NASA Emissions Research Overview
AEC Research Roadmap Meeting
Dr. Jim Heidmann, Project Manager Advanced Air Transport Technology Project
Advanced Air Vehicles Program
May 2018
Brief Outline

- Summary/Refresher – NASA Strategic Context
- FY2019 Budget Request
- Emissions-Relevant Research
  - Strategic Thrusts 3 & 4: Ultra-Efficient Commercial Vehicles and Transition to Alternative Propulsion & Energy
Global Growth in Aviation
Opportunities and Challenges

2017
4 BILLION
PASSENGER TRIPS

41,030
New Aircraft Deliveries

$6.1 Trillion
Market Value

Airbus / Europe

Bombardier / Canada

2036
7.8 BILLION
PASSENGER TRIPS

Global Competitors

Asia-Pacific Market is Nearly
40% of New Aircraft Deliveries

78% of New Aircraft Deliveries are Single Aisle Class
(including Regional Jets)

Global Competitors

Embraer / Brazil

Irkut / Russia

Comac / China

Global Growth in Aviation
Opportunities and Challenges
U.S. leadership for a new era of flight
ARMD Research Programs & Strategic Thrusts

**Airspace Operations & Safety**
- AOSP
  - Safe, Efficient Growth in Global Operations
  - Real-Time System-Wide Safety Assurance

**Advanced Air Vehicles**
- AAVP
  - Ultra-Efficient Commercial Vehicles
  - Innovation in Commercial Supersonic Aircraft
  - Transition to Alternative Propulsion and Energy

**Integrated Aviation Systems**
- IASP
  - Flight research-oriented, integrated, system-level R&T that supports all six thrusts
  - X-planes/test environment

**Transformative Aeronautical Concepts**
- TACP
  - High-risk, leap-frog ideas that support all six thrusts
  - Critical cross-cutting tool development
  - Assured Autonomy for Aviation Transformation

NASA Aeronautics Vision for Aviation in the 21st Century

ARMD Strategy
https://www.nasa.gov/aeroresearch/strategy
## FY 2019 Budget Request - Aeronautics

<table>
<thead>
<tr>
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<th>FY 2017</th>
<th>FY 2018</th>
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<tr>
<td><strong>Aeronautics</strong></td>
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**FY 2017** reflects funding amounts specified in Public Law 115-31, Consolidated Appropriations Act, 2017. **Table does not reflect emergency supplemental funds also appropriated in FY 2017, totaling $184 million.**
Subsonic Transport Technology Strategy
Ensuring U.S. technological leadership

Energy usage reduced by more than 60%
Harmful emissions reduced by more than 90%
Objectionable noise reduced by more than 65%

Prove out transformational propulsion technologies
Prove out transformational airframe technologies

Current Generation
Next Generation - Transitional -
Future Generations - Transformational -

Create technology pathway for U.S. competitive leadership

Image Credit: Denis Fedorko
Image Credit: pjs2005 from Hampshire, UK
Image Credit: Don-vip

2020
2030
2040
NDMAX Alt Fuels Flight Campaign

Technical Need:
Address FAA and NASA research needs for ground and cruise-emission measurements for improved models

Objective:
• Study soot emissions, contrail formation and growth
• Establish links between contrail characteristics and soot
• Obtain detailed cirrus and background atmospheric observations

Outcome:
• Successfully completed 39 hours of joint sampling flights in restricted airspace over Germany
• Broad international participation with 120 scientists from NASA, DLR, Max Planck Institute, Universities of Oslo, Innsbruck and Missouri S&T, NRC-Canada, Boeing, and Aerodyne Research
• Data analysis in progress, workshops and scientific papers to disseminate results being planned
Enabling U.S. Leadership in Subsonic Transport Markets

• Suite of 5 key technologies coupled into transformative configurations will win the subsonic transport future
  – Light Weight, Very High Aspect Ratio Wings
  – Propulsion – Airframe Integration, especially Boundary Layer Ingestion
  – Tailored Non-Circular Fuselage
  – Electrified Aircraft Propulsion
  – Small Core Turbine Engines

• ARMD is advancing these key technologies to create market opportunities
• Highly integrated airframe & propulsion systems can result in substantial efficiency improvements. One mechanism is Boundary Layer Ingestion that can improve overall vehicle efficiency.

• However, ingestion of the boundary layer leads to the engine having to work in the presence of disturbed inlet flow, which can have substantial engine operation and safety challenges.

• To confirm benefits and test the operations of advanced engine fan concepts, NASA conducted a first of its kind complex experiment to collect detailed data. Preliminary analysis indicates very positive benefits and engine fan tolerance.
Compact, High Overall Pressure Ratio Gas Generator (Small Core)

Objective
Enable reduced size/flow high pressure compressors and high temperature disk/seals that are critical for 50+ OPR gas generators with minimal impact on noise and component life

Technical Areas and Approaches
Hot Section Materials
• 1500F Hybrid disk & coatings
• 1500F Capable non-contacting seal

HPC for High OPR Engines
• GE NRA: develop casing treatment with large tip gap utilizing existing hardware
• P&W NRA: HPC rear block design to mitigate losses

Benefit/Pay-off
• Key technologies to help enable advanced compact gas-generator core architecture and component technologies enabling BPR 20+ growth by minimizing core size
• Thermally efficient, high OPR (50+) engines
Low NOx, Fuel-Flex Combustor

**Objective**
Reduce NOx emissions from fuel-flexible combustors to 80% below the CAEP6 standard with minimal impacts on weight, noise, or component life

**Technical Areas and Approaches**

**Fuel-Flexible Combustion**
- Develop lean-burn combustor concepts suitable for small core engines and explore active combustion control

**Benefit/Pay-off**
- Realize N+3 emission goals (80% reduction in NOx emissions lower than CAEP-6) for landing LTO conditions for high OPR (50+) small core engines
- Reduction of particulate formation at LTO conditions
- Compatible for gas-only and hybrid gas-electric architectures and ducted/unducted propulsors
- Compatible with alternative fuel blends
Electrified Aircraft Propulsion Concepts

Electrified Aircraft Propulsion systems use electrical motors to provide some or all of the thrust for an aircraft.

- **Turboelectric** systems use a turbine-driven generator as the power source. **Partially turboelectric** systems split the thrust between a turbofan and the motor driven fans.

- **Hybrid-electric** systems use a turbine-driven generator combined with electrical energy storage as the power source. Many configurations exist with different ratios of turbine to electrical power and integration approaches.

- **All-electric** systems use electrical energy storage as the only power source.
Studies Targeting Regional Jets & Single Aisle Markets

Partially and Fully Distributed Turboelectric Concepts

- NASA STARC - ABL
- Boeing/NASA SUGAR - FREEZE
- NASA N3-X (twin aisle)
- ECO-150

Parallel Hybrid Concepts

- Boeing/NASA SUGAR - VOLT
- UTRC hGTF
- Low Spool
- High Spool
- R-R LW EVE
Development & Testing of MW Class Power System

High Power Density Electric Motor Development

- NASA research (power density at electromagnetic level), 1 – 3 MW, >96% efficiency
- Various claims (100 – 200 kW)
- Siemens (200 kW)
  - System level, 95% efficiency
- Current electric vehicles
- Current industrial

Single-aisle Turboelectric Aircraft with Aft Boundary Layer Ingestion (STARC – ABL)
- Conventional single aisle tube-and-wing configuration
- Twin underwing mounted turbine engines with attached generators on fan shaft
- Ducted, electrically driven, boundary layer ingesting tailcone propulsor
- Projected fuel burn savings for single-aisle missions
MW-scale Electric Machines Research

- Motors and/or generators (electric machines) are needed on all electrified aircraft.

- NASA is sponsoring or performing work to achieve power densities 2-3 times the state of the art for machines in the MW or larger class.

- Three major machine types are being developed: permanent magnet, induction, and wound field

<table>
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<tr>
<th>University of Illinois</th>
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<th>&gt;96</th>
<th>Permanent magnet</th>
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</table>
**MW-scale Converter Research**

- Power converters are an essential component in most EAP aircraft concepts, as they are used to convert from ac to dc power, or vice versa.

- NASA is sponsoring or performing work to achieve power densities 2-3 times the state of the art for converters in the MW or larger class.

- Silicon carbide and gallium nitride prototypes are being developed with conventional cooling as well as a cryogenically cooled converter.

<table>
<thead>
<tr>
<th></th>
<th>Continuous power rating, MW</th>
<th>Specific power goal, kW/kg</th>
<th>Efficiency goal, %</th>
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Materials for Electrified Aircraft Propulsion

- New soft magnetic materials – improve performance of converter filters and electric machines
- Insulation – electrical insulation with better thermal transfer to improve electric machine performance
- High-Conductivity Copper/Carbon Nanotube Conductor – approach to reduce the mass of cables
- Superconducting Wire Development – AC superconductors which could be used for electric machines or distribution

25-mm by 1.6-km spin cast ribbon

Hyper Tech produced multifilament MgB2 superconducting wires

Transformer fabricated from spin cast ribbon

CAPS idealized magnetic field test capability for wire segments
NASA Electric Aircraft Testbed (NEAT)

**Challenge:**
Hybrid electric powertrain design requires full-scale performance validation including EMI mitigation, fault and thermal management, turbine surge/stall prevention, DC bus stability, flight-efficiency, and high power, high voltage component verification.

**Results:**
Completed the assembly of powertrain (turbo-generation & tail-cone thruster machine pairs, ARINC 664 communication protocol, 600VDC multi-bus, NPSS turbine and ducted fan with closed loop torque feedback, power regeneration, thermal management system and facility integration). Successfully operated a 600VDC powertrain configuration with approximately 460kW tail-cone thrust power with representative turbine and ducted fan performance maps through a representative flight profile.
Hybrid Electric Integrated Systems Testbed (HEIST)

- Being developed to study power management and transition complexities, modular architectures, and flight control laws for turboelectric distributed propulsion technologies using representative hardware and piloted simulations.
- Configured in the fashion of an iron bird to provide realistic interactions, latencies, dynamic responses, fault conditions, and other interdependencies for turboelectric distributed aircraft, but scaled to the 200 kW level.
- Power and voltage levels that would be considered subscale for a commercial transport, but test capability extends to the entire airplane system and can exercise all aspects of flight control, including cockpit operations.
Laying the Ground Work for Aviation in 2040

• The global aviation system of 2040 is emerging today – new companies and new systems built on advanced technologies pioneered by NASA based on steady U.S. investment

• Based on what is emerging today, what can we see for 2040:
  – An Urban Air Mobility system that is all-electric, autonomous and environmentally friendly moving billions of commuters and packages across the world’s megacities. As a result, ground-based traffic congestion will be reduced, local air quality will be improved, and urban areas will be transformed
  – Transformative subsonic airliners developed by U.S. industry will approach near-optimal levels of efficiency, reducing cost and environmental impact, and will continue to enable more people to travel around the world supporting a vibrant and growing U.S. and global economy
  – A growing segment of increasingly affordable and environmentally friendly supersonic air travel. This will once again shrink our world and project U.S. technological leadership.
  – All of this will ride upon a transformed airspace system that provides the access and efficiency to enable this broad range of business models and provides proactive and prognostic "in-time" safety assurance, providing all citizens confidence that every flight is safe and secure.