**C-1 STATEMENT OF WORK**

**Research and Technologies for Aerospace Propulsion Systems**
**(RTAPS)**

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## RESEARCH AND TECHNOLOGIES FOR AEROSPACE PROPULSION SYSTEMS (RTAPS)

## STATEMENT OF WORK

### 1.0 Objective

The objective of this proposed task order contract is to develop, demonstrate, and verify advanced propulsion system technologies as part of NASA's ongoing, long-term aerospace research programs, addressing a wide variety of propulsion issues. Applications include subsonic, supersonic, hypersonic, and rotorcraft transportation vehicles, as well as aviation safety and space exploration applications.

### 2.0 Scope

The Contractor shall furnish all personnel, facilities, equipment, material, supplies, and services, except as may be expressly set forth in the contract agreement as Government Furnished Property, and otherwise do all things necessary to, or incident to, performing and providing the work efforts set forth in the following areas. Contract scope includes analytical and experimental investigations covering a wide variety of propulsion components and sub-components having either Government, commercial, or military application. . This contract may be used to support all NASA Centers that require work within the scope of this Statement Of Work. The contractor shall perform task orders in the following technology areas:

### 2.1 Technology Area 1: Air Breathing Engine Technology

NASA has requirements for the development and demonstration of advanced turbine engine technologies that will enable revolutionary improvements in emissions, noise, capacity, and safety with increased operating efficiency and reduced fuel consumption as outlined in Appendix C-1. The accomplishment of these and other goals will in part be accomplished through the execution of task orders. The technical elements included in Technology Area 1 are as follows:

2.1.1 Concept Development and Systems Studies

The contractor shall perform concept development and system studies of nontraditional propulsion and/or vehicle arrangements and advanced aerospace systems configurations to meet NASA program goals. These concepts include conventional and unconventional heat engines, electric motors, alternative fuels, heat transfer devices, gearboxes, propulsion integration, and advanced aerospace systems. System studies include performing system analysis and design of aerospace propulsion systems and their installations on aerospace vehicles to evaluate advanced engine technologies and aerospace system concepts that have the potential for improving system performance, weight, emissions, fuel burn, noise, and costs.

The aerospace industry has adopted the NASA developed Numerical Propulsion System Simulation (NPSS) framework as a standard for performing the studies described above. Many of the tasks in this area will require the use of NPSS, therefore, the contractor must have a demonstrated knowledge of the application of NPSS model development through use in past programs or applications. The demonstrated ability to develop NPSS models for complex unconventional systems as well as integrate new models within the NPSS framework is also required.

The scope of work under this element includes the following:

(1) The contractor shall develop and validate empirical, statistical, and physics-based analytical models that are robust enough to handle non-conventional configurations. These models may be used for understanding the basic underlying physical phenomenon of the system or subsystem as well as for predicting aerospace systems and/or component performance, weight, emissions, reliability, life, and cost.

(2) The contractor shall define goals and figures of merit for overall systems as well as for individual technologies within the context of overall program and project goals and objectives.

(3) The contractor shall conduct technology trade studies, mission analyses, and market and cost scenario studies to identify and evaluate aerospace systems and assess their contributions towards meeting program and project goals and objectives.

(4) The contractor shall perform system simulations of aerospace systems and subsystems from a 0-D level up through a multi-disciplinary 3-D level.

(5) The contractor shall perform aerospace systems conceptual, preliminary and/or detailed design studies in support of advanced concept definition, development and/or testing.

(6) The contractor shall conduct risk assessments of advanced aerospace systems.

2.1.2 High Power Density Engine Turbomachinery

The contractor shall identify, evaluate, develop, and demonstrate advanced turbomachinery technologies that result in reduced fuel burn, increased efficiency, increased safety, increased durability, increased operability, reduced noise and/or improved performance of aircraft, rotorcraft, or other aerospace engine systems.

The scope of work under this element includes the following:

(1) The contractor shall develop and provide analysis of conceptual and detailed designs of advanced turbomachinery concepts. These advanced turbomachinery concepts shall contain one or more of the following features:

(a) High-bypass ratio fans and open rotors, advanced low- and high-pressure compressor and turbine components, alternative advanced components, and subsystems
(b) Low loss variable inlet guide vanes, rotors, stators, transition ducts, seals, and secondary flow systems and struts
(c) Efficient wide variable-speed operations
(d) Reduction gear systems, lubrication systems, oil-free components, rotor support systems
(e) Mitigation of leakages in high-pressure ratio, low corrected flow, and compressor rear stages
(f) Aerodynamic stage matching technologies for efficient multistage transonic compressors
(g) Advanced turbine cooling concepts and materials
(h) Advanced power turbine blades and vanes that are tolerant to large incidences
(i) Structural, aerodynamic, aeroacoustic and leakage performance assessment of turbomachinery components and systems as well as their cost and reliability
(j) Other features resulting from current system studies

(2) The contractor shall demonstrate advanced turbomachinery technologies in component test rigs including the fabrication and verification testing of advanced fan, compressor and turbine components, seals, reduction gear systems, rotor support systems, secondary flow systems, and subsystems in test rigs.
(3) The contractor shall develop and experimentally validate empirical, statistical, and physics-based

analytical models including models as they apply to turbomachinery components and systems for aerospace engines . These include models of turbomachinery, seals, reduction gear systems, rotor support systems, and secondary flow systems.

2.1.3 Advanced Combustors and Alternative Fuels

The contractor shall identify, evaluate, develop, and demonstrate advanced combustor and fuels technologies that result in reduced emissions, reduced fuel burn, increased efficiency, increased safety, increased durability, and/or improved performance for aerospace engine systems. The contractor shall also develop analytical design tools as well as identify and evaluate advanced technologies for combustor subcomponents such as fuel injectors, flame-tube and sector combustor test hardware, alternative fuels, combustor liners (metal and ceramic composite), control systems, and ancillary hardware.

The scope of work under this element includes the following:

(1) The contractor shall develop and validate empirical, statistical, and physics-based analytical models for predicting combustor performance and/or emissions. This includes empirical methods, analogy-based models, and computational combustion chemistry models robust enough to handle non-conventional combustors and fuels and accurate enough that the combustors and engine systems can be designed to a very close tolerance of the actual performance and emissions with very little margin of error.

(2) The contractor shall conduct an assessment of advanced concepts, analytical tools, non-intrusive diagnostics and barrier technologies for the design of combustors.

(3) The contractor shall develop conceptual, preliminary, and/or detailed designs of combustors and their subcomponents such as fuel injectors, combustion liners, fuel supply delivery systems and combustion instability control systems and associated test hardware.

(4) The contractor shall develop and demonstrate ancillary hardware and instrumentation to perform electronic health monitoring, monitoring of fluid/combustion control functions at real engine operating conditions, emissions and particulate measurements.

(5) The contractor shall demonstrate and validate advanced combustor technologies through fabrication and testing of components and systems. These tests may include flame tubes, sector rigs and full annular combustor rigs, and engine tests with the instrumentation required to assess the aerothermal characteristics, emissions, operability and performance of the combustor concepts.

(6) The contractor shall develop thermal management systems to overcome potential coking problem that include fundamental understanding of jet fuels/alternative fuels and fuel additives under super heated conditions.

(7) The contractor shall develop, evaluate, and test advanced alternative fuels and fuel additives for aerospace applications.

2.1.4 Low Noise Propulsion Technologies

The contractor shall develop and demonstrate advanced technologies to reduce aircraft engine noise such as fan noise, jet noise, engine core noise and propulsion/airframe interaction noise. Advanced noise reduction technologies may include those required to enable novel propulsion systems for improved overall performance which may include advanced concepts such as high-speed propfans and novel engine/airframe integrations schemes.

The scope of work under this element includes the following:

(1) The contractor shall develop and validate empirical, statistical, and physics-based analytical models for predicting engine and/or engine component noise. This includes empirical methods, acoustic analogy-based models, and computational aeroacoustics techniques robust enough to handle non-conventional geometries (variable cycle, variable duct geometry, etc.), including embedded engines. The models must be accurate enough that the aircraft can be designed to a very close tolerance of the actual noise level with little margin of error.

(2) The contractor shall develop conceptual, preliminary, and/or detailed designs of low noise propulsion technologies and low noise propulsion systems.

(3) The contractor shall design and fabricate test hardware for measurement of fan, jet, core, propfan, and engine integration/interaction noise. Additionally, the contractor shall design and develop diagnostic systems for identifying noise source locations and strength.

(4) The contractor shall demonstrate and assess advanced noise reduction concepts and technologies on component test rigs, engine tests, and flight tests.

2.1.5 Inlets and Nozzles

The contractor shall identify, evaluate, develop, and demonstrate advanced inlet and nozzle technologies that result in reduced fuel burn, increased efficiency, increased safety, increased durability, reduced noise, improved performance and/or reduced sonic boom for aerospace engine systems. In addition, the contractor shall develop and demonstrate advanced technologies that enable high-speed vehicles through use of combined cycle or variable-bypass engine cycles.

The scope of work under this element includes the following:

(1) The contractor shall develop and validate empirical, statistical, and physics-based analytical models for designing and/or predicting performance of inlets and nozzles (e.g., weight, bleed requirements, operability, stability and sonic boom signature). The contractor shall develop methods robust enough to handle non-conventional geometries (variable cycle, secondary streams, variable duct geometry, embedded configurations etc.) and accurate enough that the propulsion system can be designed to a very close tolerance of the actual performance with little margin of error.

(2) The contractor shall provide an assessment of advanced concepts, analytical tools and barrier technologies for the design of inlets and nozzles.

(3) The contractor shall provide conceptual, preliminary, and/or detailed designs of advanced inlet and nozzle systems and subsystems.

(4) The contractor shall design and fabricate test hardware for measurement and evaluation of inlet and nozzle performance.

(5) The contractor shall demonstrate and assess performance of advanced inlets and nozzles in wind tunnel, test rigs, and flight tests.

2.1.6 Variable and Hybrid Engine Systems

The contractor shall develop variable and hybrid cycle engine technologies needed to enable aircraft with enhanced capabilities such as improved performance characteristics over a wider speed range.

The contractor shall develop advanced engine technologies for supersonic aircraft to change the effective cycle of the engine from high bypass at takeoff to low bypass at supersonic cruise. These technologies may include variable geometry in the fan, compressor, and possibly the turbine. In addition, the contractor shall investigate and develop engine technologies with more flow streams than traditional turbofan engines to benefit both subsonic and supersonic aircraft by enabling higher operating efficiency of the turbomachinery at takeoff and cruise conditions.

For even higher Mach number capability necessary for hypersonic engine applications, the contractor shall investigate and develop turbomachinery technologies to withstand higher temperatures and be capable of even wider operating ranges. These high Mach engines will require additional capability to transition from turbine engine mode to alternative propulsion systems such as ramjet-scramjet.

The contractor shall investigate and develop engine technologies capable of a wide variable speed range for future rotary wing aircraft (i.e., variable speed power turbine assuming fixed speed transmission) to efficiently balance the rotor speed and power requirements between hover and cruise for low fuel burn .

The contractor shall also investigate and develop hybrid engine technologies such as the combination of constant volume combustion engine technologies with other more conventional engine cycles to evolve new propulsion systems that take advantage of the thermodynamic efficiency benefits of near-constant volume combustion. The contractor shall develop novel system designs of constant-volume-based propulsion systems, component and system analyses inclusive of high-frequency unsteady phenomena, design robust components for the constant volume environment, and fabricate and "breadboard" test associated components and systems.

The scope of work under this element includes the following:

(1) The contractor shall conduct thermodynamic analyses, develop unique flow path layouts, and assess the performance, weight, life, reliability, cost estimation, and control strategies for these advanced engine configurations.

(2) The contractor shall develop conceptual, preliminary and/or detailed designs of the advanced variable and hybrid engine systems.

(3) The contractor shall demonstrate advanced variable and hybrid engine technologies in component test rigs. In addition, the contractor shall fabricate and conduct system level verification tests of advanced variable engine systems or subsystems.

2.1.7 Integrated Component Technology Demonstrations

The contractor shall identify the most beneficial technologies for reducing fuel burn, emissions, and noise. This work will incorporate selected technologies into existing or new engines with appropriate modifications.

The scope of work under this element includes the following:

(1) The contractor shall perform all efforts necessary to incorporate advanced engine components into existing and new turbine engines.

(2) The contractor shall conduct engine tests (ground and/or flight) to validate the performance, operating characteristics and durability of these components in an engine environment.

(3) The contractor shall evaluate propulsion systems tests for system level validation.

2.1.8 Engine Icing

The contractor shall perform engine icing research and technology development to address the following challenges: characterization of cloud properties that lead to engine icing, improvements in engine design and simulation tools to prevent ice accretion or mitigate effects of icing, application of engine control methods to protect against engine icing, and technologies to detect icing hazardous conditions.

The scope of work under this element includes the following:

(1) The contractor shall assess advanced concepts, analytical and computational tools and barrier technologies with a focus on understanding and preventing ice accretion, and/or mitigating the effects of engine icing.

(2) The contractor shall develop and validate empirical, statistical, and physics-based analytical and computational models for predicting engine icing and/or its effect on engine performance.

(3) The contractor shall design and fabricate test hardware for the detection and measurement of engine icing. Additionally, the contractor shall design and develop diagnostic systems for identifying engine icing locations and vulnerabilities.

(4) The contractor shall demonstrate and assess engine ice accretion and performance prediction tools, and advanced engine icing prevention and reduction concepts and technologies in component test rigs, engine tests, and flight tests.

(5) The contractor shall identify and characterize weather properties that can lead to engine icing issues

2.1.9 Materials and Structures

The contractor shall develop advanced materials and structures technologies required to meet the aggressive performance and efficiency goals of next generation aero-propulsion systems. These goals are achievable only through increased engine operating temperature and durability in conjunction with decreasing weight of the overall propulsion system. The contractor shall develop innovative materials, structural concepts and analytical models from laboratory to component and systems level demonstrations.

The scope of work under this element includes the following:

(1) The contractor shall develop and validate advanced high temperature disk alloys with 1400°F or higher temperature capability for commercial life.

(2) The contractor shall develop and validate advanced single crystal turbine blades with advanced thermal barrier coatings. The goals for single crystal alloy development shall be increased temperature

capability, lower density, and compatibility with advanced coating systems. The goals for advanced thermal barrier coatings shall be lower thermal conductivity, increased erosion and impact resistance, and similar or improved oxidation resistance compared to the current state-of-the-art yttria-stabilized zirconia coatings.

(3) The contractor shall develop and validate ceramic matrix composites for engine components such as combustor liners, turbine blades and vanes with durable environmental barrier coatings, nozzle flaps and seals, including multi-layer coatings for durable hypersonic vehicle leading edge surfaces.

(4) The contractor shall develop and validate piezoelectric materials for sensor and actuator applications leading to improved engine efficiency and reduced noise and emissions.

(5) The contractor shall develop and validate advanced polymer matrix composites (PMC) including, but not limited to environmentally friendly PMCs with 550°F or higher temperature capability, and PMC materials and structures utilizing advanced textile architectures for lightweight engine components.

(6) The contractor shall develop and validate adaptive structures that allow tailoring of component geometry to specific portions of a mission cycle, or that can compensate for changes in component geometry due to degradation due to extended engine operation. Example structures include; variable area nozzles, active compressor flow control, active compressor blade damping and variable geometry chevrons. The contractor shall investigate the use of specialized materials, such as shape memory alloys and polymers and piezoelectric ceramics, to activate the geometry changes without weight or complexity penalties associated with electric or hydraulic actuation systems. .

(7) The contractor shall develop and validate high-fidelity computationally efficient methods for predicting the life of hot engine static and rotating structures produced from advanced materials, including ceramic matrix composites, and validate the methods with strategically selected experiments aimed at single lifing, combined lifing and multiple-factor combination effects on lifing.

2.1.10 Instrumentation, Controls, and Communications

The contractor shall research, analyze, develop and demonstrate advanced instrumentation, controls, and communications technologies for aerospace engine applications at the component and systems level.

The scope of work under this element includes the following:

(1) The contractor shall develop and demonstrate advanced technologies for controls subcomponents such as sensors, actuators, control algorithms, control and communication architectures.

(2) The contractor shall develop active component control technologies such as active compressor control, active combustion control, and active turbine tip clearance control.

(3) The contractor shall develop and demonstrate technologies enabling an engine health management system.

(4) The contractor shall develop and demonstrate communications, navigation and surveillance components and systems, including on-board wireless sensor networks, and airborne datalink capabilities.

**2.2 RESRVED**

**2.3 RESERVED**

**2.4 RESERVED**

**3.0 Work Requirements**

The contractor(s) shall have the ability to perform all work in one or more of the Technology Areas as authorized in each task order issued.

The contractor(s) shall provide a program management system that includes timely insight into the technical, cost, and schedule status and risk, as well as technical and programmatic control of work performed under the task orders.

The contractor(s) shall implement a product assurance system, as appropriate, for task orders involving hardware and/or software development. The contractor's existing product assurance plans, procedures, formats, and documentation systems that support the development of safe and reliable aerospace products, are acceptable if they are shown to satisfy the objectives of the Product Assurance Requirements listed in the Product Assurance Requirements of NASA Policy Directive NPD 8730.5 NASA Quality Assurance Program Policy—URL: http://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPD&c=8730&s=5
All work performed under this contract shall be in compliance with all applicable Federal, state, and local environmental regulations and those policies set forth in the NASA Glenn Research Center's Environmental Programs Manual This can be viewed at: http://smad-ext.grc.nasa.gov/shed/pub/epm/epm-manual.pdf

Task Orders will be issued in accordance with Clause H.9-H.11.

**Appendix C–1**

NASA has requirements for the development and demonstration of advanced engine technologies that will enable reductions in noise, emissions, fuel consumption, and sonic boom (high speed aircraft). Specific goals have been defined by NASA's Subsonic Fixed Wing (SFW) and Supersonic Projects and are summarized in Tables 1 and 2, respectively. NASA's Subsonic Rotary Wing Project has defined the goal of 50 percent variation of main rotor rotational speed needed to achieve efficient VTOL and Mach 0.5 1000 NM cruise capability, with no impact on flight handling and minimum impact to propulsion systems weight, in addition to advancing engine capabilities for future civil rotorcraft.

TABLE 1.—GOALS FOR SUBSONIC FIXED WING PROJECT

| Corners of the trade space | N+1 (2015)[a] Generation Conventional Configurations relative to 1998 Single Aisle | N+2 (2020)[a] Generation Unconventional Conigurations relative to 1997 Large Twin Aisle | N+3 (2025)[a] Generation Advanced Aircraft Concepts (relative to user-defined reference) |
|---|---|---|---|
| Noise (cum. below Stage 4) | –32 dB | –42 dB | -71dB |
| LTO NOx emissions (below CAEP/6) | –60% | –75% | Better than –75% |
| Performance: aircraft fuel burn | –33%[b] | –40%[b] | Better than –70% |
| Performance: field length | –33% | –50% | Exploit metro-plex concepts[c] |

[a]Technology Readiness Level Range = 4 to 6
[b] An additional reduction of 10 percent may be possible through improved operational capability.
[c] Concepts that enable optimal use of runaways at multiple airports within the metropolitan areas.

TABLE 2.—GOALS FOR SUPERSONICS PROJECT

| | N+1 Supersonic Business Class Aircraft (2015) | N+2 Small Supersonic Airline (2020) | N+3 Efficient Multi-Mach Aircraft (beyond 2030) |
|---|---|---|---|
| Environmental goals | | | |
| Sonic boom | 65 to 70 PLdB | 65 to 70 PLdB | 65 to 70 PLdB low boom flight; 75 to 80 PldB overwater flight |
| Airport noise (cum. below stage 4) | Meet with margin | 10 EPNdB | 10 to 20 EPNdB |
| Cruise emissions | Equivalent to current subsonic | < 10 | < 5 and particulate and water vapor mitigation |
| Performance goals | | | |
| Cruise speed, Mach | 1.6 to 1.8 | 1.6 to 1.8 | 1.3 to 2.0 |
| Range, nmi | 4000 | 4000 | 4000 to 5500 |
| Payload, passengers | 6 to 20 | 35 to 70 | 100 to 200 |
| Fuel efficiency, pass-miles per lb of fuel | 1.0 | 3.0 | 3.5 Š 4.5 |

Flight regime related factors include

**Subsonic:** Focus is on Ultra-High Bypass (UHB) ratio engine technologies for the N+1 goals and embedded engine and variable engine technologies for the N+2 goals, and also includes development of lower Technology Readiness Level (TRL) advanced technologies enabling propulsion systems for the N+3 time frame.

**Supersonic:** Focus is on variable cycle engine technologies for the N+2 goals and may also include development of advanced technologies enabling propulsion systems for the N+3 time frame. Some work may also be included to address N+1 system as required.

**Hypersonic**: The Hypersonic Project is developing technologies to enable reusable air-breathing access to space and to enable high mass planetary entry for Mars and other planets. For reusable air-breathing access to space technologies, the Project is aligned with the goal defined in the 2007 National Plan for Aeronautics Research, namely, to demonstrate sustained, controlled, hypersonic flight. Successful sustained, controlled, hypersonic flight requires continued R&D into all areas of high speed atmospheric flight, including integrated aircraft design, aerodynamics, aerothermodynamics, high-temperature structures and materials, lightweight and durable thermal-protection systems, supersonic combustion, and propulsion concepts that operate from subsonic speeds into the hypersonic regime. The Hypersonic Project R&D goals include extending the temperature and life of high-temperature materials and structures, reducing component mass, developing air-breathing propulsion technology for Two-Stage-to-Orbit vehicles, and developing physics-based integrated multi-disciplinary design tools.

**Rotary Wing:** Focus is on engine and transmission technologies needed for wide operability, variable speed propulsion systems (i.e. 50percent variable speed power turbine) for rotorcraft vehicles that meet performance, environmental (noise, emission), weight and cost goals that enable high speed (0.5 M), large payload (~90 passenger), long range civil transports. In addition, the Subsonic Rotary Wing Project is developing technologies to enable advanced engine capabilities for future civil rotorcraft.