Propulsion Efficiency - Turbomachinery Technology for High Power Density Turbine-Engines

Lead Center: GRC

Participating Center(s): AFRC

Technology Area: TA15 Aeronautics

Scope Description

NASA is looking for improvement in aeropropulsive power density and efficiency in support of its Strategic Thrust in the area of Ultra-Efficient Subsonic Transports. Focus is on small core turbofan engines for next-generation and future large commercial transport aircraft, conventional as well as electrified. The subtopic is closely aligned with NASA Aeronautics programs in the areas of Compact Gas Turbine (CGT) and Electrified Aircraft Propulsion (EAP), and will augment the corresponding Advanced Air Transport Technology (AATT) Project's Technical Challenges. Technical Challenges are targeted technology development areas. Main areas of interest include: Improved efficiency of small core engines, integrated thermal management, innovative cycles, use of artificial intelligence (AI) for turbomachinery components design and optimization, and efficient turbomachinery for EAP, including large electric power extraction in serial-hybrid electrified aircraft and efficient turbine-engines for power generation. The improvements will help airlines to reduce costs by reduced fuel burn. Future electrified airplanes that rely on turbine engines as their energy sources will also be able to maximize their advantages over conventional propulsion.

The detailed areas solicited and the corresponding specific technologies sought include:

1. Small-core engines efficiency improvements:
   1. Desensitizing performance to losses due to tip leakage, secondary flows, seals, purge flows and cooling air
   2. Compact transition ducts
   3. Active and passive flow control for improved airfoil performance and reduce tip clearance losses
   4. Innovative turbine shrouding to circumvent tip clearances loss generation

2. Turbofan thermal management:
   1. Compact thermal management systems using multi-functional structures and additive manufacturing
   2. Integrated thermal management of turbofan-electric components for more-electric and hybrid-electric aircraft
   3. Turbine high effectiveness cooling and loss reduction
   4. Innovative aviation-weight compact heat exchangers for cooling the cooling air and associated heat recovery or rejection

3. Optimized integrated combustor – turbine systems:
   1. Integration concepts of combustor and turbine for improved overall and component performance

4. Innovative methods for turbomachinery design and aerothermal analysis:
   1. Automating design of turbomachinery components using AI
   2. Automated turbomachinery computational fluid dynamics (CFD) grid generation using AI
3. CFD models for turbomachinery unsteady flows including transition and separation for accurate loss prediction
4. Components performance maps generation using Artificial Intelligence (AI) and Machine Learning (ML)
5. Use of additive manufacturing to enable designs and improvements not possible with conventional manufacturing processes
6. Remote non-contact dynamic temperature mapping in the presence of significant radiative background. Surface temperature mapping tools including efficient image processing algorithms are sought that will be compatible with silicon carbide based components with or without low thermal expansion oxide environmental barrier coating
7. Capability of fast full-wheel, unsteady, multi-stage, CFD for compressor and turbine components for aerothermal analysis

5. Innovative engine cycles as improvements alternatives to conventional engines
   1. Closed cycles for thermal management and primary propulsion (e.g., supercritical CO2 Brayton cycles, organic fluid Rankine cycles, etc.)
   2. Turbofan waste heat recovery and utilization

6. Efficient and light-weight turbomachinery for EAP and More Electric Aircraft
   1. Turbomachinery for high power extraction from turbofans. The desire is to enable larger than 20% of low pressure spool power at altitude cruise to be extracted as shaft power. The power is to electric generator(s) to provide power to electric motor-driven propulsors (example: STARC-ABL concept). Design of turbomachinery components and optimization of extraction from low- and high-pressure spools is sought.
   2. Efficiency improvements of small turboshaft engines powering turbo-generators/range-extenders used in regional EAP aircraft concepts. Small turboshafts suffer from low efficiency, and design of high effectiveness aviation-weight improvements are sought. Ideas to consider include recuperation using light-weight heat exchangers and concepts employing multifunctional and additive manufacturing approaches.

References

Links:
https://www.nasa.gov/aeroresearch/strategy
https://www.nasa.gov/aeroresearch

Summary:

NASA Strategic Plan 2018:

- Strategic Goal 3: Address National Challenges and Catalyze Economic Growth
  - Strategic Objective 3.2: Transform Aviation Through Revolutionary Technology Research, Development and Transfer

Aeronautics Research Mission Directorate (ARMD) New Strategic Thrust 3: Ultra Efficient Subsonic Transports - Thrust description: Realize revolutionary improvements in economics and environmental performance for subsonic transports with opportunities to transition to alternative propulsion and energy

Expected TRL or TRL range at completion of the project: 1 to 4

Desired Deliverables of Phase II

Prototype, Analysis, Hardware, Software, Research

Desired Deliverables Description

The objective of this subtopic solicitation is to develop technologies that contribute to increasing the power density of future turbofan engines. The deliverables of Phase I will be feasibility assessment of innovative ideas in the form
of results of numerical studies, software tools, results of experiments, or tests of demonstration prototypes. Projects showing successful feasibility may be selected for further development under Phase II.

The scope of turbomachinery includes the rotating machinery in the high and low pressure spools, transition ducts, purge and bleed flows, casing and hub. It also includes turbomachinery aspects of EAP concepts where a turbine engine is the power source. The latter includes hybrid-electric turbofan power extraction and efficiency improvements of small turbine engine powering turbogenerator/ range-extenders. This topic address only aerothermal aspects of turbomachinery. Materials, controls and other areas are not included in this subtopic and may be solicited under separate subtopics.

This solicitation's desire is to focus on the turbofan engine core, but unique novel ideas relevant to the whole engine are also sought.

State of the Art and Critical Gaps

System and technology studies have indicated that advanced gas turbine propulsion will remain critical for next-generation and future subsonic transports.

The main interest of this solicitation is in turbofan engines. Turbfans will be relevant for next-generation and future conventionally powered aircraft. They will also be relevant as power sources of future electrified airplanes.

Impressive advancements were made in turbofan technologies that increased their efficiency and performance. Most recent upcoming near term technologies being incorporated in engines as the GE9X and Rolls Royce SuperFan intend to include overall pressure-ratio (OPR) of 60, large diameter fans with low blade count and low fan pressure-ratio, bypass ratio of order 11, advanced booster designs, highly 3D airfoil designs, high compressor pressure ratio in the range of 27, application of CMC (Carbon Matrix Composites) materials in hot sections and more. Despite these advances, there is potential for additional improvements; they are possible and needed for future aircraft architecture and concepts.

In the turbine, the very high cycle temperatures demanded by advanced engine cycles place a premium on the cooling technologies required to ensure adequate life of the turbine component. New capabilities as well as challenges are provided with expected increased use of ceramic matrix composites (CMC). Presently, engines are overcooled because of uncertainty in hot section flow uniformity caused by hot streaks. Reduced cooling flow rates and/or increased cycle temperatures enabled by these technologies have a dramatic impact on the engine performance.

In the compression system, advanced concepts and technologies are required to increase stage loading and widen operating range. Interrelated to the turbine, the cooling flow presently result in high penalty caused by the typical 20% bleed air ratio; the goal is to reduce it to 5%. OPR may be increased to the order of 100. As result the overall thermal efficiency can be increased by 10-15%. Aerothermal improvements not only will improve performance, but also will lead to reduced weight and increase the core specific power.

Engines are currently designed in a time-consuming iterative manner taking several months for a complete system. AI and ML approaches are expected to speed up the process and lead to optimized designs maximizing the efficiency and power density and take it down to a matter of hours and days.

NASA and industry are actively working on electrified aircraft concepts. Many of these concepts employ turbine-engines as power sources. The impact on the turbomachinery requirement and design needs to be addressed, which, in turn, will impact the viability of the EAP concepts.

Finally, innovative methods for engine waste heat recovery and re-utilization will increase the effective engine efficiency. And alternatives to the conventional open Brayton cycle may also lead to revolutionary propulsion system, or at least to improvements of existing systems.

Relevance / Science Traceability

The solicited topics are directly relevant to NASA's Aeronautics project goals in the area of high power density cores - to lead to realizing revolutionary improvements in economics and environmental performance for subsonic transports with opportunities to transition to alternative propulsion and energy.