NASA SBIR 2022 Phase I Solicitation

A1.03 Low Emissions/Clean Power - Environmentally Responsible Propulsion

Lead Center: GRC

Participating Center(s): LaRC

Scope Title

Environmentally Responsible Propulsion - Aircraft Combustor Tools and Technologies

Scope Description

Innovative tools and technologies are required to address several challenges to improving combustor operability and durability and minimizing the impact of aircraft emissions on human health and the environment. Overcoming these challenges is important to both next-generation subsonic aircraft and potential future high-speed commercial aircraft. Particulate matter emissions from aircraft gas turbine engines, consisting primarily of ultrafine soot, contribute to adverse health and climate impacts, and new international standards on nonvolatile particulate matter emissions will start in 2023. Next-generation single-aisle aircraft are pushing towards smaller engine cores and higher overall pressure ratios, leading to challenges in combustor cooling design. Future high-speed (supersonic) aircraft also face significant combustor cooling challenges due to the need for maximizing the air available to combust with the fuel (to provide ultralow emissions of oxides of nitrogen that mitigate ozone depletion at stratospheric cruise altitudes) while operating at the harshest thermal condition during long-duration cruise. Conventional gas turbine engines operating at higher overall pressure ratios and future hybrid-electric or high-speed aircraft concepts that use the fuel as a heat sink may experience fuel injection behavior outside of current understanding and modeling capabilities. Aviation goals to reduce climate impacts from aviation will drive increased use and blending ratios of sustainable aviation fuels. To address these challenges, innovations in the following specific areas are solicited:

- Nonintrusive optical techniques to measure near-wall velocities, temperature, and/or turbulence variables for experiments with liquid-spray injection operating over a range of pressures (1 atm to at least 30 atm).
- Tools and technologies to improve combustor durability and optimize cooling in the combustor for smaller core subsonic application and/or long-duration cruise supersonic applications.
- Approaches that tightly couple convection, conduction, and radiation heat transfer in a computationally efficient manner applicable to time-accurate eddy-resolving simulations of combustion flows with liquid-spray injection.
- Fuel-sensitive soot-precursor chemistry models applicable to Jet-A and various blending ratios of Jet-A with sustainable aviation fuels.
- For multicomponent hydrocarbon fuels (conventional jet fuel and sustainable aviation fuels), models for the transition from two-phase (liquid-vapor regime with surface tension) behavior to a single-phase behavior (where no surface tension exists) that may be encountered for fuels injected into high-pressure and high-temperature combustor chamber conditions, and/or for heated fuels.
Development of measurement techniques for characterizing aircraft engine particle emissions in the 10- to 200-nm particle diameter size range and their interactions with contrails and contrail-cirrus clouds. Complete instrument systems are desired, including features such as remote/unattended operation and data acquisition and minimum size, weight, and power consumption. Instrument prototypes as a deliverable in Phase II proposals and/or field demonstrations are encouraged. Desired measurement capabilities include:

- Size-dependent number and mass concentrations at 1-Hz time resolution that differentiate volatile/nonvolatile particles or elemental/organic carbon fractions, consistent with the measurement definitions given by the standard SAE ARP6320A (https://www.sae.org/standards/content/arp6320a/). Note that the ARP is referenced only for measurement referencing and terminology; this subtopic seeks proposals for research-grade instruments that go significantly beyond the current state of the art and the baseline measurement requirements of the ARP.
- Open-path, aircraft cloud probes suitable for measuring the number and size distribution of near-field small contrail ice crystals down to a nominal 0.1- to 0.3-µm diameter lower size limit.
- Aircraft-mounted water vapor, dew point, or relative humidity probe with small enough size, weight, and power footprint that it would be suitable for integration on a commercial aircraft. Instrument should be optimized for upper tropospheric ambient measurements (nominally 20-ppm minimum sensitivity for water vapor, -40 to -70 °C static air temperature, 150- to 300-mbar static air pressure).
- Aircraft-mounted temperature probe suitable for measuring static air temperature with accuracy at or better than 0.1 °C under upper tropospheric flight conditions.
- Measurements carried out at high sample line pressures relevant for sector combustor studies and low pressures relevant for flight studies.

Expected TRL or TRL Range at completion of the Project

2 to 5

Primary Technology Taxonomy

Level 1
TX 01 Propulsion Systems

Level 2
TX 01.3 Aero Propulsion

Desired Deliverables of Phase I and Phase II

- Research
- Analysis
- Prototype
- Software
- Hardware

Desired Deliverables Description

A major deliverable will be computer simulation software to predict the best and most effective combustor configurations. Sensor development for monitoring engine emissions would be another deliverable.

Phase I should successfully demonstrate fabrication/testing of a laboratory breadboard system, overcoming a major system or subsystem technical hurdle, or foundational work that lays the groundwork for the Phase II work plan, which should be summarized in the Phase I report.

Phase II deliverables such as instrument prototypes and/or field demonstrations are highly encouraged.

State of the Art and Critical Gaps
Combustion involves multiphase, multicomponent fuel, turbulent, unsteady, 3D, reacting flows where much of the physics of the processes are not completely understood. Computational fluid dynamics (CFD) codes used for combustion do not currently have the predictive capability that is typically found for nonreacting flows. Low-emissions combustion concepts require very rapid mixing of the fuel and air with a minimum pressure loss to achieve complete combustion in the smallest volume. Areas of specific interest where research is solicited include:

- Development of laser-based diagnostics for quantitative spatially and temporally resolved measurements of fuel/air ratio in reacting flows at elevated pressure.
- Development of optical techniques for soot measurement and characterization for combustor flametube and sector tests (non-prevaporized liquid combustion, fuel Jet-A, pressures 3 to 80 atm; flame temperatures up to 2,250 K, soot diameters on the order of 10 to 100 nm)
- Development of ultrasensitive instruments for determining the size-dependent mass of combustion-generated particle emissions.
- Low-emissions combustor concepts for small high-pressure engine cores.

Relevance / Science Traceability

All of Aeronautics Research Mission Directorate (ARMD), Transformational Tools and Technologies (TTT), etc.

Achieving low emissions and finding new pathways to cleaner power are critical for the development of future air vehicles. Vehicles for subsonic and supersonic flight regimes will be required to operate on a variety of certified aircraft fuels and emit extremely low amounts of gaseous and particulate emissions to satisfy increasingly stringent emissions regulations. Future vehicles will be more fuel efficient, which will result in smaller engine cores operating at higher pressures. Future combustors will also likely employ lean-burn concepts, which are more susceptible to combustion instabilities.

Infusion/Commercial Potential: These developments will impact future aircraft engine combustor designs (lower emissions, improve operability, control instabilities) and may have commercial applications in other gas-turbine-based industries, such as power generation and industrial burners. The modeling and results can be and will be employed in current and future hydrocarbon rocket engine designs (improving combustion efficiency, ignition, stability, etc.).

References

- NASA Glenn Combustor Facilities: https://www1.grc.nasa.gov/facilities/erb/combustor/
- Procedure for the Continuous Sampling and Measurement of Non-Volatile Particulate Matter Emissions from Aircraft Turbine Engines (ARP6320): https://www.sae.org/standards/content/arp6320/