Aegis Orbital Compute Node (AOCN)

LEO Compute Architecture Constrained by Power Generation, Heat Rejection, and Serviceability

Technical Dossier · Revision 1.1

Revision 1.1 — Assumption Review

This revision corrects an internal inconsistency in the thermal control section: the prior version paired a radiator operating temperature of 350–450 K with a heat rejection rate of 500–1,000 W/m², which are mutually inconsistent by the Stefan-Boltzmann relation. The correct operating temperature for a COTS GPU cooling architecture is 290–330 K. The revised radiator area requirement is 1,800–3,300 m² per MW (compared with a prior stated range of 2,000–5,000 m²/MW). This revision also establishes solar array area (~2,500 m²/MW) as a co-equal structural driver, and adds eclipse buffering mass (~2.6 tons/MW) as a planning consideration. Substantive program conclusions are unchanged.

Program Positioning

The Aegis Orbital Compute Node (AOCN) is a modular compute platform intended for deployment in Low Earth Orbit (LEO). The architecture is defined by first-order physical constraints: electrical power generation, waste heat rejection, radiation environment, and on-orbit servicing.

AOCN is not intended to replicate terrestrial data centers in orbit. It is structured as an orbital compute accelerator for workloads where power density, thermal isolation, or space adjacency dominate over latency, interactive access, or geographic proximity.

The concept is grounded in current launch capabilities, existing space-qualified power and thermal technologies, and commercially available compute hardware. No speculative propulsion systems, materials, or unproven physics are assumed.

Design Constraints and Assumptions

1. THERMAL SCALING DOMINATES

Sustained compute output is bounded by radiator area, operating temperature, and heat transport capacity. Compute density does not set system scale.

2. INFRASTRUCTURE SEPARATION

Power generation, thermal control, shielding, and communications are treated as persistent infrastructure. Compute hardware is assumed to have a shorter refresh cycle and is designed to be replaceable.

3. INCREMENTAL DEPLOYMENT

Nodes are designed to be deployed, serviced, and upgraded independently, avoiding monolithic structures with large fault domains and high replacement risk.

Baseline Orbit and Operating Regime

Orbit	500–600 km circular LEO
Inclination	51.6° (ISS-class) or sun-synchronous variants
Eclipse fraction	~35% worst-case (β = 0°); improves toward sun-synchronous geometry. Orbital period ~96 min at 550 km; worst-case eclipse ~35 min. Battery or throttle-on-eclipse strategy required for continuous full-power operation.
Radiation environment	Magnetosphere-protected; manageable single-event upset (SEU) rates
Design life	10–15 years per node with modular refresh

LEO is selected to balance radiation exposure, servicing accessibility, communications latency, and launch cost within current operational norms.

System Architecture Overview

1. STRUCTURAL CORE

- Cylindrical or hex-prismatic pressure-tolerant module
- Aluminum-lithium primary structure
- Internal racks mounted on vibration-isolated frames
- External attachment points for radiators, solar wings, and communications booms

No rotating elements are required. Artificial gravity is unnecessary for electronic systems and would complicate thermal and structural design.

2. COMPUTE PAYLOAD

- Hardware class: Commercial GPUs, accelerators, and CPUs (COTS)
- Form factor: Ruggedized rack units with conformal coating

- Fault tolerance: ECC memory throughout, continuous memory scrubbing, checkpointed workloads, graceful degradation at the node level

The system is designed under the assumption that single-event upsets occur and are handled at the software and system level. This approach mirrors long-duration ISS avionics practices applied to modern compute payloads.

3. Thermal Management and Heat Rejection (Revised)

All electrical input power ultimately becomes waste heat. The thermal subsystem therefore sets the upper bound on continuous operation.

Correction: Operating Temperature

The prior version stated a radiator operating temperature of 350–450 K alongside a heat rejection rate of 500–1,000 W/m². These figures are mutually inconsistent. By the Stefan-Boltzmann relation ($Q = 2\varepsilon\sigma T$■ for a two-sided panel, $\varepsilon \approx 0.88$), the theoretical rejection rate at 350 K is ~1,500 W/m² and at 450 K is ~4,100 W/m² — far above the stated range. The 500–1,000 W/m² figure corresponds to panel temperatures of roughly 275–325 K, which is consistent with COTS GPU thermal requirements. The temperature label "350–450 K" has been corrected to "290–330 K" for this architecture.

CORRECTED THERMAL OPERATING REGIME:

Commercial GPUs have junction temperature limits of approximately 363 K (90 °C). A practical cooling loop delivers coolant to the radiator at roughly 300–330 K after accounting for thermal resistance across the cold plate and heat exchanger. Theoretical two-sided rejection at this temperature range is 490–760 W/m², falling to approximately 300–550 W/m² after applying a 0.6 effective factor for solar loading, view-factor losses, and degradation margin.

Outlet Temp	Two-sided (theoretical)	Effective (~×0.6)	Area per MW
275 K (2 °C)	571 W/m²	343 W/m²	2,920 m²
300 K (27 °C)	808 W/m²	485 W/m²	2,060 m²
325 K (52 °C)	1,113 W/m²	668 W/m²	1,497 m²
350 K (77 °C) — exceeds COTS limits	1,498 W/m²	899 W/m²	1,113 m²
400 K (127 °C) — exceeds COTS limits	2,555 W/m²	1,533 W/m²	652 m²

REVISED RADIATOR AREA REQUIREMENT:

Using the corrected 290–330 K operating temperature and a 0.6 effective factor, the revised radiator area per MW of sustained electrical input is approximately **1,800–3,300 m²**. The prior lower bound of 2,000 m²/MW remains within range; the prior upper bound of 5,000 m²/MW is overly conservative and has been revised downward. The lower area figures become achievable at higher coolant temperatures, which may be possible with future non-COTS hardware tolerating higher junction temperatures.

THERMAL ARCHITECTURE COMPONENTS:

- Cold plates at the compute rack level
- Pumped liquid cooling loops
- Heat exchangers feeding deployable radiator panels
- Radiators segmented, replaceable, stowable for launch
- Loop design derived from ASI tanker and station thermal heritage

4. Power Generation, Storage, and Eclipse Operations

Addition: Solar Arrays as a Co-Equal Structural Driver

Prior documentation emphasized radiator area as the dominant structural driver. Solar array area (~2,500 m²/MW) is comparable in scale and should receive equal weight in structural and launch planning. At 1 MW, total deployed surface area combining radiators and solar wings approaches 4,000–6,000 m².

PHASE 1 — BASELINE:

Solar constant at LEO	~1,361 W/m²
Array efficiency	~28–30% (triple-junction GaAs, current COTS space-grade)
Array area per MW output	~2,450–2,600 m²
Array specific power	~150–200 W/kg (modern deployable arrays)
Array mass per MW	~5–7 metric tons
Power range	1–5 MW class per node
Eclipse fraction (worst case)	~35% (35 min per 96-min orbit at $\beta = 0°$)
Eclipse buffering energy per MW	~580 kWh (worst-case 35-min eclipse at full power)
Battery mass per MW (Li-ion, 225 Wh/kg)	~2.6 tons At 2 MW: ~5.2 tons. Throttle-on-eclipse strategy can substantially reduce this penalty.

Eclipse operating strategy: For non-latency-sensitive batch workloads, throttling compute during eclipse periods (approximately 36% of orbit time at worst case) rather than buffering full power is likely the more mass-efficient approach. This reduces battery mass from ~2.6 tons/MW to a smaller buffer sized for graceful state preservation rather than full-power continuation.

PHASE 2 — ARCHITECTURE-COMPATIBLE EXTENSION:

- Nuclear heat source with Brayton conversion
- Shared radiator farms
- Power export to adjacent Aegis infrastructure
- Eliminates eclipse dependency and battery mass requirement

5. Radiation Mitigation and Shielding

- Passive aluminum hull shielding
- Targeted water shielding around compute racks
- Optional use of lunar-sourced water in later phases

This approach reduces SEU rates and thermal variability without imposing the mass penalties associated with deep-space hardening.

6. Communications Architecture

SPACE-TO-SPACE:

- Optical (laser) inter-satellite links
- High-bandwidth, low-interference backbone

SPACE-TO-GROUND:

- Hybrid optical and Ka-band RF
- Optical downlinks to dedicated clear-sky ground stations
- RF fallback for availability and legacy integration

AOCN is optimized for batch, streaming, and asynchronous workloads. The architecture does not assume ultra-low-latency interactive access.

Representative v1.0 Node Specifications (Revised)

Parameter	Value	Notes
Total Mass	40–80 metric tons	Includes structure, shielding, compute racks, solar arrays, batteries, thermal hardware
Continuous Compute Output	200–500 kW (accelerator TDP)	All accelerator power ultimately becomes heat; figure represents total rack TDP, not net "useful" output
Electrical Input	1–2 MW	—
Radiator Area (revised)	1,800–3,300 m² per MW	Revised from prior 2,000–5,000 m²/MW; based on corrected 300–330 K operating temperature with 0.6 effective factor
Solar Array Area	~2,500–5,000 m² (1–2 MW node)	Co-equal structural driver alongside radiators; ~2,500 m² per MW at 29% efficiency
Battery Mass (eclipse)	~2.6–5.2 tons (1–2 MW)	Worst-case 35-min eclipse at full power. Throttle-on-eclipse reduces this substantially.
Shielding Mass	15–50 tons (water + structure)	—
Operational Life	10–15 years	Per node with modular refresh of compute payload

Radiator area corresponds to approximately 0.34–0.62 American football fields per MW (5,350 m² per field including end zones). Solar array area adds a further ~0.47 fields per MW. Combined deployed surface area for a 1 MW node: approximately 0.8–1.1 football fields. These figures are included for physical scale reference only.

Operational Concept

- Nodes launched in modular segments
- Assembled robotically or via crewed servicing missions
- Compute payloads swappable without de-orbit
- Radiators and solar wings replaceable independently
- Nodes operate autonomously with periodic ground tasking
- Eclipse-period compute throttling as a mass-efficient alternative to full battery buffering

Representative Workload Classes

The following examples characterize workload types compatible with the architectural assumptions above (illustrative, not exhaustive):

- AI and ML training runs
- Climate and physics simulations
- High-energy rendering and modeling
- Secure government compute workloads
- Space-based autonomy and navigation processing
- Pre-processing for Earth-based data centers

AOCN does not compete with terrestrial hyperscalers; it complements them where Earth-side power, cooling, or security constraints dominate.

Integration with the Aegis Ecosystem

Servicing	Robotic + crew-compatible
Tankers	Delivery of water shielding and thermal working fluids
Long-Hauler	Logistics, relocation, and servicing
Aegis Station	Crewed maintenance and future power sharing
Gradient One	Adjacent artificial-gravity research
LMM	Space-adjacent AI workloads and autonomy research

In later phases, AOCN functions as a distributed compute layer supporting orbital and cislunar infrastructure.

Architectural Summary

In orbit, compute hardware is not the primary scaling constraint. Power generation and heat rejection dominate system size, mass, and operational complexity.

AOCN explicitly treats these constraints as first-order design drivers and organizes compute capability around infrastructure that can be assembled, serviced, and expanded using current spaceflight technologies.

Revision 1.1 corrects the thermal operating temperature assumption to align with COTS GPU constraints, establishes solar array area as a co-equal structural driver alongside radiators, and adds eclipse buffering mass as a planning consideration. The program architecture, modularity principles, and strategic positioning are unchanged.