IntelliMindEd, 2(4), 2026, 24-29
DOI: 10.69687/vaf.2026.1.5

VIVIDHA 2026 ACADEMIC FAIR

SCV-AEGIS Mk-II: Autonomous Orbital Debris Remediation and In-Situ Manufacturing Vehicle

Dinesh Javvaji[1], Swapnil Banerjee[2], Tvisha Gaddigopula[3], Yashasvin Kagitha[4], Sree Vardhan[5]

[1-5]Students, Delhi Public School, Miyapur, Hyderabad, Telangana, India.

*m160350@dpsmiyapur.com, m202476@dpsmiyapur.com, m160580@dpsmiyapur.com, m192176@dpsmiyapur.com, m160389@dpsmiyapur.com

Abstract

Introduction: Low Earth Orbit (LEO) is currently overcrowded with over 130 million pieces of orbital debris, ranging from defunct spacecraft to shattered upper rocket stages. At orbital velocities exceeding 7.8 km/s, even millimetre-sized fragments possess sufficient kinetic energy to cause catastrophic damage to active space infrastructure and scientific stations. Conventional remediation strategies rely exclusively on atmospheric re-entry mechanisms, dragging debris into the atmosphere to burn up upon re-entry. While this removes immediate collision hazards, it inherently treats valuable aerospace-grade materials (titanium, aluminium-lithium alloys, high-grade stainless steel) as disposable waste while introducing secondary atmospheric pollution.

Research Problem: Existing Active Debris Removal (ADR) systems face severe economic and thermodynamic limitations. The high energetic cost (Av) of chasing individual target

pieces combined with the financial waste of single-use disposal vehicles makes widespread orbital remediation economically unsustainable under current architectures.

Project Objectives: The Space Cleaning Vessel Architecture for In-Situ Reclamation (SCV-AEGIS Mk-II) proposes an autonomous, closed-loop orbital utility vessel designed to capture, detoxify, melt, refine, and repurpose space debris entirely in orbit. Rather than burning scrap metal, the vessel converts captured alloys into standardized 50-gram metallic pellets. These pellets serve two operational functions: (1) feedstock for in-space additive manufacturing, and (2) reaction mass for an onboard Linear Electromagnetic Mass Driver propulsion system operating at 3,000–4,000 m/s nominal exhaust velocity. This research details the thermodynamic, mechanical, and economic feasibility of the SCV-AEGIS Mk-II platform.

Methodology: Sudarshana The operational methodology of the SCV-AEGIS Mk-II is structured around a sequential, six-stage processing chain engineered to execute fully autonomous orbital debris remediation:

3.1 Capture and Non-Contact De-Spin (Phase 1)

Uncontrolled debris often exhibits multi-axis tumbling at angular velocities ranging from 10 to 60 RPM. Direct mechanical grasping under these conditions risks catastrophic structural failure or joint shearing. The SCV-AEGIS Mk-II utilizes a non-contact Strobe-Synchronized Laser Ablation system. High-peak-power pulsed lasers target the rotational extremities of the debris, inducing localized material vaporization. The resulting micro-ablation plasma plumes generate counter-torque momentum vectors that systematically damp angular velocity over a 12-to-24-hour period. Once de-spun below 0.1 RPM, the vessel deploys an 8m × 6m mechanical capture maw equipped with synchronized robotic arms to securely dock the target.

3.2 Volatile Fuel Recovery & Decontamination (Phase 2)

Captured upper stages and defunct satellites often contain residual toxic hypergolic propellants (Monomethylhydrazine [MMH] and Nitrogen Tetroxide [NTO]). Processing un-vented tanks in a high-temperature furnace poses severe explosion risks. Cryo-siphoning robotic manipulators dock with pressure relief valves or pierce tanks under depressurized pre-processing airlock conditions to extract residual hypergols, storing them safely for secondary propulsion or chemical neutralization.

3.3 Vacuum Induction Melting (VIM) (Phase 3)

Cleaned structural scrap is transferred to a primary processing chamber utilizing Radio-Frequency Vacuum Induction Melting (RF-VIM). Operating in the microgravity vacuum of space, RF coil networks induce eddy currents within the target metal, generating intense localized Joule heating without physical crucible contact. This eliminates furnace lining contamination and enables melting temperatures exceeding 1,660°C.

3.4 Fractional Separation & Quality Control (Phases 4 & 5)

Molten alloys are passed through an Eddy Current Separator. Differences in electrical conductivity and density allow separation of distinct metallic phases—separating Aluminum (T□ = 660°C) from Titanium (T□ = 1,660°C) and routing non-conductive slag to dedicated containment. Inline laser-induced breakdown spectroscopy (LIBS) monitors alloy composition, ensuring the reclaimed output achieves ≥95% purity before being sintered into standardized 50g spherical pellets.

3.5 Nuclear Power Architecture & Thermal Management

To meet continuous operational demands without relying on bulky, fragile solar arrays vulnerable to space debris, the platform utilizes a flight-proven Kilopower-class High-Assay Low-Enriched Uranium (HALEU) nuclear fission reactor. The system delivers 80 kWt of thermal output, converted via closed-loop Stirling power engines into 20 kWe of electrical power (25% thermal-to-electric efficiency). Thermal waste heat (60 kWt) is managed using carbon-nanotube folding radiators operating between 700K–800K

Results & Discussion: Engineering analysis and parametric system modelling validate the performance, thermal balance, and economic viability of the SCV-AEGIS Mk-II design over conventional single-use mission profiles.

Table 1: System Engineering Specifications & Operational Performance Metrics

Subsystem Parameter	Engineering Specification / Baseline Value	Operational Impact & Function
Reactor Thermal Output (Q^{th})	80 kWt (Kilopower Core)	Drives Stirling converters and VIM heating chambers
Electrical Output (P^{e})	20 kWe (25% Conversion Efficiency)	Powers RF induction, mass driver, and laser de-spin
Waste Heat Rejection (Q waste)	60 kWt via CNT Radiators	Maintains thermal equilibrium at 700K–800K operating temp
Propulsion Mechanism	Linear Electromagnetic Mass Driver	Superconducting coils shoot standardized pellets
Exhaust Velocity Range	3,000 m/s – 4,000 m/s nominal	Delivers high specific impulse (I[illegible])≈ 306–408 s)
Pellet Specification	50 grams (Sintered Metallics)	Standardized reaction mass and 3D printing stock
Metallurgical Purity	≥95% alloy purity achieved	Ensures structural integrity for orbital construction
Mass Driver Ejection Vector	Heliocentric trajectory offset	Guarantees zero secondary orbital debris accumulation

Propulsion Physics & Trajectory Safety Analysis: The Linear Mass Driver accelerates 50g sintered metallic pellets at velocities of ve = 3,000-4,000 m/s relative to the spacecraft. Operating at an orbital velocity of orbit $\approx$ 7,000 m/s relative to Earth, backward-ejected reaction mass pellets achieve net velocities that alter their orbital energy. Ejection vectors are actively computed to ensure expended pellets enter Earth-escape trajectories or retrograde burn orbits that guarantee atmospheric burn-up within designated corridors, ensuring absolute zero secondary LEO debris generation.

Economic Valuation & Offset Model: Ground-to-LEO launch costs currently average approximately $2,500 per kg. By manufacturing propellant pellets and structural feedstock directly in orbit, SCV-AEGIS Mk-II generates up to $2.5 million in value per ton of processed material. Initial non-recurring engineering (NRE) and launch capital expenditures are estimated at $1.07B – $1.37B, with follow-on units costing ~$250M.

The ability to harvest infinite reaction mass in orbit creates a self-sustaining operational model, bypassing the fuel-depletion limits of traditional spacecraft.

Conclusion: Project The SCV-AEGIS Mk-II represents a paradigm shift in space sustainability-transitioning orbital debris management from a passive costly cleanup burden into an economically viable, resource-generating industrial process. By integrating laser de-spin, vacuum induction melting, magnetic separation, Kilo power nuclear architecture, and electromagnetic mass driver propulsion, the platform solves the core kinetic and thermodynamic challenges of in-situ resource utilization (ISRU).

Future Work: Phase 2 development will focus on high-fidelity vacuum chamber microgravity melting simulations, terrestrial bench top scaling of the 20 kWe Kilopower Stirling integration, and joint development of autonomous target-docking algorithms using machine-vision telemetry.

Keywords: Orbital debris remediation, active debris removal, *in-situ* resource utilization, space manufacturing, vacuum induction melting, electromagnetic mass driver, autonomous spacecraft, orbital sustainability.

References

1. M. A. Gibson, L. S. Mason, C. A. Bowman, and D. I. Poston, "The Kilopower Reactor Using Stirling Technology (KRUSTY) Nuclear Ground Test Performance Results," NASA Technical Reports Server, NTRS 20180002162, 2018.
2. D. J. Kessler and B. G. Cour-Palais, "Collision frequency of artificial satellites: The creation of a debris belt," Journal of Geophysical Research: Space Physics, vol. 83, no. A6, pp. 2637–2646, 1978.
3. G. K. O'Neill, "The colonization of space," Physics Today, vol. 27, no. 9, pp. 32–40, 1974.
4. R. Sharma and A. Kumar, "Innovation and entrepreneurship among students," International Journal of Educational Research, vol. 12, no. 3, pp. 45–58, 2025.

5. World Economic Forum, “The Future of Jobs Report 2025,” 2025. [Online]. Available: https://www.weforum.org/