National Aeronautics and Space Administration

The NASA Fixed Wing Project: Green Technologies for Future Aircraft Generations

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Fixed Wing Project
NASA Fundamental Aeronautics Program

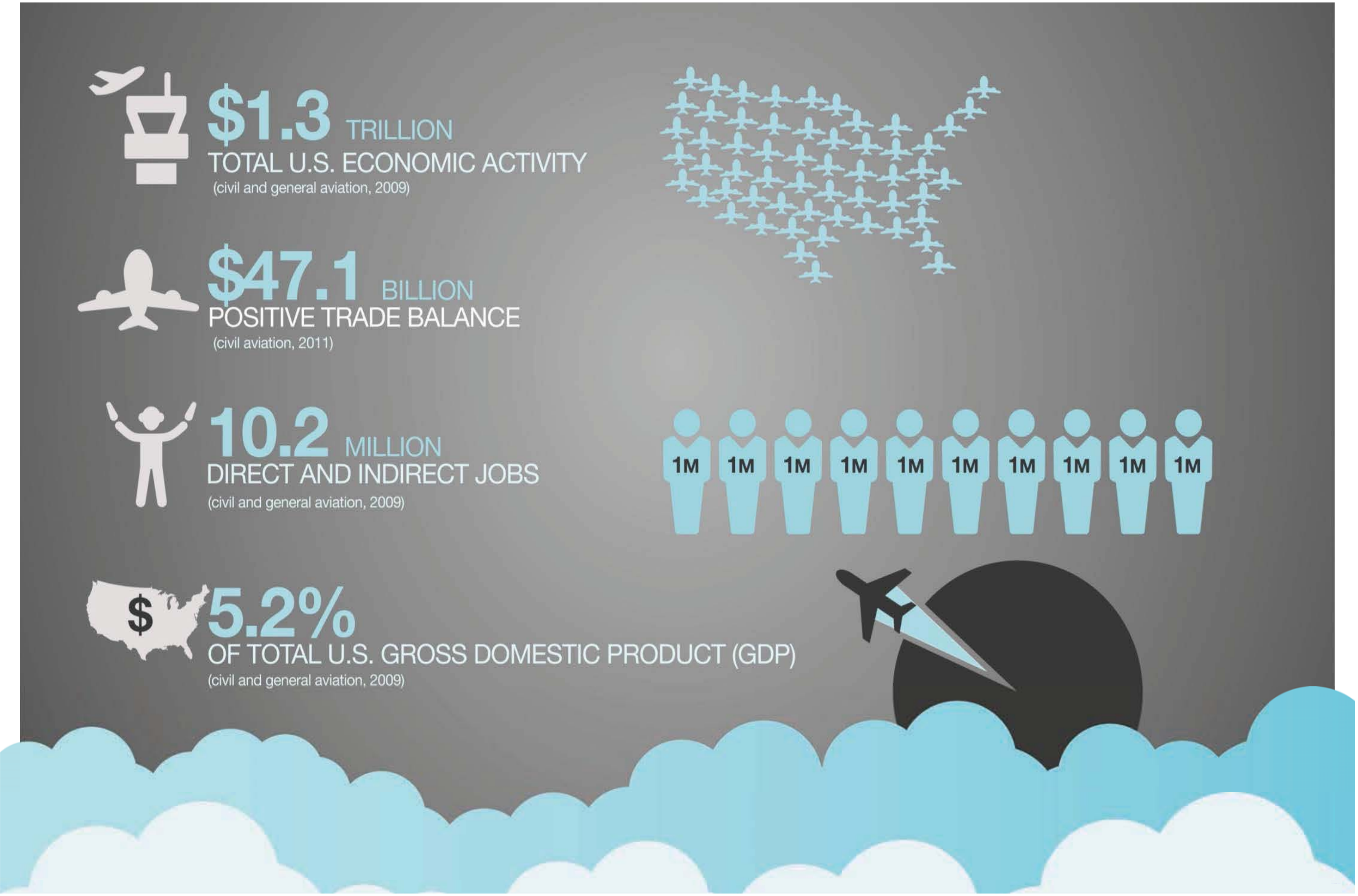
Fedden Lecture
Cranfield University, Cranfield, United Kingdom
8 July 2014

Outline of Talk

- Introduction
- Future Challenges for Commercial Aviation
- NASA Fixed Wing Project and Subsonic Transport Metrics
- NASA Fixed Wing Project Research and Technology Portfolio Highlights
- Enabling Electric Propulsion for Large Aircraft
- Concluding Remarks

Why is aviation so important?

The air transportation system is critical to U.S. economic vitality



Energy and Environmental Impact of Aviation

U.S. commercial carriers burned 19.6B gallons of jet fuel; DoD burned an additional 4.6B (2008 data). At $3/gallon, fuel cost was $73B

More than 250 million tons of CO_2 released each year into the atmosphere in U.S.

LTO NOx emissions affect local air quality; 40 of the top 50 U.S. airports are in areas that do not meet EPA standards for local air quality

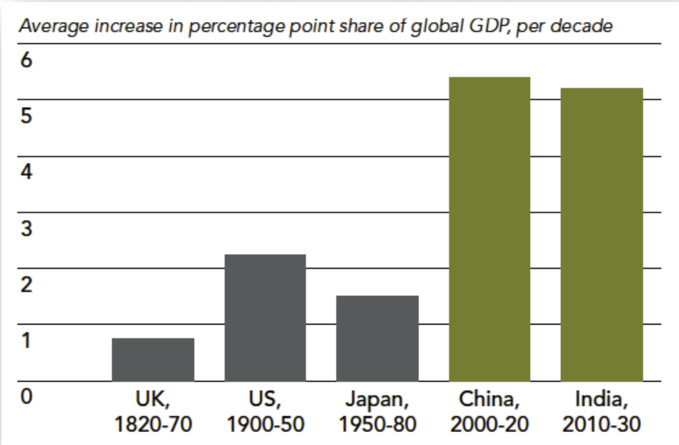
Aircraft noise continues to be regarded as the most significant hindrance to system growth

FAA has invested over $5B since 1980 in airport noise abatement programs for homes

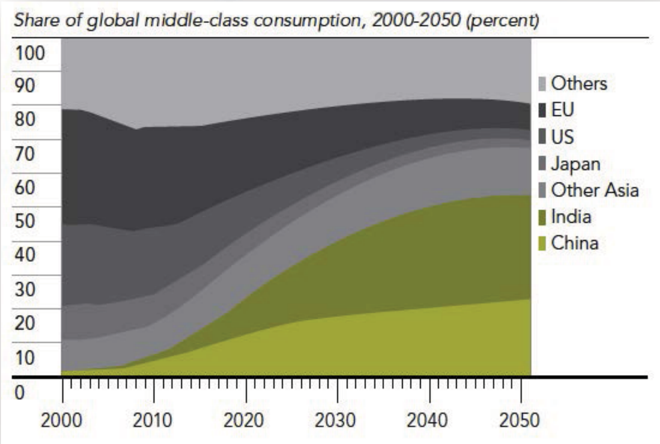
In 2007, aircraft in the U.S. spent 213 million minutes taxiing and in ground holds – delays cost industry and passengers $32.9B

Some Emerging Global Trends

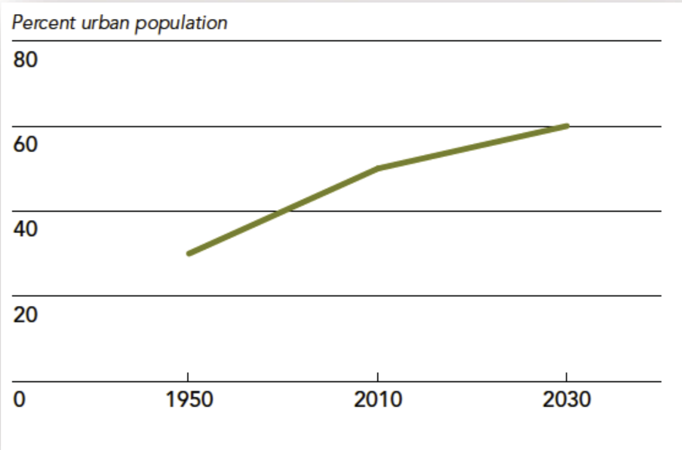
China and India growing economically at unprecedented rates



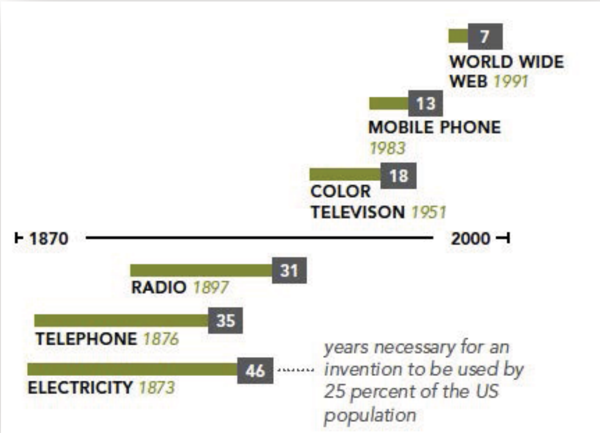
Asia-Pacific will have the largest middle class



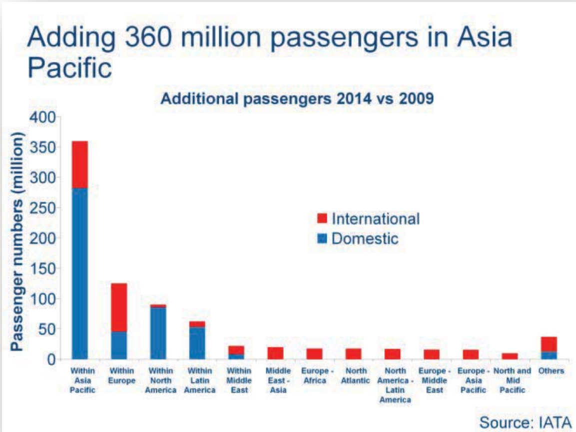
The world will be predominantly urban



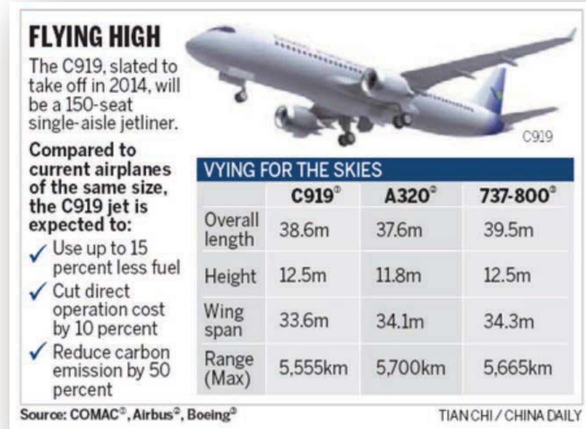
Revolutionary technology development and adoption are accelerating



Why Are These Trends Important?



They drive global demand for air travel…



FLYING HIGH

The C919, slated to take off in 2014, will be a 150-seat single-aisle jetliner.

Compared to current airplanes of the same size, the C919 jet is expected to:

- ✓ Use up to 15 percent less fuel
- ✓ Cut direct operation cost by 10 percent
- ✓ Reduce carbon emission by 50 percent

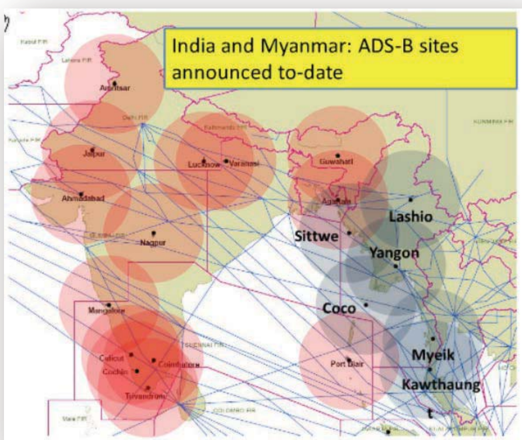
C919

VYING FOR THE SKIES

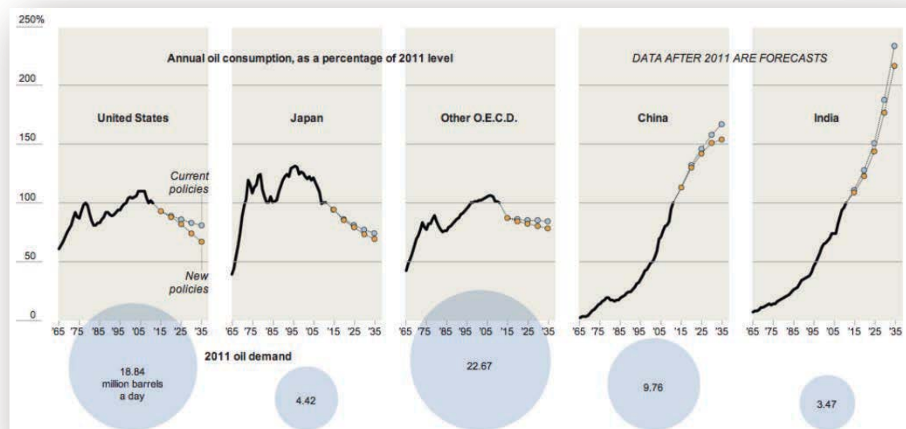
	C919[1]	A320[2]	737-800[3]
Overall length	38.6m	37.6m	39.5m
Height	12.5m	11.8m	12.5m
Wing span	33.6m	34.1m	34.3m
Range (Max)	5,555km	5,700km	5,665km

Source: COMAC[1], Airbus[2], Boeing[3] TIAN CHI / CHINA DAILY

They drive expanding competition for high-tech manufacturing…



They drive"leapfrog" adoption of new technology/infrastructure…

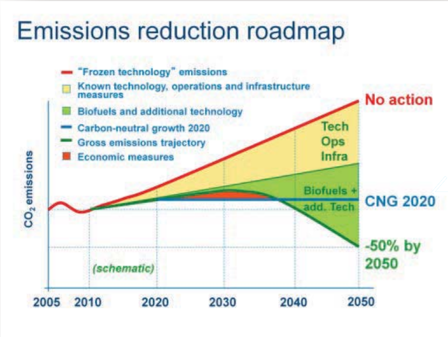


They drive resource use, costs, constraints and impacts…

How Do These Trends Affect Aviation?

Three mega-drivers emerge

Traditional measures of global demand for mobility – economic development, urbanization -- are growing rapidly

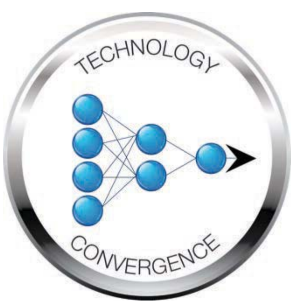


Severe energy and climate issues create enormous affordability and sustainability challenges

Revolutions in automation, information and communication technologies enable opportunity for safety critical autonomous systems

How is NASA Responding?

NASA Aeronautics research is organized around six strategic R&T thrusts



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

Innovation in Commercial Supersonic Aircraft
- Achieve a low-boom standard

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

Transition to Low-Carbon Propulsion
- Characterize drop-in alternative fuels and pioneer low-carbon propulsion technology

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

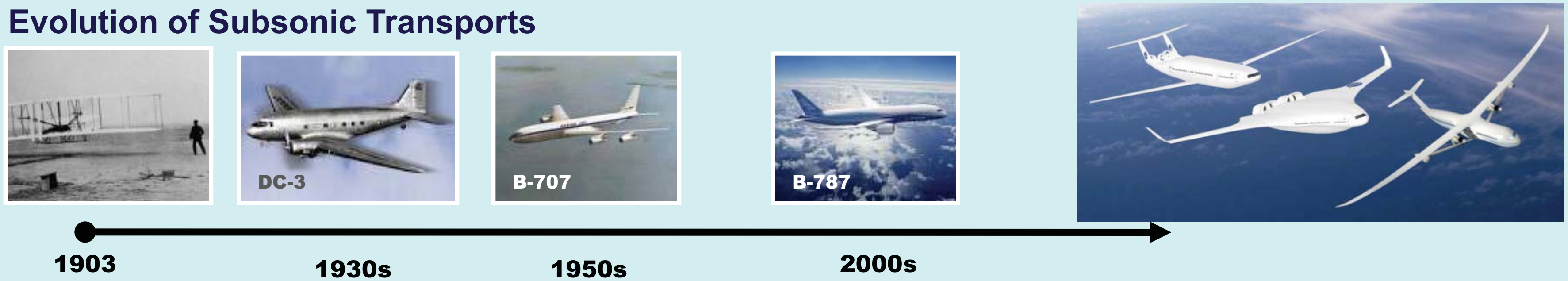
Assured Autonomy for Aviation Transformation
- Develop high impact aviation autonomy applications

The NASA Fixed Wing Project

Explore and Develop Technologies and Concepts for Improved Energy Efficiency and Environmental Compatibility for Sustained Growth of Commercial Aviation

- Early stage exploration and initial development of game-changing technologies and concepts for fixed wing vehicles and propulsion systems
- Commercial focus, but dual use with military
- Along with Environmentally Responsible Aviation (ERA) project focused on subsonic commercial transport vehicles
- Research vision guided by vehicle performance metrics developed for reducing noise, emissions, and fuel burn

Evolution of Subsonic Transports

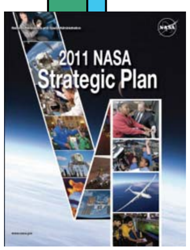


NASA Subsonic Transport System Level Metrics

Strategic Thrusts

1. Energy Efficiency

2. Environmental Compatibility



v2013.1

TECHNOLOGY BENEFITS*	TECHNOLOGY GENERATIONS (Technology Readiness Level = 4-6)		
	N+1 (2015)	N+2 (2020**)	N+3 (2025)
Noise (cum margin rel. to Stage 4)	-32 dB	-42 dB	-52 dB
LTO NOx Emissions (rel. to CAEP 6)	-60%	-75%	-80%
Cruise NOx Emissions (rel. to 2005 best in class)	-55%	-70%	-80%
Aircraft Fuel/Energy Consumption‡ (rel. to 2005 best in class)	-33%	-50%	-60%

* Projected benefits once technologies are matured and implemented by industry. Benefits vary by vehicle size and mission. N+1 and N+3 values are referenced to a 737-800 with CFM56-7B engines, N+2 values are referenced to a 777-200 with GE90 engines

** ERA's time-phased approach includes advancing "long-pole" technologies to TRL 6 by 2015

‡ CO_2 emission benefits dependent on life-cycle CO_2e per MJ for fuel and/or energy source used

Research addressing revolutionary far-term goals with opportunities for near-term impact

N+3 Advanced Vehicle Concept Studies Summary

Advanced concept studies for commercial subsonic transport aircraft for 2030-35 Entry into Service (EIS)

Boeing, GE, GA Tech

NG, RR, Tufts, Sensis, Spirit

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GE, Cessna, GA Tech

Technology Trends:

- Tailored/multifunctional structures
- High aspect ratio/laminar/active structural control
- Highly integrated propulsion systems
- Ultra-high bypass ratio (20+ with small cores)
- Alternative fuels and emerging hybrid electric concepts
- Noise reduction by component, configuration, and operations improvements

MIT, Aurora, P&W, Aerodyne

NASA, VA Tech, GT

NASA

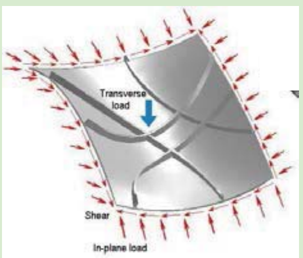
Advances required on multiple fronts…

Fixed Wing Project Research Themes

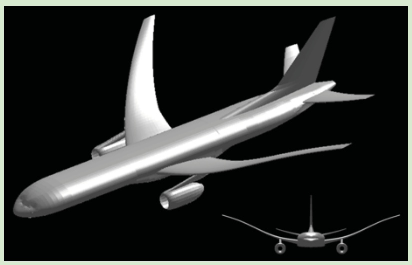
Based on Goal-Driven Advanced Concept Studies

Goals Metrics (N+3)	Noise Stage 4 – 52 dB cum	Emissions (LTO) CAEP6 – 80%	Emissions (cruise) 2005 best – 80%	Energy Consumption 2005 best – 60%

Goal-Driven Advanced Concepts (N+3)

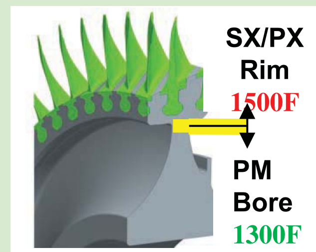


1. Lighter-Weight Lower Drag Fuselage

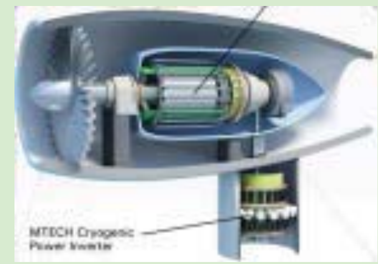


2. Higher Aspect Ratio Optimal Wing

3. Quieter Low-Speed Performance

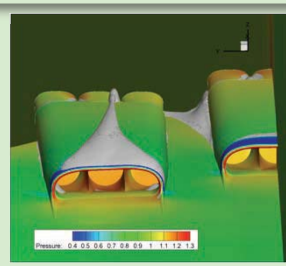


4. Cleaner, Compact Higher BPR Propulsion



5. Hybrid Gas-Electric Propulsion

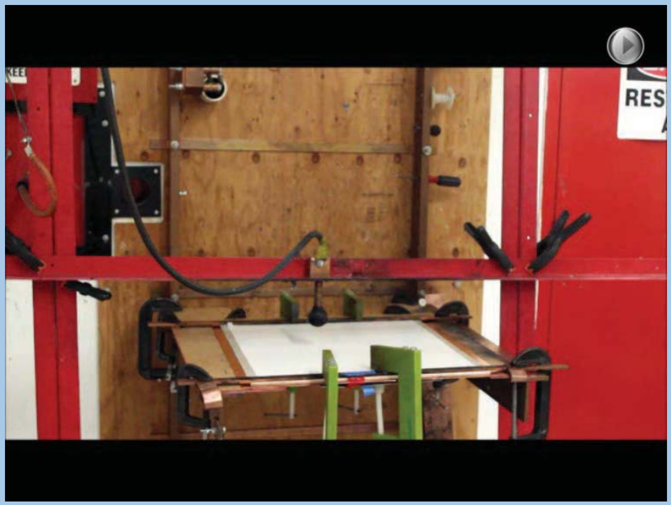
6. Unconventional Propulsion Airframe Integration

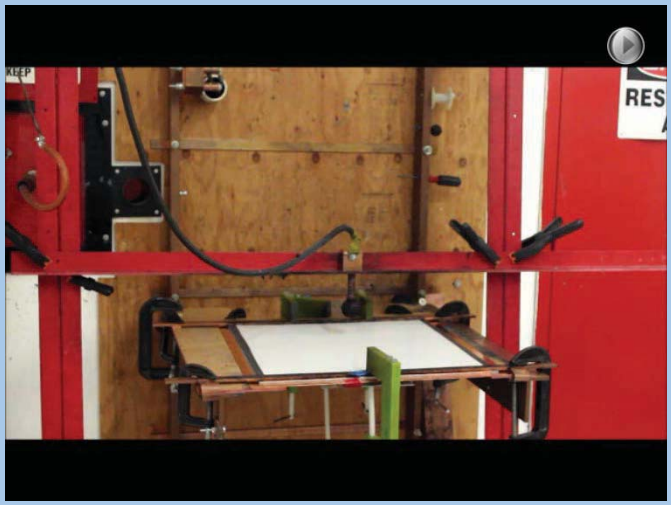


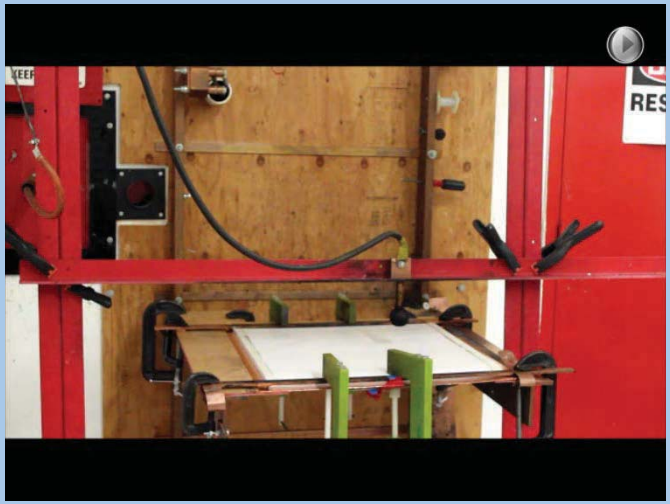
7. Alternative Fuel Emissions

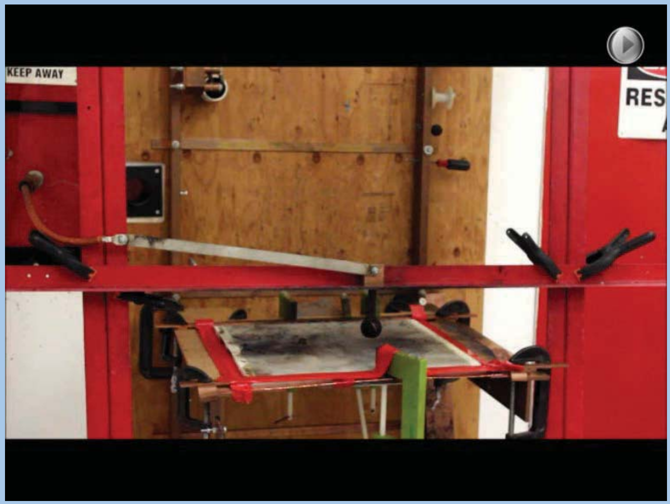
Research Themes with Investments in both Near-Term Tech Challenges and Long-Term (2030) Vision

Structural Concepts for Reduced Weight



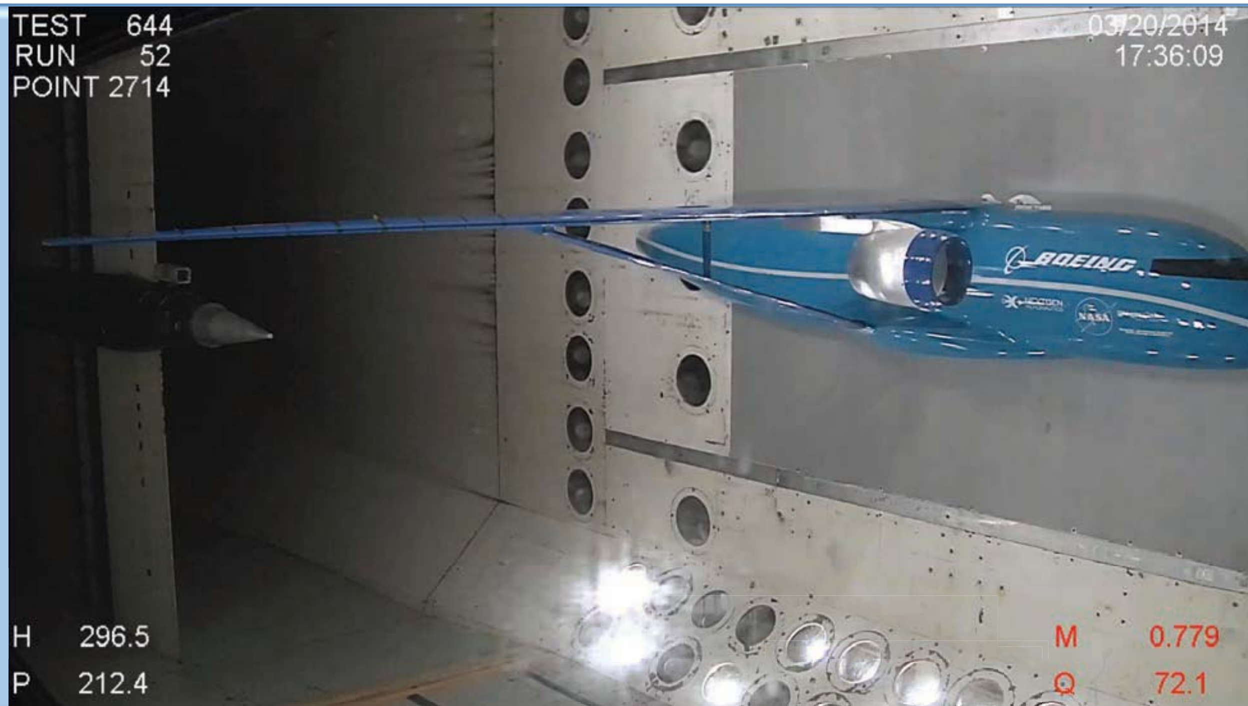






Lightning Strike Testing of STAR-C2 (Smoothing, Thermal, Absorbing, Reflective, Conductive, Cosmetic) Material

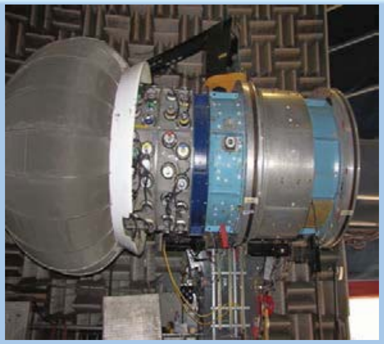
Higher Aspect Ratio Wings



Images overlaid

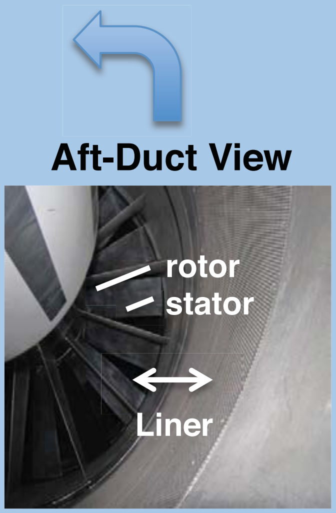
Boeing Truss-Braced Wing SUGAR Concept Testing in the NASA Transonic Dynamics Tunnel

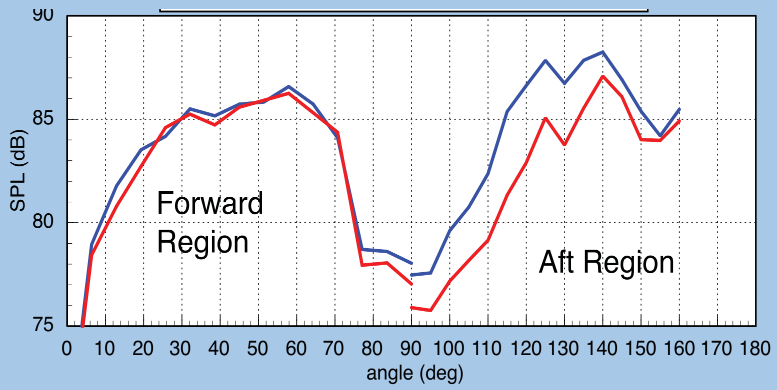
Concepts for Reduced Airframe and Fan Noise



Advanced MDOF Aft-Duct Liner installed downstream of stator.

Aft-Duct View

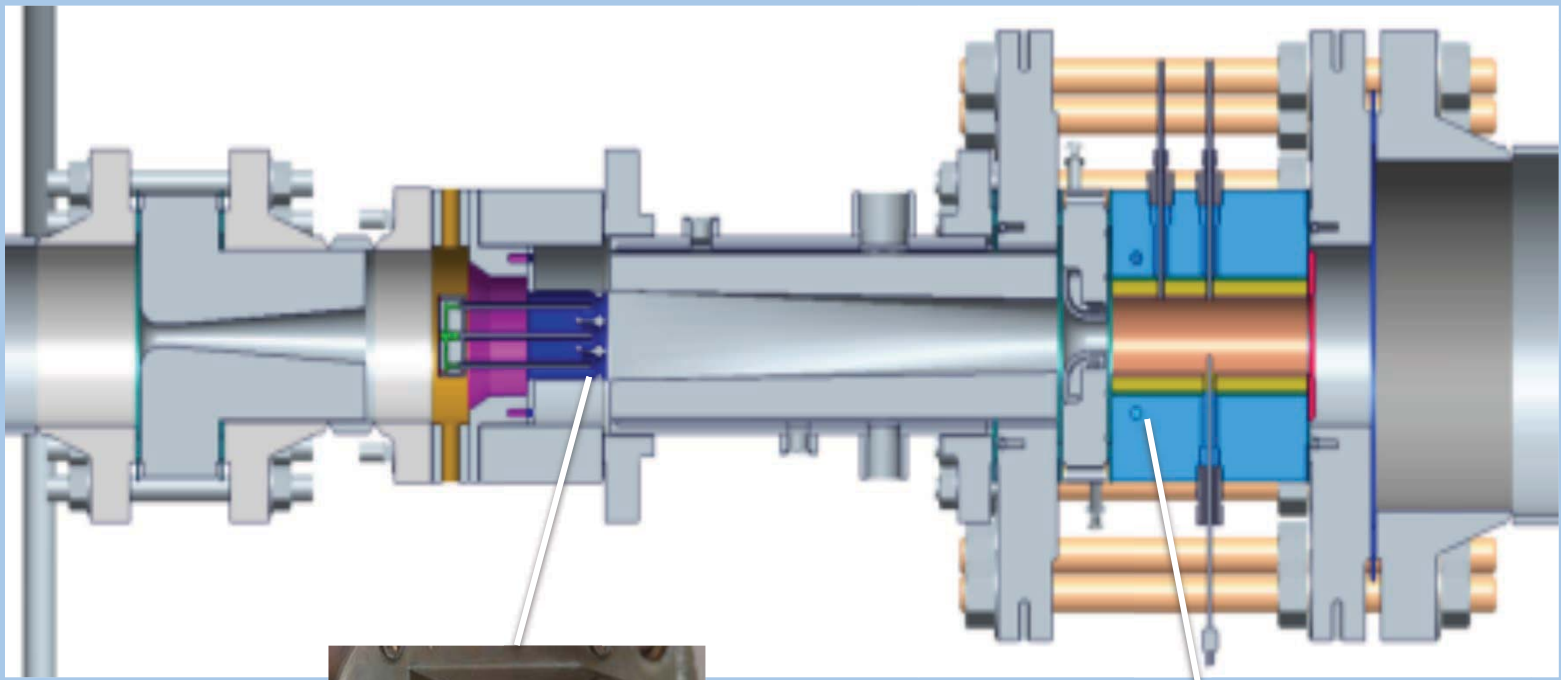


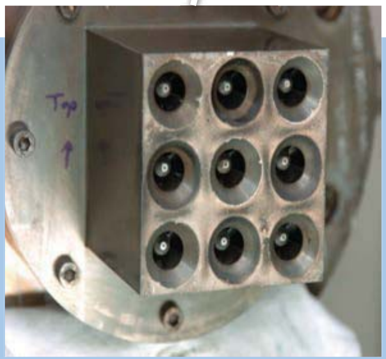


Far-field Directivity Results Broadband SPL (2.5 to 3.5 BPF) MDOF Liner (in Red) Follows Anticipated Trends in Aft Noise Reduction Compared To Hard-Wall (in blue)

Rig Tests of Advanced Multiple-Degrees of Freedom (MDOF) Acoustic Liner

Low Emissions and Low Noise Combustors



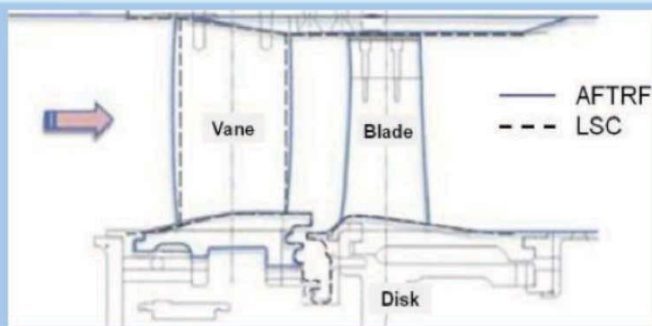


Acoustic Spool Dynamic P & T

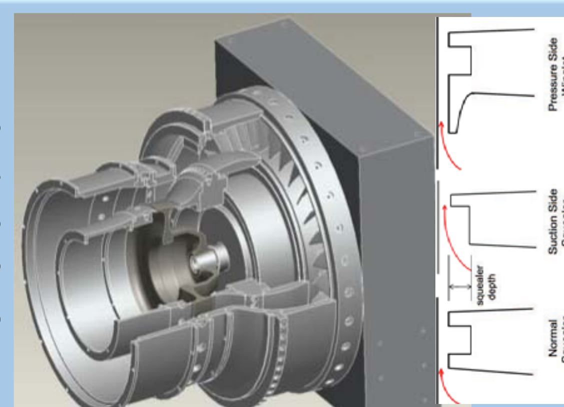
Combined Combustion Dynamics and Acoustics Testing of Low NOx Multi-Point Injector

High Pressure Ratio Small Core Gas Generators

Pratt & Whitney
Penn State U

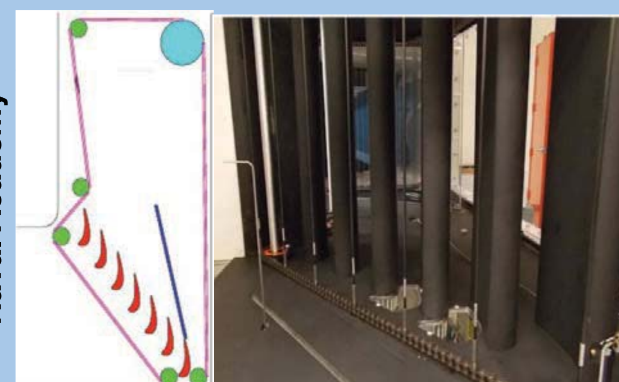


Honeywell
U Notre Dame

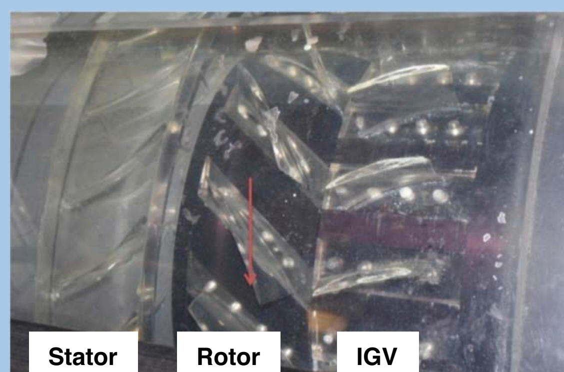


Purdue Univ

Naval Academy

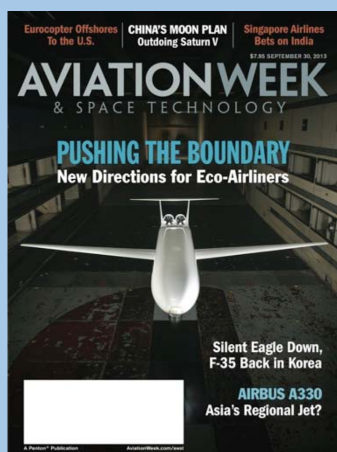


Johns Hopkins U
(optically transpaent)



Understanding and Mitigating Tip and Endwall Losses in Turbomachinery

Understanding Boundary Layer Ingesting Propulsion

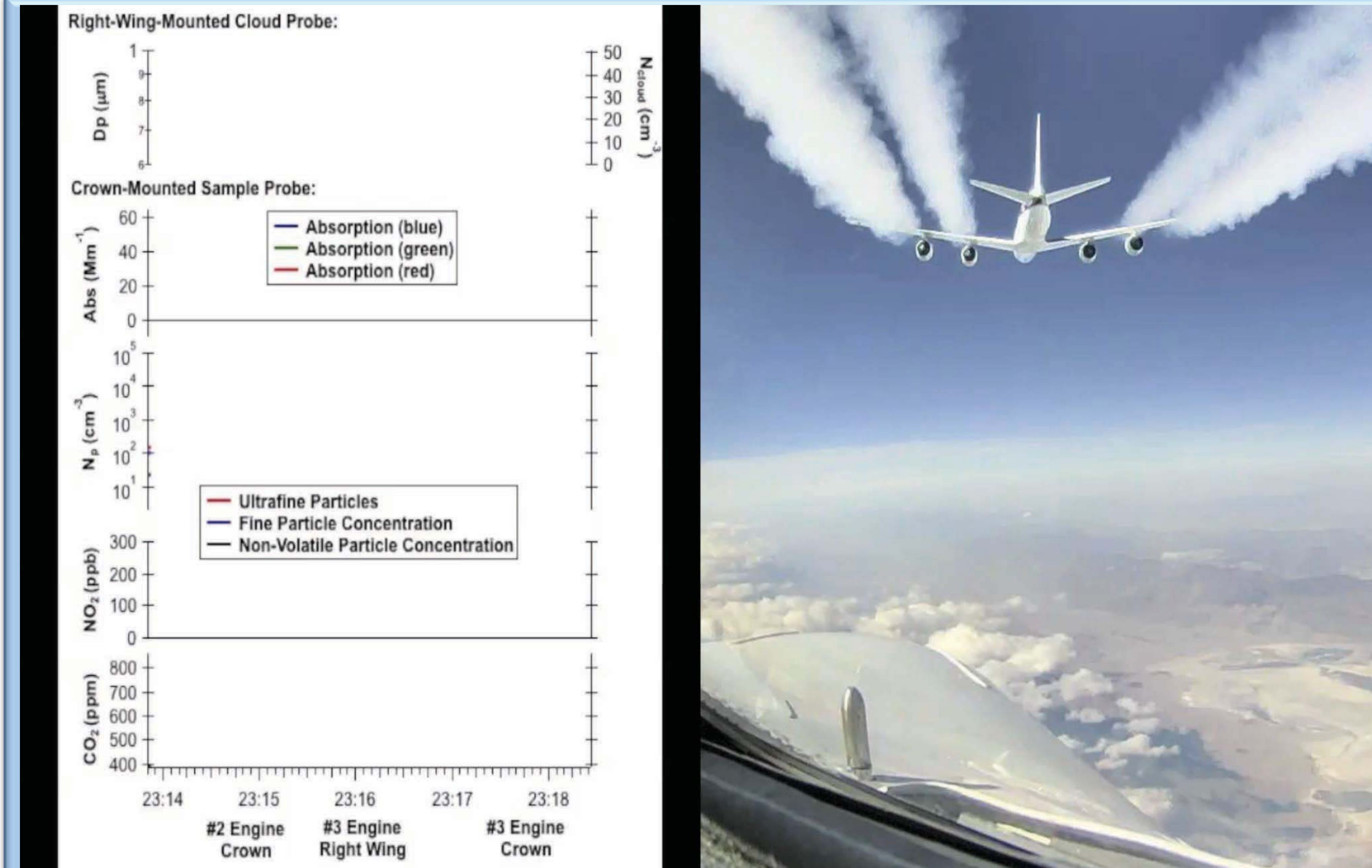


Aviation Week. Sept. 30, 2013

Direct comparison of podded and integrated configurations

Low-Speed Wind Tunnel Testing of the MIT D8 Concept

Characterizing Emissions from Alternative Fuels



Alternative Aviation Fuel Flight Experiment

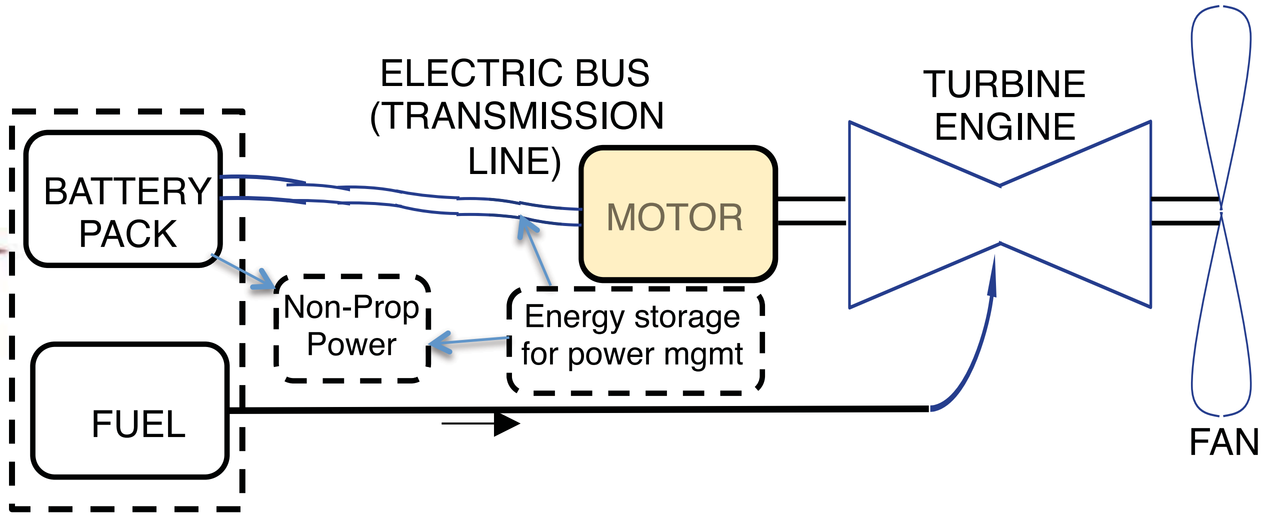
Electric Propulsion for Large Aircraft

Develop and demonstrate technologies that will revolutionize large commercial transport aircraft propulsion and accelerate development of all-electric aircraft architectures

- Why electric?
  - Less emissions (cleaner skies)
  - Less atmospheric heat release (less global warming)
  - Quieter flight (community and passenger comfort)
  - Better energy conservation (less dependence on fossil fuels)
  - More reliable systems (more efficiency, less delays)
- Considerable success in development of “all-electric” light GA aircraft and UAVs
- Creative ideas and technology advances needed to exploit full potential
- NASA can help accelerate key technologies in collaboration with OGAs, industry, and academia

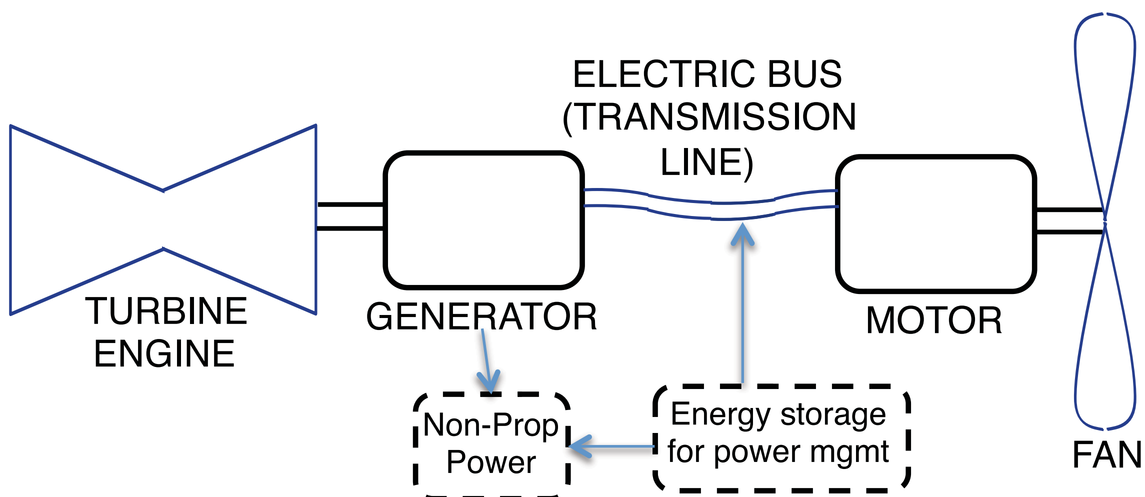
Possible Future Commercial Large Transport Aircraft

Hybrid Electric



Both concepts can use either non-cryogenic motors or cryogenic superconducting motors.

Turbo Electric



Benefits Estimated From Fixed Wing Studies

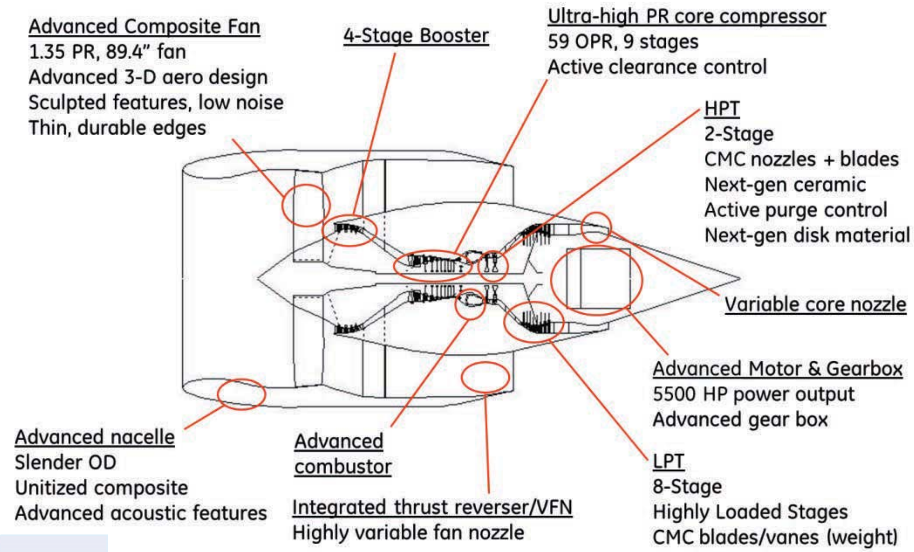
Boeing SUGAR (baseline Boeing 737, 2008 technologies)

- ~60% fuel burn reduction
- ~53% energy use reduction
- 77-87% reduction in NOx
- 24-31 EPNdB cum noise reduction

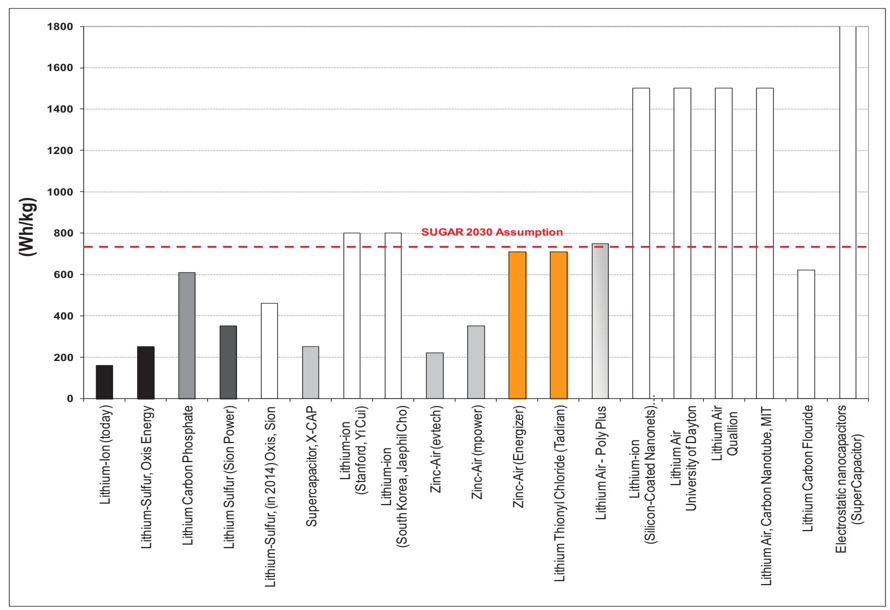
NASA N3-X (baseline Boeing 777-200)

- ~63% energy use reduction
- ~90% NOx reduction
- 32-64 EPNdB cum noise reduction

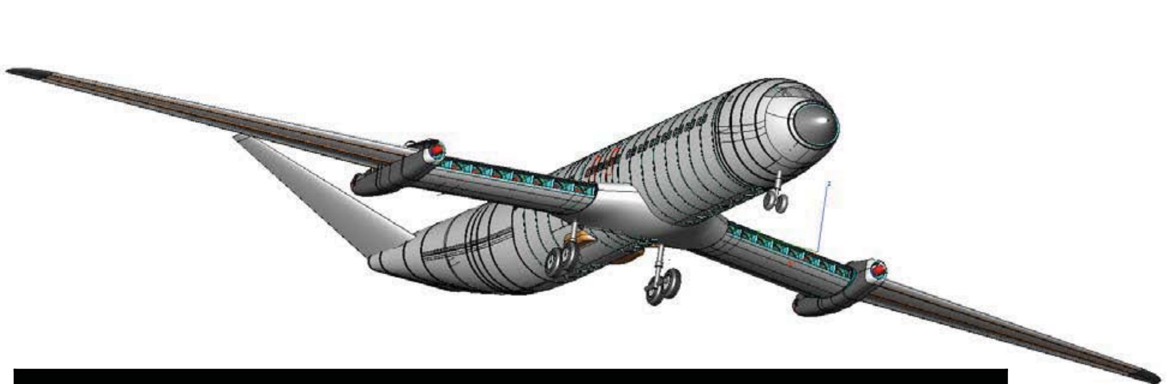
Boeing-GE "SUGAR-Volt" Hybrid Electric Propulsion

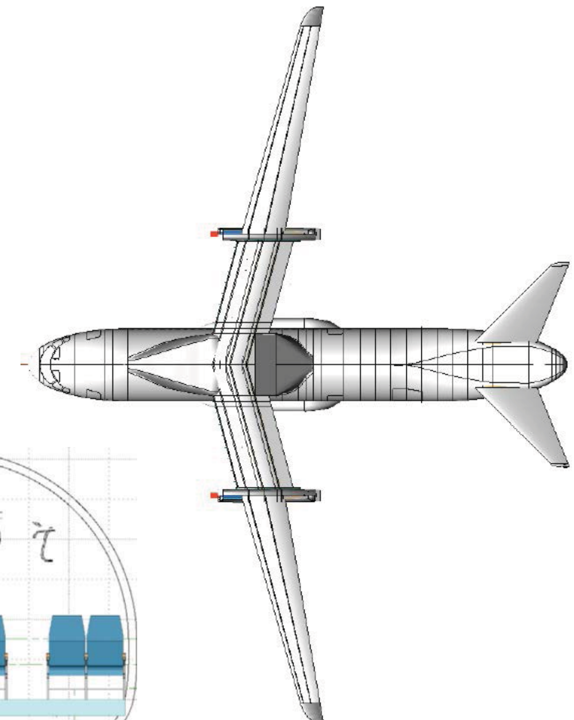


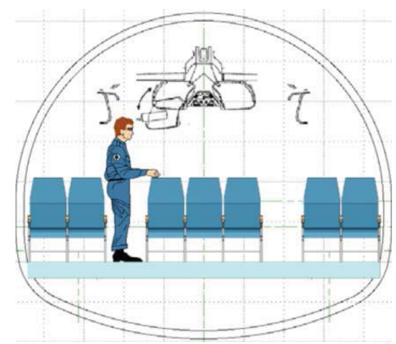
Engine	SUGAR FREE CFM56	Refined SUGAR gFan+	SUGAR Volt hFan
SLS Thrust (lbf)	27300	18800	18800
TOC Thrust (lbf)	5962	3145	4364
Cruise SFC (%)	Base	-29.7%	-49.0%
Bypass Ratio	5.1	13	13
Fan Diameter (in)	61	86	80
Propulsion Sys Wt (lbs)	5257	7096	10475
Fuel Burn (%/seat)	Base	-38.9%	-63.4%

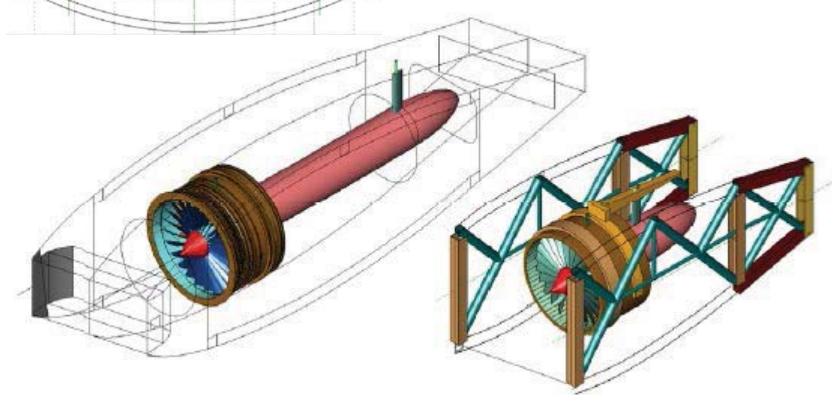


ESAero ECO-150 and Dual-Use Split-Wing Turboelectric Configuration









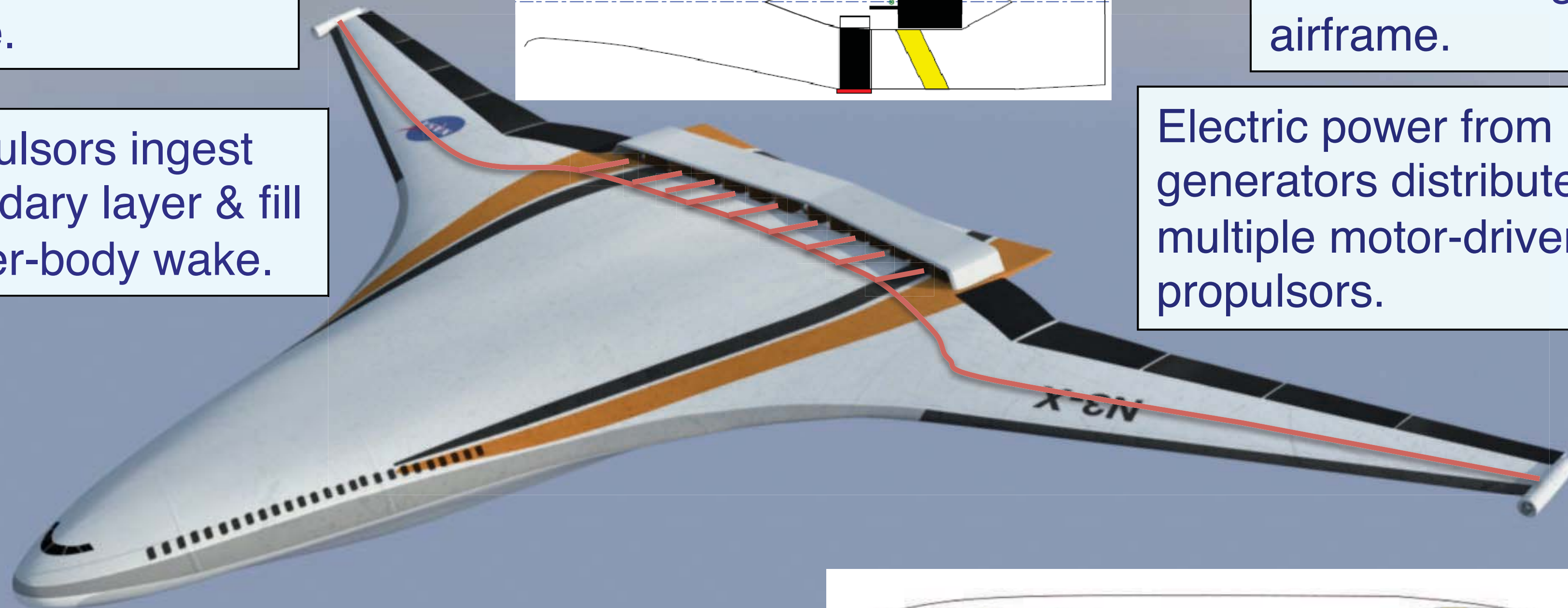
	ECO-150 (3-3)	DU-Civil (2-3-2)	737-700 (3-3)
TOGW	139,700	142,400	154,500
Propulsion Wt (“dry”)	28,350	27,820	10,430
Payload*	30,000	30,000	24,000
Fuel*	28,900	28,900	46,612
Seat-Mile/ Gal	121	118	65
Motor hp/lb	2.46	Gen hp/lb	4.30

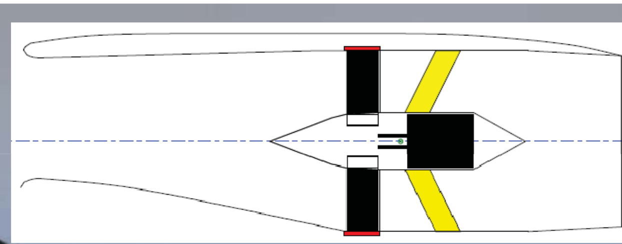
* At 3440 nm range

NASA N3X Turboelectric Distributed Propulsion

Low velocity core exhaust reduces noise.

Propulsors ingest boundary layer & fill center-body wake.

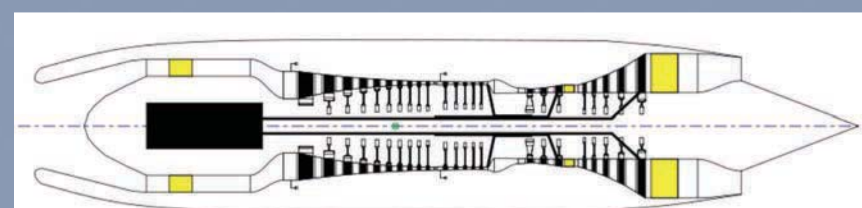




Forward and aft fan noise shielding by airframe.

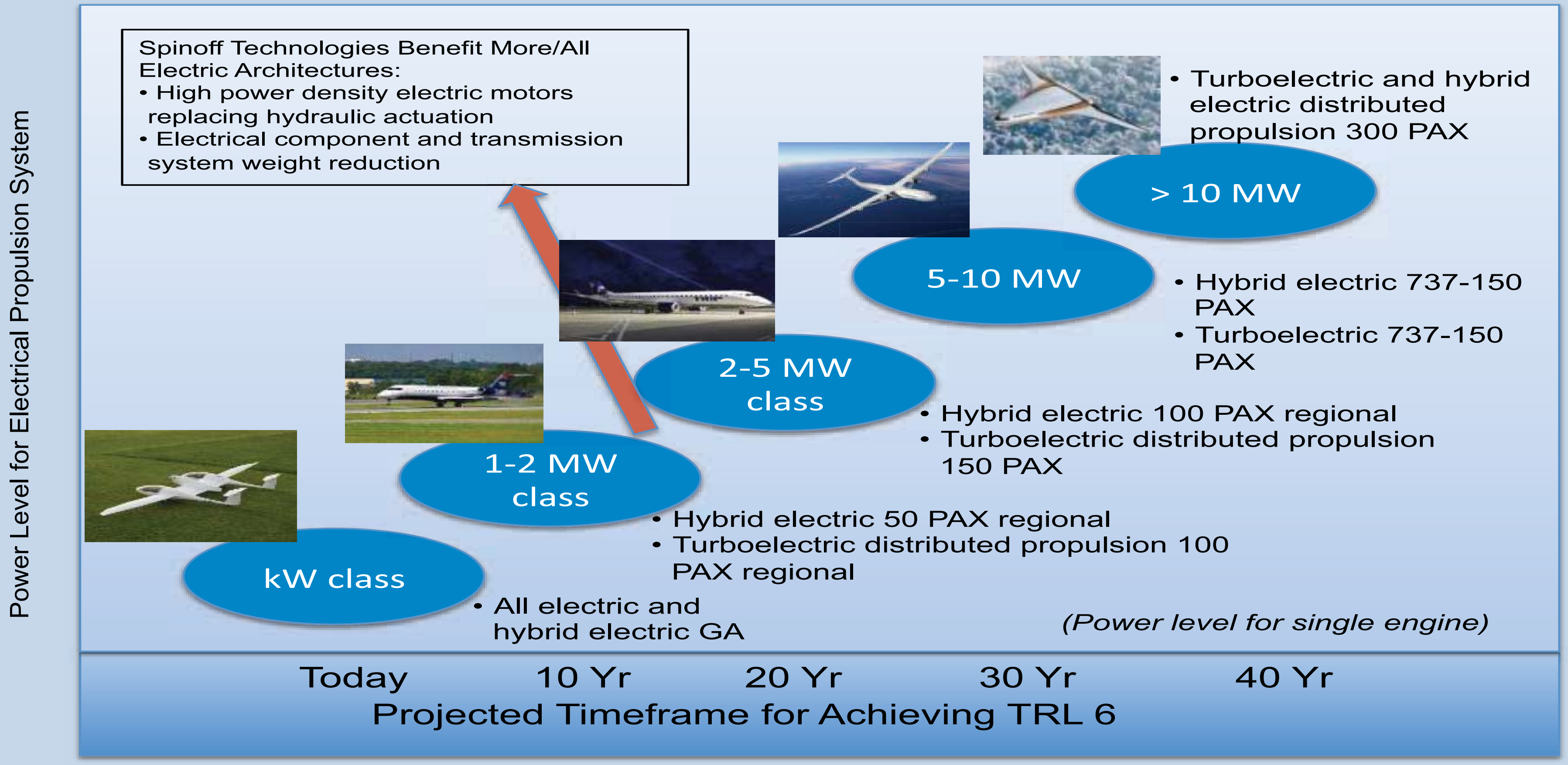
Electric power from generators distributed to multiple motor-driven propulsors.

Many small fans give a large total fan area and very high effective bypass ratio



Large efficient engines with freestream inlets drive superconducting generators.

Hybrid Electric Propulsion (HEP) Systems for Aviation



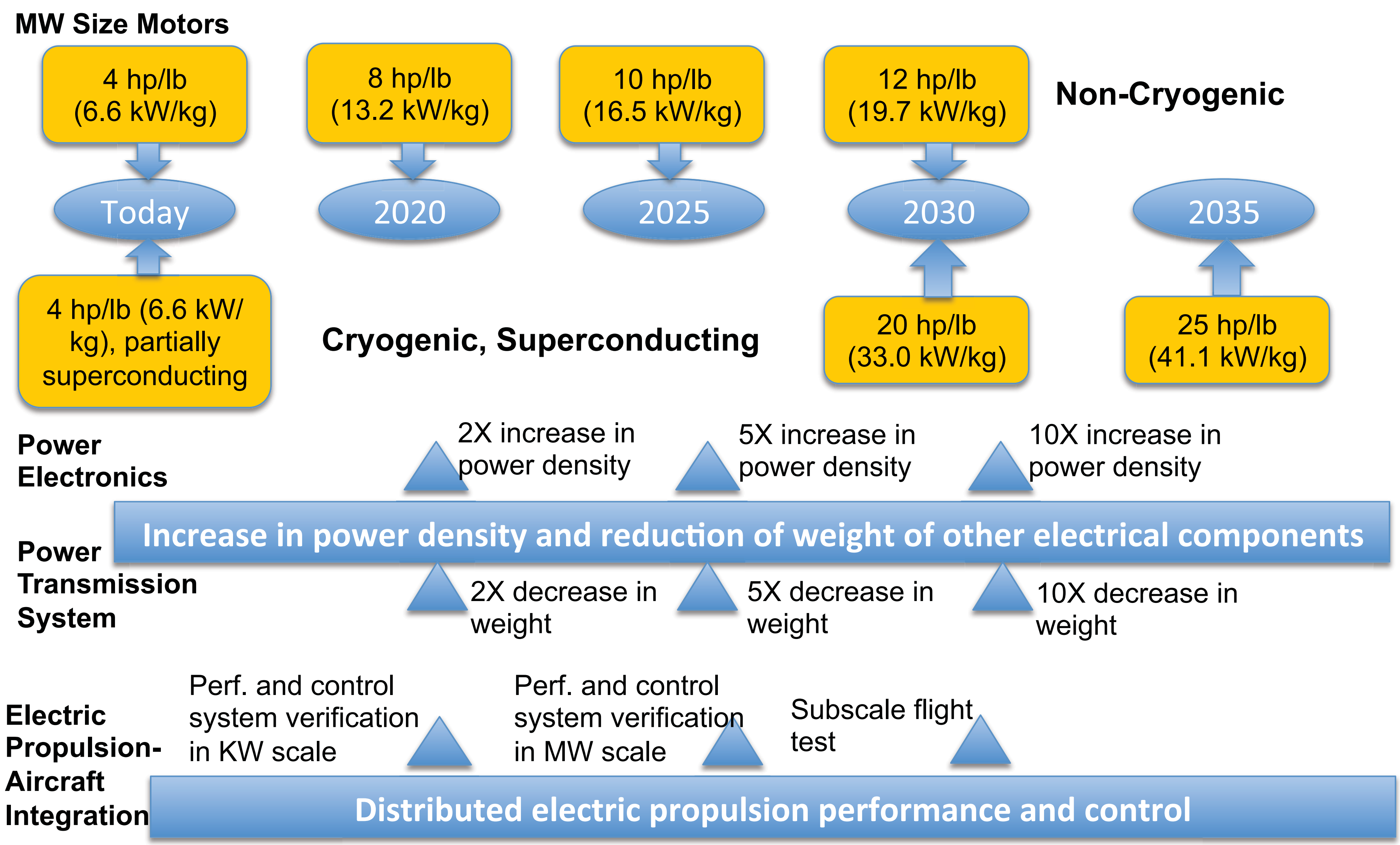
What is needed?

- Conceptual designs of aircraft and propulsion systems
- Higher power density generators and motors
- Flight-weight power system architectures and simulations
- Higher energy density energy storage systems (non-NASA)
- Extensive ground and flight testing

Progression of Electric Technology for Commercial Transport Aircraft (NASA Projection)

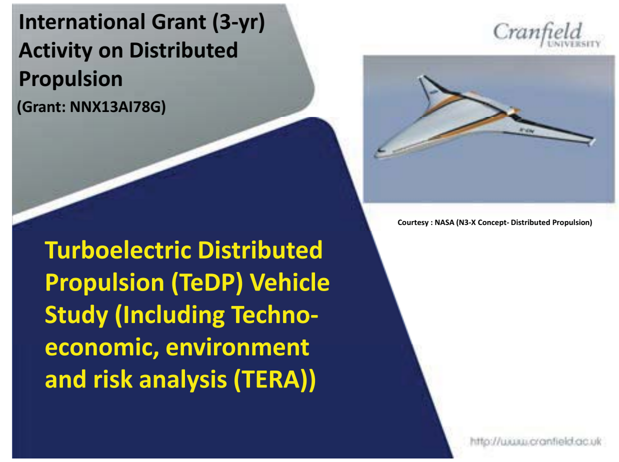
	Conventional	More Electric Architecture	All Electric Architecture	Hybrid Gas Turbine-Electric Propulsion		Electric Propulsion
				"Turboelectric Distributed" Gas Turbine Power, Decoupled Distributed Electric Propulsors	"Hybrid Electric" Gas Turbine and Electric Dual Power, Coupled Propulsor	
				Ambient Temperature or Cryogenic and Superconducting		
Propulsive Power Source	Gas Turbine	Gas Turbine	Gas Turbine	Gas Turbine + Electric	Gas Turbine + Electric	Electric
Non-Propulsive Power Source	Gas Turbine	Gas Turbine + Electric	Electric	Gas Turbine + Electric	Gas Turbine + Electric	Electric
Generation	< N	N, N+1	N+2,N+3	N+3, N+4		> N+4
		Current industry focus is on more/all electric architectures for commercial transports		Recommended NASA Investment Target (with likely adoption of common technologies for more/all electric architecture in N+2/N+3 timeframe)		

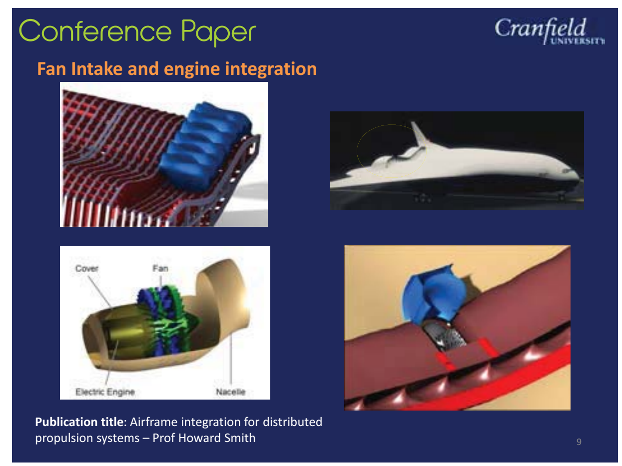
NASA HEP Technology Investment Strategy



Cranfield University
Turboelectric Distributed Propulsion Vehicle Study

- Thanks to the generosity of John Murnin, a Scottish space enthusiast, who bequeathed half of his estate to NASA.
- NASA awarded Cranfield University a grant to identify advanced TeDP vehicle configurations, and evaluate vehicle and propulsion system performance
  - Review and summarize prior distributed propulsion concepts studies
  - Investigate electric propulsion and power systems
  - Explore new and or advanced classes of TeDP
  - Techno-economic, environment and risk analysis (TERA)
- Opportunity to collaborate and jointly improve simulation and analysis capabilities for distributed propulsion concepts





Concluding Remarks

- Addressing the environmental challenges and improving the performance of subsonic aircraft
- Undertaking and solving the enduring and pervasive challenges of subsonic flight
- Understanding and assessing the game changers of the future
- Strong foundational research in partnership with industry, academia, and other Government agencies
- Exciting challenges for an industry that was deemed as being “mature”

Impact of NASA Research Over the Years

Boeing 787

NASA's work on these technologies

- Advanced composite structures
- **Chevrons**
- Laminar flow aerodynamics
- **Advanced CFD and numeric simulation tools**
- **Advanced ice protection system**

Was transferred for use here →

824 confirmed orders through August 2012

Boeing 787

Benefits →

- 20% more fuel efficient/ reduced CO_2 emissions
- 28% lower NO_x emissions
- 60% smaller noise footprint

Source: Boeing

Boeing 747-8

NASA's work on these technologies

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- **Advanced CFD and numeric simulation tools**

Was transferred for use here →

106 confirmed orders through August 2012

Boeing 747-8

Benefits →

- 16% more fuel efficient/ reduced CO_2 emissions
- 30% lower NO_x emissions
- 30% smaller noise footprint than 747-400

Source: Boeing

P&W PurePower 1000G Geared Turbofan

NASA's work on these technologies

- **Low NO_x Talon combustor**
- **Fan Aerodynamic and Acoustic Measurements**
- **Low noise, high efficiency fan design**
- **Ultra High Bypass technology**
- **Acoustics Modeling and Simulation tools**

Was transferred for use here →

Proposed for Airbus A320NEO, Bombardier C-Series, Mitsubishi Regional Jets

P&W PurePower 1000G Geared Turbofan

Benefits →

- 16% reduction in fuel burn/ reduced CO_2 emissions
- 50% reduction in No_x
- 20dB noise reduction

Source: Pratt & Whitney

CFM LEAP-1B

NASA's work on these technologies

- **Compression system aerodynamic performance advances**
- **Low NO_x TAPS II combustor**
- **Low pressure turbine blade materials**
- **High-pressure turbine shroud material**
- **Nickel-aluminide bond coat for the high pressure turbine thermal barrier coating**

Was transferred for use here →

Proposed for Airbus A320NEO, Boeing 737MAX

CFM LEAP-1B

Benefits →

- 15% reduction in fuel burn/ reduced CO_2 emissions
- 50% less NO_x
- 15dB noise reduction

Source: CFM

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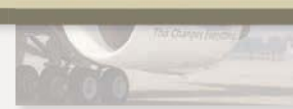
Source: Boeing

Boeing 747-8

What goes on this chart 20 to 30 years from now?

- Fan Aerodynamic and Acoustic Measurements
- Low noise, high efficiency fan design
- Ultra High Bypass technology
- Acoustics Modeling and Simulation tools

Proposed for Airbus A320NEO, Bombardier C-Series, Mitsubishi Regional Jets



P&W PurePower 1000G Geared Turbofan

reduced CO_2 emissions
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20dB noise reduction

Source: Pratt & Whitney

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NASA