NASA STTR 2021-II Solicitation

PROPOSAL NUMBER:	21-2- **T5.04-1614**
PHASE 1 CONTRACT NUMBER:	80NSSC21C0114
SUBTOPIC TITLE:	Quantum Communications
PROPOSAL TITLE:	Quantum-memory Wavelength-Division Multiplexing (QWDM)

SMALL BUSINESS CONCERN (SBC):
Physical Sciences, Inc.
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Estimated Technology Readiness Level (TRL) :
Begin: 3
End: 5

Technical Abstract (Limit 2000 characters, approximately 200 words)

Physical Sciences Inc. (PSI) and the University of Illinois Urbana-Champaign (UIUC) will develop integrated optical frequency shifters to enable Quantum-memory Wavelength-Division Multiplexing (QWDM). Our approach will enable the connection of multiple quantum memory registers across a free-space or fiber optical channel, increasing the bandwidth of near-term quantum networks by 10–100x. As most optical quantum memories operate at a single wavelength we cannot readily apply wavelength-division multiplexing (WDM) techniques to increase the bandwidth of a quantum link. To overcome this challenge, we utilize high-efficiency frequency shifters at the transmitter to shift each quantum register within a memory unit onto a separate wavelength channel that we can combine using standard WDM techniques. After transmitting the multiplexed signal over a free-space or fiber link, a complimentary device at the receiver will de-multiplex the photons and a second set of frequency shifters will shift the wavelengths back to original native frequency of the quantum memory's register. These devices will pave the way for the creation of a highly scalable quantum networks using QWDM.

Potential NASA Applications (Limit 1500 characters, approximately 150 words)

The development of quantum communications and networks are a key technology to enable secure communication, sensor arrays, and quantum computer networks. Our proposed technology will enable wavelength-division multiplexing techniques to greatly increase the bandwidth of NASA's free-space or fiber quantum links, such as those interfacing quantum memories as well as heterogeneous single- and entangled-photon sources.

Potential Non-NASA Applications (Limit 1500 characters, approximately 150 words)

Future quantum networks will require quantum memories (QM) that are linked by photons transmitted over physical channels. As most QMs utilize a fixed optical frequency, QWDM are a general-purpose component to scale bandwidth without introducing additional physical channels. Such frequency conversion methods are applicable to photons from QMs, as well as the sources of the photons themselves.

Duration: 24

PROPOSAL NUMBER: 21-2- **T8.07-1939**

PHASE 1 CONTRACT NUMBER: 80NSSC21C0063

SUBTOPIC TITLE: Photonic Integrated Circuits

PROPOSAL TITLE: High-Performance On-chip Spectrometer for Space Applications

SMALL BUSINESS CONCERN (SBC):
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Estimated Technology Readiness Level (TRL) :
Begin: 3
End: 5

Technical Abstract (Limit 2000 characters, approximately 200 words)

The program will develop a spectrometer with chip-scale footprint and performance rivaling high-end benchtop spectrum analyzers leveraging an innovative digital Fourier Transform (dFT) architecture, which uniquely enables **exponential** scaling of performance. Specifically, the Phase II project will build on the accomplishments from Phase I and fabricate the photonic circuits via AIM Photonics' Si photonics foundry service. The chips will then be packaged in a commercial packaging house to establish a robust optical, thermal, and mechanical interface with other components in the spectrometer module. We will also develop the second generation electronics using custom-designed components such that the module can be co-integrated in a single matchbox-sized package. We will also mature the data acquisition and processing algorithm and develop a user application with easy-to-use graphic user interface. The project will thus lead to a market-ready, "plug-and-play" spectrometer module product.

Potential NASA Applications (Limit 1500 characters, approximately 150 words)

- Surface and atmospheric analysis on CubeSats and planetary landers
- Monitoring of volatile organic compound (VOC) contaminants in spacecraft cabin atmospheres
- Point-of-care diagnostics for astronauts

Potential Non-NASA Applications (Limit 1500 characters, approximately 150 words)

- Food and water sensing
- Chemical, petrochemical, agrochemical and pharmaceutical process control
- Environmental contaminant detection
- Telecom and datacom channel monitoring

Duration: 24

PROPOSAL NUMBER: 21-2- **T5.04-2489**

PHASE 1 CONTRACT NUMBER: 80NSSC21C0125

SUBTOPIC TITLE: Quantum Communications

PROPOSAL TITLE: Entangled Photon Pair Source Based On Thin-Film Lithium-Niobate-On-Insulator Photonic Integrated Circuits

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Estimated Technology Readiness Level (TRL) :
Begin: 2
End: 4

Technical Abstract (Limit 2000 characters, approximately 200 words)

Herein, PSI propose a system-on-chip (SoC) solution for an entangled photon pair source (EPPS) based on thin-film lithium niobate on insulator (TFLNOI) photonic integrated circuits (PIC). Using integrated photonic devices such as fiber coupler, waveguide, modulator, splitter/combiner and micro-ring, the proposed EPPS can generate and process the entangled photons with high efficiency and speed. In phase I effort, we developed theoretical models to study the spontaneous parametric down conversion (SPDC) conversion efficiencies based on both hybrid and ridge waveguide LNOI PIC designs. We have successfully demonstrated an in-situ monitored periodically poling process with small poling periods and large poling gaps. Leveraging other on-going PSI projects, we have also fabricated and characterized the key PIC components for the proposed EPPS chip, including low-loss waveguides, fiber coupler, high extinction splitter/combiner, micro-ring resonator and high-speed modulator. The phase I result paved a solid foundation toward a high-efficiency EPPS PIC chip. In phase II, we will continue the PIC components development focusing on the ridge waveguide designs, and experimentally demonstrate all the key PIC components. We will further refine the periodically poled LNOI (PPLNOI) process with improved accuracy and automation. Through the collaboration with RIT, our subcontractor, who has significant experiences in quantum photonic system testing and characterization, we will demonstrate the entanglement of the SPDC generated photon pair. Lastly, we will perform initial integration and packaging for the EPPS chip based on advanced photonic wire-bonding technology. Based on our pioneer work in TFLNOI PICs development and with our successful experiences in commercialization of SBIR research efforts, PSI is poised to develop, package, qualify and commercialize the proposed EPPS chip for tomorrow's quantum communication demands.

Potential NASA Applications (Limit 1500 characters, approximately 150 words)

High quality entangled photon pair is needed almost in all quantum technologies from quantum communication to quantum computing. As NASA explore deep space in the next decades, reliable, secure and high-volume data communication is in urgent demands. Having a high-efficiency, high-speed, low SWaP-C, reconfigurable, integratable PIC-based entangled photon source will not only meet the challenge for many current system, but will also enable many new applications such as quantum internet, high-sensitive sensing and quantum computation.

Potential Non-NASA Applications (Limit 1500 characters, approximately 150 words)

Rapid development in quantum information technology demands high-efficiency, reliable and integrated quantum light source. Similarly, photon-based quantum computing also requires entangled photon generation as well as complicated processing. The potential commercial market of the proposed PIC chip is vast. To this end, a SOC PIC-based source is the only viable solution to meet the requirements.

Duration: 24

PROPOSAL NUMBER:	21-2- **T9.02-2587**
PHASE 1 CONTRACT NUMBER:	80NSSC21C0064
SUBTOPIC TITLE:	Rapid Development of Advanced High-Speed Aerosciences Simulation Capability
PROPOSAL TITLE:	Moving Discontinuous Galerkin Solver for Hypersonic Aerothermodynamics

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Estimated Technology Readiness Level (TRL) :
Begin: 3
End: 6

Technical Abstract (Limit 2000 characters, approximately 200 words)

Corvid Technologies (Corvid) and North Carolina State University (NCSU) are employing a novel moving Discontinuous Galerkin with Interface Conservation Enforcement (MDG+ICE) approach. The MDG+ICE method represents a fundamentally grounded and break-through approach and is specifically designed for flows with discontinuities and therefore especially attractive for hypersonic flows. During Phase I, Corvid and NCSU developed and demonstrated a compressible Euler solver with thermochemical nonequilibrium models based on the MDG+ICE approach. High order capabilities were developed to enable solutions up to *P2* (third-order accurate) on quadratic (curved) elements. This new approach was shown to capture shocks (discontinuities) and the associated jumps in thermodynamic properties exactly, while using a fraction of the grid cells typically used in second-order solvers. *MDG2D* was verified on several 1-D shock tube problems, as well as steady 2-D problems with a 5-species, 2 temperature air chemistry model. Excellent agreement was demonstrated when comparing to NASA's state-of-the-art codes DPLR and LAURA for 2-D blunt bodies in hypersonic flows. This work represents the first time any group has applied the moving Discontinuous Galerkin approach for a reacting mixture of gases with two temperatures. Based on this success, our efforts in Phase II will be focused on developing a prototype software (*MDGFLO*) based on the MDG+ICE approach to solve the compressible Navier-Stokes equations with thermal and chemical nonequilibrium, in three dimensions on massively parallel computing systems. In particular, we will investigate if the MDG+ICE method can be effectively used for accurately computing both hypersonic heating and after-body flow field and validate it against available test data.

Potential NASA Applications (Limit 1500 characters, approximately 150 words)

The proposed solution would directly benefit all of NASA's on-going and upcoming EDL programs by delivering a high-order, robust CFD modeling capability for reentry modeling. Programs include Orion, Mars sample return, Mars2020, deployable heatshield programs (HIAD, ADEPT), and planetary missions. This capability would also greatly improve the fidelity and turn-around times for modeling of the different spacecraft being developed by NASA's commercial partners such as SpaceX, Boeing, and Sierra Nevada.

Potential Non-NASA Applications (Limit 1500 characters, approximately 150 words)

The proposed solution would also greatly benefit the Defense Industry. Applications in the Army, Navy, Air Force and Missile Defense Agency, as well as the large defense prime contractors such as Raytheon, Lockheed Martin, Boeing, and Northrop Grumman could use the CFD capabilities developed in this work.

Duration: 24

PROPOSAL NUMBER: 21-2- **T6.07-2911**

PHASE 1 CONTRACT NUMBER: 80NSSC21C0124

SUBTOPIC TITLE: Space Exploration Plant Growth

PROPOSAL TITLE: Spectroscopic System for the Accurate Determination of [O2], [CO2], d18O-O2, d13C-CO2, and Ethylene in Plant Chambers

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Estimated Technology Readiness Level (TRL) :
Begin: 3
End: 6

Technical Abstract (Limit 2000 characters, approximately 200 words)

In this STTR program, Nikira Labs Inc. and Colorado State University (CSU) will collaborate to develop an analyzer that measures oxygen (O_2), carbon dioxide (CO_2), oxygen isotope ($d^{18}O\text{-}O_2$), carbon isotope ($d^{13}C\text{-}CO_2$), and ethylene fluxes in plant chambers for direct quantification of photosynthesis, respiration, and plant health.

In Phase I, Nikira Labs and CSU demonstrated technical feasibility by developing, testing, and deploying an analyzer for plant studies. The analyzer was found to measure [$^{12}CO_2$], [$^{13}CO_2$], [$^{16}O^{16}O$], and [$^{18}O^{16}O$] to

better than ±3.5 ppm, ±0.85 ppm, ±400 ppm, and ±15 ppm (1 sigma, 30 s), sufficient to show photosynthesis and respiration. Moreover, the analyzer provided a linear response (R^2 > 0.99) for all four isotopomers. The analyzer and was then deployed at CSU to study plants under a variety of conditions. Plants were measured under water, heat, and salinity stresses, showing changes in photosynthesis, respiration, and assimilation/respiratory quotients. Another set of plants were subject to ^{13}C-doping under dark and light conditions, showing ^{13}C fixing due to photosynthesis. Finally, the Phase I results were used to identify improvements for the Phase II instruments.

In Phase II, Nikira Labs and CSU will incorporate the improvements to develop, test, deploy, and deliver 2 analyzers. The first analyzer will measure [$^{12}CO_2$], [$^{13}CO_2$], [$^{16}O^{16}O$], and [$^{18}O^{16}O$] with higher accuracy in a more compact form factor. The second unit will extend the technology to measure ethylene with ppb-level sensitivity. Both systems will be deployed at CSU and incorporated into a custom, controlled plant chamber for plant stress studies. Data analytics will be developed to identify abnormal behavior and signal initial signs of plant stress prior visual evidence. After extensive experimentation, both analyzers will be deployed at Kennedy Space Center into existing plant habitats. Finally, the analyzers will be delivered to NASA for further studies.

Potential NASA Applications (Limit 1500 characters, approximately 150 words)

Growing plants in space has advantages in life support systems, including CO_2 removal, O_2 generation, and food production. Plants can be used for human colonies and provide fresh vegetables for shorter missions. NASA has found that plant growth in microgravity is impeded. To compensate for this, NASA must measure plant health and control system variables. The STTR instrument can study plants and provide early indications of stress. It can also be used in other NASA functions to evaluate bioreactors and human health.

Potential Non-NASA Applications (Limit 1500 characters, approximately 150 words)

Nikira Labs is commercializing the technology for environmental research and semiconductor gas monitoring. Phase I innovations were incorporated into commercial instruments, yielding more than $200k in revenue. Within 5 years of the completion of the Phase II effort, we estimate commercial revenue of more than $20M from products resulting from this STTR effort.

Duration: 24

PROPOSAL NUMBER: 21-2- **T6.06-1195**

PHASE 1 CONTRACT NUMBER: 80NSSC21C0368

SUBTOPIC TITLE: Enabling Spacecraft Water Monitoring through Nanotechnology

PROPOSAL TITLE: New-generation spacecraft water monitoring with flight ready solid state nanopores

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Estimated Technology Readiness Level (TRL) :
Begin: 3
End: 5

Technical Abstract (Limit 2000 characters, approximately 200 words)

In order to provide a fast, simple and reliable way of monitoring water quality on long-duration manned missions, such as transit to, and surface exploration of, the moon and Mars, we propose to develop a miniature analytical sensing instrument based on solid-state nanopore technology. The nanopore sensor would enable in situ detection and quantification of multiple inorganic and organic analytes by utilizing a low-noise and sensitive silicon nitride material. The sensor reader is designed to be compact (cm-scale) and easy to operate, and is integrated with automatic data processing and interpretation. Sensor's specifications will be outlined and developed to satisfy the detailed and stringent NASA mission requirements, in consultation with NASA scientists. The technical objectives include: 1) fabricate low-noise sensors (ultrathin SiN nanopore chips), 2) establish the optimal sensor protocol (cleaning, coating and storage) methods, 3) develop the protocols for detecting target analytes in pure samples, 4) demonstrate and validate measurement capability in the matrix of simulant ISS water samples and confirm the sensor sensitivity and selectivity, 5) develop an integrated data processing system with validated functionalities of fast, reliable and automatic data analysis and visualization with minimum manual intervention, 6) create a database of all the above measurement results including all parameters, and 7) specify flight readiness parameters needed for NASA mission, and discuss with NASA stakeholders on the specific requirements and expectation of deliverables and the remote simultaneous testing in NASA labs and Goeppert lab. This Phase II project will focus on improving the overall analytical capability of the sensor in the context of environmental water samples and optimizing the data analysis efficiency and effectiveness that serves as a reliable miniaturized water monitoring platform and can be rapidly fused in current or future NASA crewed missions.

Potential NASA Applications (Limit 1500 characters, approximately 150 words)

Our technology features a novel single-molecule detection method designed for water monitoring in spacecrafts. This advanced instrument can be crucial to support the life of crew during long-duration manned missions. The maintenance of safe living conditions is important to support the scientific activities of the crew when away from Earth, including the Artemis Gateway and exploration of the Moon and Mars, both on the surface and in transit, and to ensure their safe and unharmed return to Earth upon mission completion.

Potential Non-NASA Applications (Limit 1500 characters, approximately 150 words)

The proposed nanopore sensor architecture, with its miniaturized and robust design has potential in a wide variety of terrestrial applications ranging from DNA sequencing, point-of-care diagnostics, human pathogen surveillance to agricultural. Additionally, the small molecule analysis capability can be applied to the EPA and USDA needs for measuring water quality.

Duration: 24

PROPOSAL NUMBER:	21-2- **T8.07-1991**
PHASE 1 CONTRACT NUMBER:	80NSSC21C0091
SUBTOPIC TITLE:	Photonic Integrated Circuits
PROPOSAL TITLE:	Ultra-narrow Linewidth Lasers for Deployed Quantum Timing Applications

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Estimated Technology Readiness Level (TRL) :
Begin: 2
End: 4

Technical Abstract (Limit 2000 characters, approximately 200 words)

Vescent Photonics, LLC (Vescent) in collaboration with the Massachusetts Institute of Technology Lincoln Laboratory (MIT-LL) proposes to develop a compact ultra-narrow linewidth laser based on photonic integrated chip (PIC) technology for next-generation fieldable quantum sensor applications including optical atomic clocks, two-way time transfer, and precision inertial force and gravity sensing. Atomic clocks represent the most precise and accurate instruments developed by scientists to date and enable applications including the measurement of weak gravitational fields in near-zero gravity as well as accurate positioning, navigation, and timing (PNT) onboard a spacecraft. However, high-performance optical atomic clocks, including Sr^+ trapped-ion clocks, currently only exist in laboratory settings due to constraints on the size, weight, power, and cost (SWaP-C) *and* environmental susceptibility of critical technology subsystems. One of the key subsystems so far hindering the transition of these high-performance optical clocks outside the laboratory is the ultra-narrow-linewidth (< 100 Hz) laser required to interrogate the atoms. The solution proposed here for the development of an ultra-narrow linewidth laser is an extension to the initial demonstrations by Dr. William Loh at MIT-LL with fiber-based stimulated Brillouin scattering (SBS) lasers which have been demonstrated in an operating Sr^+ trapped-ion clock, resulting in an ADEV of 3.9E-14/(Tau)^(0.5). Using these fiber-based results as a baseline, recent

measurements conducted by the MIT-LL team have shown an evolution toward PIC-based waveguide cavities that can support ultranarrow-linewidth lasers via SBS. The effort proposed here seeks to integrate necessary chip-scale components to move towards a design where the entire ultra-narrow-linewidth laser system is contained on a chip-scale device.

Potential NASA Applications (Limit 1500 characters, approximately 150 words)

This proposal directly addresses two of NASA's research topic areas: S1.10 Atomic Quantum Sensors and Clocks and T8.07 Photonic Integrated Circuits. The laser hardware developed under this effort will be suitable for optical atomic clocks, atomic interferometers, and any applications requiring small, low-power lasers for remote sensing including the following missions: Moon to Mars, CLPS, Flight OPPS, and ISS.

Potential Non-NASA Applications (Limit 1500 characters, approximately 150 words)

Vescent has identified several applications that would benefit from a low SWaP ultranarrow linewidth laser and include: optical atomic clocks, time and frequency transfer, ultralow microwave phase noise generation, dual comb and precision spectroscopy, precision inertial force and gravity sensing, and lidar.

Duration: 24

PROPOSAL NUMBER: 21-2- **T10.04-1550**

PHASE 1 CONTRACT NUMBER: 80NSSC21C0369

SUBTOPIC TITLE: Autonomous Systems and Operations for the Lunar Orbital Platform-Gateway

PROPOSAL TITLE: REALISE - Remote Experimentation and Analysis Laboratory In SpacE

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Estimated Technology Readiness Level (TRL) :
Begin: 5
End: 6

Technical Abstract (Limit 2000 characters, approximately 200 words)

We are proposing the fully autonomous science facility REALISE for suspended biological cultures that can both incubate organisms over long periods of time (30 days to 9 months) but also perform in-situ analysis of samples using bright-field and three-color fluorescence microscopy. REALISE will be based heavily on functionality, components, and experience from past Shuttle, ISS, and Orion heritage flight hardware but is intended to set new standards for in-situ scientific analysis, long-term cell culturing, as well as automation. The in-situ automated microscopy compartment will set new standards in characterizing cell adaptations in space over time as opposed to only start and end conditions. The fluorescent analysis -in addition to bright-field microscopy for morphological changes- will be used to characterize microbiological processes such as cell metabolism, cell health, and cell function. While REALISE is developed specifically for the Lunar Orbital Platform Gateway, it will have future applications also on commercial space stations and lunar surface habitats both manned and unmanned as well as for more automated and less crew-intensive experiments onboard the International Space Station. REALISE is proposed to be a two locker system that will be permanently deployed onboard the Lunar Orbital Platform Gateway and can store and actively support cell cultures fully thermally-controlled for up to 9 months. Once an experiment or production is terminated, REALISE is designed to be serviced on-orbit while the crew is present for consumable swap out so that the unit can initiate another autonomous operation cycle. Potential applications are radiation studies over multiple generations to characterize the response of organisms or the effectiveness of countermeasures for future long-term human spaceflights as well as cell production facilities for unique terrestrial cell culture treatments that can only be grown in the space environment.

Potential NASA Applications (Limit 1500 characters, approximately 150 words)

REALISE will provide NASA the capability to conduct autonomous long-term cell culture studies ranging from microbiology (yeast, protein crystals,) to mammalian cell cultures (bone cells, heart cells, blood

cells, stem cells) in deep space. As REALISE is specifically designed for the Gateway Lunar Orbital Platform, novel radiation studies over multiple generations under long-term exposure to the space environment are imminent examples that are critical to inform NASA about the risks and mitigation of future human space exploration missions.

Potential Non-NASA Applications (Limit 1500 characters, approximately 150 words)

REALISE will provide autonomous large scale cell culture productions for commercial companies that can produce unique cell culture lines onboard the Gateway in the deep space environment. However REALISE is expandable to ISS, commercial space stations, and/or planetary surfaces. Subcomponents such as automated manufacturing as well as in-situ analysis methods can also be individually marketed.

Duration: 24

PROPOSAL NUMBER:	21-2- **T12.07-1562**
PHASE 1 CONTRACT NUMBER:	80NSSC21C0405
SUBTOPIC TITLE:	Design Tools for Advanced Tailorable Composites
PROPOSAL TITLE:	An Efficient High-fidelity Design Tool for Advanced Tailorable Composites

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Estimated Technology Readiness Level (TRL) :
Begin: 5
End: 6

Technical Abstract (Limit 2000 characters, approximately 200 words)

To harness the potential of advanced tailorable composites for lightweighting aerospace structures with enhanced performance, AnalySwift proposes to develop an efficient high-fidelity Design tool for Advanced Tailorable Composites (DATC). Building upon our accomplishments in Phase I, DATC will be developed based on the efficient high-fidelity constitutive modeling capability of mechanics of structure genome (MSG) and its companion code SwiftComp, the versatile structural analysis capabilities of two finite element analysis (FEA) packages Abaqus and MSC.Patran/Nastran, the general-purpose optimizer Dakota, and the state-of-the-art machine learning (ML) package TensorFlow. DATC will integrate all these tools into a unified and intuitive design framework, facilitating design setups and enabling innovative designs of structures made of tow-steered composites. MSG computes the location-dependent shell properties for FEA and Dakota performs optimization for varying fiber orientations, ply coverages (varying ply thickness and ply drops), and different materials with manufacturing constraints. ML provides ultra-efficient surrogate models to accelerate the optimization from days to hours. The associated computer codes are developed with an open architecture to allow users to add new functionalities for specific problems. Several realistic aerospace structures will be employed to verify the validate the developed tool and demonstrate the benefits from tailorable composites in reducing the structural weights and/or improving the load-bearing capacity. We expect to release DATC by the end of the Phase II as a user-friendly graphic user interface (GUI) plug-in for MSC.Patran/Nastran and Abaqus so that engineers familiar with these two FEA codes can easily use DATC to carry out analysis, parametric studies, and design optimizations of highly tailorable composite structures.

Potential NASA Applications (Limit 1500 characters, approximately 150 words)

- Lightweight structures for satellite buses, landers, rovers and other exploration vehicles, solar arrays, and antennas.
- Cryogenic tanks, pressurized habitats, other primary space structure components, including dry & unpressurized, such as lander truss cages, landing gears.
- Next-generation airframe tech (hybrid/blended wing body); highly flexible wings.
- Highly fatigue and damage tolerant structures for revolutionary vertical lift aircraft.

Potential Non-NASA Applications (Limit 1500 characters, approximately 150 words)

- High performance, lightweight commercial space/aerospace structures and components (with improved predictive capabilities).
- Validated design and analysis tools for the realization of tailorable composites in secondary markets (energy/wind, auto, marine, etc.).
- Improved designs for high-performance tailorable structures (prosthetics, fishing rods, golf clubs, tubes, etc.) with reduced cost & time.

Duration: 24

PROPOSAL NUMBER: 21-2- **T13.01-1411**

PHASE 1 CONTRACT NUMBER: 80NSSC21C0268

SUBTOPIC TITLE: Intelligent Sensor Systems

PROPOSAL TITLE: Wireless Networked, High Temperature, Wide Bandwidth Pressure Sensors for Propulsion System Monitoring

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Estimated Technology Readiness Level (TRL) :
Begin: 4
End: 6

Technical Abstract (Limit 2000 characters, approximately 200 words)

This NASA Phase II STTR program would develop wireless networked, high temperature, wide bandwidth pressure sensors for use in propulsion systems during ground test and launch operations. Both applications require broadband and in particular high frequency response for adequate diagnostics, and operation at very high temperatures in rocket engine environments. The team proposes major changes in pressure sensor fabrication and implementation to allow order of magnitude increases in their temperature range, from their current 250 °C upper temperature limit to 1000 °C and above. Such modifications involve 1) improved packaging processes to reach approximately 500 °C continuously, 2) the use of very high temperature polymer-derived ceramic thermal barrier materials to reach 1000 °C intermittently, and 3) the optimization of wide bandwidth frequency response of DC to above 5MHz with thermal barrier materials. The team will transition the wireless networked, high temperature, high frequency pressure sensors from their current concept to prototype stage products of use for rocket engine applications.

Potential NASA Applications (Limit 1500 characters, approximately 150 words)

The proposed wireless networked, high temperature, wide bandwidth pressure sensors can be used in the propulsion systems during ground test and launch operations. Currently, there are no commercial pressure sensors that can cover the wide frequency bandwidth from DC to 5MHz, even without high temperature capacities. The advantage of the proposed sensors over these existing low temperature products is their DC to 5MHz frequency response.

Potential Non-NASA Applications (Limit 1500 characters, approximately 150 words)

Primary customers would be university, government laboratory and industry researchers. Customers for wireless networked, high temperature, high frequency pressure transducers will be the manufacturers of engines and of high-speed vehicle and flight control system designers and manufacturers Broader commercial sensor opportunities include oil and gas down-hole measurements.

Duration: 24

PROPOSAL NUMBER: 21-2- **T14.01-1272**

PHASE 1 CONTRACT NUMBER: 80NSSC21C0266

SUBTOPIC TITLE: Advanced Concepts for Lunar and Martian Propellant Production, Storage, Transfer, and Usage

PROPOSAL TITLE: Heat Transfer Correlations for Complete Cryogenic Pool Boiling Curve

SMALL BUSINESS CONCERN (SBC):
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RESEARCH INSTITUTION (RI):
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Estimated Technology Readiness Level (TRL) :
Begin: 2
End: 4

Technical Abstract (Limit 2000 characters, approximately 200 words)

The proposed effort concerns technologies related to cryogenic propellant production, storage, transfer, and usage to support NASA's in-situ resource utilization (ISRU) goals. They include a broad range of applications, scales, and environments consistent with future NASA missions to the Moon and Mars. More specifically, the project will address development of a piecewise-smooth set of correlations for use in lumped node codes to facilitate prediction of the entire cryogenic pool boiling curve (local wall heat flux versus wall-to-fluid temperature difference) encountered in cryogenic storage and transfer systems. This will include development of sub-models for all regions and transition points of the boiling curve as well as experimental validation of the same.

Potential NASA Applications (Limit 1500 characters, approximately 150 words)

The project will address development of correlations for use in lumped node codes to facilitate prediction of the entire cryogenic pool boiling encountered in cryogenic storage and transfer systems. Such predictive tools are expected to have broad application in several of NASA's cryogenic applications, including cooling in Earth-orbiting satellites, rocket transfer, nuclear thermal propulsion, fuel management for in-space chemical rockets, and cryogenic fuel depots.

Potential Non-NASA Applications (Limit 1500 characters, approximately 150 words)

The main commercialization outcome for our firm will be robust, user-friendly software to enable thermal design and analysis of cryogenic space systems for use by not only NASA but aerospace companies as well, including SpaceX, Blue Origin, and United Launch Alliance.

Other terrestrial applications include data centers, aircraft avionics, hydrogen storage, and both hybrid and electric vehicles.

Duration: 24

PROPOSAL NUMBER: 21-2- **T6.07-2266**

PHASE 1 CONTRACT NUMBER: 80NSSC21C0123

SUBTOPIC TITLE: Space Exploration Plant Growth

PROPOSAL TITLE: A Smart Spectral Polarimetric Imager for Autonomous Plant Health Monitoring

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Estimated Technology Readiness Level (TRL) :
Begin: 5
End: 6

Technical Abstract (Limit 2000 characters, approximately 200 words)

For future long-duration space exploration missions, NASA expressed the need for plant systems that may provide a nutrient dense supplement to crew diet and possibly other life support functions, such as CO2 removal, O2 production, water recovery, and waste recycling. Current and future infrastructure for plant growth include chambers with controlled environments. To ensure optimal growing conditions in these chambers, the plants will require precise monitoring of health throughout the plant life cycle. These monitoring systems will need to operate autonomously with little crew involvement. Current plant monitoring instruments include multispectral and hyperspectral sensing that require post-process algorithms to detect physiological phenomena. In Phase I, Space Lab Technologies (Space Lab) and the Space Plants Lab at the University of Florida (UF) investigated an improved approach for monitoring space plant health using a smart spectral polarimetric (SSP) imager to monitor morphological features and stresses. The Phase II work builds upon the prototypes and analyses completed in Phase I, which includes a deliverable of an engineering demonstration unit (EDU) to NASA Kennedy Space Center. The EDU is compact and intended for use in the ground-based plant growth chamber equivalents of the Advance Plant Habitat (APH) or VEGGIE.

Potential NASA Applications (Limit 1500 characters, approximately 150 words)

- Plant Health Monitoring in Space Habitats
- Space Crops Food Safety
- Spacecraft Structural Stress or Fracture Detection
- Remote Sensing of Earth
- Planetary Science

Potential Non-NASA Applications (Limit 1500 characters, approximately 150 words)

- Agriculture - Crop Health
- Controlled Environment Agriculture
- Food Processing and Safety
- Mechanical Stress and Fracture Detection
- Industrial Process Monitoring
- Laboratory Polarized Spectrometer for Research

Duration: 24

PROPOSAL NUMBER:	21-2- **T12.05-3097**
PHASE 1 CONTRACT NUMBER:	80NSSC21C0208
SUBTOPIC TITLE:	Use of Additive Manufacturing for Thermal Protection Systems
PROPOSAL TITLE:	3D Printing of High Temperature Thermoset Foams for Space Vehicular Thermal Protection Systems

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Estimated Technology Readiness Level (TRL) :
Begin: 3
End: 5

Technical Abstract (Limit 2000 characters, approximately 200 words)

Based on the knowledge and expertise gained in partnership with the University of Tennessee at Knoxville (UTK) during the NASA/STTR Phase I work, re:3D proposes the development of a pilot system for the deposition of a phenolic foam TPS surface onto a scaled demonstration article in parallel with refinements and improvements to the foam's material characteristics.The Phase II research activities at UTK will focus on understanding the processing requirements to scale up production of the foam feedstock to 3D print large-scale test articles, refine the foam to further lower density and increase temperature stability, explore novel printing approaches to tailor effective density and elastic modulus and/or incorporate graded composition to raise temperature stability at the outer surface, and continued plasma arc jet torch testing of the developed materials and architectures.During Phase II, re:3D will be responsible for designing, developing and building the systems and mechanisms required for a pilot material extrusion system of the phenolic foam onto a scaled demonstration article consisting of an aluminum dome with a radius of curvature of approximately 1 meter and a 1-meter base diameter. The system would be comprised of the following elements:

1. **Mixing of the foam components, either outsourced or performed in-house as determined by a feasibility study during the course of the Phase II investigation at UTK**

2. **Transport of the foam from the mixing containers to the deposition nozzle through the use of an appropriate metering pump**

3. **Conformal deposition of the foam onto the aluminum dome with in-situ defect monitoring and advanced motion planning using a gantry printer based on re:3D's existing Terabot platform and a custom-designed extruder with added degrees of motion**

4. **Curing of the foam in an appropriate industrial oven**

5. **Post-process machining to achieve the final desired finish of the TPS surface**

Potential NASA Applications (Limit 1500 characters, approximately 150 words)

This process has applicability mission requiring an EDL phase dependent on parasitic surfaces for spacecraft survival. Current methods are expensive, labor intensive and result in non-optimum layering. In addition to cost benefits through material savings and automation, AM application of TPS surfaces offers real-time component certification, integration of sensors into the TPS during fabrication, & implementation of digital thread paradigms where TPS surfaces are generatively designed around engineering requirements.

Potential Non-NASA Applications (Limit 1500 characters, approximately 150 words)

Outside of research institutions, to our knowledge there are no commercially available large-scale printers capable of applying thermoset foams to conformal, non-planar surfaces. With the resources of a Phase II grant, our collaboration with UTK, and partnerships with industry, we believe this project is achievable and will result in a process to industries beyond space and DoD customers.

Duration: 24

PROPOSAL NUMBER:	21-2- **T10.05-1207**
PHASE 1 CONTRACT NUMBER:	80NSSC21C0264
SUBTOPIC TITLE:	Integrated Data Uncertainty Management and Representation for Trustworthy and Trusted Autonomy in Space
PROPOSAL TITLE:	Machine Learning Explainability and Uncertainty Quantification to Support Calibration of Trust in Automated Systems

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Estimated Technology Readiness Level (TRL) :
Begin: 3
End: 6

Technical Abstract (Limit 2000 characters, approximately 200 words)

The Explanations in Lunar Surface Exploration (ELSE) capability applies Mosaic ATM's Explainable Basis Vectors (EBV) method for explainable machine learning (xML) and likelihood scores approach to uncertainty quantification (UQ) to lunar surface exploration. In Phase I, Mosaic ATM demonstrated the ability to generalize our EBV method from discrete numerical or binary inputs (e.g., wind speed or the presence/absence of rain) to computer vision classification problems. We demonstrated the feasibility of extracting various types of information from within a deep learning model to inform qualitative and quantitative judgments of whether the machine learning (ML) model is trustworthy. Such judgments can help human *and automated system* users of ML model outputs decide when to trust/distrust, the system's recommendations. Such an approach to appropriately calibrate trust in automated systems is crucial to expanding their use in high risk environments like deep space exploration.

In Phase II, we propose to apply the EBV method to classification of lunar terrain features to support trusted autonomy in lunar exploration, to include:

- Use the EBV method to produce information from within the underlying ML model to support assessment of the veracity of lunar terrain judgment model results.
- Incorporate EBV explanations and uncertainty quantification (UQ) into a lunar rover analog to demonstrate the ability to inform an automated system of the trustworthiness of the model.
- Incorporate EBV explanations into a user interface (UI) to demonstrate the ability to support appropriate calibration of human trust in an automated system.
- Evaluate the ELSE concept and prototype in an analog environment.

We have assembled a multi-disciplinary team, partnering with the Universities Space Research Association (USRA) as a research institution and the University of Central Florida (UCF), bringing together experts in lunar exploration, ML, and human-automation interaction.

Potential NASA Applications (Limit 1500 characters, approximately 150 words)

ELSE will apply our xML and UQ methods to contribute to:

- Successful implementation of autonomous systems to support deep space exploration, in line with efforts within Exploration Systems Development Mission Directorate (ESDMD) like Moon to Mars.
- Human-rover teaming in tasks involving path planning and navigation.

Advances in these areas also will contribute to progress more generally in assured autonomy research, which is of interest across NASA Directorates.

Potential Non-NASA Applications (Limit 1500 characters, approximately 150 words)

Non-NASA applications include robotics systems operating remotely, where increasingly autonomous operations can reduce the need for teleoperation, such as:

- Underground mines
- Radiation-contaminated sites
- Search and rescue in dangerous areas

Duration: 24

PROPOSAL NUMBER: 21-2- **T14.01-1649**

PHASE 1 CONTRACT NUMBER: 80NSSC21C0089

SUBTOPIC TITLE: Advanced Concepts for Lunar and Martian Propellant Production, Storage, Transfer, and Usage

PROPOSAL TITLE: Continuous Correlations for Complete Boiling Curves of Cryogenic Fluids

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Estimated Technology Readiness Level (TRL) :
Begin: 4
End: 7

Technical Abstract (Limit 2000 characters, approximately 200 words)

Future space exploration missions will rely on in situ production, storage, and transfer of cryogenic rocket propellants. Engineers need accurate and efficient modeling tools to design the next generation of lightweight, efficient cryogenic propellant management devices and processes. Predictive models for key fluid dynamics and heat transfer behavior must be tailored for use with cryogenic propellants and easily implemented in existing modeling frameworks. To meet this need, we propose to develop a suite of pool boiling correlations developed specifically for common cryogenic fluids and propellants, including hydrogen, oxygen, and methane. In Phase I, we proved the feasibility of our approach by measuring critical heat flux for cryogenic nitrogen and argon under novel conditions, assembling a comprehensive database for CHF in cryogenic fluids, and developing correlations for critical heat flux (CHF) that beat NASA's requirements for predictive accuracy and are more accurate than existing correlations. In Phase II, we will create a database of existing cryogenic pool boiling data for all boiling regimes from the literature. We will augment the database with new data collected from our cryogenic pool boiling test apparatus in both steady boiling and quenching modes, and we will produce new correlations that are piecewise smooth across all pool boiling regimes.

Potential NASA Applications (Limit 1500 characters, approximately 150 words)

Improved pool boiling correlations tailored for cryogenic fluids will benefit the design of propellant transfer, management, and storage systems for oxygen, methane, and hydrogen as part of critical programs such as the Human Landing System. Our improved correlation will help minimize chilldown times, minimize liquid venting during propellant fill, and design systems to prevent propellant boiloff due to static heat gain during operations.

Potential Non-NASA Applications (Limit 1500 characters, approximately 150 words)

CFM is also important for electronics cooling, directed-energy weapons cooling, and liquid natural gas storage and transport. Our pool boiling heat transfer correlations will support the design of these systems for high efficiency.

Duration: 24

PROPOSAL NUMBER:	21-2- **T11.05-1825**
PHASE 1 CONTRACT	80NSSC21C0372

NUMBER:

SUBTOPIC TITLE: Model-Based Enterprise

PROPOSAL TITLE: Digital Twin Data Acquisition System for Institutional Facility Management

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Estimated Technology Readiness Level (TRL) :
Begin: 5
End: 7

Technical Abstract (Limit 2000 characters, approximately 200 words)

Emerging Technology Ventures Inc. (ETV) and its research and development (R&D) partners, Navajo Technical University (NTU) and New Mexico Institute of Mining and Technology (NMT), proposed to develop and demonstrate a “Digital Twin (DT) Data Acquisition System for Institutional Facility Management”. The innovation addresses Industry 4.0 digital transformation initiatives in Building Information Modelling (BIM) and Facility Management (FM) which have created critical demand for up-to-date digitized building assets for effective implementation in predictive, condition-based maintenance (CBM) strategies in FM. The team’s proposed use of

autonomous, multi-modal systems and analytics to create DTs representing near real-time status of the built environment for FM offers an opportunity for responsive, labor efficient CBM.

This Phase II proposal continues the work completed in Phase I and results in a deployable capability to NASA's Marshall Space Flight Facility for user evaluation and feedback in an iterative "Research-Design-Build" process. This project continues collaboration between ETV and its R&D partners which have ongoing supporting technology initiatives including the National Aeronautics and Space Administration (NASA) Minority University Research and Education Project (MUREP) Innovation Tech Transfer Idea Competition with NTU and the Department of Defense (DoD) Autonomous Inspection, Damage Classification, and Repair Support System for Aircraft Mission Readiness with NMT. This joint proposal represents the next step in the team's vision to build a fundamental and applied research collaborative in autonomous sensing and predictive analytics in complex environments. The innovation aims to meet market opportunities in critical infrastructure inspection (aerospace, facilities, renewable energy), precision agriculture, and public safety.

Potential NASA Applications (Limit 1500 characters, approximately 150 words)

The proposed innovation addresses NASA's articulated Small Business Technology Transfer (STTR) needs in the delivery of an end-to-end DT system for integrated Building Information Management (BIM) and Facility Management (FM). These outcomes will support NASA as it implements its Digital Transformation objectives and moves towards a "Smart Center" environment for its facility constellation.

Potential Non-NASA Applications (Limit 1500 characters, approximately 150 words)

ETV recently submitted a response to a Sources Sought entitled "Optimizing Facilities Leveraging Digital Twin Using Modeling, Simulation, and Analysis Tools" to the National Center for Manufacturing Sciences (NCMS) on behalf of their US Army customer.

Duration: 24

PROPOSAL NUMBER:	21-2- **T11.05-1297**
PHASE 1 CONTRACT NUMBER:	80NSSC21C0357
SUBTOPIC TITLE:	Model-Based Enterprise
PROPOSAL TITLE:	Model-based Enterprise Architecture for Institutional Management Digital Twins

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Estimated Technology Readiness Level (TRL) :
Begin: 4
End: 7

Technical Abstract (Limit 2000 characters, approximately 200 words)

NASA manages $40B in facility assets with an inventory of more than 5,000 facilities. Over 83% of this infrastructure is beyond its design life, and the agency faces a deferred maintenance backlog of $2.77B. An effective method to address this challenge and achieve digital transformation is through Enterprise Architecture (EA) and the use of Model-Based Systems Engineering (MBSE) methods.

During Phase I, guided by stakeholders from NASA Goddard Space Flight Center (GSFC) and headquarters, Global Technology Connection and Georgia Tech's Aerospace Systems Design Laboratory successfully demonstrated the feasibility and value of using the Unified Architecture Framework (UAF) to create a model of NASA enterprise. This interlinks NASA's missions, projects, facilities, capabilities, timelines and more using their connected attributes. Doing so enabled rapid, accurate, and more data-driven decision-making to guide and prioritize investments around NASA's aging infrastructure. We identified pertinent use cases and demonstrated how our approach can lead to informed decisions for Institutional Construction of Facilities (I-CoF) projects.

The objective of Phase II is to mature and implement the model-based enterprise architecture for institutional management digital twins (EA-MBSE) at GSFC leveraging UAF to enable decision-making with increased insight and velocity for I-CoF projects.

Specifically, we will address three use cases which we have identified as the most pressing and the most beneficial for NASA stakeholders.

Facilities prioritization for master planning of greenbelt facilities
Institutional CoF budget re-allocation and justification
Multi-facility energy conservation measure (ECM) projects prioritization

For easy extraction and dissemination of these insights, we will generate user specific views with streamlined interactivity. A technology plan addressing technical & operational challenges will also be developed.

Potential NASA Applications (Limit 1500 characters, approximately 150 words)

As NASA moves from center-based to agency-level decision making, it is crucial to have an easily and a scalable solution for viewing connected information across domains. Our solution provides NASA with a tool to

- Conduct institutional CoF budget re-allocation and justification
- Perform facilities prioritization analysis for master planners
- Analyze and prioritize multi-facility energy conservation measure (ECM) projects

Our solution enables these tasks to be accomplished cost effectively and without human induced errors.

Potential Non-NASA Applications (Limit 1500 characters, approximately 150 words)

Our solution is also applicable to large government agencies such as DoE, NIH, and DoD agencies to large universities. It provides objective and crucial information rapidly and effectively with reusable views for decision-makers. This enable fully informed investment prioritization decisions cost effectively especially in rapidly changing budget environments and scenarios.

Duration: 24

PROPOSAL NUMBER: 21-2- **T10.03-1245**

PHASE 1 CONTRACT NUMBER: 80NSSC21C0408

SUBTOPIC TITLE: Coordination and Control of Swarms of Space Vehicles

PROPOSAL TITLE: Autonomous Swarming for Teams of Exploration Robots (ASTER)

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Estimated Technology Readiness Level (TRL) :
Begin: 4
End: 6

Technical Abstract (Limit 2000 characters, approximately 200 words)

NASA will use swarms of robot vehicles for future planetary exploration, including Moon explorations in support of a sustained lunar presence. Advanced robotic and autonomous systems can overcome challenges inherent in navigating extreme terrain. Other tasks, such as obtaining mineral or ice samples from a wide area of a planetary surface or exploring terrain that blocks the transmission of signals to Earth or satellites (e.g., canyons, caves, lava tubes), lend themselves to robotic systems composed of multiple vehicles working in a coordinated fashion (i.e., multi-robot swarms). In addition to sharing work across the team, these swarms can adapt to changing exploration needs, and provide resiliency to failure of single vehicles while being scalable to accept additional vehicles when needed. Charles River Analytics and the Novel Engineering for Swarm Technologies (NEST) Laboratory at Worcester Polytechnic Institute will design and demonstrate Autonomous Swarming for Teams of Exploration Robots (ASTER). We introduce three compelling innovations to swarm systems: (1) a "theory of mind" task allocation method in which robots use what they know of others to plan their own next task; (2) the extension of heterogeneity to include health and status of robots; and (3) anticipating future world state and robot health and status based on data received and knowledge about what robots are performing what tasks. ASTER will use three technologies: Task allocation algorithms informed by Charles River's Swarm Coordination Framework, the Buzz swarm programming language for implementing algorithms and behaviors for physical and simulated robots, and the ARGoS multi-physics simulation engine for simulation and evaluation. We will deploy and evaluate algorithms on physical robots in real-world environments. We aim to reach TRL 6 during our Phase II effort and we will focus on the real-world utility of these algorithms to support future NASA missions.

Potential NASA Applications (Limit 1500 characters, approximately 150 words)

The innovations proposed under ASTER are relevant to the NASA Small Spacecraft Technology Program (SSTP) and the 2018 NASA Strategic Plan's focus on advanced robotic and autonomous systems. Plans to use Commercial Lunar Payload Services to return humans to the Moon and establish a sustained lunar presence will depend on exploring the lunar surface for resources necessary to maintain operations. Lessons learned from using robot swarms on the Moon will inform future voyages to planets (e.g., Mars) and asteroids.

Potential Non-NASA Applications (Limit 1500 characters, approximately 150 words)

The Army's Air Launched Effects (ALE) program, US Navy's RAIDER, DARPA's OFFSET, and work at other Government agencies will benefit from these innovations, as will commercial companies working with the Government (e.g., AeroVironment). We have started to pursue commercial uses of swarms in disaster response, search and rescue, and smart agriculture, and will continue to explore these in Phase II.

Duration: 24

PROPOSAL NUMBER: 21-2- **T15.04-1416**

PHASE 1 CONTRACT NUMBER: 80NSSC21C0399

SUBTOPIC TITLE: Full-Scale (2+ Passenger) Electric Vertical Takeoff and Landing (eVTOL) Scaling, Performance, Aerodynamics, and Acoustics Investigations

PROPOSAL TITLE: Full-Scale eVTOL Aircraft Performance and Aeroacoustic Test, Evaluation, and Modeling

SMALL BUSINESS CONCERN (SBC):
Continuum Dynamics, Inc.
34 Lexington Avenue
Ewing NJ 08618 - 2302
Phone: (609) 538-0444

RESEARCH INSTITUTION (RI):
Pennsylvania State University
101 Hammond Building
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Estimated Technology Readiness Level (TRL) :
Begin: 5
End: 6

Technical Abstract (Limit 2000 characters, approximately 200 words)

The recent upsurge in development and prospective applications of Electric Vertical Takeoff and Landing (eVTOL) vehicles has the potential to transform the vertical flight landscape. Among the several classes of aircraft under development for projected Advanced Air Mobility (AAM) applications are vehicles with distributed multiple-rotor systems. Such multicopters offer potential benefits in simplified flight control, redundancy, and conversion between vertical lift and forward flight. However, multirotor systems pose considerable design challenges in terms of quantifying the effect of rotor-rotor interactions on integrated performance, rotor/airframe interactional aerodynamics, flight mechanics, vibratory loads, and noise. Computational models exist that can analyze these vehicles, however, as identified by NASA in the Phase I solicitation, high-quality, full-scale experimental data to validate these models is not currently available. The proposed Phase II STTR effort will address this need by providing extending Phase I work, providing both a computational model and an additional body of flight test data for a full-scale multirotor eVTOL aircraft. Phase II flight testing will provide both performance and noise data that extends initial Phase I results. An ambitious work scope is proposed by leveraging the advanced state of development of models and resources available to the proposing team, including both a full-scale aircraft that has already undergone low altitude hover flight tests and industry-

standard modeling and analysis software currently in use by NASA and eVTOL AAM aircraft developers performing vehicle concept evaluation, analysis and design.

Potential NASA Applications (Limit 1500 characters, approximately 150 words)

The proposed research effort will provide performance, aerodynamics and acoustics flight test data and computational modeling for full-scale eVTOL AAM multicopters, directly supporting NASA's ARMD Strategic Thrust 4: Safe, Quiet, and Affordable Vertical Lift Air Vehicles by addressing the increasing demand for knowledge about how to design, build and fly these types of vehicles. The test data obtained in this effort helps fill a vital, missing link impeding the progress of those at NASA and in industry developing eVTOL AAM vehicles.

Potential Non-NASA Applications (Limit 1500 characters, approximately 150 words)

CDI provides engineering services and software to numerous eVTOL AAM air taxi vehicle developers. The new full-scale test data will be used to validate our tools, and software enhancements produced will be instrumental in the success of this new generation of entrepreneurial organizations who have an immediate need for improved modeling and analysis it will engender.

Duration: 24

PROPOSAL NUMBER:	21-2- **T7.04-2835**
PHASE 1 CONTRACT NUMBER:	80NSSC21C0068
SUBTOPIC TITLE:	Surface Construction
PROPOSAL TITLE:	Low-Energy Additive Construction for the Moon and Mars

SMALL BUSINESS CONCERN (SBC):
Masten Space Systems, Inc.
1570 Sabovich Street
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RESEARCH INSTITUTION (RI):
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Estimated Technology Readiness Level (TRL) :
Begin: 4
End: 6

Technical Abstract (Limit 2000 characters, approximately 200 words)

The technology presented in this proposal has the capability of providing surface stabilization for landing pads, and a low-energy solution to build roads and other early components of infrastructure that are needed to kickstart a functional lunar or Martian base. The proposed innovation is a novel binder chemistry for the formation of a high-strength, heat-tolerant, regolith-binder composite material, suitable for lunar surface and Martian surface construction, notably landing pads, as well as hardware for mixing and production of the binder material. This binder is unique because it requires no energy input to cure and can be sourced from 100% in-situ sources on the moon and mars but with the option for immediate demonstration testing using terrestrially sourced, low mass-fraction binder.
The fully in-situ sourcing option for the material would significantly reduce the cost of deploying a base camp on the surface of the Moon or Mars. Along with the above benefits of this specific landing pad technology/chemistry, the proposed hardware to be developed in this phase II effort will be compatible with state-of-the-art thermoset and thermoplastic binders for regolith, allowing it to deploy and validate a wide portfolio of lunar landing pad technologies on any future demonstration mission.

Potential NASA Applications (Limit 1500 characters, approximately 150 words)

This technology enables NASA's goal of near-term and frequent landings on the lunar surface under the Artemis program while mitigating risk to surface and orbital assets and personnel. The low energy usage and wide terrestrial availability of the low mass-fraction binder allows for near-term deployment of this material as a landing pad, while the in-situ sourcing opportunity and flexibility of the deployment hardware make the technology valuable for supporting a sustained lunar presence and for spearheading future Martian missions.

Potential Non-NASA Applications (Limit 1500 characters, approximately 150 words)

This low energy, heat tolerant, in-situ derived construction solution is compelling for a number of prospective lunar and Martian infrastructure companies. This may include companies like Masten Space Systems or SpaceX, but also orbital groups like OrbitFab or Axiom who may expand to surface operations. In this competitive space, few are willing to commit before demonstration missions.

Duration: 24

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