Carbon Neutral Aerospace Hybrid Electric Propulsion

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Large Scale Electric Propulsion

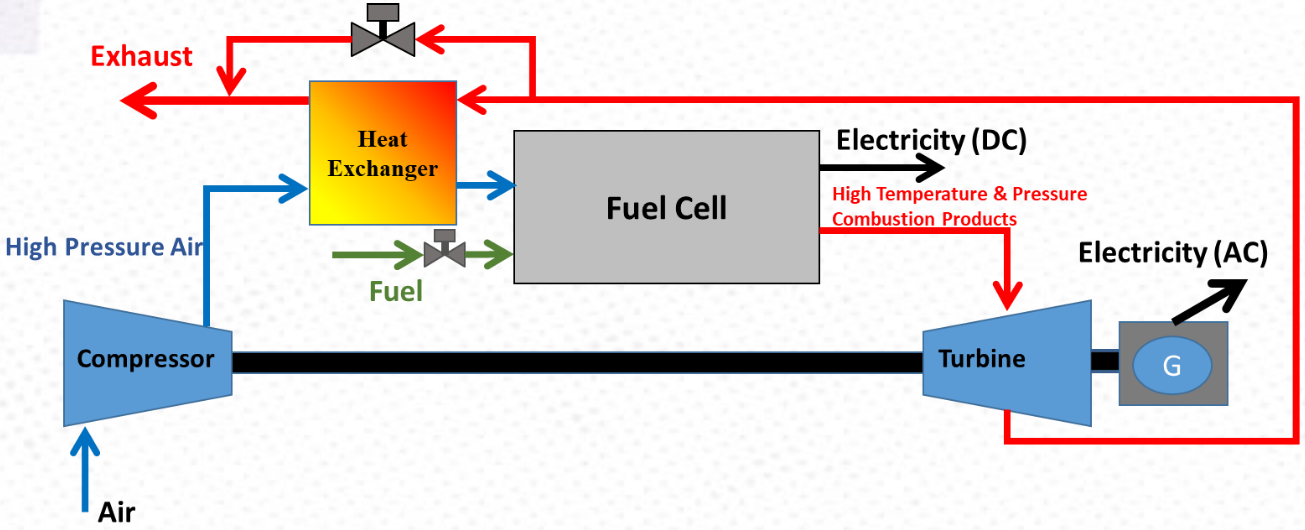
Approach

- Requires high conversion efficiency to drive down:
  - $/passenger mile
  - Net zero Emissions
  - Meet current fuel storage requirements
- Vehicle level top-down design approach
- Responsive dynamic system for power generation
- High power density electric centric systems, ARPA-E Programs
  - Electric power production (REEACH) Range Extenders for Electric Aviation with Low Carbon and High Efficiency
  - Electric propulsors (ASCEND) Aviation-class Synergistically Cooled Electric-motors with iNtegrated Drives
  - Electrical distribution system (CABLE) Connecting Aviation By Lighter Electrical Systems
- Manage 100’s kWs low quality heat thermal management

Large Scale Electric Propulsion

- Challenges
  - Must operate at altitudes of **35,000 ft**
  - Vast range of operating load, pressures and temperatures
  - Provide high density and high efficiency electrical power
  - Reliability and redundancy
  - Thermal management of the aerospace systems including SOFC

Conventional Hybrid Fuel Cell-Gas Turbine (FC-GT) For Aerospace



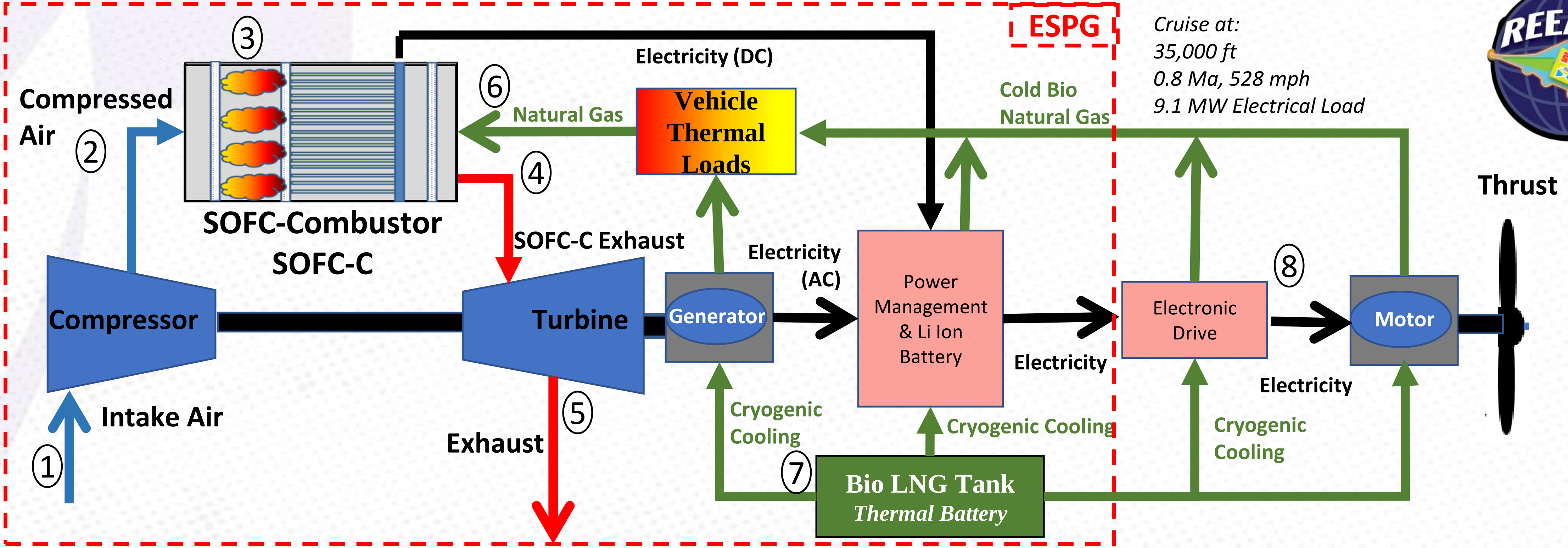
Pros

- **FC-GT provides ultra high chemical-to-electrical conversion efficiency**
- **Provides pressurized environment at high altitudes**

Cons

- **Large massive systems with low specific power**
- **Large thermal mass, sluggish response to perturbations**
- **Long cold startup times**
- **Complex thermal management of FC typically with large valves**

Proposed SOFC-C-TG Concept for Aerospace



Cruise at:
35,000 ft
0.8 Ma, 528 mph
9.1 MW Electrical Load

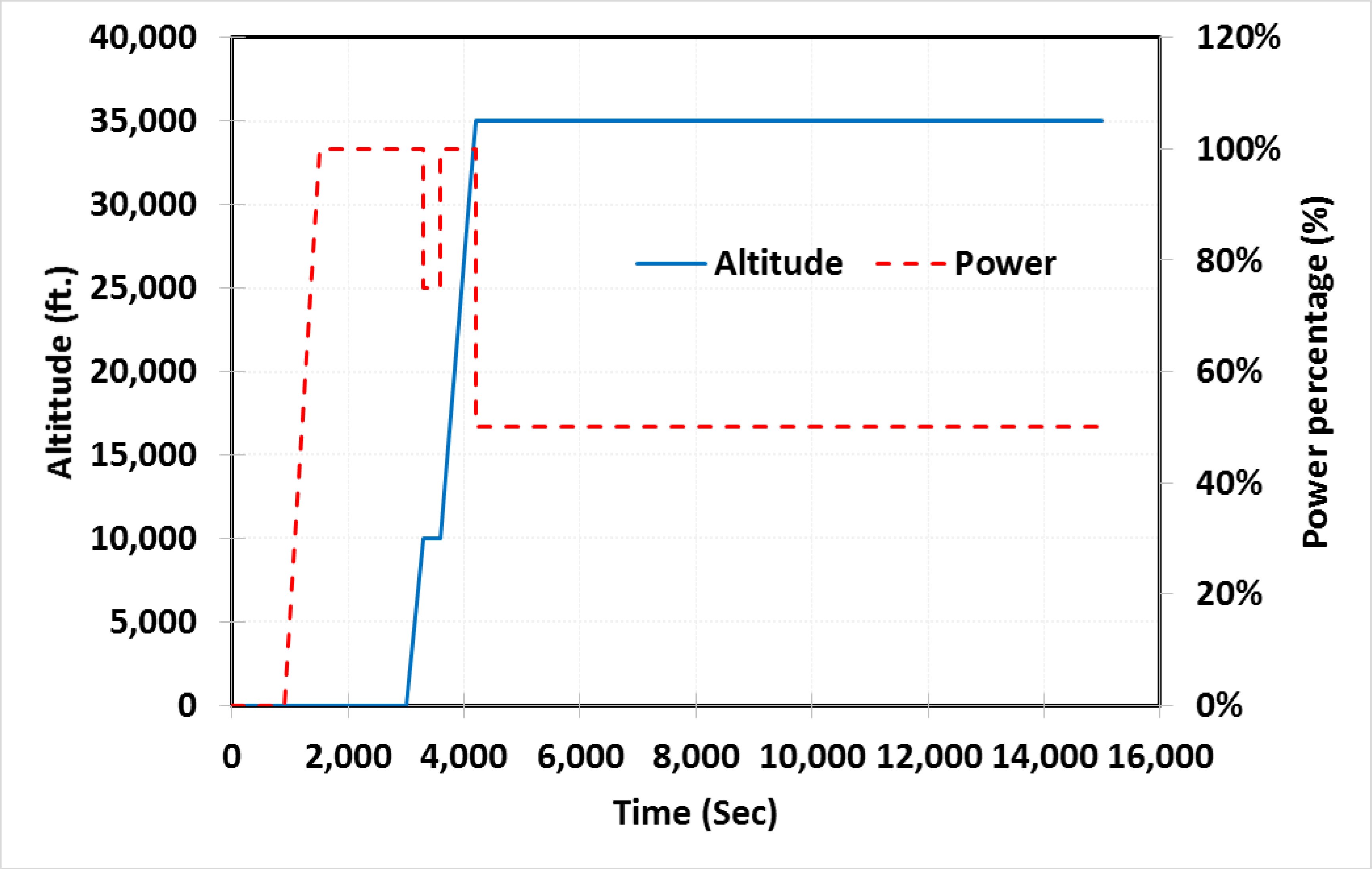
Pros

- SOFC-C-TG eliminates cathode heat exchangers, large thermal mass
- Rapid response to perturbations: load, inlet temperature and pressure
- Minimized use of valves
- Redundancy and reliability

Cons

- New concept, never been fully demonstrated

Flight Profile



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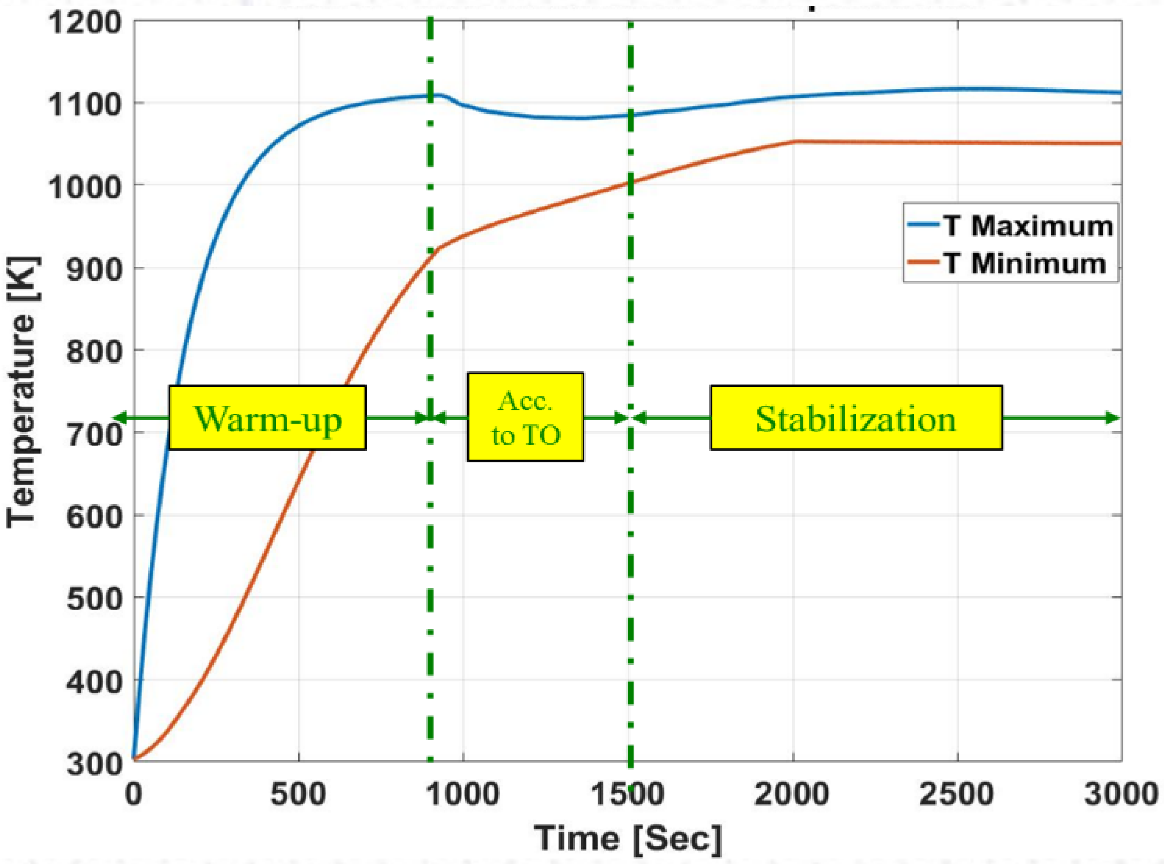
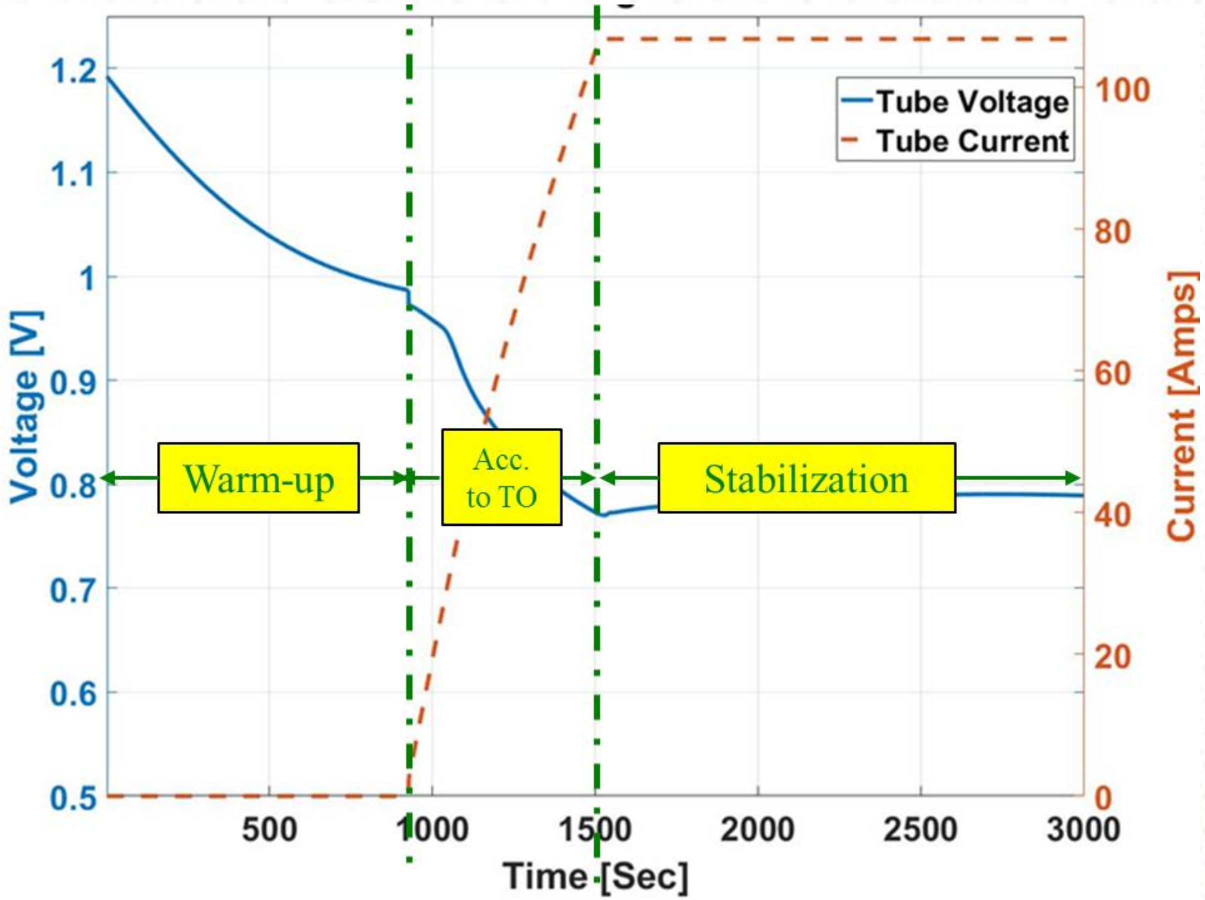
SOFC Warm-up

SOFC stack initial warm up and loading 15 minutes



SOFC stack to full load in 25 minutes



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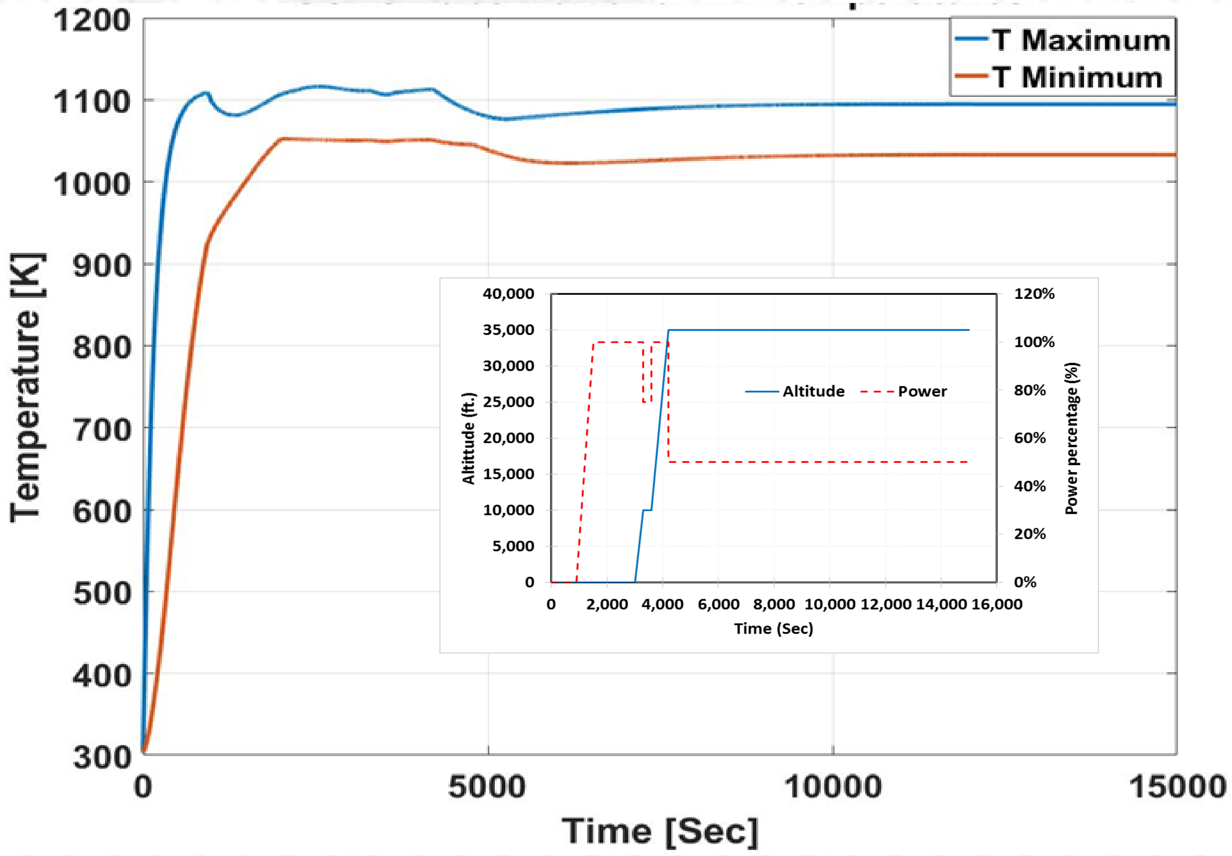
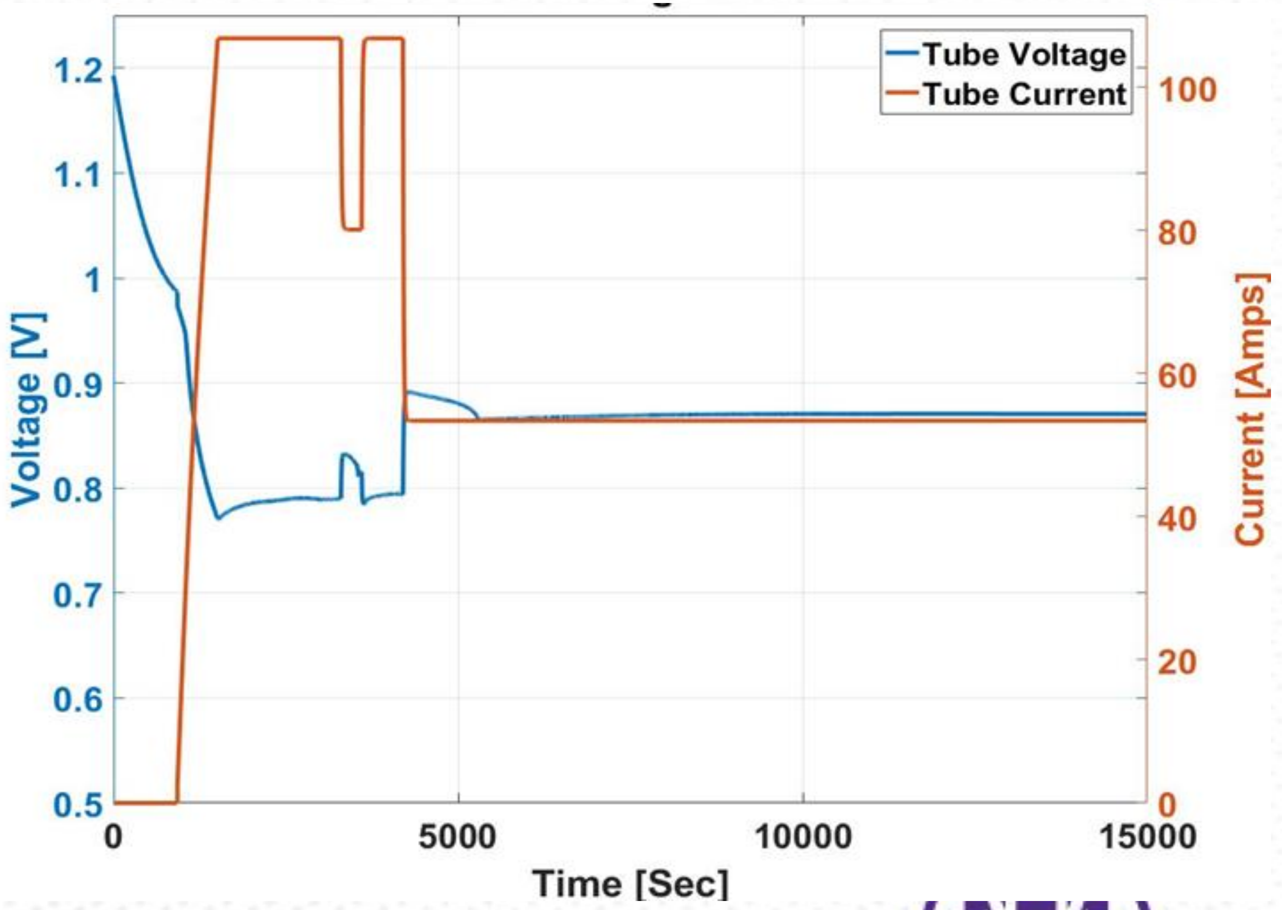
SOFC-TG Flight





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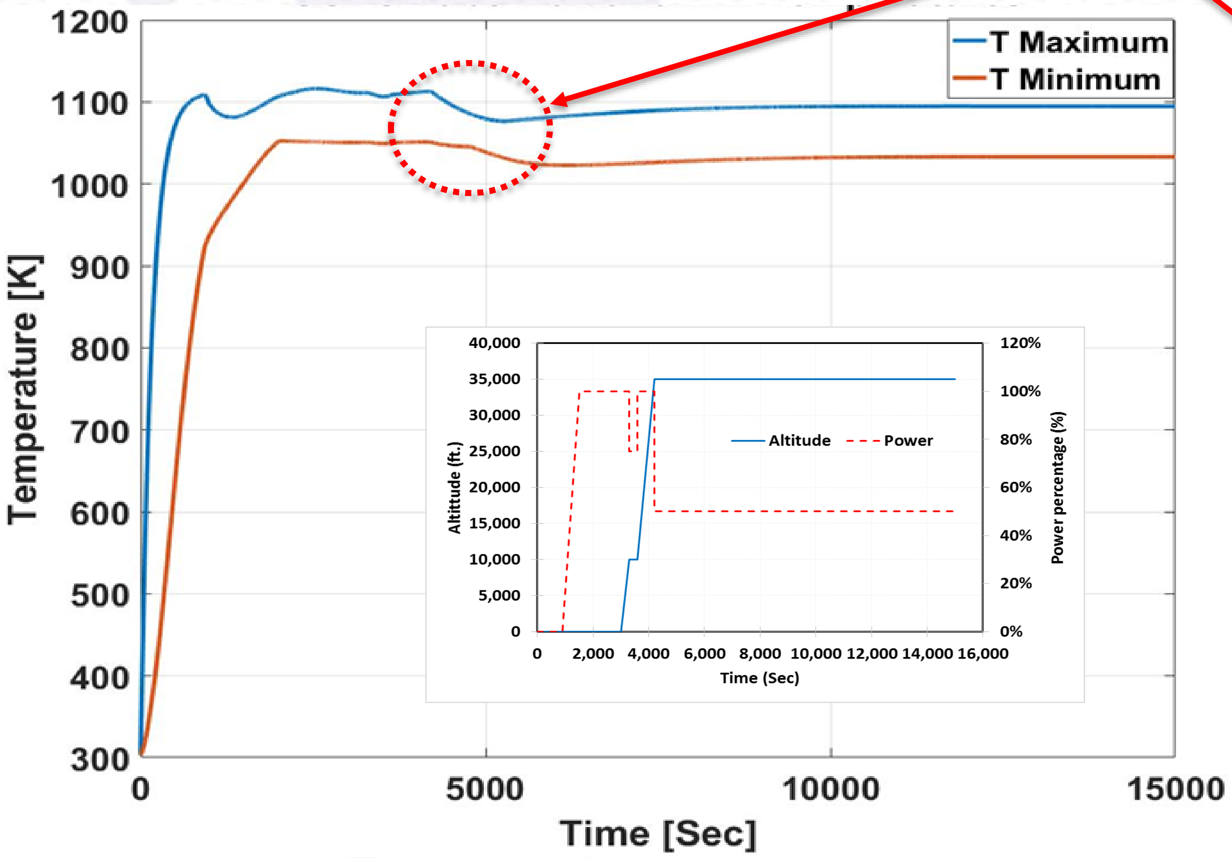
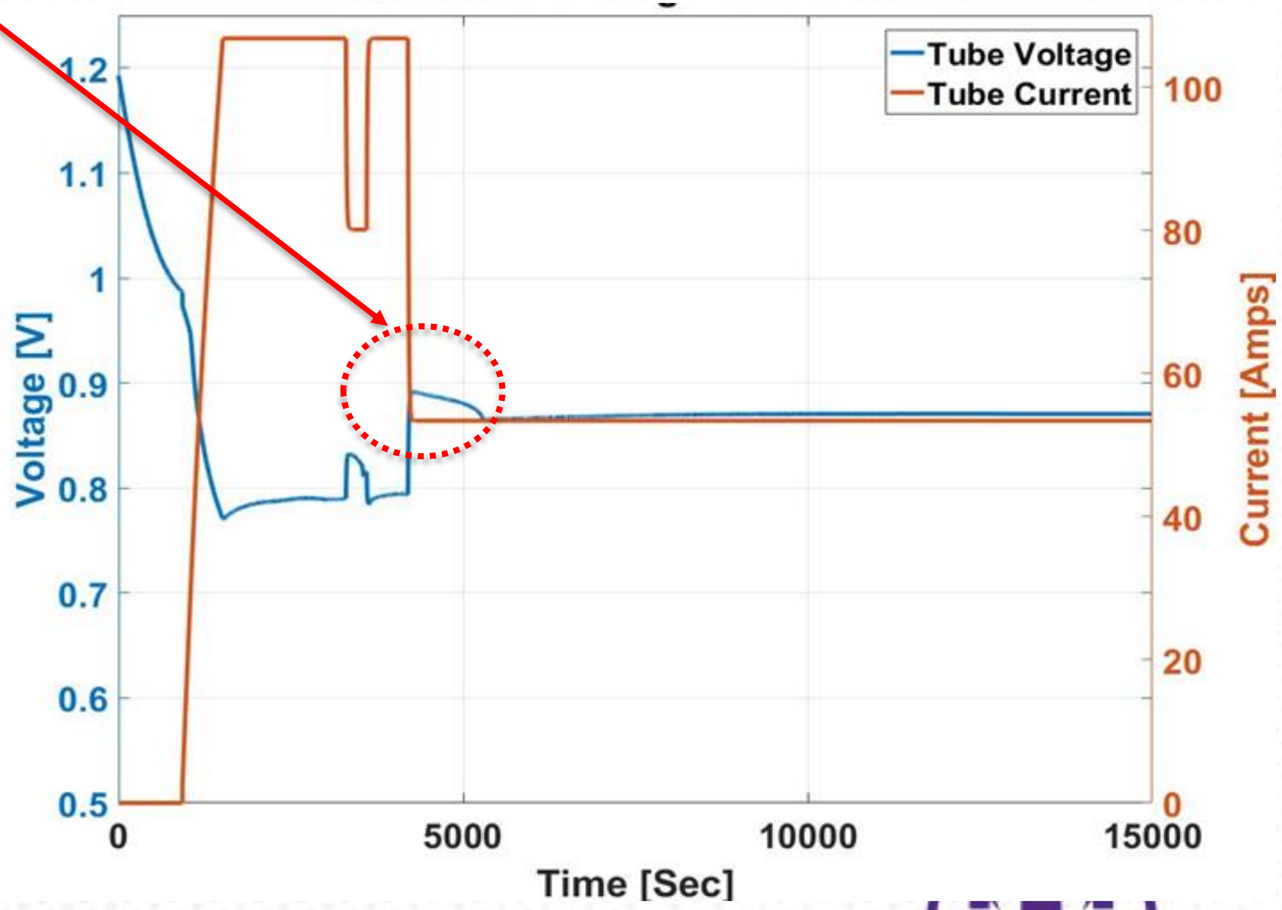
SOFC-TG Flight

Voltage response to change in temperature





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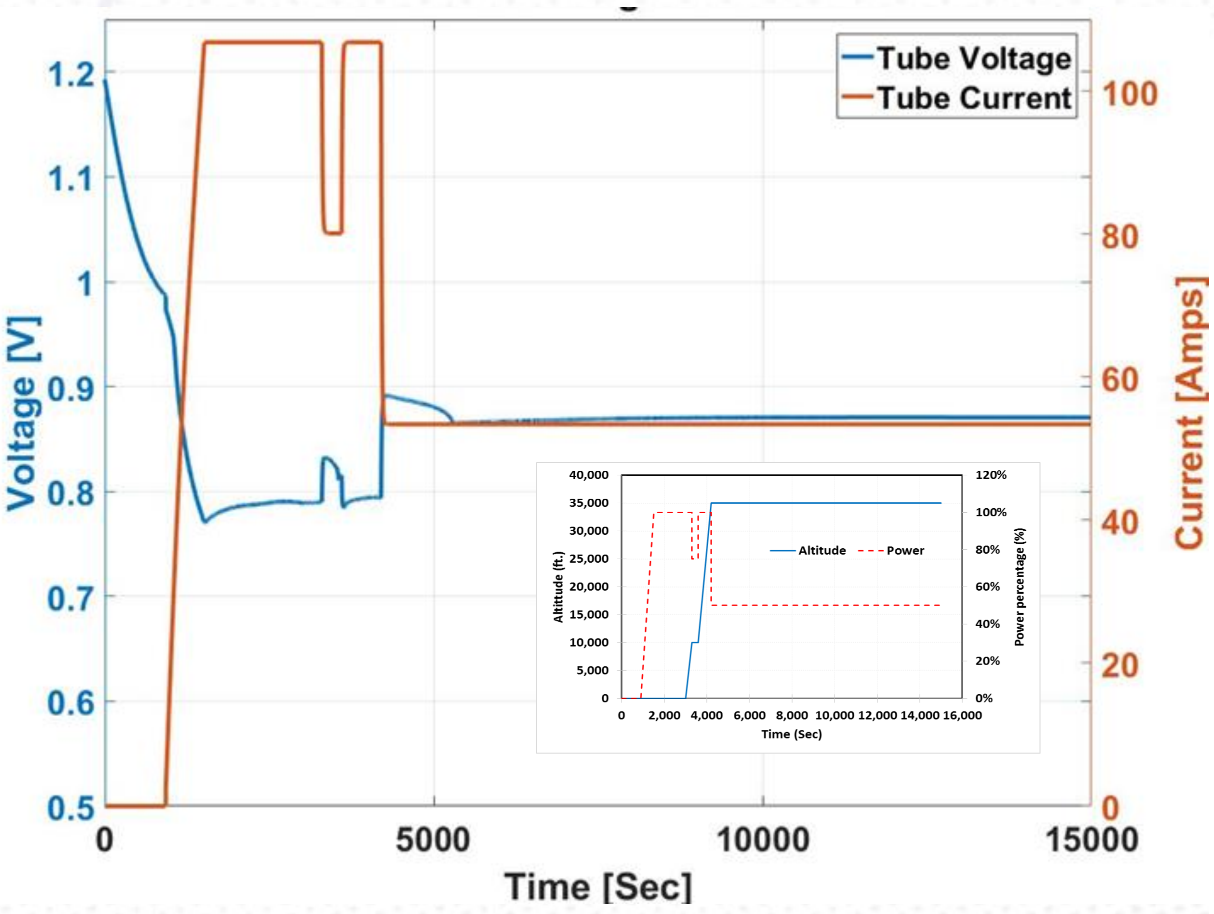
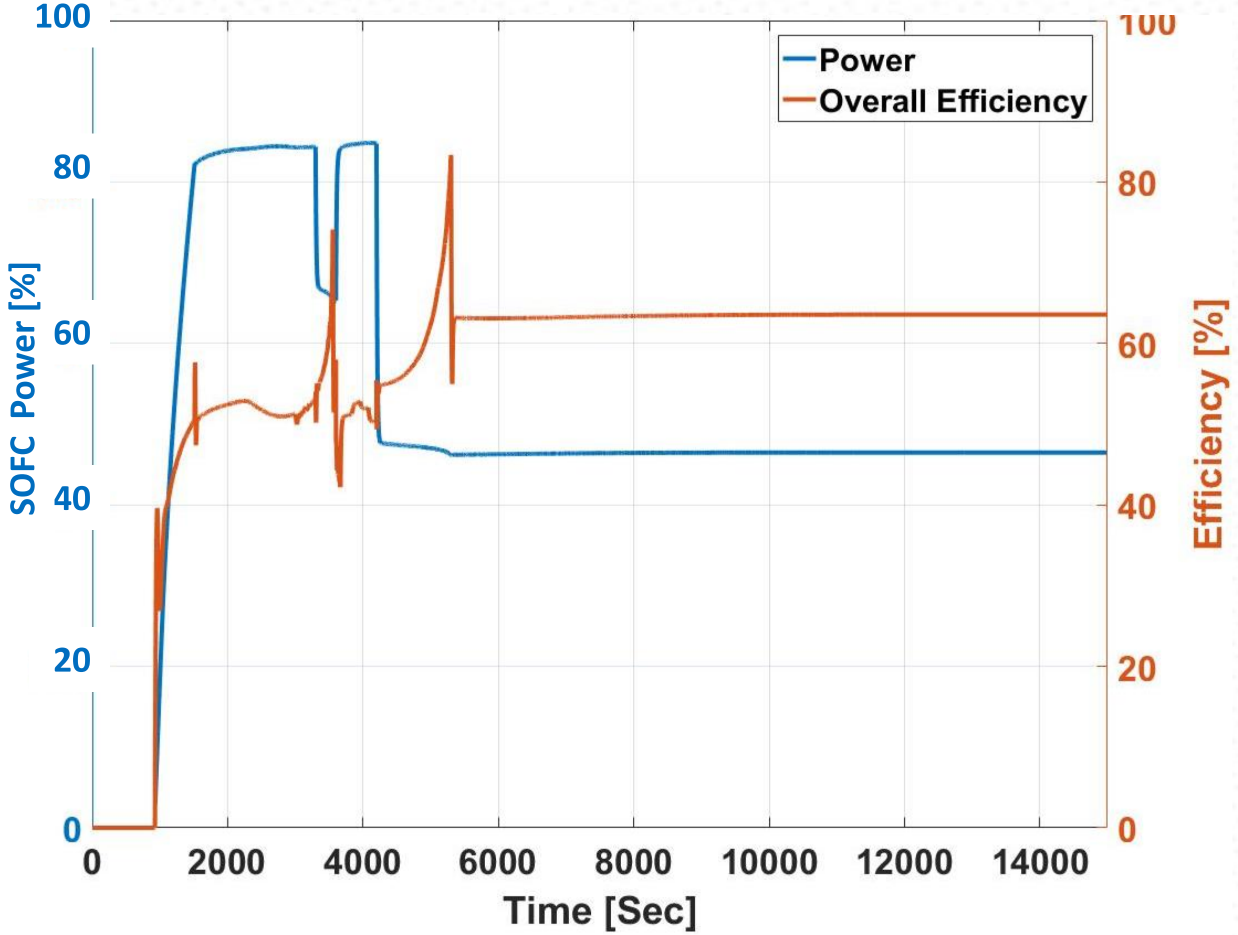
SOFC-TG Electrical Performance





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SOFC-TG Hybrid Systems Summary

- SOFC hybrid systems can be designed to operate dynamically in a load following regime
  - Reduction of thermal mass in the system improves system response
  - Demonstrated through simulation, plans to demonstrate with hardware
- SOFC hybrid system can possibly achieve rapid startup
  - Demonstrated through simulation
  - Plan to demonstrate at the SOFC stack level
- Reduction of system components will help reduce cost and maintenance

Thank You

Acknowledgements

Acronyms

- SOFC-C- Solid Oxide Fuel Cell Combustor
- SOFC-C-TG - Solid Oxide Fuel Cell Combustor-Turbogenerator System
- TG - Turbogenerator
- FC-GT - Fuel Cell –Gas Turbine hybrid system
- SWaP – Size, weight and power
- BC- Boundary conditions
- SPS – Special Power Sources
- WSU - Wright State University
- RTRC - Raytheon Technologies Research Center
- TTU- Tennessee Tech University
- BoP- Balance of Plant
- LNG – Liquified natural gas
- ESPG – Electrical Storage and Power Generation