Preliminary Dynamic Modeling of a Quarter-Scale Distributed Electric Propulsion Aircraft

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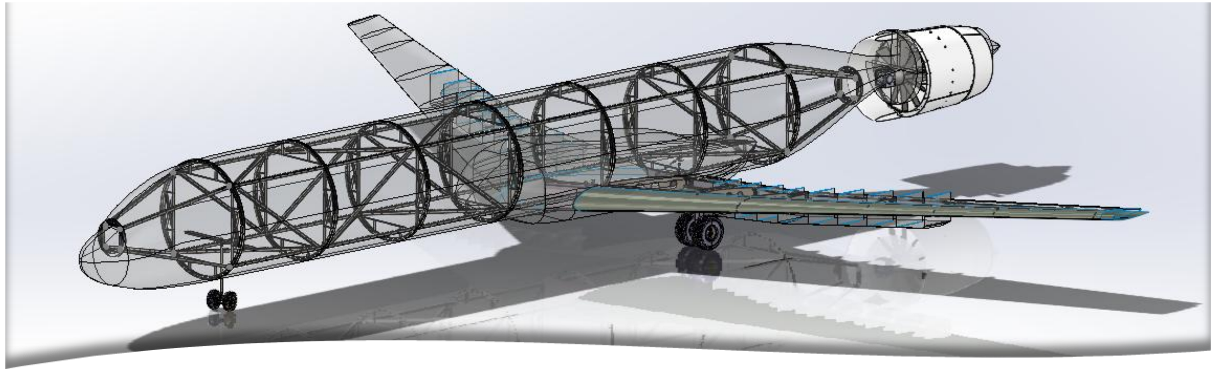
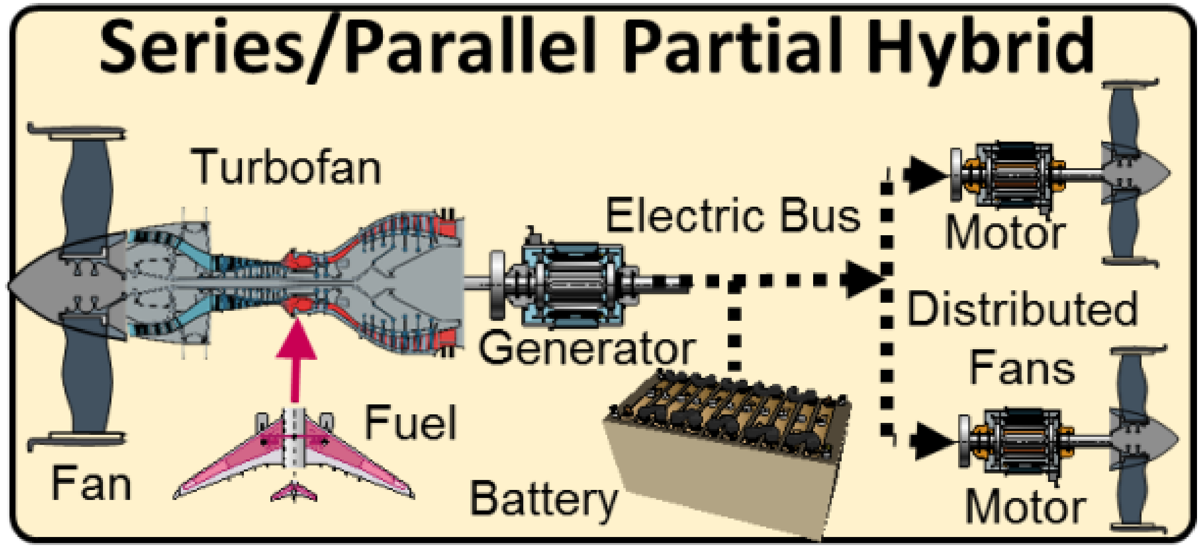
Objective

- To create a quarter-scale dynamic model of a distributed propulsion aircraft
  - The planned vehicle was to fly
  - The powertrain architecture was specified
  - The planned vehicle was to have no tail so it would require integrated flight and propulsion control with thrust vectoring
- The model described here gets part way to the final product



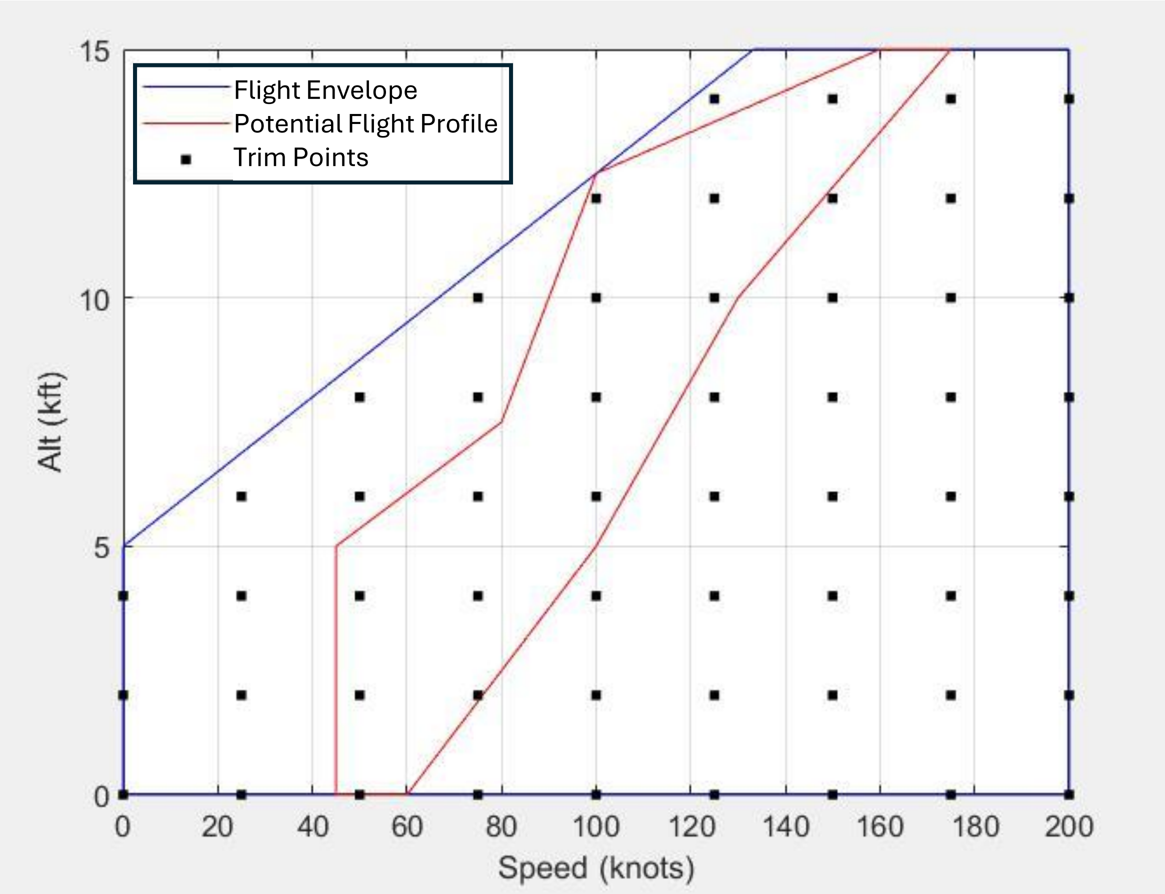
Starting Point

- Had a working full-scale model of a distributed electric propulsion concept aircraft with a series/parallel partial hybrid powertrain
- Had a design for the quarter-scale series/parallel powertrain and integrated thermal management system
- Had some characterized hardware components



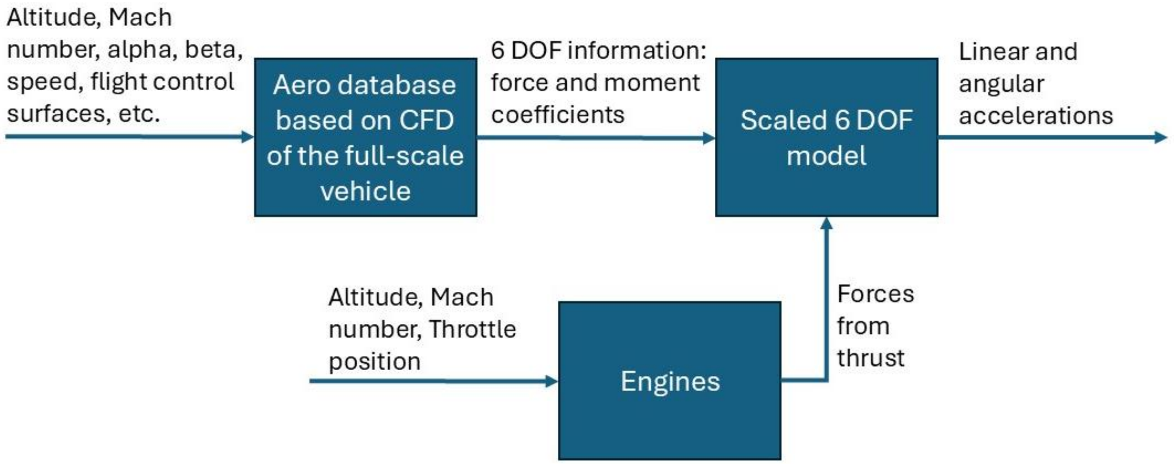
Subscale Design Flight Envelope

	Nominal Altitude (ASL)	Nominal Speed (knots)	Max Altitude (ASL)	Max Speed (knots)
Takeoff	0	45	0	60
Climb	Between 0 and 10,000 ft	45 to 130	Between 0 and 15,000 ft	60 to 175
Cruise	10,000 ft	130	15,000 ft	175
Descent	Between 10,000 and 0	130 to 45	Between 15,000 and 0	175 to 60
Landing	0	45	0	60



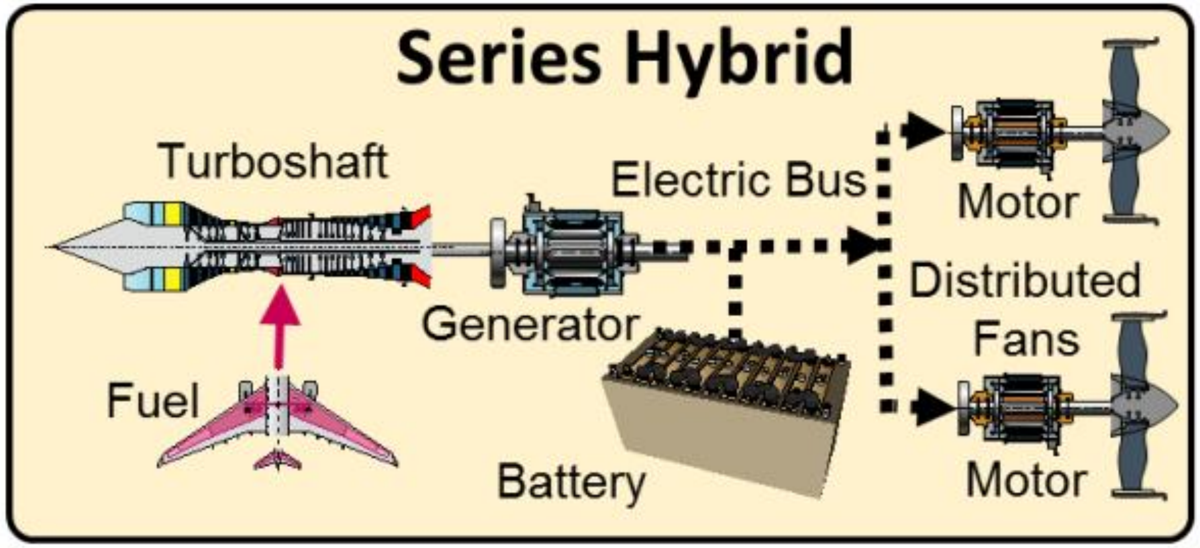
Airframe

- Used the full-scale airframe (with tail) aerodynamic database, but scaled down to appropriate size
- Scaling approach is the same as that used to related subscale wind tunnel models the full-scale vehicle performance
- The powertrain data comes from the subscale design



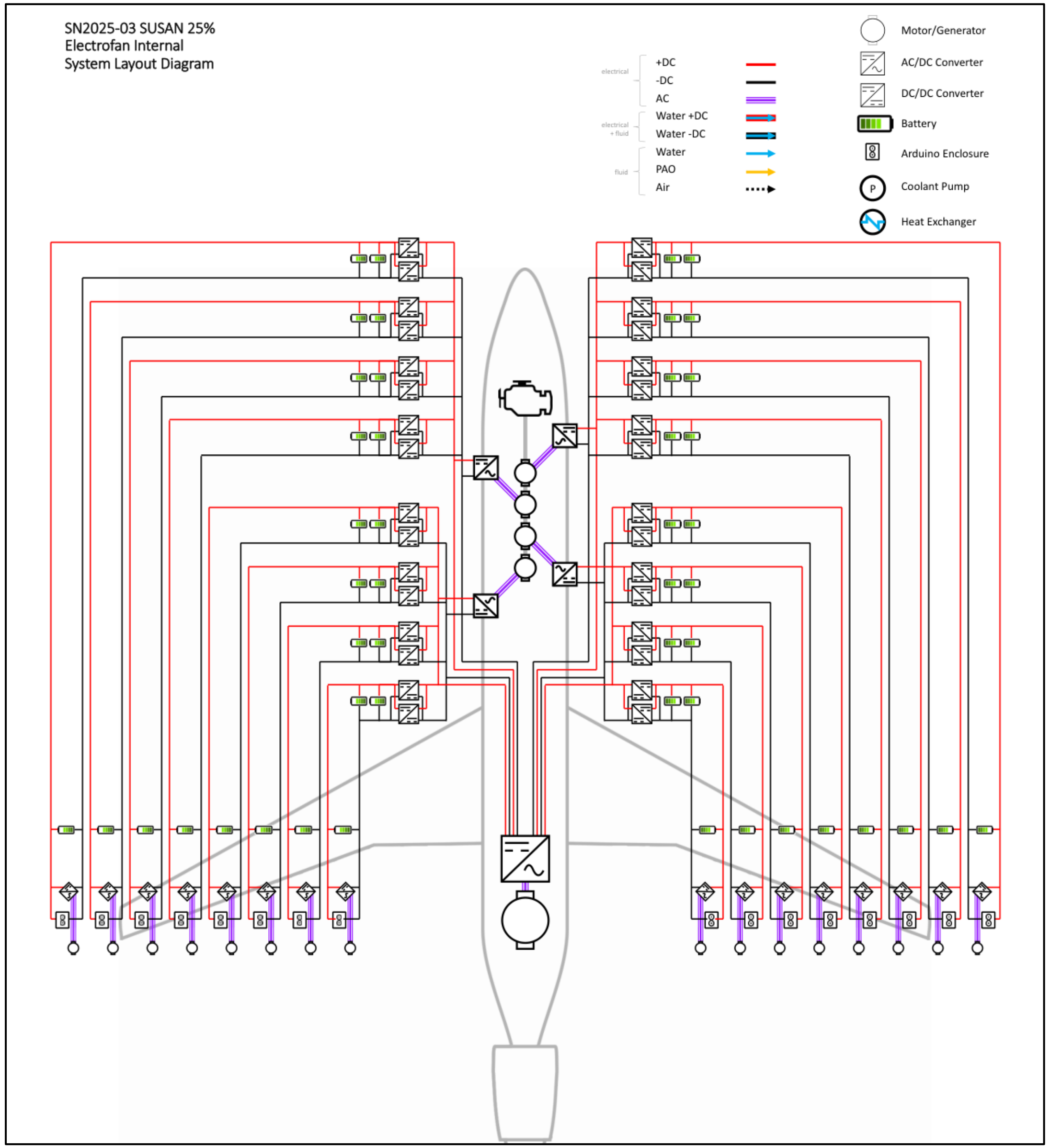
Powertrain Model

- Built using NASA-developed Open-Source MATLAB/Simulink®-based modeling tools
  - Toolbox for the Modeling and Analysis of Thermodynamic Systems (T-MATS) https://github.com/nasa/t-mats
  - Electrical Modeling and Thermal Analysis Toolbox (EMTAT) https://github.com/nasa/EMTAT



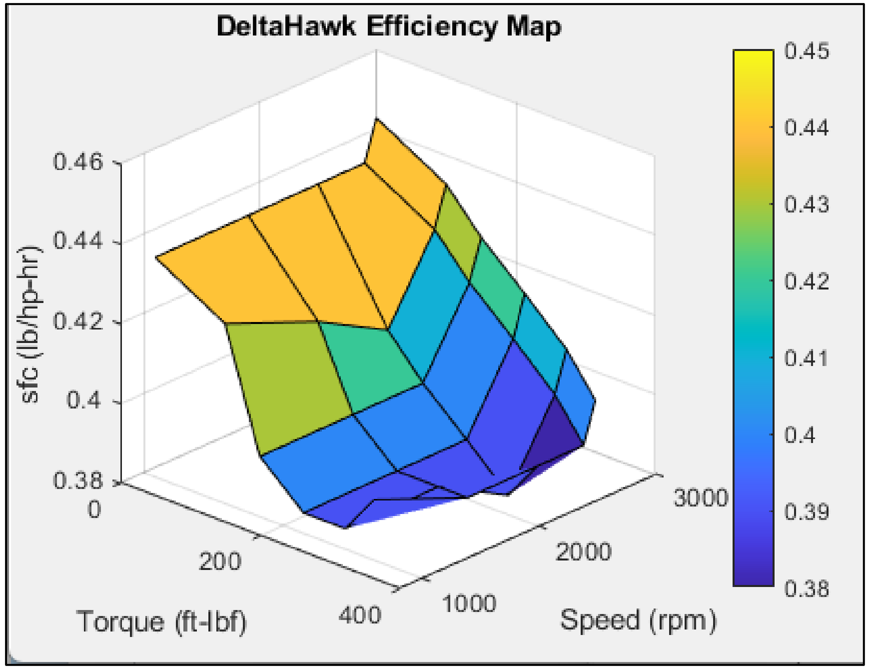
Powertrain Model

- DeltaHawk engine provides power
- Four generators produce electricity
- 16 ducted electric fans are mounted under the wings, eight on each side
- One larger ducted electric fan is in the tail



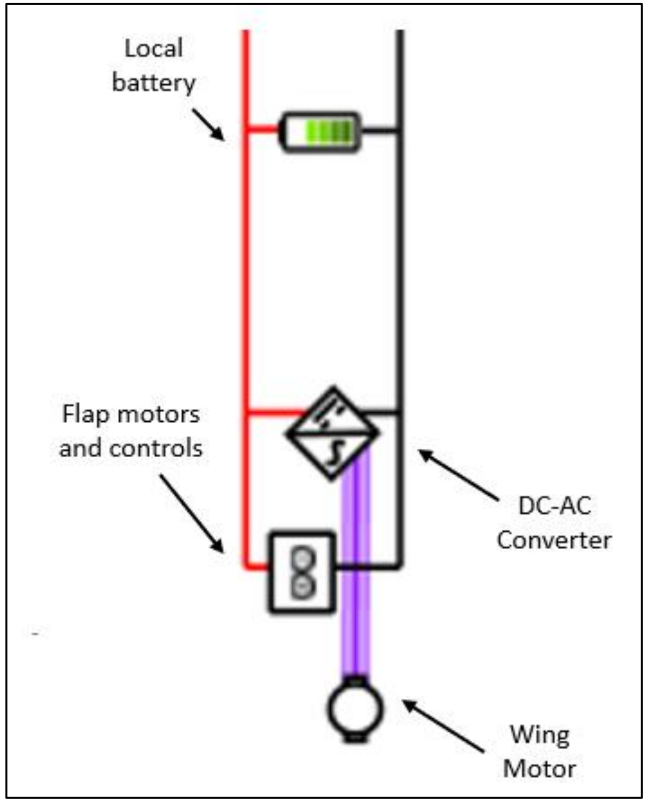
DeltaHawk Engine

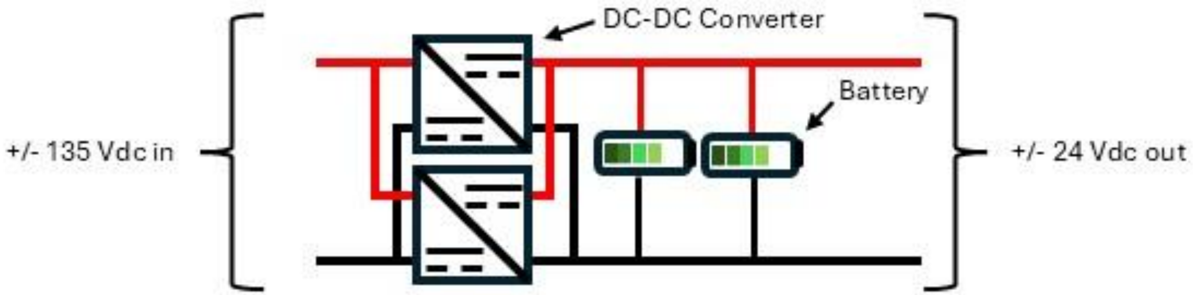
- It has a super charger and turbo charger, so the effect of altitude is neglected and airflow isn't considered in the model
- Lacking data beyond what is in the spec sheet, a generic efficiency map was used in the model.
- The peak efficiency is in the high speed, high torque region where SFC is minimized
- the least efficient is in the low torque region



Power Electronics

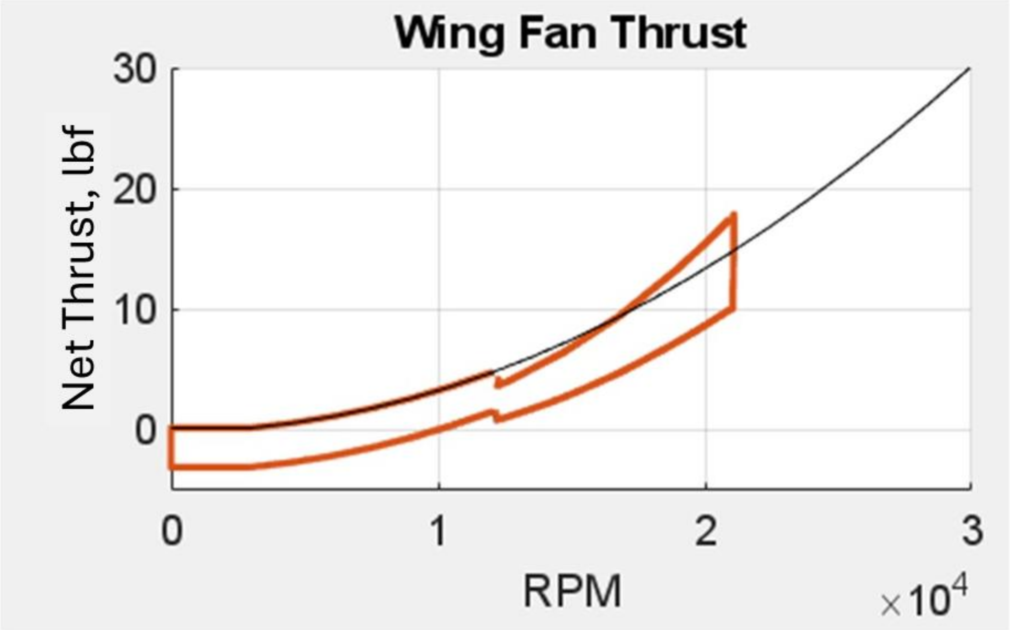
- Powertrain consists of a combination of commercial and NASA-developed components
- Modeled using EMTAT with appropriately parameterized component blocks





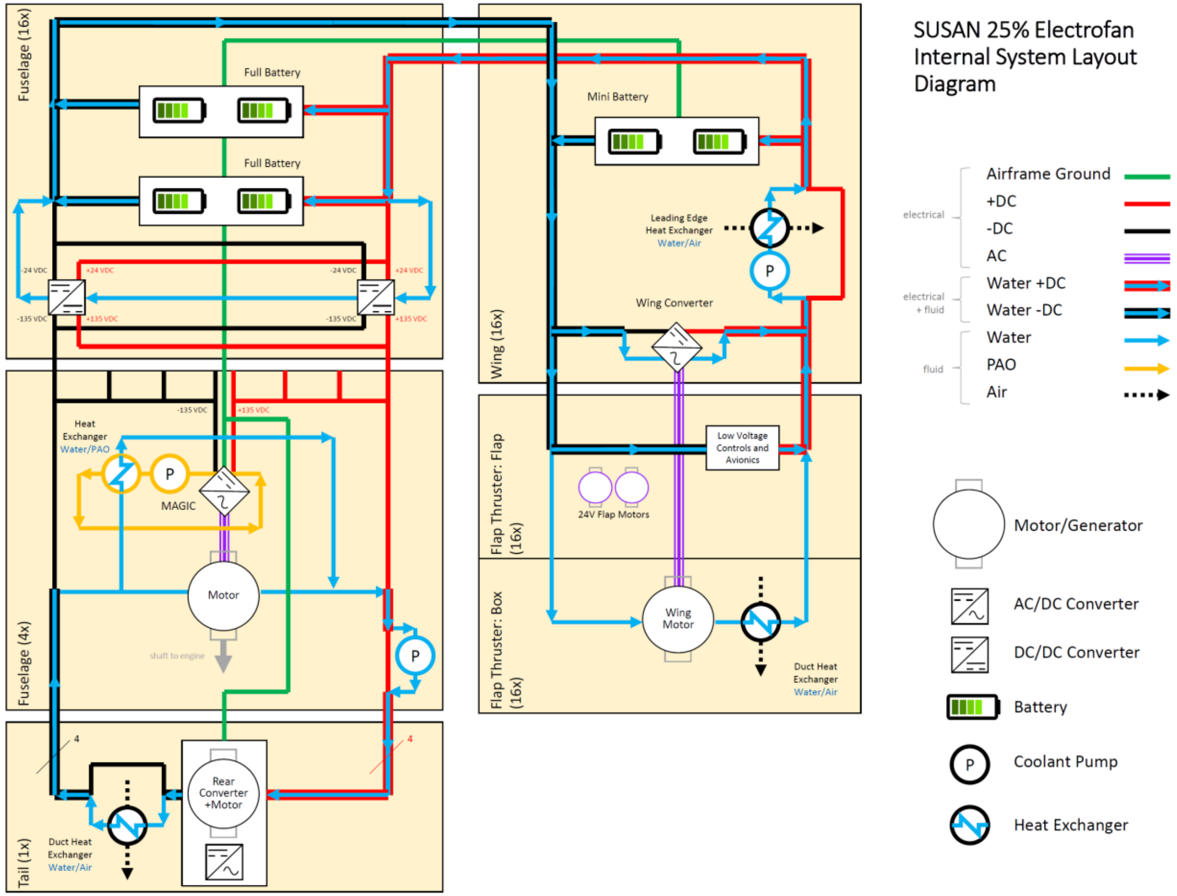
Electric Fans

- Fan models are based on commercial fans characterized in a wind tunnel
- Higher speed operation is modeled using T-MATS
- At lower speeds, the T-MATS model does not converge, so a static model is used
- Operation switches between the two models based on speed, resulting in a small discontinuity



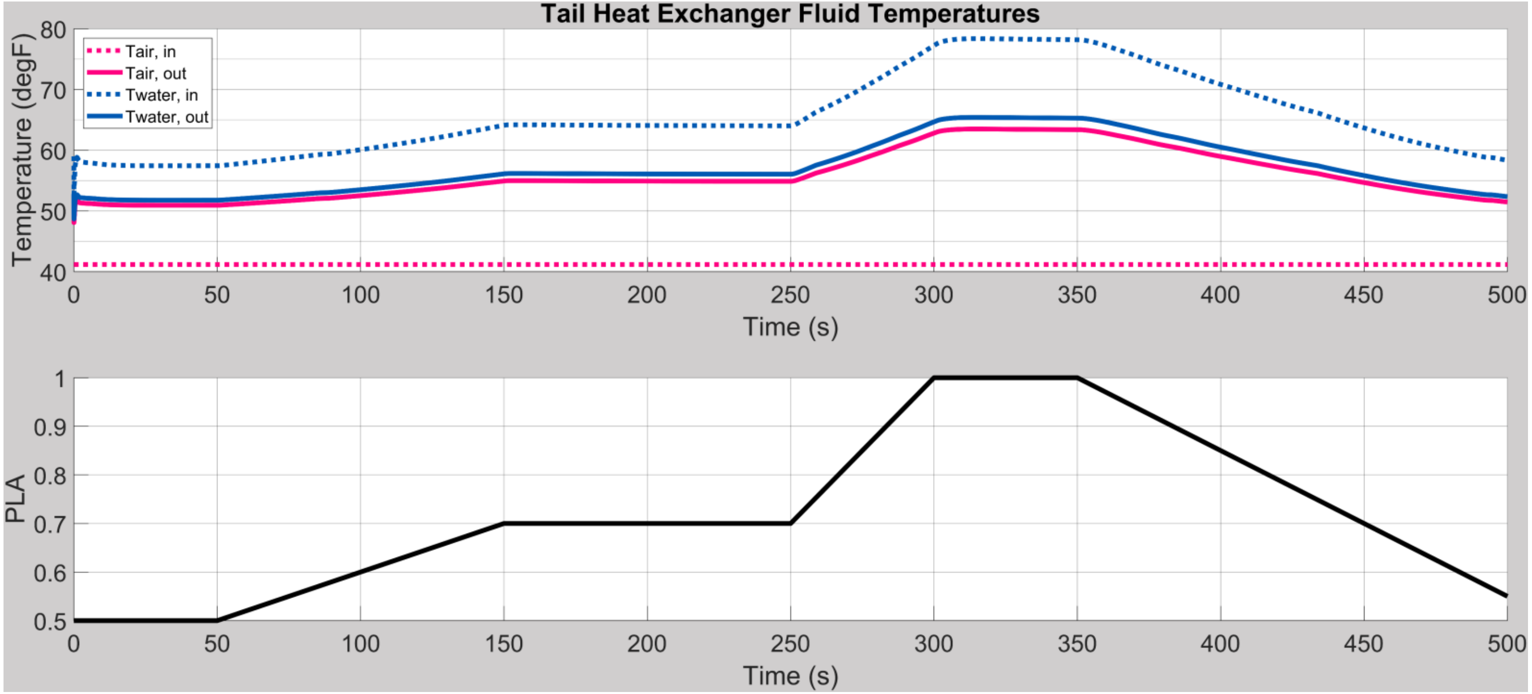
Thermal Management System

- The TMS includes several innovative concepts including
  - Leading edge heat exchanger
  - Duct heat exchanger
- Modeled using EMTAT with appropriately parameterized component blocks



Tail Fan Duct Heat Exchanger

- Coolant (water) carries heat from the fan motor and electronics to the duct
- Ram air passing through the duct removes the heat



Altitude = 5,000 ft, Mach Number = 0.2.

Flight Testing in Piloted Flight Simulator

- The aircraft is stable and generally handles well, but appears to be underpowered, possibly because of the drag from the tail
- The pilot could land and take off, generally getting speed down to between 50 and 60 kts just before touchdown
- The aircraft could reach a reasonable speed of about 115-120 kts at various flight conditions, at least temporarily
- The aircraft had difficulty climbing faster than about 100 ft/min consistently, which is much slower than expected

Flight Testing in Piloted Flight Simulator

- When the simulation was initialized at 5000 ft, the pilot could climb and was essentially able to maintain level flight at 5300 ft 120 kts, with a small amount of porpoising (about +/- 80 ft/min vertical) (no autopilot was present)
- When initialized at 7500 ft and 10,000 ft and 130 kts, the pilot was unable to maintain altitude

Conclusions

- This effort demonstrates the complexity of developing a complete system model of this magnitude and fidelity, especially given that the quarter-scale vehicle design has not been finalized
- Implementation and integration of the individual subsystem designs provides a working aircraft model that does not perform fully according to specification
- Nevertheless, leveraging the yearslong iterative design process the original SUSAN Electrofan concept went through gives a good baseline for the quarter-scale distributed electric propulsion vehicle design and the model developed from it
- Further testing with the model can inform any future iterations of the quarter-scale design

Acknowledgments

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NASA