

NASA Aeronautics Overview & Propulsion Challenges

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Manager, Advanced Air Transport Technology (AATT) Project

Three Aviation Mega Drivers

NASA Aeronautics research strategy proactively addressing critical long-term needs



Traditional measures of global demand for mobility - economic development & urbanization - are growing rapidly and creating transportation and competitive opportunities and challenges

- Increasingly urbanized world
- Rising global middle class driven by Asia-Pacific
- Urban transportation increasingly congested



Large and growing energy and environmental issues create enormous affordability and sustainability challenges

- Continuing pressure to reduce noise & local air quality impacts
- Aviation industry sets challenging CO_2 reduction goals through mid-century



Revolutions in the integration of automation, information, communication, energy, materials and other technologies enable opportunity for transformative aviation systems

- Networked communications & sensors, embedded artificial intelligence, and big data converging with traditional systems and technologies
- On-demand service models disrupting traditional industries



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

NASA Aeronautics Strategic Thrusts









1. **Safe, Efficient Growth in Global Operations**
   Enable full NextGen and develop technologies to substantially reduce aircraft safety risks



2. **Innovation in Commercial Supersonic Aircraft**
   Achieve a low-boom standard



3. **Ultra-Efficient Commercial Vehicles**
   Pioneer technologies for big leaps in efficiency and environmental performance



4. **Transition to Alternative Propulsion and Energy**
   Pioneer new propulsion options for a wide range of air vehicles and characterize drop-in alternative fuels



5. **Real-Time System-Wide Safety Assurance**
   Develop an integrated prototype of a real-time safety monitoring and assurance system



6. **Assured Autonomy for Aviation Transformation**
   Develop high impact aviation autonomy applications

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

Research Programs Align with Strategic Thrusts

MISSION PROGRAMS

Airspace Operations & Safety

AOSP

Safe, Efficient Growth in Global Operations



In-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

FY 2020 Budget Request – NASA Aeronautics

$ Millions	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Aeronautics	$690.0	$724.8	$666.9	$673.6	$680.3	$587.1	$587.0
Airspace Operations and Safety	118.7	105.7	121.2	130.6	133.5	136.2	138.9
Advanced Air Vehicles	237.7	272.1	188.1	203.3	212.2	219.3	224.2
Integrated Aviation Systems	221.5	209.6	233.2	209.4	202.2	97.1	87.2
Transformative Aeronautics Concepts	112.2	137.4	124.4	130.3	132.3	134.6	136.7

FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan.

FY 2019 reflects funding as enacted under Public Law 116-06, Consolidated Appropriations Act, 2019, as adjusted by NASA's FY 2019 Operating Plan.

* Beginning in FY 2020, Aeronautics budget no longer includes the Aeronautics Evaluation and Test Capabilities (AETC) project of approximately $56M. AETC was transferred to the Safety Security and Mission Support account.

Where Does NASA Aeronautics Research Happen?

Aeronautics research takes place at four of NASA's ten field centers

ATM Research and Technology & Integration



AMES

Flight Research



ARMSTRONG

Propulsion Research and Technology



GLENN

Vehicle Research and Technology



LANGLEY



Major Areas of Inter-Center Collaboration

Langley/Glenn: Propulsion-Airframe Integration

Ames/Langley: Flight Deck & Ground Based Automation Integration; Flight Mechanics; Aerodynamics

Armstrong/Other Research Centers: Flight Experiment Integration

Overcoming the Barriers to Commercial Supersonic Flight

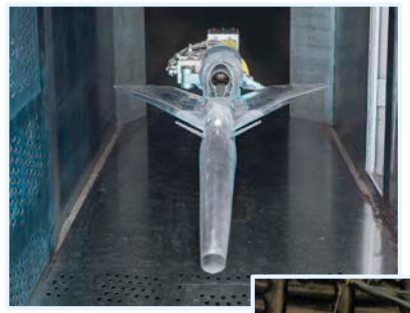
Standards Needed to Replace Current Prohibitions



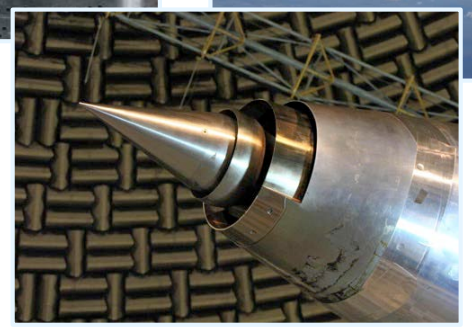
- **New Environmental Standards are needed to open the market to supersonic flight**
- **An En Route Noise Standard is the biggest challenge**
  - Requires proof of new design approaches, test procedures, and response metrics
  - No relevant data exists to define limits
    - Community data from large, diverse population is a requirement
  - Standard must be accepted internationally

Overcoming the Barriers to Commercial Supersonic Flight

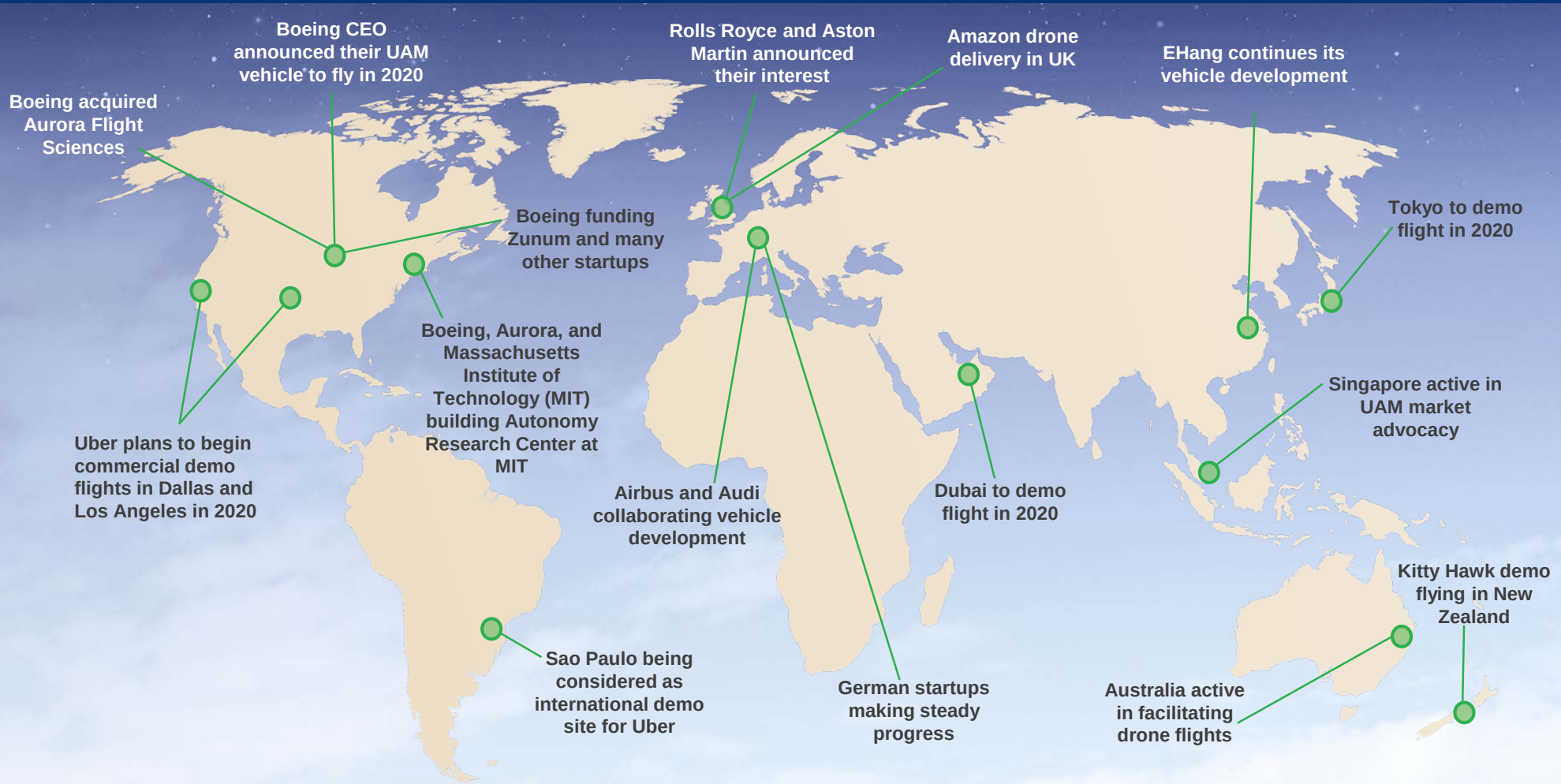
- Supersonics represents a game changer for transcontinental and intercontinental commercial flight but also must be able to fly supersonic over land
- NASA's efforts aim for a supersonic aircraft that has low boom signature and is
  - Efficient
  - Cost effective
  - Sustainable
- Low-Boom Flight Demo Goal:
  To provide data that could enable change in current supersonic overland flight regulations







Urban Air Mobility (UAM) Market Emerging



Large projected market––McKinsey analysis of demand by 2030 in 15 major U.S. cities:

- 500 million annual Unmanned Aircraft Systems (UAS) package deliveries
- 750 million annual passenger trips

Extrapolation to the global market would likely increase demand by 5 to 10 times

Urban Air Mobility and UAS Integration

NASA led the U.S. community with the UAS Traffic Management (UTM) & UAS in the NAS projects

- Integration of commercial systems is now beginning to emerge
- UTM is now the accepted concept all over the world

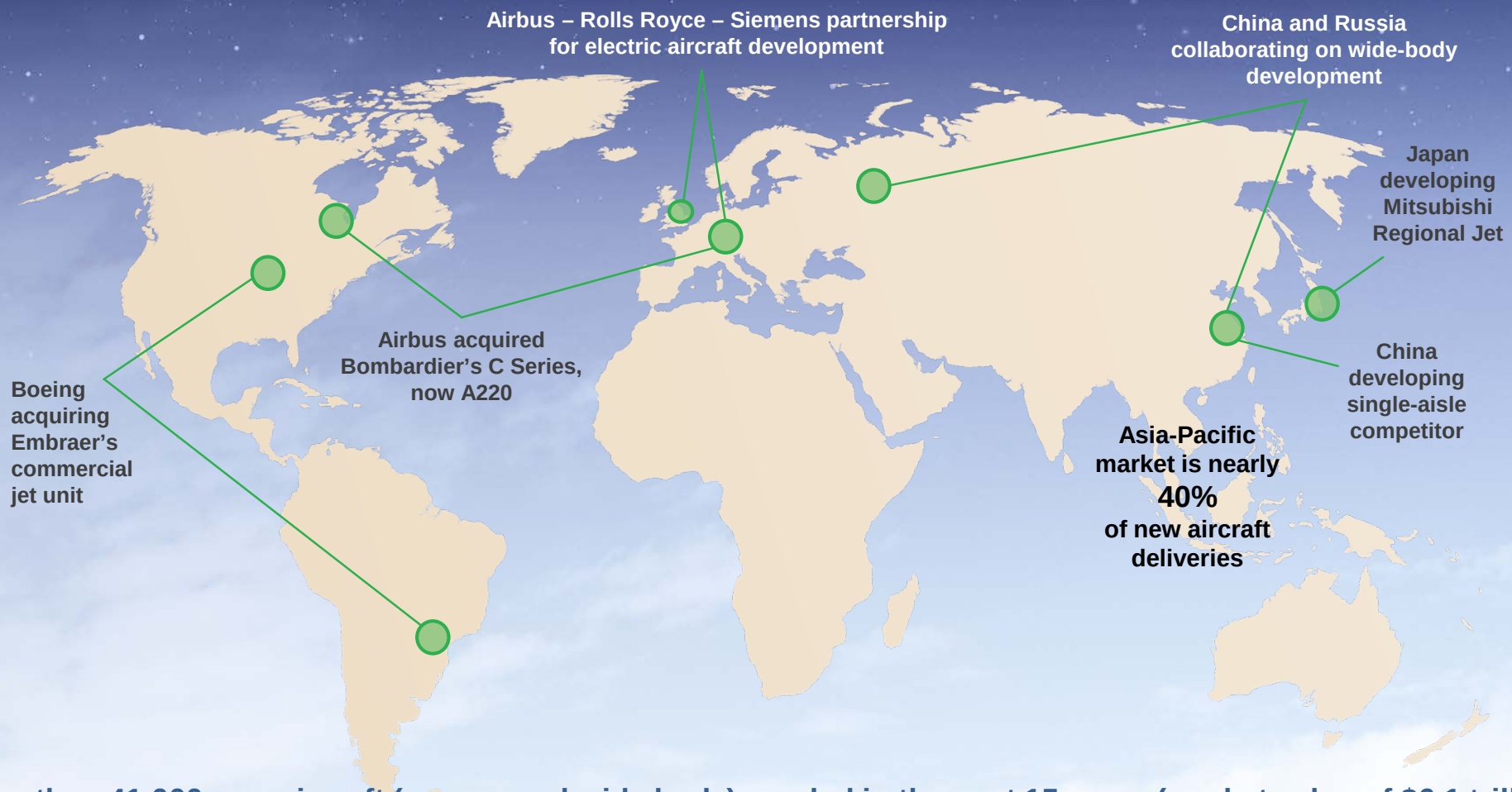




Urban Air Mobility (UAM) is fast on the heels of UAS integration

- U.S. industry looking for NASA leadership now to help overcome key barriers

Subsonic Transport Market on the Move



More than 41,000 new aircraft (narrow and wide body) needed in the next 15 years (market value of $6.1 trillion)

- 78% for narrow body including regional jet

Regional jet demand to peak in 2025 as current fleets are retired

- Over 5,000 new regional jets needed just for the North American market in the next 20 years, 2 times more than the next largest market, Europe

NASA Subsonic Transport System-Level Measures of Success

Use industry pull to mature technology that enables aircraft products that meet near-term metrics and push to mature technology that will support development of new aircraft products that meet or exceed mid-term and far-term metrics.

TECHNOLOGY BENEFITS*	TECHNOLOGY GENERATIONS (Technology Readiness Level = 5-6)		
	Near Term 2015-2025	**Mid Term** 2025-2035	**Far Term** beyond 2035
Noise Reduction (cum below Stage 4)	22 – 32 dB	32 – 42 dB	42 – 52 dB
LTO No_x Emissions Reduction (below CAEP 6)	70 – 75%	80%	> 80%
Cruise No_x Emissions Reduction (rel. to 2005 best in class)	65 – 70%	80%	> 80%
Fuel/Energy Consumption Reduction (rel. to 2005 best in class)	40 – 50%	50 – 60%	60 – 80%

*** Note:** Reference is best commercially available or best in class in 2005.



Evolutionary Revolutionary Transformational

Changing Landscape in Subsonic Transport Market

Current market is growing and expanding

- Boeing and Airbus have strong product lines with significant numbers of orders (737MAX, 787, 777X, A320neo, A350)
- Strong demand for increased production rates are driving both airframe and engine companies

Interests in electrification of aircraft is rapidly growing

- Advances in battery technologies are motivating the industry to develop alternative propulsion system
- Short-haul / Thin-haul market interests are rapidly growing
- International competition in development is being heated up
  - Airbus / Rolls Royce / Siemens announced partnership for electric aircraft in 2017



Potential Benefits of Electrified Aircraft Propulsion (EAP)

Offers improvements to highly-optimized aircraft like single-aisle transports

- Significant fuel burn reduction from alternative architectures & operational schemes
- Complement benefits from improved engine cores & airframe efficiencies



Helps open Urban Air Mobility market

- Enable new VTOL configurations to transform transportation & services



Revitalizes economic case for small short-range aircraft services

- Combine EAP & higher levels of autonomous operations to reduce operating costs of small aircraft
- Open access to community airports resulting in economically viable regional connectivity



Electrified Aircraft Propulsion – The Big Picture

A range of vehicles for a range of needs

	UAS	UAM	Small A/C	RJ	Single Aisle	Twin Aisle
						
Implementation Status	All electric vehicles in operation	All electric or hybrid applications being developed		Potential for hybrid or turbo-electric within 10 years		Significant progress needed for practical implementation
NASA Role	NASA research not needed	NASA focus on informing standards, regulations & design tools		NASA focus on enabling technologies, demonstrating benefits, addressing safety needs		Still too long term – not yet a NASA focus

Small Vehicle EAP

Energy & cost efficient, short range aviation

Transport Scale EAP

Energy & cost efficient, transport aviation

Leverage learning at smaller size to inform scale-up

Fundamental challenges span range of sizes

Electrified Aircraft Machine Power Requirements

MW-Class Focus

Largest Electrical Machine on Aircraft

Non-cryogenic | 100 kW | 1 MW | 3 MW | 10 MW | 30 MW | Superconducting

9 Seat
0.5 MW Total Propulsive Power
50 - 250 kW Electric Machines



19 Seat
2 MW Total Propulsive Power
0.1 - 1 MW Electric Machines



50 Seat Turboprop
12 MW Total Propulsive Power
0.3 - 6 MW Electric Machines





50 Seat Jet
12 MW Total Propulsive Power
0.3 - 6 MW Electric Machines





150 Seat
22 MW Total Propulsive Power
1.5 - 2.6 MW Electric Machines (STARC-ABL)
1 - 11 MW Electric Machines





300 Seat
60 MW Total Propulsive Power
3 - 30 MW Electric Machines





Left side of each power range bar is representative of the minimum size electric machine showing potential benefit through distributed propulsion for a partially electrified airplane

Right side is the size of a generator for a twin turboelectric system for a fully electrified airplane

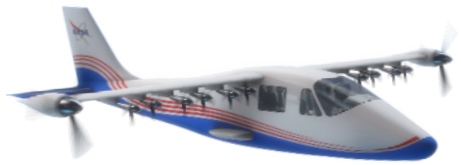
Current efforts targeting **1MW machines** have broad applicability across aircraft classes.

PS–01758–1115

NASA Electrified Aircraft Propulsion Strategy

2020s

Gain experience through integration and demonstration on progressively larger platforms



2030s

Increase electric aircraft propulsion with minimal change to aircraft shape



2040s

Advanced configurations with fully integrated hybrid electric propulsion and airframe



NASA Electrified Aircraft Propulsion Research

Objective

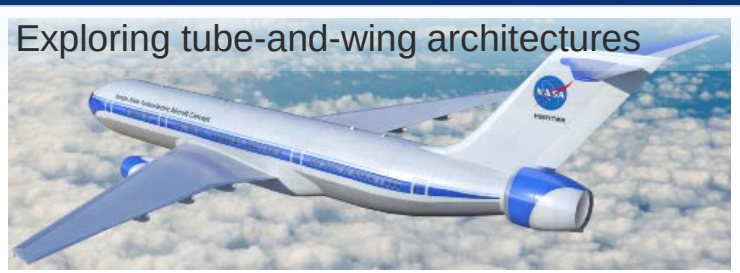
Develop viable concepts, establish key component performance parameters, and mature technologies for MW-class electrified aircraft propulsion systems for commercial transport aircraft

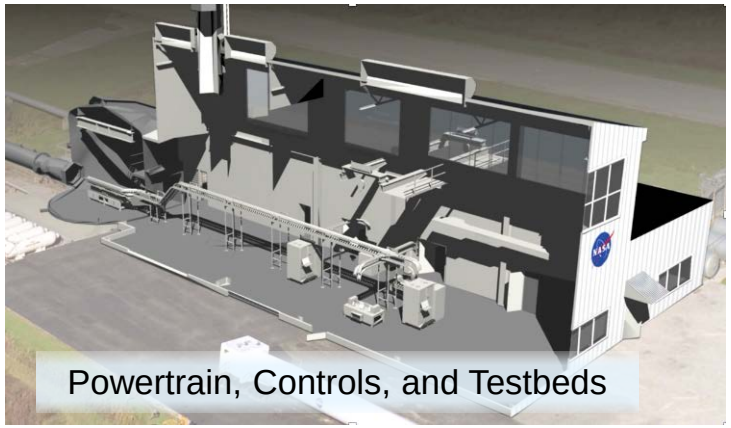
Technical Areas and Approaches

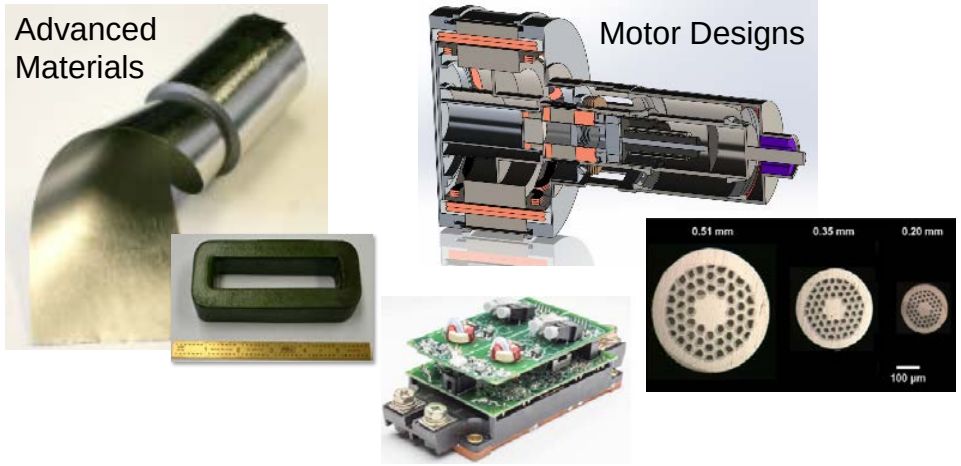
- Propulsion System Conceptual Design
- Integrated Subsystems
- High Efficiency/Power Density Electric Machines
- Flight-weight Power System and Electronics
- Enabling Materials

Benefit/Payoff

- Enable paradigm shift from gas-turbine to electrified propulsion
- Reduce fuel/energy consumption, emissions, and noise

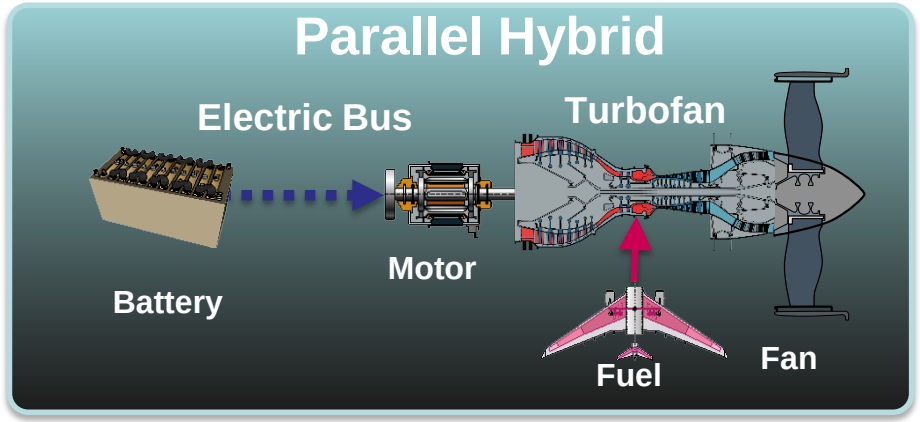


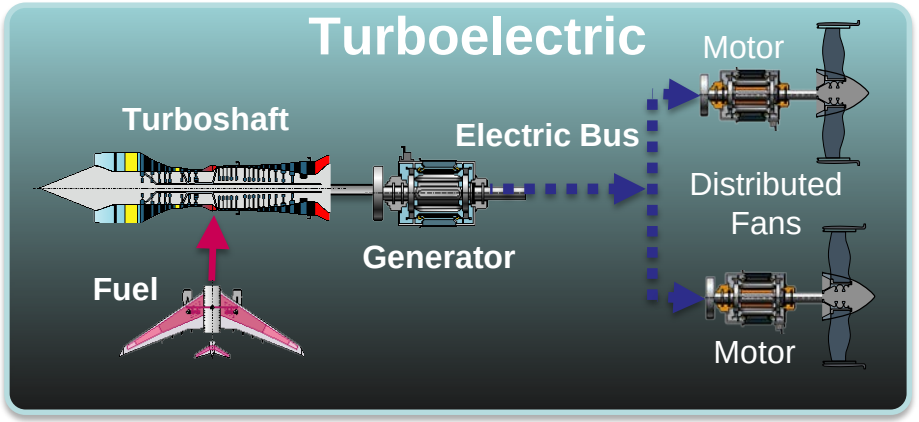


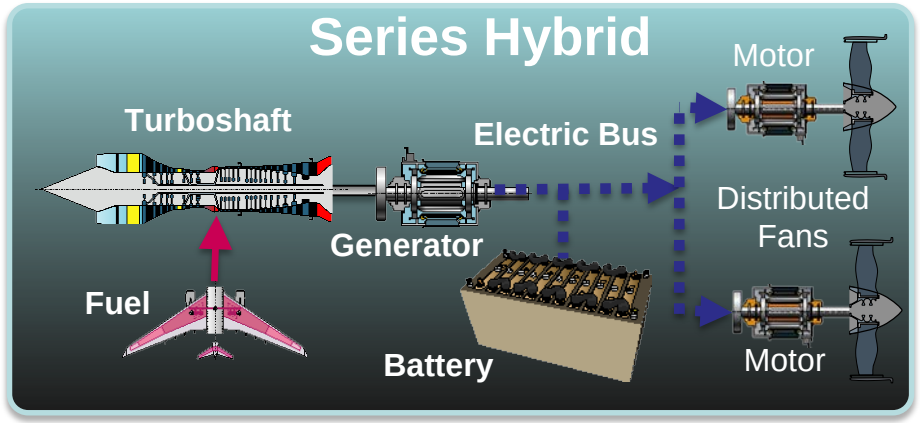


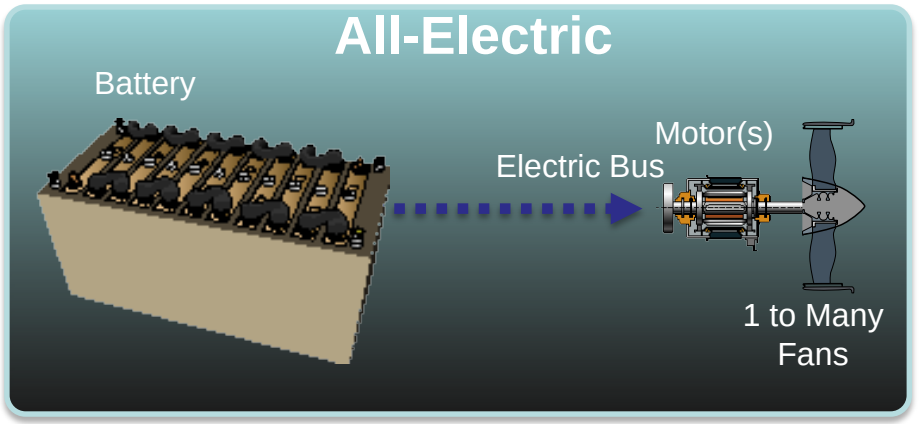
Novel Designs for Flightweight Power

Four Principal Electrified Propulsion Architectures









NASA STARC-ABL Concept

An Example of Mid Term “Partial” Turboelectric Architecture

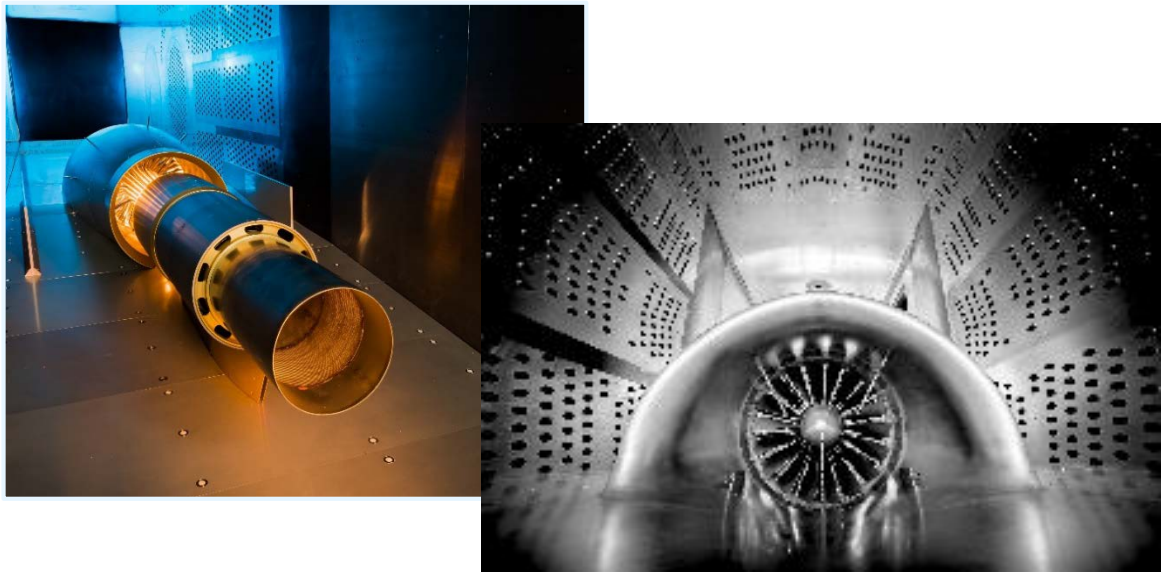


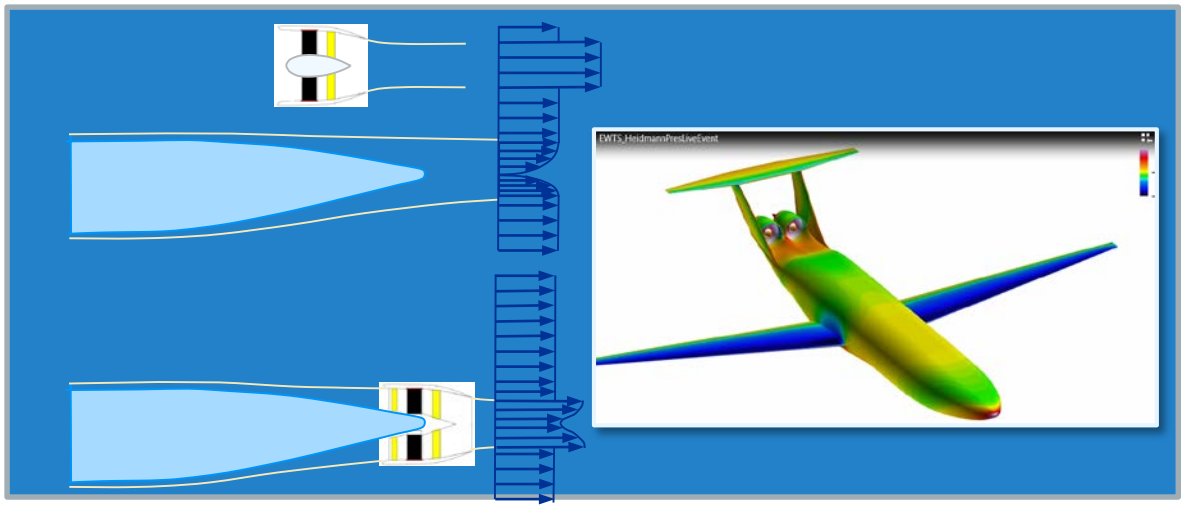
NASA N3-X Concept

An Example of Far Term Fully Turboelectric Architecture



NASA Boundary Layer Ingestion Research





Embedding engines inside the wing or fuselage energizes aircraft boundary layer reducing drag and increasing efficiency

First-ever integrated inlet and distortion-tolerant fan at 8- by 6-Foot Supersonic Wind Tunnel (180^{o} distortion – similar to Aurora D8)

Plans in development for 360^{o} distortion “tailcone thruster” BLI test (representative of NASA STARC-ABL)



Aurora D8 “Double Bubble” Concept

Example of Boundary Layer Ingestion & NASA Wind Tunnel Experiment



Gas Turbine Technology Critical to EAP Success

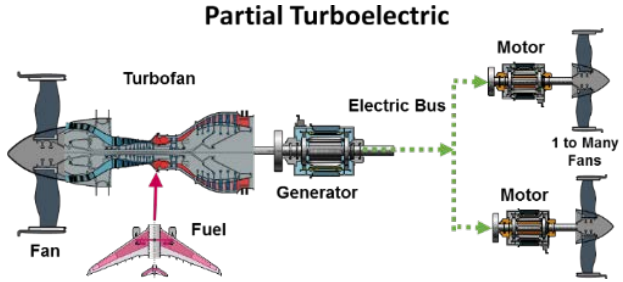
Partially and Fully Distributed Turboelectric Concepts

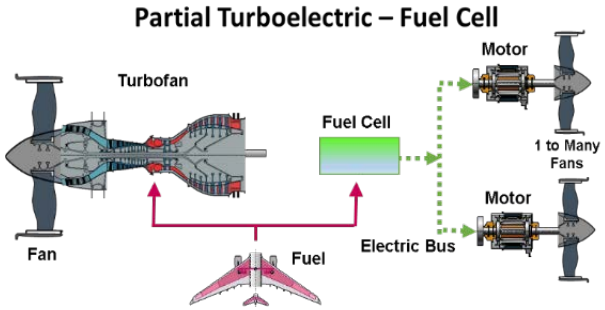


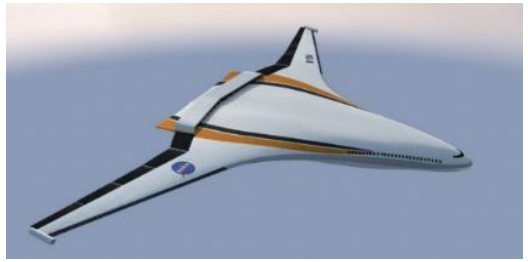
NASA STARC - ABL



Boeing/NASA SUGAR - FREEZE







NASA N3-X

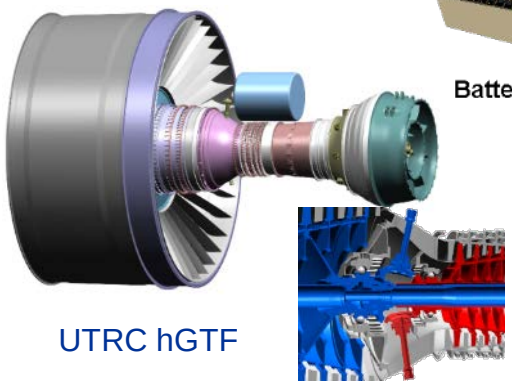


ECO-150

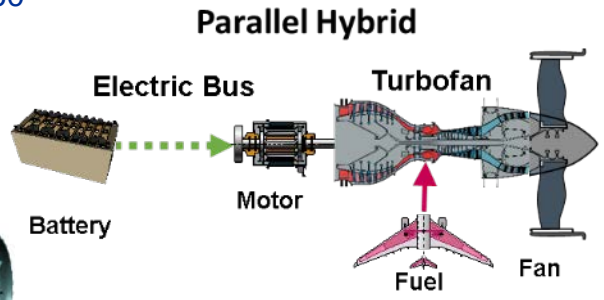
Parallel Hybrid Concepts



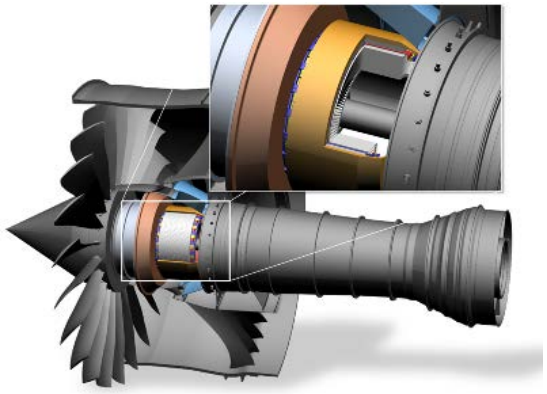
Boeing/NASA SUGAR - VOLT



UTRC hGTF



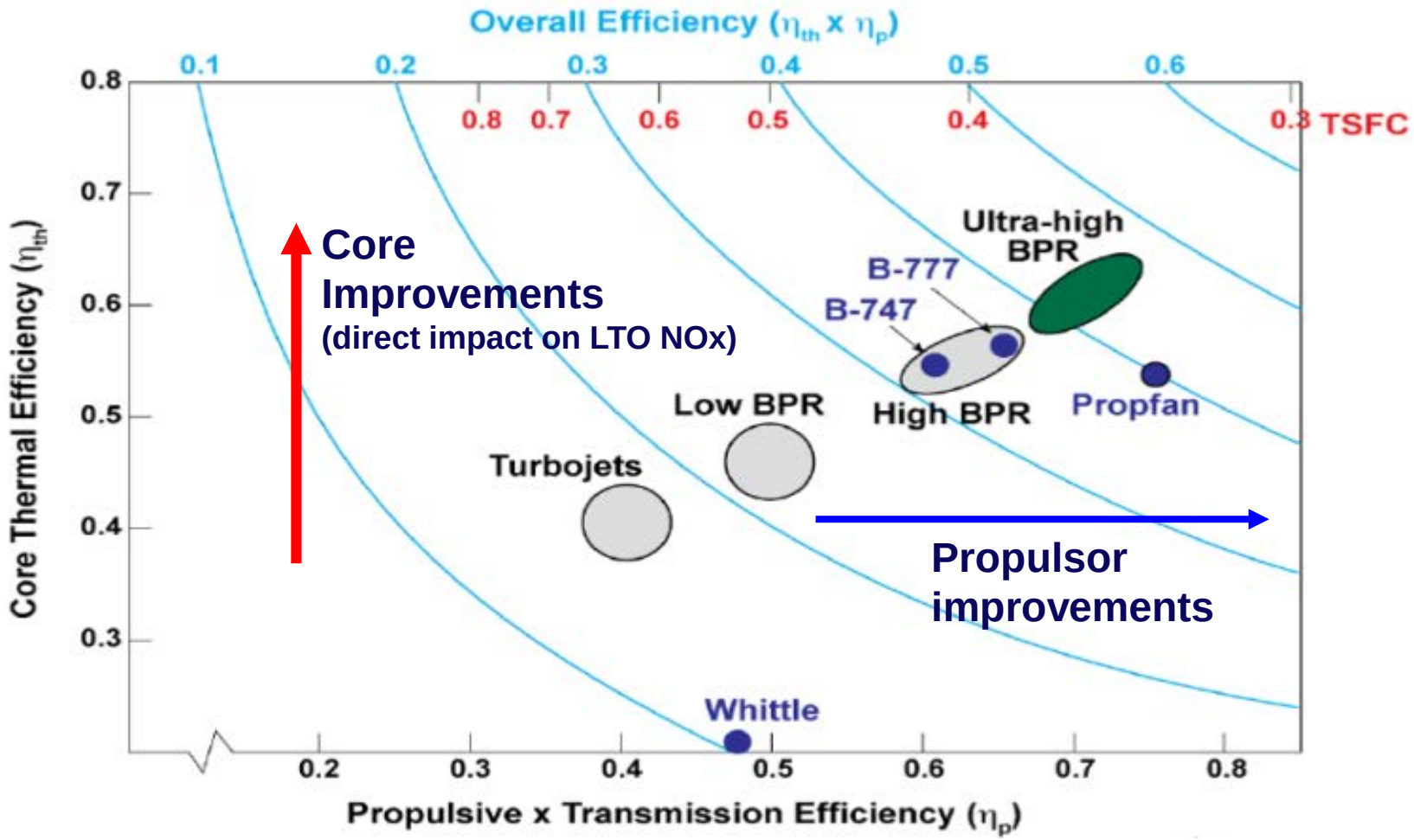
Low Spool
High Spool



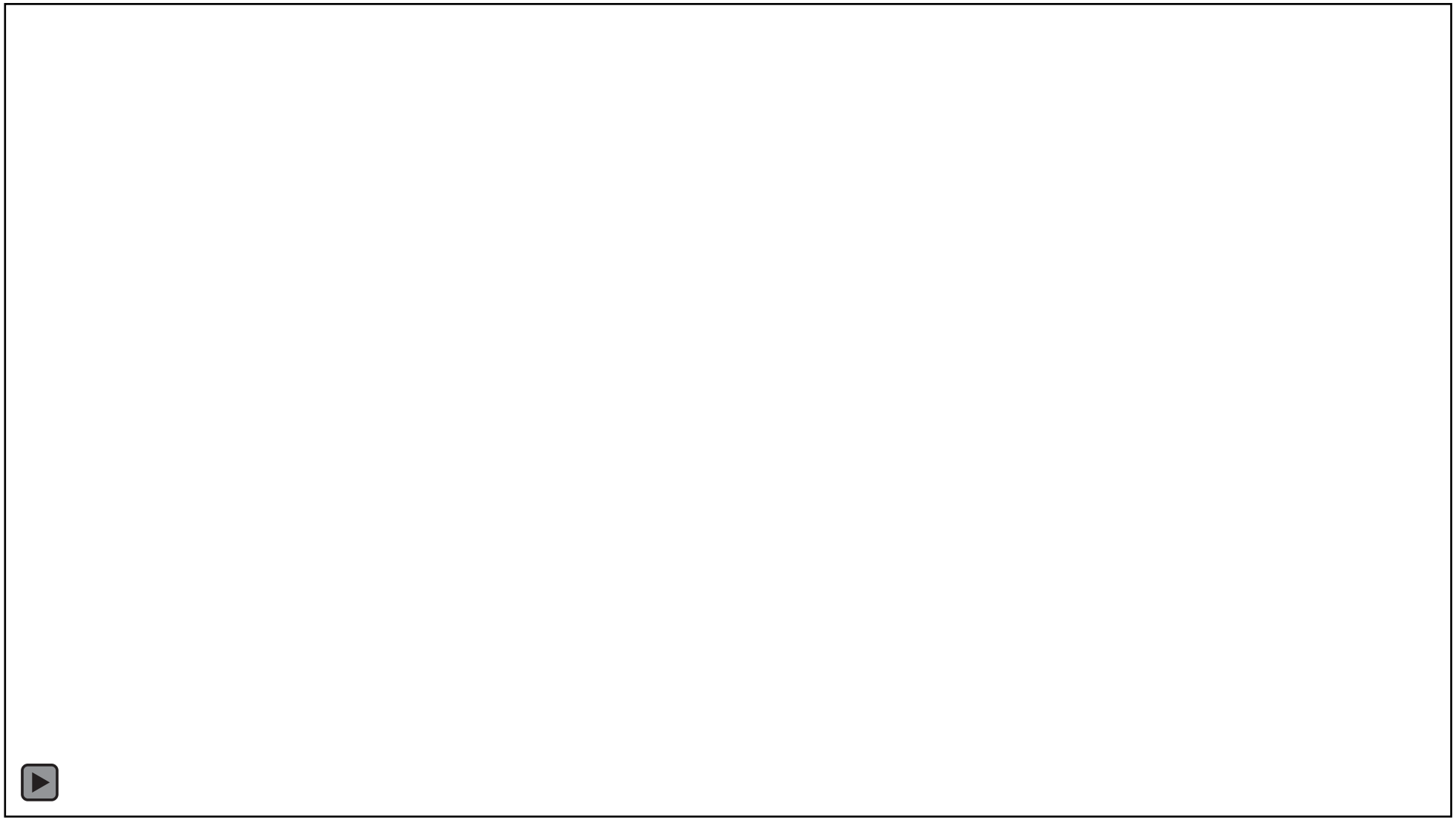
R-R LW EVE

Gas Turbine Technology Opportunity

Propulsion system improvements require advances in both propulsor and core technologies



High Power Density Core



High Power Density Core

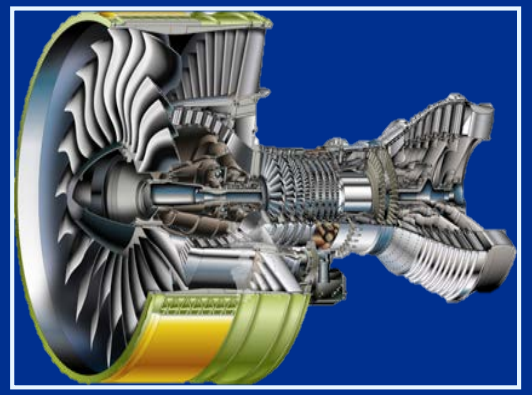
Engine Core Technologies for Future Transports and Electrified Aircraft Propulsion

- Compact gas-generator core architecture and component technologies enabling BPR ~20 growth by minimizing core size
- Thermally efficient, high OPR (50+) engines
- High-level turbine power extraction and integrated thermal management
- 80% NOx reduction at cruise and 80% below CAEP6 at LTO and reduced particulates

Lower aerodynamic losses and new cooling methods



Additive manufacturing creating new opportunities for all engine components



High-temperature materials key to enabling higher efficiencies

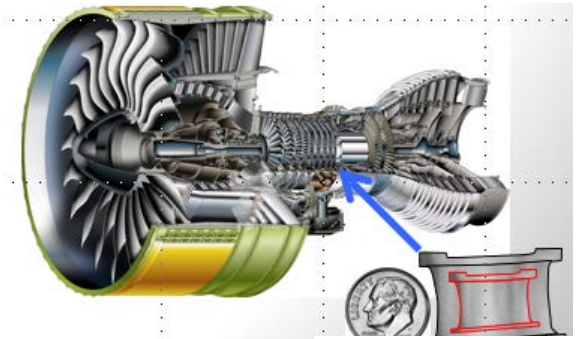




High Power Density Core

Small Core Gas Turbine Propulsion
Advanced gas turbine power generation offers multiple benefits:

- Improved thermal efficiency reduces fuel burn
- Reduced size facilitates high bypass ratio engine integration
- Impacts conventional or electrified aircraft



There are multiple challenges to achieving this performance in a smaller size

NASA is working with industry partners to 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

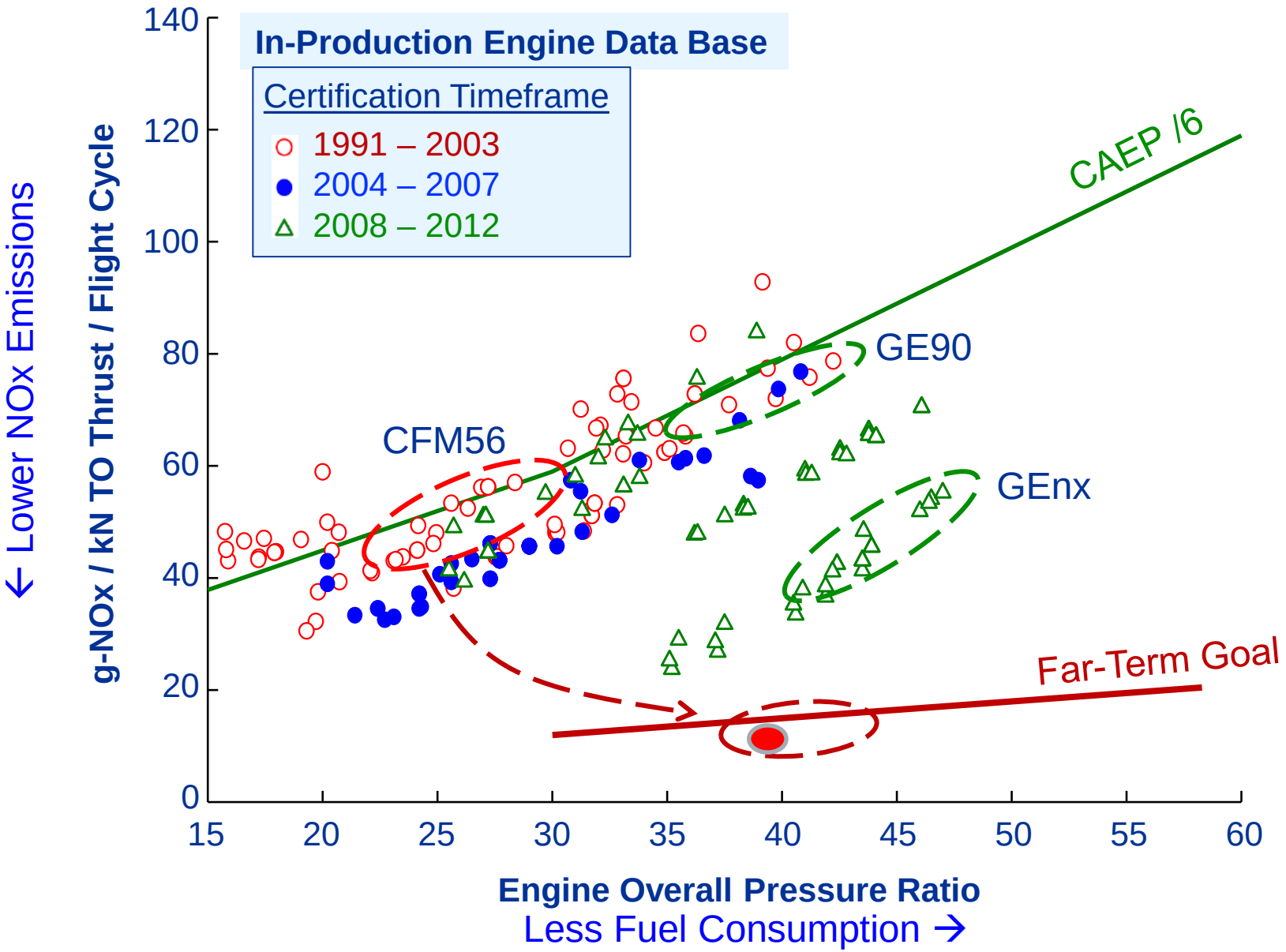


Boeing 737-700 (left) vs B737 MAX 8 (right)

Pratt & Whitney: HPC rear block design to mitigate losses
General Electric: Develop casing treatment with large tip gap utilizing existing hardware

Small Core Improvements Are Critical for EAP to Enable Efficient, Compact Power Generation and Improved Overall Propulsion System Performance

High Power Density Core NOx Challenge



Low NOx, Fuel-Flexible Combustor

Objective

Reduce NOx emissions from fuel-flexible combustors to 80% below the CAEP/6 standard with minimal impacts on weight, noise, or component life

Technical Areas and Approaches

Fuel-Flexible Combustion

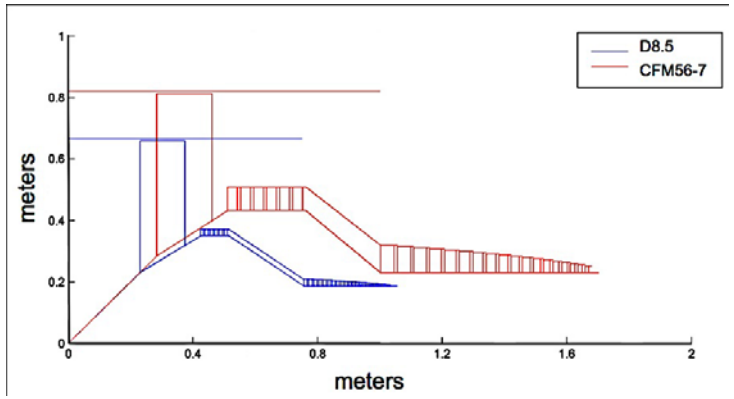
- Develop lean-burn combustor concepts suitable for small core engines and explore active combustion control

Benefit/Pay-off

- Realize emission goals (80% reduction below 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 & un-ducted propulsors
- Compatible with alternative fuel blends

Far Term LTO NO_X goal achievable with small core compatible combustor concept

Advanced small core combustors required for both gas turbine and hybrid architectures







Low Emission, Fuel-Flexible Combustor

Scale core by 50% and achieve 80% goals



Evaluate Alt Fuel Emissions at Altitude



NASA Aircraft Engine Noise Research

Objective

To help meet aggressive noise goals, must reduce fan and core noise with minimal impact on weight and performance

Technical Areas and Approaches

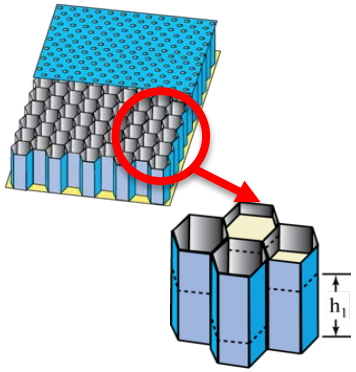
- Multi-Degree-of-Freedom Low-Drag Liners
  - B737-MAX Flight Test (TRL 7)
- Low Pressure Ratio Fan Testing and Development
- Engine Core Noise Testing and Mitigation

Benefit/Payoff

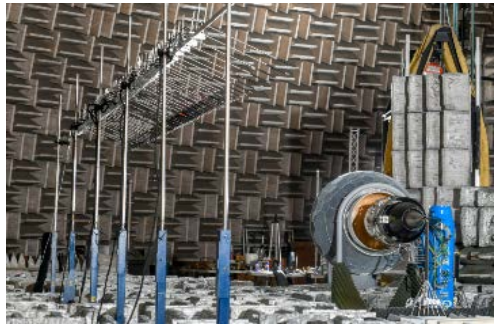
Aircraft component noise reduction to meet future noise stringencies with minimal impact on weight and aircraft performance

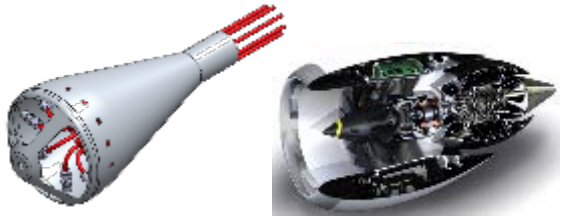
*Significant NASA effort in airframe noise reduction not represented here
System-level noise benefit requires both airframe and engine acoustic improvements





NASA Low-Drag Multi-Degree-of-Freedom Liner Concept





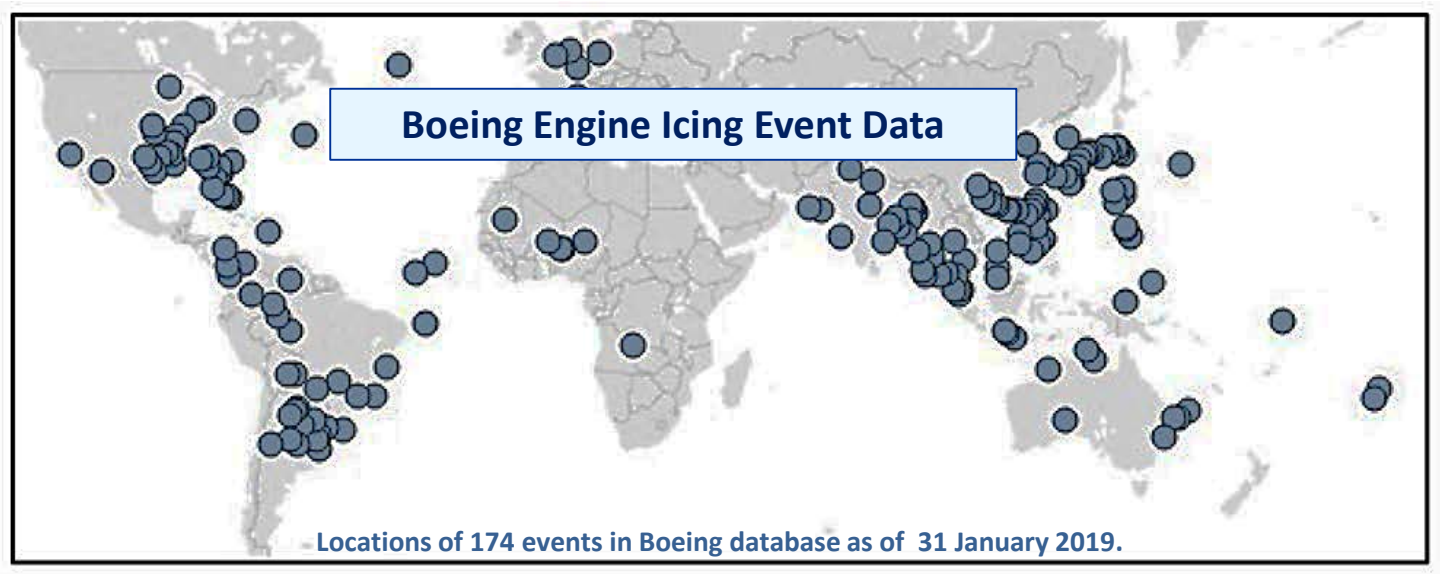
Engine Core Noise



Low Pressure Ratio Fan / Short Inlet Noise

Ice Crystal Icing Threat to Industry

- Ice Crystal icing is still causing engine power loss, damage, and vibration events
- Engine Manufacturers are trying to improve engine design to avoid failure modes
- Industry trying to understand how to meet the Means of Compliance for the ice crystal icing regulations.
- Threat to smaller cores and higher pressure ratio engines
- Industry seeks a 3D tool that supports the design and certification of engines.



Bravin, M. and Strapp, J.W., "A Continuing Investigation of Diurnal and Location Trends in an Ice Crystal Icing Engine Event Database," SAE Technical Paper 2019-01-1964, 2019, doi:10.4271/2019-01-1964.

Engine icing simulation models must incorporate correct physics

NASA Engine Icing Test Capability



Final Thoughts

- NASA Aeronautics has identified several key investment areas:
  - Commercial Supersonic Flight
  - Urban Air Mobility
  - Electrified Aircraft Propulsion
- For subsonic transport aircraft, NASA seeks to advance technologies that can meet aggressive metrics, as well as strengthen and/or open new aviation markets
- Electrified Aircraft Propulsion, Boundary Layer Ingestion, and High Power Density Core are three main approaches toward meeting these objectives
- Must also address increasingly stringent NOx, Noise, and Engine Icing challenges
- NASA's Advanced Air Transport Technology (AATT) Project is advancing this suite of subsonic transport technologies in collaboration with the aviation community

https://www.nasa.gov/aeroresearch/programs/aavp/aatt

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