The Electrifying Future of Air Transportation

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Dr. Hassan A. Hassan Distinguished Lecture
NC State University, Raleigh, NC, November 16, 2018

NASA Vision for the Future of Aviation

U.S. leadership for a new era of flight

The Era of Aviation Electrification

- This era is unfolding now!
- Completely transform aviation and air travel
- Open up the skies to new ways of moving people and cargo
  - Drones, personal air vehicles, on-demand urban air mobility
- Lead to radically new and better designs for commercial subsonic transport aircraft

Images courtesy of: Amazon, Airbus, Vision, Joby, NASA

Electrification of Air Transportation

WHEN?

WHY?

WHAT?

HOW?

Electrification of Air Transportation

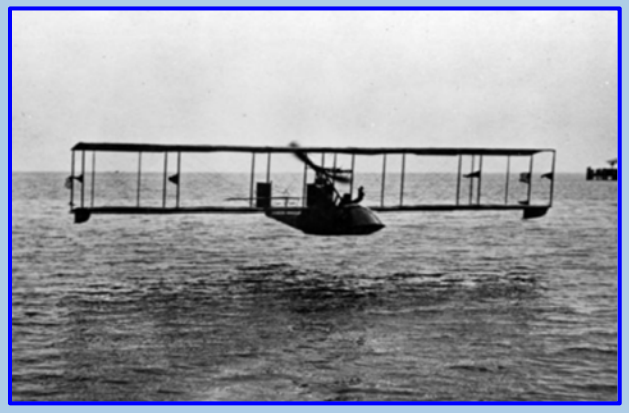
WHEN?

WHY?

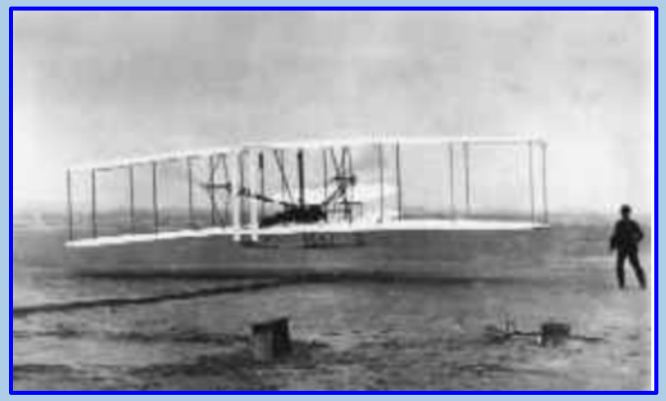
WHAT?

HOW?

The Era of Flight



Benoist XIV Flying Boat. First Scheduled Commercial Airline Service, 1914



Wright Flyer, 1903

Boeing 307 Stratoliner, First commercial aircraft with pressurized cabin, 1938

Images courtesy of: Wikipedia

The Jet Era

Whittle Engine, 1937

De Havilland Comet, 1952

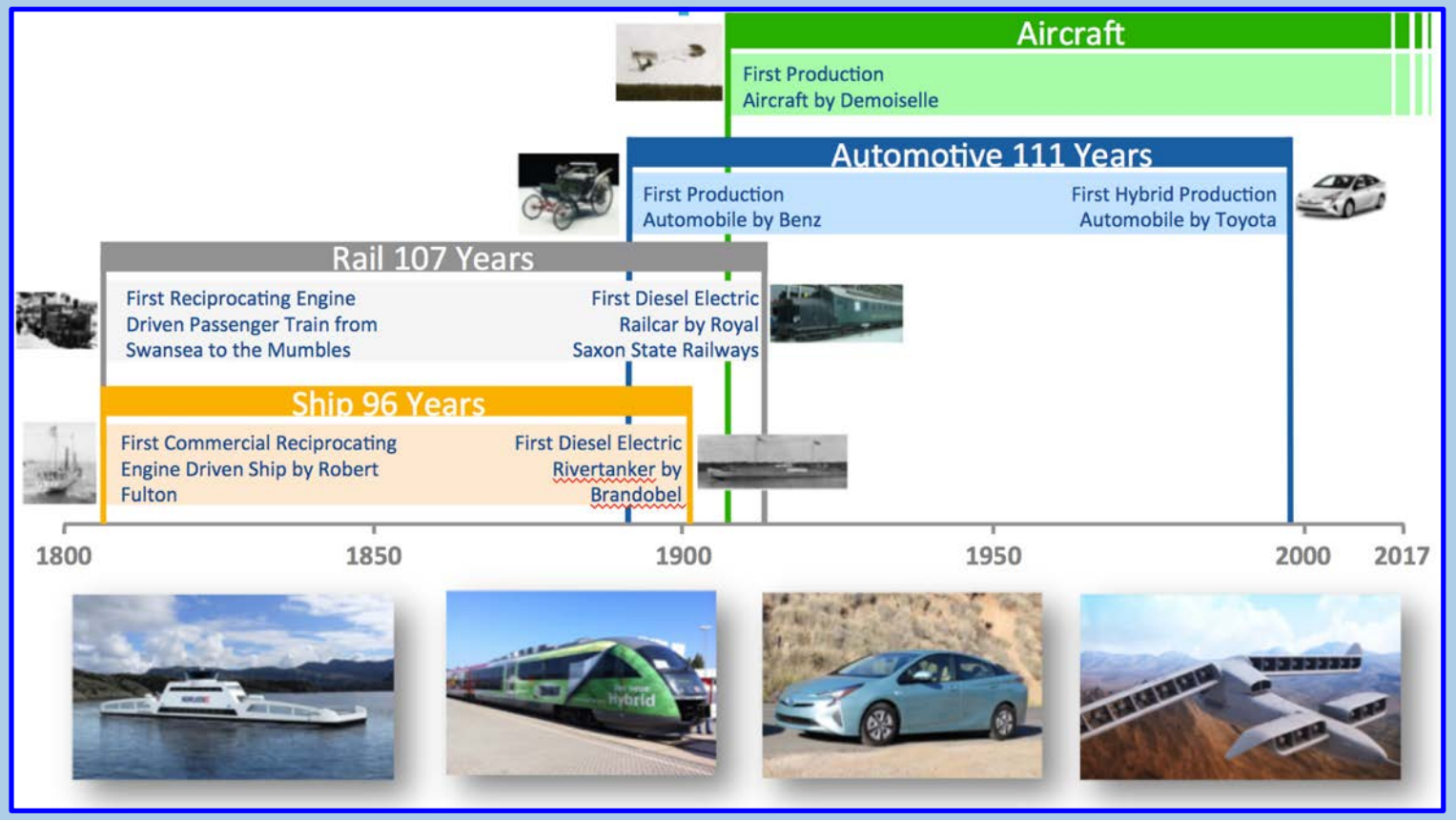
Boeing 707, 1958

Concorde SST, 1976

Boeing 787 Dreamliner, 2011

Images courtesy of: Wikipedia

The Electrification Era: History Says the Time is Now!



Electrification of Air Transportation

WHEN?
Now!

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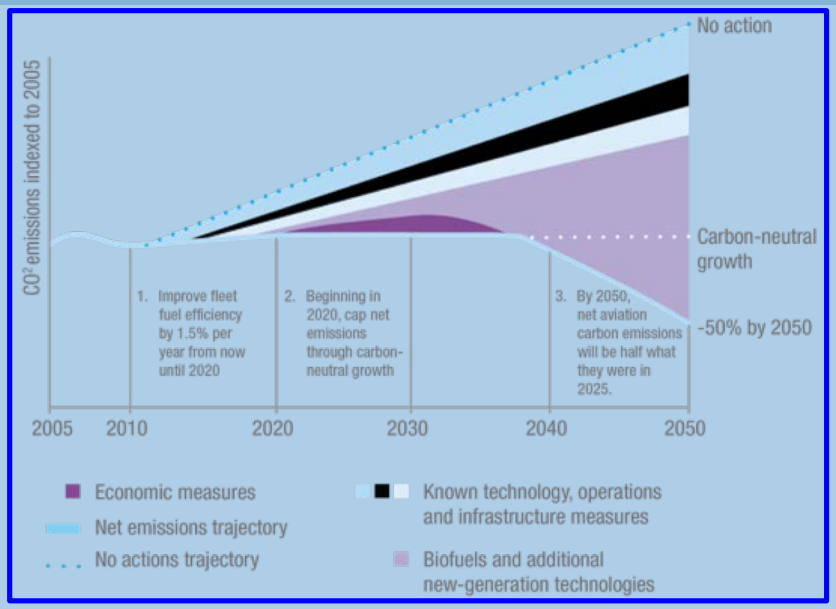
Aviation's Grand Challenge: Sustainability



Reduce carbon footprint by 50% by 2050, while…

- meeting increasing demand
- meeting landing and takeoff noise regulations
- meeting emissions regulations
- reducing aircraft development, manufacturing, and operational costs

Source: http://aviationbenefits.org/environmental-efficiency/aviation-and-climate-change/our-climate-plan/

Growth Projections for Commercial Aviation

2017

4 BILLION

PASSENGER TRIPS

2036

7.8 BILLION

PASSENGER TRIPS

Airbus / Europe

Bombardier / Canada

Irkut / Russia

Comac / China

Embraer / Brazil

Global Competitors

41,030
New Aircraft Deliveries

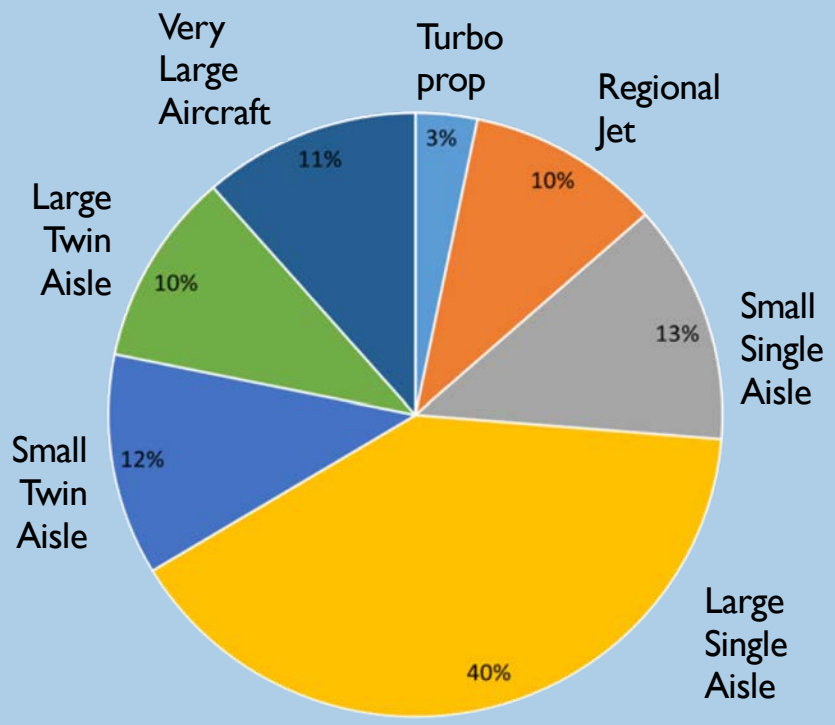
$6.1 Trillion
Market Value

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

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

Focus on Single-Aisle Class Aircraft

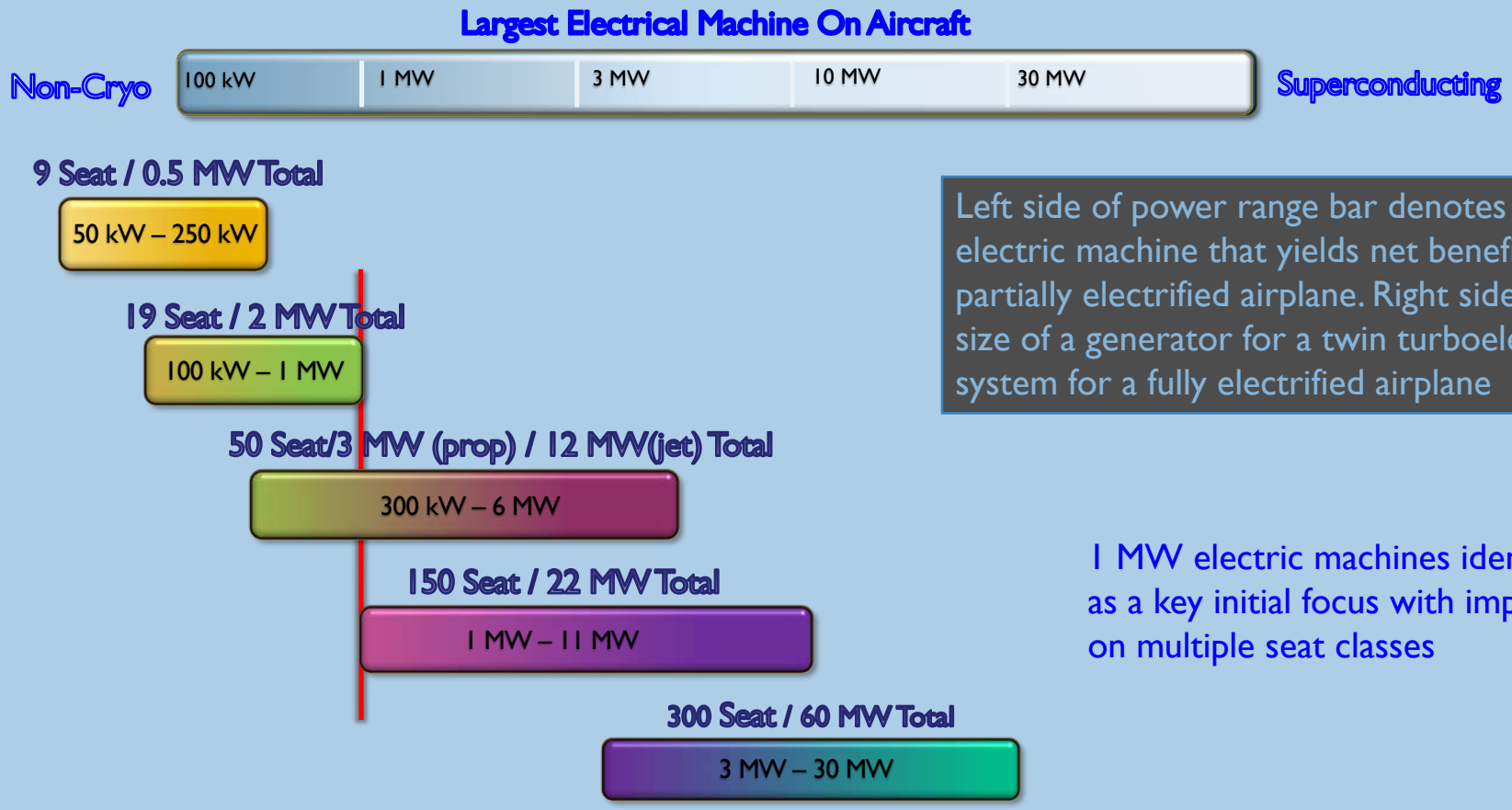
2012 Fuel Consumption



100+ passenger aircraft consumed 87% of fuel!

Analysis of FAA US Operations Data by H. Pfaender, GA Tech

Targeting Single Aisle Class Can Impact Wide Range of Aircraft Sizes



Left side of power range bar denotes smallest electric machine that yields net benefit for a partially electrified airplane. Right side is the size of a generator for a twin turboelectric system for a fully electrified airplane

1 MW electric machines identified as a key initial focus with impact on multiple seat classes

Electrification of Air Transportation

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U.S. leadership in Global, Sustainable, and Transformative aviation

WHAT?

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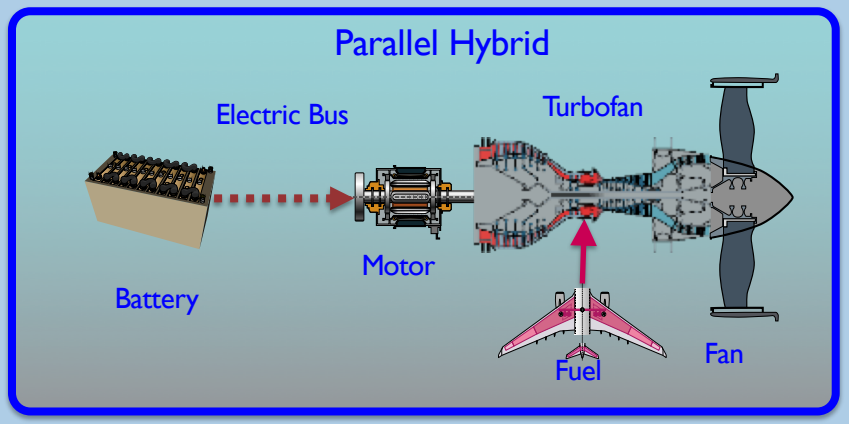
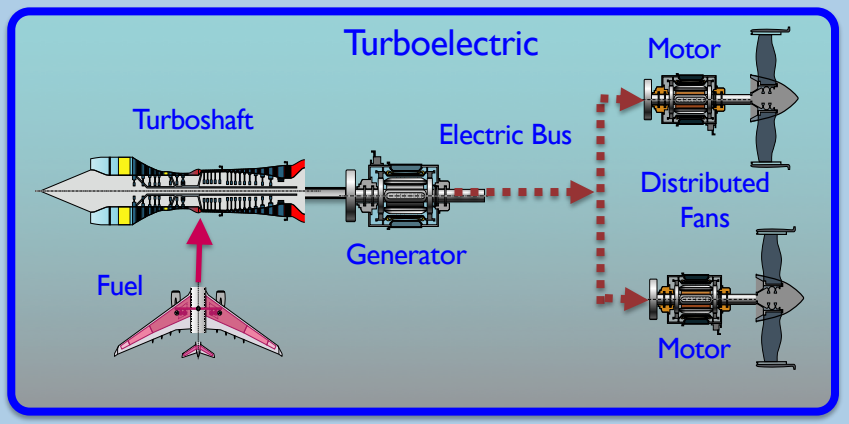
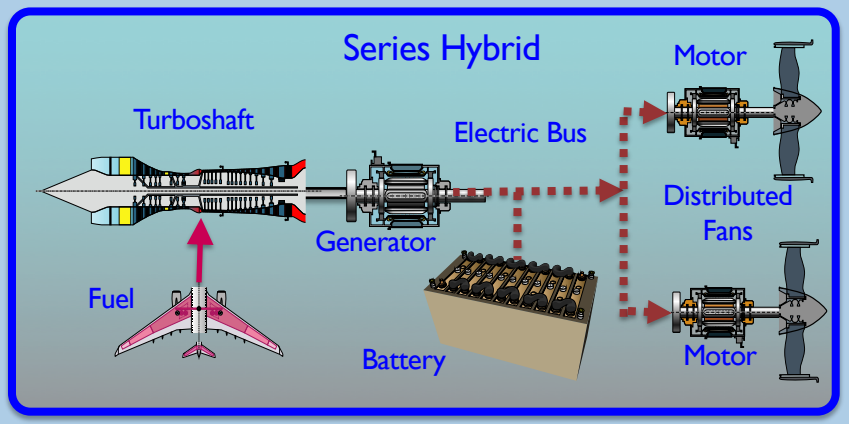
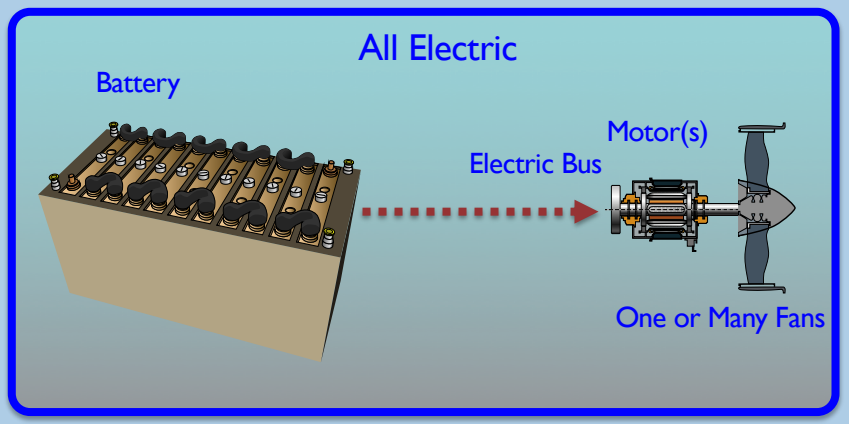
Electric Architecture Choices









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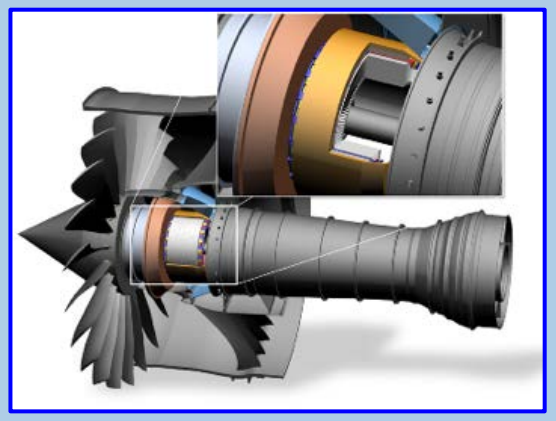
WHAT?
The future face of aviation

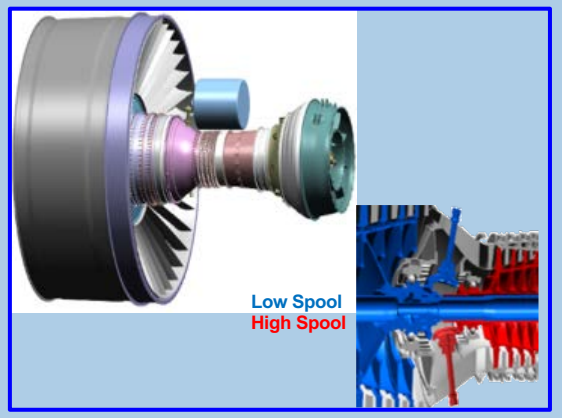
HOW?

Parallel Hybrids

Boeing Sugar Volt with GE hFan Engine



Rolls-Royce EVE Electrically Variable Engine



UTRC hGTF Hybrid Geared TurboFan Engine

Making Electrification Work: Offsetting Electrical System Penalties

- Use stored energy judiciously
- Improve aerodynamic and propulsive efficiency
- Target weight reductions in other systems
- Leverage flexibility offered by decoupling of power and propulsion functions
- Think exciting configuration options beyond "tube-and-wing"

Boundary Layer Ingestion

Wing Tip Propulsors

Distributed Propulsion

Near-Term Impact:
NASA STARC-ABL Partially Turboelectric Concept

Future Electrified Aircraft Concepts

NASA STARC-ABL

Boeing TTBW with Tailcone Thruster

NASA Pegasus

ESAero Eco-150

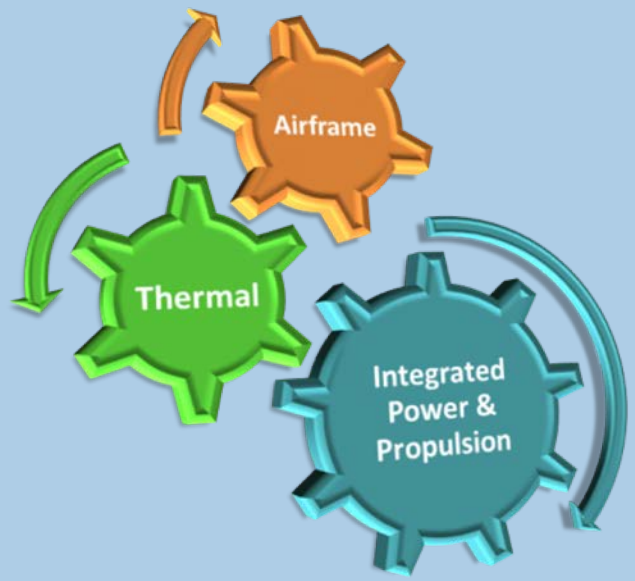
NASA N3X

Airbus/RR eThrust

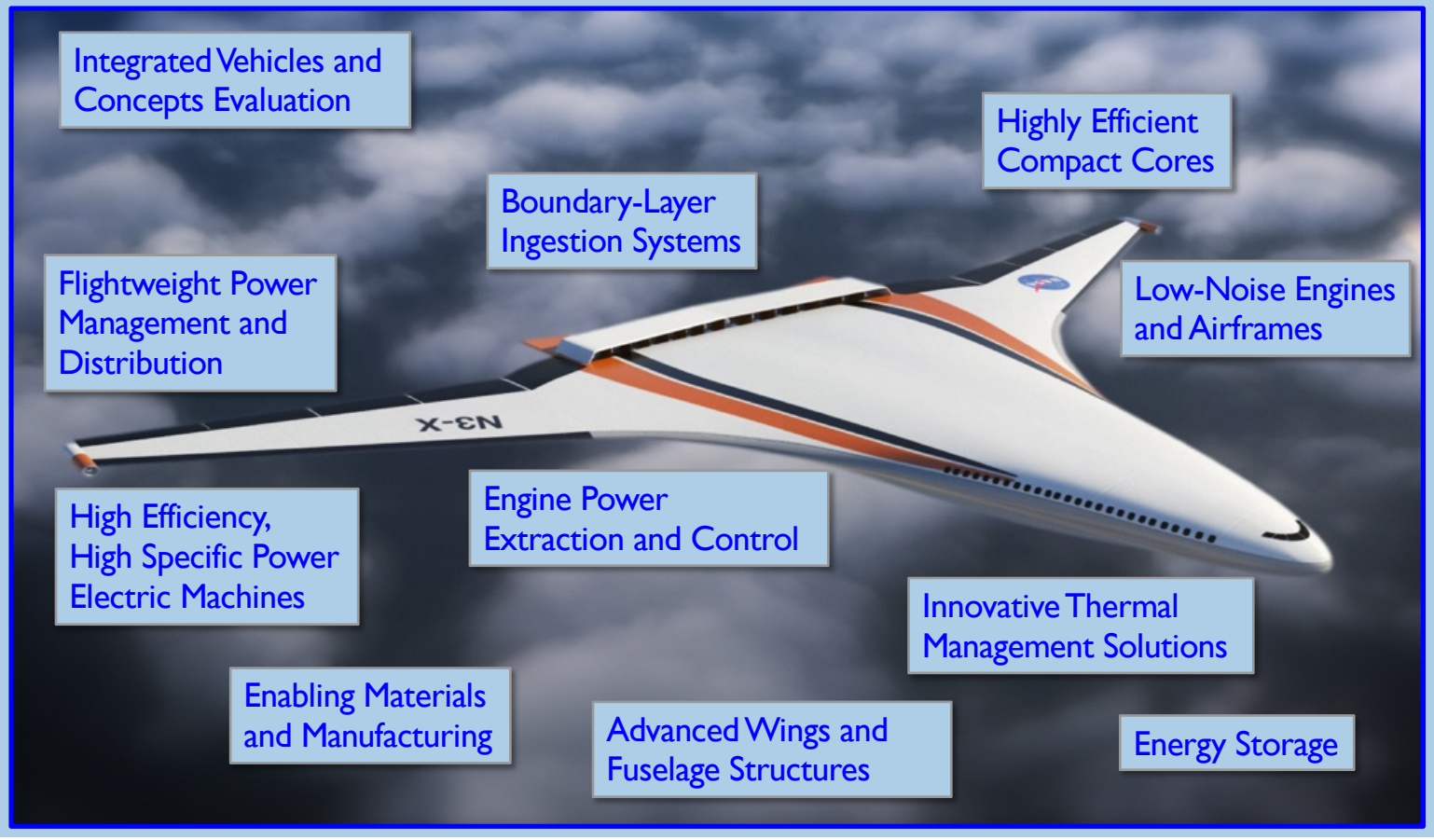
Integrated system concepts with overall performance benefits

Electrification: Key Technical Challenges

- Electrical system weight and efficiency
- Energy storage capabilities
- High voltage
- Thermal management
- Flight controls
- Safety
- Certification

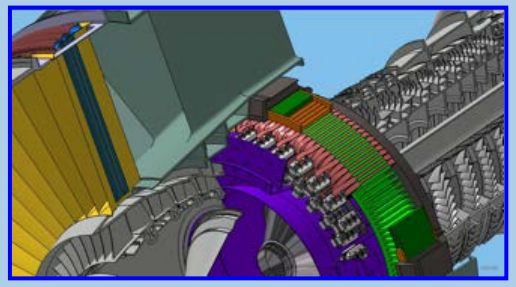


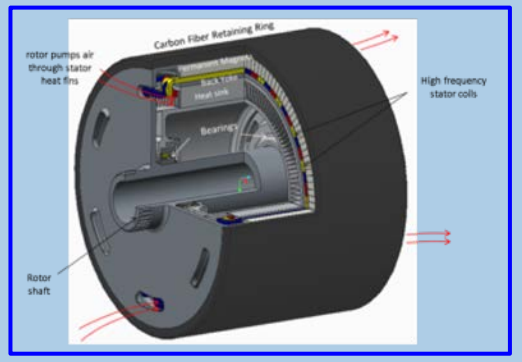
What Technologies are Needed?



MW-Class Electrical Machines

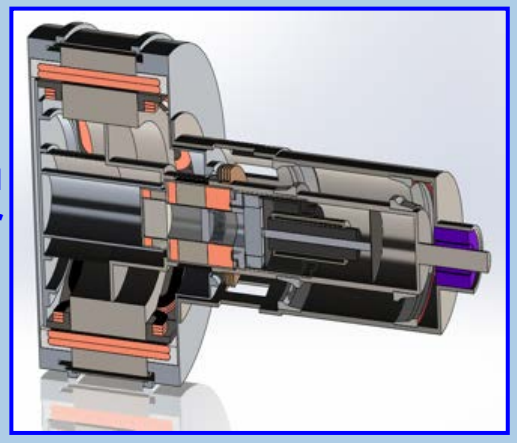
OSU Ring Motor

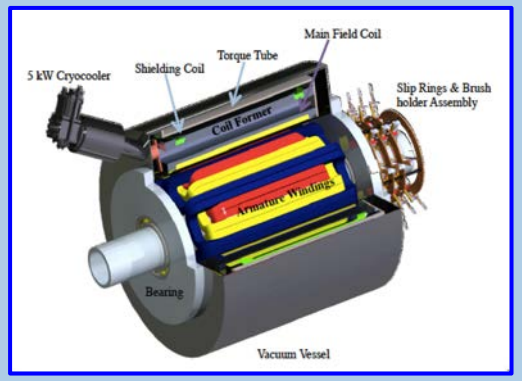




UIUC PM Motor

NASA HEMM Motor



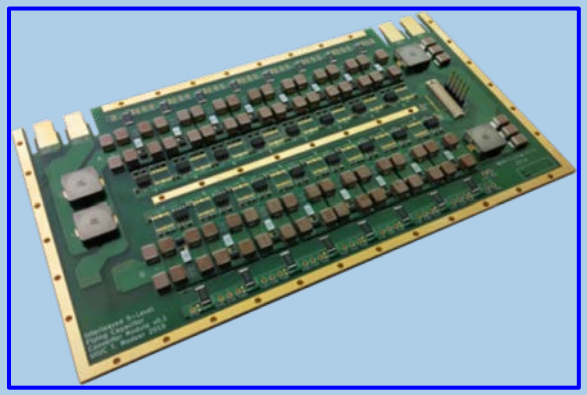


UIUC Partially SC Motor

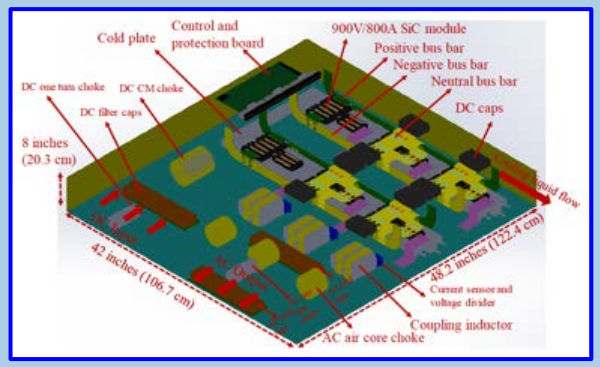
Scalable high efficiency (>96%) and high specific power (>13 kW/kg, 3x Current SOA) MW-class Machines

Flight-Weight Power Converters

GE SiC-based Inverter



UIUC GaN-based Inverter

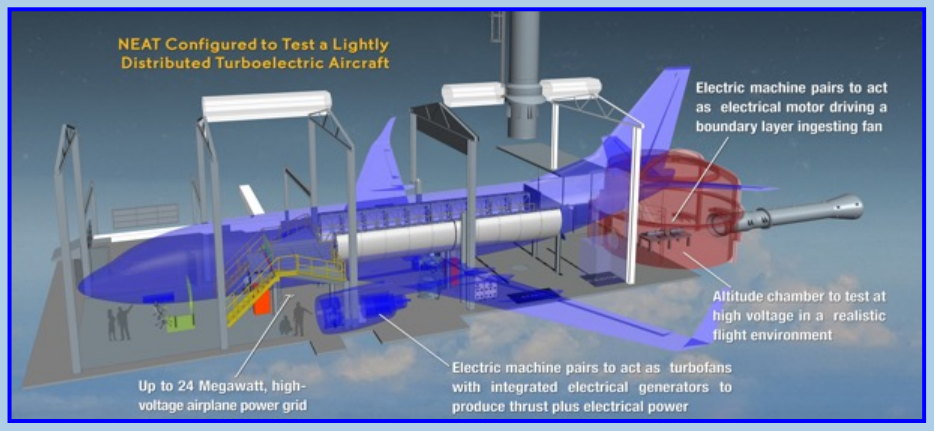


Boeing/UTK Cryo Inverter

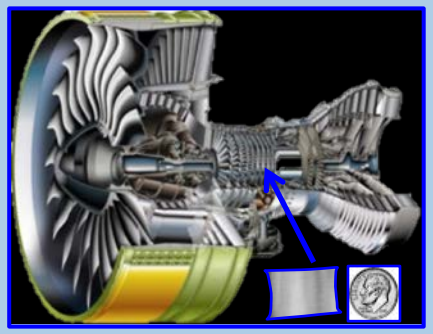
MW-class high specific power and efficiency converters, 19 kW/Kg, 99% (non-cryo); 26 kW/Kg, 99.3% (cryo)

NASA Electric Aircraft Testbed (NEAT) Facility

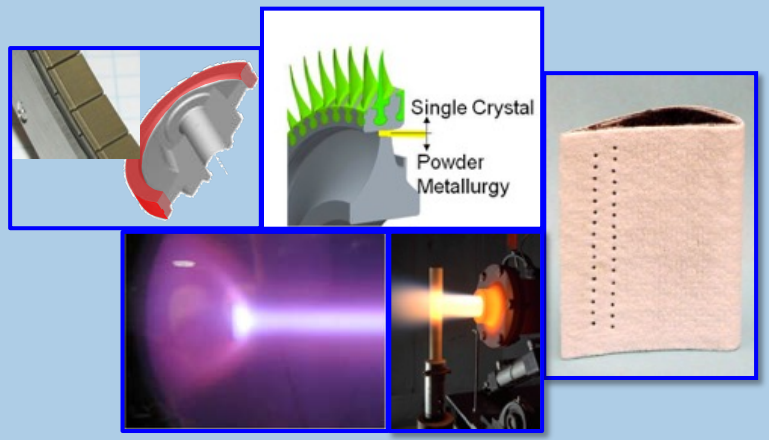
- Reconfigurable testbed for full-scale large aircraft powertrain testing
- 24 MW input power, cryogenic handling, multi-MW cooling, and 120K ft. altitude flight environment capability
- Demonstrated sub-scale (600VDC, 500kW power) STARC-ABL powertrain using COTS components
- Mature powertrain technologies and validate at system level including at altitude



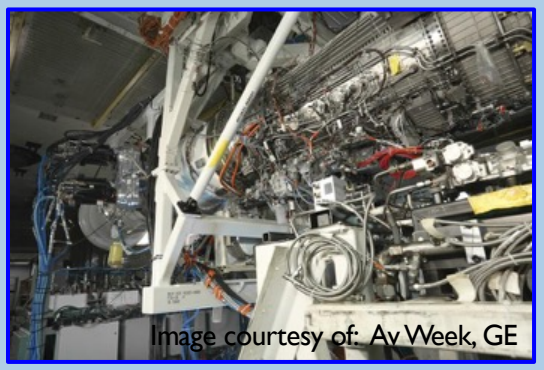
Advanced Propulsion Technologies



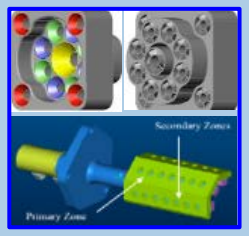
High Efficiency Compact Cores



Materials, Coatings, and Manufacturing



Dual-Spool Electrical Power Extraction



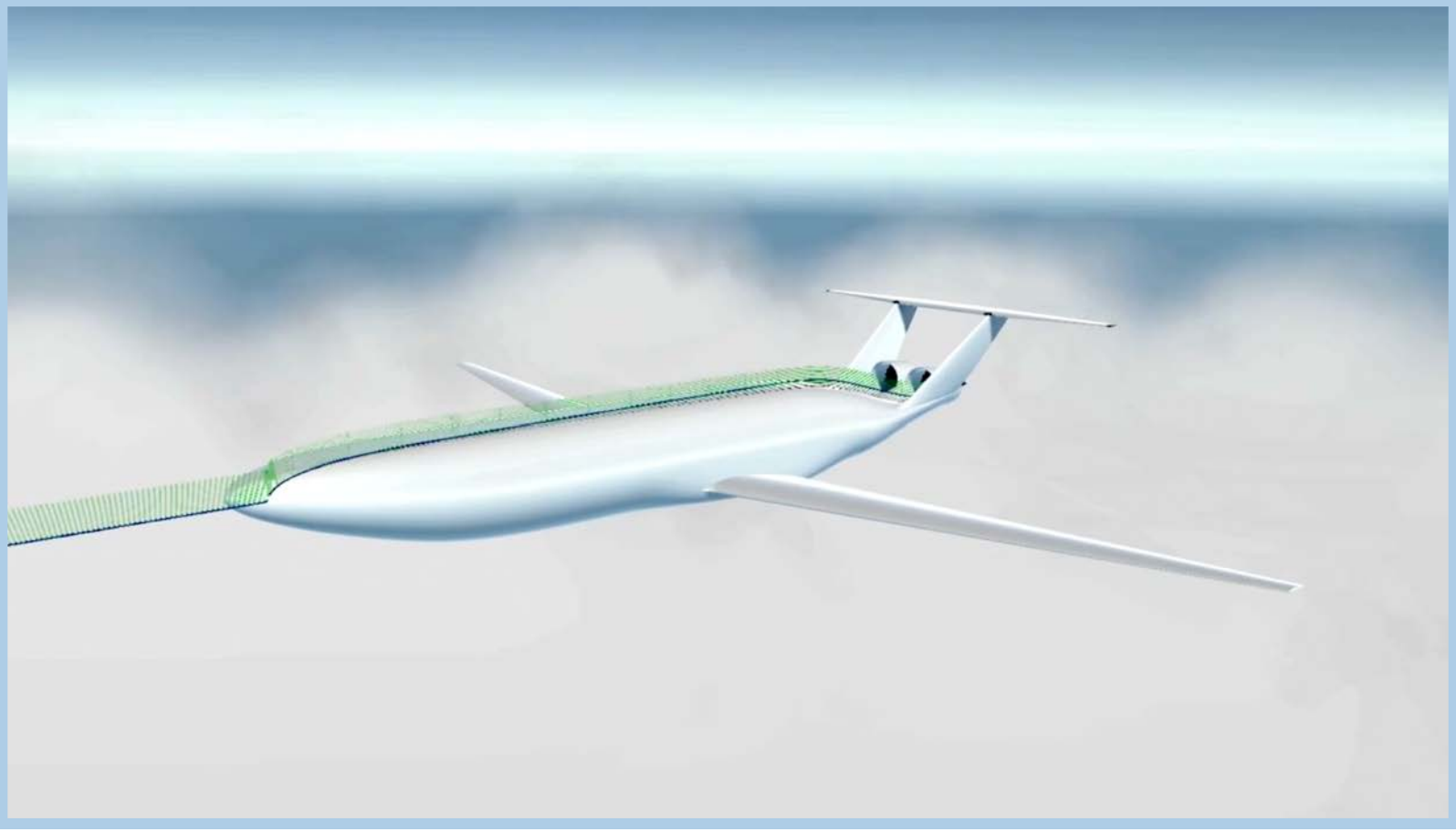
Low-NOx Fuel-Flex Combustors

Alt Fuel Emissions Characterization in Flight

Boundary Layer Ingestion

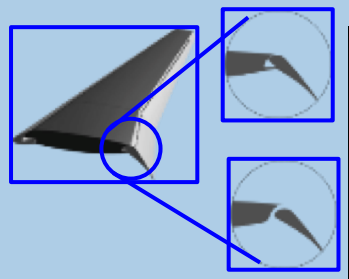
Advanced Propulsion-Airframe Integration

First-ever Transonic Test of Boundary Layer Ingesting Distortion Tolerant Fan and Integrated Inlet

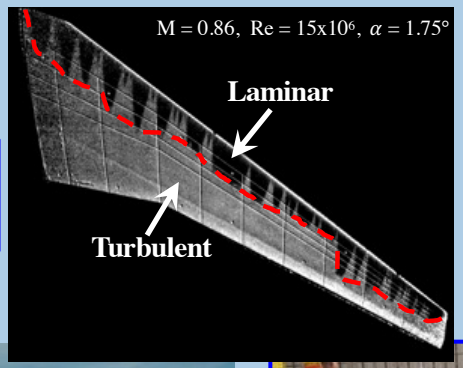


Advanced Wing and Fuselage Structures

LM Over-the-Wing Nacelle



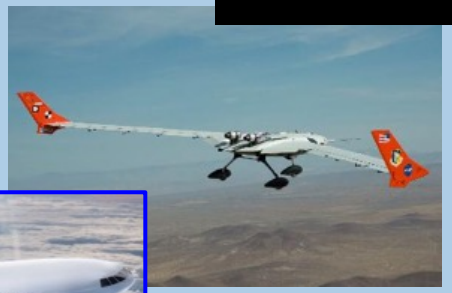
AFC-based high lift



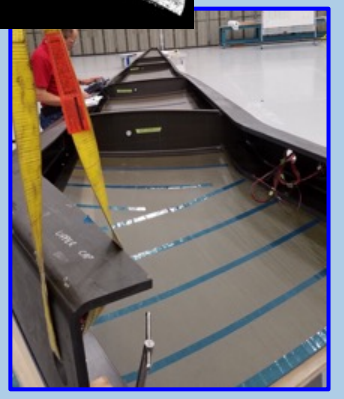
Crossflow-Attenuated Transition NLF

High-Aspect Ratio Wing

Unconventional Fuselages



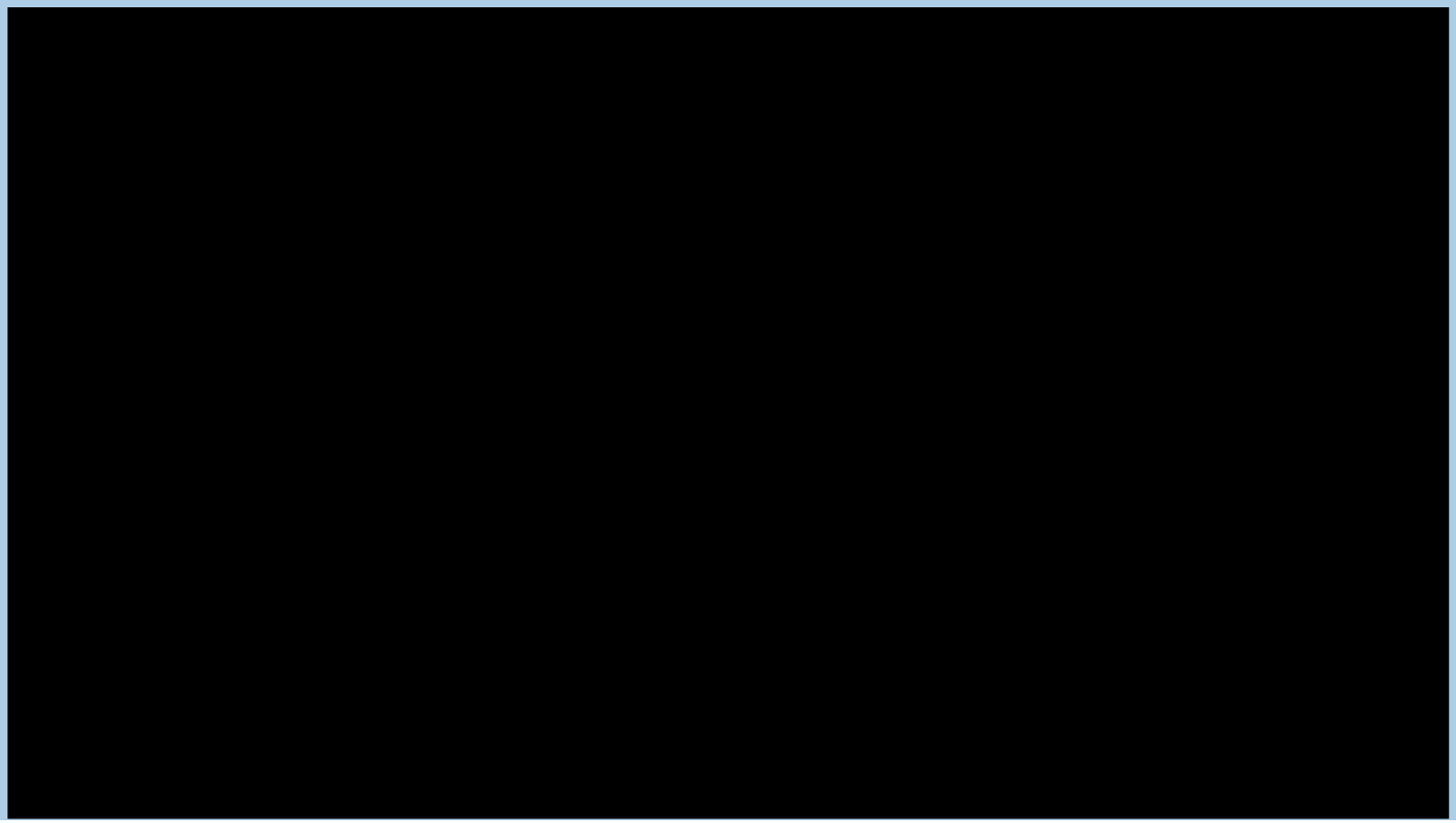
Active controls and load alleviation



Topology Optimized Wing Internal Structure

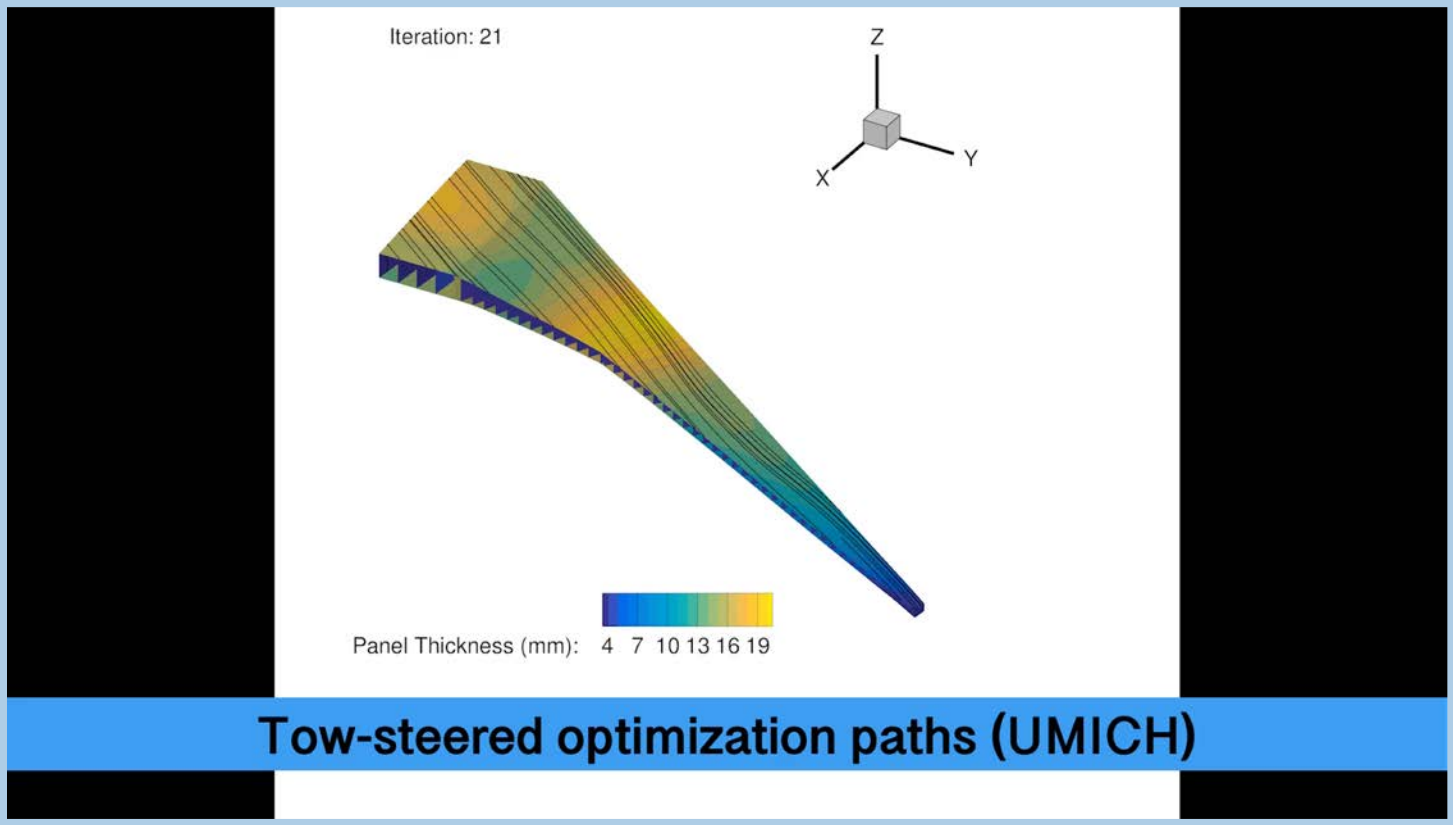
Active Flutter Suppression

X-56 Performance Adaptive Aeroelastic Wing Flight Demonstration



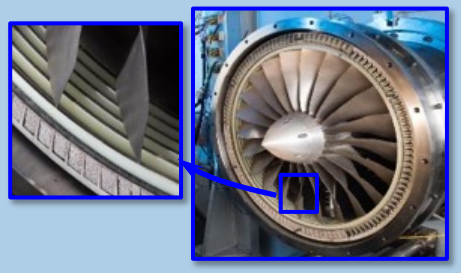
Passive Tailoring of Airframe Structures

Aurora/U of MI/NASA Demonstration of 39 ft. Tailored Composite High Aspect RatioWing



Tow-steered optimization paths (UMICH)

Acoustics Technologies



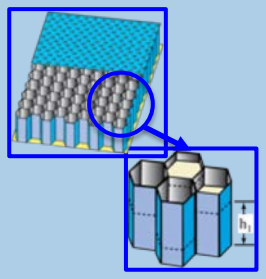
Fan Acoustic Casing Treatments

Low Pressure Ratio Fans with Short Inlets

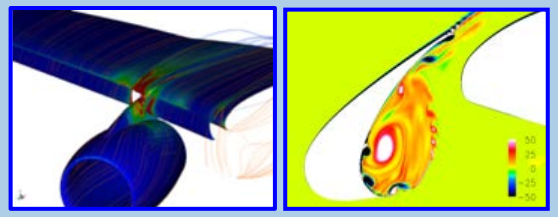
DGEN Aeropropulsion Research Turbofan (DART)

DART Core Noise Characterization

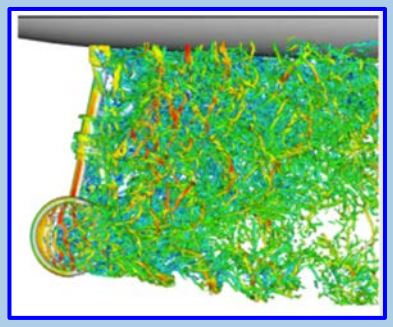
Novel Fan Noise Reduction Concepts



MDOF Acoustic Liners



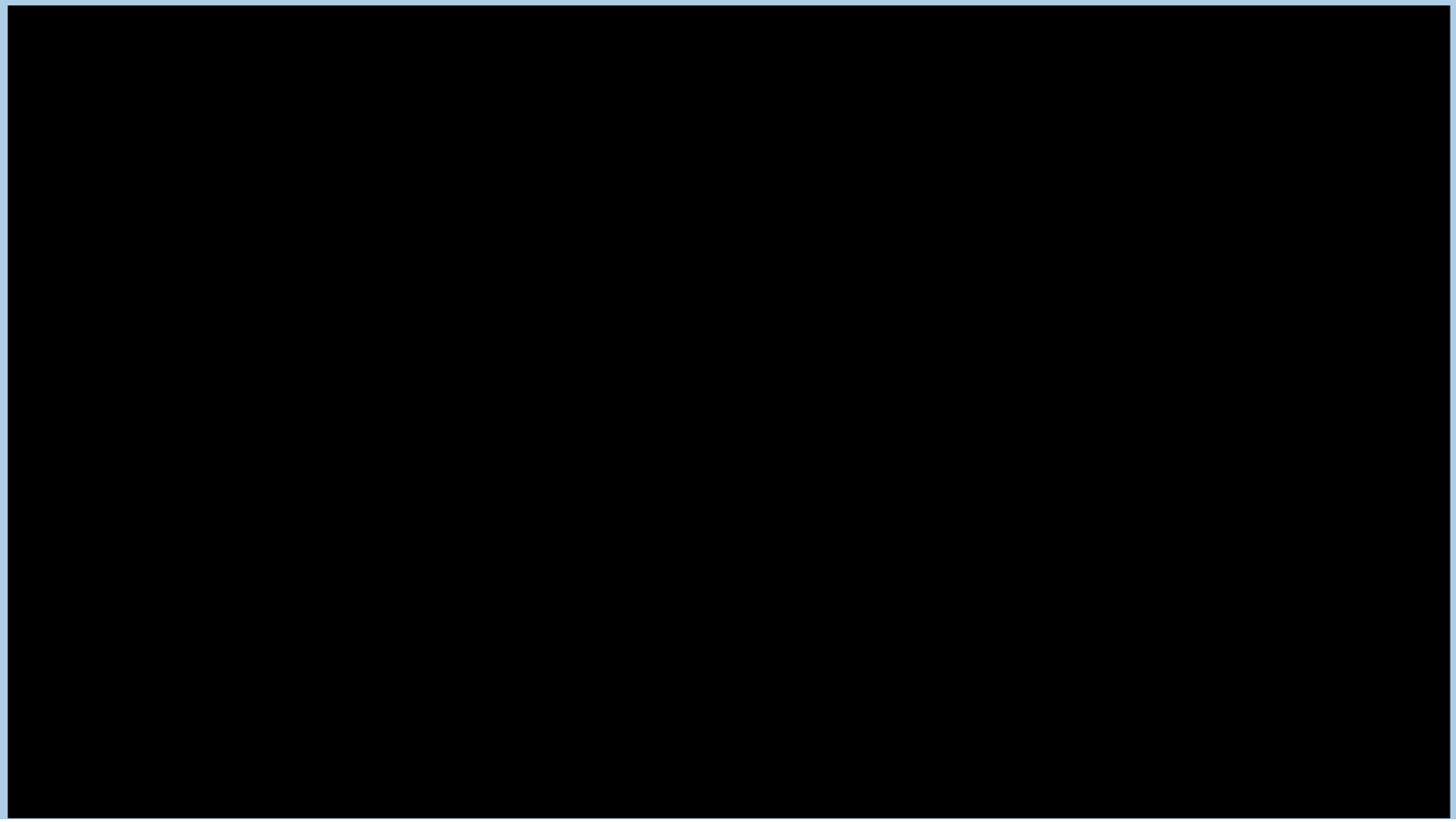
Flap/Slat Noise Reduction Concepts

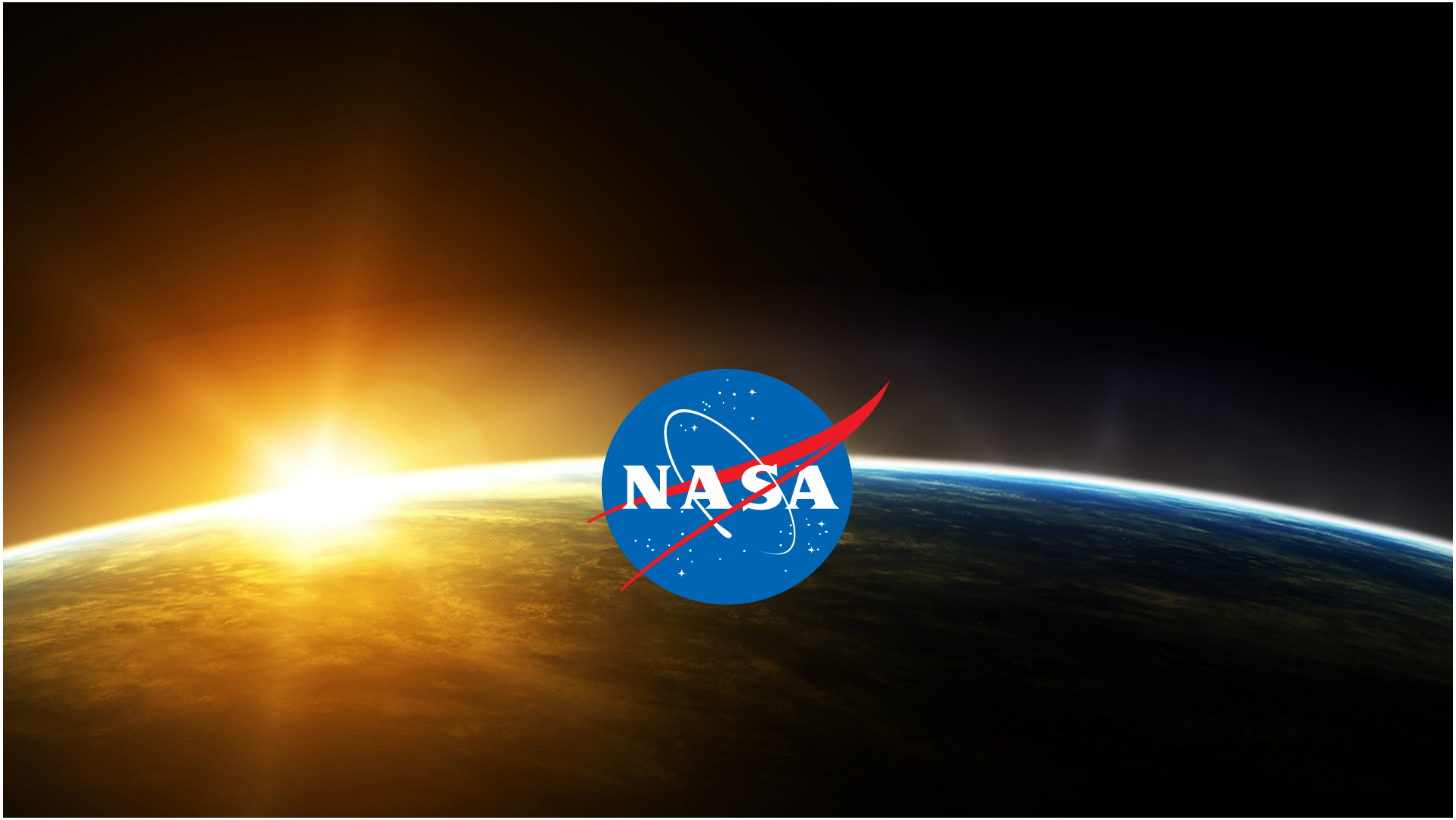


Hi Fidelity Landing Gear Noise Simulations

Acoustics Technologies

Low Drag Acoustic Liner Flight Test on 737-MAX Demonstrating 30% Liner Drag Reduction, 0.7 EPNdB Cum Noise Reduction




NASA