AMENDMENT NO. 1 TO THE NASA RESEARCH ANNOUNCEMENT (NRA) ENTITLED "RESEARCH OPPORTUNITIES IN AERONAUTICS – 2023 (ROA-2023)," NNH23ZEA001N, RELEASED NOVEMBER 15, 2022

Changes are made to the following:

- Updated Table of Contents
- Table 5. Solicited Research Programs (in order of proposal due dates)
- Table 6. Solicited Research Programs (in order of Appendices A-D)
- Appendix D.2 – Transformational Tools and Technologies Project (TTT)

TABLE 5. SOLICITED RESEARCH PROGRAMS (IN ORDER OF PROPOSAL DUE DATES)

APPENDIX	PROGRAM	NOI DUE DATE	PROPOSAL DUE DATE
D.2	Transformational Tools and Technologies Project (TTT)	December 9, 2022	January 13, 2023, 5PM EST

TABLE 6. SOLICITED RESEARCH PROGRAMS (IN ORDER OF APPENDICES A–D)

APPENDIX	PROGRAM	NOI DUE DATE	PROPOSAL DUE DATE
D.2	Transformational Tools and Technologies Project (TTT)	December 9, 2022	January 13, 2023, 5PM EST

APPENDIX D: Transformative Aeronautics Concepts Program

D.1 Program Overview

The Transformative Aeronautics Concepts (TAC) Program cultivates cross-cutting concepts and capabilities that inspire new solution paths to aeronautics technical barriers, enable innovative designs, and lead to breakthrough technologies that transform aviation. In this context, a "breakthrough" technology has a significant positive impact. For instance, it may greatly improve system performance or open up a new market. Because of its "seedling" nature within the NASA Aeronautics enterprise, the TAC Program impacts a wide variety of systems, subsystems, vehicles, operations, tools, and applications of technology within the aeronautics community.

The TAC Program objectives are:

1) Support and challenge strategic and tactical planning via early convergent innovation; and
2) Advance the strategic thrusts by providing transformative capabilities within single disciplines and at system-level.

The TAC Program supports all six of the ARMD Strategic Thrusts and consists of three projects:

The Transformational Tools and Technologies (TTT) Project advances state-of-the-art computational and experimental tools and technologies that enable aviation applications in the six strategic thrusts.

The Convergent Aeronautics Solutions (CAS) Project performs rapid feasibility assessments of early-stage innovations that challenge existing technical approaches, create alternate paths to solutions, or enable new strategic outcomes.

The University Innovation (UI) Project provides an opportunity for U.S. colleges and universities to demonstrate leadership by forming teams that explore novel solutions to complex aviation problems.

For more information on TACP, please visit http://www.aeronautics.nasa.gov/programs-tacp.htm

D.2 Transformational Tools and Technologies (TTT) Project

D.2.1 Project Overview

The Transformational Tools and Technologies (TTT) Project advances state-of-the-art computational and experimental tools and technologies that are vital to aviation applications supporting the six NASA Aeronautics strategic thrusts. The project enables fast, efficient design and analysis of advanced aviation systems from first principles by developing physics-based tools/methods and cross-cutting technologies. The project also provides new multi-disciplinary design, analysis and optimization (MDAO) and systems analysis tools and supports exploratory research with the potential to result in breakthroughs. These tools and technologies are intended to offer the potential for high payoff outcomes through their application within the mission programs/projects of the Aeronautics Research Mission Directorate (ARMD) toward completion of their Technical Challenges and toward progress in achieving the ARMD Strategic Implementation Plan (SIP) goals and objectives. The project strives to be relevant across all ARMD SIP Thrusts and a value-adding contributor toward the success of key outcomes and critical commitments.

To achieve its vision and objectives, the TTT Project has established an organizational structure that emphasizes two purposes: Enduring Disciplines to sustain NASA ARMD's leadership role for advancing the state of the art by supporting foundational research and technology development in the traditional core competency discipline areas and Subprojects to incentivize a more focused and inter-disciplinary approach for contemplating longer-term research and development solutions and the potential impact of these solutions on key challenges advocated in the NASA ARMD SIP and prioritized by ARMD.

TTT Project currently encompasses the following three focused Subprojects, each of which uniquely combines various disciplinary perspectives toward a NASA ARMD SIP key challenge.

1. **Foundational Electrified Aircraft Propulsion (FEAP) Subproject** which supports the enduring electrified propulsion research needs of the ARMD Mission Programs with the development of innovative materials, components, tools, and methods that enable the performance, reliability, and durability of these systems;
2. **Revolutionary Aviation Mobility (RAM) Subproject** which provides leading edge tools, technologies, and research findings to enable increasingly autonomous Advanced Aerial Mobility (AAM) transportation in the Urban Air Mobility (UAM) Maturity Level (UML)-4+ time frame; and
3. **Reduced Life Cycle Cost (RLCC) Subproject** which supports the reduction of the life cycle cost of aircraft to help the US aircraft industry stay competitive worldwide.

The TTT Project currently encompasses the following traditional core competency discipline areas: Aerosciences, Materials and Structures, Multi-disciplinary Design/Analysis/Optimization and Systems Analysis, Combustion, Flight and Propulsion Controls, Innovative Measurements, Communication, Navigation & Surveillance, and Autonomous Systems. Each discipline area encompasses one or more research elements and lower-level task activities. Research elements embody the longer-term, important areas of research necessary to advance the state of the art.

The Revolutionary Computational Aeroscience (RCA) Discipline research portfolio includes development of high-order robust numerical methods, transition and turbulence modeling aided by AI/ML, direct numerical simulation, large eddy simulation, and canonical flow physics experiments. The main objective of the research is to develop high-fidelity analysis capability for aerodynamic and propulsion flows that provides orders-of-magnitude speed increases by exploiting emerging high-performance computing hardware. Research is focused on capturing the potential of emerging high-order scale-resolving methods and automated high-order mesh generation to impact the design and analysis of aircraft and turbomachinery flows. Efficient knowledge extraction from large scale simulations is another important area of research as is algorithmic development for exploiting the potential of emerging quantum computer technology.

The Materials and Structures (M&S) Discipline emphasizes improved multifunctional and high temperature materials for airframe and engine application, as well as integrated multiscale modeling and simulation tool development to improve validated first-principles materials and structural modeling. The investment in specific models and a cyber-physical-social ecosystem framework is consistent with the recently developed 2040 Vision study results. Three swim lanes of composites, metallic materials, and electric aircraft, as well as their respective major focus areas, underpin the M&S discipline portfolio. This portfolio constitutes a balanced computational modeling and experimental program, wherein fundamental advancements in physics-based and data driven modeling infrastructure development will be undertaken while at the same time pursuing specific complementary experimental material technology developments. This pushes the mechanistic understanding and validation of the associated modeling toolsets.

The Multi-disciplinary Design/Analysis/Optimization and Systems Analysis, (MDAO) Discipline develops MDAO and aircraft system-level tools to improve integration of discipline-based technologies and enable improved assessment of system-level benefits. An open-source framework is emphasized to better leverage external partners, increase interaction, and benefit the community.

The Combustion Discipline addresses several significant challenges that ultimately govern combustor performance and its influence on key overall propulsion/aircraft system performance. The scope of work includes: (1) non-volatile particulate matter (nvPM) emissions, (2) fully-coupled engine core (compressor-combustor-turbine) simulations, (3) reduced cooling and improved durability of engine hot section components, and (4) expanding unique experimental databases and direct numerical simulations of fuel spray atomization. These topics are important to both subsonic and supersonic aircraft.

The Flight and Propulsion Controls Discipline encompasses work across aircraft flight controls and advanced propulsion controls. Flight Controls research focuses on technologies and methods which concurrently develop models and control algorithms for flight vehicles that result in dramatically shortened development and certification timelines, reduced costs, and potentially provide improved flight safety and reliability. Two key enabling technologies are real-time modeling and learning adaptive controls. Propulsion Control research focuses on the operability, performance, and safety of increasingly complex propulsion systems for advanced air vehicles. Research emphasizes the development of dynamic modeling and analysis tools that seek to inform the system designer about complex interactions between engine operability, power and energy management, thermal management, system integration, and their impact on vehicle performance.

The Innovative Measurements Discipline is responsible for the development of enhanced sensing and optical measurement techniques which are useful for a broad range of aerospace applications. The optical methods effort is sub-divided into two areas: surface measurements and flow field measurements. In surface measurements, research will seek to extend the temperature range of pressure sensitive paints. In flow field measurements, molecular-based high precision point techniques to simultaneously measure velocity and temperature will be developed. A luminescence-based thermal and environmental barrier coatings (TBCs/EBCs) method developed for turbine engine components will be investigated to map temperature and damage progression. A research effort will focus on a measurement technique to allow components with sub-optimal residual strain distributions to be screened before they reach service.

The Communication, Navigation and Surveillance (CNS) enduring discipline addresses the most challenging CNS technology gaps necessary for enabling UML-4+ operations. UAM aircraft will require multiple CNS services, including vehicle telemetry, command, pilot/passenger voice, cooperative separation assurance, navigation and timing sources, non-cooperative surveillance, and vertiport proximity CNS services to ensure safe landings and departures at high-volume vertiports.

The Autonomous Systems (AS) Discipline addresses capability gaps facing safe, increasingly autonomous operations for aviation. AS is focused on enabling urban air mobility (UAM) and designing its airspace infrastructure through foundational autonomy research. The AS discipline currently supports a variety of UML-4+ activities. UML-4+ signifies an intermediate to mature state where there are a hundreds to thousands of simultaneous operations in a given area; highly distributed networks; autonomous aircraft and remote fleet management; high weather tolerance; and high-volume manufacturing [1]. Activities fall into two primary categories: scalable management of many air vehicles by a small number of agents (m:N) and autonomous airspace coordination.

[1] Goodrich, K. H. and Theodore, C. R., "Description of the NASA Urban Air Mobility Maturity Level (UML) Scale," AIAA SciTech Forum, January 2021, AIAA 2021-1627. https://doi.org/10.2514/6.2021-1627]

D.2.2 Description of Solicited Research

In this solicitation, TTT is seeking proposals for work in the development of uncertainty quantification for CFD and multidisciplinary analysis, high-fidelity structural modeling for complex aeroelastic vehicle design, industry-relevant application for analytic derivatives in multidisciplinary design analysis and optimization, responsibility designation in scalable m:N architectures, collective behavior of air mobility systems, and water drop impingement measurement capability.

The following list summarizes the specific topics for which proposals are sought. Details for each topic are provided in the following subsections.

D.2.2.1 TTT Proposal Topics
- D.2.2.1.1 – Uncertainty Quantification for CFD and Multidisciplinary Analysis
- D.2.2.1.2 – High-Fidelity Structural Modeling for Complex Aeroelastic Vehicle Design
- D.2.2.1.3 – Industry-Relevant Application for Analytic Derivatives
- D.2.2.1.4 – Responsibility Designation in Scalable m:N Architectures
- D.2.2.1.5 – Collective Behavior of Air Mobility Systems
- D.2.2.1.6 – Water Drop Impingement Measurement Capability

Topic D.2.2.1.1 – Uncertainty Quantification for CFD and Multidisciplinary Analysis

Objectives:

Develop efficient uncertainty quantification methods and tools for computational fluid dynamics and multidisciplinary analysis.

Scope of Research:

Uncertainty quantification (UQ) theory encompasses both aleatoric (e.g., stochastic/random processes) and epistemic (e.g., parameters as distributions, range of models, etc.) sources of uncertainty. The NASA sponsored study on aircraft certification by analysis (CbA) [1] highlighted the need for creating efficient uncertainty quantification methodology and characterized it as a key technical challenge toward enabling computational methods as a credible alternative for CbA in lieu of flight testing. Since analysis using computational fluid dynamics (CFD) is a computationally intensive task and UQ generally requires a large number of CFD solves, it is important to develop strategies that reduce the computational cost for UQ to be employed routinely in CFD and multidisciplinary analysis applications.

This subtopic focuses on both the forward propagation of epistemic sources of uncertainty and the inverse estimation of epistemic input model parameters using data obtained from state-of-the-art CFD simulations. Standard approaches include the estimation of statistics via dense- and sparse-tensored quadrature [2], chaos-like polynomials [3], random sampling [4], Bayesian statistics [5], and machine learning [6]. The computational cost of these approaches is often reduced by employing multilevel approximation, surrogate models, or partial differential equations (PDE) reduced-order modeling. So that approaches developed under this subtopic can be routinely used in CFD calculations, the proposed approaches must enable very significant (perhaps, an order of magnitude) reduction in the overall computational effort for quantification of uncertainty and ideally be compatible with NASA CFD codes. In multidisciplinary analyses, CFD constitutes the most resource intensive element and, therefore, efficient UQ approaches for CFD should also enable quantification of uncertainty in high-fidelity multidisciplinary analysis. The proposed approaches should address the outstanding deficiencies in current forward or inverse uncertainty propagation approaches, e.g., estimation of output probability density function (PDF) statistics for distributions that have a significant departure from a normal distribution. Computational fluid dynamics calculations often yield output quantity of interest uncertainty distributions that depart from a normal distribution due to: (1) nonlinearity of the underlying PDEs and (2) presence of shock wave discontinuities in the high Reynolds number limit. Distributions from these calculations may be multi-model (multiple peaks) and/or exhibit PDF slope discontinuities in the high Reynolds number limit.

The ultimate goal of the research effort is to develop a framework for uncertainty quantification for CbA, which requires building confidence in numerical simulations and establish their credibility on equal footing with flight testing. Such a framework will be all encompassing, ranging from the characterization of sources of uncertainty to the propagation of uncertainties through multidisciplinary simulations. As stated in Ref [1], the technical challenges of UQ for CbA include the ability to deal with large parameter spaces, techniques for interpolation and extrapolation from validation data, realistic assessment of the effect of model form uncertainties within large complex simulations, and rare statistical event predictions, which are paramount for safety considerations. Therefore, reliable methods must be developed to estimate errors present in numerical simulations. Model form error in turbulent flow simulations is among the key sources of uncertainties for such applications and needs to be considered.

In the longer term, treatment of output uncertainties that depend discontinuously with respect to input uncertainties is another area of research in UQ. Transonic and supersonic aerodynamic calculations at high Reynolds number often contain nearly discontinuous shock waves propagating through space and time. The position of these discontinuities may depend on input sources of uncertainty so that output quantities of interest have a discontinuous dependence in the limit of increasing Reynolds number. This can severely degrade the performance of classical uncertainty quantification methods that utilize global approximation, e.g., global chaos polynomials, global quadrature, etc. While this area of research is important in UQ for CFD, in general, our first priority is to develop and mature UQ capability for CbA applications (for aircraft in take-off and landing configurations). It was indicated in Ref. [1] that scale-resolving methods may be required to significantly improve predictive capabilities for separated flows associated with CbA applications. While this remains the ultimate goal, proposers can use RANS-based approaches to demonstrate the UQ capability provided they are extendable to scale-resolving methods. Proposers are referred to various presentations at the recently held AIAA High-Lift Prediction Workshop – 4 (Ref. [7]) for various methodologies used to compute aircraft maximum lift.

Expected Outcomes:

1. Computational methods and tools that reduce the cost of UQ by an order of magnitude.
2. The developed UQ approach will have a suggested path to allow incorporation of the technology in NASA CFD codes.

[1] T. Mauery et al., A Guide for Aircraft Certification by Analysis, NASA/CR-20210015404, 2021.
[2] T. Gerstner and M. Griebel, Numerical Integration Using Sparse Grids, Num. Alg., Vol. 18, 1998.
[3] N. Weiner, The Homogeous Chaos, Am. J. Math., Vol. 50, 1938.
[4] N. Metropolis and S. Ulam, The Monte Carlo Method, J. Am. Stat. Assoc., Vol. 44, 1949.
[5] P. Bessiere, Bayesian Programming, CRC Press, 2013.

[6] Z. Ghahramani, Probablistic Machine Learning and Artificial Intelligence, Nature, Vol. 521, 2015.
[7] https://hiliftpw.larc.nasa.gov/

Topic D.2.2.1.2 – High-Fidelity Structural Modeling for Complex Aeroelastic Vehicle Design

Objectives:

Develop structural finite element (FE) modeling tools aimed at realistic aerospace vehicle configurations. Research will be conducted to develop and utilize a FE capability that can handle complex structural nonlinearities, and efficiently couple to computational fluid dynamics (CFD) codes for scalable high-fidelity aeroelastic analysis.

Scope of Research:

Current state-of-the-art aeroelasticity tools typically combine high-fidelity CFD analysis with a linear mode-based structural analysis. The required modal data can be obtained, a-priori, from commercially available FE tools (NASTRAN, ABAQUS, etc.). The resulting coupled framework can be used for both static and dynamic aeroelastic analysis but is limited to small structural displacements.

The next generation aircraft of interest to the aerospace community will utilize highly flexible wing structures, which undergo large deflections and vibrations. These structural nonlinearities can be computed by the aforementioned FE codes, but robust and scalable time-domain analysis that can be utilized for in-core coupling to other disciplines, such as CFD solvers, is challenging. Available open-source FE tools may be more amenable to CFD coupling, but these tools are unlikely to accommodate the relatively large finite element library required by modern aerospace structural models.

Under this subtopic, research will be conducted to develop a highly scalable FE tool which can (1) accommodate the wide array of element types and solution methodologies typically utilized in the aerospace industry; (2) compute complex structural geometric and material nonlinearities; and (3) demonstrate in-core coupling to an external CFD solver in an efficient manner, for both static and dynamic aeroelastic analysis. This tool will be made available for coupling with NASA CFD codes and will enable high-fidelity early-stage aeroelastic design of complex vehicle configurations, in addition to certification by analysis (CbA) efforts.

The final tool will be demonstrated on relevant aerospace configurations with large and complex finite element models. Example uses of the envisioned code include multidisciplinary wind up turn analyses or long duration simulations for transonic flutter and limit cycle oscillations of highly flexible aircraft such as the Transonic Truss-Braced Wing. To the extent possible, the input deck for the code will be compatible with the industry-standard NASTRAN code. Scalability of the FE analysis may be achieved with strong scaling or use of hardware accelerators such as GPUs. Finally, the work will be conducted in such a way as to enable downstream future efforts aimed at extending this framework towards the computation of coupled adjoint sensitivities for multidisciplinary design optimization (MDO).

Expected Outcomes:

1. Demonstration of a FE capability aimed at aerospace vehicle models composed of element types and solution methodologies typical of realistic industry applications.
2. Demonstration of a FE capability that can handle complex geometric and material nonlinearities.
3. Demonstration of an interface that can utilize in-core coupling with CFD solvers for static and dynamic aeroelastic simulations.
4. Demonstration of adequate scalability of the FE solver.

Topic D.2.2.1.3 – Industry-Relevant Application for Analytic Derivatives

Objectives:

The multidisciplinary design analysis and optimization (MDAO) research community has developed tools and techniques using analytic derivatives that drastically improve the efficiency of gradient-based optimization and widen its applicability to a new range of problems, but adoption of that research by the broader engineering community lags far behind the research itself. This topic solicits research aiming to close the adoption gap by identifying its root causes and then developing new techniques, tools, and demonstration problems that address them.

The outcomes of this research should demonstrably improve the ability of non-optimization-expert practitioners to apply state-of-the-art gradient-based optimization methods to their system-level design problems involving three or more distinct disciplines.

Scope of Research:

Modern research has already made some progress in improving the accessibility of state-of-the-art optimization techniques. Algorithmic differentiation tools have reduced the effort required to compute analytic derivatives and recently, due in part to a renewed interest from the machine learning community, they have become significantly more capable and widely available. At the same time, frameworks such as NASA's OpenMDAO have made it possible to integrate 10's of different disciplines along with their analytic derivatives efficiently, even when using high-fidelity tools and high-performance computing environments with distributed memory.

Despite these advancements, multiple barriers remain. Two of the most serious are overly simple problem formulation, which make it hard to extend methods to practical design efforts and lack of analytic derivatives for low- or mid-fidelity analyses critical to industry design processes. Proposals to this topic should include a collaboration between optimization researchers and design practitioners to identify a specific key barrier (i.e., a specific critical analysis missing derivatives, or a specific problem formulation that needs to be addressed) and propose a clear research path to reduce or eliminate that barrier.

One potential way this could be achieved would be through close collaboration with an industry partner providing formal input or help to define a challenge problem, specific boundary conditions, or context for how a specific analysis is used in practice. Although an industry partner might have proprietary tools and problems, the scope and aim of this topic is to advance the general ability for the broad community to adopt state-of-the-art gradient-based optimization techniques. Hence the primary outcomes of the work should be built on top of open-source tools, use publicly available data (e.g., grids, geometries, constraints), and generally be delivered in a widely distributable form.

Specific multidisciplinary areas of interest, based on known challenges in existing aircraft design capability, include (but are not limited to):

- Aero-structural-thermal design of ducted heat exchanger systems
- Aero-propulsive design of propulsion systems considering both internal-flow and external-flow
- Aero-structural-propulsive design of aircraft concepts such as boundary layer ingesting, distributed propulsion
- Aero-propulsive-acoustic design of propeller and/or rotors for eVTOL aircraft
- Electromagnetic-structural-thermal design for electric aircraft propulsion motor/drive systems (geared or direct-drive)
- Conceptual design for novel aircraft configurations including hybrid propulsion systems, all electric propulsion systems, and thermal management systems, or tight aero-propulsive integration

Expected Outcomes:

Proposals for this topic should aim to deliver one or more of the following research outcomes:

1. Novel optimization benchmark problems consisting of three or more disciplines; All analyses, geometry, and critical data should be included along with at least one solution approach
2. One or more new open-source low- or mid-fidelity analysis tools with analytic derivatives, along with a demonstration study (potentially including some other non-open-source analyses) showing how they are used to construct industry-relevant problem formulations and successfully solve them.
3. One or more new open-source tools to compute derivatives for existing close-source (i.e., commercial) analysis tools or to integrate close-source analysis tools with derivatives into a tightly coupled multi-disciplinary model, along with a demonstration study showing how they are used to construct industry-relevant problem formulations and successfully solve them.

Topic D.2.2.1.4 – Responsibility Designation in Scalable m:N Architectures

Objectives:

Explore the delegation of responsibility and authority between humans and increasingly autonomous aircraft in the context of Advanced Air Mobility (AAM) to achieve scalability through m:N operational architectures (i.e., a small number of humans [m] managing a larger number of autonomous vehicles [N]). There is a dearth of research on this topic, which needs to be explored using modeling and simulation techniques and/or human-in-the-loop experimentation.

Scope of Research:

The vision of Advanced Air Mobility seeks to introduce a range of missions that will expand the capacity to transport people and goods to locations in rural and urban environments. Using aircraft of all sizes, this vision will be achieved by leveraging higher levels of automation and increasingly autonomous technologies, with applications ranging from commercial transport and air taxi services (e.g., Urban Air Mobility [UAM]) to drone surveillance and inspection operations [1]. Yet an expansion of air transportation services will also exacerbate (or be limited by) a looming shortage of qualified pilots to support even current operational demands. To address this challenge, uncrewed aerial vehicle (UAV) concepts are being considered [2], with the goal of enabling fewer human operators to manage more increasingly autonomous vehicles (i.e., m humans-to-N vehicles, or m:N) to grow scalability potential. Studies in related fields indicate that humans can manage a limited number of vehicles before performance rapidly declines. This limit, however, is partially due to delegation of responsibility (and therefore authority) between human and automated components. This delegation is largely driven by regulatory constraints that ultimately require a human to be responsible for the safety and operation of aircraft (e.g., Pilot in Command). It is unlikely that the operational tempo or scale envisioned in AAM will be feasible if a shift in responsibility from the human to automation and increasingly autonomous systems is not addressed. Moreover, this implicit requirement may lead to operational architectures in which humans monitor increasingly autonomous system components but are still held responsible for actions over which they have little authority. Although a monitor role allows responsibility to remain with the human, humans are inherently poor monitors with limited attentional resources. NASA's Transformational Tools and Technologies-Revolutionary Aviation Mobility (T^3-RAM) subproject has identified Human-Autonomy Teaming as a critical area of research required to enable m:N operations with scalability potential [2]. The concept of a human "teaming" with a technology fundamentally alters the assumptions of traditional human-automation interaction paradigms, as the technology is required to assume many of the responsibilities traditionally held by humans within the overall system.

Recommendations generated from this subtopic will inform critical areas where operation and vehicle autonomy must be mature and reliable, while also focusing Human-Autonomy Teaming efforts on architectures where human skills are appropriately employed. This topic is also directly related to the T^3-RAM m:N Technical Challenge [3] and its goal of increasing operations scalability. This subtopic seeks proposals that address one or more of the following topics to support the scalability potential in AAM by shifting responsibility and authority from the human to automation and increasingly autonomous systems in m:N architectures (N.B., this work is targeted at UAM, but open to other UAV operations more broadly within AAM):

- Narrow down possible m:N configurations that are feasible, given the delegation of responsibility and authority of human-autonomy teams.
- Identify tradeoffs associated with shifting responsibility from a human to automated and increasingly autonomous systems.

- Modeling and simulation and/or human-in-the-loop experimentation investigating m:N fleet management scenarios with varying delegation of responsibilities in human-autonomy teams.
- Identify candidate functions to remove from human oversight, given existing or projected technical capabilities and limitations.
- Generation of certification considerations/recommendations in scalable m:N architectures.

Proposers shall clearly describe the approach including the objectives, supporting research, method, proposed analyses, schedule, and expertise available for executing proposed work. Deliverables will include periodic reports and presentations, and electronic files of all work products generated (e.g., manuscripts).

Expected Outcomes:

1. Recommendations for assigning appropriate human-autonomy team responsibilities and authorities in a representative AAM m:N architecture
2. Documentation describing developed models, literature reviews, method, and results supporting human-autonomy teaming responsibility and authority delegations in an AAM m:N architecture
3. Plan for disseminating recommendations and enabling derivative work

References:

[1] National Academies of Sciences, Engineering, and Medicine, "Advanced Aerial Mobility: A National Blueprint," The National Academies Press, Washington, DC, 2020.
[2] J. B. Holbrook, L. J. Prinzel III, E. T. Chancey, R. J. Shively, M. S. Feary, Q. V. Dao, M. G. Ballin, and C. Teubert, "Enabling Urban Air Mobility: Human-autonomy teaming research challenges and recommendations," in *2020 AIAA AVIATION*, Virtual Meeting, 2020.
[3] V.V. Aubuchon, K.E. Hashemi, R.J. Shively, J.M.Wishart, “Multi-Vehicle (m:N) Operations in the NAS – NASA’s Research Plans,” in *2022 AIAA Aviation*, Chicago, 2022. https://doi.org/10.2514/6.2022-3758

Topic D.2.2.1.5 – Collective Behavior of Air Mobility Systems

Objectives:

Develop models of the emergent behavior of collective autonomous air mobility systems consisting of vehicles, operators of vehicles, and providers of airspace services operating in a closed network of ports and sharing the same airspace. Develop metrics that are useful to assess the performance of the collective autonomous mobility system, such as its ability to self-operate persistently in a safe, orderly, fair, and efficient manner, under high levels of uncertainty and complexity. Based on the models and metrics, develop methods for the dynamic coordination among the system agents to enable more persistent and effective self-operation. The methods may represent edge or cloud-based capabilities assuming high levels of autonomy with no human intervention. The models should be drawn from existing examples of distributed, collective, autonomous mobility systems that can be generalized to represent the future behavior of autonomous air mobility systems. Where data is available, develop data-science methods for analyzing historical data about such example systems to infer and learn their behavior into valid models for autonomous air mobility.

Scope of Research:

Air mobility is expected to undergo transformative changes that are needed to accommodate new markets enabled by new vehicle technologies, such as electric vertical takeoff and landing (eVTOL), supersonic, high altitude long endurance (HALE), among others, and advances in digital connectivity and intelligent computing. Autonomy is one key element of this transformation, as the current centralized, human-centric paradigms of operating the vehicles and the airspace do not provide the scalability needed for these new markets and demands. Unmanned aerial vehicles will become increasingly dominant, operated from the ground, with one operator managing increasingly higher numbers of vehicles, and, ultimately, able to fly autonomously with no human supervision. Airspace and traffic services will become increasingly distributed, depending largely on vehicle-to-vehicle coordination, with digital, cloud-based application support. While vehicles are able to fly most of their mission autonomously with only human supervision or oversight, the autonomous coordination among multiple heterogeneous autonomous vehicles sharing the same airspace is still a major challenge.

NASA is conducting research to advance autonomy in air mobility to support and unlock an increasing number of use cases. They include urban air mobility (UAM), firefighting, regional cargo delivery, among others. Initial entry of these new operations may be based on structured approaches such as isolating them from other traffic and with significant human role. However, large-scale operations will need to be supported by high levels of autonomy that feature less structure and less human intervention, enabled by highly automated and distributed schemes. This sub-topic is aimed at understanding such end-state high-autonomy paradigms and studying their viability and effectiveness:

- This research concerns the autonomous interaction among vehicles as opposed to the autonomous mission completion by a single vehicle.
- The system consists of vehicles, vehicle operators, and airspace services that self-operate persistently in a closed network of ports, thus ensuring an integrated perspective.
- This research assumes the human role is reduced to a minimum level of oversight without intervention and aims to identify the edge and cloud capabilities that enable this high level of autonomy.
- This research aims to enable autonomy to self-operate anywhere (autonomy level 5 [1]), under high to extreme levels of uncertainty and complexity in the environment not under a limited operational domain.

A major challenge in modeling and evaluating such a futuristic system is lack of precedence and supportive data and observations. The research should draw from existing examples of distributed, collective, autonomous mobility systems that can be generalized to represent the future behavior of autonomous air mobility systems. Examples of such systems include autonomous air traffic operations under visual flight rules without centralized air traffic control, where general aviation flights can see each other, avoid each other, follow each other, negotiate their landing sequence, among other coordination behaviors. Other examples include autonomous surface traffic, biological communities or swarms, the internet, among others. The research should identify and propose relevant models from different domains. A key interest of this research is to identify underlying utilities that drive the autonomous agents (vehicles, operators and services) behavior towards competing, colluding, or coordinating among each other and thus dynamically producing structure where and when needed, while affording as much flexibility as possible for individual mission objectives. These models can be useful to inform dynamic coordination and structure allocation mechanisms in the future autonomous air mobility, such as information sharing, negotiation of access, and convoy formation. Where data are available, this research should develop data-science methods for analyzing historical data about such example systems to infer and learn their behavior into valid models for autonomous air mobility.

Expected Outcomes:

1. Relevant examples of collective autonomous systems that can be representative and useful for identifying models for collective autonomous air mobility
2. Models of such collective, autonomous mobility systems
3. Metrics for assessing the performance of collective, autonomous air mobility and its emergent behaviors
4. Validation of the models and metrics against historical data and evaluation of their effectiveness in representing future autonomous air mobility use cases, such as urban air mobility, cargo delivery, firefighting, among others
5. Methods based on these models that can be used as edge- or cloud-based capabilities to enable persistent self-operation of the collective system of vehicles, operators, and services
6. Publication of the research in conference and journal venues

References:

[1] SAE International, ISO, “Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles,” SAE J3016, SAE International/ISO, 2021.

Topic D.2.2.1.6 – Water Drop Impingement Measurement Capability

Objectives:

Design, build, test and verify an experimental measurement capability to quantify the distribution of water mass impinging on a aerodynamic surface. The source of the impinging water is a cloud of drops emanating from a spray system in an icing wind tunnel.

Scope of Research:

In the field of aircraft icing, a critical measurement is the amount of water that strikes the aerodynamic surface of interest during transit through a cloud of supercooled water. The ratio of water mass flux at a specific location on the surface to the mass flux available in the freestream is referred to as local collection efficiency or local catch efficiency. The integrated distribution of local collection efficiency is referred to as the total collection efficiency or total water catch. Determining the amount of water and its location that strikes a surface is an important consideration for ice protection systems and is a key step in the numerical prediction of ice growth. Computer simulation of ice accretion involves the tracking of water drops and prediction of their impact on the surface to determine the local collection efficiency. An experimental measurement capability is needed to quantify the local collection efficiency that supports validation of computer simulations and promotes further understanding of the surface water transport phenomena in the initial stages of ice growth on aerodynamic surfaces.

The importance of water drop impingement measurement was recognized in past research conducted by the National Advisory Committee for Aeronautics (NACA). Von Glahn et al. [1] and Gelder et al. [2] used a dye-tracer technique to create a collection efficiency database for aerodynamic surfaces including a set of NACA airfoil sections. In this method, the spray water was treated with a dye and impinged onto strips of blotter paper attached to the aerodynamic surface. Very short durations of water spray were used to saturate the blotter paper which was subsequently removed for colormetric analysis. Segments of the blotter strip were removed and dissolved in distilled water. The concentration of the dye in the resulting solute was then measured through absorbance of light at a particular wavelength. The concentration of dye was then related back to the mass of impinging water.

The need for an expanded collection efficiency experimental database led to several studies conducted in the late 1980s, 1990s and early 2000s. Papadakis et al. (for example, Ref. [3], [4] and [5]) used a similar dye-tracer method, but employed a laser reflectance spectroscopy method to determine dye concentration on the blotter paper and hence the local collection efficiency. This approached was applied directly to the blotter strips and did not require segments of the paper to be dissolved in water. However, the method did rely on calibrations performed via the colormetric analysis. Papadakis et al. applied this method to over 20 different aerodynamic surfaces including airfoils, wings, engine inlets and other geometries. These databases cover a large range of drop sizes with the median volumetric diameter (MVD) of the distributions ranging from “standard icing” less than 40 μm to large drops with MVD up to 170 μm. The databases has been used in numerous icing simulation software development and validation efforts.

As these databases have been employed and analyzed over the years, questions have been raised about the uncertainty and applicability of the experimental results. For example, the dye-tracer method requires very short spray duration which led to questions about nozzle stabilization and cloud repeatability. The short spray duration combined with the need to add dye to the water resulted in the development of a dedicated spray system used for the testing. The installation and calibration of this spray system added time, complexity and cost to the impingement measurements. For tests with large-diameter drops, splashing on the surface can lead to mass loss, which was further complicated by a lack of understanding of blotter paper’s ability to replicate a typical aircraft surface such as aluminum. A paper by Bodoc and Berthoumieu [6] suggests that drop splashing on a bare metal surface versus blotter paper shows important differences in secondary drop generation. This can affect the rate of water impingement and the resulting ice growth if not properly understood and modeled. In addition to this potential limitation, the previous databases were limited in terms of the median drop sizes investigated and freestream speeds.

Computer simulation tools for icing applications continue to be developed and advance in capability. New experimental data for water drop impingement are required to validate the computer simulation of drop impingement. The 1st Ice Prediction Workshop [7] emphasized the need for updated collection efficiency databases with complex three-dimensional geometries where the experimental uncertainties are well understood and quantified. NASA is currently developing an icing simulation tool called GlennICE [8] to predict water drop impingement and ice growth on three-dimensional aerodynamic surfaces and thus has an inherent interested in developing a corresponding experimental database for local collection efficiency.

This subtopic focusses on the development, fabrication, test and verification of new experimental methods for measuring local collection efficiency in icing wind tunnels. Offerors should consider and propose applicability to relevant icing conditions for a given aircraft segment. For example, fixed wing airplanes may encounter icing at speeds in excess of 200 knots in both standard icing conditions (e.g. Title 14 Code of Federal Regulations Part 25, Appendix C) and in freezing drizzle and freezing rain (Title 14 Code of Federal Regulations Part 25, Appendix O). Offerors should consider and address whether or not special spray systems are needed including additives to the spray water for the proposed measurement method. The ability or the proposed method to utilize existing water spray systems without any or minimal modification is desired. Offerors should describe an approach to quantify the experimental uncertainty in the proposed method. Offerors should consider and address the ability of the proposed method to investigate potential mass loss from the splashing events associated with large drops. Offerors should propose demonstration tests in an appropriate icing wind tunnel along with candidate test article(s).

Expected Outcomes:

1. Development of an experimental capability to quantify the distribution of water mass from drops impinging on an aerodynamic surface. This includes documentation of the theoretical basis for the methods, limitations of implementation and required calibrations.

2. Testing of a prototype system in an appropriate icing wind tunnel.

3. Characterization and quantification of the experimental capability in terms of the relevant variables such as cloud drop size, size distribution, liquid water content, temperature and flight speed.

4. Characterization and quantification of the experimental uncertainty in the measured local collection efficiency.

5. Publication of the research in appropriate conferences and journals.

References:

[1] Von Glahn, U. H., Gelder, T. F., and Smyers, W. H., “A Dye-Tracer Technique for Experimentally Obtaining Impingement Characteristics of Arbitrary Bodies and a Method for Determining Droplet Size Distribution,” NACA TN 3338, March 1955.

[2] Gelder, T. F., Smyers, W. H., and Von Glahn, U. H., “Experimental Droplet Impingement on Several Two-Dimensional Airfoil with Thickness Ratios of 6 to 16 Percent,” NACA TN 3839, December 1956.

[3] Papadakis, M., et al. “An Experimental Method for Measuring Water Droplet Impingement Efficiency on Two- and Three-Dimensional Bodies,” NASA CR 4257, November 1989.

[4] Papadakis, M., et al. “Experimental Water Droplet Impingement Data on Airfoils, Simulated Ice Shapes, and Engine Inlet and a Finite Wing,” NASA CR 4636, December 1994.

[5] Papadakis, M., et al, “Experimental Study of Supercooled Large Droplet Impingement Effects,” DOT/FAA/AR-03/59, September 2003.

[6] Bodoc, V. and Berthoumieu, P., “Experimental Investigation of High Speed SLD Impact,” SAE Technical Paper 2019-01-2006, 2019, doi:10.4271/2019-01-2006.

[7] Laurendeau, E., et al., “Summary from the 1st AIAA Ice Prediction Workshop,” AIAA Paper 2022-3398, June 2022.

[8] Wright, W.B., Porter, C.E., Galloway, E.T., and Rigby, D.L., “GlennICE 2.1 Capabilities and Results,” AIAA Paper 2022-3309, June 2022.

D.2.3. Programmatic Considerations

D.2.3.1 General Information

The Transformational Tools and Technologies Project anticipates investing a total of $1.5-$2.0M per year in the solicited subtopics over the next three years. The maximum period of performance will be three years, with nominal budgets in the range of $150K-$250K per year. The actual number and value of the awards will depend on the quality of the proposals received and the scope of the proposed work. There is no guarantee that an award will be made in each subtopic area. Multi-year awards are subject to funding availability in subsequent fiscal years. In some cases, only a portion of a proposal may be selected for award.

The intent of the NRA process is to seek and fund the best research proposed to the solicited topics from outside of NASA. NASA also seeks to collaborate with awardees in a manner that adds value towards the research and development of the innovative concepts. Therefore, proposed informal collaboration with NASA researchers is encouraged where it a) adds value towards achieving the research objectives of the topic area, and b) serves as a direct and beneficial form of technology transfer into NASA. The proposers may propose such informal collaborative activities, but without specifying NASA researchers' names in the proposal. If a proposal is selected for negotiation towards a potential award, then and only then can the details of any proposed collaboration including time in residency at a NASA Center, if applicable, be discussed and finalized. Communications with NASA during the solicitation period can only occur through the designated POC (see Sections 5 and 6). There can be no direct or indirect communications with NASA researchers and managers from the time this solicitation is posted to NSPIRES until proposal selections are final.

Annual oral presentations made as part of an open technical exchange meeting for purposes of technology transfer and knowledge dissemination are required. In particular, there will be a kick-off meeting at the beginning of the award period, and an annual review meeting. These meetings will be held at a NASA Aeronautics Center (NASA Ames Research Center, NASA Armstrong Flight Research Center, NASA Glenn Research Center, or NASA Langley Research Center), and must be attended by at least the principal investigator (or a designated representative) for the award. A written report that completely documents the approach and results shall be submitted for each year's effort (no later than 30 days before the end of the 12-month period), and quarterly written status reports shall also be provided. The information in the annual report will be one of the factors used to determine whether adequate progress has been made.

A final report documenting the approach, results, recommendations, and conclusions of the entire contract shall be submitted no later than 30 days before the end of the contract period of performance. This report shall be suitable for publication as a NASA Contractor Report (Reference: NFS 1852.235-73 Final Scientific and Technical Reports). Sensitive information may be provided to NASA in a proprietary appendix. Software developments and/or enhancements shall be developed in modular form and delivered in appropriate computer file formats.

D.2.3.2 Proposal Preparation Requirements and Organization

General Requirements

A competitive proposal will clearly and concisely: (1) describe the proposed innovation(s) and/or research approach(s) relative to the state-of-the-art; (2) address the scientific, technical merit and feasibility of the proposed activities, and (3) relevance and significance to NASA's stated needs.

Format Requirements

Unless otherwise noted, all proposals submitted in response to this solicitation shall be in accordance with Chapter 2 Proposal Preparation and Organization and Chapter 3 Proposal Submission of the *NASA Guidebook for Proposers Responding to a NASA Funding Announcement, Edition: February 2022*. Proposals that do not follow the formatting requirement are subject to rejection during administrative screening.

The technical section of the proposal is the most important for selection. The proposal must address a particular topic, identified from the above sections. It shall clearly describe: the background and objectives of the proposed research; the approaches to be considered; the workforce required; the anticipated results; and the contribution of the work. The proposal shall identify milestones with measurable metrics toward achieving the proposer's goal, with a minimum of one milestone per year. The proposal shall address requirements of the topic to which it is responding.

The following checklist describes the minimum information expected in the science-technical and management section of the proposal. It must clearly describe:

a. Topic area and challenge(s) the proposal is addressing
  - Objectives and technical approach
  - Targeted/anticipated result
  - Expected impact/benefits if successful
  - Quantifiable metrics to evaluate progress

b. Detail work plan
  - Schedule with milestones with success criteria
  - Technology transfer plan
  - Plan for oral presentations, interim reports, and a final report
  - Detail budget – level of effort, estimated costs, travel, etc.
  - Team members - qualifications and experience
  - Organization capabilities and resources
  - Computing requirements*

* If any NASA computational resource is proposed, include specific computing requirements (CPUs, hours, timeframe, etc.) and state its criticality to the proposed work (select from below):
  1) Require NASA computation resources as go/no go for proposed work
  2) Optional need for NASA computation resources to enhance research execution

NASA is committed to the dissemination of federally funded research, and is responsible for making data from awarded research activities as widely and freely available as possible, while also safeguarding the privacy of participants, and protecting confidential and proprietary data. To facilitate increased access to non-proprietary data, all proposals or project plans submitted to NASA for scientific research funding will be required to include a Data Management Plan (DMP) as described in the section entitled "Increasing Access to the Results of Federally Funded Research" (Section II.c of the ROA). If data will not be made available during the course of the research activity, the DMP shall explain why data sharing and/or preservation are not possible or scientifically appropriate. At a minimum, DMPs must describe how data sharing and preservation will enable validation of published results, or how such results could be validated if data are not shared or preserved.

Reasonable costs associated with the DMP (i.e., costs of sharing, preservation, etc.) may be included in the proposal budget. However, the DMP and its associated costs will not be measured according to the evaluation criteria in section 4. Furthermore, the DMP will not be subject to the page limitation given for the proposal. Specific questions regarding a DMP should be directed towards the POCs in Section 6 as they may provide guidance to proposers and awardees, in addition to their responsibility for compliance with DMPs.

D.2.3.3 Intellectual Property

A clear statement is required of what intellectual property is expected to be available to the

Government, U.S. aeronautics community, and public at the conclusion of the work. It is NASA's preference that all deliverables under the contract be provided to NASA with unrestricted/unlimited rights; thus, any restrictions must demonstrate a significant net benefit to the Government.

D.2.3.4 Proposal and Submission Information

Proposal Submission Site

Proposers must submit electronic proposals in response to this solicitation to the NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES [3]; http://nspires.nasaprs.com). The NSPIRES system will guide proposers through submission of all required proposal information. The presentation *NSPIRES Organization Registration,* located in the "Tutorials and User Guides" section of this website, provides information on how to register an organization in NSPIRES.

In order to be able to submit a proposal all investigators must be preregistered in NSPIRES and have received a User ID and password. This includes the Principal Investigator, all listed Co-Investigators and Collaborators. NSPIRES registration can be done at the website https://nspires.nasaprs.com/external/aboutRegistration.do. Early registration is advised. A Help Desk is available at (202) 479-9376 or by E-mail at nspires-help@nasaprs.com.

Proposal Deadline Requirements

No late proposals will be accepted or reviewed.

Pre-award costs

Pre-award costs are not allowable.

Notice of Intent to Propose

Notices of Intent (NOIs) are encouraged but not required for this solicitation.

D.2.4. Evaluation Criteria and Basis for Award

The evaluation criteria in Chapter 4 and Appendix D of the *NASA Guidebook for Proposers Responding to a NASA Funding Announcement, Edition: February 2022* are superseded by the following criteria.

The principal elements considered in evaluating a proposal are its relevance to NASA's objectives, technical merit, effectiveness of the proposed work plan (including cost and team qualifications), and technology transfer plan (a separate and distinct plan from the Data Management Plan described above). Failure of a proposal to be highly rated in any one of the following elements is sufficient cause for the proposal to not be selected.

1. Relevance to NASA's Objectives (weight 20%):
Evaluation of a proposal's relevance to NASA's objectives includes consideration of the potential contribution of the effort to the specific objectives and goals given in the solicitation. The proposer is required to:

- Identify the specific topic and subtopic to which the proposal is submitted and what specific challenge(s) within the subtopic is/are being addressed.
- Provide a discussion of the impact if the proposed research is successful.

2. Technical Merit (weight 40%):

- Overall scientific or technical merit of the proposal, including unique and innovative methods, approaches, or concepts.
- Evaluation will also include: credibility of technical approach, including a clear assessment of primary risks and a means to address them; techniques, or unique combination of these, which are integral factors for achieving the proposal's objective.
- The selection process will also assess the proposal against the state-of-the-art.

3. Effectiveness of the Proposed Work Plan (weight 30%):

- Comprehensiveness of the proposed work plan, effective use of resources, management approach, and proposed schedule for meeting the objectives.
- Proposed team qualifications and experience.
- Suitability of proposed computational and/or experimental facilities to meet the objectives.
- Proposed cost realism and reasonableness.
- Milestones or objectives with measurable metrics towards achieving those.
- Annual oral presentations made as part of an open Technical Exchange Meeting for purposes of technology transfer and knowledge dissemination are required.
- Documentation of approach and results in the form of final written technical reports is required.

4. Technology Transfer Plan (weight 10%)

- A plan for knowledge/technology transfer to NASA is required. Any proposed collaboration with NASA researchers (including synergistic research goals, residency at a NASA center, development of computer code modules compatible with NASA software, and potential use of facilities) should be discussed in this section. Collaboration is encouraged where it a) adds value towards achieving the research objectives of the topic area, and b) serves as a direct and beneficial form of technology transfer into NASA.

D.2.5 Proposed Use of Unique NASA Capabilities

Proposers are encouraged to carry out a substantial portion of the overall work objectives (experimental and computational) prior to using a NASA facility and consider NASA facilities for the final validation of concepts or models.

Proposers wishing to use NASA facilities should refer to Section I (c) of ROA- FY 2023 for general proposal requirements.

Each NASA facility is managed differently. If use of NASA facilities is proposed, prior to submitting proposals the proposers should have a general discussion with the facility manager –

can they accommodate you, order of magnitude cost details, who pays etc. Only for tests at NASA facilities managed by Aerosciences Evaluation and Test Capabilities, if the proposal gets awarded then it will be a non-reimbursable test under the TTT Project, i.e., at a lower cost to the proposer.

If use of NASA facilities is proposed, the costs associated with fabricating test articles, fixtures, instrumentation, and testing required should be included in the proposed cost. Specific timeframe and duration of testing will be negotiated upon selection of a proposal. For use of a NASA facility, a letter of commitment from the facility manager, or equivalent, should be included in the proposal.

General information on NASA test and evaluation facilities, including points of contact, can be found using the websites given below.

Armstrong Flight Research Center
https://www.nasa.gov/centers/armstrong/capabilities/index.html
https://www.nasa.gov/aeroresearch/programs/iasp/fdc

Ames Research Center
Air Traffic Management Simulations:
https://aviationsystems.arc.nasa.gov/facilities/index.shtml

Ames Wind Tunnels:
https://www.nasa.gov/centers/ames/orgs/aeronautics/windtunnels/index.html

Glenn Research Center
https://www1.grc.nasa.gov/facilities/

Langley Research Center
https://researchdirectorate.larc.nasa.gov/facilities-capabilities/

Advanced Supercomputing
Information on NASA Advanced Supercomputing facilities can be found at https://www.nas.nasa.gov/hecc/resources/
A letter of support for supercomputing is not possible during the proposal submission phase. If awarded, one can apply for supercomputing allocation under the TTT Project.

D.2.6 Summary of Key Information

Expected annual program budget for new awards	Between \$1.5M - \$2.0M will be invested annually in these NRAs over the next 3 years.
Number of new awards pending adequate proposals of merit	1 or more per topic
Maximum duration of awards	3 years
Due date for Notice of Intent to propose (NOI)	December 9, 2022
Due date for proposals	January 13, 2023, 5PM EST
General information and overview of this solicitation	See the *Summary of Solicitation* in the ROA.
Detailed instructions for the preparation and submission of proposals	See the *NASA Guidebook for Proposers Responding to a NASA Funding Announcement, Edition: February 2022* at https://www.nasa.gov/sites/default/files/atoms/files/nasa_guidebook_for_proposers_-_feb._2022.pdf
Page limit for the central Science-Technical-Management section of proposal	See Section 2.7 of the *NASA Guidebook for Proposers Responding to a NASA Funding Announcement, Edition: February 2022*
Submission medium	Electronic proposal submission is required; no hard copy is required. See also Section IV in the *Summary of Solicitation* of the ROA and Chapter 3 of the *NASA Guidebook for Proposers*.
Web site for submission of proposal via NSPIRES	http://nspires.nasaprs.com/(help desk available at nspires-help@nasaprs.com or (202) 479-9376)
Expected contract type	Cooperative Agreement
Funding opportunity number	NNH23ZEA001N-TTT1
NASA technical point of contact concerning this program	Email questions to: LaRC-2023-TTT-NRA@mail.nasa.gov Written responses will be provided individually via email, and posted online on NSPIRES Technical POC: Joseph H. Morrison NRA Manager: Tracey M. Frisby
NASA Procurement point of contact concerning this program	Morris Hicks, morris.hicks@nasa.gov