Synergistic Aviation Electric Propulsion

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Abstract

Aviation electric propulsion is a disruptive technology frontier offering significant benefits, yet currently attracts minimal NASA investment. Langley is investigating synergistic electric propulsion integration to overcome the current energy storage density shortfall through three very different mission concepts.

A high efficiency/low CO_2, conventional takeoff transport

A regenerative, long endurance UAV for low altitude hurricane penetration

An ultra quiet, low emission, close proximity, vertical takeoff vehicle

Based on these efforts, electric propulsion offers tremendous new degrees of freedom in aircraft system design, with a nearly scale-free integration into cross-disciplinary roles. There is potential for tremendous value to missions desiring environmental friendliness, short range, or where large differences in propulsion system sizing exist between takeoff and cruise. A vehicle sharing all these characteristics is the ideal platform for synergistic integration.

Aviation Electric Propulsion Introduction

- **Benefits:**
  - **Zero:** Emissions, Power lapse with altitude
  - **Low**: Noise, Vibration, Cooling drag, Volume, Maintenance, Operating Costs
  - **High:** Efficiency, Reliability, Safety, Engine power to weight
  - Scale free integration relating to power to weight and efficiency
  - Variable rpm output at full power without a gearbox
  - Emergency power increase of 50-100% for 30 to 120 seconds
- **Penalties:**
  - High energy storage cost and weight (gasoline provides 65x higher kW hr/kg)
- **Unknown:**
  - Volume production cost of electric propulsion systems
  - Ability to certify with FAA cost effectively

What If?

Commercial transports could use 70% less fuel?
(in the near-term)

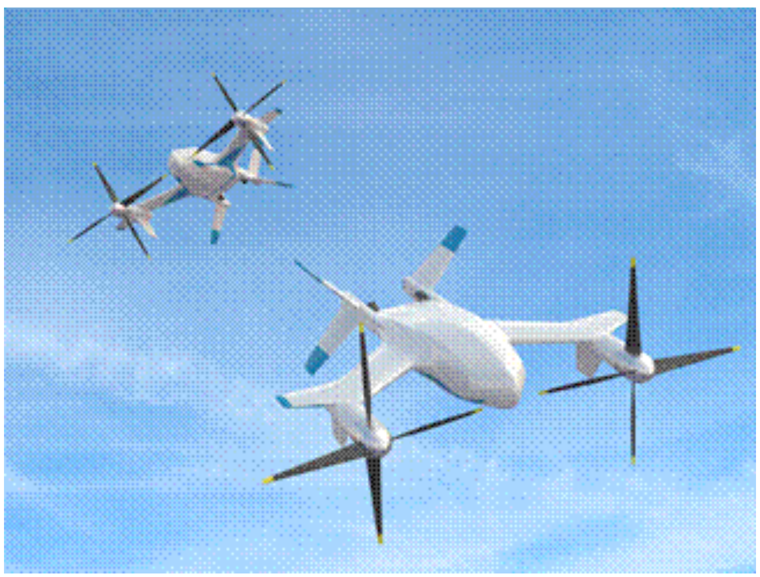
A UAV could persist within a hurricane during it's entire life cycle?

A single person aircraft could takeoff and land anywhere,
quietly and efficiently?

Electric Propulsion Advanced Concepts

High efficiency/low CO2, conventional takeoff transport

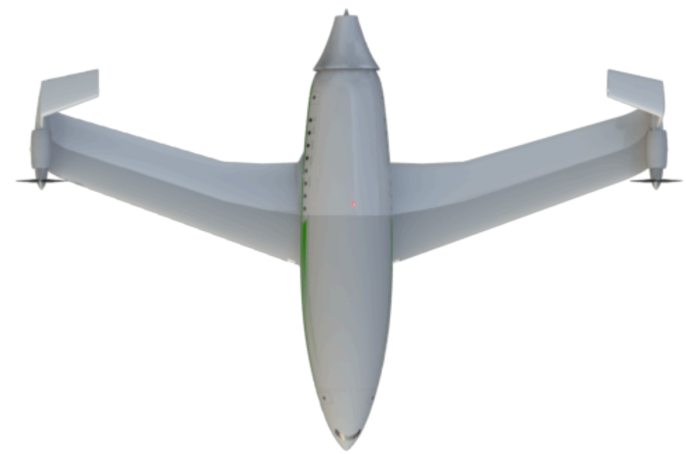
Regenerative, long endurance UAV
for low altitude hurricane penetration



Ultra quiet, low emission,
close proximity,
vertical takeoff vehicle

Value-Based Design Focused on National Priorities

The future is uncertain, so instead of predicting it, we should offer many solutions that address the many possibilities.



Are all goals equally important to the U.S. considering energy independence and global warming?

What if, instead of a balanced approach that addresses meeting all SFW goals, we focus only on efficiency (which automatically addresses emissions)?

Efficiency is the only goal that has an economic benefit to provide an incentive for technology market penetration.

High Efficiency/Low Emission CTOL Transport

Reduce Induced Drag (up to 40%)

- Wingtip vortex turbo-props, with ability to handle engine-out through IVHM technologies

Reduce Parasite Drag (up to 40%)

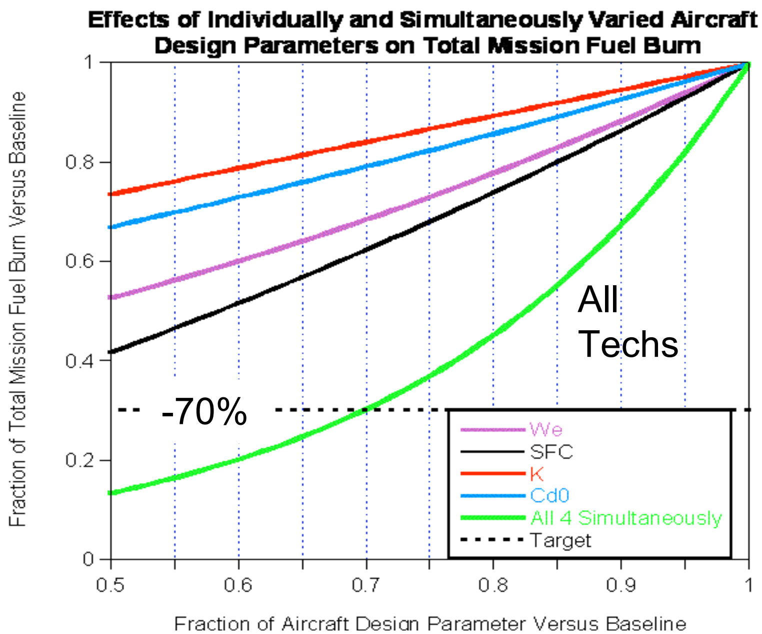
- Passive wing laminar flow through Reduced Mach/sweep, Reduced maintenance coating
- Active and passive fuselage laminar flow through favorable pressure gradient, coating

Reduce Empty Weight (up to 20%)

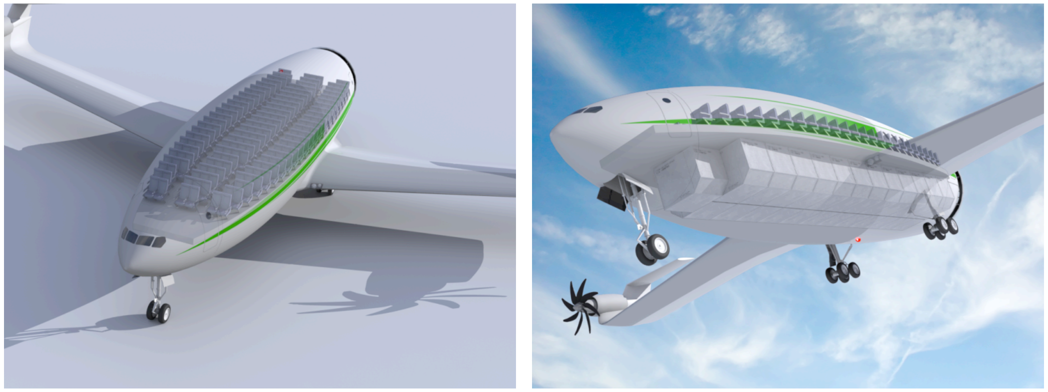
- Optimum fuselage cross-section/pax and LDs, Reduced aft fuselage/nacelle wetted area, Engine wing load alleviation, Reduced height gear

Reduce Specific Fuel Consumption (up to 45%)

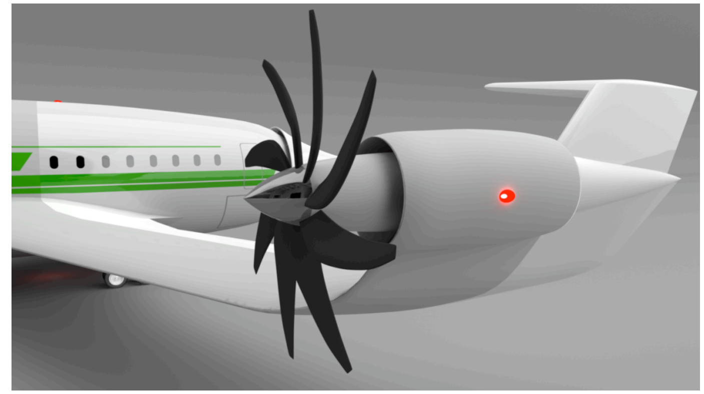
- Ultra high bypass wingtip engines, fuselage boundary layer ingestion inlet with no ram air



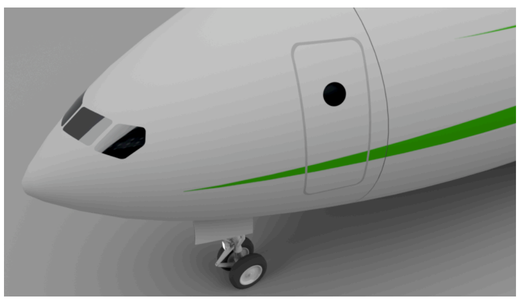
High Efficiency/Low Emission CTOL Transport



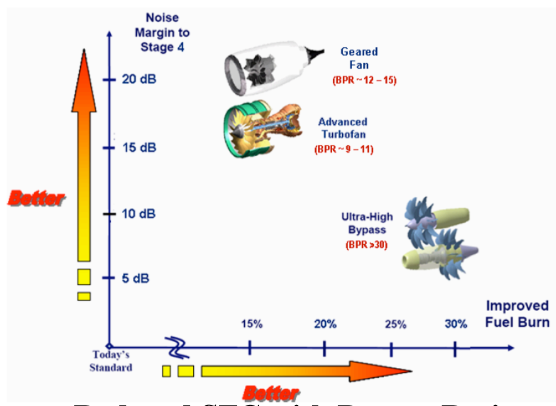
Reduced Fineness Ratio / Increased Packing Efficiency / Reduced Wetted Area



Wingtip Propeller Vortex Interaction

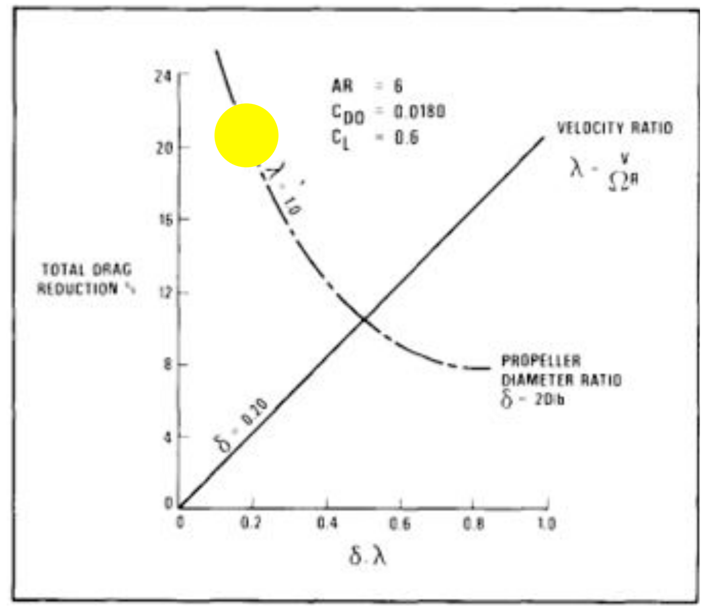


Cabin Air Suction Slot and Favorable Pressure Gradient Nose Laminar Flow



Reduced SFC with Bypass Ratio

NASA DFRC PIK-20 Test bed

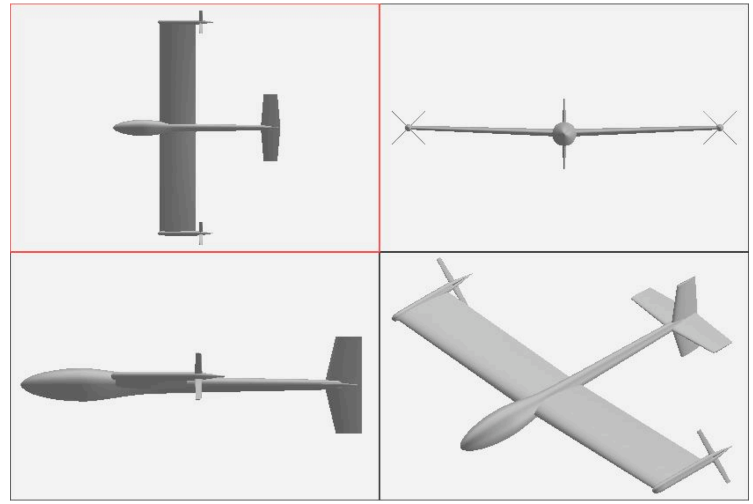


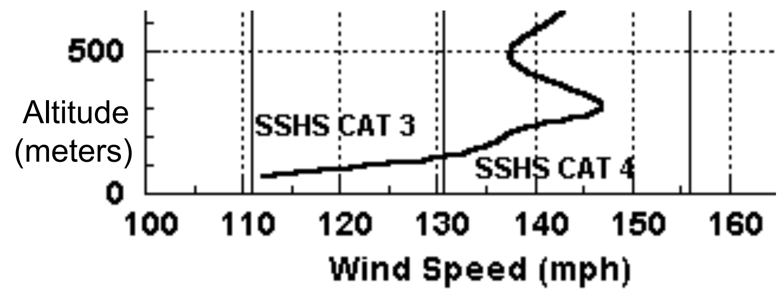
Effect of Wingtip Propeller Diameter and Velocity on Total Drag Reduction (Miranda, Lockheed, 1986)

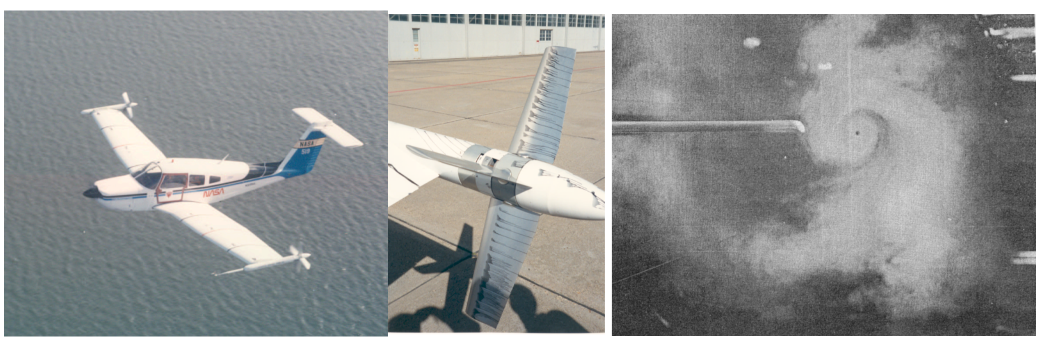
Regenerative Low Altitude Hurricane Penetrator

Albatross UAV

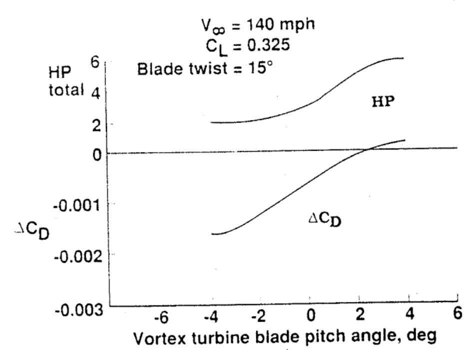
- Wing Span: 9 ft
- Gross Weight: 72 lbs
- Maneuver Velocity Range: 85 to 35 kts
- Tip Turbine Diameter: 1.38 ft
- Tip Turbine Power: ~100 Watts (@ zero drag penalty)
- Motor Power: 1 hp per wingtip (sized for climb)
- Power Required for level flight: 1.2 kw (1.6 hp)

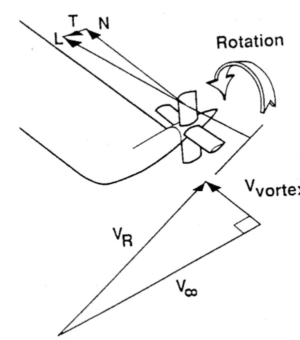




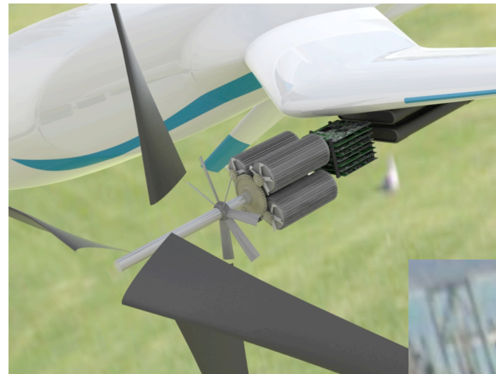


NASA Langley Flight Tests (1985)





Ultra Quiet, Close Proximity VTOL



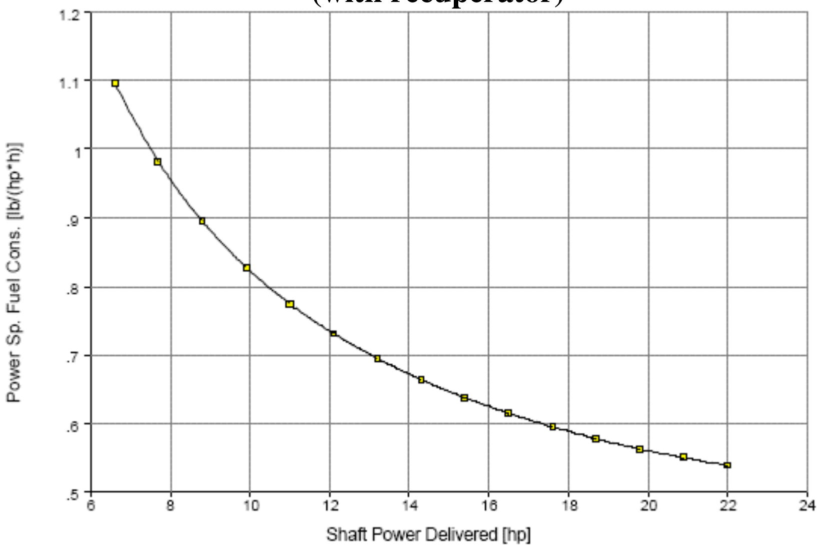
Quiet, Safe VTOL through Primary Electrics

- Extremely quiet engine and prop-rotor
- Elimination of High/Hot Engine Sizing: Electric propulsion is insensitive to these factors
- Reduction of Engine-Out Penalty: Redundant, scaled electric motors (no cross-shafts)
- Optimal Speed Prop-Rotor: Slower tip speeds at cruise for greater efficiency

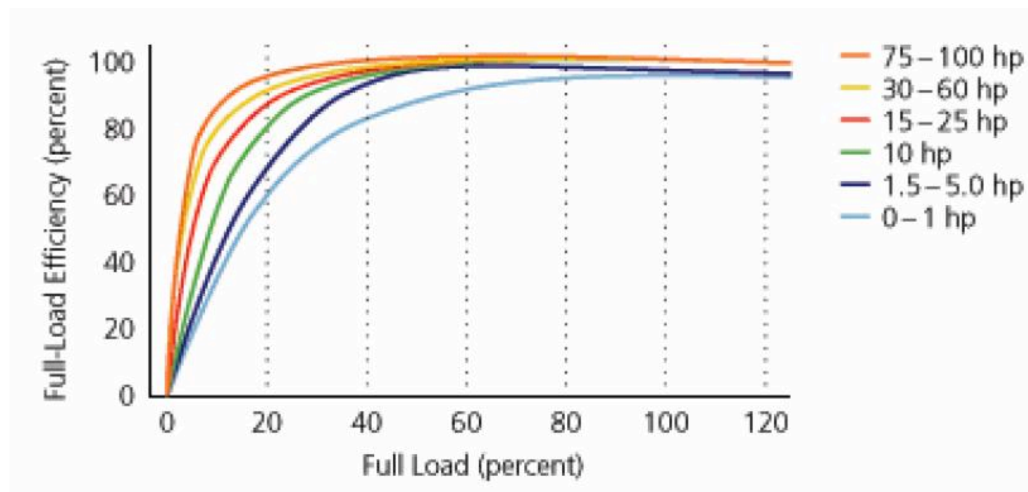
Engine Part Power Efficiencies and Scale Effects

Micro-turbine Engine Power vs sfc

(with recuperator)



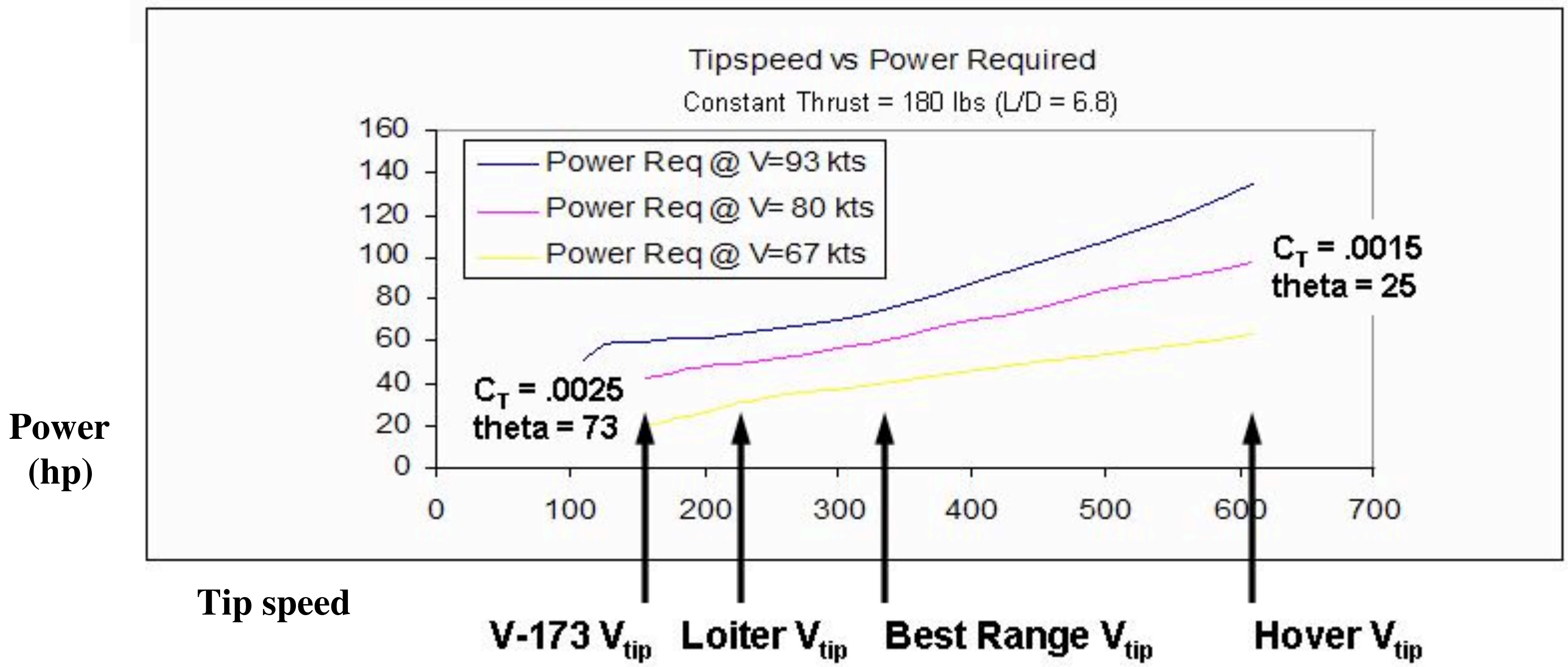
Electric Motor Power vs Efficiency



Turbine and reciprocating engines suffer from poor sfc when run at low power.

With concentric electric motors, both redundancy and high efficiency down to 20% load is achieved for motors as small as 15 hp.

Optimal Speed Prop-Rotor



Blade element method analysis of a prop-rotor capable of variable rpm, showing the sensitivity of power reduction with cruise tip speed.

Electric motors have a 50% rpm range with efficiency over 90%, combining this with the Aveox dual concentric motor concept will permit rpm from 25 to 100% with over 90% efficiency at any almost any power setting.

Distributed Aviation Gridlock Commuter Mission

- **Vehicle Characteristics**
  - Quiet, Efficient, Zero emission, Primary-Electric Vehicle
  - High capacity Heliport CONOPs
  - Skid-stall transition approach (no zoom climb)
  - 600 lb gross weight, 200 lb passenger, 100 lb battery
  - 60 hp max power (hover)
  - 400 ft/sec hover tip speed, high solidity, teetering bi-level prop-rotor (typically 725 ft/sec)
  - 200 ft/sec cruise tip speed with high efficiency 50-100% power capability
  - Cruise hp ~20 hp with >100 MPGe at 150 mph, ~50 mile range (using SOA batteries)
  - Elimination of cyclic control
  - Flat plate equivalent drag of ~.5 ft^2
  - Cruise L/D ~18
  - Load factor of 100%!

QuickTime™ and a
decompressor
are needed to see this picture.

Summary

- Electric propulsion offers new exciting possibilities at the system integration level that could have tremendous value to missions desiring environmental friendliness, short range, or where large differences in propulsion system sizing exist between takeoff and cruise.
- Electric propulsion could be a game changer for close proximity VTOL operations, which has been a dream since the Wright brothers, (and a nightmare for residents of Long Island).
- System integration of electric propulsion for air vehicles is up for grabs – there are no experts yet!
- Energy storage technologies are changing daily, with huge industry investment as ground electric vehicles go into production. A 3x improvement in energy density in 7 years is possible (and drastically improves feasibility).
- Since electric propulsion is a new frontier, it requires creative approaches, with the recognition that there will be dead-ends and new lessons learned.

Electric Propulsion NASA Team

- **A NASA, University, Industry partnership has been established to conduct a detailed system study utilizing higher-order, physics-based tools.**
  - NIA (Jinwei Shin): Prop-Rotor Structural Dynamics Analysis (Dymore)
  - GaTech (Jeremy Bain): Integrated High Fidelity Aerodynamics / Aeroacoustics (Overflow, WopWop)
  - MIT (Jonathan How): Tail-sitter Stability, Control and Transition (MIT Controls Lab Toolset)
  - LaRC (Mark Moore): Synergistic Vehicle Conceptual Design Analysis (ACSYNT, BEM, Electric)
- **Potential to partner with NIA on future DARPA work in this area as well**
  - *"TTO is interested in concepts, systems, and supporting technologies that would enable an individual soldier or small squad to be semi-autonomously transported by air across a battlefield, land safely, take-off and return. A single individual should be able to manage all phases of the operation and should not require airfields for operation. Key issues include operation in complex urban terrain, survivability, ground mobility, payload, and simplicity of operation. Key performance parameters would be system weight, range, safety, and cost. TTO is interested in innovative technologies and design approaches for vertical flight aircraft rotors and rotor systems. Technologies are sought that offer dramatic improvements for military rotorcraft in affordability, performance (esp. typical envelope limits), vibration and loads, susceptibility, operational availability and sustainability (durability, vulnerability, reliability, safety), and in other operational attributes."*

Quiet VTOL Key Research Objectives

- Aerodynamic and aero acoustic feasibility of a 400 ft/sec (7.5’) prop-rotor that can achieve an order of magnitude reduction in community noise for close proximity UAS and mobility missions.
- Electric powertrain capable of achieving a redundant propulsion system that is robust (fault tolerant), safe, quiet, lightweight, and able to vary rpm while at full engine power
- Transition from takeoff to forward flight, and forward flight to hover, through only the use of control surfaces that are embedded in the prop-wash flow. Feasibility of a semi-constant altitude skid-stall approach instead of a zoom-climb approach that requires altitude back-down.
- Achieve a low weight, cost, complexity, and maintenance prop-rotor hub that can be dynamically stable while providing the desired combination of noise, redundancy, and transition control characteristics.

Intercenter Electric Propulsion Working Group

- **In order to cultivate new opportunities in this research area, an intercenter Electric Propulsion Working Group (EPWG) has been established**
  - Under guidance of J.F. Barthelemy, Fay Collier, Peter Coen, and Guy Kemmerly to provide input for RTC 4b, Subsonics, Supersonics, and Green Strategy Team.
  - Develop a white paper concerning potential research missions, concepts, and synergistic technologies across UAV/GA, Commercial Subsonic, and Supersonic mission areas.
  - Identify potential platforms for flight demonstration of EP technologies.
  - Quantify the SOA of electric propulsion to better understand TRLs and when EP may fit into specific research areas.
  - Understand current research activities at Universities and Industry, and if appropriate prepare a STTR/SBIR topic area.
  - Collect references, resources, and design tools.
  - Members

    LARC: Mark Moore (Systems Analysis), Paul Stough (Crew Systems)

    DFRC: Jonathan Barraclough, Al Bowers, Kevin Walsh, Craig Stevens,

    GRC: Hyun Dae Kim, Jerry Brown, Jim Felder, Jeff Berton

    Ames: Mike Dudley