The Griffiths Dual-Ring Superconducting Artificial-Gravity Habitat Architecture: Counter-Rotating Magnetic Levitation Design for Long-Duration Deep-Space Habitation

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Abstract: Long-duration human habitation beyond Earth's magnetosphere requires artificial gravity to prevent the progressive musculoskeletal, cardiovascular, and neurovestibular deterioration observed in sustained microgravity exposure. Existing artificial gravity concepts tethered systems, single-ring centrifuges, and rotating drums each exhibit fundamental limitations in gyroscopic stability, physiological adequacy, structural scalability, or integration with active propulsion and defence architectures. This paper presents the Griffiths Dual-Ring Superconducting Artificial-Gravity Habitat Architecture: a counter-rotating, magnetically levitated habitat system providing 0.8 g at the outer habitation ring (100 m outer diameter, 50 m radius) and 0.6 g at the inner laboratory ring (75 m outer diameter, 37.5 m radius), both at a common rotation rate of 3.78 RPM (ω = 0.396 rad/s). Counter-rotation eliminates net angular momentum, removing gyroscopic coupling with attitude control systems and enabling free reorientation of the combined habitat. Superconducting toroidal coils provide magnetic levitation, structural rigidity, and electromagnetic bearing functionality with field stability maintained at ±0.01 T through closed-loop flux feedback. The governing framework quantifies centripetal acceleration, hoop stress in the ring structure, magnetic levitation force balance, thermal radiative equilibrium, and angular momentum cancellation conditions. Coriolis acceleration at walking speed (1 m/s) is 0.79 m/s² (8.1% of local gravity), within published adaptation limits. The gravity gradient across a 1.8 m crew height is 3.6%, negligible relative to physiological thresholds. The architecture integrates with the Griffiths Reactive-Field Framework (GRFF) four-layer defence envelope, GNMT propulsion, NGLS EVA logistics, and the DIGSP governance protocol, forming a complete deep-space habitation system within the Griffiths Canon. The habitat architecture is now explicitly integrated with the GNMT v7.0 Nuclear Microwave-Thermal propulsion system and its Rotating Electromagnetic Nozzle (REMN) stacks, providing a unified propulsion–habitation interface. Dedicated EVA logistics ports support the Griffiths Free-Flying EVA Logistics Sled (NGLS) for external maintenance, cargo movement, and distributed construction. Two experimental bays in the central spine are reserved for compact superconducting EM-curvature test modules, leveraging shared REBCO-class coil technology while maintaining full isolation from the levitation system. These integrations align the habitat with the broader Griffiths Canon and its propulsion, logistics, and experimental frameworks.

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1. Introduction

Continuous microgravity exposure during long-duration spaceflight causes progressive, compounding physiological deterioration across multiple body systems. Bone mineral density losses of 1–2% per month have been documented on the International Space Station [1], accompanied by skeletal muscle atrophy, cardiovascular deconditioning, fluid cephalad shift inducing intracranial pressure elevation, and neurovestibular adaptation that reduces

operational effectiveness [2,3]. Countermeasure regimens requiring 2–3 hours of daily exercise impose significant crew time demands and do not fully prevent bone and muscle loss on missions exceeding twelve months [4]. For interplanetary missions lasting two to three years and interstellar transit regimes, microgravity countermeasures alone are insufficient to preserve crew health and operational capacity. Artificial gravity through centrifugal acceleration provides a continuous, passive physiological countermeasure that eliminates microgravity exposure rather than compensating for it. Rotating habitats have been a feature of long-duration mission architecture since the 1950s [5], with landmark design studies including the Stanford Torus. [6] and O'Neill Cylinder [7] establishing engineering principles. However, these designs were conceived for colonisation-scale structures; neither provides a compact, mission- scalable solution integrated with high-performance propulsion and active defence architectures for the crew sizes of near-term deep-space missions. Single-ring rotating habitats introduce gyroscopic coupling between the spinning structure and the vehicle's attitude control system, requiring either continuous momentum compensation or restricted reorientation capability [8]. Tethered counter-rotating systems eliminate gyroscopic coupling but introduce structural complexity, deployment risk, and limited modularity. Static artificial-gravity concepts (gravity-gradient stabilisation) provide insufficiently controlled gravity levels for physiological adequacy.

This paper presents the Griffiths Dual-Ring Superconducting Artificial-Gravity Habitat Architecture, which addresses these limitations through three integrated innovations: counter- rotation of two concentric rings to achieve zero net angular momentum; superconducting magnetic levitation providing contactless bearing support and structural rigidity without mechanical wear; and modular architecture integrating with the complete Griffiths Canon of propulsion, governance, EVA, and defence systems. The architecture is presented with full governing equations, corrected and self-consistent physical parameters, TRL assessment, comparative analysis against published designs, and failure mode characterisation. The paper is structured as follows: Section 2 provides a technology readiness assessment. Section 3 defines the habitat geometry and corrected rotation parameters. Section 4 addresses superconducting ring design. Section 5 covers artificial gravity gradient and human tolerance. Section 6 defines thermal regulation. Section 7 addresses power distribution. Section 8 characterises failure modes. Section 9 presents the governing equations. Section 10 provides comparative analysis. Section 11 covers integration with Griffiths Canon systems. Section 12 identifies future research directions. Section 13 presents conclusions.

2. Technology Readiness Profile

The Dual-Ring Habitat integrates technologies spanning TRL 3 to TRL 9. Table 1 summarises the readiness of each major subsystem, with corrected physical parameters consistent with the governing equations in Section 9.

Table 1. Technology Readiness Level Summary for Dual-Ring Habitat Subsystems.

Subsystem	TRL Band	Status	Notes
Rotating habitat ring structures (general)	6–7	Ground-demonstrated / flight-analogues	Centrifuge habitats studied extensively; ISS rotary joint mechanisms provide heritage for ring bearing design.
Counter-rotating dual-ring configuration	4–5	Component-level demonstrated	Angular momentum cancellation through counter-rotation is well-established in spacecraft attitude control. Dual-ring habitat implementation is an engineering integration task.
Superconducting toroidal coils for structural/levitation	5–6	Ground-validated	Toroidal superconducting coils are well- established (ITER, MRI). Space-rated cryo- systems at this scale are an engineering challenge; heritage from superconducting flywheel energy storage.
Closed-loop flux feedback for field stability (±0.01 T)	5–6	Ground-demonstrated	Active magnetic bearing control with flux feedback is TRL 6 in terrestrial applications; space qualification of control electronics adds development risk.
Magnetic levitation bearing (non-contact ring support)	4–5	Ground-demonstrated at smaller scale	Maglev bearing systems are mature terrestrially; scaling to habitat ring mass (hundreds of tonnes) requires development.

Phase-change thermal buffering in space structures	6–7	Flight-demonstrated	PCM thermal storage is used on current spacecraft; integration at habitat ring scale is an engineering task.
Radiative thermal rejection arrays (250 kW class)	7–8	Flight-demonstrated	ISS radiator heritage; 250 kW rejection is within demonstrated ranges for modular radiator panels.
Triple-redundant superconducting power bus	4–5	Ground-demonstrated components	Superconducting power distribution is mature terrestrially; space-rated implementation requires development.
GRFF defensive envelope integration	3–4	Architecture-defined (see companion paper)	Integration interfaces are defined; hardware validation follows GRFF development roadmap.

3. Habitat Geometry and Rotation Parameters

The outer ring has an outer diameter of 100 m (radius r_o = 50 m) and a cross-sectional diameter of 8 m, providing approximately 1,260 m of habitable floor length around the ring circumference at a usable floor width of 4 m. The inner ring has an outer diameter of 75 m (radius r_i = 37.5 m) and a cross-sectional diameter of 6 m, providing approximately 940 m of laboratory floor length. The central spine has a diameter of 10 m. Total pressurized volume is approximately 45,000 m³ in the outer ring and 20,000 m³ in the inner ring, supporting a design crew of 24 persons with NATO-standard habitation volume allowances. Note: the companion GRFF paper [10] references a 100-person habitat at these outer dimensions; the present architecture as detailed supports 24 persons, with expansion to 100 persons achievable through ring diameter scaling per the governing relationships in Section 9.

3.1 Rotation Rate and Gravity Levels

The gravity level at radius r under rotation at angular velocity ω is $a_c = \omega^2 r$. For a target of 0.8 g at the outer ring floor (r = 50 m):

$$\omega = \sqrt{g\_target / r\_o} = \sqrt{(0.8 \times 9.81 / 50)} = 0.396\, rad/s = 3.78\, RPM \text{(Eq. 1)}$$

At the same rotation rate, the inner ring floor at r_i = 37.5 m provides:

$$a\_i = \omega^2 \times r\_i = (0.396)^2 \times 37.5 = 5.88\, m/s^2 = 0.60\, g \text{ (Eq.2)}$$

The 0.6 g laboratory environment is appropriate for research activities requiring partial gravity while maintaining cardiovascular and musculoskeletal loading above the thresholds associated with microgravity pathology [2]. Table 2 presents the complete rotation parameter set.

Table 2. Dual-Ring Habitat Rotation and Gravity Parameters.

Parameter	Outer Ring	Inner Ring	Units
Ring radius (floor level)	50.0	37.5	m
Angular velocity ω	0.396	0.396 (counter)	rad/s
Rotation rate	3.78	3.78 (counter)	RPM
Artificial gravity (floor)	0.80	0.60	g
Centripetal acceleration	7.85	5.88	m/s²
Coriolis acceleration (1 m/s walk)	0.792	0.792	m/s²
Coriolis as % of local gravity	10.1	13.5	%
Gravity gradient over 1.8 m head-to-foot	3.6	4.8	% of floor g

Ring cross-section diameter	8.0	6.0	m
Pressurised floor area (estimated)	~5,040	~2,820	m²

3.2 Coriolis Environment Assessment

Coriolis acceleration acts perpendicular to crew motion in the rotating frame, creating apparent forces that affect balance, coordination, and fluid dynamics. At 3.78 RPM, Coriolis acceleration for a crew member walking at 1 m/s radially is:

$$a\_Cor \ = \ 2\omega \ \times \ v \ = \ 2 \ \times \ 0.396 \ \times \ 1.0 \ = \ 0.792 \, m/s^2 \qquad \text{(Eq. 3)}$$

This represents 10.1% of local gravity in the outer ring. Published human factors research identifies 3 RPM as a commonly cited tolerance threshold, but controlled adaptation studies have demonstrated acceptability at 5–6 RPM following appropriate acclimatisation regimes [9,11,12]. At 3.78 RPM with the outer ring's 0.8 g floor level, the Coriolis environment is within the adaptation range for trained crew. Operational protocols mandate a structured adaptation period before free rotation at full speed, with initial slow-roll habituation beginning at 1.0 RPM and stepping to 3.78 RPM over 7–14 days per published centrifuge acclimatisation data [11].

4. Superconducting Ring Design and Magnetic Field Architecture

Each ring contains a toroidal superconducting coil system providing three simultaneous functions: electromagnetic bearing support eliminating mechanical contact between ring and spine; structural rigidity supplement reducing dynamic hoop stress; and magnetic field generation for the GRFF Layer 1 interface. Operating temperature is maintained below the superconductor critical temperature through integrated cryogenic cooling.

4.1 Coil Configuration and Materials

The toroidal coil winding follows the ring circumference in a continuous superconducting loop. High-temperature superconductor (HTS) materials operating at 20–40 K are specified in preference to low-temperature superconductors (LTS, <10 K) to reduce cryogenic system mass and complexity while maintaining field strengths of 1.0–2.0 T adequate for levitation and bearing functionality. Candidate HTS materials include REBCO (rare-earth barium copper oxide) coated conductors, which have demonstrated sustained critical current densities above 200 A/mm² at 20 K and 2 T field [13], and are rated for the combined radiation, thermal, and vibration environment expected in deep space.

4.2 Magnetic Levitation Force Balance

The superconducting coil system provides levitation force F_lev balancing the ring's gravitational and centrifugal loading on the central spine. Per unit cross-sectional area A of the air gap:

$$F \ = \ B^2 \ \times \ A \ / \ (2\mu_0) \qquad \text{(Eq. 4)}$$

At B = 1.5 T and μ_0 = 4π × 10^{-7} H/m, the levitation pressure is approximately 895 kN/m². For a bearing contact length of 20 m and a 0.5 m radial gap width, this provides ~8.95 MN of total levitation force per bearing zone, adequate to support the ring mass while maintaining a nominal air gap of 20–50 mm with ±0.01 T closed-loop field stability.

4.3 Field Stability and Flux Feedback

Field stability of ±0.01 T is maintained through a distributed array of Hall-effect sensors monitoring flux density around the toroidal gap. Sensor outputs feed a PID control loop governing the current coil, with a control bandwidth of 10 Hz sufficient to reject perturbations from crew mass redistribution, manoeuvre-induced load changes, and thermal drift. The feedback architecture is triple-redundant with independent sensor arrays and control channels; loss of any two channels degrades to a reduced-bandwidth single-channel mode while maintaining levitation.

4.4 Cryogenic System Architecture

The HTS coil system operates at 20–40 K, maintained by a closed-cycle cryocooler using the Gifford-McMahon or pulse-tube cycle. Cryocooler heat rejection interfaces with the habitat thermal loop, routing waste heat to the primary radiator array. A cryogenic buffer volume provides thermal inertia of 8–12 hours against cryocooler loss, allowing time for backup cryocooler activation before coil warmup begins. Quench detection and protection circuitry

monitors coil voltage; a detected quench initiates controlled current dump into resistive shunt elements within 50 ms, preventing thermal damage to coil conductors.

4.5 Multi-Scale Magnetic Architecture

Recent advances in compact REBCO-class superconducting inserts enable a multi-scale magnetic architecture within the levitation system. Bulk toroidal coils (1–2 T) provide primary levitation and stiffness, while embedded high-field micro-coils (5–20 T localised) act as fine-trim actuators for field-gradient shaping, vibration damping, and desynchronisation suppression. These inserts operate within the same 20–40 K cryogenic envelope and impose negligible thermal load. The multi-scale architecture improves bearing stiffness, reduces flux ripple, and enhances stability during GNMT thrusting, crew movement, and ring-to-ring mass redistribution.

5. Artificial Gravity Gradient and Human Tolerance Envelope

The physiological adequacy of the habitat's artificial gravity environment is determined by three coupled parameters: gravity level at the floor; gravity gradient from floor to head height; and Coriolis acceleration at operational movement speeds. All three must lie within published human tolerance envelopes for indefinite habitation without deleterious adaptation.

5.1 Floor Gravity Level

The 0.8 g outer ring floor level is selected based on evidence from ground-based centrifuge studies [9,11] and extrapolation from partial-gravity analogue environments. A floor gravity of 0.8 g is expected to maintain bone mineral density within 5% of baseline over mission durations of up to three years, compared to losses of 15–20% projected for sustained microgravity [1,4]. The 0.6 g inner ring laboratory level provides a reduced-gravity environment for research requiring conditions between microgravity and Earth normal, while still maintaining meaningful physiological loading.

5.2 Head-to-Foot Gravity Gradient

The variation in centripetal acceleration between a crew member's feet and head (height h = 1.8 m) in the rotating frame is:

$$\Delta a = \omega^2 \times h = (0.396)^2 \times 1.8 = 0.282 \text{ m/s}^2 \qquad \text{(Eq. 5)}$$

Expressed as a fraction of floor gravity, this is 0.282 / 7.85 = 3.6% in the outer ring and 4.8% in the inner ring. Published tolerance criteria place the acceptable gradient threshold below 10% of floor gravity [9,12]; both ring environments comply with substantial margin. The gradient is below the threshold for disorienting head-movement effects and falls within the range reported as physiologically imperceptible during normal habituation.

5.3 Cross-Ring Gravity Transition Protocols

Crews moving between the outer and inner rings pass through the central spine's zero-gravity or near-zero-gravity transfer corridors. Transition protocols require movement speed ≤0.5 m/s in transfer zones and mandatory 60-second gravity-stabilisation pause at each ring entry airlock. DIGSP governance software monitors crew physiological state during transitions and can recommend deferral if cardiovascular indicators suggest transitional intolerance.

5.4 Emergency Spin-Down

Emergency de-rotation capability is provided by electromagnetic braking through the superconducting coil system. A controlled spin-down from 3.78 RPM to zero can be achieved in approximately 20 minutes at a deceleration rate of ≤0.003 rad/s² to remain below vestibular onset-rate thresholds. Emergency rapid spin-down (≤5 minutes) is available at the cost of vestibular discomfort; this mode is reserved for structural emergency scenarios only.

6. Thermal Regulation and Radiative Balance

This study aimed to assess the adoption readiness and feasibility of electric aircraft for regional air transport in the The habitat thermal system must reject heat from crew metabolic loads (~100 W per person × 24 crew = 2.4 kW), electronic systems (~50 kW), superconducting coil cryocooler operation (~30 kW), and auxiliary systems, totalling approximately 100–150 kW under nominal operation with peak loads up to 250 kW during high-intensity operations.

6.1 Radiative Rejection

The primary thermal rejection mechanism is radiation from deployable panel arrays mounted on the outer ring's non-habitable exterior surface. The Stefan-Boltzmann radiative power per unit area at radiator temperature T_r with surface emissivity ε is:

$$P\_rad = \varepsilon \sigma T\_r^4 \quad \text{(Eq. 6)}$$

For $\varepsilon = 0.90$ and $T_r = 320$ K (nominal radiator operating temperature), $P\_rad = 535$ W/m². A total radiator area of 467 m² is required for 250 kW rejection at this temperature. The outer ring circumference at the equatorial plane is $\pi \times 100 = 314$ m; a 1.5 m-wide deployable panel strip around the complete outer circumference provides 471 m², meeting the requirement with margin. Two independent panel circuits provide N+1 redundancy against single-circuit failure.

6.2 Phase-Change Thermal Buffering

Phase-change material (PCM) thermal storage buffers transient thermal loads arising from solar illumination transitions, high-activity crew periods, and propulsion events. PCM units embedded in the outer ring wall use a paraffin-based compound with a melting point of 315 K and a latent heat of ~200 kJ/kg. A PCM mass of 500 kg provides 100 MJ of buffer capacity, sufficient to absorb 250 kW of unrejected heat for approximately 7 minutes while radiator orientation adjusts or backup radiators deploy.

6.3 Cryogenic Thermal Isolation

The superconducting coil system at 20–40 K is thermally isolated from the habitable environment by multi-layer insulation (MLI) blankets providing an effective emissivity below 0.01. Heat leak from the 300 K habitat environment to the 30 K coil system through a 0.5 m MLI stack is estimated at 0.5 W/m² of insulation area; for a total coil surface area of approximately 400 m² per ring, total parasitic heat leak is approximately 200 W per ring, within cryocooler design margins.

7. Power Distribution and Redundancy

Primary power is supplied from GNMT or MSH propulsion systems via a rotating power transfer assembly at the central spine interface. Slip-ring assemblies rated for 500 kW at 600 V DC provide continuous power transfer to both counter-rotating rings without mechanical contact degradation through the use of liquid metal or brush-and-ring assemblies rated for the expected multi-year contact lifetime.

7.1 Triple Superconducting Bus Architecture

Power is distributed within each ring via a triple-tiered superconducting bus. Bus A serves life support and safety-critical systems; Bus B serves habitat systems and laboratory equipment; Bus C serves auxiliary, propulsion interface, and non-essential loads. Under nominal operation all three buses are powered from the primary supply. Loss of primary supply causes automatic load-shedding of Bus C; loss of Bus A primary triggers immediate switch to battery backup with a 72-hour minimum capacity at life-support-only loads.

7.2 Magnetic Isolation and Solar Event Protection

High-energy solar particle events (SPE) and GCR flux can induce transient voltages in power distribution wiring and degrade electronics. The superconducting bus architecture provides inherent magnetic isolation between distribution segments due to the diamagnetic shielding effect of superconducting conductors. Additionally, rad-hardened electronics are specified for all control systems. The GRFF Layer 2 hydrogen-rich membrane contributes to GCR and SPE dose reduction for sensitive electronics located within the habitat wall structure.

7.3 Propulsion and Experimental Power Interfaces

The central spine includes two high-capacity power taps (5–20 kW each) for GNMT-REMN diagnostics, NGLS recharge, and EM-curvature experimental modules. These taps are electrically isolated from the levitation bus and routed through independent converters to prevent cross-coupling with the superconducting bearing system.

8. Failure Modes and Contingency Protocols

The habitat's failure mode architecture is designed around three principles: no single failure threatens crew survival; all critical failures have automated initial responses and crew- executable recovery procedures; and structural failure modes default to stable configurations rather than catastrophic outcomes.

8.1 Ring Desynchronisation

Loss of synchronisation between inner and outer ring rotation rates introduces net angular momentum, imposing gyroscopic torques on the habitat-vehicle interface. Automated desynchronisation detection compares ring tachometer signals with 100 Hz; a difference exceeding 0.01 RPM for more than 2 seconds triggers-controlled speed rebalancing through differential electromagnetic braking on the leading ring. If desynchronisation cannot be corrected within 60 seconds, both rings initiate controlled spin-down to zero. The central spine's attitude control system compensates for induced torques during the desynchronisation event using GNMT or MSH thrust vectoring.

8.2 Magnetic Field Collapse

Partial or total loss of superconducting coil field removes magnetic levitation, transferring ring loads to mechanical backup contact bearings sized for 110% of total ring mass. Backup bearings support the rings for up to 72 hours at reduced rotation rates (≤1.0 RPM, providing 0.07 g in the outer ring—below physiological minimum but survivable) while cryogenic recovery is attempted. If field cannot be restored within 72 hours, controlled spin-down to zero and emergency habitat reconfiguration is initiated. The cryogenic buffer volume ensures a minimum 8-hour response window before coil warmup begins.

8.3 Thermal Overload

Radiator failure scenarios are managed through load-shedding protocols that reduce non- essential power consumption to remain within the surviving radiator capacity. With 50% radiator loss, a load-shedding sequence reduces habitat power demand to 125 kW within 5 minutes through staged shutdown of non-safety-critical systems. The PCM buffer absorbs transient overloads during the load-shedding transition. A thermal ceiling of 330 K for habitable volume air temperature is enforced by DIGSP, which initiates load-shedding recommendations before crew action is required.

8.4 Structural Ring Breach

The habitat rings are divided into eight independent pressurised sectors per ring, each with automatic isolation valves responding to pressure differential >0.5 kPa/s. Breach of any single sector seals that sector within 3 seconds. GRFF Layer 2 self-sealing elastomers provide first-line puncture closure for MMOD impacts before sector isolation is required. Loss of any two non-adjacent sectors can be tolerated without crew evacuation at reduced rotation rate; loss of two adjacent sectors initiates controlled spin-down and crew transfer to the opposing ring.

9. Governing Equations

This section presents the complete governing equation set with derivations, physical parameters, and evaluated results for the Dual-Ring Habitat reference design.

9.1 Centripetal Acceleration

The artificial gravity experienced at radius r in a habitat rotating at angular velocity ω is the centripetal acceleration:

$$a\_c(r) \ = \ \omega^2 \, r \quad \text{(Eq. 7)}$$

For the design values ω = 0.396 rad/s and r_o = 50 m: a_c = 7.85 m/s² = 0.80 g. For r_i = 37.5 m: a_c = 5.88 m/s² = 0.60 g. The required angular velocity for a target gravity level g_t at radius r is ω = √(g_t / r); for 0.8 g at r = 50 m this gives ω = 0.396 rad/s = 3.78 RPM, correcting the originally stated value of 2.0 RPM, which would produce only 0.18 g at 50 m radius.

9.2 Hoop Stress in the Ring Structure

The centrifugal loading on the rotating ring structure generates hoop stress σ_h in the ring wall material. For a thin-walled ring of density ρ, radius r, and angular velocity ω:

$$\sigma\_h \ = \ \rho \, r^2 \, \omega^2 \quad \text{(Eq. 8)}$$

For a carbon-fibre composite ring structure with ρ = 1,600 kg/m³ at r = 50 m, ω = 0.396 rad/s: σ_h = 1,600 × 2,500 × 0.157 = 0.629 MPa. The tensile strength of aerospace carbon-fibre composite is approximately 1,500 MPa, yielding a safety factor of approximately 2,400. Structural loading is dominated by internal pressure and MMOD impact resistance rather than rotational stress, confirming that rotation-induced hoop stress is not a design driver.

9.3 Magnetic Levitation Force Balance

The magnetic pressure P_mag generated by a magnetic field of flux density B in free space provides the levitation support force per unit area:

$$P\_mag = B^2 / (2\mu_0) \quad \text{(Eq. 9)}$$

For B = 1.5 T: P_mag = (1.5)² / (2 × 4π × 10⁻⁷) = 895,000 Pa ≈ 895 kN/m². Field stability is maintained at ±0.01 T through closed-loop flux feedback, corresponding to a levitation force variation of ±(2 × 1.5 × 0.01) / (2μ₀) ≈ ±12 kN/m², or ±1.3% of nominal levitation force — adequate for smooth bearing operation without mechanical contact.

9.4 Angular Momentum Cancellation

For zero net angular momentum enabling free vehicle reorientation, the angular momenta of the two counter-rotating rings must be equal in magnitude:

$$L\_net = I_1\omega_1 + I_2\omega_2 = 0 \quad \text{(Eq. 10)}$$

For rings approximated as thin toroids with moments of inertia I = m r², and equal rotation rates $|\omega_1| = |\omega_2|$ = ω in opposite senses, the cancellation condition requires:

$$m\_o\, r\_o^2 = m\_i\, r\_i^2 \implies m\_o / m\_i = (r\_i / r\_o)^2 = (37.5 / 50)^2 = 0.5625 \quad \text{(Eq. 11)}$$

The inner ring must therefore be more massive than the outer ring by a factor of 1/0.5625 = 1.778 — that is, the inner ring mass must be 177.8% of the outer ring mass for perfect angular momentum cancellation. In practice, active electromagnetic trim using differential current in the coil systems provides fine cancellation, with the passive mass ratio designed to within ±5% of the ideal value.

9.5 Thermal Radiative Equilibrium

Under steady-state conditions the habitat radiates all internally generated heat Q_into deep space:

$$Q\_in = Q\_out = \varepsilon\, \sigma\, A\_rad\, T\_r^4 \quad \text{(Eq. 12)}$$

where ε is radiator emissivity, σ = 5.67 × 10⁻⁸ W/(m²·K⁴) is the Stefan-Boltzmann constant, A_rad is radiator area, and T_r is radiator temperature. For Q_in = 250 kW, ε = 0.90, T_r = 320 K: A_rad = 250,000 / (0.90 × 5.67 × 10⁻⁸ × 320⁴) = 250,000 / 534.6 = 467 m². The design provides 471 m² through a 1.5 m equatorial strip around the 100 m outer ring circumference.

9.6 Coriolis Acceleration

In the rotating reference frame, a crew member moving at velocity v relative to the ring experiences a Coriolis acceleration:

$$a\_Cor = 2\, \omega \times v \quad \text{(Eq. 13)}$$

The maximum Coriolis acceleration for normal locomotion at v = 1 m/s is 2 × 0.396 × 1.0 = 0.792 m/s². At the outer ring this is 10.1% of floor gravity; at the inner ring it is 13.5% of floor gravity. Cross-ring head movements at angular velocity v_head = 0.5 rad/s produce Coriolis acceleration a_Cor,head = 2 × 0.396 × 0.5 × 0.15 m = 0.059 m/s² (0.6% of floor g) well below vestibular detection thresholds.

10. Comparative Analysis

Table 3 compares the Dual-Ring Habitat against four established artificial-gravity design concepts across key performance dimensions.

Table 3. Comparative assessment of artificial-gravity habitat architectures.

Parameter	Stanford Torus [6]	O'Neill Cylinder [7]	Tethered Counter-Rotating	Single-Ring Centrifuge	Dual-Ring (this work)
Outer radius	900 m	3,200 m	Variable (tether length)	Typically 10–50 m	50 m

Rotation rate for 1 g	1.0 RPM	0.5 RPM	Variable	4–13 RPM	3.78 RPM (0.8 g)
Net angular momentum	Non-zero	Zero (dual cylinder)	Near-zero (tether)	Non-zero	Zero (by design)
Gyroscopic coupling	Significant	Eliminated	Minimised	Significant	Eliminated
Coriolis environment	Very low (large r)	Very low (large r)	Moderate	Severe (small r)	Moderate, within tolerance
Structural complexity	High (solar sail scale)	Extreme	Moderate	Low	Moderate
Mission-crew scalability	Colony- scale only	Colony-scale only	Moderate	High	High
Propulsion integration	Not addressed	Not addressed	Limited	Limited	Full Canon integration
Active defence integration	Not addressed	Not addressed	Not addressed	Not addressed	GRFF integrated
TRL estimate	2–3	2–3	4–5	5–6	4–6 (subsystem range)

10.1 Against Large-Scale Classical Designs

The Stanford Torus [6] and O'Neill Cylinder [7] are colony-scale architectures designed for populations of 10,000–1,000,000 persons at radii of 900 m and 3,200 m respectively, where Coriolis effects are physiologically negligible and structural challenges are dominated by mass supply constraints rather than rotation mechanics. Neither concept addresses propulsion integration, active defence, or mission crew-scale operation. The Dual-Ring Habitat occupies a different design space: missions of 12–100 crew for durations of one to ten years, integrated with high-performance propulsion and defence architectures.

10.2 Against Tethered Counter-Rotating Systems

Tethered counter-rotation achieves near-zero net angular momentum without the superconducting coil complexity of the Dual-Ring approach, at lower structural mass. However, tether systems require careful deployment and retrieval procedures, are vulnerable to micrometeoroid tether severance, and provide limited integration with the habitat's structural shell for GRFF defence layer mounting. The rigid dual-ring architecture provides a more integrated platform for the GRFF defence envelope at the cost of higher structural mass.

10.3 Against Single-Ring Centrifuges

Small-radius single-ring centrifuges (r = 10–50 m) require high rotation rates (4–13 RPM) to achieve adequate gravity levels, producing Coriolis environments that are physiologically problematic without extensive adaptation. They also introduce substantial gyroscopic coupling with vehicle attitude control. The Dual-Ring Habitat resolves both issues while maintaining a mission-relevant crew capacity.

11. Griffiths Canon System Integration

11.1 Integration with GNMT v7.0 and REMN Propulsion

The Dual-Ring Habitat is structurally and thermally keyed to the GNMT v7.0 Nuclear Microwave-Thermal propulsion architecture. The spine-mounted water-tank pod array used by GNMT for dual-use shielding and propellant storage aligns with the habitat's longitudinal axis, providing 20–40 cm water-equivalent shielding in the crew-facing direction. Mechanical and thermal interfaces ensure that GNMT radiator fields do not impinge on the habitat's radiator belt, preserving independent thermal loops while allowing cross-strapped contingency operation.

11.2 NGLS EVA Logistics Integration

The habitat incorporates four NGLS-compatible EVA logistics ports on the outer ring and two on the central spine. Each port provides mechanical capture fixtures, power/data umbilicals, and standardized cargo rails for DIMDCP-fabricated components. Clearance envelopes allow NGLS operation while the rings rotate at 3.78 RPM, with approach corridors aligned to minimize Coriolis workload.

11.3 DIMDCP Fabrication and External Construction

DIMDCP-fabricated components (radiator panels, coil housings, truss elements) are delivered externally via NGLS and mounted using standardized EVA-safe interfaces. This enables distributed construction and repair without reliance on robotic arms.

11.4 EM-Curvature Experimental Hosting

Two experimental bays in the spine are reserved for compact superconducting EM-curvature test modules. These bays share HTS technology lineage with the levitation coils but are electrically and mechanically isolated to prevent perturbation of the bearing fields. Power allocation (5–20 kW), thermal rejection, and vibration isolation are treated as governed boundary conditions [15].

12.   Future Research Directions

Six priority research directions are identified. Physiological validation at 3.78 RPM: controlled human centrifuge studies with extended adaptation protocols (>30 days) are needed to confirm the operational viability of the 3.78 RPM environment for missions exceeding one year. Published short-duration studies support viability; long-duration data at this rotation rate does not exist yet. HTS coil system space qualification: radiation-hardened REBCO coated conductor performance under combined GCR, HZE particle, thermal cycling, and mechanical vibration loads characteristic of deep-space transit requires dedicated test programme development. Magnetic levitation bearing scaling: terrestrial maglev bearing demonstrations at habitat-ring mass scales (hundreds of tonnes) have not been performed; a sub-scale ring demonstrator at 10–20 m radius is the recommended development step. ISRU-enhanced ring mass from in-situ resources: lunar or asteroid regolith-derived material for inner ring ballast mass could eliminate the requirement to launch the 1.78× inner-to-outer mass ratio from Earth, significantly reducing mission cost. Multi-mission ring expansion: the architecture's modularity supports ring circumference extension by insertion of additional structural segments; structural analysis of ring joint interfaces and coil continuity across added segments requires dedicated study. GRFF–habitat integrated testing: the combined behaviour of GRFF active field systems and rotating superconducting habitat coils under simultaneous operation must be characterised to verify electromagnetic compatibility and absence of resonant coupling. Future work includes integration testing with GNMT-REMN thrust transients, NGLS EVA logistics workflows, and the EM-curvature experimental modules hosted in the spine bays.

13.   Conclusions

The Griffiths Dual-Ring Superconducting Artificial-Gravity Habitat Architecture presents a physically self-consistent, mission-scalable solution to the long-duration deep-space habitation problem that addresses the fundamental shortcomings of single-ring and large- radius classical designs. The architecture's principal contributions are a counter-rotating dual-ring configuration achieving zero net angular momentum and eliminating gyroscopic coupling with attitude control, with the angular momentum cancellation condition formally derived (Eq. 10); physically corrected rotation parameters establishing 3.78 RPM as the required rate for 0.8 g at 50 m outer radius and 0.6 g at 37.5 m inner radius (Eqs. 1–2), correcting the original published value; a superconducting toroidal coil system providing magnetic levitation, structural support, and field stability at ±0.01 T with a proven HTS materials basis; a Coriolis environment at 10.1% of floor gravity that is within published adaptation limits; and a radiative thermal system providing 250 kW rejection through 467 m² of deployable panels at 320 K. The architecture integrates cleanly within the Griffiths Canon, with defined structural, power, thermal, and governance interfaces to GRFF, GNMT, MSH, NGLS, and DIGSP. The GRFF four-layer defence envelope mounts directly to the outer ring structure, providing habitat survivability in the micrometeoroid and radiation environments of deep space. Priority future work includes long-duration physiological validation at 3.78 RPM, HTS coil space qualification testing, and a sub-scale maglev bearing demonstrator. The architecture as defined provides a complete engineering framework and a clear development roadmap for the first operationally credible compact artificial-gravity habitat system for deep-space human missions.

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14. References

[1] LeBlanc, A. D., Schneider, V. S., Evans, H. J., Engelbretson, C., & Krebs, J. (1990). Bone mineral loss and recovery after 17 weeks of bed rest. Journal of Bone and Mineral Research, 5, 843–850. https://doi.org/10.1002/jbmr.5650050807.

[2] Shackelford, L. C. (1996). Musculoskeletal response to space flight. In C. Leach Huntoon, V. Antipov, & A. Grigoriev (Eds.), Humans in spaceflight (pp. 151–170). American Institute of Aeronautics and Astronautics. https://doi.org/10.1007/978-1-4939-9889-0_19.

[3] Charles, J. B., & Lathers, C. M. (1991). Cardiovascular adaptation to spaceflight. Journal of Clinical Pharmacology, 31, 1010–1023. https://doi.org/10.1002/j.1552-4604.1991.tb03665.x.

[4] Lang, T., LeBlanc, A., Evans, H., Lu, Y., Genant, H., & Yu, A. (2004). Cortical and trabecular bone mineral loss from the spine and hip in long-duration spaceflight. Journal of Bone and Mineral Research, 19, 1006–1012. https://doi.org/10.1359/JBMR.040307.

[5] Simons, D. G. (1961). Symposium on the medical and biological aspects of the energies of space. Columbia University Press.

[6] Johnson, R. D., & Holbrow, C. (Eds.). (1977). Space settlements: A design study (NASA SP-413). National Aeronautics and Space Administration. Retrieved from https://ntrs.nasa.gov/citations/19770014162.

[7] O'Neill, G. K. (1974). The colonization of space. Physics Today, 27, 32–40. https://doi.org/10.1063/1.3128863.

[8] Gurrisi, C., Seidel, R., Dickerson, S., Didziulis, S., Frantz, P., & Ferguson, K. (2010, May). Space station control moment gyroscope lessons learned. In Proceedings of the 40th Aerospace Mechanisms Symposium.

[9] Clément, G., & Bukley, A. (Eds.). (2007). Artificial gravity. Springer. https://doi.org/10.1007/0-387-70714-X.

[10] Griffiths, W. (2025). The Griffiths reactive-field framework (GRFF) v5.0: An integrated five-technology, four-layer active/passive defence architecture for deep-space habitats. Acta Astronautica (Submitted).

[11] Oman, C. M., Lichtenberg, B. K., Money, K. E., & McCoy, R. K. (1988). M.I.T. ELF rotating room experiments: NASA artificial gravity workshop. NASA Johnson Space Center.

[12] Young, L. R. (1999). Artificial gravity considerations for a Mars exploration mission. Annals of the New York Academy of Sciences, 871, 367–378. https://doi.org/10.1111/j.1749-6632.1999.tb09198.x.

[13] Wang, K., Dong, H., Huang, D., Shang, H., Xie, B., Zou, Q., ... & Ding, F. (2022). Advances in second-generation high-temperature superconducting tapes and their applications in high-field magnets. Soft Science, 2(3), N-A. https://doi.org/10.20517/ss.2022.10.

[14] Griffiths, W. (2024). The Griffiths free-flying EVA logistics sled (NGLS v3.0). Zenodo. https://doi.org/10.5281/zenodo.18169752

[15] Griffiths, W. (2025). The Griffiths dual-intellect governance and supervisory protocol (DIGSP) v4.0. Acta Astronautica (Submitted).

[16] Griffiths, W. (2024). The Griffiths nuclear-powered, microwave-thermal propulsion architecture (GNMT v5.2). Zenodo. https://doi.org/10.5281/zenodo.18275070

[17] Griffiths, W. (2024). The Griffiths methane-steam hybrid regenerative propulsion system (MSH v4.1). Zenodo. https://doi.org/10.5281/zenodo.18165748.

15. Biography

Wayne Griffiths is an independent researcher specialising in deep-space systems architecture, propulsion engineering, habitat design, and autonomous governance systems. His work spans the Griffiths Canon of integrated space systems including GNMT nuclear-microwave propulsion, Methane-Steam Hybrid propulsion, NGLS free-flying EVA logistics, the GRFF active/passive defence framework, and DIGSP human–synthetic supervisory governance. His research focuses on integrated mission architectures for sustained human presence beyond the inner solar system.

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17. Conflict of Interest

Declarations of interest: none.

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