositioning, suitability for distributed maintenance, human-in-the-loop decision support, and far lower mass and complexity. Robotic arms excel at fixed-point manipulation; the NGLS excels at free-space logistics and distributed maintenance.

## **8.4 EVA Logistics Gap Analysis**

Before the NGLS, EVA logistics suffered from three systemic gaps. The mass-handling gap arises because astronauts cannot safely maneuver loads above 25–40 kg in microgravity without risk of drift, collision, or fatigue. The mobility gap stems from existing EVA mobility systems being unable to carry heavy payloads, reposition quickly, or operate autonomously. The distributed-maintenance gap reflects the reality that large structures require multi-vector access, free-flying positioning, and rapid transit between worksites. The NGLS directly addresses all three.

## **8.5 Comparative Strength Summary**

Across all categories, the NGLS consistently excels in heavy-payload transport, precision maneuvering, autonomous stabilization, collision-avoidance safety, free-flying mobility, integration with canon architectures, low operational complexity, and compatibility with EVA workflows. The sled occupies a unique operational niche: true EVA logistics mobility, enabling tasks that neither astronauts, robotic arms, nor legacy maneuvering units can perform.

# **9. Mission Integration and Operational Doctrine**

This section formalizes how the NGLS operates within real EVA workflows, deep-space maintenance cycles, and multi-module vessel architectures.

## **9.1 EVA Logistics Workflows**

The NGLS transforms EVA from a purely human-scale activity into a logistics-driven operational discipline. A standard EVA logistics workflow consists of four phases. Pre-sortie preparation covers payload selection and mounting, sled diagnostics and autonomy checks, tank pressure verification, sensor calibration, and habitat-to-sled interface confirmation. The transit phase involves free-flying maneuvering to the worksite with autonomous drift correction and collision-avoidance envelope active. Worksite operations cover precision alignment, payload installation or retrieval, assisted docking for tool exchange, and micro-adjustments via thruster systems. The return phase covers dead-man stabilization if required, autonomous return-to-base, controlled docking, payload handoff, and post-sortie diagnostics.

## **9.2 Sled-to-Habitat Logistics Interfaces**

The NGLS integrates directly with the Dual-Ring Habitat's EVA infrastructure through spine-mounted docking ports, magnetic capture rings, and EVA corridor alignment guides. Payload interfaces include modular racks compatible with the habitat exterior, quick-release clamps for radiator segments, and standardized mounting plates. Operational integration includes a DI-HCL telemetry link for predictive safety, a habitat-based teleoperation console, and a shared collision-avoidance map. The sled becomes the habitat's external logistics arm, enabling maintenance and expansion without robotic arms or tether-based systems.

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### 9.3 Payload Handling and Installation

The NGLS is optimized for heavy, bulky, or awkward payloads that exceed astronaut handling limits. Supported payload classes include radiator panels, flux-coil housings, truss elements, DIMDCP-fabricated components, replacement sensors and instruments, and thermal-manifold modules. The installation workflow proceeds from payload securing to free-flight transit, assisted docking alignment, payload placement and mechanical fastening, and verification via onboard sensors. This workflow enables tasks that would otherwise require multiple EVA sorties or robotic arm intervention.

### 9.4 Safety Doctrine and Crew Interaction

The NGLS incorporates a layered safety doctrine. Pilot-centered safety includes dead-man stabilization, fail-closed valves, redundant thruster pathways, and emergency tether points. Autonomy-centered safety covers the collision-avoidance envelope, return-to-base logic, safe-mode damping, and sensor-fusion redundancy. Crew interaction principles ensure the

sled never approaches crew at speed, that crew maintain handhold contact during payload operations, that teleoperation is available for hazardous tasks, and that DI-HCL telemetry provides predictive alerts.

### 9.5 Operational Phases and Checklists

The NGLS follows a standardized six-phase operational sequence: Phase 1 — Activation (power-up, sensor calibration, autonomy stack initialization); Phase 2 — Payload Integration (mount payload, verify load distribution, confirm centre-of-mass offset); Phase 3 — EVA Deployment (undock from habitat, begin free-flight transit); Phase 4 — Worksite Operations (precision alignment, payload installation or retrieval); Phase 5 — Return and Docking (autonomous or piloted return, controlled docking, payload handoff); Phase 6 — Post-Sortie (diagnostics, tank pressure check, battery recharge, mission log entry).

## 10. Failure Modes, Predictive Diagnostics and Contingency Protocols

### 10.1 Failure-Mode Philosophy

The NGLS safety architecture is built on three core principles. Fail-closed, never fail-open: all valves, thrusters, and control pathways default to a safe, non-propulsive state. Autonomy before escalation: if the pilot becomes incapacitated or loses control, the sled immediately stabilizes attitude, nulls translation, enters safe-mode damping, and prepares for return-to-base. Predictive diagnostics over reactive response: sensor fusion and DI-HCL telemetry allow the sled to detect drift instabilities, thruster degradation, tank pressure anomalies, sensor dropout, and thermal excursions before they become operational hazards.

### 10.2 Primary Failure Modes

The NGLS is engineered to handle six primary failure classes: thruster failure (single-nozzle failure, cluster-pathway dropout, gimbal actuator stall); propellant system faults (tank leak, regulator malfunction, valve stuck open or closed); control-system failures (IMU dropout, PID instability, controller reboot, rod-controller disconnect); sensor failures (LIDAR blind sectors, stereo-vision occlusion, ultrasonic sensor dropout); power system faults (battery undervoltage, bus isolation event, avionics thermal overload); and pilot incapacitation (fatigue, loss of grip, medical emergency). Each failure mode is paired with a corresponding mitigation pathway.

### 10.3 Predictive Diagnostics

The sled continuously evaluates its own health using a multi-layer diagnostic system covering sensor fusion health checks (IMU cross-validation, LIDAR versus stereo-vision depth agreement, ultrasonic proximity sanity checks), propulsion health monitoring (thrust-vector deviation detection, valve response-time profiling, tank pressure decay analysis), structural and load monitoring (payload offset estimation, vibration signature analysis, hardpoint stress trending), and thermal diagnostics (regulator temperature drift, electronics bay heat load, tank cooling rate anomalies). The sled can also stream telemetry to the habitat's DI-HCL system, enabling predictive failure alerts, recommended aborts, safe-mode triggers, and return-to-base advisories.

### 10.4 Contingency Protocols

When a failure is detected, the sled follows a strict layered response sequence. Thruster or valve failure: isolate faulty thruster, redistribute control authority, switch to micro-thruster cluster if gimbal fails, enter reduced-authority mode if needed. Propellant leak: close upstream valves, stabilize attitude, initiate immediate return-to-base. Sensor dropout: switch to redundant sensor, degrade autonomy level, maintain position hold if safe, request teleoperation

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if needed. Controller dropout: activate dead-man stabilization, null rotation and translation, await pilot recovery or teleoperation. Pilot incapacitation: detect inactivity, enter safe-mode damping, autonomously return to habitat docking port. Power system fault: shed non-critical loads, prioritize stabilization and return, disable high-draw sensors if required.

## **10.5 Canon-Wide Safety Integration**

The NGLS safety architecture is fully interoperable with the rest of the Griffiths Canon. Integration with the Dual-Ring Habitat includes a DI-HCL telemetry link, shared collision-avoidance map, and habitat-based teleoperation console. Integration with GNMT-Drive and MSH-Drive covers safe-distance envelopes, thermal hazard zones, and thrust-phase cooldown protocols. Integration with DIMDCP covers safe-handling of fabricated components, payload-mass verification, and structural-integrity checks. The sled becomes part of a distributed safety ecosystem, not an isolated EVA device.

## **11. Narrative Signals, Canonical Resonance and Symbolics Motifs**

### **11.1 The Sled as the “Hands” of the Canon**

Within the canon’s symbolic structure, GNMT-Drive is the heart (energy, motion, intent), the Dual-Ring Habitat is the body (home, stability, life), DIMDCP is the forge (creation, repair, fabrication), and the NGLS is the hands — the manipulator, the carrier, the extender of human capability. The sled embodies precision, reach, and agency. It is the architecture that allows humans to touch, adjust, build, and maintain the vast structures that define the canon.

### **11.2 EVA-Scale Human-Machine Symbiosis**

The NGLS is not a tool; it is a partner. Its autonomy stack, stabilization logic, and safety envelope create a relationship where the human provides judgment, the sled provides strength and precision, and together they form a hybrid capability neither could achieve alone. This mirrors the canon’s broader theme of dual-intellect collaboration — human intuition paired with engineered precision and becomes a microcosm of the DI-HCL philosophy: two minds, one action.

### **11.3 Logistics as Narrative Function**

In the canon, logistics is not a background detail, it is a narrative driver. The NGLS enables construction of large habitats, maintenance of propulsion modules, expansion of distributed vessel networks, installation of DIMDCP-fabricated components, and continuous upkeep of deep-space infrastructure. Without logistics, the canon cannot grow. Without the sled, logistics cannot scale. Thus the NGLS becomes a story enabler, the quiet force that makes every other architecture possible.

### **11.4 Symbolic Alignment with the Green Man Motif**

The Green Man motif represents renewal, growth, human-machine harmony, and the living continuity of the canon. The NGLS aligns with this motif through its role in maintaining the living exterior of habitats, tending to the garden of deep-space infrastructure, enabling continuous renewal through repair and replacement, and acting as the caretaker of the canon’s physical manifestations. Where the Green Man symbolizes life sustained, the NGLS symbolizes life maintained.

### **11.5 Rotational Harmony and Free-Space Precision**

The sled’s ability to operate safely around rotating habitats and dynamic structures ties it directly to the canon’s theme of harmonic motion. It embodies balance, precision, and controlled interaction with moving systems, mirroring the Dual-Ring Habitat’s rotational grace and the GNMT-Drive’s directed momentum. The sled is the precision instrument that interacts with these larger harmonies.

### **11.6 The Sled as a Character in the Canon**

Like all Griffiths architectures, the NGLS carries a personality: steady, reliable, quietly powerful, always present when needed, never dramatic, always essential. It is the EVA companion that crews trust implicitly — the partner that catches them, carries their burdens, and returns them safely home. In narrative terms, the sled is the unsung hero of the canon.

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## 12. Future Research Pathways and Expansion Opportunities

### 12.1 Advanced Cold-Gas Technologies

Cold-gas propulsion is simple, safe, and reliable, but can be improved through higher-efficiency nozzles with optimized expansion ratios and additive-manufactured micro-channels, variable-pressure regulators for finer impulse control and reduced propellant waste, and cryogenic-compatible tanks offering higher storage density and longer sortie durations. These upgrades preserve the sled's safety profile while extending its operational envelope.

### 12.2 Autonomous EVA Robotics

The NGLS is a natural foundation for semi-autonomous or fully autonomous EVA robotics, including manipulator-arm modules for tool handling and autonomous fastening, inspection-focused variants with high-resolution cameras and thermal imagers, and fully autonomous logistics sleds operating on pre-programmed maintenance routes with automated delivery of DIMDCP components. This transforms the sled from a piloted platform into a distributed robotic workforce.

### 12.3 ISRU Propellant Production

For long-duration missions or permanent installations, propellant resupply becomes a bottleneck. Future pathways include in-situ nitrogen extraction from the Martian atmosphere, icy-moon volatiles, or asteroid regolith, combined with on-site

compression and storage via habitat-integrated compressors and modular COPV refill stations. This enables closed-loop logistics where sleds refuel locally and EVA operations become self-sustaining, aligning with the canon's long-term vision of self-maintaining deep-space infrastructure.

### 12.4 Hybrid Propulsion Upgrades

While cold-gas remains the safest baseline, hybrid systems could expand capability through cold-gas combined with electric micro-thrusters for higher  $\Delta v$  and improved fine-control authority, cold-gas combined with reaction-wheel stabilization for silent attitude control and reduced thruster wear, and cold-gas combined with gas-generator boosters for rapid repositioning around large structures. These hybrids maintain EVA safety while expanding mission flexibility.

### 12.5 Multi-Sled Fleet Operations

As habitats and vessels grow, a single sled becomes insufficient. Fleet-level operations include coordinated multi-sled logistics for synchronized delivery of large components, fleet autonomy with shared collision-avoidance maps and DI-HCL-coordinated task allocation, and sled-to-sled docking for modular payload transfer and cooperative stabilization. This transforms the NGLS from a single EVA tool into a logistics ecosystem.

### 12.6 Integration with Future Canon Architectures

As the canon expands, the sled will integrate with next-generation habitats, ark-class vessels, deep-space construction yards, autonomous repair drones, and long-baseline sensor arrays. The NGLS becomes the universal logistics interface, the connective tissue of the canon.

## 13. Conclusion

The Griffiths Free-Flying EVA Logistics Sled (NGLS) establishes a new operational tier within the Griffiths Canon: a dedicated, purpose-built logistics-layer EVA architecture that enables the construction, maintenance, and long-term viability of large deep-space systems. Where traditional EVA mobility solutions were designed around personal manoeuvring or emergency return, the NGLS is engineered from first principles to move mass, not just astronauts and to do so safely, precisely, and repeatedly. By integrating dual high-pressure cold-gas propulsion, full six-degree-of-freedom control authority, autonomous stabilization, modular cargo interfaces, and a layered safety envelope, the sled transforms EVA from a physically taxing, manually constrained activity into a predictable, scalable logistics workflow. Its ability to transport 50–200 kg payloads, deliver 50–150 m/s operational  $\Delta v$ , and operate in both piloted and unmanned modes makes it uniquely suited to the demands of modern deep-space infrastructure. The NGLS also fits seamlessly into the broader Griffiths Canon. It services the exterior of the Dual-Ring Habitat, supports inspection and maintenance of GNMT-Drive and MSH-Drive propulsion modules, and acts as the last-mile carrier for DIMDCP-fabricated components. In doing so, it completes the four-pillar operational chain of the canon: propulsion, habitation, fabrication, and logistics.

As deep-space vessels grow in scale and complexity, the NGLS becomes not merely useful but essential. It is manufacturable, near-term, and grounded in proven technologies, yet extensible enough to evolve into autonomous fleets, hybrid-propulsion variants, and ISRU-supported logistics networks. In short, the NGLS is not an accessory to the canon; it is a foundational architecture. It is the system that allows every other system to be built, maintained, and expanded. It is the quiet enabler of deep-space civilization, the hands that keep the canon alive.

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