Mars Exploration Program Funded Technology Development Projects (FY 2025)

James Abshire
Goddard Space Flight Center
Mini-MARLI, a small lidar for measuring of atmospheric wind and dust profiles from Mars orbit

NASA's Mars Exploration NEX-SAG has identified atmospheric wind measurements as key science objective for a future Mars orbiter. Winds are critical to understanding atmospheric transport and to answering fundamental questions about the CO_2, H_2O, and dust cycles of the Mars climate. Only few direct observations of Mars winds exist, which leaves many basic questions unanswered.

Our team previously developed a prototype of the MARLI lidar to measure the height-resolved wind and aerosol profiles continuously from orbit. MARLI was designed to observe the atmosphere from a nominal 400 km polar orbit. The lidar is designed to continuously measure aerosol backscatter profiles and the component of the aerosol Doppler shift from wind profiles along the lidar's line-of-sight. Although our work showed MARLI works well and is practical for space, its mass and power are too large for NASA's new emphasis on smaller Mars missions.

We recently developed a new approach for a smaller version called Mini-MARLI for the Mars Exploration Program. The lidar approach is similar to MARLI's, but it uses a much smaller semiconductor-based laser with much better power efficiency and more sensitive detectors. These allow improved wind measurements with a lidar that has lower mass and power. Mini-MARLI is being designed to obtain atmospheric profile measurements with 900-m vertical resolution. Its performance depends on the atmospheric dust distribution and averaging time. Our model assumes averaging over 20 seconds (~1° latitude). Its results show that from the surface to 30 km the wind speed errors were typically 2 to 3 m/s, except during dust storms. We are currently developing a breadboard version of the lidar. We plan to evaluate it the fall of 2025 and use it in the spring of 2026 to demonstrate atmospheric backscatter and wind profiling measurements from our laboratory.

Erik Brandon
Jet Propulsion Laboratory
Small RTGs for distributed Mars instruments

A long-standing goal of the planetary science community — to place a network of distributed science instruments on the surface of Mars — is now within reach, thanks to a new small-scale radioisotope thermoelectric generator (RTG) design. This technology can provide both heat and power for small impactor probes, enabling them to collect atmospheric and geophysical data over vast regions and multiple Martian seasons.

The new power source is being designed to be highly durable and to withstand a hard landing on the Martian surface. It can be fueled with either plutonium-238 (Pu-238) from the U.S.

Department of Energy or americium-241 (Am-241), a radioisotope which will become increasingly available from commercial sources in the coming years. The small RTG will deliver more than 60 watts of thermal power and approximately 3 watts of electrical power, enough to keep the payload alive and operate the scientific instruments, electronics, and a transmitter for up to 10 years.

This innovation is also made possible by new approaches to entry, descent, and landing, including the use of additively manufactured, crushable materials that absorb impact forces. These distributed Mars instruments are vital for surveying future human landing sites, as the probes can be equipped with sensors to measure temperature, radiation levels, dust, and wind velocity — all vital data for ensuring astronaut safety.

William Brinckerhoff
Goddard Space Flight Center
Shared front-end sample pre-processing (SPP) technologies for astrobiology

This project seeks to advance technologies for shared front-end sample pre-processing of ice-rich surface and subsurface samples for analytical instruments on future astrobiology missions to Mars in two focus areas:

- T1: Gas and Liquid Chemical Preparation and Extraction -- will develop a Gas and Liquid Extraction Module (GLEM) to process multiple aliquots of cryogenic fines with high ice fraction to interface to bulk analyses of both gas and liquid phases
- T2: Precision Manipulation for Chemical Imaging and Subsampling -- will develop a Precision Core Retainer/Manipulator (PCRM) and other intact chip cryogenic sample positioning mechanisms for multiple imaging and chemical micro-analyzers

The long-term goal of SPP is to enable and optimize common pre-processing capabilities for multiple instruments, provided by science teams across the Mars community, achieving both resource efficiencies and science advantages of shared analytical front-ends. The SPP technology can serve as “astrobiology payload middleware” interfacing both to sample acquisition systems and multiplexed analytical instruments in a variety of configurations.

Roland Brockers
Jet Propulsion Laboratory
Extended robust aerial autonomy (ERA)

The objectives of this task are to expand the range of terrains that a future Martian Helicopter can safely operate over and to enable low-cost automated aerial mobility. This includes maturing critical technology to enable flight over challenging terrain, such as robust visual-inertial odometry (VIO), landing hazard detection and safe landing, onboard localization based on orbital maps (HiRISE/CTX), and an autonomy framework that supports in-flight decision making. By demonstrating these technologies in Mars-terrain analogs on next-gen avionics, ERA increases their technology readiness for future mission opportunities.

The technology is scalable to any aerial platform and supports medium-size mission vehicles (e.g. Mars Science Helicopter or C) and low-cost aerial mobility missions using e.g. an Ingenuity-class vehicle. It can also be adapted to enable autonomy, divert and safe landing for low-cost landers.

Brandon Burns/Erik Brandon
Jet Propulsion Laboratory
Next generation Mars aerial vehicle advanced power system

Building on the success of the Mars Ingenuity helicopter technology demonstration mission, this task is developing new power systems to enable larger, more capable planetary rotorcraft. These innovations will allow the next generation of vehicles to both carry science payloads and fly for longer durations and distances.

Future Mars helicopters will need to carry a significant amount of mass, including scientific instruments, added structural components, and more cabling, batteries, and electronics. This makes executing these missions even more challenging since flight occurs in the very thin Mars atmosphere. To address this challenge, JPL is designing, building and testing a new class of high-efficiency power converters based on a switched capacitor design. This technology will reduce reliance on traditional heavy magnetic components used in power electronics, and support a higher operating voltage, which in turn reduces the mass of the power cables and harnessing on the helicopter.

In parallel, this task is evaluating and developing advanced battery cells that can store more energy and handle higher power levels for a given mass. These new cells feature advanced, higher capacity electrodes as well as custom electrolytes, which are being developed for future battery modules that can be recharged at lower temperatures. This reduces the amount of energy needed to heat the batteries to allowable flight temperatures and allows flights to occur earlier in the Martian morning, when atmospheric conditions are more favorable for flying.

These advancements are crucial for unlocking the full potential of planetary rotorcraft, allowing scientists to explore new areas of Mars and collect vital data that was previously not possible with only ground-based assets such as landers and rovers.

Nacer Chahat
Jet Propulsion Laboratory
Improved UHF capabilities using medium gain antennas

This task is developing a multi-element, electronically beam-steered orbiter antenna to enhance UHF proximity link capabilities to support the next generation of smaller, low-cost Mars surface explorers. By offering a UHF link that can dynamically adjust its gain, beam shape, and pointing, the system ensures optimized communication performance for a wide range of mission scenarios. This antenna is designed to leverage capabilities that already exist in the UST-lite radio being developed by JPL and commercial partners, which provides multiple outputs with phase and amplitude control.

The primary objective of this task is to achieve up to a 10x improvement in direct to orbit communications for very small missions on the surface of Mars, with no change required in the surface asset. This makes these small assets 10x more cable in science return**.** This enhancement will enable direct communication with low Size, Weight, and Power (SWAP) assets on the Martian surface, such as helicopters, small rovers, and tubebots, facilitating more efficient data transfer and mission flexibility and vastly extend the area of operation.

The secondary objective is to retain the current UHF capabilities while introducing adaptive telecommunications features. These advanced capabilities will allow for intelligent communication solutions, making the system versatile and suitable for a broad range of future Mars missions.

Utilizing the existing capabilities of the UST-lite radio, the new antenna will offer two operational modes:

- a traditional low-gain broad beam (to maintain current capabilities)
- a high-gain beam with electrical steering (±45°)

Each mode is controlled via UST output ports, which imposes the phase and amplitude of each element, thereby eliminating the need for a complex power divider and T-R (transmit-Receive) modules. Existing Mars orbiters such as Mars Odyssey, MRO, MAVEN, TGO, are using quadrifilar helix low-gain antennas (LGA) with gain ranging from 0dBic to 3dBic to communicate with Mars rovers and landers. The most recent orbiters are using adaptative data rate (ADR) to achieve data rate ranging from 1 to 2048 kilobits per second (kbps). By incorporating a hemispherical helical antenna, we can increase the element gain by 4 dB compared to the existing orbiter UHF antenna. With the UST-lite radio's capabilities, we plan to array 4 elements to achieve these modes. The HGA configuration will provide up to 6dB of additional gain, resulting in a total improvement of 10 dB at boresight.

Consequently, this will allow us to use an output RF power that is 10 times smaller on Martian assets, enabling the use of smaller vehicles while maintaining the same data rate. For example, the MRO Electra Tx Power is 7 W (~ 37.5 dBm) and the MSL Electra Lite Tx Power is 8 W (~ 39.5 dBm). This would allow us to achieve the same data rates with RF output power under 1W which is compatible with smaller platforms like helicopters or small rovers. For reference, the latest low-SWAP radio (ARKE) developed by JPL for small platforms to communicate with orbiters will support 2W RF output power.

Moogega Cooper
Jet Propulsion Laboratory
Advanced biotechnology metagenomics technology for Mars exploration

Spacecraft cannot be cleaned perfectly, so they carry measurable bioburden. Life detection instruments can only succeed if they measure a signal above or different from this background. This task will develop a standardized, nucleotide-based, laboratory technique coupled with an open-access bioinformatics reporting tool from the NASA Ames Research Center (ARC) for discriminating potential biosignatures on Mars from Earth-sourced bioburden. This process will be flight project-ready, i.e. ready to be used in Phases C/D. This technology will:

- provide the foundation for an in-situ life detection payload element
- validate and verify capabilities of future life detection instruments
- enable low-cost missions meet Planetary Protection requirements

This approach covers the range of detection of microbial species from all domains of life. The benefit of this one-year research effort is a standardized life-detection protocol using technologies that have been optimized to detect life at low quantities, coupled with a NASA ARC open-access bioinformatics reporting tool for discriminating potential biosignatures on Mars from Earth-sourced bioburden.

Soumyo Dutta
Langley Research Center
Development of higher fidelity atmospheric models for Mars flight mechanics simulations

All Mars EDL missions rely on flight mechanics simulations to predict performance. These simulations in turn rely on quality atmospheric models that characterize the environment over challenging Martian terrains or over variability with seasons, like dust season. The accuracy of future EDL missions will be improved by enhancing the atmospheric characterization process, and this can be used by future projects without additional development cost.   Atmosphere, especially winds, is a large component of EDL performance at Mars. Current best practice in atmospheric modeling for Mars EDL simulations rely on mesoscale models, but the discretization of the data for simulations and characterizing bounds, like mean and standard deviation, does not maintain the physics. For example, spatial correlations might be broken to compute statistics from many different days of the data. Developing a Machine Learning (ML) or reduced order-based model will allow all future Mars missions, whether low-cost or flagship, to train models to the higher-fidelity mesoscale data and capture the inherent physics in the base atmospheric data while still generating dispersed atmospheric profiles for EDL simulations.

Jared Espley
Goddard Space Flight Center
Preparing for aerial magnetic surveys at Mars

Local scale magnetic maps of Mars are important for understanding Mars' geologic history, the distribution of ionizing radiation on the surface, and for characterizing the subsurface. Such maps will be best produced via aerial surveys. This task is developing technology to prepare for such surveys. Specifically, we are miniaturizing existing fluxgate magnetometers, investigating COTS sensors for science use, surveying current best practices for accommodation of magnetometers onto aerial vehicles, and conducting magnetic characterizations of prototype aerial vehicles.

This work is directly relevant to the Mars Exploration Program's (MEP) science and exploration objectives and the associated technology needs. These objectives and technology needs are laid out in the Exploring Mars Together (EMT) plan which in turn derives from the Planetary Science and Astrobiology Decadal Survey and MEPAG goals. Our specific science and exploration objectives are broadly described as:

- Understanding the geological history of Mars
- Understanding the effects of mini-magnetospheres on radiation on the surface of Mars
- Characterizing the subsurface structure of Mars at local and regional scales.

Ryan Ewing
Johnson Space Center
LASSIE-M: legged autonomous surface science in analog environments

This task is investigating high mobility legged robots with terrain sensing technologies to offer a new approach to exploring Mars in which the robot itself is as much an instrument for scientific discovery as it is for mobility. This approach differs from the state-of-the-art capabilities of wheeled rovers, which serve primarily as mobile platforms that support instruments, and provides new-to-Mars surface operation concepts that support Mars exploration objectives.

Results from this project show that with a better understanding of how deformable and heterogenous substrates respond to leg interaction, legged robots exhibit high mobility in negotiating rough and unconsolidated terrains that could support accessing extreme or hazardous terrains that rovers or human explorers cannot safely traverse. Accessing a greater range of terrains expands exploration areas and increases the potential for discoveries. These force-sensing signals also provide direct geotechnical measurements for understanding the mechanical behaviors of the substrate, such as friction and cohesion, at every step along the robot's path.

The research conducted in the LASSIE-M project has accelerated the integration of robotics, science, and operations. It has advanced the capability of legged robots to switch gaits when they encounter differences in terrain, including challenging steep terrain and scientifically-interesting terrains. Vision and depth sensing payloads advance detection of variable terrain types that, in addition to the leg proprioception, enable gait switching and provide key information for autonomous or human-in-the-loop decisions. Continuous path-based measurements by the legs and payloads have driven new operations approaches that use autonomy for path planning and scientific-sampling decisions in cooperation with humans in the field and in a backroom.

Looking ahead, it is envisioned that agile legged robots will serve as scouts: characterizing regolith geotechnical properties, flagging hazardous soft-sand regions, and identifying high-value science targets. Such scouting capability would directly enhance operational planning for wheeled rovers and astronaut explorers, extending the reach and safety of future Mars missions.

Brian Glass
Ames Research Center
Mars Exploring by Analog Drilling (MEAD)

This project will demonstrate the feasibility of drilling missions to Mars and show the scientific value of such a mission for Mars subsurface exploration. It will demonstrate geotechnical sensors for local subsurface mapping, as well as biomarker detection technology in a realistic field simulation, using a Signs of Life Detector (SOLID) that was a proposed instrument in a 2019 Discovery mission proposal. ARIA, the Astronaut Raman instrument for ISRU and Astrobiology, will also test a fieldable capability for determining mineral compositions and trace organics and volatiles, including organic thermal maturity (changes that have occurred in organic matter in rock layers due to heat).

The search for evidence of ancient climates, extinct life, resources for human exploration, and potential habitats for extant life on Mars, given the desiccated, oxidated, and irradiated conditions near the surface, requires drilling or some other form of subsurface access. Given lightspeed delays for missions beyond the Moon (tens of minutes) that are much longer than the time required (seconds) to get a drill stuck, deep space drilling and sampling operations must be automated and resilient. Fully hands-off drilling is beyond the capabilities of current Earth industry or existing spacecraft instruments, but application of AI/automation techniques offers a modest standalone autonomous capability. Current and planned Mars drilling missions have had to “drill blind” with little knowledge of the below subsurface, but by using a drill’s vibration with a deployed seismic node (e.g., a Fleetspace “Geode”), the Drill Excitation for Seismic-tomography Imaging (DESI) approach can potentially enable local subsurface mapping to direct drilling in avoiding buried obstacles and optimizing the science return.

Havard Grip
Jet Propulsion Laboratory
High-solidity and supersonic tip speed rotor test for Mars rotorcraft

With their ability to rapidly traverse long distances over difficult terrain, rotorcraft have the potential to revolutionize Mars exploration. The *Ingenuity* helicopter proved the feasibility of rotorcraft operations on Mars, albeit at small scale. To unleash the full potential of rotorcraft on Mars, new rotor technology enabling *larger* vehicles is required.

High-solidity rotors: Concepts studies for large Mars rotorcraft, including the *Chopper* rotorcraft concept, have shown that the combination of low atmospheric density and significant volume constraints requires a larger proportion of the rotor disk to be covered by blades than what is typical for terrestrial helicopters. The power performance of such a *high-solidity* design is critical for the feasibility of large-scale Mars rotorcraft, but it is not yet well-understood, because rotorcraft built for hover or edgewise flight on Earth are universally designed with low solidities. The project will fill this knowledge gap by:

- designing and building a custom high-solidity rotor for Mars applications; and
- testing the power performance of the rotor in Martian atmospheric conditions.

Supersonic tip speeds: Mars rotorcraft are currently designed to maintain a strict margin against the speed of sound at the blade tips, even during a worst-case wind gust, on the assumption that *drag divergence* near the speed of sound could be fatal to the rotorcraft. This assumption may be overly conservative, and relaxing the assumption would have direct benefit in terms of liftable mass. This project will examine this question by spinning the test rotor at near-supersonic speeds and using an external fan to temporarily bring the advancing rotor tips into the supersonic regime. This exploratory effort will shed light on whether current assumptions are overly conservative or not, potentially opening the door to a relaxation of assumptions that would allow for carrying more mass.

Elizabeth Jens
Jet Propulsion Laboratory
Deep throttling monopropellant engine

Any spacecraft that is designed to land on a planetary body, such as the moon or Mars, requires a method of slowing itself down as it descends in order to execute a gentle landing. The terminal descent of nearly all lunar and planetary landers to date has been accomplished via rocket engines. Rocket engines that are suitable for landing must involve either a method of throttling across a range of thrust-to-weight ratios or off-pulsing, also known as Pulse Width Modulation (PWM). The ability to throttle engine thrust enables smaller, lower-cost landers as compared with PWM propulsion systems. Throttled engines avoid all of the following: complex and expensive propulsion system development required for PWM systems (including avoiding propulsion subsystem hot fire testing), more difficult and expensive entry descent and landing algorithms and modeling, increased plume/surface interactions produced by PWM systems, and the mass penalties and loss of landing precision of airbags. This effort is focused on developing a deep throttling monopropellant engine for precision landing of small payloads on Mars. Such an engine could also be used for future lunar and asteroid belt landers.

The primary focus of this effort is the design and test of a new Small Thruster Throttle Valve (STTV) capable of mating to a heritage, fixed-thrust 300 N (70-lbf) class monopropellant engine to produce a throttling engine. The STTV is designed to achieve a 10:1 throttle range, with flow rates in family with the demonstrated operating limits of the monopropellant engine. The STTV is designed to remain in cavitation across the full throttle range. Cavitation across the valve removes any concerns with potential feed-couple instabilities or flow coupling between different engines in the propulsion system (a key aspect of avoiding the need for a system hot fire test). The valve is also designed to seal closed following touchdown without requiring electrical power to maintain that state. All wetted valve materials are selected for compatibility with hydrazine. The valve is actuated by a custom actuator which utilizes a number of Commercial Off-The-Shelf (COTS) components including the motor and controller. The project will progress the valve and actuator design from an initial concept, through PDR, early development testing, CDR, to manufacture and water flow testing of an Engineering Model of the assembled STTV. In a potential follow-on effort, the STTV would be mated to an existing thruster and *hot-fire tested*.

Andrew Johnson
Jet Propulsion Laboratory
Mars intelligent landing system

The Mars Intelligent Landing System (MILS) is a lidar-based navigation system for anytime/anywhere planetary landing that combines three component technologies in development of the last decade: a photon-counting multi-function lidar (ELSA) recently tested in the field, a multi-core high-performance space computer (HPSC) available for evaluation in early 2026, and three lidar navigation algorithms. The lidar algorithms included in MILS are terrain relative navigation (position) via both surface contour matching and digital elevation map-relative localization, odometry (velocimetry), and landing hazard detection (safe landing). This system will benefit future Mars landing by de-coupling algorithm performance from solar illumination angle at the time of landing, thereby extending the possibility to land any time of day (even at night), increasing the acceptable atmospheric dust tau conditions from 0.8 to 3.0, and adding on-board hazard detection that wouldn't require a priori hazard map generation. The applications of MILS are to any future Mars mission, as well as providing a complete navigation system for south pole lunar landing and for exploration of icy moons and small planetary bodies.

Mike Kobayashi
Jet Propulsion Laboratory
UST-Lite Mars relay radio technology development

UST-Lite is the next-generation of Mars relay software-defined radios (SDRs). It is designed from the ground up to be modular and to have a small form factor, making it adaptable to a wide variety of mission needs, including small, power-constrained missions. UST-Lite supports legacy ultra-high frequency (UHF) proximity communications at low megabits per second, as well as emerging S-band and X-band proximity communications with data rates up to hundreds of megabits per second. Based on the Consultative Committee for Space Data Systems (CCSDS) standards, UST-Lite's SDR architecture ensures interoperability and allows for reprogramming post-launch, providing the flexibility to accommodate new collaborators and adapt to evolving mission needs.

UST-Lite integrates cutting-edge digital processing and direct waveform sampling to enable higher data rates over multiple frequency bands simultaneously, while also provisioning precise navigational services. UST-Lite is being developed as a collaboration between JPL and industry partner Argotec, Inc. and other industry partners, to deliver cost-effective, space-grade radios to NASA and non-NASA customers. UST-Lite inherits all the capabilities of legacy Electra UHF SDRs, while advancing the Mars Exploration Program's initiatives to deploy high-performance communication systems critical for the future exploration of Mars.

David North/Christopher Meeks
Langley Research Center
MERF: Mars electric reusable flyer

This project's primary objective is to significantly enhance aerial exploration capabilities within Mars' atmospheric environment through advanced aircraft design and testing methodologies. Aerial exploration of Mars became a reality with the successful deployment of the Mars Ingenuity helicopter; however, endurance and range can be significantly improved through the implementation of wing-borne flight systems. The Mars Electric Reusable Flyer (MERF), featuring a flying wing, vertical takeoff and landing (VTOL) configuration, enables more efficient flight with superior range capability per unit of battery energy consumed. The MERF is capable of transitioning from hover to faster, wing-borne flight modes, representing a significant advancement in Mars aerial vehicle technology. In addition, the design was improved during this effort to allow for a more robust "belly" landing where the vehicle lands on its tail and then lowers itself into a stable position. The "belly" lander reduces the complexity of heavy and high drag landing gear.

The challenging Martian atmospheric environment, characterized by extremely low density (approximately 1% of Earth's atmospheric density) and unique Reynolds number flight conditions, necessitates specialized aircraft designs that differ substantially from terrestrial counterparts. These environmental constraints demand innovative approaches to aerodynamic design, propulsion systems, and structural configurations to achieve viable flight performance.

Building upon a comprehensive three-year NASA Langley Internal Research and Development (IRAD) project that concluded in 2018, which successfully converged on and developed the baseline vehicle design through extensive theoretical analysis and preliminary testing, the work in this project focuses on refining and optimizing the vehicle concept. Specifically, two distinct structural configurations with extremely low wing loading were developed and analyzed, accompanied by comprehensive aerodynamic and performance analyses utilizing both computational and experimental methodologies.

Furthermore, 50%-scale versions of the MERF concepts were constructed and tested at Earth sea-level conditions to benchmark lightweight construction techniques, validate design methodologies, and gather critical performance data for future full-scale development. Flight testing of these prototype vehicles is currently ongoing, providing valuable empirical data for design validation and refinement.

Hari Nayar
Jet Propulsion Laboratory
Achieving more with less: improved surface mobility performance

This project focuses on developing a low-cost, extreme-terrain rover for lunar and Martian exploration. The ERNEST (Exploration Rover for Navigating Extreme Sloped Terrain) vehicle, featuring a novel two-degrees-of-freedom active gimbal suspension, has been built to traverse diverse terrains using optimized gaits. This design minimizes actuators, reducing cost and complexity while maximizing ability to navigate steep and rugged landscapes. ERNEST will enable access to currently inaccessible terrain, increase scientific return through shorter traverses over difficult areas, and achieve higher drive speeds for extended missions. The algorithms currently under development will facilitate autonomous surface mobility operations on Mars, where long communication delays preclude ground-in-the-loop control.

Our objective is to demonstrate the rover's ability to adapt to and traverse challenging terrain types using onboard autonomous algorithms. These algorithms leverage perception and proprioceptive sensors to control the active suspension system and apply terrain-optimized gaits. We are investigating two autonomous control methods for the active suspension:

- Reinforcement Learning (RL), involving training on a high-fidelity dynamics simulator and then transferring to the physical rover, and
- Motion planning, utilizing a model of the active suspension system and terrain

Autonomous active-suspension mobility will be showcased on an obstacle course at JPL's MarsYard. Significant progress has been made with the RL approach, demonstrating autonomous mobility over wheel-height step obstacles and rippled terrain in separate demonstrations. These will be integrated into a single mobility algorithm that can seamlessly transition between step obstacles, rippled terrain, and steep slopes. Furthermore, progress has also been made in developing software components for the motion planning pipeline, as well as the rover's perception and localization systems.

Masahiro Ono
Jet Propulsion Laboratory
S4: next-gen Mars surface mobility with HPSC

Stereo vision has long been a critical technology for Mars rovers, enabling the reconstruction of 3D terrain geometry and facilitating obstacle avoidance. Since the Mars

Exploration Rovers mission in the early 2000s, the foundational algorithm for stereo processing has remained largely unchanged. While demonstrating reliability and robustness, it possesses limitations, such as the creation of “holes” in terrain maps under unfavorable lighting conditions (e.g., the opposition effect). Concurrently, available onboard compute resources are projected to increase dramatically with the advent of space-qualified high-performance computing. Meanwhile, substantial advancements have been made in terrestrial autonomous driving, primarily propelled by deep learning algorithms. This project endeavors to leverage the latest advancements in onboard computation and algorithms to enhance the robustness of onboard stereo processing, particularly in suboptimal lighting conditions and on featureless terrains. We are currently evaluating multiple learning-based and non-learning-based techniques using over 10,000 image pairs from the Perseverance rover to compare their accuracy, robustness, and computational requirements.

The primary benefit out of this project is the creation of a new stereo processing approach, including downsampling, pre- and post-filtering, and stereo correlation, that is suitable for future low-cost mobility missions on Mars. The new technology will be applicable for both ground and aerial mobility. Furthermore, the project will aim to produce short-term benefits by improving Perservance’s stereo performance through parameter changes. This could include a selection of a different de-Bayering approach and updating the look-up table for bit downsampling. This project's primary benefit is the development of a novel stereo processing approach, encompassing downsampling, pre- and post-filtering, and stereo correlation, specifically designed for future low-cost mobility missions on Mars.

Keith Peterson
Ames Research Center
Automated manufacturing development of MERINO-LD

This project will advance MERINO-LD thermal projection system (TPS) technology from TRL 2 to TRL 5 and prepare to make use of flight test opportunities. MERINO-LD is a next generation, low-cost, rapidly producible TPS material currently under development at NASA ARC. The MERINO-LD process starts by blending and opening carbon and phenolic fibers before running them through a carding process to produce either flat billets of material, or batting material that can be needle punched into a near net shape. The end product is a flexible carbon phenolic ablative TPS blanket that is capable of operating in environments up to 500 W/cm^2 and 0.5 atm.

An ablative TPS blanket, like MERINO-LD, simplifies the design, analysis, and integration processes required, which dramatically reduces manufacturing cost and schedule by more than 65% when compared to traditional rigid PICA ablator systems. The technology is enhanced further using automated needle-punching operations to produce single piece Near Net Shaped (NNS) heatshields. These NNS heatshields improve reliability and eliminate the need for six-sided tile machining, complex tile placement, and gap filling operations used in heritage Mars tiled TPS heatshields, further reducing production cost and schedule. While the initial focus of the proposed effort will be on forebody TPS fabrication, the automated needle punching operation is applicable to aftbody TPS for MEP missions and a broad range of other TPS materials.

Jamshid Samareh/Zachary Ernst
Langley Research Center
Low-cost Mars EDL solutions

The cost of arriving at Mars is projected to decrease in the future thanks to growing commercial spaceflight interests. For a mission planner, these conditions could mean lower transportation costs and more mission opportunities. But for surface missions, the atmospheric entry system required to deliver it through entry, descent, and landing (EDL) has historically been a complex and costly system that is custom designed for each mission. Non-recurring engineering and development costs are high, typically around five to ten times the production cost. The ideal solution from the mission planners' perspective would be a "package delivery service" of EDL: when you ship a package somewhere, you don't worry about designing the box it goes in, you buy one that has already been developed.

The objective of this project, a collaboration between NASA's Langley Research Center, Ames Research Center, and the Jet Propulsion Laboratory, is to study ways to lower the cost of EDL solutions for low-mass Mars missions using a family of common entry vehicle systems or components. Single-unit costs can be lowered by amortizing development costs over a production run, and the size of the production run can be made larger if the entry vehicle is to be used for multiple missions. Therefore, this project also includes conducting a survey of low-cost or low-mass Mars missions to identify commonalities in payload requirements such as mass, volume, and environmental constraints. A single entry vehicle design could be used for missions with substantially similar requirements; a limited number of vehicle designs might be able to support a broad range of the mission requirement space, including soft landers, impactors or penetrators, and aerocapture to orbit. Developing such a family of vehicles would benefit an organization like NASA considering multiple missions.

Initial development is focused on the architecture selection and parametric design of small entry vehicles, either using a rigid aeroshell or a deployable decelerator, designed to meet the requirements of multiple science missions. With the design of a single reconfigurable vehicle, trade studies will investigate the cost-effectiveness of the concept compared to designing custom entry vehicles for each mission.

Jonathan Sauder/Kim Aaron
Jet Propulsion Laboratory
Low-cost Mars telecom relay antenna

This project explores the option of flying at Mars, for telecommunications relay purposes, a 3-m diameter deployable mesh reflector developed for Earth's geosynchronous orbit. The intent is to understand and develop any technology development activities needed by the different environment at Mars and on the way to Mars.

During the first portion of this activity, a Technical Interchange Meeting (TIM) was held at Tendeg, the company developing the perimeter truss reflector (PTR). At this meeting, JPL representatives for RF, mechanical, thermal and systems engineering provided feedback and suggested actions needed to increase the TRL of the PTR to 5 and later to TRL 6 if additional funding is secured. As the work progresses, we intend to perform analyses and component testing to address the concerns raised during the discussion.

Some of the important differences between the earth GEO environment and a Mars Telecom relay system are the extended duration of partial deployment (and potential for creep) during cruise, greater exposure to solar ionizing radiation outside the protection of the van Allen belts, increased heating during aerocapture and aerobraking using the Martian atmosphere to slow the spacecraft and reduce its orbit altitude, the more frequent eclipses imposing greater swings in temperature and lower average temperatures, and the need for improved thermal stability to ensure accurate pointing over the much greater distances involved.

Peter Sullivan
Jet Propulsion Laboratory
Global composition of Mars at 6-meter scale

This task develops a concept to determine the surface composition of Mars from a dedicated orbiter using 6 m/pixel shortwave infrared (SWIR) imaging spectroscopy and diffraction-limited thermal infrared (TIR) radiometry. A mission duration of one Mars year in a near-polar orbit and an f/1.9 optical system allows the payload to achieve high sensitivity over 94% of the Mars surface. More than 10,000 high-value targets with 6x6 kilometer area can be collected and downlinked directly to Earth; an optical relay or other telecommunication enhancements could increase the data volume substantially. Requirements and point designs for the orbit, spacecraft, and instrument subsystems are established to enable a technology readiness assessment of 5 at the end of the study.

Measuring the surface composition of Mars with coincident SWIR and TIR data will address all three science themes of NASA's future Mars Exploration Plan. Specifically, these data will: (1) Explore the potential for Martian life by addressing the uncertainties in the timing, duration, and transitions of aqueous settings, (2) Discover dynamic Mars by measuring frosts, ices, and determining the volatile cycles of H_2O and CO_2, and (3) Support human exploration of Mars by mapping minerals, ice, and thermophysical surface properties at scales needed for planning astronaut sorties from any landing site and potential for resource utilization.

The SWIR spatial sampling improves upon that of MRO/CRISM by a factor of three, and the TIR spatial sampling improves upon Mars Odyssey/THEMIS by a factor of eight, while still meeting the required sensitivity in each channel. Developing the implementation approach readies the concept to take advantage of future, low-cost flight opportunities to Mars.

Zaid Towfic/Nacer Chahat
Jet Propulsion Laboratory
Miniaturized UHF radio for direct-to-orbit comm

The Arke transponder, developed by NASA's Jet Propulsion Laboratory (JPL), represents a breakthrough in ultra-compact, energy-efficient flight communication systems tailored for the next generation of SWaP-constrained missions. Inspired by the limitations faced by pioneering platforms like the Ingenuity helicopter and CADRE, Arke addresses the need for direct-to-orbit communication without reliance on bulky relay systems. By leveraging a highly integrated System-on-Chip (SoC) and RF Integrated Circuit (RFIC), Arke enables surface assets—rovers, landers, helicopters, and CubeSats—to maintain robust links to orbiters across Mars and lunar environments, even in challenging terrain. Its compact form factor (targeting as small as 85x55mm) and low power draw (<12W DC) make it ideal for missions where size and energy are at a premium.

Designed to support a wide range of mission classes (Class-D to Class-A/B), Arke offers UHF and S-band configurations optimized for Mars and lunar relay networks, with extensibility to other bands and protocols including 3GPP/4G network stack and other protocols. The transponder's PolarFire SoC and RF Integrated circuits that make the platform extendable for other applications besides telecom and traditional radiometrics, including radars, RF system characterization (S-parameter measurement), among other RF applications. With complementary antenna designs and scalable power output (2W RF at UHF, 4W at S-band), Arke delivers a complete, software-defined RF solution for future planetary exploration. Whether aboard a SmallSat, aerobots, or a compact rover, Arke empowers mobility and autonomy with cutting-edge communication capability.

Peter Willis
Jet Propulsion Laboratory
Mars biosignature extractor (MABEX)

The Mars Biosignature Extractor (MABEX) uses subcritical water extraction (SCWE) to extract a wide range of biosignatures from complex mixtures including liquid, ice, or soil, and then transfers that filtered liquid to other instruments for chemical analysis. As part of past PSTAR efforts, an early TRL-4 MABEX prototype was remotely operated as the front end for an electrophoresis analyzer aboard the ARADS rover in the Atacama Desert. This was the first and only report of the use of liquid extraction and analysis in simulated Mars mission operations, enabling parts-per-billion level detection of amino acids in soil with zero human intervention. In the current effort, we advance MABEX to TRL-5, by demonstrating amino acid extractions in newly built and optimized extraction chambers in a Mars-like environment. In addition to enabling life detection on Mars missions, MABEX can also be used to process and filter melted ice mixtures for chemical analysis, to determine if these sources of water could be used as a resource by human explorers.

Scott Wilson/Gina Dugala
Glenn Research Center
Small Stirling technology exploration power (Small STEP)

There are several mission concepts for Mars exploration that could utilize a small-sized and low-power radioisotope power system (RPS). These include, but are not limited to, networked nodes using long-lived small spacecraft for global meteorological monitoring and high-resolution imaging, and RPS rovers to enable deployment of multiple science stations or communication repeaters in key locations on the surface of Mars. RPS are advantageous because they can operate through cold, dark, and dusty environments. RPS convert heat from isotope sources, like plutonium-238 or alternatives like americium-241, to usable electricity for spacecraft. Thermoelectric generators offer around 6% efficiency while dynamic generators offer 3-4 times higher efficiency. For that reason, high efficiency power conversion technologies are critical to maximizing the utility of isotope fuel. Stirling power convertors are a mature option for high efficiency power conversion. NASA has invested in Stirling technology maturation over the past two decades. Stirling power conversion enables a robust, long-lived source of power for operations and science payloads on Mars. An electronic controller is used for AC-DC power conversion and maintains the power provided to the spacecraft. The objectives of this effort are focused on the lab demonstration of an electrically-heated small Stirling RPS generator, including the key Stirling convertor and controller technologies. Performance estimates suggest this concept could reach system efficiencies as high as 23% while providing 59 watts of usable continuous dc power output to user loads, with an estimated specific power of 5.5 W/kg.