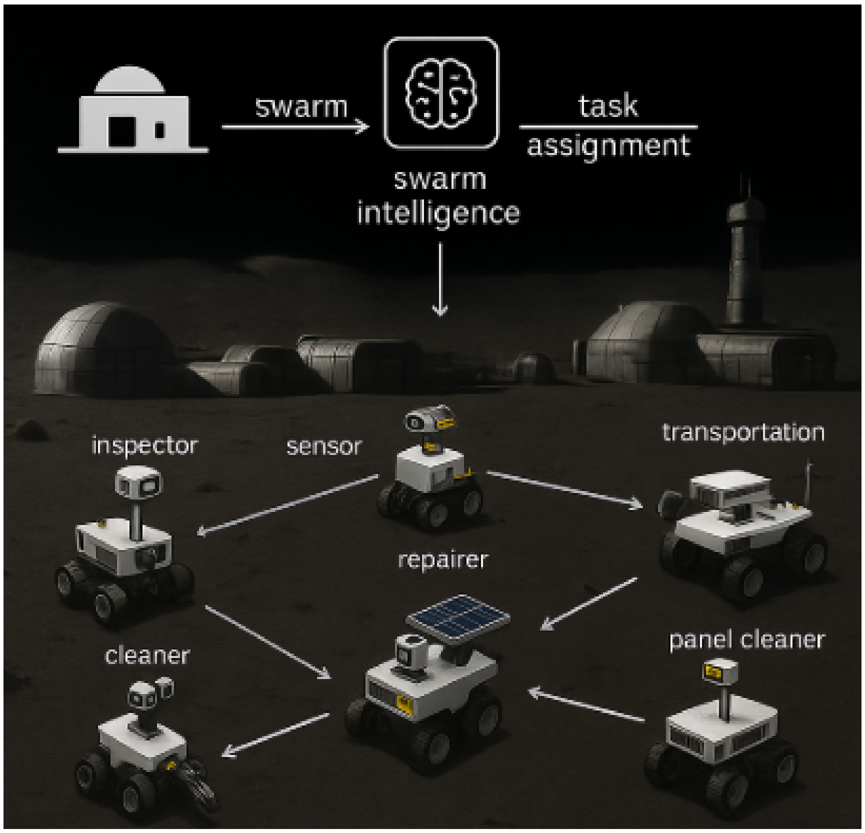
Lunar & Planetary Servicing Swarm Robots



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Abstract

The NASA Artemis program aims to attain a consistent lunar presence through the establishment of a Lunar Base Camp on the Lunar South Pole (Steigerwald, 2023) and a Moon Fission Surface Power Source (Bausback, 2024). The initiative would lay the foundation to humanity's transformation into a multi-planetary species, but the first phase of development presents unprecedented engineering and logistical challenges that demand advanced extraterrestrial repair, construction, and maintenance relying on operating autonomously. Innovative technologies such as NASA's ARMADAS system (Gregg, 2023), MIT and Aurelia Institute's TESSERAE project (Axiom Space Research, Accessed 2025), and the Canadian Utility Rover (Government of Canada, 2025) are pioneers in autonomous construction, self-assembling, and robotic tool utilization respectively. Building on these effects, the proposed Lunar & Planetary Servicing Swarm robots aim to integrate the strengths of these emerging technologies into one cohesive system. Employing a multi-robotic system, the heterogeneous swarm features two types of agents: (1) repairer robots equipped with interchangeable end-effectors for inspection, construction, and maintenance, and (2) block-like, self-assembling robots capable of adaptive structural formation. The team plans to utilize the $10,000 grant to develop a simple, small-scale prototype in 12 months: A non-homogenous swarm demonstrating autonomous coordination, object recognition, hand-tool manipulation, and self-assembly and collaboration - each demonstrated by its respective robot subtype. Team 11 will leverage university resources and makerspaces, especially the Swissler Innovative Robotics Lab and NJIT ECE Robotics lab of our two academic embedded SMEs, if selected. The Work Development plan will follow structured phases, from design review and simulation to integration, testing, and final demonstration by the 12th month. Furthermore, the mechanism performance will be evaluated based on the five key Figures of Merit: autonomy, communication, efficiency, scalability, and self-assembly quality across both types of robotic agents within the swarm.

Technology and Merit Work Plan

Concept Description

The Lunar and Planetary Servicing Swarm Robots are designed to be a non-homogeneous swarm. The hybrid swarm intelligence algorithm would enable the robots to operate as a unified, smart system rather than as simple, isolated units. It would be achieved by exchanging data and sensor readings, sharing individual locations with other robots, allocating tasks to specific units, accessing the overall swarm task progress and synchronizing behavior with one another in real time. This coordination will be implemented through a hybrid of the Consensus-Based Bundle Algorithm (CBBA) and a Gossip Consensus protocol. CBBA will allow each agent to autonomously bid for and claim tasks based on proximity, available energy, and capability, ensuring distributed task allocation without central control. The Gossip Consensus algorithm will maintain shared awareness among agents by asynchronously propagating updates on position, status, and progress across the swarm, enabling fault-tolerant and delay-resilient communication. This heterogeneous swarm will have 2 main types of robotic agents with vastly different physical designs and programming to cover all facets of autonomous space infrastructure operations. One set of the non-homogeneous swarm will be composed of "Repairer bots" with removable end-effectors that allow the units to attach a specific robotic manipulator that may be more suited to the task at hand. With end-effectors varying from suction cups, drills, grippers, welding torches and more, these robots will be capable of a variety of tasks - ranging from inspection and maintenance to infrastructure construction and repair - either individually or cooperatively. For navigation and obstacle avoidance, the repairer bots will utilize the D* Lite algorithm for dynamic path planning on unpredictable lunar terrain, complemented by the Optimal Reciprocal Collision Avoidance (ORCA) algorithm to prevent inter-agent collisions in real time. Object recognition and tool manipulation will be achieved through a TensorRT-optimized YOLOv8-nano model for visual detection and a Damped Least Squares inverse kinematics solver for precision arm control. The baseline design of this type of robotic unit includes a durable, waterproof electronics box body that protects a repairer robot's on-board computer, hazard avoidance and navigation cameras, an inertial measurement unit, a LiDAR, frequency antennas, a brushed DC motor, and other electronics. The suspension system shall be an aluminum 4-wheel and 360-degree turn with individual motors, similar to NASA's Perseverance (Lindsey, 2025). In contrast, the second set of robots will be the "Robricks": autonomous, mobile, and self-assembling triangular prism units that implement algorithms enabling the swarm to configure itself into any needed geometry quasi-stochastically. The robricks' self-assembly behavior will be modeled on fire-ant swarm bridge formation algorithms and Northwestern's Kilobots SDASH algorithm, both using local interaction rules and load-based attachment decisions to build ramps, stairs, or platforms collectively. Each unit will follow decentralized attachment heuristics, forming stable temporary structures that can adaptively reconfigure when the swarm's task priorities change. The robricks will be capable of reconfiguring themselves into a stair-like formation, providing the repairer robots with different levels of elevation needed for operations of higher reach. By combining these two highly distinct physical abilities within one swarm, the robots will be able to communicate as one and behave as two interconnected systems to provide autonomous inspection and maintenance for future lunar and planetary infrastructures, and even become the infrastructure itself if necessary. The components and complexity of the prototype will be of much lower quality than the usual space specs to fit within the $10,000 budget, but will serve as a stepping stone to the autonomous extraterrestrial habitat construction ideal these Lunar & Planetary Servicing Swarm Robots have the potential to become. The original quad chart is included in the appendix.

Application Description

There have been numerous development plans for plausible lunar and Martian bases over the years, but Thales Alenia Space's Lunar Multi-Purpose Habitat aims to be the first outpost on the moon, marking a significant project in the Artemis program. Even if Artemis does not move forward with the proposed habitat, scientists and engineers from space agencies, academia and the private sector have determined that there are specific operational necessities that any kind of lunar infrastructure will have. Decreasing the amount of lunar infrastructure development work for astronauts is essential; automating the operations is an optimal solution. Lunar & Planetary Servicing Swarm Robots aim to achieve this by introducing a heterogeneous swarm capable of maintenance and repair. The self-assembling part of the swarm aims to provide structural support by elevating itself, transforming into stair-like blocks that enable the rover-like robots to reach higher and perform their tasks. Besides the obvious lunar infrastructure development, one of the most important tasks identified is the preparation of landing/launching pads. It has already been proposed to use a lunar rover to deal with relative positioning, site leveling, boundary delineation, and revetment construction in the designated landing/launching pad area (Yifeng et al, 2025). In addition, lunar roadbeds are a necessity to provide the stable surface needed to support the movement of rovers, cargo vehicles, and construction equipment around a lunar base or exploration site; which (Yifeng et al, 2025) also attribute a lunar road-paving vehicle to be a great solution. Magnetrons, solar and laser methods are discussed in the paper. Either way, developing end-effectors designed for pad positioning and lunar soil melting for the rover-like Lunar & Planetary Servicing Swarm Robots would address these applications. Another specific need for construction robotic systems NASA has identified is the development and maintenance of lunar solar power sources. These power stations are supposed to provide the amount of electricity any kind of lunar habitat will need to sustain itself, which creates a need for kilometers-long cable inspection, mobility and connection between the power plants and human lunar habitats. A need a robotic swarm could meet by providing multiple regions of grip for cable deployment. Other potential task examples are transporting cargo, inspecting scientific stations, scouting for lunar regolith and other materials, supporting or replacing astronauts during spacewalks in hazardous areas, among other routine operations.

State of the Art Overview and Metric

Established lunar and planetary robotics efforts focused on advanced navigation, autonomy and sample collection in extreme environments; such as the Perseverance, Curiosity, among other historic rovers. However, the space sector is moving away from singular large vehicles and exploring sets of multiple robots. JPL's Cooperative Autonomous Distributed Robotic Exploration, or CADRE, is leading the charge in exploiting multi-robot teams capable of cooperative mapping and decision making without continuous human input. On another front, emerging technologies such as NASA's Automated Reconfigurable Mission Adaptive Digital Assembly Systems - ARMADAS - aim to develop the hardware and software needed to develop robots that autonomously assemble materials to make a variety of functional lunar structures via their inchworm-like robots (Gregg, C.E, 2023). On the other hand, university-company collaborations such as MIT and Aurelia Institute attempt to autonomize the infrastructure itself via self-assembling, adaptive, and reconfigurable structures with their Tessellated Electromagnetic Space Structures for the Exploration of Reconfigurable, Adaptive Environments -TESSARAE - project, which are 20 hexagonal tiles and 12 pentagonal tiles. (Aurelia Institute, Accessed 2025). In addition, the Canadian Utility Rover is designed for transportation, logistics, science, and other operations that can be accomplished with robotic tools to allow astronauts to focus on tasks where human judgment and initiative are required. (Canadian Space Agency, 2025). Both ARMADAS and TERRASAE are in the beginning prototyping and testing stages. ARMADAS has already demonstrated, at NASA's Ames Research Center, that it is possible to build a system of robots that work collaboratively to autonomously construct a shelter structure made of hundreds of building blocks (Figliozzi, 2024). Meanwhile, TESSARAE has had 2 International Space Station demonstrations, where it showed improved algorithmic design for autonomous self-assembly and modifications to the physical shell to improve bonding reconfigurability. The Canadian Utility Rover is currently in the early concept development phase (Canadian Space Agency, 2025). Besides the achievements mentioned above, the public is unaware of the qualitative metrics and capabilities. Nevertheless, these technologies serve as baselines for primitive swarm coordination behavior and self-assembly algorithms.

Improvement of the SOA and its Limitations

The Lunar and Planetary Servicing Swarm Robots improve the State of the Art by shifting from existing single, remotely operated, and high-mass systems - e.g., Canadarm2, Dextre, OSAM-1, and TESSERAE - to a heterogeneous swarm capable of distributed servicing, cooperative manipulation, and adaptive self-assembly on planetary surfaces. Task allocation and collective decision making among the swarm, using CBBA and Gossip Consensus, occur in real-time and do not rely on a central controller; D* Lite and ORCA allow for adaptive navigation and collision avoidance in unstructured lunar terrain (Choi et al., 2009). The capabilities of autonomous tool use via YOLOv8 perception and Damped Least Squares IK enable operating far beyond traditional space manipulators that continuously require a human supervisor. Nevertheless, these algorithms have some consequential considerations: CBBA and Gossip Consensus will suffer rapidly with limited communication (Koulouriotis et al., 2025); D* Lite navigation requires reliable sensing which can then be challenged further in lunar dust and limited light (Gaier et al., 2020); ORCA depends on velocity exchanges, which can be delayed due to effects of lunar attenuation; and vision-based data may not always be accurate in direct sunlight or filth on regolith. Overall, nonetheless, despite limitations, this type of System, providing scalable and fault-tolerant multi-agent autonomy, indicates a considerable advance in the current State of the art of lunar servicing and construction work in the future.

Key Technical Challenges and Risk Mitigation

Overall Swarm (both types of units):

Fault Tolerance, and Performance Continuity: In such a large robot network, a singular failure must not jeopardize the mission during remote missions. The swarm robots must still be able to carry out tasks as assigned, despite a unit or multiple units malfunctioning, which poses a challenge in designing systems which can detect failures fast and reassign tasks intelligently amongst functional networks and dynamically reconfigure formation to ensure the mission continues. To mitigate the issue, local peer-to-peer meshes and a decentralized autonomy - meaning no leader whatsoever within the swarm - will allow for robot networking while still maintaining independent capabilities.

Collective Communication in Robust Environments: Unstable atmospheric conditions - dust accumulation, for example - and geographical terrains - craters. rocks, etc - can impact a robot's antennas and sensors causing malfunction and disrupting the inter-robot links (Zhang et al, 2025); causing errors in inter-swarm communication, and thus coordination. A reliable mesh networking architecture with fail tolerant communication protocols and a physically suitable design - radiation-resistant, thermally resistant, durable, etc - are necessary to mitigate the situation.

Repairer Bot:

Swarm Intelligence Algorithm: Designing algorithms for swarm coordination can be challenging; especially when balancing cost and functionality. Using the pre-existing open-source swarm intelligence algorithms as a baseline, the bots will 1) move forward, 2) rotate, 3) communicate with nearby neighbors, 4) measure distance to nearby neighbors, and 5) have sufficient memory to run (Rubenstein et al., Accessed 20205)

Navigation & Control: The repairer bots will utilize the D* Lite algorithm for dynamic path planning on unpredictable lunar terrain, complemented by the Optimal Reciprocal Collision Avoidance - ORCA - algorithm to prevent inter-agent collisions in real time. Object recognition and tool manipulation will be achieved through a TensorRT-optimized YOLOv8-nano model for visual detection and a Damped Least Squares inverse kinematics solver for precision arm control.

Data Relays: Minimal human interaction and reporting is still required for higher level system management (Jet Propulsion Laboratory, 2024), but storing and sending too much information in short amounts of time can be challenging for the swarm. However, programming the robots with an opportunistic robotic sync will give them the ability to hold onto data locally and relay it within communication range, compress data for storage management, delete relayed and redundant data, and prioritize data by mission relevance in situations of limited bandwidth and energy (Shahzad et al., 2023).

Modular Integration and Interface Standardization (Maintenance Tasks): Complexity constraints in mass, power, standardized tools, power, data interfaces, and cross-compatibility among its interchangeable end-effectors will be essential to enable scalable servicing missions across different off-planet conditions (Dias et al., 2021). This presents design and integration challenges as interfaces must be capable of quick reconfigurations or upgrades to avoid mission downtime.

Robricks:

Swarm Intelligence Algorithm: The units must follow decentralized attachment heuristics, forming stable temporary structures that can adaptively reconfigure when the swarm's task priorities change. Their self-assembly behavior will be modeled on fire-ant swarm bridge formation algorithms, using local interaction rules and load-based attachment decisions to build ramps, stairs, or platforms collectively, as well as Northwestern's Kilobots SDASH algorithm.

Modular Integration and Interface Standardization: The units must move, align, and mate reliably despite surface roughness, tilt, and manufacturing tolerances during assembly. Thus, the rodbricks must not be energy expensive nor fall victim to small compounding errors. Team 11 addresses the energy and mobility issues by equipping the robobricks with a dependable number of actuators and retractable wheels, enabling them to drive themselves to a desired location and assemble, respectively.

Load Capacity: An individual robricks must tolerate loads significantly larger than their own mass to create the necessary ramp-like structures needed to provide elevation to the repairer bots. This can be achieved by designing a clear load path, adding a distributed control algorithm for load sharing, implementing energy-efficient locking for rapid initial staging,g and using heavier materials - in comparison to the repairer bots - to build the robricks.

Key Performance Parameters (KPP) and Minimum Performance Metrics

The minimum performance metrics require that each robot clears a 1.5-foot obstacle, escapes partial burial, carries 30 kg in loose soil, operates for 48 hours, and maintain 100-ft robot-to-robot communication. Algorithmic thresholds include conflict-free CBBA task assignment, stable consensus convergence, >95% successful replanning via D* Lite, and collision-free ORCA performance during multi-agent mobility. These metrics must achieve a 95th percentile success rate in simulation, desert, and rocky-terrain tests. Collectively, these capabilities surpass State-of-the-Art systems, such as Canadarm2, Dextre, OSAM-1, and TESSERAE, which rely on single large manipulators or structured environments. The proposed swarm replaces these limitations by offering fault-tolerant, surface-ready, decentralized autonomy with cooperative manipulation, real-time replanning, and dynamic self-assembly.

Table 1. Key Performance Parameters

KPP	Threshold	Objective
Autonomy Level	Semi-autonomous; human check-in every 30–60 min	High autonomy; human check-in <10 min/hr
Swarm Communication	≥ 85% reliable data delivery	≥ 98% reliable data delivery
Task Efficiency	≥ 60% efficiency vs baseline	≥ 85% efficiency vs baseline
Battery Life	≥ 3 hours continuous operation	≥ 6 hours continuous operation
Payload Support/Modularity	Supports 1 tool/module swap	≥ 3 swappable modules + auto tool swap
Coordination Accuracy	≥ 75% successful coordinated operations	≥ 95% coordinated operations
Scalability	Stable up to 10 robots	Stable at 50+ robots
Load Capacity (repairer bot)	≥ 80% successful at lifting ½ its mass	≥ 90% successful at lifting 1.5 its mass
Load Capacity (robricks)	≥ 100% robot mass, ≥ 80% success	≥ 150% robot mass, ≥ 90% success

Note. Supporting data sources are listed in the reference section

Development Work Plan Overview

The Lunar & Planetary Servicing Swarm Robots final deliverable will be approached with a series of structured and sequential phases during the 12-month grant period to ensure technical maturity, traceability, and timely achievement of the project's objectives. These development phases begin with a review of requirements and performance parameters during the first 3 weeks, followed by finalizing component trade studies by the 2nd month. By the third month, the team will establish the testing environment and strategies, and complete simulation development by the fifth month. Manufacturing and hardware integration is scheduled to be completed by the ninth month, with thorough testing of swarm coordination and individual robot manipulation taking place around the tenth month. The final two months will focus on needed redesigns and system fixes to meet the Key Performance Parameters. Ultimately, a final demonstration is scheduled by the end of the 12th month. Each phase is supported by milestone reviews to address any technical or logistical issues early, ensuring a robust and capable swarm robotic system.

Implementation Challenges

Deploying the Lunar and Planetary Servicing Swarm Robots entails several technical considerations, including distributed autonomy, heterogeneous hardware, and operation in harsh environments. The primary challenge lies in ensuring multi-robot coordination reliably using CBBA and Gossip Consensus. These algorithms operate effectively in ideal scenarios but assume regular communication across the swarm. Lunar occlusion of the terrain, dust, or misalignment of antennas can limit usable bandwidth, resulting in the late reassignment of tasks, incoherent shared maps, or sluggish convergence of consensus. Stable coordination will necessitate fallback modes, adaptive communication schedules, and preventions against conflicting assignments. In addition to these challenges, navigation presents further problems. D* Lite operates on accurate and frequent update maps from the LiDAR, IMU, and cameras, but lunar environments are known for extreme . ORCA supports safe motion from multiple robots; however, the algorithm is contingent on timely and accurate exchanges of velocities. Communication latency or packet loss could result in slow movement, misleading safety margins, or lead to deadlock in cluttered environments (Van den Berg et al., 2011). Carefully tuning, redundancy of different sensing modalities, and extensive simulation will be necessary to fuse these algorithms into the same navigation stack before any evaluation in the field. The heterogeneous design of the swarm adds mechanical and integration risks. Repairer bots must support multiple end-effectors, multi-degree-of-freedom arms, and a rugged mobility system that can navigate through soft soil and rocky terrain, all while staying within the restrictive $10,000 hardware budget. Robrick units shall achieve reliable self-assembly using compact drive systems, retractable wheels, magnets, and precise local sensing, while adhering to the stringent constraint of maintaining structural stability with non-space-rated components. There are also challenges regarding manipulation and tool interaction. YOLOv8-based perception and Damped Least Squares IK require consistent pose estimation and calibrated cameras; lunar-like lighting conditions may reduce detection accuracy and compromise manipulation performance (Jocher, 2023). The design of interchangeable tool interfaces is further complicated because the robots have different arm geometries. Testing and verification continue to be major challenges. It is challenging to validate swarm behavior through repetitive multi-robot trials across diverse terrain, as lab spaces in universities, budget constraints, and hardware wear and tear limit testing possibilities. Meeting all the threshold performance metrics of obstacle traversal, load-bearing, soil escape, 48-hour endurance, and 100-ft communication with necessary reliability will call for iterative redesign and careful risk management.

Similarities and Differences from Internal and External NASA Technology Development Efforts

Team 11 takes some inspiration from NASA's Perseverance Rover: Implementing a warm electronics box as the repairer units' "body", hazard avoidance and navigation cameras - Ultra High, X-Band High, and X-band low - Frequency Antennas, gently curved, robust aluminum wheels for rough terrain endurance, and a 4-wheel suspension system connecting said wheels (Lindsey, 2025). Components of a much lower quality for the swarm prototyping phase to fit within the $10,000 budget. One of the main differences between the Lunar and Planetary Servicing Swarm Robots and previous rovers is the collaborative decision making, task allocation, and coordinated navigation capabilities, which drives the originality of this robotic system. To achieve the uniqueness mentioned above, the robots shall possess slightly varied sensing ranges, velocity limits, payload capacities, numbers of articulated joints, complexities in their robotic end-effectors, and additional instruments, depending on task specialization. An important distinction will be the individual robotic arms of the swarm robots. Perseverance is a singular rover with a turret that functions as an end-effector that allows it to hold scientific instruments for different scientific objectives, ranging from drilling to sample collecting. (Bailey et al, 2022). Unlike past space robots, each unit will have a robotic arm with varied mass, reach, ultimate load capacity, degrees of freedom, rotational control and maneuver complexity from the other robots depending on mission designation. Another difference will be the power source. Lunar and Martian rovers typically feature a radioisotope power system, a technology utilizing the natural radioactive decay of plutonium-238, which is best suited for dark and dusty extraterrestrial environments (Barnett, 2025). This technology will not be employed in our final swarm deliverable. When it comes to the self-assembling part of the swarm, unlike TERASSAE, the robots will have wheels that allow them to move to their desired position, and retract their wheels to allow for a planar surface for other robots to lay. Nevertheless, just like TERASSAE, the robots will implement magnets to ensure the swarm formation stays in position. In contrast, the code shall be modified but draw inspiration from Fire-ants and Kilobots.

Table 2. Solicitation Requirement: Similarities and Differences

Solicitation Requirement	Current State of the Art (SOA)	Similarities	Differences

Autonomous lunar surface operating robotic systems	Large single-agent autonomous robot (Canadram2, Dextre, NASA OSAM1)	Aimed for autonomous maintenance and servicing operations	SOA is still human dependent with limited automation and some are not surface operable.
Swarm coordination	Fire-ant and Kilobots	Collective task coordination goal	No proven multi-robot servicing on lunar terrain
Dexterous repairs/assembly robotic manipulation	Microgravity robots (ISS Robonaut, Canadarm2) and robotic arms	Usage of autonomous robotics for movement and manipulations	Large Current systems are large, single-point manipulators with limited maneuverability
Modular and reconfigurable robotic systems	Limited modularity (ROSA, NASA OSAM1, TERASSAE)	Goal of reconfigurability and adaptability	No lunar-ready standard robots with inter-connected robotic interface
Human-swarm collaboration frameworks	Single/independent human-robot control	Intuitive human oversight for critical management	Lacks support for large scale robotic network with limited use of AI
Distributed decision making for remote operations	Existing path finder tools and mission scheduler for large robotic operation	Need for autonomous determination of mission planning	No distributed, fault-tolerant planning with self-healing for swarms
Power source	Lunar and Martian Rovers	None	Space robots usually have a radioisotope power system. The Solicitation prototype will have batteries.

Note. All supporting data sources are listed in the reference section

Statement of Expectation Matching and Exceeding of New Technology against SOA's performance

The proposed Lunar and Planetary Servicing Swarm Robots are expected to match and exceed current state-of-the-art technologies by providing faster responses and greater redundancies. Unlike existing systems such as NASA's ARMADAS or MIT's TESSERAE, which focus primarily on autonomous construction and adaptive infrastructure, the swarm approach integrates collective decision-making and distributed task execution in dynamic environments. This enables the system to perform complex tasks together; significantly improves efficiency and operational flexibility while maintaining full functionality despite individual unit failures. By combining non-homogeneous swarm intelligence with real-time adaptive coordination, the project aims to achieve a higher level of autonomy and scalability in extraterrestrial operations, ultimately surpassing current SOA capabilities.

Project Management Approach

New Technology's Project Management Development Approach

The project employs a structured approach aligned with system engineering best practices to guide the development of lunar and planetary servicing swarm robots. Word proceeds through clearly defined stages like the requirements reviews, design, component analysis, simulation, prototyping, integration, and validation. Each are set milestones and deliverables. Each phase ends with a system engineering review to evaluate progress and address risks early. Task allocation leverages team expertise in robotics, software development and hardware engineering. Iterative development cycles with built-in margins allow the team to adapt quickly to technical challenges. Continuous documentation, milestone reviews, and scheduled testing ensure technical maturity and timely achievement of objectives, culminating in a robust and automated swarms system ready for demonstration in under one year.Setbacks are absorbed by built-in time margins, protecting the overall timeline. System engineering reviews will be conducted during each phase to maintain quality and traceability.

Schedule, Major Milestones and Deliverables Identification

- **Completion of requirements and design review (Month 1):** Establish all functional and performance requirements and complete a preliminary design package including autonomy architecture, mechanical concepts, and verification plans.
- **Component trade study and subsystem architecture (Month 2):** Review major hardware for the repairer bot. Find hardware and software components for the other robots through structured trade studies and finalize subsystem architectures for mobility, perception, communication, and autonomy.

- **Simulation testing of swarm algorithms (Month 5):** Develop a high-fidelity simulation environment and validate core swarm algorithms (CBBA, Gossip Consensus, D* Lite, ORCA, self-assembly behaviors) under various communication and terrain conditions.
- **Prototype manufacturing and integration (Month 9):** Manufacture robot components, assemble mechanical and electrical subsystems, and integrate firmware, perception modules, and preliminary autonomy functions.
- **Physical swarm coordination testing (Month 10):** Conduct multi-robot tests to validate task allocation, coordinated navigation, self-assembly, and tool-use capabilities in real environments.
- **Final demonstration and validation (Month 12):** Resolve hardware and software issues, ensure all minimum performance metrics are met, and deliver a final full-system demonstration of coordinated swarm servicing and self-assembly.

Statement of Required Resources, Funding, Direct Cost & Skills

Project execution will rely on a combination of university-provided facilities, specialized hardware, open-source software resources, and team expertise. Access to institutional makerspaces, AI and robotics laboratories, and high-performance computing clusters will support both the design and simulation phases without additional direct cost. Components chosen and cost estimates are based on previous robotics projects and institutional resources, ensuring each phase is properly supported; with the specified hardware being recommended by Dr. Wilex.

Repairer Bot: Hardware Requirements and Cost Estimates:

- NVIDIA® Jetson Orin™ Nano Super Developer Kit – $249 per unit: Used as the primary onboard computing platform for perception, control, and swarm communication algorithms.
- Adafruit 9-DOF Orientation IMU Fusion Breakout (BNO085/BNO080) – $24.95 per unit: Provides inertial data for motion tracking, navigation, and stabilization across varying lunar terrains.
- RPLIDAR A2M12 360° Laser Range Scanner – $279.25 per unit: Enables spatial mapping, obstacle detection, and real-time environment modeling for autonomous navigation.
- ZED Mini Stereo Camera -
- 24 V Brushed DC Gear Motor 30 Nm
- RoboClaw 2x60A Motor Controller - $134.95 per unit.
- Software Tools (ROS2, Eigen C++ library, Gazebo, and OpenCV, etc) - $0.00 (Imagines of some of the components are in the appendix)

Lab space, manufacturing equipment, swarm and robotics professionals provided by university, thus free of cost. The direct costs are limited to only the types of essential physical materials (robot frames, motors, sensors, IMUs, and Li-ion batteries), and should be less than $10,000. These contributions include access to high-performance computing, 3D printing, electronics workstations, and assembly space, with no rental or usage costs. In addition, it includes the specific materials and sensors for the self-assembling robots, provided by Dr. Swissler and the Swissler Innovative Robotics lab. Software development and simulations are accomplished entirely with cost-free, open-source software, which contributes only in terms of hours of human labor.

Necessary Hours and Skills Declaration

Project Phase	**Primary Activities**	**Estimated Hours**	**Cost Type**
Requirements & Design	System specifications, CAD modeling, and documentation	150	Free (university resources)
Simulation & Software Development	ROS2, Gazebo simulations, swarm-algorithm programming	300	Free (open-source software)
Hardware Procurement & Manufacturing	Component assembly, sensor calibration, wiring, mechanical fabrication	350	Direct (materials & tools)
System Integration & Testing	Swarm communication, coordination trials, field testing	250	Free (university lab space)

Validation & Final Demonstration	Performance evaluation, redesigns, reporting, and presentation	200	Free (institutional support)

Teaming and Workforce Development

Name	University	Role / Weekly Time	Experience
Tatiana Mejia Camargo	New Jersey Institute of Technology (NJIT)	Principal Investigator (PI) 8-10 hours per week	→ Two years experience as an undergraduate researcher at Swisser Innovative Robotics Lab dealing with Swarm, self-assembly and harsh-environment robotics → Robotics Engineering Intern at Andromeda Space working on autonomous satellite docking systems → Possesses certificate in advanced manufacturing and mechatronics → Conducting research on utilising AI-based metal 3D printing fracture repair under the NJ Space Grant Consortium → 3-month GNC engineering internship at Kearfott Corporation
Santiago Rojas	Florida State University	Project Manager (PM)	→ Ongoing research on exoskeletons for driver assistance underwater; working on design utilizing SOLIDWORKS. → Experience building Pet Feeder using Arduino and Fusion 360 → Member of the FSU AIAA student chapter.
Adalys Urena Almonte	NYU Tandon of Engineering	Engineering Manager 8-10 hours per week	→ Deputy Project Manager of Resources at NASA L'SPACE Summer 2025. → Was the Head of Electrical and Computation for the MediMinder project. → Experienced in SOLIDWORKS, leadership, engineering design, collaboration, and advocacy.
Elijah Kenney	Florida Polytechnic University	Software Coordinator 8-10 hours per week	→ A member of IEEE → Experience within Intelligent Automation with AI agents, programming with robotics in VEX, and building numerous data analytics projects
Mansour Doumbia	Harvard College	Administrative Lead	→ Experiences with machine learning, Bayesian analysis methods of large datasets, computer vision and object detection. →Designed battery management systems for Mars Rover Competition and designed a magnetorquer and orientation detection-correction systems for CubeSat Team. → Fluent in C, C++, Java, Python, and other machine learning packages
Anish Kulkarni	Georgia Institute of Technology	Mechanical Engineer	→ Background in GNC modeling, VEX robotics, and mechanical simulation
Mahir Asef		Electronics Engineer	→ Specialises in FPGA, embedded systems, power distribution design, and microcontroller programming

Sai Nagamalla	UNC Chapel Hill	Swarm Intelligence Scientist	→ Specializes in CS, programming and controls
Faris Faizal	NC State	Software Engineering	→ Experience with embedded systems and several programming languages
Sriya Chakravarthula	Purdue University	Ground Control Programmer	→Designs mission control interfaces and data analysis systems for human-swarm communication and telemetry visualization

Role

Appendix

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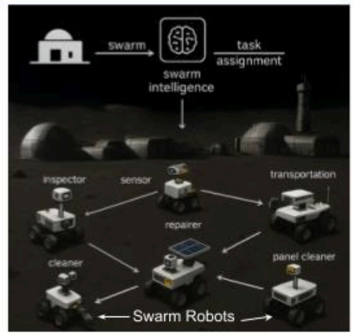
Ouad Chart

Lunar & Planetary Servicing Swarm Robots

PI: Tatiana Mejia Camargo, PM: Santiago Rojas, Team #11

Goal / Objective

- **Need:** Provide flexibility in repair, manufacturing and construction tasks in lunar and planetary surfaces without explicit human involvement. Specially needed during the development process of moon and/or mars bases to transform humanity into a multi-planetary species.
- **Solution:** Using swarm intelligence, these robots will be capable of conducting specific functions on extraterrestrial terrain at an individual scale or in groups for more complex jobs. Examples of tasks these swarm robots could perform are transporting cargo, infrastructure assembly, solar farm maintenance, cleaning and inspection of scientific stations, help astronauts with performing dangerous jobs or exploring hazardous areas, among other daily tasks.
- **Method:** Develop digital models of small robots while implementing the swarm coordination algorithm for communication. By building and testing prototypes for movement as well as developing algorithms for autonomous operation we will be able to test it.
- **NTR Qualification:** This concept does qualify for an NTR as it uniquely approaches extraterrestrial terrain operations utilizing swarm technology.
- **Funded Product:** A swarm robotic system demonstrating autonomous coordination and maintenance capability; including hand-tool manipulation and object recognition.



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Team Overview

Sai Nagamalla – UNC Chapel Hill, Computer Science
Elijah Kenney – Florida Polytechnic University, Computer Science
Mahir Asef – CUNY City College, Computer Engineering
Santiago Rojas – FSU, Mechanical Engineering
Faris Faizal – NC State, Computer Science
Tatiana Mejia – NJIT, Mechanical Engineering
Anish Kulkarni – Georgia Tech, Aerospace Engineering
Sriya Chakravarthula – Purdue University, Computer Science
Adalys Urena Almonte – NYU – Mechanical Engineering
Mansour Doumbia - Harvard College - Mechanical Engineering

- **Relevant Knowledge/Skills:** Swarm robotics, machine learning, artificial intelligence, data management, programming, system integration, telecommunications, product development, guidance, navigation and controls.
- **Relevant Resources/Facilities:** University-provided makerspaces, computing resources, and software libraries.
- **Taxonomy:** TX04.2.6 Collaborative Mobility, TX04.3.1 Dexterous Manipulation, TX04.6.1 Modularity, Commonality and Interfaces, TX10.2.1 Mission Planning and Scheduling, TXT10.3.1 Joint Knowledge and Understanding.

Metrics and Key Performance Parameters

Deploying multiple cooperative robots enables servicing tasks to be performed in parallel, decreasing downtime and extending the lifetime of critical infrastructure. Autonomous task allocation allows maintenance operation without needing to wait for human supervision from earth ensuring faster recovery from failures. Swarm robots can be mass produced making it simpler to reuse, and replace individually making it cheaper to implement and operate. They also have low liability due to the redundancy and fault tolerance (if one fails, other replace) lowering mission-critical risk for human crews and other space assets.

Metric	State of Art	Swarm Robots	Improvement
Response time	24-48 hours	3-5 hours	~75% faster
Crew risk	High	Low (fully autonomous)	~80% reduction
Mission Cost	High	Moderate (low human labor)	30-40% reduction
Single-point failure	High (single large robotic system)	Very low (redundant swarm)	>50% risk reduction

National Aeronautics and Space Administration	**Disclosure of Invention and New Technology (Including Software)**	Form Approved O.M.B. NO. 2700-0009	DATE 11/09/2025
		INT. DOCKET NO./ CONTRACTOR TRACKING NO.	NASA CENTER NTR BELONGS TO:
		NASA CASE NO. (OFFICIAL USE ONLY)	e-NTR Number (OFFICIAL USE ONLY)

This is an important legal document. Carefully complete and forward to the Patent Representative (NASA in-house innovation) or New Technology Representative (contractor/grantee innovation) at NASA. Use of this report form by contractor/grantee is optional; however, an alternative format must at a minimum contain the information required herein. NASA in-house disclosures should be read, understood and signed by a technically competent witness in the witness signature block at the end of this form. In completing each section, use whatever detail deemed appropriate for a "full and complete disclosure." Contractors/Grantees please refer to the New Technology or Patent Rights – Retention by the Contractor clauses. When necessary, attach additional documentation to provide a full, detailed description.

1. NEW TECHNOLOGY TITLE
Lunar & Planetary Servicing Swarm Robots

2. INNOVATOR(S) *(For each innovator provide: Name, Title, Work Phone Number, Org Code, and Work E-mail Address. If multiple innovators, number each to match Box 5.)*
Tatiana Isabel Mejia Camargo, Principal Investigator, (973) 866 - 7554, New Jersey Institute of Technology, tim6@njit.edu
Santiago Rojas, Project Manager, (561) 502 - 3397, Florida State University, santirojas9383@gmail.com
Adalys Urena Almonte, Mechanical Engineering Student, New York University Tandon School of Engineering, aurena616@gmail.com
Mahir Asef, Computer Engineering Student, The City College of New York, (929) 369 - 5308, mahirasef02@gmail.com

3. INNOVATOR'S EMPLOYER WHEN INNOVATION WAS MADE--PLACE OF PERFORMANCE *(For each innovator provide: Name, Department/Division and Address of Employer. If multiple innovators, number each to match Box 5.)*
New Jersey Institute of Technology, Department of Mechanical and Industrial Engineering. University Heights, Newark, New Jersey 07102
Florida State University, 222 S Copeland St, Tallahassee, FL 32304
New York University Tandon School of Engineering, 1 Metrotech Ctr, Brooklyn, NY 11201
The City College of New York, 160 Convent Ave, New York, NY 10031

4. CURRENT EMPLOYER INFORMATION *(Address(es) where Innovator is currently employed.. If multiple innovators, number each to match Box 5)*
Same as above

5. EMPLOYER STATUS *(choose one for each innovator)*

Innovator #1	Innovator #2
CU	CU
Innovator #3	**Innovator #4**
CU	CU

GE = Government
CU = College or University
NP = Non-Profit Organization
SB = Small Business Firm
LE = Large Entity

6. CONTRACT/GRANT INFORMATION

Innovator #1
✓Grant/Cooperative Agreement No. 80NSSC24M0180
☐Prime Contract No. _____
☐Subcontract _______

Innovator #2
☐Grant/Cooperative Agreement No. 80NSSC24M0180
☐Prime Contract No. _____
☐Subcontract _______

Innovator #3
☐Grant/Cooperative Agreement No. 80NSSC24M0180
☐Prime Contract No. _____
☐Subcontract _______

Innovator #4
☐Grant/Cooperative Agreement No. 80NSSC24M0180
☐Prime Contract No. _____
☐Subcontract _______

6a. Is this innovator an inventor on this technology? *An Inventor is defined as: An individual who creatively contributed in the making of the invention such as: helped conceive an element or step of the invention or helped conceive any new improvements on an element or step of the invention.*

Innovator #1	Innovator #2
✓	—
Innovator #3	**Innovator #4**
—	—

6b. For each Innovator, select all roles that apply:

Innovator #1
POC: ✓
Software Author:
Contributor: ✓

Innovator #2
POC:
Software Author:
Contributor:

Innovator #3
POC:
Software Author:
Contributor: ✓

Innovator #4
POC:
Software Author:
Contributor: ✓

7. CONTRACTOR/GRANTEE NEW TECHNOLOGY REPRESENTATIVE *(POC)* and ADDITIONAL REVIEWERS (Provide Name, E-mail, Company, Contract and role)
John Dankanish, LSPACE@asu.edu, NASA Marshall Space Flight Center, 80NSSC24M0180

8. BRIEF ABSTRACT *(Describe your technology.)*
Employing a multi-robotic system, known as MRS, the Lunar & Planetary Servicing Swarm Robots are a heterogeneous swarm featuring two types of agents: rover-like robots with interchangeable end-effectors for inspection, construction and maintenance, as well as brick-like, self-assembling robots capable of adaptive structural formation. Combining these two highly different physical abilities within one swarm, the robots are able to communicate as one and behave as two connected systems to provide autonomous inspection and maintenance to future lunar and planetary infrastructures, and become the infrastructure itself if necessary. Ultimately solving the lack of infrastructure development autonomy in lunar and planetary surfaces.

9. DESCRIPTION OF THE PROBLEM OR OBJECTIVE THAT MOTIVATED THE INNOVATION'S DEVELOPMENT *(General description of problem/objective or unique problem characteristics.)*
The NASA Artemis program aims to attain a consistent lunar presence through the establishment of a Lunar Base Camp. This will include designing habitats, communication and navigation systems and fission surface power sources to enable sustainable long-term and deep-space activities. The initiative would lay the foundation to humanity's transformation into a multi-planetary species, but the first phase of development presents unprecedented engineering and logistical challenges. To achieve such levels of structural ambition, significant advancements in extraterrestrial repair, construction and maintenance without explicit human involvement are required. Some of the most important lunar infrastructure maintenance tasks NASA has identified are the preparation of landing/launching pads, cable handling and deployment to connect lunar habitats to power stations, lunar roadbed pavement, hazardous exploration, tool and cargo collection and transport, building inspection, among others. Developing a system of robots capable of handling all aspects of infrastructure inspection, development, repair and maintenance will be the solution to the issue.

10. TECHNICALLY COMPLETE DESCRIPTION OF INNOVATION *(Purpose and description of innovation/software and explanation of mode of operation referring to drawings, sketches, photographs, graphs, flow charts, and/or parts or ingredient lists illustrating the components; functional operation; alternate embodiments of the innovation/software and supportive theory.)*
Lunar & Planetary Servicing Swarm Robots is a heterogeneous swarm composed of 2 types of robotic agents: rover-like robots with interchangeable end-effectors for inspection, construction and maintenance, as well as tile-like, self-assembling robots capable of adaptive structural formation. With vastly different physical design and programming to cover all facets of autonomous space infrastructure operations, the swarm is still capable of cooperative behavior and decision making. One set of the non-homogeneous swarm will feature rover-like robots, with removable end-effectors that allows the units to attach a specific robotic manipulator that may be more suited to the task at hand. End-effectors varying from suction cups, drills, grippers, welding torches and more; these robots will be capable of a variety of tasks, ranging from inspection and maintenance to infrastructure construction and repair - either individually or cooperatively. It offers increased adaptability; enabling improved performance in routine operations by deploying a unit with a robotic manipulator specifically designed for the task. The baseline design of this type of robotic unit includes a durable warm electronics box body protecting the robots' computer and electronics, hazard avoidance and navigation cameras, inertial measurement units, LiDAR technology, SLAM algorithms, frequency antennas, and an aluminum 4-wheel and 360 degree turn suspension system with individual motors. In contrast, the second set of robots will be tile-like autonomous, mobile and self-assembling units implementing algorithms that enable the swarm to quasi-stochastically configure itself into any needed geometry. Serving as "patchers", these flat robots are programmed to detect infrastructure damage, mobilize themselves to the affected area, connect with each other to cover all the broken sections and remain there to maintain structural integrity while the rover-like part of the swarm takes its time to inspect and repair the defects. In addition, the robricks will create an elevated formation - reconfigurable stairs - to allow the rover-like robots to reach higher if needed.

11. UNIQUE OR NOVEL FEATURES *(Provide brief details focused on what component(s) or method step(s) differentiate(s) the new technology from other similar technologies (aka the "secret sauce"). Include as attachments any presentations, images, flowcharts, etc. that help identify the unique component(s) or method step(s). If there are no unique component(s) and method step(s) (e.g. NTR submitted only for software release), state "None.")*
Emerging technologies such as NASA's Automated Reconfigurable Mission Adaptive Digital Assembly Systems - ARMADAS - aim to develop the hardware and software needed to develop robots that autonomously assemble materials to make a variety of functional lunar structures. On the other hand, university-company collaborations such as MIT and Aurelia Institute attempt to autonomize the infrastructure itself via self-assembling, adaptive, and reconfigurable structures with their Tessellated Electromagnetic Space Structures for the Exploration of Reconfigurable, Adaptive Environments -TESSARAE - project. In addition, the Canadian Utility Rover is designed for transportation, logistics, science, and other operations that can be accomplished with robotic tools to allow astronauts to focus on tasks where human judgment and initiative are required. All these projects strive to revolutionize autonomous operations in space, but Lunar & Planetary Servicing Swarm robots offer a promising solution by combining the best aspects of these emerging technologies into one product. ARMADAS uses a combination of AI algorithms and digital assembly systems to autonomously assemble small modular vortex units through a wireless network, but a set of the Lunar & Planetary Servicing Swarm robots will utilize a swarm hybrid swarm intelligence algorithm and a rover-like body for collaborative decision making, task allocation and cooperative construction without limiting itself to very restrictive building blocks. On the other hand, the second set of tile-like robots will be able to build and repair off-world habitats by connecting and reshaping to whatever needed shape to become part of lunar structures themselves, just like TESSARAE. Serving as a heterogeneous swarm capable of collective communication, decision making and task allocation while maintaining individual capability of behavior depending on task speciality, this robotic system enables optimal performance in all possible aspects of lunar and planetary infrastructure development. Unlike any of the aforementioned technologies, the robobricks part of the heterogenous swarm will allow its fellow repairer robots to reach higher by rearranging themselves into stair-like structures if needed.

12. COMMERCIALIZATION POTENTIAL *(Identify other applications for this technology beyond the specific NASA use. What type of industries would be most applicable for this technology? Are there related commercial products that you're aware of that would benefit from this technology? List any companies that you've contacted, or think may be interested in using this technology.)*
This possesses a great commercialization potential beyond its intended NASA applications. By integrating swarm intelligence, the system can be adapted for various terrestrial operations. Swarm robots could be employed for large-scale projects, tunnels, automated inspection, reducing human labor, and much more. In mining and resource extraction, their ability to navigate and coordinate across different types of terrains would enable autonomous mapping, material transport, and safety inspections around these terrains. In agriculture, it would help by creating multi-agent coordination that would enable precision planting and crop monitoring, to name a few examples. Swarm intelligence could also optimize warehouse logistics and manufacturing lines by coordinating material flow and reducing human labor. The adaptability of this system by major robotics and automation, including different types of companies that could directly benefit from implementing swarm coordination and self-assembly algorithms. Different types of aerospace and defence companies can also use this, such as Lockheed Martin and Blue Origin. Academically, NASA's Jet Propulsion Laboratory represents valuable research pathways for further development. These organizations demonstrate strong alignment with the project's objectives that could play a key role in advancing its commercialization. Lastly, swarm robotics has been investigated and developed for search and rescue in disaster

recovery; a use the team is well aware of with Swissler's Innovative Robotics Lab. In conclusion, the adaptability of the Lunar and Planetary Servicing Swarm Robots makes them a bridge between academic innovation and industrial implementation of transforming how autonomous systems are deployed beyond Earth.

13. DEGREE OF TECHNOLOGY SIGNIFICANCE (Which best expresses the degree of technological significance of this innovation?)

☐Modification to Existing Technology ✓ Substantial Advancement in the Art ☐ Major Breakthrough

14. QUESTIONS FOR SOFTWARE ONLY

a. Does this technology include custom software, developed wholly or in part under NASA funding? ✓ YES ☐NO

b. Is this technology primarily a software product or computer program technology (versus primarily a hardware technology)? ✓ YES ☐NO

c. Could the software be used or adapted for other applications outside of your project? ✓YES ☐NO

d. Does the software contain any embedded, third-party code? ✓YES ☐NO

If yes, list each third-party code by title and version, under what license they were obtained, and either cut and paste the license below or provide the URL for the license to the downloaded version of the third-party code:

Swarm-IITKgp/kilobots, GitHub Open Source, https://github.com/Swarm-IITKgp/kilobots

e. Does the software call any third-party code when it runs? ✓ YES ☐NO

If yes, list each third-party code by title and version, under what license they were obtained, and either cut and paste the license below or provide the URL for the license to the downloaded version of the third-party code:

f. Can the software be distributed without third-party code? ✓ YES ☐NO

g. Copyright registered? ☐YES ☐NO ✓ UNKNOWN

If yes, then by whom?

h. Are there any programmatic restrictions or other sensitivities that impact release/distribution of the software (e.g., contains Government sensitive information/command and control/spaceflight software, etc.)? ☐YES ✓NO ☐ UNKNOWN

If yes, explain

i. State of Development (for software only)

☐ Concept Only ✓Requirement Phase ☐Design Phase ☐Code Completed ☐Code Testing Complete ☐Used in Current Work

15. STATE OF DEVELOPMENT (*For software only, complete State of Development in question 14i.*)

✓Concept Only ☐Design ☐Prototype ☐Modification ☐Production Model ☐Used in Current Work

16. ADDITIONAL DOCUMENTATION (*Include copies or list below any pertinent documentation which aids in the understanding or application of the innovation (e.g., articles, contractor reports, engineering specs, assembly/manufacturing drawings, parts or ingredients list, operating manuals, test data, assembly/manufacturing procedures, etc.).*)

17. Does the invention or software being reported contain any restrictive notices or other indication that it includes proprietary/restricted information of a non-Government entity? (*copyright, proprietary, applicable licenses, Limited Rights/Restricted Rights, SBIR rights, etc.)?*

☑ Yes

☐ No

If yes, indicate type(s):

18. Are there any publications or public disclosures to report for this technology?

☐ Yes

☑ No

If yes, list each public disclosure, including planned disclosures. (*Include Title of Disclosure, Type of Disclosure, Disclosure By and Date of Disclosure, Location of Disclosure, Link to Document and Additional Information):*

NPWEE Quad Chart selections, Online, 10/16/2025, Zoom

19. Has any intellectual property protection (patents or copyright) been sought for this technology?

☐ Yes

☑ No

If yes, enter information on any prior patents or patent applications disclosing or related to this new technology *(list Application Serial Number, Application Filing Date, Patent Number and Patent Issue date):*

20. Does this technology have any related technologies (past or current New Technology Reports)?
- ☐ Yes
- ☑ No

If yes, list Case Number and Titles below:

21. Funding Mission directorate:
- ☐ Aeronautics Research Mission Directorate
- ☐ Human Exploration and Operations Mission Directorate
- ☐ Science Mission Directorate
- ☑ Space Technology Mission Directorate
- ☐ Other: _____

Project Name: NASA Proposal Writing and Evaluating Experience Academy (NPWEEA)
☐Unknown; the project this technology has been developed under is unknown
☐Not applicable; this technology is not associated with a funded project

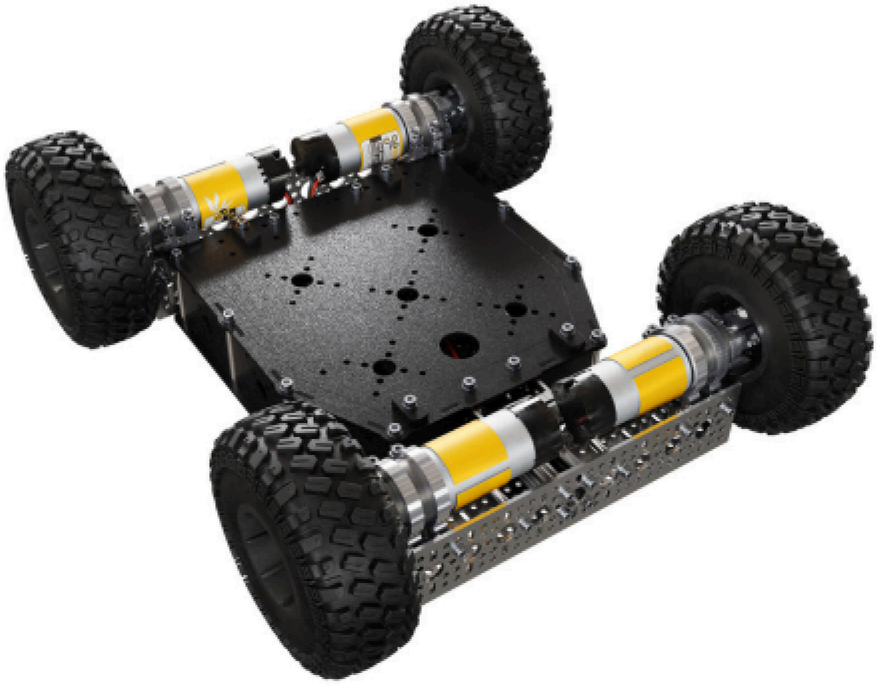
22. Contribution of innovators *(if jointly developed, provide the contribution of each innovator)*

Tatiana Isabel Mejia Camargo: Principal Investigator and inventor of the idea. Defined physical and software design, intended applications.
Santiago Rojas: Aided in identifying multiple other uses for the technology aside from the intended use.
Adalys Urena Almonte: Aided in the development plan and define merit for the technology.
Mahir Asef: Helped define implementation challenges and key performance parameters.

23. SIGNATURES OF INNOVATOR(S), WITNESS(ES), AND NASA APPROVAL

TYPED NAME AND SIGNATURE *(Innovator #1)*	DATE	TYPED NAME AND SIGNATURE *(Innovator #2)*	DATE
Tatiana Isabel Mejia Camargo	11/09/2025	Santiago Rojas	11/09/2025
TYPED NAME AND SIGNATURE *(Innovator #3)* Adalys Urena Almonte	DATE 11/09/2025	TYPED NAME AND SIGNATURE *(Innovator #4)* Mahir Asef	DATE 11/09/2025
TYPED NAME AND SIGNATURE *(Witness #1)*	DATE	TYPED NAME AND SIGNATURE *(Witness #2)*	DATE

NASA APPROVED	TYPED NAME	SIGNATURE	DATE



Chassis