Electrified Aircraft Propulsion Development

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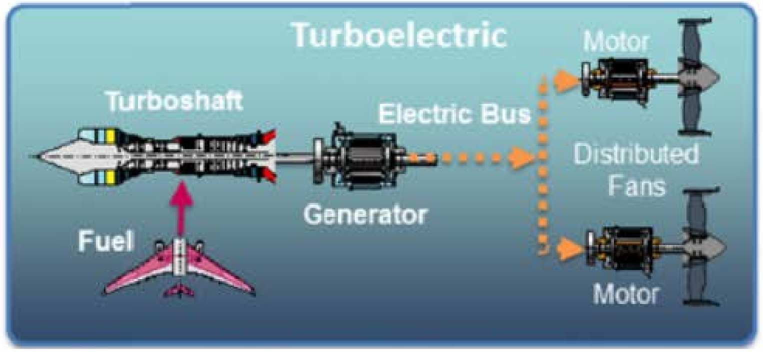
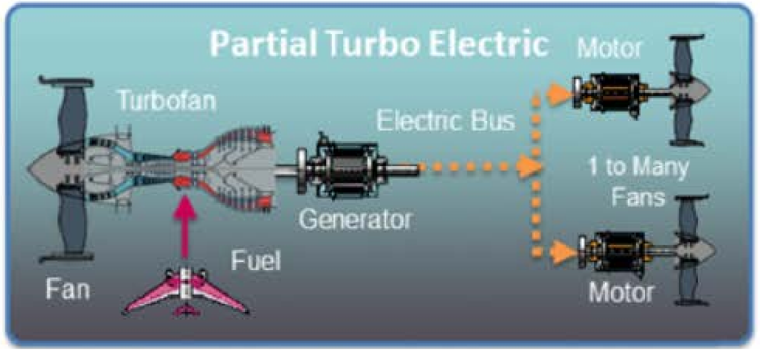
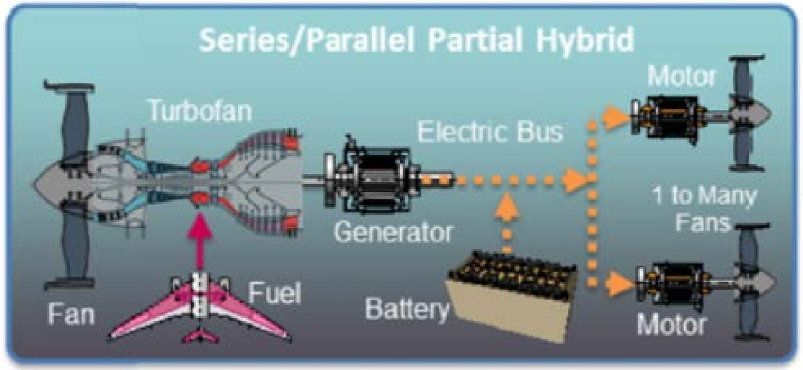
Electrified Aircraft Propulsion Concepts

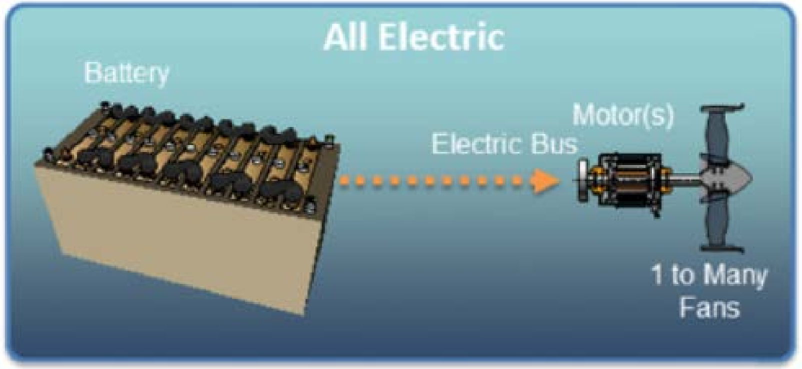
- Electrified Aircraft Propulsions systems use electrical motors to provide some or all of the thrust for an aircraft
  - Turboelectric systems use a turbine driven generator as the power source. Partially turboelectric systems split the thrust between a turbo fan and the motor driven fans





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

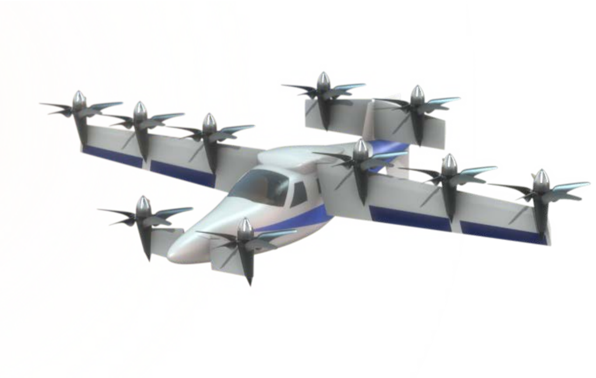




  - All Electric systems use electrical energy storage as the only power source.

Benefits of Electrified Aircraft Propulsion

- Improvements to highly optimized aircraft like single aisle transports
  - Potential fuel burn reduction estimated using turbo electric distribution to BLI thruster in addition to other benefits from improved engine cores or airframe efficiencies. Later developments could be more advanced electrical distribution and power storage.
- Enabling new configurations of VTOL aircraft
  - The ability to widely distribute electric motor driven propulsors operating from one or two battery or turbine power sources, enable new VTOL configurations with potential to transform short and medium distance mobility through 3x-4x speed improvement.
- Revitalizing the economic case for small short range aircraft services
  - The combination of battery powered aircraft with higher levels of autonomous operation to reduce pilot requirements could reduce the operating costs of small aircraft operating out of community airports resulting in economically viable regional connectivity with direct, high-speed aircraft services.


Subsonic Transport Technology Strategy

Ensuring U.S. technological leadership

Prove out transformational propulsion technologies

Prove out transformational airframe technologies

Energy usage reduced by more than

60%

Harmful emissions reduced by more than

90%

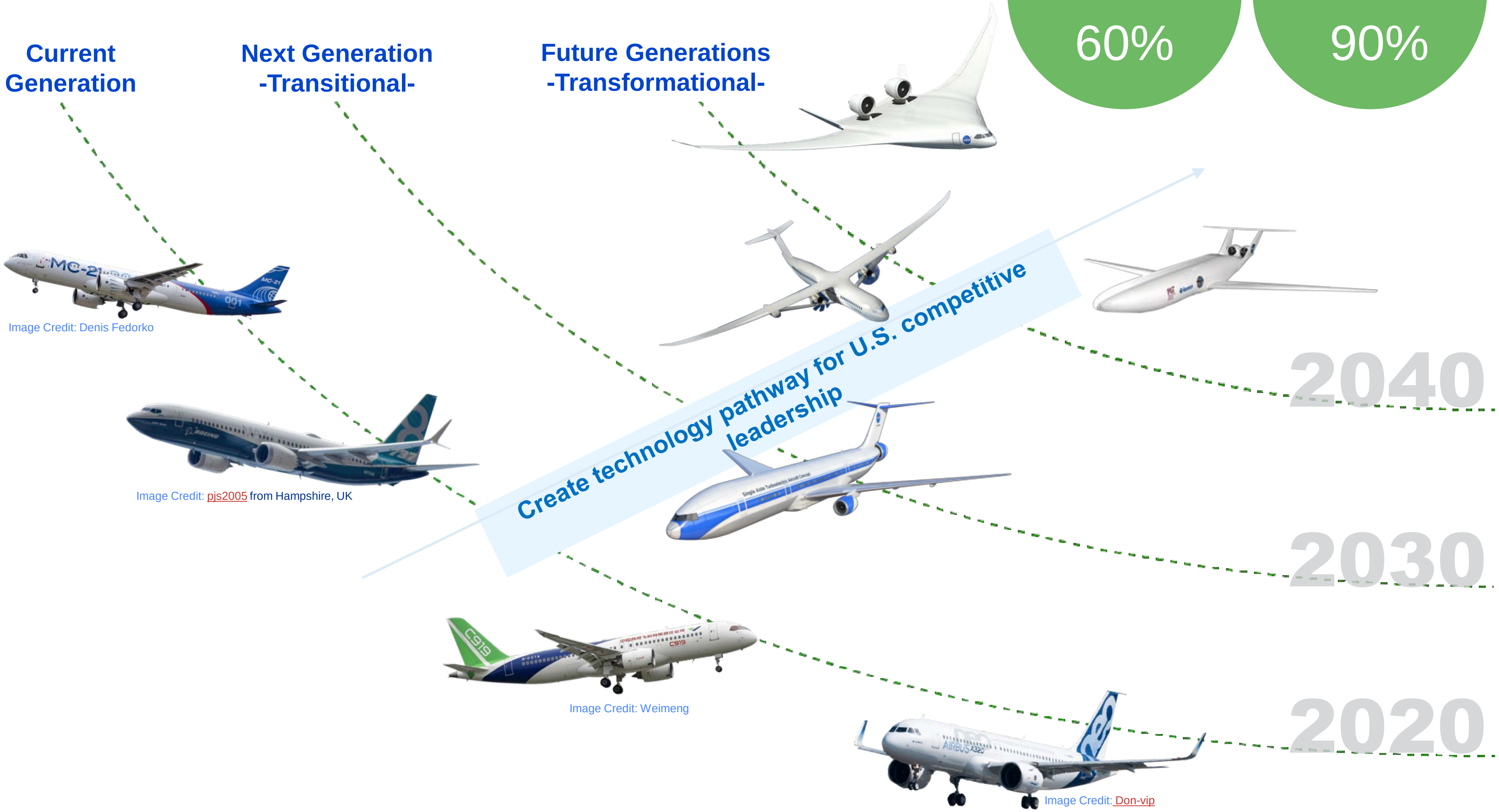
Objectionable noise reduced by more than

65%

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: Weimeng

Image Credit: Don-vip

Transforming Propulsion – A Breakthrough Opportunity

Turbo-Electric Propulsion Architecture

Boundary-Layer
Ingesting Propulsor(s)

Ultra-Efficient “Small
Core” Turbofan

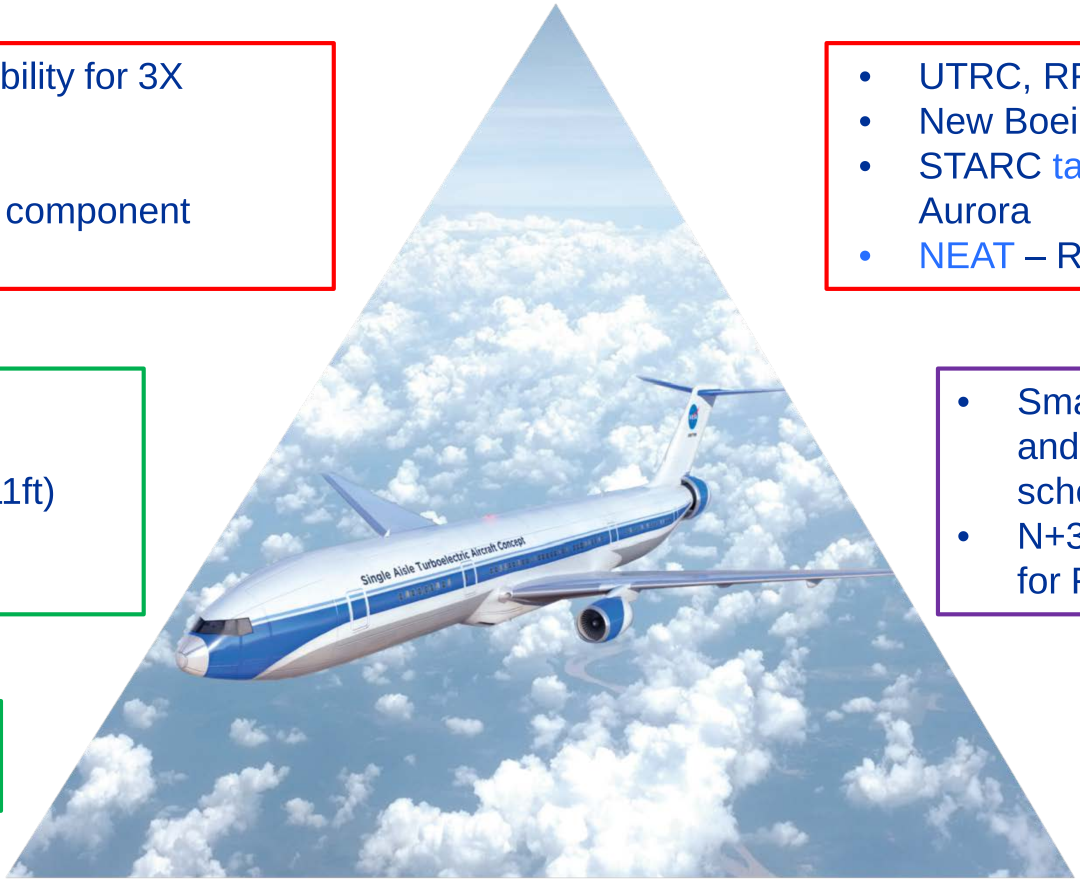
In whole or in part, transformational propulsion enables the next generation transitional subsonic transport configuration and enables future generation transformational subsonic transports

Transforming Propulsion – A Breakthrough Opportunity

Turbo-Electric Propulsion Architecture

- U of I Electric Machine showed feasibility for 3X increase in power density
- GE inverter outpacing original plans
- Customizing soft magnetic alloys for component improvements

- UTRC, RR hybrid electric studies
- New Boeing and RR 150 PAX studies
- STARC tailcone thruster series – in-house and Aurora
- NEAT – Running 1st powertrain test



- Successful completion of BLI2DTF
- Fan inlet distortion studies in W-8
- Planning test in Wind Tunnel (ARC 11ft) Tailcone BLI

- Small Core Compressor work with P&W and GE progressing well. Testing on schedule for late FY18
- N+3 Combustor test with UTRC scheduled for FY19

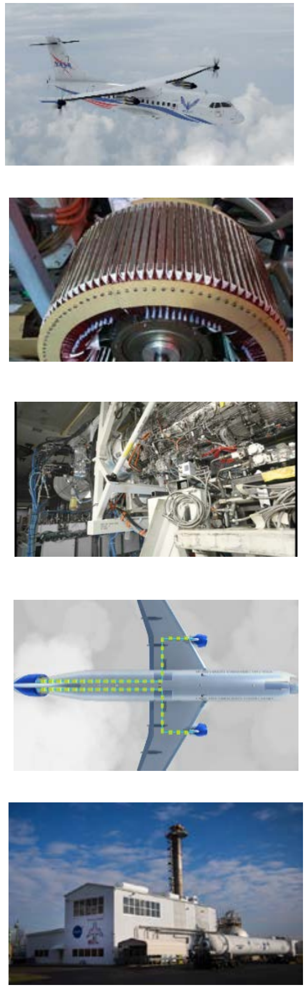
Boundary-Layer Ingesting Propulsor(s)

Ultra-Efficient "Small Core" Turbofan

In whole or in part, transformational propulsion enables the next generation transitional subsonic transport configuration and enables future generation transformational subsonic transports

Electrified Aircraft Propulsion Strategy for Commercial Transport

Initial focus on turboelectric aircraft



Concept Definition and System analysis

Novel integration and BLI

MW flightweight electrical component development

Integrated systems testing

Advanced cores with large power extraction

Flight demonstration

Impact Regional Market and Single Aisle Class by 2030s

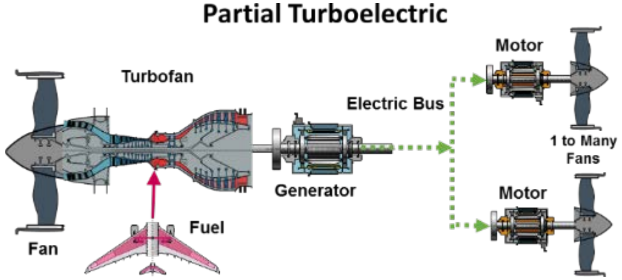
Hybrid electric option to be considered with advances in battery technology

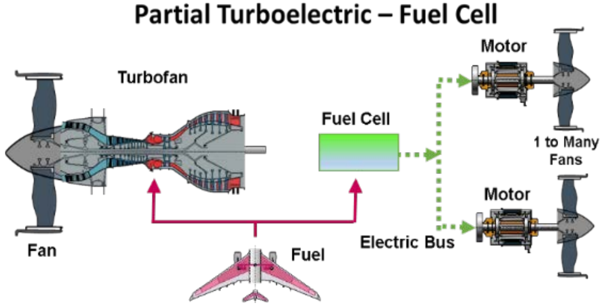
Studies Targeting Regional Jets and Single Aisle Markets

- Partially and Fully Distributed Turboelectric Concepts

NASA STARC - ABL

Boeing/NASA SUGAR - FREEZE

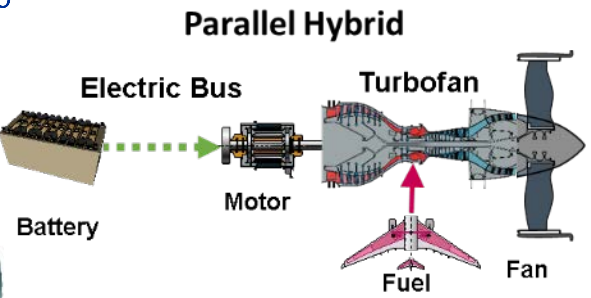




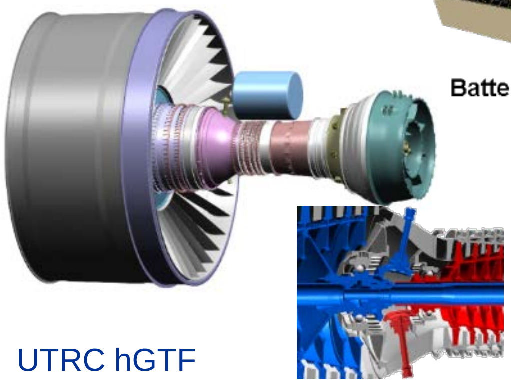
NASA N3-X

ECO-150

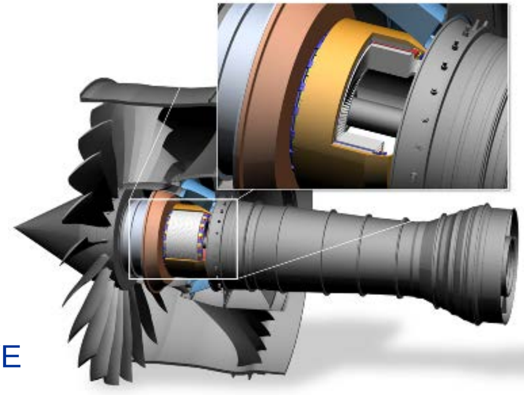
- Parallel Hybrid Concepts



Boeing/NASA SUGAR - VOLT



UTRC hGTF



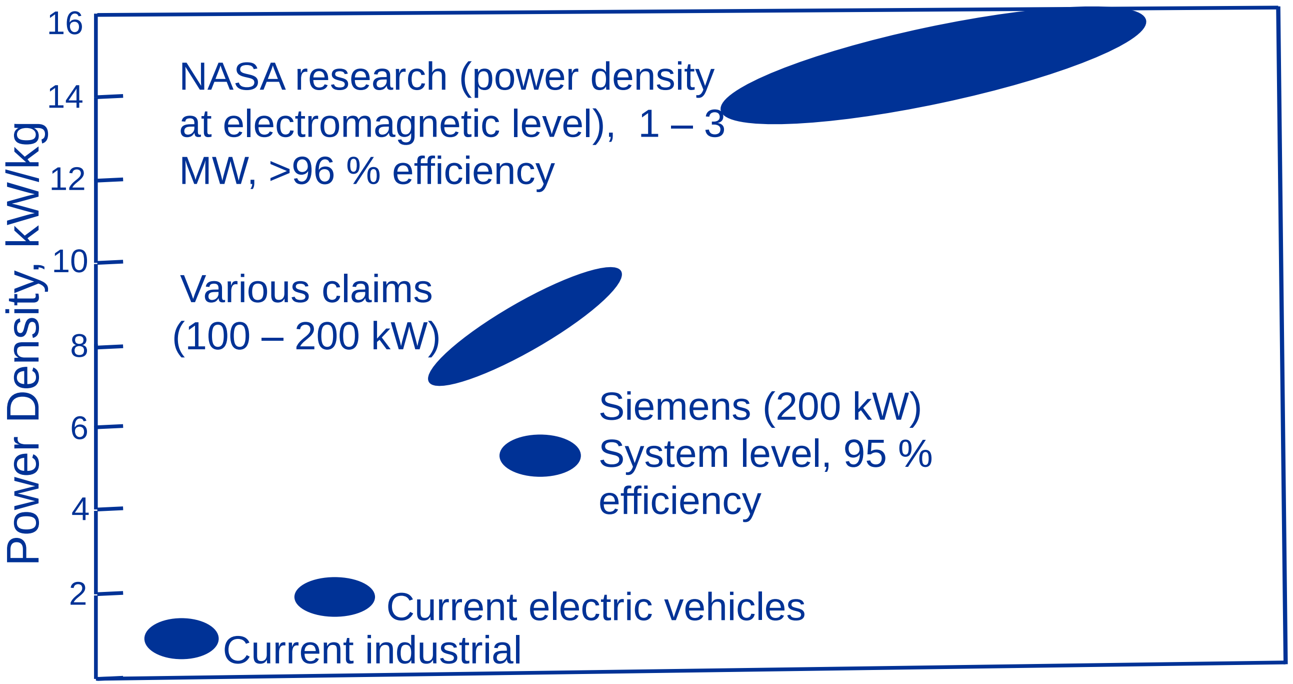
R-R LW EVE

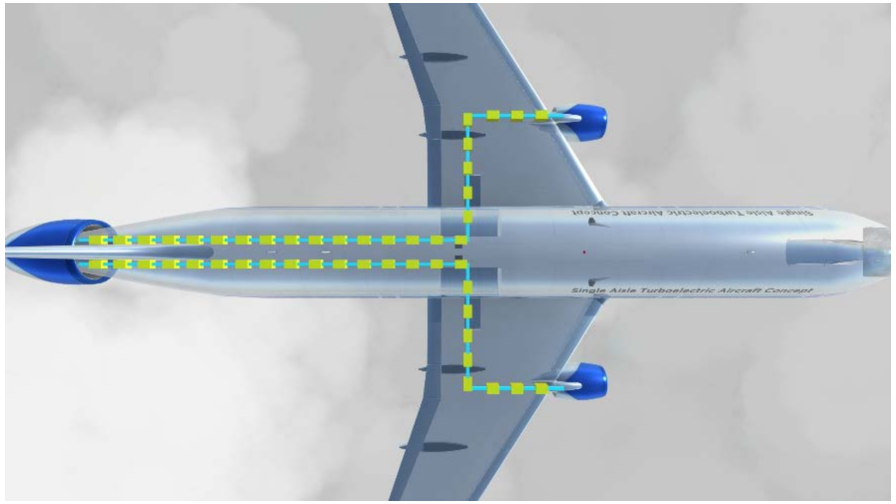
Electrified Aircraft Propulsion

NASA Electric Aircraft Testbed (NEAT)

Development and Testing of MW Class Power System

High Power Density Electric Motor Development



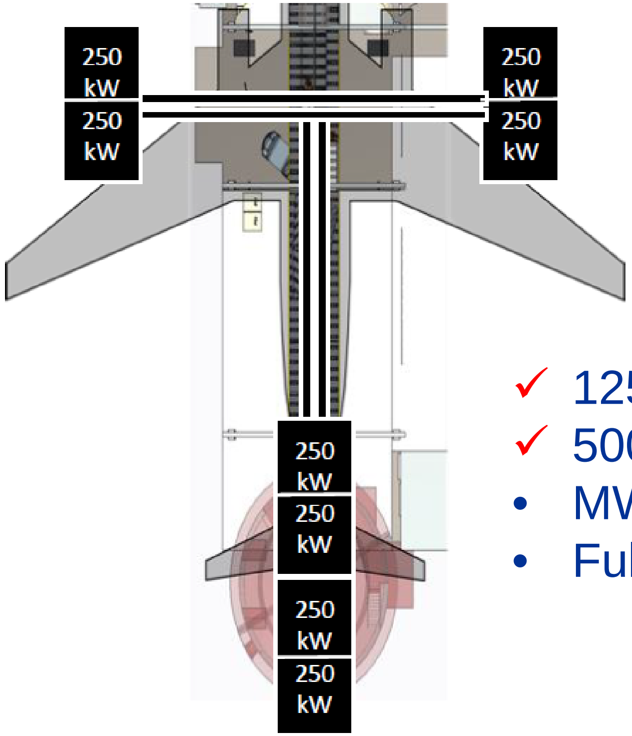


Single-aisle Turboelectric Aircraft with Aft Boundary Layer Ingestion (STARC – ABL)

- 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 7 – 12 % fuel burn savings for 1300 nm mission

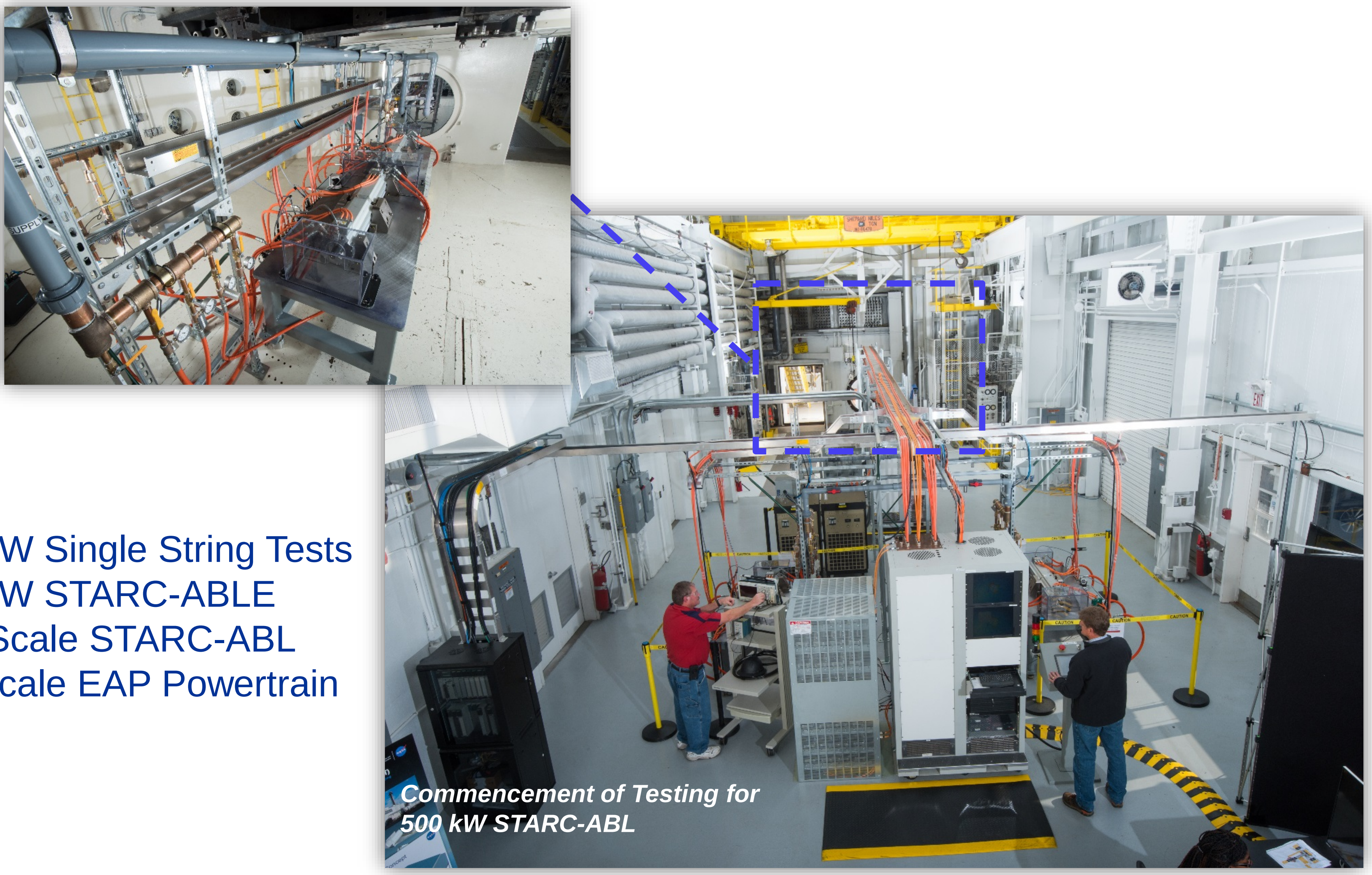
NASA Electric Aircraft Testbed (NEAT) for testing multi MW level power system

NEAT: From Concept to Operation in Three Years



500 kW STARC-ABL Configuration

- ✓ 125 kW Single String Tests
- ✓ 500 kW STARC-ABLE
- MW-Scale STARC-ABL
- Full-scale EAP Powertrain



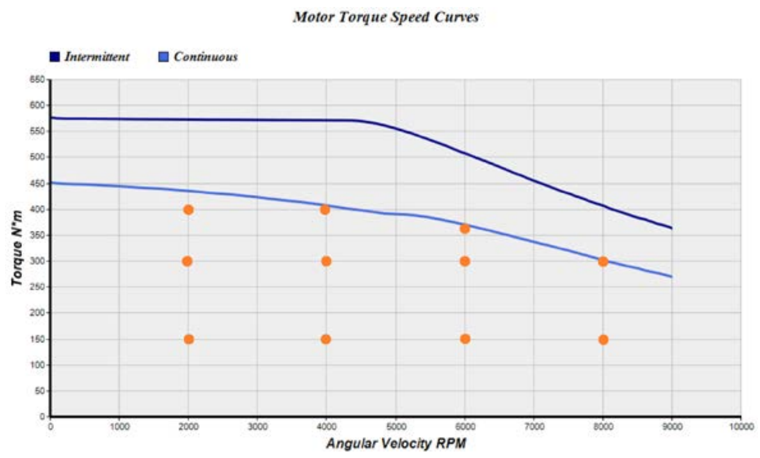
Commencement of Testing for 500 kW STARC-ABL

NEAT: Status and Results for 500 kW Testing

Long-term Objective: Mature Electrified Aircraft Power (EAP) powertrain technologies and validate at the system level including

- Powertrain architectures
- EMI mitigation
- Fault and thermal management
- DC bus stability
- Flight-efficiency, and high power, high voltage component verification

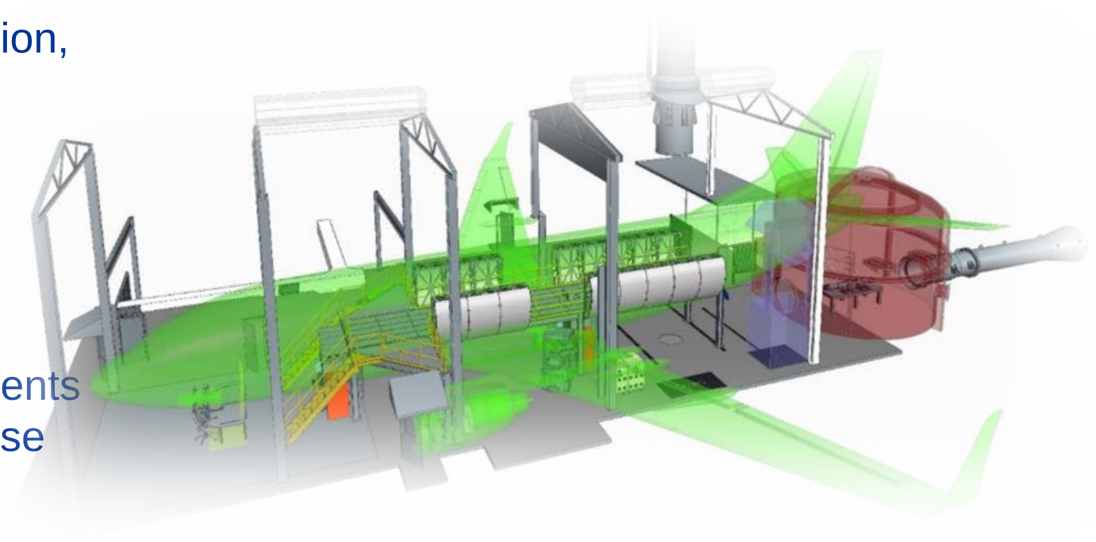
FY18 Objective: Establish subscale STARC-ABL powertrain w/ COTS equipment and run complete flight-profiles w/ turbine and ducted fan emulation



Configuration: 600 V, 500 kW multi-bus, ARINC 664 communication, power regeneration, facility thermal mgt.

Results:

- ✓ Successfully operated at 600V, 460 kW (500 kW by March 2018)
- ✓ informing next design
- ✓ Validated emulation scheme
- ✓ Quantified system communication choke points and power transients
- ✓ Measured important issues with load balance and control response
- ✓ Continuing to refine and add fidelity throughout year



Learning significant amount, results will be presented summer 2018

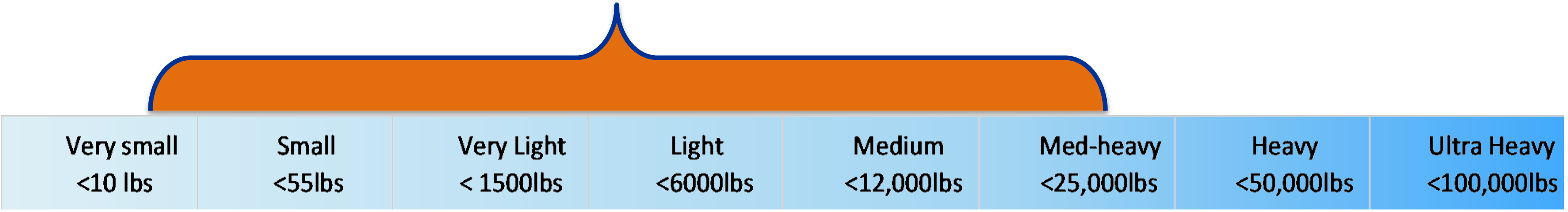
NASA Technology Investment Strategy

Overarching Vertical Lift Strategy

Enable a broad expansion of vertical lift applications

- **Improve current configuration cost, speed, payload, safety, and noise**
- **Open new markets with new configurations and capability**
- **Capitalize on convergence of technology in electric propulsion, autonomy and flight controls**

NASA technology emphasis



Very small	Small	Very Light	Light	Medium	Med-heavy	Heavy	Ultra Heavy
<10 lbs	<55lbs	< 1500lbs	<6000lbs	<12,000lbs	<25,000lbs	<50,000lbs	<100,000lbs

Technology applicability scales up and down in many areas

NASA-developed Concept Vehicles for UAM

Objective: Identify NASA vehicles to serve as references to openly discuss technology challenges common to multiple concepts in the UAM community

(Choose one feature from each column to arrive at a vehicle to study)

- ☐ Open, publicly-available configurations
- ☐ Provide focus for trade studies and system analysis
- ☐ Push farther than current market trends
- ☐ Provide a range of configurations
- ☐ Cover a wide range of technologies and missions that are being proposed

Passengers	**50 nm trips per full charge/ refuel**	**Market**	**Type**	**Propulsion**
1	1 x 50 nm	Air Taxi	Multicopter	Battery
	2 x 37.5 nm			
2	2 x 50 nm	Commuter Scheduled	Side by Side (no tilt)	Parallel hybrid
4	4 x 50 nm	Mass Transit	(multi-) Tilt wing	Turboelectric
6	8 x 50 nm	Air Line	(multi-) Tilt rotor	Turboshaft
15			Lift + cruise	Hydrogen fuel cell

NASA-developed Concept Vehicles for UAM

NOT “BEST” DESIGNS; NO INTENT TO BUILD AND FLY

Passengers	50 nm trips per full charge/ refuel	Market	Type	Propulsion
1	1 x 50 nm	Air Taxi	Multicopter	Battery
	2 x 37.5 nm			
2	2 x 50 nm	Commuter Scheduled	Side by Side (no tilt)	Parallel hybrid
4	4 x 50 nm	Mass Transit	(multi-) Tilt wing	Turboelectric
6	8 x 50 nm	Air Line	(multi-) Tilt rotor	Turboshaft
15			Lift + cruise	Hydrogen fuel cell

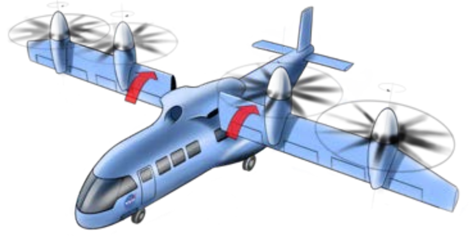
- Aircraft designed through use of NASA conceptual design and sizing tool for vertical lift, NDARC.
- Concepts described in detail in publications “Concept Vehicles for Air Taxi Operations,” by Johnson, Silva and Solis. AHS Aeromechanics Design for Transformative Vertical Lift, San Francisco, Jan. 2018 and ”VTOL Urban Air Mobility Concept Vehicles for Technology Development,” by Silva, Johnson, Antcliff and Patterson. AIAA Aviation 2018, Atlanta, GA, June 2018.

Quadrotor “Air Taxi”

Side by Side “Vanpool”

Lift+Cruise Air Taxi

Tilt wing “Airliner”



Relevant Research Areas for UAM

PROPULSION EFFICIENCY

high power, lightweight battery
light, efficient, high-speed electric motors
power electronics and thermal management
light, efficient diesel engine
light, efficient small turboshaft
efficient powertrains

PERFORMANCE

aircraft optimization
rotor shape optimization
hub and support drag minimization
airframe drag minimization

ROTOR-ROTOR INTERACTIONS

performance, vibration, handling qualities
aircraft arrangement
vibration and load alleviation


Quadrotor + Electric


Tiltwing + TurboElectric


Side-by-side + Hybrid

Lift+Cruise + TurboElectric

ROTOR-WING INTERACTIONS

conversion/transition
interactional aerodynamics
flow control

SAFETY and AIRWORTHINESS

FMECA (failure mode, effects, and criticality analysis)
component reliability and life cycle
crashworthiness
propulsion system failures
high voltage operational safety

STRUCTURE AND AEROELASTICITY

structurally efficient wing and rotor support
rotor/airframe stability
crashworthiness
durability and damage tolerance

OPERATIONAL EFFECTIVENESS

disturbance rejection (control bandwidth, control design)
all-weather capability
passenger acceptance
cost (purchase, maintenance, DOC)

NOISE AND ANNOYANCE

low tip speed
rotor shape optimization
flight operations for low noise
aircraft arrangement/ interactions
cumulative noise impacts from fleet ops
active noise control
cabin noise
metrics and requirements

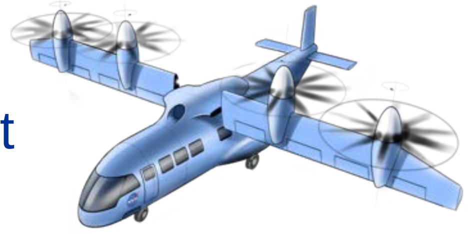
AIRCRAFT DESIGN

weight, vibration
handling qualities
active control

Red = primary focus
Blue = secondary focus

Summary

NASA RVLT is focused on



- Overcoming significant barriers to the use of vertical lift vehicles in expanded missions
- Providing technology leadership
  - Technologies and tools to enable low noise design and operations and reduce annoyance
  - Efficient configuration concepts that reduce fuel burn
  - Technologies that improve safety, mobility, payload and speed

- Developing vision of the future for vertical lift; identifying technical challenges for new markets
  - Methods to assess advanced innovative concepts
  - Pathfinder for next gen emerging market technologies

Concept Vehicles to Focus Urban Air Mobility Research

- Open, publicly-available reference vehicle configurations
  - Cover a wide range of technologies and missions
  - Provide focus for trade studies and system analysis
  - Assess failure modes and hazards of concept vehicle EAP architectures

- One passenger (250-lb payload)
- 50-nm range
- electric quadrotor

- Fifteen passengers (3000-lb payload)
- 8x50 = 400-nm range
- turbo-electric tiltwing

- Six passengers (1200-lb payload)
- 4x50 = 200-nm range
- hybrid side-by-side helicopter

- Six passengers (1200-lb payload)
- 2x37.5 = 75nm range
- turbo-electric Lift+Cruise VTOL

- *Aircraft designed using NASA conceptual design and sizing tool, NDARC.*
- *References – “Concept Vehicles for Air Taxi Operations,” by W. Johnson, C. Silva and E. Solis. AHS Aeromechanics Design for Transformative Vertical Lift, San Francisco, CA Jan. 2018 and ”VTOL Urban Air Mobility Concept Vehicles for Technology Development,” by Silva, Johnson, Antcliff and Patterson. AIAA Aviation 2018, Atlanta, GA, June 2018.*

Back up

Thin Haul Commuter (Conventional Takeoff and Landing)

NASA Flight Testing – X57 Aircraft

X-57 “Maxwell”

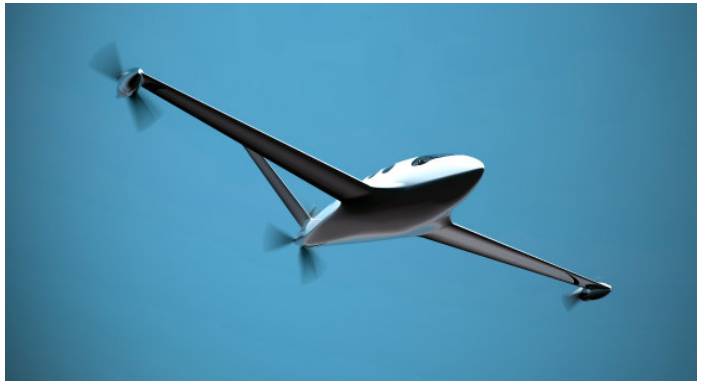
- Cruise-sized wing: enabled by DEP system for takeoff/landing performance
- High-efficiency cruise propellers: electric motors mounted at wingtips
- All-electric propulsion system: 40+ kWh battery, 240 kW across 14 motors
- Fully redundant powertrain

Current Effort:

- Demonstration of technologies and advanced concepts through flight tests
- Develop technologies to extend the range

Commercial (9-10 passenger)

Zunum Aero
(Hybrid electric)

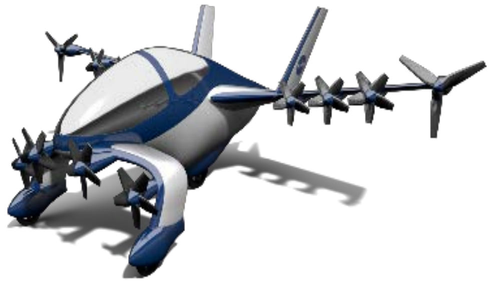


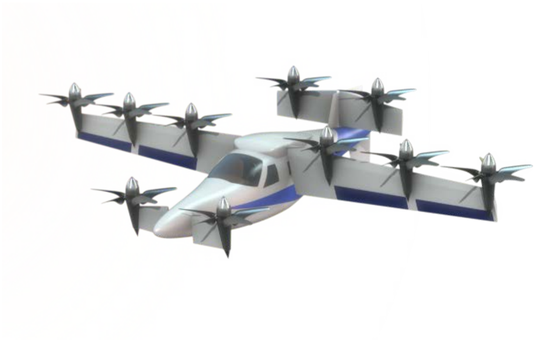
Eviation (all electric)

9-10 passenger, commercial introduction planned for 2022 – 25 time frame

Urban Air Mobility – Vertical Takeoff and Landing (VTOL)

Move people inside congested urban areas from point to point using a vertical takeoff air vehicle





Technologies

- Electric & hybrid -Electric distributed electric propulsion (~300-400 kw HEP)
- Fault tolerant propulsion, flight systems
- Low-noise/annoyance
- Small ground/air footprint in low-visibility
- 300 Wh/kg battery pack
- Battery integration and safety
- High-speed charging
- Autonomous system capability
- All weather operation
- High speed interoperable digital communications network
- Higher efficiency small gas turbine for hybrid electric

Significant commercial interest, initial commercial introduction likely to be in 2022 timeframe

NASA strategy under development – will influence initial and subsequent generations

Hybrid Electric Integrated Systems Testbed (HEIST)

- The HEIST is 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
- The HEIST is 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.
- HEIST has 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.