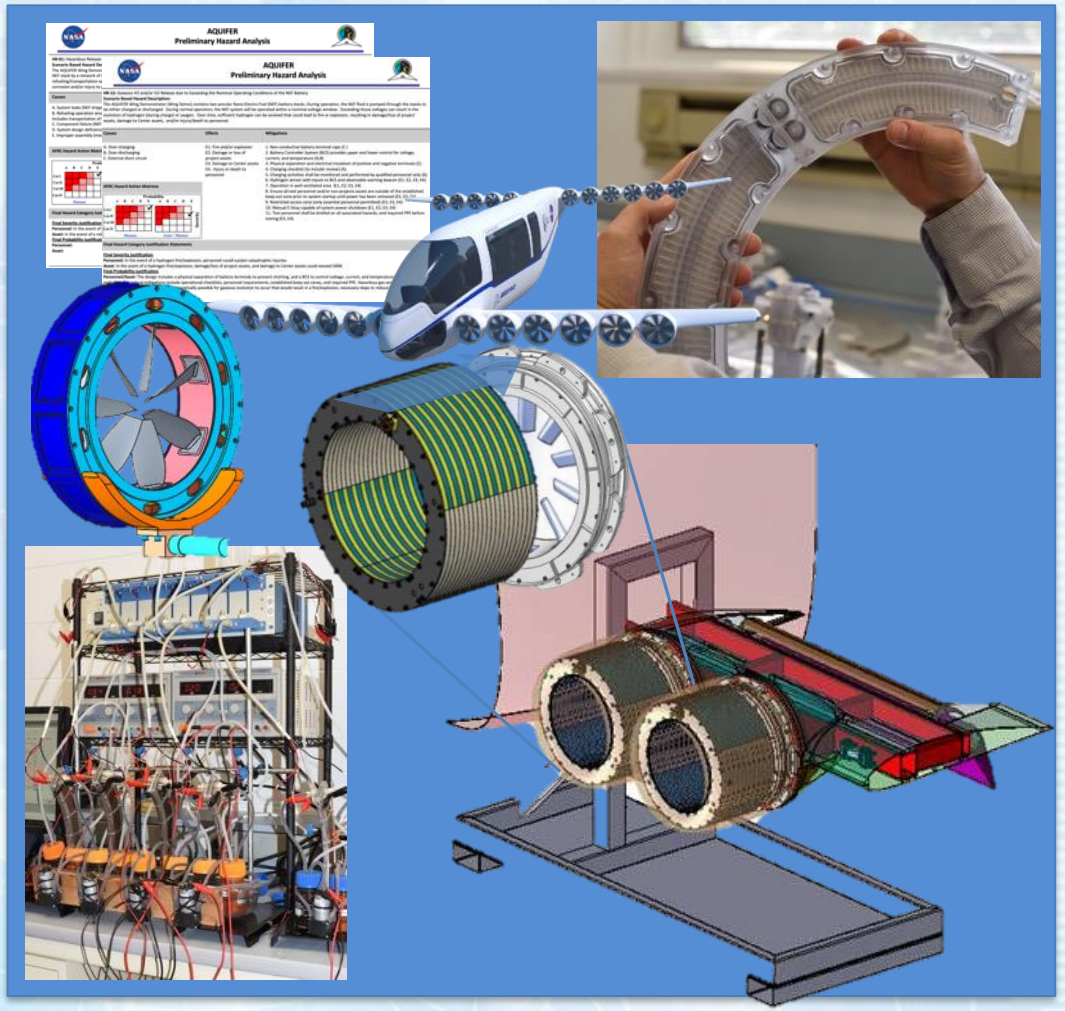
Aqueous, Quick-charging battery Integration For Electric flight Research (AQUIFER)

- **Idea/Concept:**

Aqueous QUick-charging battery Integration For Electric flight Research (AQUIFER) subproject is investigating the technological feasibility of Nano-Elector Fuel (NEF) batteries integrated with Rim-Driven Motors (RDMs) to retire fire and explosion hazards, decouple power and energy, and reduce EMI and acoustic signature for multiple electrified aircraft configurations.

- **Transition opportunities/status:**
  - Space Act Agreement annex with Boeing completed and both parties producing value for AQUIFER (NASA) and ZEST (Boeing)
  - Looking into flying test within the Flight Demonstration Capabilities project
  - Looking at bearing and motor testing within Revolutionary Vertical Lift Technologies project
  - Intelligence Advanced Research Projects Activity (IARPA) identifying AQUIFER acoustics test at Langley as a partnership to include air bearing solution

- **Current status/Feasibility Criteria:**
  - NEF technology demonstrated to retire both fire and explosion hazards for a battery technology (other than multiple simultaneous failures to non-related systems)
  - NEF final feasibility criteria: 100 mA/cm^2 discharge
    - Initial (pre-CASTInG) charge/discharge values: 5 mA/cm^2
  - NEF discharge current density 15 mA/cm2
  - NEF charging demonstrated to 40 mA/cm2 (4x improvement from time of CASTInG),
  - RDM fans (RDF) complete and first blade set delivered



Participating Centers: AFRC, GRC & LaRC
External Collaborators: Boeing, ES Aero, Influit, Engineer Precision, Electricore

Current Status

- All 3 contractors (ESAero, Influit, and Engineering Precision) under contract
- Space Act Agreement with Boeing finalized
- CAS Touch Point 1, 2, and 3.1 & 3.3 completed
- CAS Touch Point 3.2 scheduled for – 9/23/19
- Nano-electrofuel (NEF) preliminary design review completed – 5/21/19
- NEF changing demonstrated to 40 mA/cm^2 (4x improvement from time of CASTInG), but subsequent discharge was poor, may have secondary reaction occurring – 9/10/19
  - Discharge data still being tested, will update when available
  - CAS Feasibility metric is 100 mA/cm^2 discharge
  - NASA SME's present during testing (Pat Loyselle & Bri Demattia)
- Rim-driven fan (RDF) design completed, 3-D printed, to be delivered on 9/15/19
- In negotiations with AFRL and IARPA to investigate air bearings for Rim-Driven Motor (RDM) in the Langley acoustics tunnel (LSAWT)
- NEF, RDM, and Wing Demo critical design review scheduled for 11/13/19 and 11/14/19

AQUIFER

Aqueous, **QU**ick-charging battery **I**ntegration **F**or **E**lectric flight **R**esearch

National Aeronautics and Space Administration

Determining technology feasibility of non-flammable / non-explosive Nano-Electro Fuel (NEF) batteries and acoustically-superior Rim-Driven Motors (RDMs) with air-bearings for electric flight

Overview / Description

The NEF is a new take on tradition flow battery, with anode and cathode fluids pumped across a membrane to create an electric current, and suspends specially-coated nano-particles to drastically improve the energy carrying capacity of the fluid. Until very recently, flow batteries were only feasible in large, terrestrial grid-power installations where weight wasn't a design driver. But with these new breakthroughs in nano-particle coating, the electric potential of the fluid can be dramatically improved, increasing the nano-particle density in the fluid from single-digit weight percentage to as high as 80%, while still maintaining the ability to pump the fluid. Another significant benefit of a fluid battery concept is the ability to pump the fluid in and out of the system and charge the fluid off-board at a designated charging station, therefore reducing the "charging" time of this electric propulsion concept to the time it takes to pump out the discharged fluid and pump in the charged fluid. Current estimates suggest the fluid can be recharged 1000 times before needing to be reformulated.

The RDM concept is an electric motor without a hub and driven from the outer circumference to reduce the fan tip Mach number (and therefore noise signature). The RDM technology was investigated as part of the AFRL's Great Horned Owl (GHO) project, but was ultimately not chosen because the outer bearings (roller) did not achieve the noise levels required. While AFRL chose to go in a different direction, there was a desire to continue the concept, with an air or magnetic bearing system. NASA, Boeing, Intelligence Advanced Research Projects Activity (IARPA), and Engineering Precision are actively investigating a novel air-bearing solution for the 14" RDMs, to realize the acoustics advantages of removing hub and mechanical bearing systems.

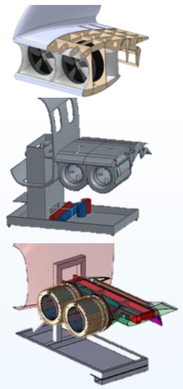
NASA / Boeing Collaboration

BOEING

ZEST
with AQUIFER "vision system"

NASA

Wing Demo
with AQUIFER "GEN 1"



Feasibility Assessment

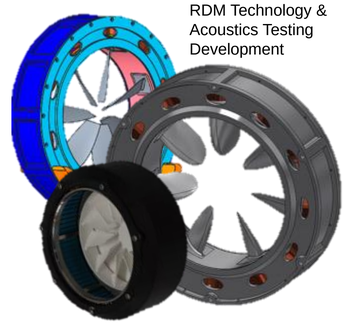
Electric Propulsion Barriers

- ✗ Fire / Explosion Hazards
- ✗ Recharging Time
- ✗ Radiated EMI
- ✗ Coupled Power & Energy
- ✗ Range Limitations
- ✗ Noise Concerns

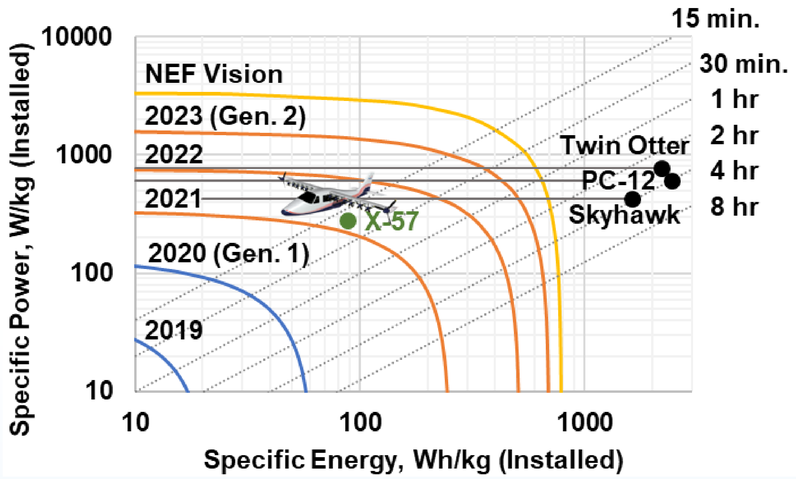
AQUIFER Technology Benefits

- ✓ Aqueous fuel
- ✓ Charging time equal to fuel pumping
- ✓ Co-locating power & energy, no long cables
- ✓ Need more power – more stack area
- ✓ Need more range – more fuel
- ✓ No hub or blade-tip interference noise

Adapting & Developing NEF Technology (GEN 1)



RDM Technology & Acoustics Testing Development



Current NEF GEN 1 specific energy estimate:	10-29 Wh/kg
GEN 1 max specific energy estimate:	81 Wh/kg
X-57 Battery System (installed):	125 Wh/kg
NEF GEN 2 max theoretical specific energy:	745 Wh/kg

Partners

- **Armstrong Flight Research Center (AFRC) –** *PI; Integration Center; test stand development & instrumentation; determining feasibility of system*
- **Glenn Research Center (GRC) –** *Co-PI; RDM system analysis, controller development & design development support; NEF battery development support*
- **Langley Research Center (LaRC) –** Co-PI; *Aircraft studies, System ConOps and market fit; acoustic estimation for blades and motor bearings*
- **Boeing –** *electric short takeoff and landing vehicle concept; system consulting & analysis; cost-sharing partnership*
- **ESAero –** *Prime contractor; NEF / motor integration, design, testing & demonstration*
- **Influit Energy –** *NEF battery development*
- **Engineering Precision –** *RDM design & development*
- **Electrocore –** *Project support; battery industry research*
- **IARPA –** *Interagency partnership investigating air-bearing acoustics (pending)*

Recent Results / Status

- Completed Touch Point 3.2 – NEF discharge performance measured to 15 mA/cm^2
- Project pivot from NEF GEN 1 to NEF GEN 2 (air/anolyte chemistry) and conventional ring bearings to air-bearings
- In process of completing interagency agreement with IARPA for air-bearing acoustics testing

Next Steps

- Air-bearing final design: Nov '19
- Prototype build of RDM with air-bearing: Jan '20
- NEF GEN 2 hardware test setup operational: Mar '20
- Acoustics testing at NASA Langley: Apr '20

CONVERGENT AERONAUTICS SOLUTIONS

Principal Investigator: Kurt Papathakis (AFRC) – kurt.papathakis@nasa.gov
Co-Principal Investigator: Pat Loyselle (GRC) – patricia.l.loyselle@nasa.gov
Co-Principal Investigator: Robert McSwain (LaRC) – robert.g.mcswain@nasa.gov