Incorporation of Electrical Systems Models into an Existing Thermodynamic Cycle Code

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Overview

- **Background**
  - **NPSS – the existing thermodynamic code**
  - **NASA electrical systems modeling**
- **Incorporation of electrical systems models into NPSS**
- **Basic inputs and outputs**
- **Sample results**
- **Limitations of the codes**
- **Future plans and possible analyses**
- **References**
- **Contact information**

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NASA Electrical Systems Modeling

High-altitude, long-endurance aircraft power and propulsion

- Colozza, Anthony J., *Effect of power system technology and mission requirements on high altitude long endurance aircraft*, NASA CR-194455
- An analysis that determined how various power system components and mission requirements affect the sizing of a solar and regenerative fuel cell-powered long endurance aircraft

Planetary science aircraft power and propulsion

- Colozza, Anthony J., Miller, Christopher J., Reed, Brian D., Kohout, Lisa L., and Loyselle, Patricia L., *Overview of Propulsion Systems for a Mars Aircraft*, NASA TM-2001-210575
- An exploration of Mars aircraft propulsion systems with an emphasis on the constraints of the Martian atmosphere

High-altitude stationkeeping airship power and propulsion

- Ongoing studies addressing different missions and concepts including earth science, communications, and surveillance

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NASA Electrical Systems Modeling

Flywheel electrical power storage

- Truong, Long V.,Wolff, Frederick J., and Dravid, Narayan V., *Simulation of a Flywheel Electrical System for Aerospace Applications*, NASA TM-2000-210242
- A flywheel electrical system model was developed as a replacement for the battery system of the International Space Station
- Model included a permanent magnet synchronous motor/generator, power electronics, system controller and the flywheel

General aviation power and propulsion

- NASA FY02 internal study of the feasibility of fuel cell-powered general aviation aircraft and the technology improvements required for the application
- Larger 50 and 100-place aircraft were also analyzed at a lower level of fidelity to determine scalability of systems

Fuel cell Auxiliary Power Units (APUs) for commercial aircraft

- Current NASA contract with Boeing to study the replacement of the current gas turbine aircraft APU with a fuel cell-powered APU on future commercial aircraft

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Why NPSS?

- Integration of entire system
  - Fuel cells, motors, propulsors, thermal/power management, compressors, etc.
- Use of existing, pre-developed NPSS capabilities
  - Optimization tools
  - Gas turbine models for hybrid systems
  - Increased interplay between subsystems
  - Off-design modeling capabilities
  - Altitude effects
  - Existing transient modeling architecture
- Easier transfer between users and groups of users
- General aerospace industry acceptance and familiarity
- Flexible analysis tool that can also be used for ground power applications

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Basic I/O: Gas Turbines

- Inputs
  - Mach no. and altitude are main input for cycle deck
  - Design point conditions such as compressor design pressure ratio and speed
  - Primary performance data for components are typically input in a performance map or table
  - Other correlations from experimental data, CFD, etc.
- Outputs
  - Thrust, fuel and air flow, power, node thermodynamic data such as pressures, temperatures
  - Outputs are typically organized in a form that is readable for airframe sizing codes

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Basic I/O: Electrical Systems

- Inputs
  - Design point conditions such as fuel cell current density, motor rotational speed
  - Any performance data or correlations such as motor power/speed/efficiency map or fuel cell polarization curve
  - Fuel and airflow characteristics
- Outputs
  - Power, fuel and air flow, physical requirements for the fuel cells, node thermodynamic data such as pressures, temperatures
- Data is transferred to and from gas turbine components depending on the system design

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Sample results

- NASA ZeroCO_2 Project (FY02)
  - First application of the integrated thermodynamic cycle analysis/electrical systems model
  - The objective was to determine the feasibility of electrically-powered flight and identify the technology required for success
  - Two general aviation airplanes were chosen as baseline airframes and electrical systems were developed and analyzed within those systems
  - Larger airplanes were included at a lower fidelity to provide further insight into scalability
  - A summary paper and presentation were prepared as the final deliverables

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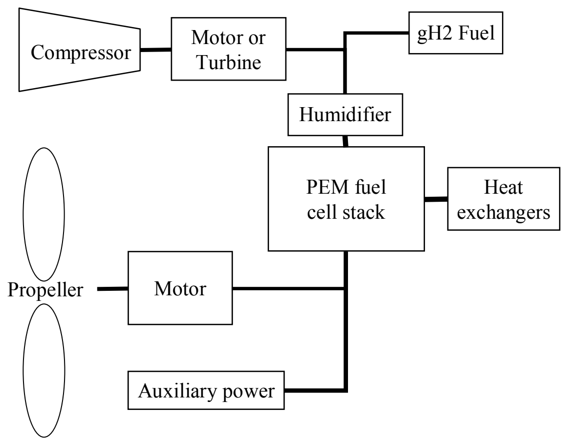
ZeroCO$_2$ Model Organization



- **Model can evaluate altitude and Mach Number effects on entire system**
- **For example:**
  - **High altitude, low Mach Number**
    - **More compressor power required for constant fuel cell inlet pressure**
      - **Therefore, less fuel cell power available for propeller motor**
        - **And less propeller thrust**

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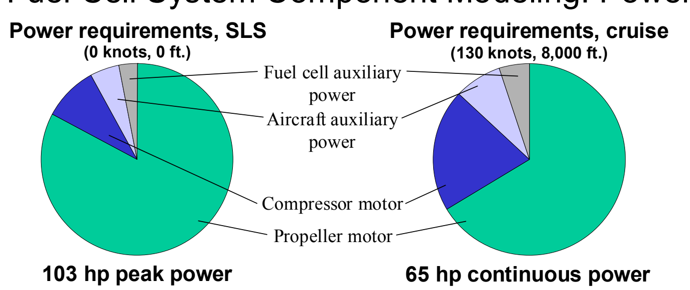
ZeroCO$_2$ Results

PEM Fuel Cell System Component Modeling: Power



- Propeller: 79% of total power at SLS, 62% of total power at cruise
- Compressor: 9% of total power at SLS, 19% of total power at cruise
- Auxiliary powers remain constant, therefore higher percentage at cruise

➢ Percent power to propeller motor decreases with altitude due to increased compressor requirements

AT Electric Power and Propulsion Modeling — NASA Intercenter Systems Analysis Team, ZeroCO$_2$ FY02 Final Presentation 7

* Reference 2

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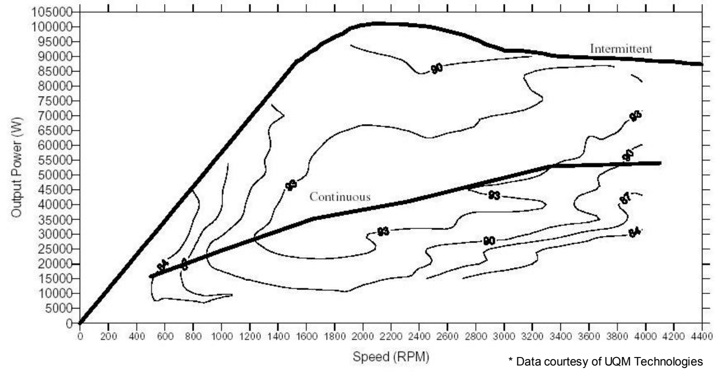
ZeroCO$_2$ Results

Electric Motor Modeling

- Motor efficiency map vs. power and speed from Unique Mobility data
- The map was coded into NPSS and provided a more accurate efficiency value over off-design conditions



* Data courtesy of UQM Technologies

Electric Power and Propulsion Modeling

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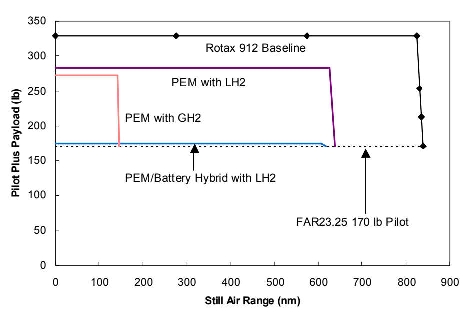
ZeroCO$_2$ Results

MCR01 ULM Fuel Cell Conversion

Payload-Range Assessment (Rotax and Current Technology Fuel Cell Engines)

Concessions Made for Fuel Cell Installation:

- Reduced power propulsion system relative to Rotax 912.
- Reduced payload / pilot baggage.
- Reduced cruise speed and altitude.
- But, with these weight, performance, and packaging assumptions, it *does work!*



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* this chart produced with output data from NPSS used as input for FLOPs airframe sizing code

* Reference 4

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Model Limitations

- NPSS was not designed as an electrical systems software package
  - Retrofit has not been difficult, but further detail may be challenging
- NPSS primarily developed and maintained at NASA
  - Funding and personnel required for new components and algorithm/configuration changes
  - Validation of software also requires
- Electrical components have been developed in-house and validation of electrical system has not been completed due to lack of funding/personnel

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Future Plans

- Model improvement
  - Solid oxide fuel cell and reformer models are currently being incorporated in partnership with the National Fuel Cell Research Center
  - Electric motor and power electronics models are being improved in partnership with other NASA GRC offices
  - Possible sources for higher-fidelity electrical systems models are being investigated for tie-in with NPSS
- Model validation
  - NASA GRC is developing an electrical systems testbed for development and testing of entire electrical system for aerospace applications and model validation

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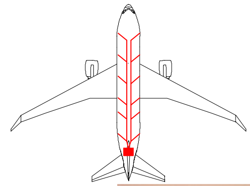
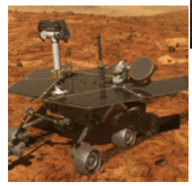
Potential Future Analyses



- Full electric auxiliary power unit for airplanes with fuel cell as primary power source
- Electrical high-altitude, long-endurance airplanes/airships
- On-board space electrical power sources
- Ground power applications such as distributed, hybrid fuel cell/gas turbine systems



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References

1. NPSS User’s Guide and Reference, NASA Publication, 2002
2. ZeroCO_2 Final Summary Presentation, NASA Publication, September 2002
3. PowerPhase100.pdf, www.uqm.com/Technologies/products.html, UQM Technologies, Boulder, CO
4. FLOPs Manual, NASA Publication, 2002
5. Computer Program for Calculation of Complex Chemical Equilibrium Compositions and Applications, NASA RP 1311

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Contact Information

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