National Aeronautics and
Space Administration

Enabling Electric Propulsion for Flight

Starr Ginn
Chief Engineer for
Aeronautics Research

NASA Armstrong
Flight Research Center

www.nasa.gov

**Special Thanks to
AFRC Researchers:**

Kurt Kloesel, EE, AE
Propulsion Branch

Yohan Lin, EE
System Integration Branch

Sean Clarke, EE
System Development Branch

Aamod Samuel, AE
System Development Branch

Jim Murray, AE
Aerodynamics Branch

We Fly What Others Only Imagine – Hugh L. Dryden


X-1

Space Shuttle Approach
and Landing Tests


M2-F1

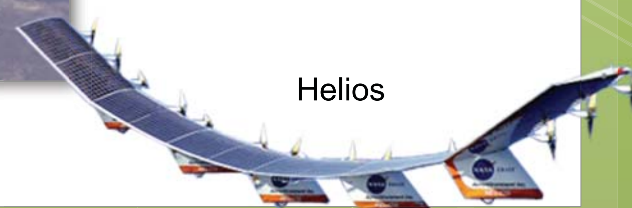
Lunar Landing Research Vehicle


X-29


F-8


X-43

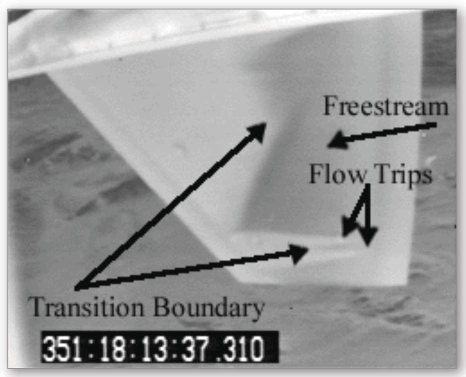

X-15


Helios

Criteria for Flight Research

1. Fits the national research agenda
2. Flight is the best (or only way) to obtain the relevant environment
   - Because research is sensitive to
     - Aerodynamic scaling or enthalpies that cannot be simulated on the ground
     - Properties of the natural atmosphere
     - Complexities that cannot be modeled
3. Appropriate for the government when
   - Results will have broad value and applicable to a class of applications
     - Unbiased testing is of national benefit
     - Technical or programmatic risk is too high for industry
     - Only required for NASA mission

Flight research doesn't merely come at the end of the project, it actually informs the direction of the research and manufacturing. *– National Research Council*



Future Innovation Lies Between Disciplines

Aeronautics Research Strategic 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

Aeronautics Mission Programs

MISSION PROGRAMS

Airspace Operations and Safety Program

AOSP

Safe, Efficient Growth in Global Operations

Real-Time System-Wide Safety Assurance

Assured Autonomy for Aviation Transformation

Advanced Air Vehicles Program

AAVP

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Integrated Aviation Systems Program

IASP

Flight research-oriented, integrated, system-level R&T that supports all six thrusts

X-planes/ test environment

* Transition to Low Carbon Propulsion

SEEDLING PROGRAM

Transformative Aeronautics Concepts Program

TACP

High-risk, leap-frog ideas that support all six thrusts

Critical cross-cutting tool development

NARI Team SEEDLING PROGRAM

Armstrong Flight Research Center

Aeronautics Mission Programs

MISSION PROGRAM

Advanced Air Vehicles Program (AAVP)

AAVP

Ultra-Efficient Commercial Vehicles

Innovation in Commercial Supersonic Aircraft

Transition to Low-Carbon Propulsion

Assured Autonomy for Aviation Transformation

Advanced Air Transport Technology Research

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)






Research Themes

- Research Theme 1 (2030): Lighter-Weight, Lower-Drag Fuselage
- Research Theme 2 (2030): Higher Aspect Ratio Optimal Wing
- Research Theme 3 (2030): Quieter Low-Speed Performance
- Research Theme 4 (2030): Cleaner, Compact, Higher BPR Propulsion
- Research Theme 5 (2030): **Hybrid Gas-Electric Propulsion**
- Research Theme 6 (2030): Unconventional Propulsion-Airframe Integration
- Research Theme 7 (2015): Alternative Fuel Emissions



Achieving N+3 energy consumption goals will require Fixed Wing investment in all research themes and increased funding for hybrid electric propulsion

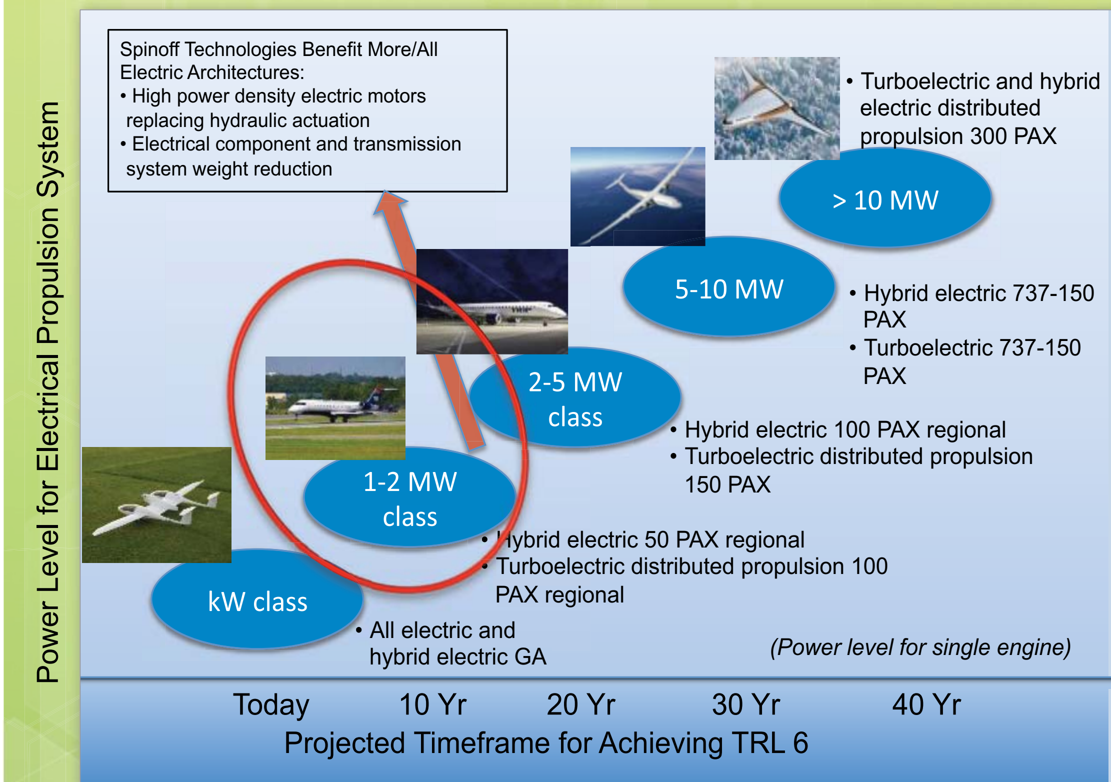
Hybrid Electric Propulsion (HEP) Systems for Aviation

Low Carbon Propulsion

- NASA studies and industry roadmaps have identified hybrid electric propulsion systems as promising technologies that can help meet national environmental and energy efficiency goals for aviation

Potential Benefits

- Energy usage reduced by more than 60%
- Harmful emissions reduced by more than 90%
- Objectionable noise reduced by more than 65%



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

Hybrid Electric Propulsion (HEP) Systems for Aviation

1-2 MW Class

Weight: 32,250 lb   Wingspan: 131ft   357 mph   60,000ft

"We are beginning to shift our focus to smaller classes – regional jets and turboprops." *– Nateri Madavan, NASA Fixed Wing Project Scientist*

Sept. 30, 2013

ADVANCED PROPULSION

Hybrid Hopes

Turbine-electric propulsion shows promise for keeping aviation's efficiency improvements going beyond 2030

Graham Warwick Washington

If there is a model for the application of hybrid electric propulsion to aviation, it may not be the automotive sector's Toyota Prius. It may instead be the maritime industry, says Rolls-Royce, which is drawing on its experience powering aircraft carriers and cruise liners as it begins work on hybrid electric propulsion for airliners.

driven conventionally by burning jet fuel to power the turbine, or electrically by batteries powering a motor on the fan shaft, or through some combination of both to optimize energy usage over the mission.

Phase 2 study results were delivered to NASA in June, says Marty Bradley, Boeing technical fellow and Sugar principal investigator. They show that, while the conventionally powered Sugar High would burn 54% less fuel than a 737-800, NASA's goal of a 60% fuel-burn reduction could be achieved by the Sugar Volt with 1,750-hp electric motors driving the fans.

This is what Boeing calls the "balanced" hybrid-electric aircraft, where the relatively small motors operate across the entire mission. A configuration with 7,150-hp electric motors was also studied. "It can do part of the cruise on fully electric power [eliminating emissions], but we have to upsize the aircraft to carry more batteries," he says.

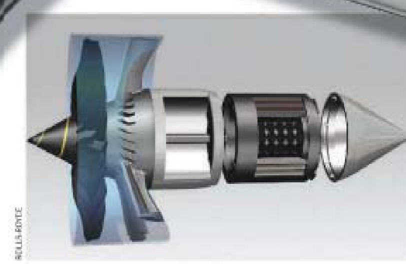
Because energy is now stored in both jet fuel and batteries, total energy usage and not just fuel burn becomes important. The Phase 2 study shows the balanced Sugar Volt consumes 60% less fuel and 54% less total energy, while the larger hybrid-electric aircraft burns 64% less fuel, but uses only 46% less energy than the baseline 737.

"We increase the fuel-burn reduction, but now it is clear we are cheating, as we are trading off fuel energy for electrical storage energy," says Bradley. "As the aircraft is getting heavier, we are actually using more total energy—an indicator that perhaps we have gone a little too far."

The study also looked at emissions and energy costs. The Sugar High achieves a carbon dioxide (CO^2) reduction of 53.5% over its lifetime, including emissions from fuel refining, aircraft manufacturing, maintenance and end-of-life disposal. "How green the hybrid is depends on how you are charging up the batteries," says Bradley.

Using the U.S. average grid, where electricity predominantly comes from coal, lifetime CO^2 reduction for the balanced Sugar Volt is 43.6% "You are doing worse than the conventional aircraft," he says. Using renewable wind energy to recharge the batteries gives a CO^2 reduction of 58.9%.

E-Thrust is a superconducting series-hybrid propulsion system in which a single gas turbine (in tail) charges a battery pack that electrically powers six distributed fans on the wings.



Inside each electrically driven fan, superconducting "pucks" (middle module) power the rotor driving the fan.

more of the fleet is. But as we look at hybrid electric, we are beginning to shift our focus to smaller classes—regional jets and turboprops," says Nateri Madavan, NASA Fixed Wing project scientist. "We are beginning to get the sense that early advances could happen in 30-, 50-, 80-passenger aircraft."

NASA's technology road map foresees 1-2-megawatt motors being ready within 10 years to power a turbo-electric 50-seater, 2-5 megawatts within 20 years for a 100-passenger regional aircraft and 5-10 megawatts within 30 years for a 737-class 150-seater. The agency has plans to demonstrate both conventional non-cryogenic and cryogenic superconducting motors and power electronics for both hybrid and

As a first step, NASA is on track to run a sub-scale fully superconducting motor in the 2017 timeframe, Madavan says, and the agency plans to test a 1-megawatt-scale, 8hp/lb. power-density non-cryogenic motor in the 2019 timeframe. The agency is working on superconducting materials and components, including cryo-coolers and wires using magnesium diboride, an inexpensive, flexible superconducting material with a relatively high critical temperature of 39K.

In the U.K., Rolls-Royce has been working with Airbus Group Innovations and Cambridge, Cranfield and Manchester universities on a series of studies. These include the two-year Programmable Superconducting AC Machine (PSAM) demonstration, which concluded in December and fed into the two-year Distributed Electrical Aerospace Propulsion (DEAP) study, which will run to early 2015. Just beginning is the three-year, U.K.-funded Integrated Power and Propulsion Architecture (IPPA) study, which also involves General Electric, United Technologies, Honeywell, Raytheon and Spirit AeroSystems.

The £1 million ($1.6 million) DEAP project is focused on a 100-passenger, 2,000-nm-range, Mach 0.75-cruise concept aircraft with a superconducting propulsion system, called E-Thrust, in which a single embedded gas turbine generates electricity to drive six distributed fans. These are mounted so that, as well as producing thrust, they ingest the boundary layer over the inboard wing and fuselage to reduce drag. PSAM involved work on the programmable superconducting motors that would drive the distributed fans. IPPA will look at the systems integration of electrical technology with the airframe.

As a follow-on to DEAP, the 10-year, €98 million ($130 million) Propulsion Concepts (ProCon) project is being proposed under Europe's new Clean Sky 2 aeronautics research program. Partners are still being signed up for the anticipated project, to be led by Airbus, which would focus on flight testing distributed fans for drag reduction, not thrust, on a 100-seat aircraft. ProCon came out of E-Thrust, Daffy says, as a way of conducting a project in the short term that would provide the needed adrenaline to mature the technology.

Under ProCon, an existing aircraft would be modified with electrically driven auxiliary fans mounted around the fuselage or tail to suck down the boundary layer and reenergize

AirVolt Single String Propulsor System

PROPULSION

Going Electric

NASA Dryden is building testbeds to advance understanding of electric propulsion for aircraft

Graham Warwick Washington

Electric propulsion is already here, albeit on a small scale, and now NASA is looking ahead to the technology that would be required to power a regional aircraft in 10-20 years or a narrowbody airliner in 30-40 years.

But the agency intends to start small, with tests to first understand, then model the behavior and efficiency of electric propulsion system components. These will feed into ground, and potentially flight, tests of a distributed propulsion system that would be closely integrated with the airframe.

NASA has laid out a technology road map that would enable 1-2-megawatt electric propulsion for a 50-seat regional in 10 years, 2-5 megawatts for a 100-seat aircraft in 20 years, and 5-10 megawatts for Boeing 737-class airliners in 30 years. Funding is scarce, however, so development is starting at the kilowatt level, but this could spin off to the general-aviation industry, enabling new concepts in light aircraft.

The critical design review has just been completed for an electric propulsion test stand, says Starr Ginn, Aeronautics Mission NASA flight systems engineer. The single-string stand will be capable of producing up to 500 lb. of thrust from a 6-ft.-dia. propeller. Initial tests will involve a 40-kw power train. "We will be able to isolate a given component and to validate its efficiency before we put it into a stack of propulsors," he says.

As a next step, NASA Dryden has awarded a contract to Empirical Systems Aerospace to build the Hybrid Electric Integrated System Testbed (Heist). This will be an 80-kw ground test bench for turbo-electric distributed propulsion, with a flight-like architecture sized for eventual flight testing—by modifying Dryden's TG-14 motor glider or designing and building a dedicated testbed aircraft. "The nice thing about electric propulsion is you are not stuck with traditional aircraft designs," notes Ginn.

Heist, which recently began, is an 18-month program and hardware should be entering test in a year, says Clarke. The test bench is planned to have a turbo-generator, AC/DC converter, battery system, electronic controller and a DC bus distributing power to 8 or 12 4-6-in. ducted fans, each with its own electric motor and speed controller. "Whether it is just a stand to test power management and distribution or is integrated into an airframe-like structure" is under discussion, says Ginn.

In addition to the real-time management of generator loading, battery capacity and power demand, Heist will allow study of distributed-propulsion algorithms that synthesize individual propulsor commands based on total system thrust targets set by the pilot. "We will study how to schedule loads on the generator, and charging and discharging of the batteries in different flight modes," says Clarke.

DC bus stability is an issue as power levels are scaled up, because the magnetic inertia of large motors induces electromotive force (called back-EMF) on the bus. This can lead to motor runaways. Heist will allow the issue to be assessed on a power scale compatible with a flight vehicle, he says.

NASA plans to increase its research into distributed electric propulsion over the next couple of years, demonstrating a kilowatt-class architecture as a step toward the megawatt power levels needed for commercial aircraft. So far, for Dryden, "it's not an increase in resources, but a shift, because it's strategic for us to get into hybrid electric," says Ginn.

The ultimate goal on NASA's road map is 10-megawatt-plus hybrid-electric propulsion for a 300-seat airliner, which could be 40 or more years away. "We recognize a great deal of technology development is needed [to get there]. But there is an opportunity to begin gathering data today," she adds. "What we are starting to work on can be scaled up to larger aircraft. A low-cost kilowatt-class prototype can exercise in a flight environment technology that is scalable to 2-5 megawatts."

NASA's AirVolt test stand will measure the efficiency of individual electric propulsion system components.

...GY/SEPTEMBER 30, 2013

AviationWeek.com/awst

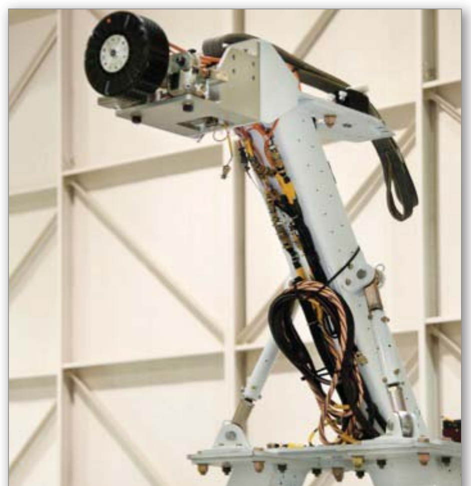
Plug-and-Play Electric Propulsion Kit

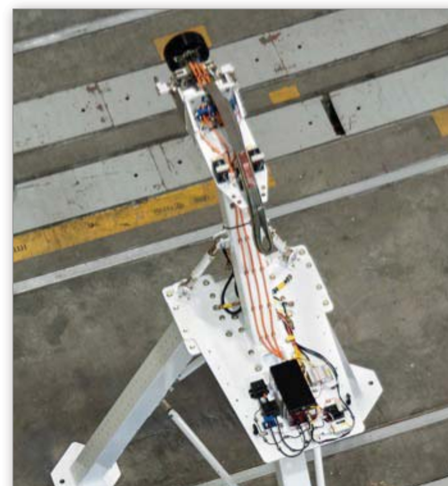
- Pipistrel Electro-Taurus Motor
  - 40 kW Peak, 53 hp
  - 30 kW continuous
  - 240 VDC

- Measurements
  - 500 lbf thrust
  - 500 ft*lbs torque
  - 0-40,000 RPM
  - 500 Amps
  - Acoustic signature

AirVolt Single String Propulsor System

- Collect high-fidelity, high-bandwidth ground-based test data of motor, motor controller, battery system efficiencies, thermal dynamics and acoustics, independent of manufacturers
- V&V of components and system interfaces
- Evaluation of low TRL components
- Model single system before transitioning to multiple motors
- Gain knowledge in test methodologies, processes, and lessons learned





Ironbird – HEIST Hybrid Electric Integrated System Testbed

Integration and Performance Challenges are Studied so Larger, More Advanced Electric Propulsion System Testbeds Can Be Designed

- Study system complexities of 2 power sources
- COTS and low TRL components
- Laid out in the actual configuration of the aircraft, using real line lengths
- Discover incompatibilities
- Validate vital aircraft system
- Effects of failure and subsequent treatment
- Electric switch w/variable interruptions, times are studied to assess their impact on the computers and components
- EMI effects
- Ironbird is controlled from a flight simulator

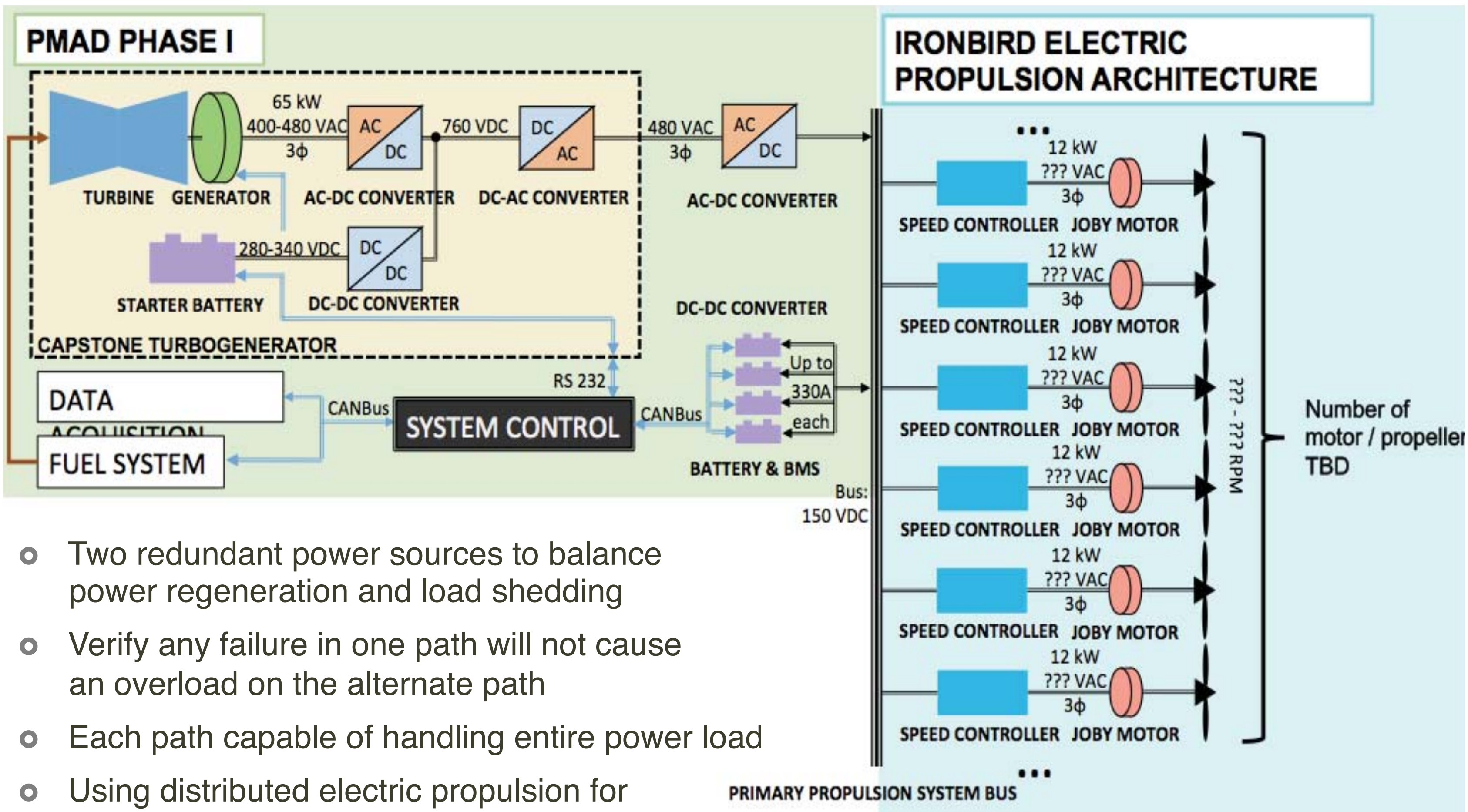
Ironbird – HEIST Hybrid Electric Integrated System Testbed

Power Management and Distribution Research

- **Embedded Flight Control Computer** will Host
  - **Distributed Propulsion Electronic Controller**: Translate thrust targets with simulated pilot inputs into individual thrust commands for each of the propulsors, controlling roll and yaw
  - **Power Management Algorithm**: Manage the loading of the power generator, the real-time capacity of the energy storage buffer (e.g., battery system) and the power demand of the collection of propulsors
  - **Peek Seeking Control**: Use real-time measurements and quickly adapt to environmental changes, to reduce drag, increase performance and energy savings

HEIST Modular Architecture to Allow for Multiple Configurations

(TeDP/Hybrid/All-electric; serial; or parallel buses)



- Two redundant power sources to balance power regeneration and load shedding
- Verify any failure in one path will not cause an overload on the alternate path
- Each path capable of handling entire power load
- Using distributed electric propulsion for flight control by nature are dynamic, with lots of moves, adds and changes going on all the time

Aeronautics Mission Programs

MISSION PROGRAMS

Airspace Operations and Safety Program — AOSP

- Safe, Efficient Growth in Global Operations
- Real-Time System-Wide Safety Assurance
- Assured Autonomy for Aviation Transformation

Advanced Air Vehicles Program — AAVP

- Ultra-Efficient Commercial Vehicles
- Innovation in Commercial Supersonic Aircraft
- Transition to Low-Carbon Propulsion
- Assured Autonomy for Aviation Transformation

Integrated Aviation Systems Program — IASP

- Flight research-oriented, integrated, system-level R&T that supports all six thrusts
- X-planes/ test environment

* Transition to Low Carbon Propulsion

SEEDLING PROGRAM

Transformative Aeronautics Concepts Program — TACP

- High-risk, leap-frog ideas that support all six thrusts
- Critical cross-cutting tool development

NARI Team
SEEDLING PROGRAM

Aeronautics Mission Programs

Seedling Program

National Aeronautics Research Institute (NARI)

NARI

Early-Stage Innovative and Novel Concepts to Revolutionize the Future of Aeronautics

LEAPTech

Leading Edge Asynchronous Propeller Technology

July 7, 2014

RESEARCH & DEVELOPMENT

Electrifying Aviation

Light aircraft are early targets for the efficiency and safety benefits touted for electric propulsion

Graham Warwick Atlanta

Aviation did not enter the Jet Age overnight, and a decades-long journey to the next propulsion paradigm may already be underway. At NASA, the exploration has begun with plans for ground and flight tests to determine whether hybrid and distributed electric propulsion could be the next disruptive shift in civil aviation.

personal air vehicles around electrical propulsion and increasing autonomy, beginning this spiral exploration with small unmanned aerial systems (UAS) (see page 20) and light aircraft.

"What problems are we trying to solve in general aviation?" Mark Moore, advanced concepts engineer at NASA Langley Research Center, reflects. His answer is many, and they encompass the low efficiency; poor safety, emissions and ride quality; and high operating costs of some light aircraft and helicopters.

Distributed electric propulsion promises dramatic increases in aerodynamic and propulsive efficiency, and reductions in noise and energy costs. "It is not just about general aviation, but they are earlier adopters at a smaller scale, faster and cheaper," Moore says.

Electric propulsion is not without its penalties. Energy-storage weights are far worse than those of aviation fuel, and battery-pack costs are high. But electric motors are more efficient than turbines or pistons across a wide rpm range, and power-to-weight ratios are higher; they are quiet, compact and reliable, with zero emissions and energy costs that are much lower than for aviation fuel. And, crucially for aircraft design, efficiency and power-to-weight are independent of size.

Modifying the wing on a Technam P2006T light twin would directly compare distributed electric and conventional propulsion.

"You can have multiple small electric motors with the same output as a large one without much penalty. You can put them anywhere around the aircraft, versus heavy piston engines that can only go in one or two places," says Joby Aviation's Alex Stoll, chief designer of the Lotus small UAS and two-seat S2, both vertical-takeoff-and-landing designs using distributed electric propulsion. "You can use them to make a personal air vehicle practical, versus an expensive, noisy, unsafe helicopter."

To test the premise that the tighter propulsion-airframe integration possible with electric power will deliver efficiency, safety and environmental and economic benefits, NASA has partnered with Empirical Systems Aerospace (ESAero) and Joby to propose the Leading Edge Asynchronous Propeller Technology (LEAPTech) demonstrator as an X-plane testbed for distributed electric propulsion.

A traditional light aircraft needs a large wing to meet the low stall-speed requirement for certification, but this is inefficient in cruise. LEAPTech replaces the big wing with one that is one-third the size for lower drag, and has three times the wing loading for better ride quality. Cruise lift-to-drag ratio at 200 mph is greater than 20, versus 11 for a comparable Cirrus SR22, NASA estimates.

To achieve the required 61-kt. stall speed with such a small wing, LEAPTech mounts an array of small propellers along the leading edge. These accelerate airflow over the wing, increasing dynamic pressure at the leading edge and more than doubling the maximum lift coefficient (C_{Lmax}) at low speed. "In computational fluid dynamics, we have seen lift coefficients of 5.5. We need 4.5 for a 61-knot stall," says Stoll. Unblown, at the 61-kt. stall condition at lower cost than a wind-tunnel test.

"NFAC [National Full-Scale Aerodynamics Complex wind-tunnel facility] would have cost more than the entire budget [for Heist]," says Moore. "And we need to get to this scale to have reasonable data." The wing will float on an airbag system in the truck to minimize vibration from the lakebed, and the remaining noise will be removed during post-processing to obtain lift measurements with less than 5% error, he says.

ESAero is the prime contractor for Heist. Joby Aviation is building the test rig, wing, motors and props. Combined, the 18 propellers will generate 300 hp and the wing will provide 3,500 lb. of lift. ESAero will conduct from batteries to propeller. A year from now, this will be upgraded to the Airvolt Hybrid, with a Rolls-Royce M250 turboshaft, electric motor/generator and enlarged batteries. This will be arranged so that both the gas turbine and electric motor can drive the propeller, and will be used to look at power-transfer stability issues with parallel hybrid propulsion.

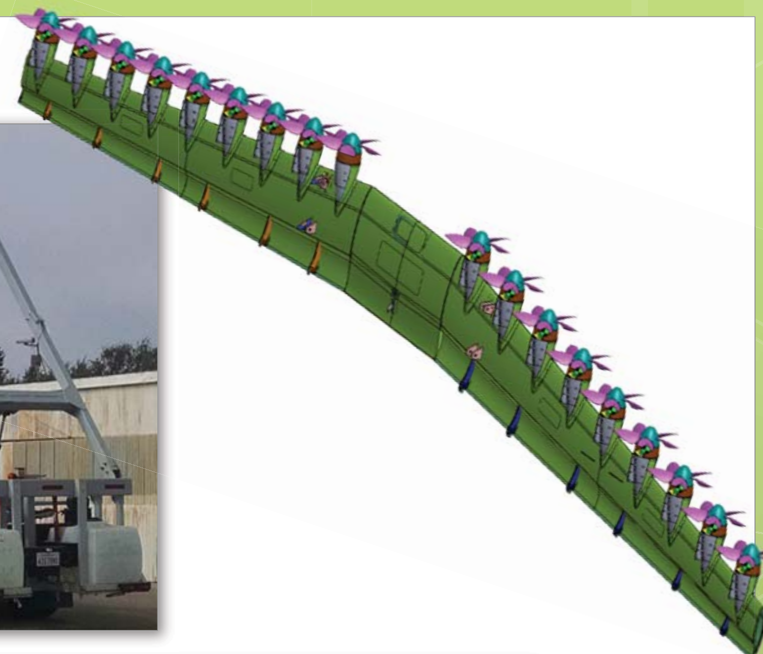
In February 2016, NASA Armstrong plans to begin the Heist power management and distribution (PMAD) ground demonstration. This will be a static propulsion test stand co-located with Airvolt and used as a long-term research platform. NASA plans to evaluate stability issues inherent in parallel-hybrid electric bus architectures, characterize

Armstrong Flight Research Center

Team – NASA LaRC, AFRC, ARC, industry partners Joby Aviation and ESAero.

LEAPTech

Leading Edge Asynchronous Propeller Technology



Armstrong Flight Research Center

Team – NASA LaRC, AFRC, ARC, industry partners Joby Aviation and ESAero.

LEAPTech

Leading Edge Asynchronous Propeller Technology

Lessons to be Learned

- Battery weight and capacity versus HP and test time
- Experience with motor/motor controller/BMS
- Hoping for a coefficient of lift of ~5
- Power loss and voltage spike due to line length
- Propeller fatigue due to vortex shedding from neighbor propeller
- What is the minimum set of data to achieve objectives
- Aeroelastic frequency measurement
- Qualitative acoustics
- Characterize open loop control
- Testing capability for future wing designs

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SEEDLING PROGRAM

Armstrong Flight Research Center

Aeronautics Mission Programs

Transformative Aeronautics Concepts Program

Convergent Aeronautics Solutions Project

TACP

High-risk, leap-frog ideas that support all six thrusts

Critical cross-cutting tool development

Convergent Electric Propulsion Technologies Sub-Project

Early Flight Evaluation Allows Timely Exposure to Benefits and Issues

2017 Demonstrator

- 400 empg/pax efficiency
- 80% reduction in life cycle GHG emissions
- 40% reduction in total operating cost
- 25 dB reduction in community noise

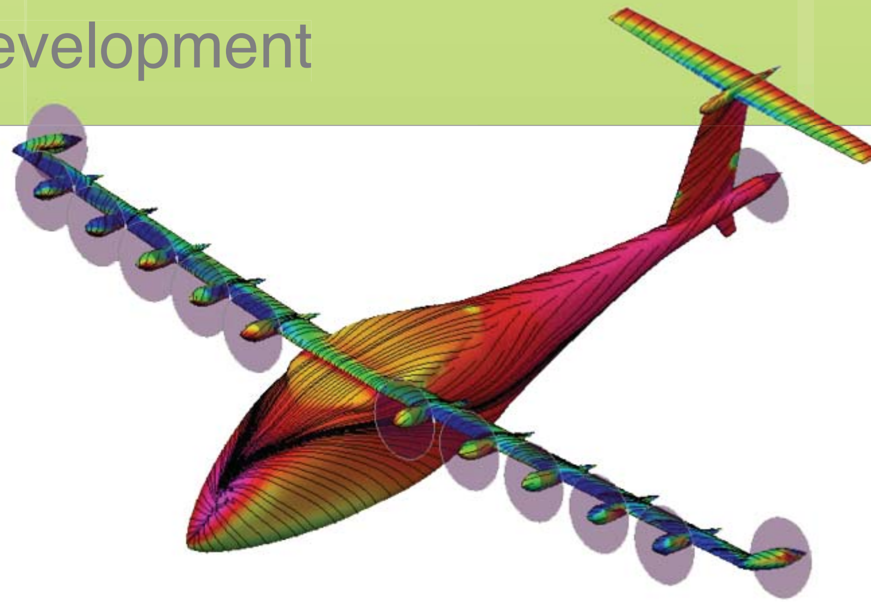
Distributed Electric Propulsion Integration Approach

- Tight aero-propulsion coupling increases effective C_{Lmax} from 1.8 to ~5.0
- Wing loading is increased from 17 lb/ft^2 to ~50 lb/ft^2, with the same stall speed and field length performance capability
- Electric motors don't experience power lapse with altitude
- Inner span propellers can be stopped and folded back at cruise
- This permits the inner propellers to be optimized for ultra low noise at takeoff/landing, without cruise penalty

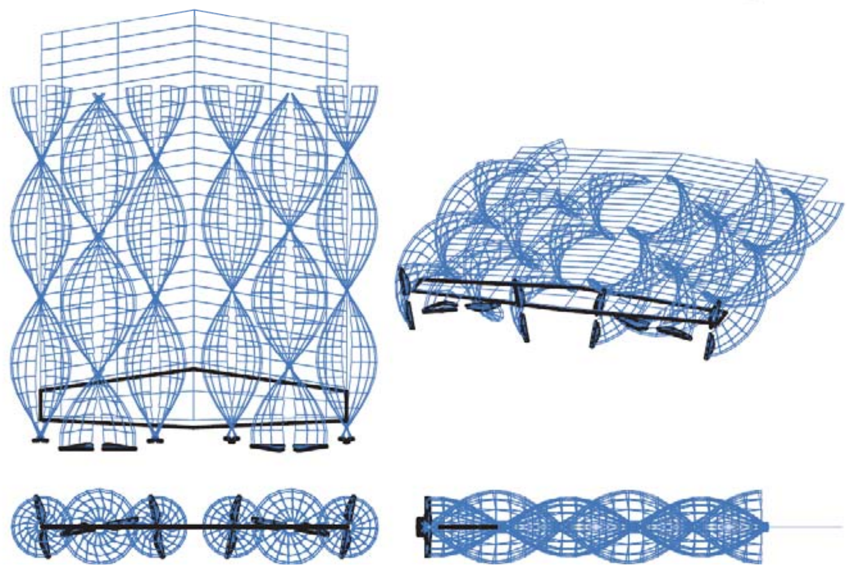
Convergent Electric Propulsion Technologies Sub-Project

Critical Cross-Cutting Tool Development

- Tool validation
  - Conceptual design process
  - MDAO optimization capability
  - Acoustic benefits
  - Aeroelastic effects
  - Use challenge problems to focus development and demonstrate capabilities



- Propulsion effects are largely ignored during aerodynamic modeling, which greatly limits investigation of tightly coupled aero/propulsion technologies
  - Develop a rapid, medium-fidelity aerodynamic analysis of distributed propulsion interaction with lifting surfaces suitable for parametric analysis



Spiral Development

From kW to MW at lower costs

kW System Understanding

- Tool validation
- System complexities
- Weight restrictions
- Volume restrictions
- Heat restrictions
- Dynamic aero loading
- Battery requirements for flight profiles
- Environmental effects; cold, hot, gust, airflow variables on inlets
- DEP crossflow characterization and aero/propulsion interaction for stall margins and cruise
- EMI concerns
- Pilot input to fly-by-wire propulsion control
- Emergency recover

Armstrong Electric Propulsion Roadmap

FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20

1-2 MW Flight Project

Capturing Complexities of Hybrid Architectures

Adv Air Transport Tech

PMAD Research & Integrated Systems IronBird

Convergent Aeronautics Solutions

~2500lb

Spiral Development for MW scale

Risk Reduction for kW airplane

Team Seedling

Risk Reduction Testing for Airplane

Small Business Initiative Research

Turbo-Generator

SBIR/METIS/Phase II

Lightweight turbine generator (40 kW)

ePHM

SBIR/ESAero/GA/Phase II

Fault tree and failure mode, effects and criticality analysis

HEIST

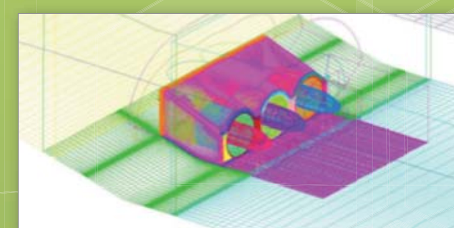
SBIR/ESAero/Phase III

IronBird instrumentation and data acquisition

Boundary Layer Ingestion Efficiency

LEARN/RHRC/Phase II

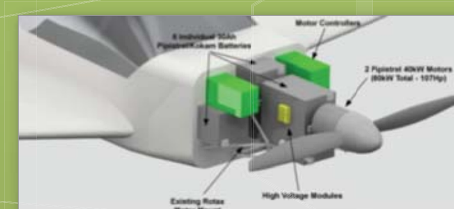
Characterize propulsion airframe interaction using closely spaced ducted electric motors



A/C Conversion Study

STTR/RHRC/Phase II

Modular flight testbed for studying various hybrid architectures



(The purpose of flight research) is to separate the real from the imagined problems and to make known the overlooked and the unexpected.

— *Hugh L. Dryden*

Questions?

NASA

Quotes

- The first thing we want to do is test the technology in small aircraft. In long term the drive system will also be used in large-scale aircraft. “It may be small but it’s a start on the road to the VoltAir.” – *EADS (Cri-Cri), 2011* 25 years to Transport
- The packaging of old ideas using new technologies. The question is how to enable this creative wackiness to thrive within an industry that is increasingly averse to risk, and with a customer base that is increasingly unwilling to fund R&D that does not promise to deliver near term capabilities. – *Avweek, October 2012*
- “Real Scientists” steered clear of such low-payoff frontiers, preferring to focus on research that could yield useful technologies and solve well-defined problems in the near-term. However, play it safe research aimed at achieving technology evolution rarely leads to revolutionary break-throughs. – *Frontiers of Propulsion Science (Rutan), 2009*