X-57 Maxwell Aircraft

EMI/EMC Integration Lessons Learned

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Motivation for X-57 Mod II; Retiring Electric Propulsion Barriers

- Raises the TRL of EP components and improves the airworthiness assessment capability in order to independently inform certification authorities
  - Mature high voltage lithium batteries with intrinsic propagation prevention and passive thermal management
  - Establish motor/inverter ground and flight test program
  - Design a crew interface and human factors approach to manage workload for complex propulsion systems
- Provides a pathfinder for aircraft electric traction system standards
  - Lessons learned used to inform FARs and standards
- Reduces electrified system development risk for a Mod III and IV configuration through early testing on a proven vehicle configuration
- Develops capability within NASA to design, analyze, test, and fly electric aircraft

The value of X-57 lies in advancing the Nation's ability to design, test, and certify electric aircraft, which will enable entirely new markets (AAM)

X-57 Final system integration and test

https://nasa.gov/x57/technical

Inverter & Battery Compatibility

- Perfect storm for incompatibility
  - SiC-based inverter with minimal gate rise/fall time and wideband DC bus capacitance
  - DC distribution bus uses “flat” ribbon-like cable resulting in extremely low inductance
  - Battery module sensor boards are coupled to the cells without filterer or a drain to ground
- Resulted in loss of battery module comms when inverters were active (even while power delivery was good)
- Fix is tuned to the flight hardware
  - Measured noise on actual flight units
  - Developed custom T-filter to absorb switching transients between inverter and battery

Custom Flat Cable

Common-mode T-Filter

Hardware test setup using X-57 batteries, inverter, motor

Conducted Interference from Inverter/Motor

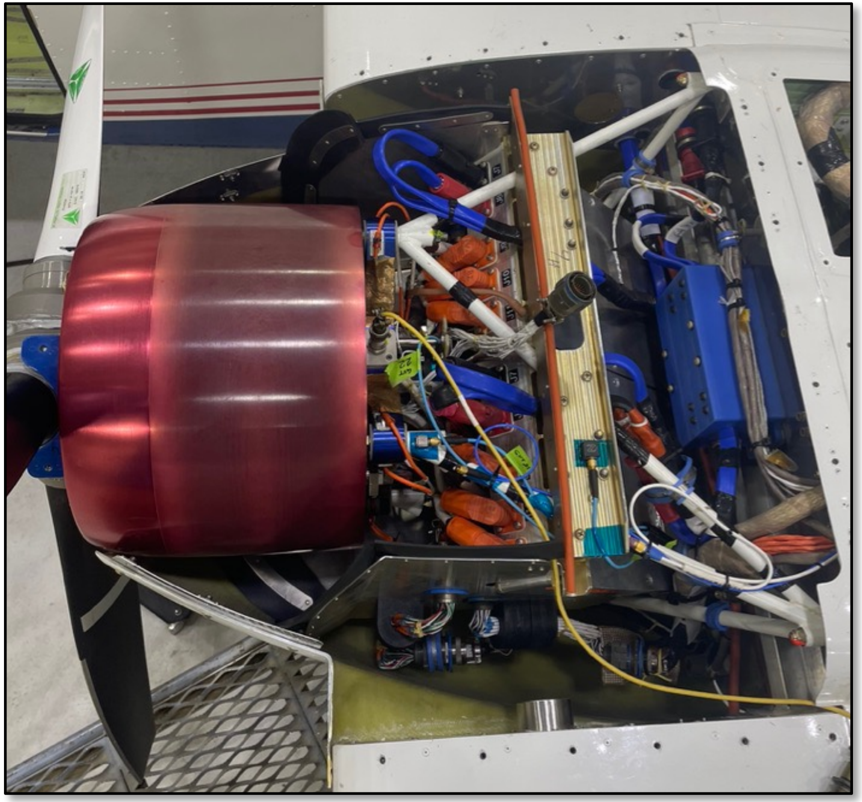
- Grounding design vs reality
  - Battery, Inverter, Motor were intended to be isolated from vehicle structure and other system grounds.
  - Tight clearances between case/heatsink, mounting structure, baffles, vibration mounts resulted in multiple rounds of 'surprise' ground paths
- Inverter/motor act as a system and must be solidly bonded
  - EM coupling between rotor and stator induced current to flow through bearings and into vehicle structure
  - Spare slipring channel is used to drain rotor currents to CMC chassis/T-filter

Close quarters in the nacelle resulted in unintentional grounding

Slip ring must be rugged and provide reliable rotor-stator coupling

Tolerating Residual Radiated Interference

- Electric Engines have many adjacent systems
  - Prop governor (actuator and speed pickup), tachometer, blade angle sensor, motor and air duct temperature sensors, accelerometers, and strain gages are all within inches of the inverter/motor.
  - Remote aircraft systems also saw switching noise including instrumentation throughout the vehicle, annunciator panel, audio comms, and flap indicator/controller.
- Contain and absorb the noise at the nacelle
  - Common-mode chokes were installed on all wiring bundles that entered the electric engine bay
  - Grounding improvements were made to stock systems: don’t use structure for power return path, route return with supply and use shields with drains.



Electric Engine Nacelles includes many proximate subsystems and this one includes many common-mode chokes

Informing the path forward for electrification

- NASA is furthering innovation challenge
  - Open and able to inform entire industry
- Lessons learned provided to the FAA to inform standards and regulations
- Generating the technical basis for new standards and thresholds
- NASA subject matter experts participating in working groups and standards bodies
- Lessons learned fed into EPFD

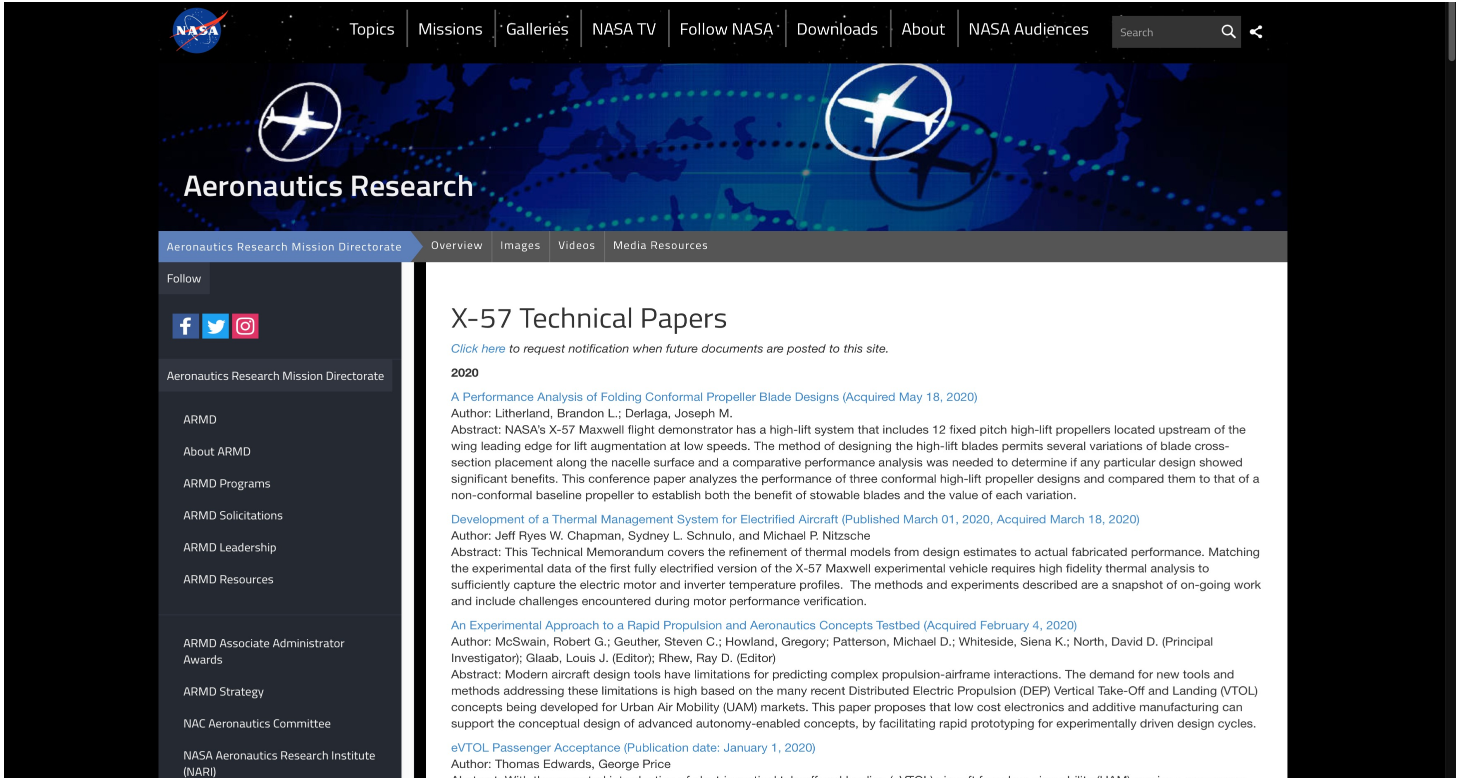
X-57 Knowledge Transfer: Make More Documents Available

- Internal document library includes over 640 documents and counting
  - Wide ranging and includes overall vehicle and project architecture information, insight into how design and airworthiness is assured for flight
    - Descriptions of the vehicle systems and how engineering and operations crew interface with the system in design, maintenance, and flight modes
  - Includes Project Plans, Requirements, Operational Plans, Verification/Validation Matrices, Specifications, Procedures, Interface Control Documents, Analyses, Safety Reports, System Test Plans, CAD
  - Flight Readiness Review, Tech Briefs, and Airworthiness Flight Safety Board documents will be produced as we get closer to Mod II flights

- Request to stakeholders: What do you want to see? What are the gaps? What types of documentation would be helpful for us to prioritize?

Further Reading

https://nasa.gov/x57/technical



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X-57 Technical Papers

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2020

A Performance Analysis of Folding Conformal Propeller Blade Designs (Acquired May 18, 2020)
Author: Litherland, Brandon L.; Derlaga, Joseph M.
Abstract: NASA's X-57 Maxwell flight demonstrator has a high-lift system that includes 12 fixed pitch high-lift propellers located upstream of the wing leading edge for lift augmentation at low speeds. The method of designing the high-lift blades permits several variations of blade cross-section placement along the nacelle surface and a comparative performance analysis was needed to determine if any particular design showed significant benefits. This conference paper analyzes the performance of three conformal high-lift propeller designs and compared them to that of a non-conformal baseline propeller to establish both the benefit of stowable blades and the value of each variation.

Development of a Thermal Management System for Electrified Aircraft (Published March 01, 2020, Acquired March 18, 2020)
Author: Jeff Ryes W. Chapman, Sydney L. Schnulo, and Michael P. Nitzsche
Abstract: This Technical Memorandum covers the refinement of thermal models from design estimates to actual fabricated performance. Matching the experimental data of the first fully electrified version of the X-57 Maxwell experimental vehicle requires high fidelity thermal analysis to sufficiently capture the electric motor and inverter temperature profiles. The methods and experiments described are a snapshot of on-going work and include challenges encountered during motor performance verification.

An Experimental Approach to a Rapid Propulsion and Aeronautics Concepts Testbed (Acquired February 4, 2020)
Author: McSwain, Robert G.; Geuther, Steven C.; Howland, Gregory; Patterson, Michael D.; Whiteside, Siena K.; North, David D. (Principal Investigator); Glaab, Louis J. (Editor); Rhew, Ray D. (Editor)
Abstract: Modern aircraft design tools have limitations for predicting complex propulsion-airframe interactions. The demand for new tools and methods addressing these limitations is high based on the many recent Distributed Electric Propulsion (DEP) Vertical Take-Off and Landing (VTOL) concepts being developed for Urban Air Mobility (UAM) markets. This paper proposes that low cost electronics and additive manufacturing can support the conceptual design of advanced autonomy-enabled concepts, by facilitating rapid prototyping for experimentally driven design cycles.

eVTOL Passenger Acceptance (Publication date: January 1, 2020)
Author: Thomas Edwards, George Price