Working Group Update

ELECTRIC PROPULSION (EP) & CONFIGURATION INTEGRATION (CI)

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Scope

- Electric Propulsion (EP)
  - Impacts operating costs, efficiency, emissions, community noise, and ride quality.
  - Propulsion systems comprised of propulsors, motors, digital motor controllers, and energy storage systems that make ODM aviation economics and carbon footprint competitive to other transportation solutions.
  - Practical Implementation: Target short range trip markets with high utilization aircraft.
  - Strategy: Near-term certification for small aircraft -> Early adoption -> Technology acceleration -> Use across larger commercial aircraft -> Significant carbon impact within 30 years to align with renewable based electricity grid
- Configuration Integration (CI)
  - Electric propulsion characteristics are drastically different than piston or turbine, with scale-free nature leading to highly inter-disciplinary and distributed integrations.
  - Integration of EP required to understand technology potential and impact.
    - Push beyond simple retrofit solutions to achieve highly synergistic solutions.
- Early flight demonstrators of hybrid-electric systems provide practical learning of fundamentally different technology issues.

On-Demand Mobility Goals

10 Prioritized Feasibility Barrier Goals

Ease of Certification	Affordability	Safety	Ease of Use	Door to Door Trip Speed	Average Trip Delay	Community Noise	Ride Quality	Efficiency	Lifecycle Emissions
Metric Time/Cost Required	Metric Total Operating Cost/Pax Mile	Metric Fatal Accidents per Vehicle Mile	Metric Required Operator Training Time & Cost	Metric mph	Metric Time	Metric Perceived Relative Annoyance @ Community Stand-off Distance	Metric Passenger Comfort Index	Metric Energy/Pax Mile	Metric Total Emissions /Pax Mile

EP & CI Contributions to ODM Goals

Safety

Metric
Fatal Accidents per Vehicle Mile

- Propulsion system redundancy through scale-free distributed propulsion.
- Digital control of thrust across airframe provides additional control with enhanced opportunities for direct coupling into flight control system.
- Top safety opportunities
  - Loss of single engine thrust source
  - Loss of control
  - Decrease in motor complexity, increase in motor reliability
  - Elimination of fuel contamination

EP & CI Contributions to ODM Goals

Affordability

<u>Metric</u>
Total Operating Cost/Pax Mile

- Lower operating cost through lower energy use and cost
  - Motors are 2 to 4x higher efficiency
  - Synergistic integration offers 1.2 to 2.0x increase in aero-propulsive efficiency
  - Electricity costs of $.07 at industrial rates and $.14 at residential rates versus $.18 for AvGas
- Motors have single moving part (bearings) that suggest lower cost and longer TBO than current reciprocating or turbine engines.

EP & CI Contributions to ODM Goals

Ease of Use <u>Metric</u> Required Operator Training Time & Cost

- Direct digital control of thrust with easier coupling to digital flight control systems.

EP & CI Contributions to ODM Goals

Door to Door Trip Speed

<u>Metric</u>
mph

- Reduced ground inspection and warm-up time
- Reduced recurring maintenance and higher reliability
- In-flight restart reliability with decreased altitude and temperature sensitivity.
- Lower community enhances closer proximity operations and reduced curfews on operations.

EP & CI Contributions to ODM Goals

Average Trip Delay <u>Metric</u> Time

- Short duration excess power availability can provide additional thrust during transient altitude icing build-up to decrease icing conditions sensitivity and weather delays.

EP & CI Contributions to ODM Goals

Community Noise <u>Metric</u> Perceived Relative Annoyance @ Community Stand-off Distance

- Dramatically lower motor noise
- Ability to take advantage of low tip speed propulsors with minimal penalties due to variable rpm capability with high efficiency, as well as enhanced integration freedom.

EP & CI Contributions to ODM Goals

Ride Quality

<u>Metric</u>
Passenger Comfort Index

- Electric motors are low vibration.
- Lower interior cabin noise.
- Aero-propulsion integration enables higher wing loading and lower gust sensitivity.

EP & CI Contributions to ODM Goals

Efficiency

Metric
Energy/Pax Mile

- Electric motors are dramatically higher efficiency than thermal combustion based motors.
  - Motors are 2 to 4x higher efficiency
- Synergistic configuration integration offers 1.2 to 2.0x increase in aero-propulsive efficiency.

EP & CI Contributions to ODM Goals

Lifecycle Emissions

Metric

Total Emissions /Pax Mile

- Same as efficiency contributions
- Electricity provides a path to the use of renewable based energy with the lowest possible carbon.

EP & CI Technology List (Existing TDSs)

- Investigation of sensitivities to revised reserve requirements, in particular for aircraft only capable of short distance trips. Work with FAA and GAMA to determine feasibility to modify regs.
- Multi-engine vehicle and pilot training requirements relating to distributed electric propulsion systems, including design practices and certification of multi-engine controller integration into the flight system to promote greater safety.
- Highly accurate energy state management/monitoring of electric aircraft, including human interface understanding issues for decision making that can account for environment and battery/hybrid state condition.
- Determination of stall speed and margin requirements for aero-propulsive coupled system comprised of distributed, independent, and highly reliable electric propulsors.
- Development and testing of a hybrid-engine system, both as parallel and series hybrid approaches to understand integration and certification issues as part of the overall bus architecture and inclusive of the battery system. Determination of requirements for certification, along with experiments that will assess requirements and provide a public dataset to assist with the certification basis. Determination of flight criticality of different hybrid integrations (i.e. range extender series hybrid integration for energy augmentation versus parallel hybrid integration for direct power augmentation).
- Optimal electric flight trajectory investigations of constant weight vehicles that have no power lapse with altitude, as well as flexible short duration power output levels with a focus on shorter range missions.
- Standards and best practices for high voltage electric propulsion systems, including understanding the sensitivity to changes in density and how to mitigate this issue.

Prior Workshop EP & CI Technology Ideas

- Active Participation in ASTM F39.05/F44 Electric Propulsion Certification Efforts
- Certification standards that capture the unique attributes of EP (single engine-out/failure/stall criteria, redundancy guidelines, partial energy loss, PAI effects).
- Standards: Energy load management/bus, recharge connectors, power quality, energy state/reserve determination and interface to pilot decision making, fault accommodation management (potential for re-use of existing standards?)
- Hybrid technologies (series/parallel architecture investigations), APU range extender (for cruise or for takeoff/landing augmentation) certification of non-flight critical and re-use of automotive engines (as TSO-like component?) manufactured with QA revisions, sensitivities of power split
- Studies of optimal electric trajectories (constant GW vehicles without lapse)
- Heat rejection/radiator design with low quality heat (and other unique attributes relating to electric propulsion thermal management)
- Reserve requirements specific to short range electric aircraft (potential for special conditions that reduce IFR 45 min + alternate range which is > design range?)
- High voltage issues identification (especially with altitude)
- High power electric motors/controllers and Power electronics module reliability
- Potential for a joint Generic Issue Paper focused on specific applications (ie. Electric VTOL or Thin-Haul Commuter?

Prior Workshop EP & CI Technology Ideas

- Leveraging of other research initiatives (i.e. DOE) efforts, investigation and comparison of various battery chemistry efforts to meet aviation specific needs, establish our priorities versus others to better understand unique contribution
- Installation mass overhead reduction of mounting/integration of EP components
- Health monitoring, prognostic system development specific to EP components, maintainability, algorithms for determination of battery state/BMS research
- Noise and control coupling investigations (phasing variable rpm signature, propulsion control augmentation)
- Manufacturing reliability and cost studies relating to EP components, determination of EP cost trends and production volume scaling potential.
- Non propulsion energy management and conservation (i.e. cabin climate control and other vehicle system energy requirements)
- EP Infrastructure: High voltage chargers, battery swapping (with certification decoupling from vehicle?) with conformity standards relating to the original vehicle certification, TSO component process use for swappable components?
- Investigation of indirect power coupling
- Secure and affordable wireless and/or optical communications for distributed EP components

Prior Workshop EP & CI Technology Ideas

- **Best practices handbooks (leveraging SAE, IEEE, AIAA, and space power systems)**
  - Energy storage safety, installation and hybrid architecture practices
  - Bus architecture/stability in harsh environments, Separation and partitioning of EP from other non-propulsion electrical system components (i.e. avionics)
  - EMI and HIRF (High Intensity Radiative Fields) sensitivity, environmental testing
  - Lightning issues relating to high voltage systems, Static electricity buildup sensitivity
  - Reliability assessment of redundant systems, Preliminary safety assessment methods, MTBF basis of EP components
  - Maintenance standards, overhaul, inspections, life limitations, TSO-like EP component standards, ability to treat different battery types similar to alternate fuels for engines
  - Catastrophic failure containment (in distributed systems) without lower level of safety
  - Component design specifications/documentation/conformity (research determines level of specificity required across components and boundaries of use)
  - Methods for establishing worst case basis for distributed EP systems, safety criticality
  - EP component software certification guidance (based on implicit safety criticality)
  - Crashworthiness of energy storage systems (use of fuse links), protection solutions
  - Comparative component performance and expert EP component trend predictions