Electric Propulsion Platforms at DFRC

Jonathan Barraclough, DFRC/RF

NASA Dryden Flight Research Center is a world-class flight research facility located at Edwards AFB, CA. With access to a 44 sq. mile dry lakebed and 350 testable days per year, it is the ideal location for flight research. DFRC has been undertaking aircraft research for approximately six decades including the famous X-aircraft (X-1 through X-48) and many science and exploration platforms. As part of this impressive heritage, DFRC has garnered more hours of full-sized electric aircraft testing than any other facility in the US, and possibly the world. Throughout the 80's and 90's Dryden was the home of the Pathfinder, Pathfinder Plus, and Helios prototype solar-electric aircraft. As part of the ERAST program, these electric aircraft achieved a world record 97,000 feet altitude for propeller-driven aircraft. As a result of these programs, Dryden's staff has collected thousands of man-hours of electric aircraft research and testing.

In order to better answer the needs of the US in providing aircraft technologies with lower fuel consumption, lower toxic emissions (NOx, CO, VOCs, etc.), lower greenhouse gas (GHG) emissions, and lower noise emissions, NASA has engaged in cross-discipline research under the Aeronautics Research Mission Directorate (ARMD). As a part of this overall effort, Mark Moore of LaRC has initiated a cross-NASA-center electric propulsion working group (EPWG) to focus on electric propulsion technologies as applied to aircraft. Electric propulsion technologies are ideally suited to overcome all of the obstacles mentioned above, and are at a sufficiently advanced state of development component-wise to warrant serious R&D and testing (TRL 3+). The EPWG includes participation from NASA Langley Research Center (LaRC), Glenn Research Center (GRC), Ames Research Center (ARC), and Dryden Flight Research Center (DFRC). Each of the center participants provides their own unique expertise to support the overall goal of advancing the state-of-the-art in aircraft electric propulsion technologies. DFRC will leverage its vast experience in flight test to assist in the integration and flight test phases of any electric propulsion program.

DFRC's core competencies, that have particular relevance to the goals of the EPWG, include flight research planning and execution and providing aircraft test beds for researching and testing electric propulsion concepts and equipment. There are three flight regimes that the EPWG is focusing on: subsonic small GA and UAV, subsonic transport class, and supersonic. DFRC proposes two classes of test bed aircraft, to answer the early- and mid-phase testing requirements of all flight regimes the EPWG is concerned with. First, a highly efficient PIK motor glider will be used to test concepts and equipment associated with the subsonic GA and UAV aircraft regime (N+1). Second, a small fleet of subscale remotely-piloted aircraft test beds, similar to the X48B Blended Wing Body aircraft tested at Dryden, will be developed to answer the unique testing requirements of the subsonic GA and UAV, subsonic transport and possibly the supersonic class of aircraft (N+2, N+3). These aircraft can be tested in either serial stages or concurrent stages, depending on the actual test requirements and program schedules. Both classes of test bed aircraft are described below.

<u>Stage 1 Aircraft:</u> The PIK-20 E motor glider (Figure 1), currently located at DFRC, is a highly efficient motor glider platform originally used for laminar flow and low Reynolds number flight research in the late '80s. The PIK has a 15m wingspan and is constructed of epoxy resin laminates with load-critical areas reinforced using carbon fiber spars. The motor glider currently has a Rotax 46 hp 2-stroke engine with a 2-blade fixed pitch propeller mounted on a retractable arm. The PIK, with the motor retracted, is capable of an L/D of 41 with a minimum sink rate of 138 fpm at 55 mph. The PIK is an ideal low-cost platform for testing basic electric propulsion systems and components. This aircraft would serve two main purposes. First, it would familiarize Dryden flight test personnel with the unique test requirements and current state-of-the-art technologies in electric propulsion components and systems. Second, it would provide real-world test data of unique components and concepts deemed useful to the overall goals of the EPWG. The following are some of the areas that can be tested using the PIK as a platform:

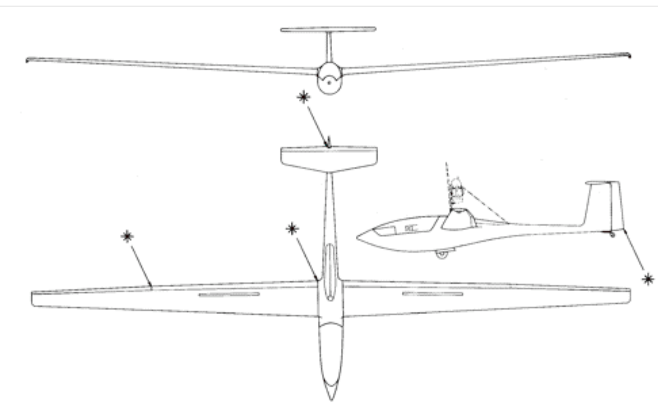


Figure 1: PIK-20 E Motor-Glider

<u>Electric motors and speed controllers:</u> proper sizing methods/calculations, distributed propulsion (wingtip motors, embedded wing/fuselage motors), optimum motor and drive topologies for electric flight, mounting considerations, thermal performance and cooling methods, integrated thrust and torque sensors for real-time efficiency feedback, altitude performance, EMI/EMF mitigation, mechanical loads (thrust bearings, off-axis gust loading, etc.), and many more.

<u>Batteries / Energy Storage:</u> proper sizing methods/calculations (voltage and capacity), optimum chemistries for electric flight, thermal performance and cooling/heating methods, cycle life degradation, safety mitigation strategies, distributed packs, robust battery management system (BMS) requirements, state-of-charge (SOC) determination, roundtrip efficiency performance, robust interconnection strategies, vibration performance and mechanical mounting, and many more.

<u>Hybrid configurations:</u> fuel cell (hydrogen, methanol, etc.) performance vs. altitude / temperature, fuel cell stack pressurization and humidification requirements, series-hybrid power management schemes, engine-generator performance

considerations, super-capacitor augmentation testing, alternative fuels testing, emissions modeling, fuel storage and safety considerations, and many more.

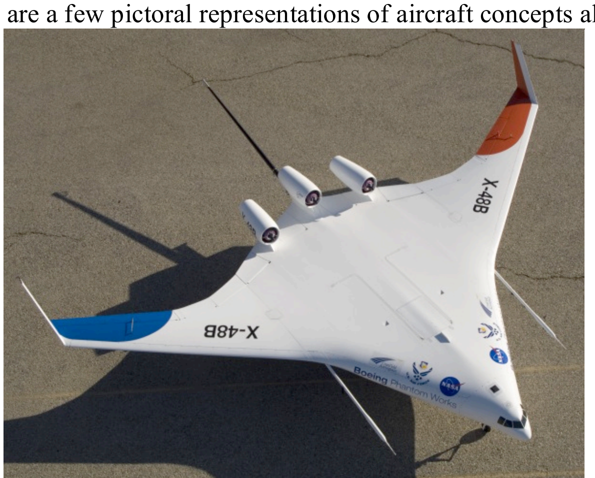
Propellers: low-noise propeller design, design requirements and optimization for electric drive, distributed propulsion, variable pitch and real-time efficiency control loops, mechanical mounting and off-axis loads, materials and weight optimization, and many more.

Advanced aerodynamics: laminar flow research, boundary layer ingestion (BLI) propulsors, distributed propulsion / wing-tip propulsion, dynamic lift enhancement, STOL / CESTOL research, and many more.

Stage 2 Aircraft: Whereas the PIK is ideal for early stage electric propulsion component research and testing, it does not lend itself well to advanced integrated designs (N+2, N+3). Much of the advantage of using electric propulsion on aircraft can only be obtained through an integrated systems approach, designing from the ground up. Advanced aerodynamic and structural concepts must be used in conjunction with electric propulsion to maximize the performance of the overall aircraft, placing it on par with the performance of conventional fueled aircraft. To answer this unique requirement cost-effectively, a small number of scale test vehicles, similar to the X-48B (image below), can be fabricated for flight research purposes. The X-48B test program at Dryden has been a decided success, and can provide a pattern for flight-testing other scale aircraft with precise design requirements. The following are a few of the research areas that can be explored using this class of aircraft:

- Blended-wing bodies
- Distributed electric fan propulsion (currently a DARPA-funded area of research)
- Super-conducting electric motors/generators
- Wing/fuselage-embedded propulsion
- Boundary layer ingestion, and other laminar flow extension concepts

Below are a few pictoral representations of aircraft concepts already proposed by members of the EPWG.



Conclusion: DFRC, with its historic electric aircraft test programs and many years of flight research experience, is perfectly suited to carry out the electric aircraft research programs envisioned by the inter-NASA-Center EPWG. DFRC would take a two-stage approach. First, test electric propulsion components and systems, as well as advanced aerodynamic concepts, onboard the highly efficient and currently available PIK-20 E motor glider. This stage would not only provide valuable real-world flight test data for salient electric propulsion components and concepts, but also serve to sharpen the skills of the current Dryden Flight Test Engineer workforce in the unique area of electric aircraft propulsion. Second, test advanced aerodynamic and aero-propulsive concepts using a small fleet of unconventional purpose-designed subscale unmanned aircraft. This stage would enable the research of integrated designs that promise substantial advances in aircraft performance. The completion of these two stages will ideally result in an aircraft, technology, or concept ready for advancement to either a full-size aircraft flight research program or actual industry product development.