NASA Emissions Research Overview
AEC Research Roadmap Meeting

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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

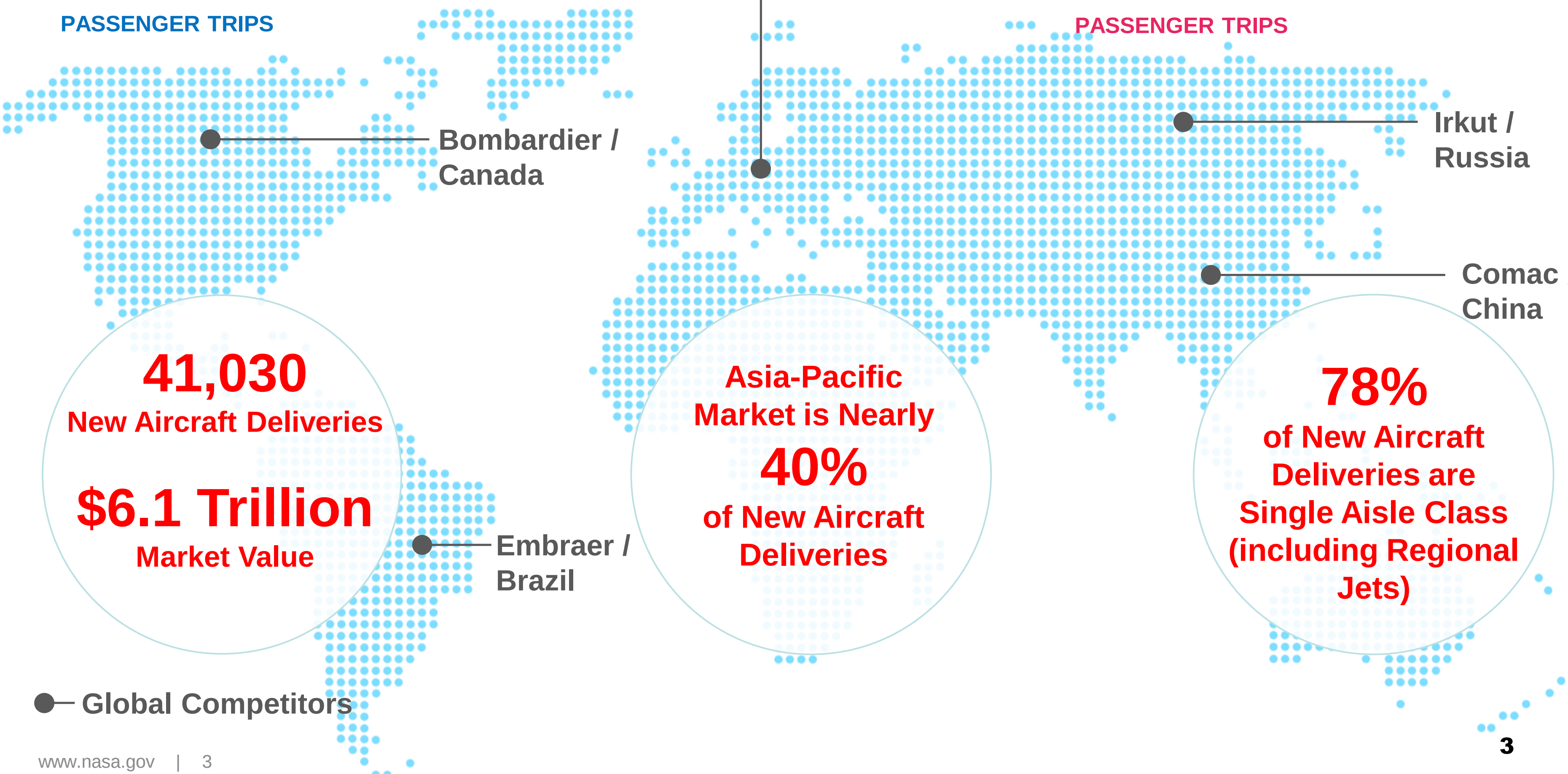
4 BILLION

PASSENGER TRIPS

2036

7.8 BILLION

PASSENGER TRIPS



41,030
New Aircraft Deliveries

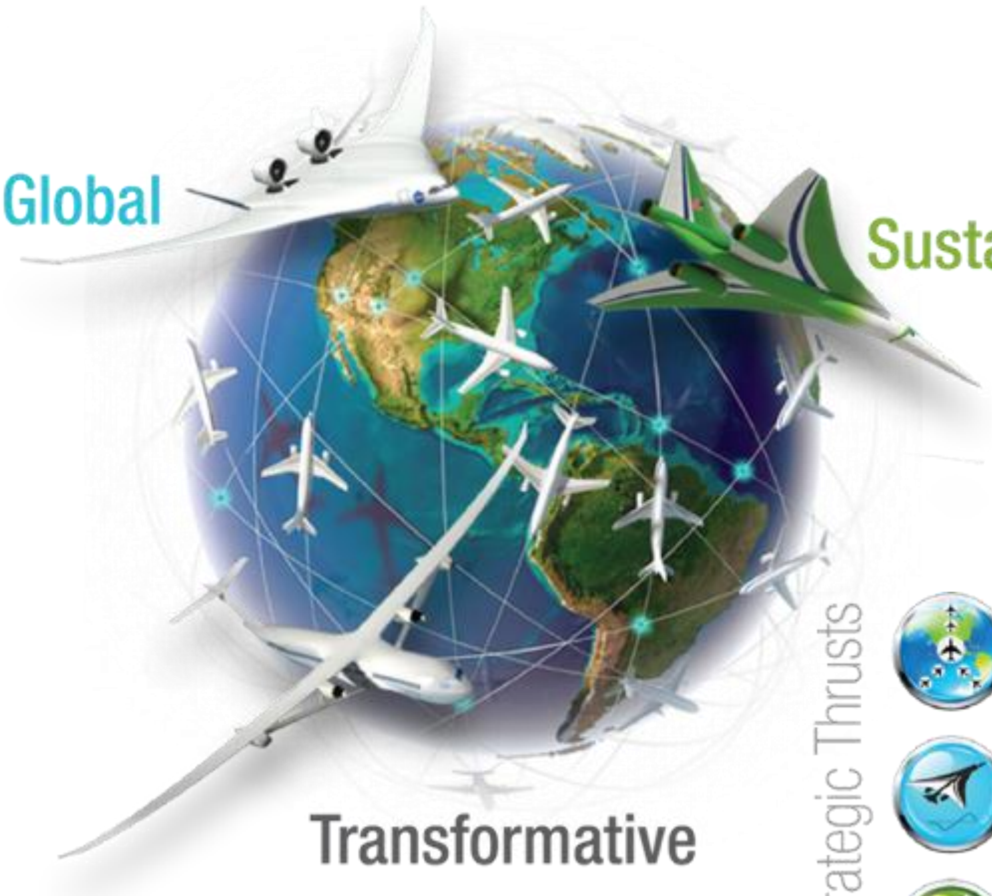
$6.1 Trillion
Market Value

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

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

NASA Aeronautics

NASA Aeronautics Vision for Aviation in the 21st Century



ARMD continues to evolve and execute the Aeronautics Strategy *https://www.nasa.gov/aeroresearch/strategy*

6 Strategic Thrusts

- Safe, Efficient Growth in Global Operations
- Innovation in Commercial Supersonic Aircraft
- Ultra-Efficient Commercial Transports
- Transition to Alternative Propulsion and Energy
- In-Time System-Wide Safety Assurance
- Assured Autonomy for Aviation Transformation

U.S. leadership for a new era of flight

ARMD Research Programs & Strategic Thrusts

MISSION PROGRAMS

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

SEEDLING PROGRAM

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

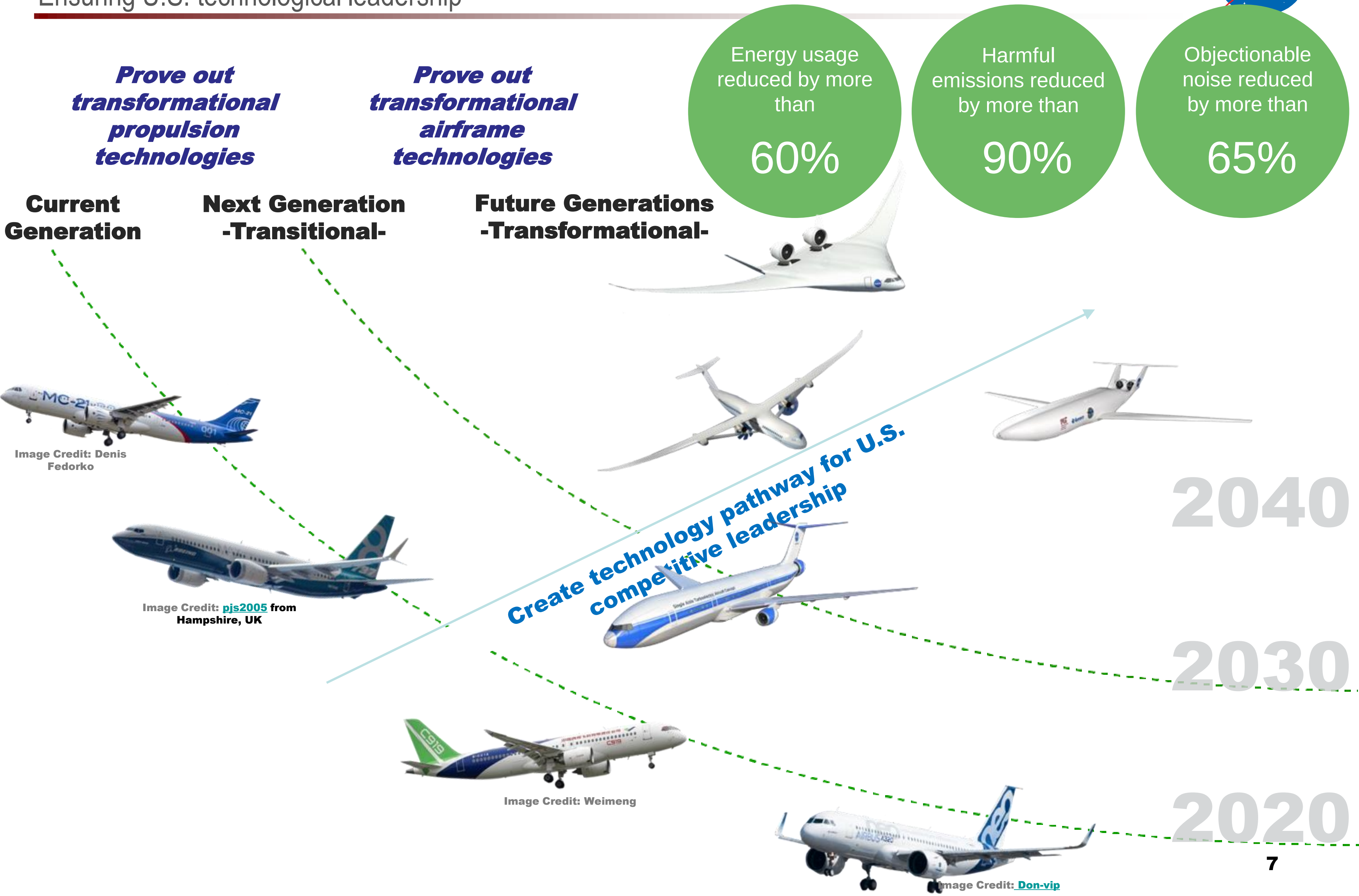
FY 2019 Budget Request - Aeronautics

$ Millions	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Aeronautics	**$656.0**	**$685**	**$633.9**	**$608.9**	**$608.9**	**$608.9**	**$608.9**
Airspace Operations and Safety	140.6		90.8	96.2	120.4	122.7	122.9
Advanced Air Vehicles	274.6		230.6	248.5	257.1	257.8	258.3
Integrated Aviation Systems	125.0		189.2	154.1	106.6	103.3	102.5
Transformative Aeronautics Concepts	115.8		123.3	110.1	124.9	125.1	125.1

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



NDMAX Alt Fuels Flight Campaign

Technical Need:

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

Objective:

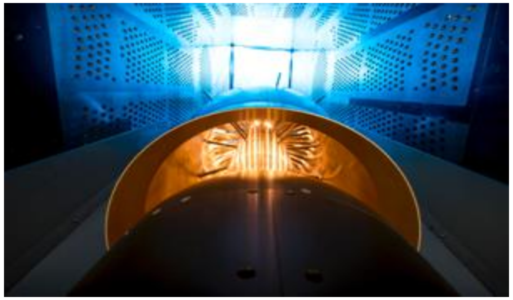
- Study soot emissions, contrail formation and growth
- Establish links between contrail characteristics and soot
- Obtain detailed cirrus and background atmospheric observations

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



Boundary Layer Ingestion

Very High Aspect Ratio Wing

Hybrid Electric Propulsion

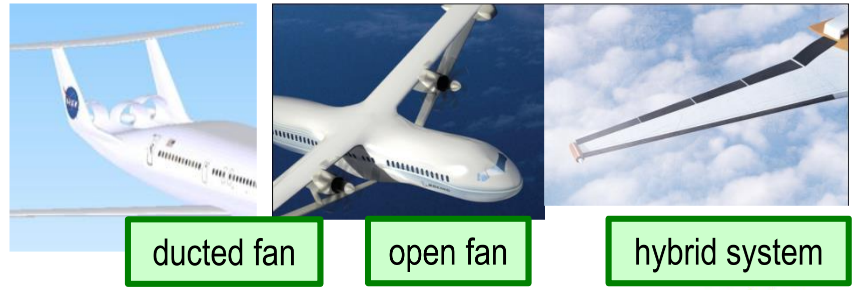
Boundary Layer Ingestion Test

- 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

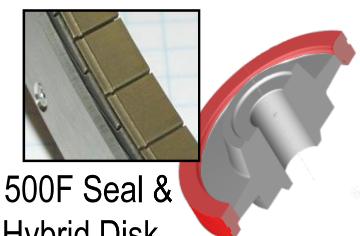
Enable reduced size/flow high pressure compressors and high temperature disk/seals that are critical for 50+ OPR gas generators with minimal impact on noise and component life



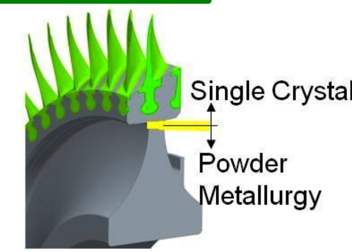
Technical Areas and Approaches

Hot Section Materials

- 1500F Hybrid disk & coatings
- 1500F Capable non-contacting seal

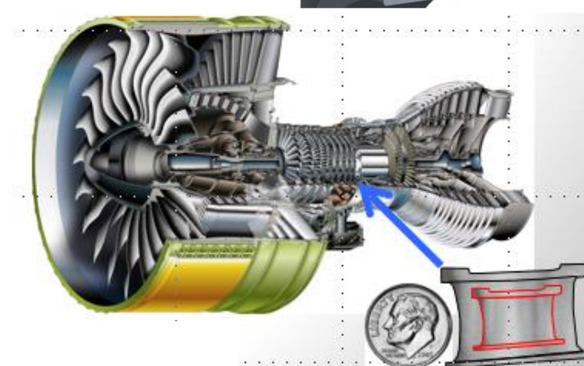


1500F Seal & Hybrid Disk



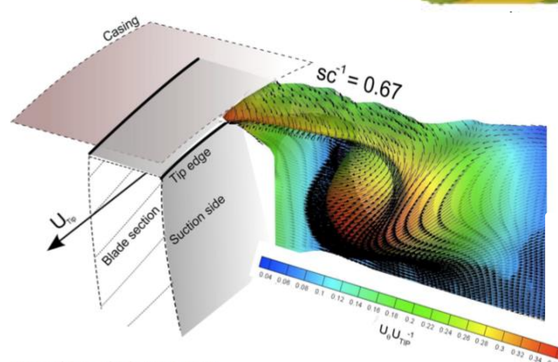
HPC for High OPR Engines

- 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



Tip/Endwall Aerodynamic Loss Mitigation

Wu et al. Exp. Fluids, 2010, 1011
Miorini et al., J. Turbomachinery 2012, AIAA Journal 2012

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

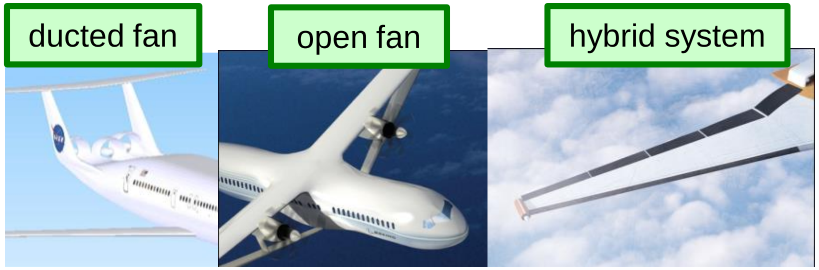
Technical Areas and Approaches

Fuel-Flexible Combustion

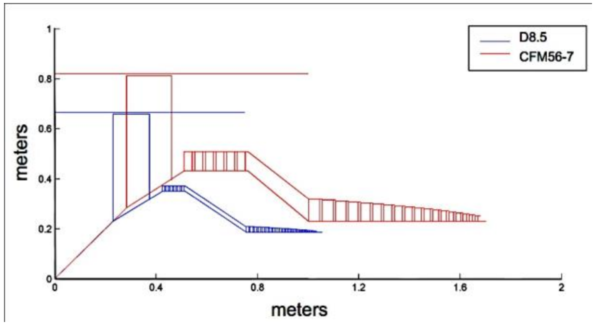
- Develop lean-burn combustor concepts suitable for small core engines and explore active combustion control

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



Advanced Small Core Combustors required for gas-only and hybrid architectures



Low emission , fuel flexible Combustor

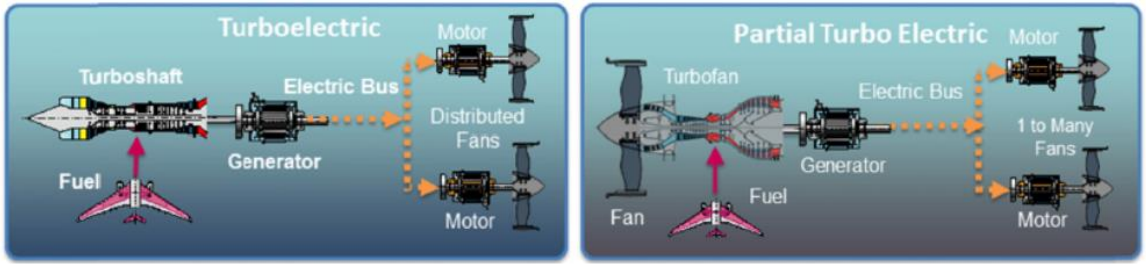
Adapting ERA N+2 Comb to N+3 small core goals

Evaluate Alt Fuel Emissions at Altitude

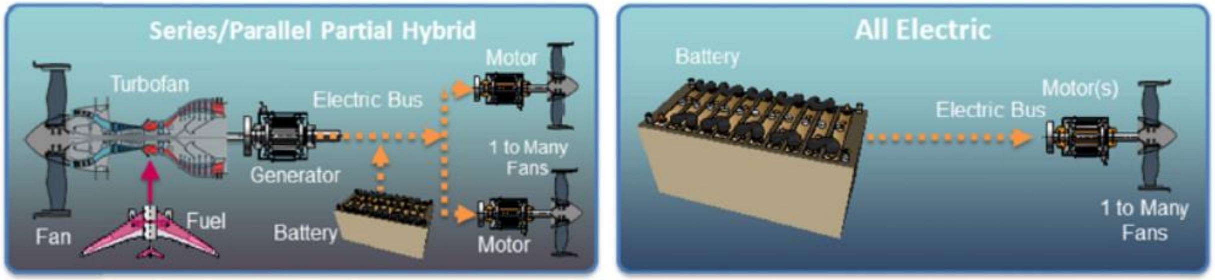
Electrified Aircraft Propulsion Concepts

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.

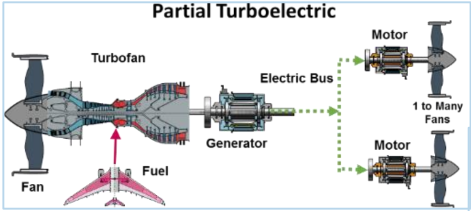


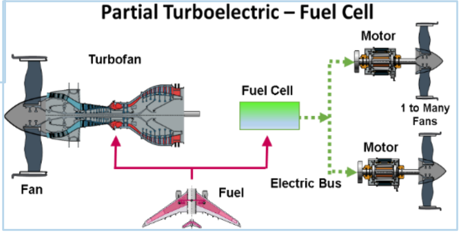
Studies Targeting Regional Jets & Single Aisle Markets

Partially and Fully Distributed Turboelectric Concepts

NASA STARC - ABL

Boeing/NASA SUGAR - FREEZE

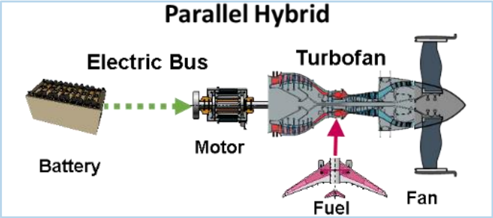




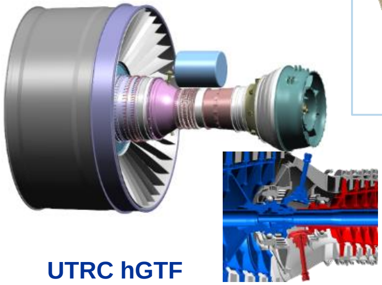
NASA N3-X (twin aisle)

ECO-150

Parallel Hybrid Concepts

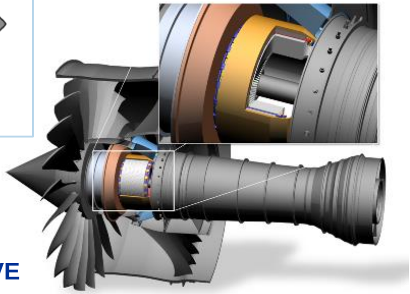


Boeing/NASA SUGAR - VOLT



UTRC hGTF

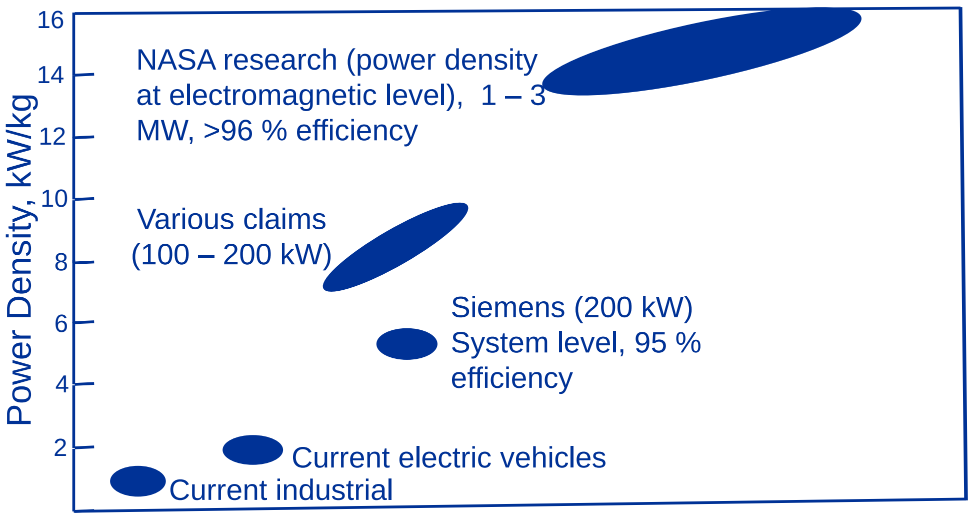
Low Spool
High Spool

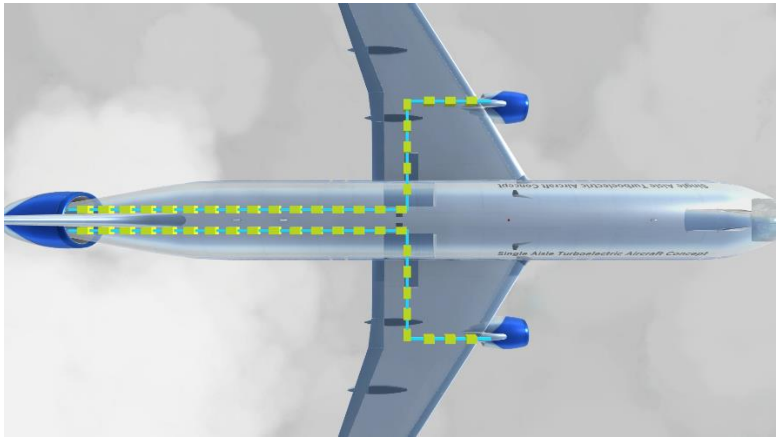


R-R LW EVE

Development & Testing of MW Class Power System

High Power Density Electric Motor Development





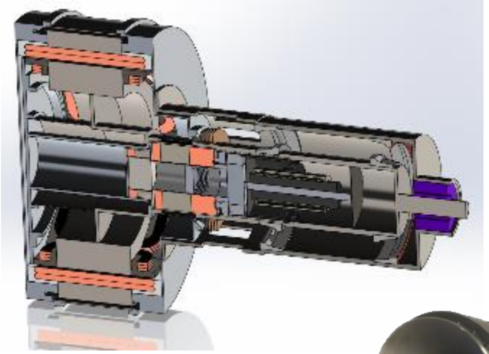
NASA Electric Aircraft Testbed (NEAT) for testing multi-MW level power system

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

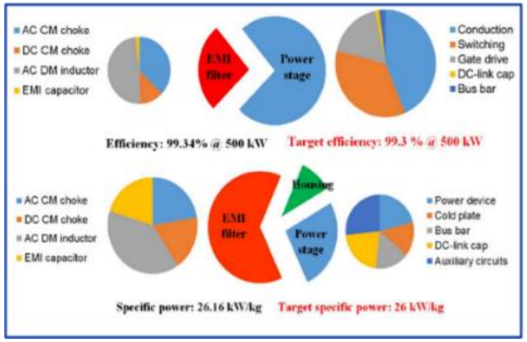
- **Motors and/or generators (electric machines) are needed on all electrified aircraft.**
- **NASA is sponsoring or performing work to achieve power densities 2-3 times the state of the art for machines in the MW or larger class.**
- **Three major machine types are being developed: permanent magnet, induction, and wound field**



	Continuous power rating, MW	Specific power goal, kW/kg	Efficiency goal, %	Motor type	Speed	Nominal dimensions
University of Illinois	1	13	>96	Permanent magnet	18,000	Cylinder 0.45 m by 0.12 m
Ohio State University	2.7	13	>96	Induction	2,500	Ring 1.0 m by 0.12 m
NASA Glenn Research Center	1.4	16	>98	Wound field	6,800	Cylinder 0.40 m by 0.12 m

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**

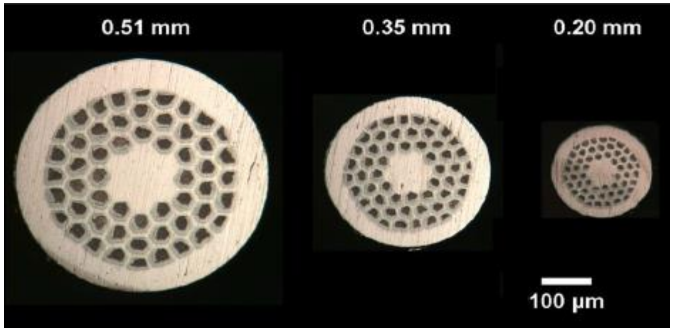


	Continuous power rating, MW	Specific power goal, kW/kg	Efficiency goal, %	Topology	Switch material	Cooling
General Electric	1	19	99	3 level	SiC/Si	Liquid
University of Illinois	0.2	19	99	7 level	GaN	Liquid
Boeing	1	26	99.3		Si	Cryogenic

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

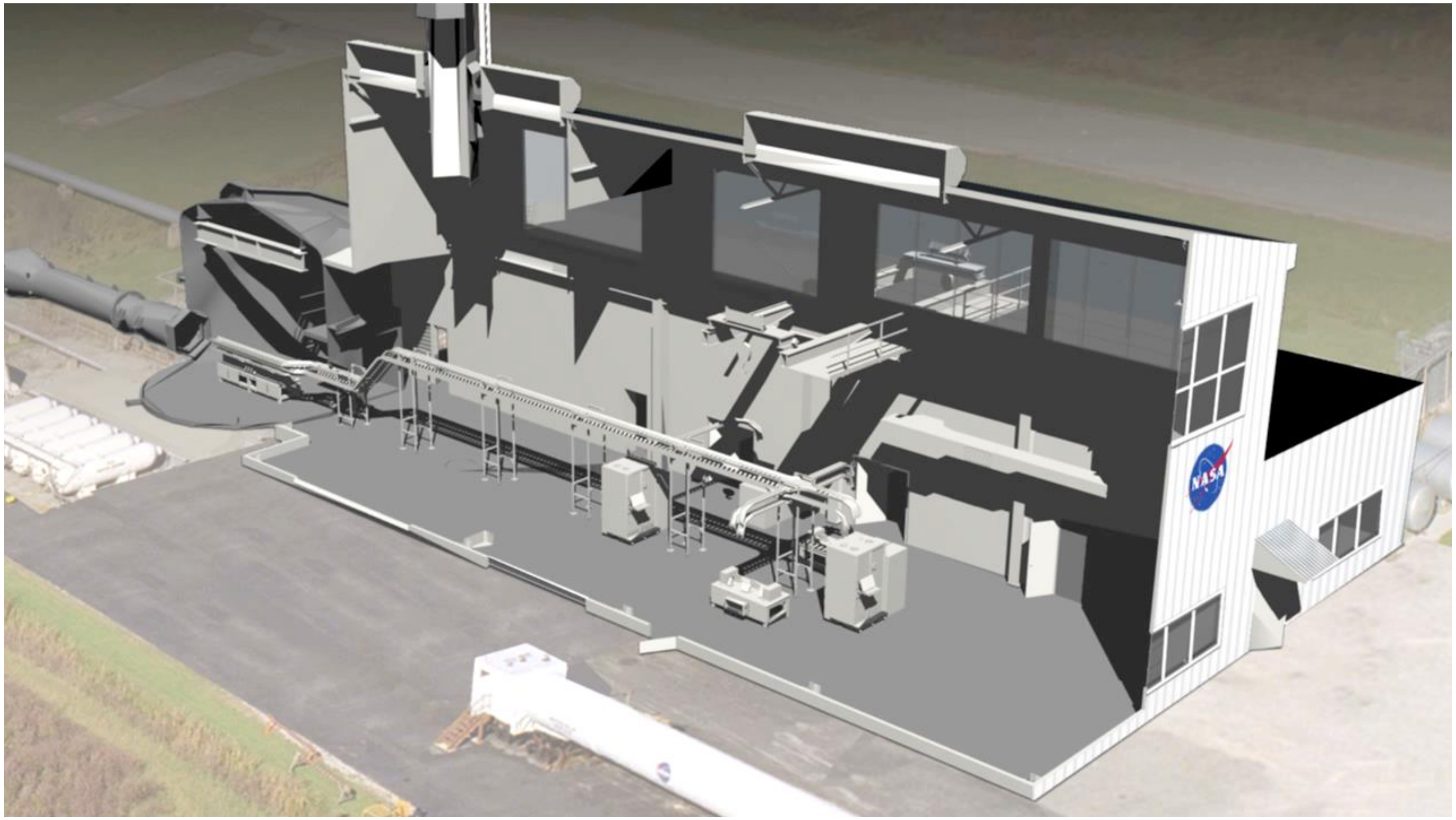


Hyper Tech produced multifilament MgB2 superconducting wires

Transformer fabricated from spin cast ribbon

CAPS idealized magnetic field test capability for wire segments

NASA Electric Aircraft Testbed (NEAT)

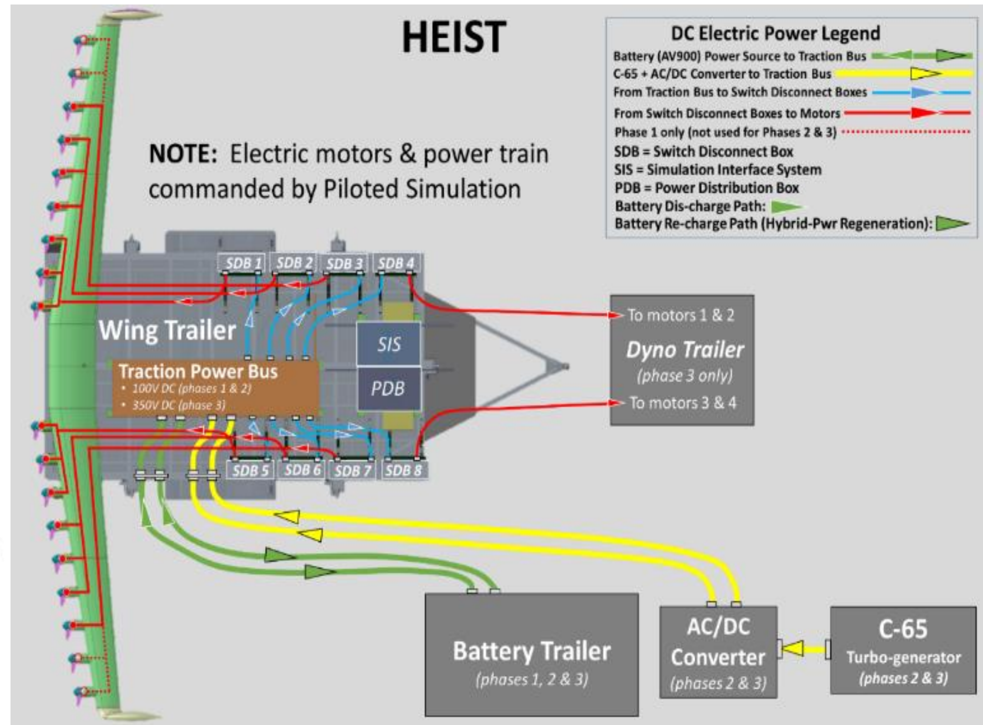


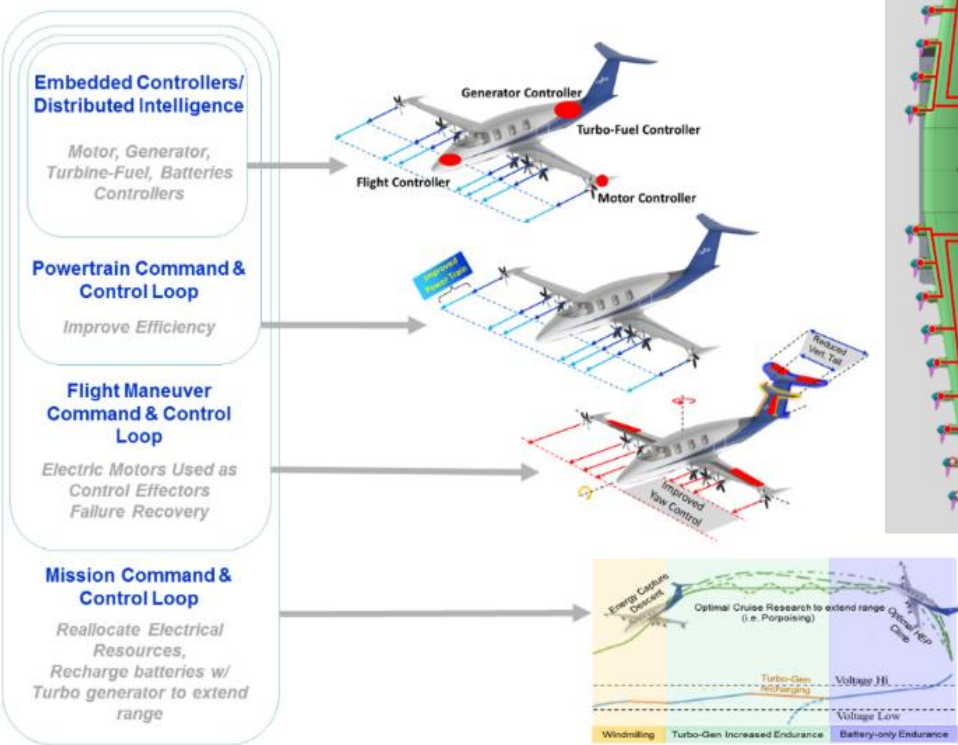
Challenge:
Hybrid electric powertrain design requires full-scale performance validation including EMI mitigation, fault and thermal management, turbine surge/stall prevention, DC bus stability, flight-efficiency, and high power, high voltage component verification.

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.

NASA