Dynamic Modeling and Controlling Ammonia Fueled SOFCC-GT Hybrid System for Commercial Aviation

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Griffin Layhew
gjlayhew42@tntech.edu
Tennessee Tech University

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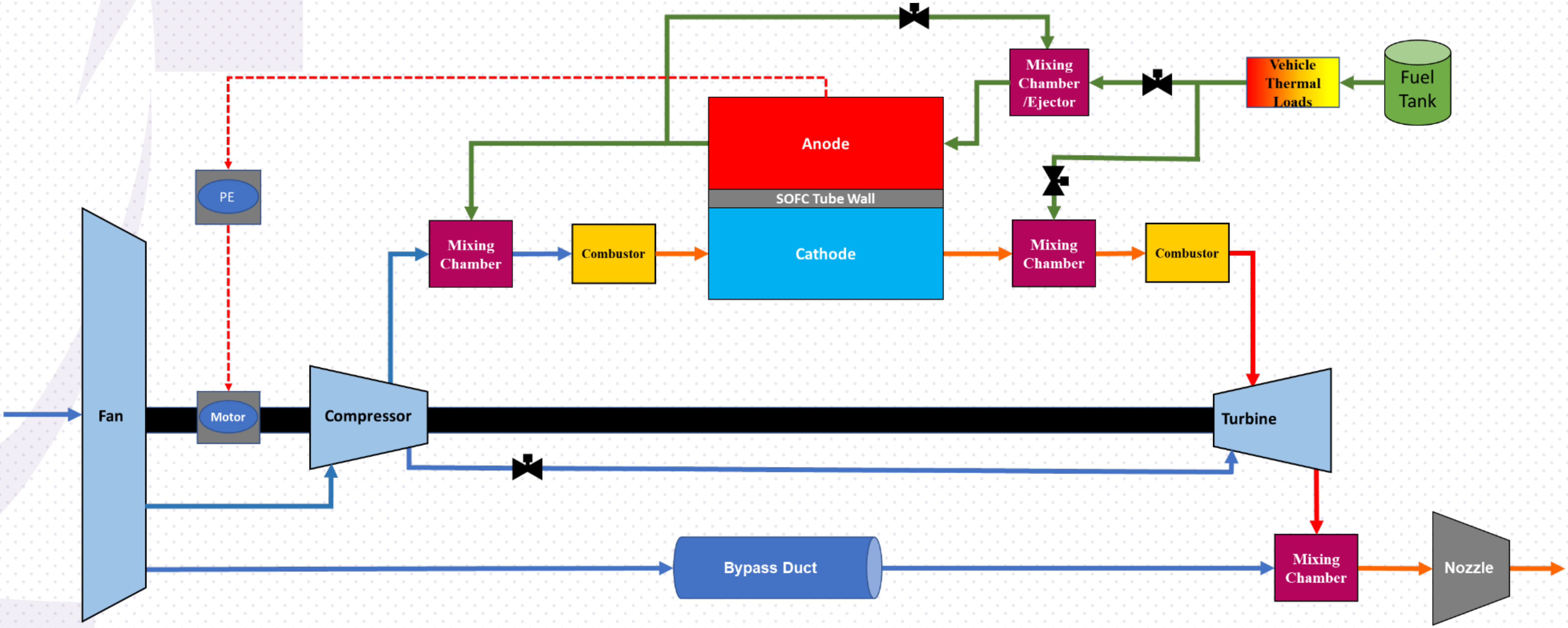
CLEAN
CarbonLess Electric AviatioN

Background

- Develop >150 Passenger Commercial Aircraft with Zero Carbon Emissions and Minimal NOx Emissions
- Ammonia(NH_3) Used as Fuel to Eliminate Carbon Emissions
- Intended to Retrofit Boeing 737 Aircraft for Hybridization
- Solid Oxide Fuel Cells (SOFC's) used as Alternative to Batteries for Electric Power

System Layout



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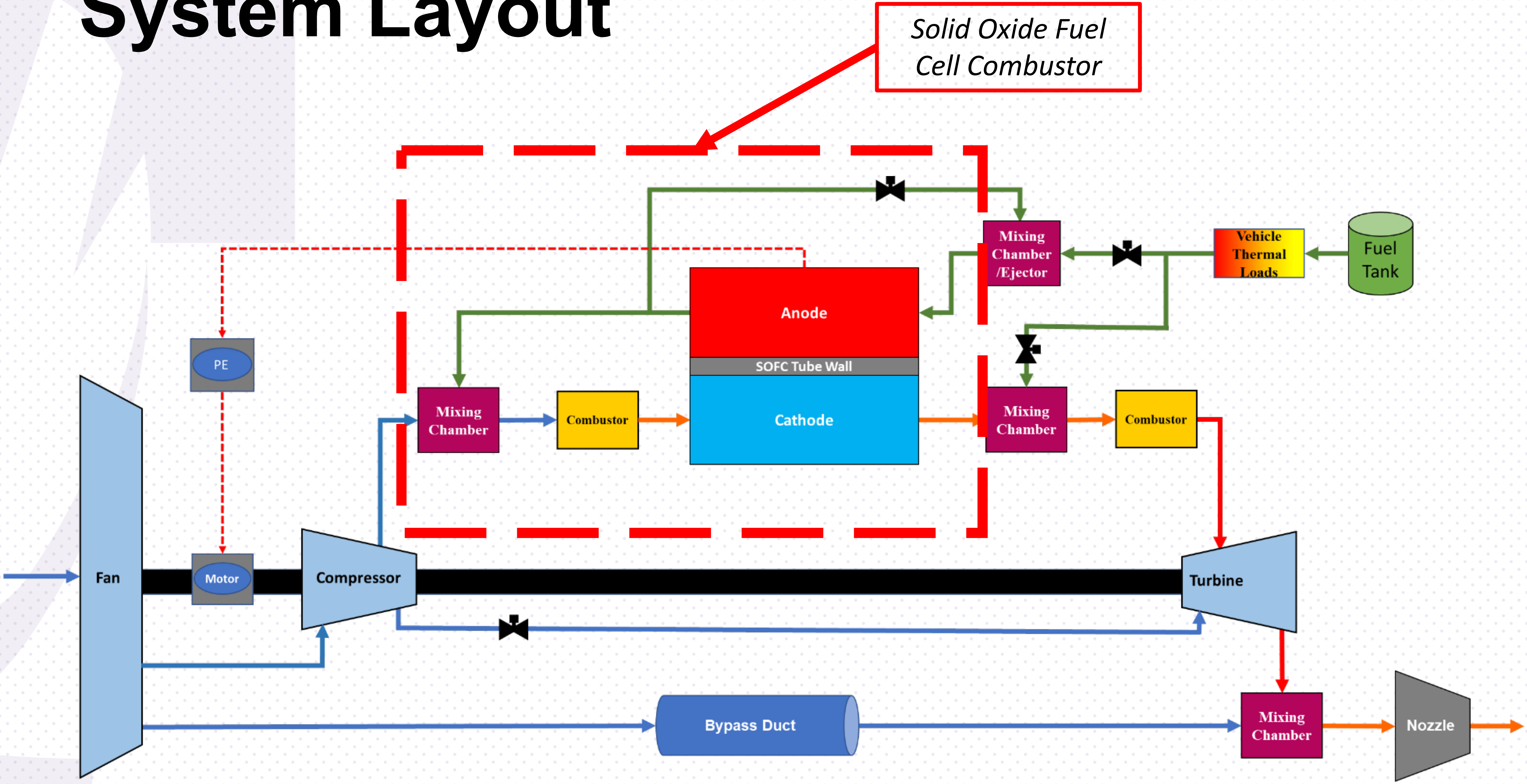

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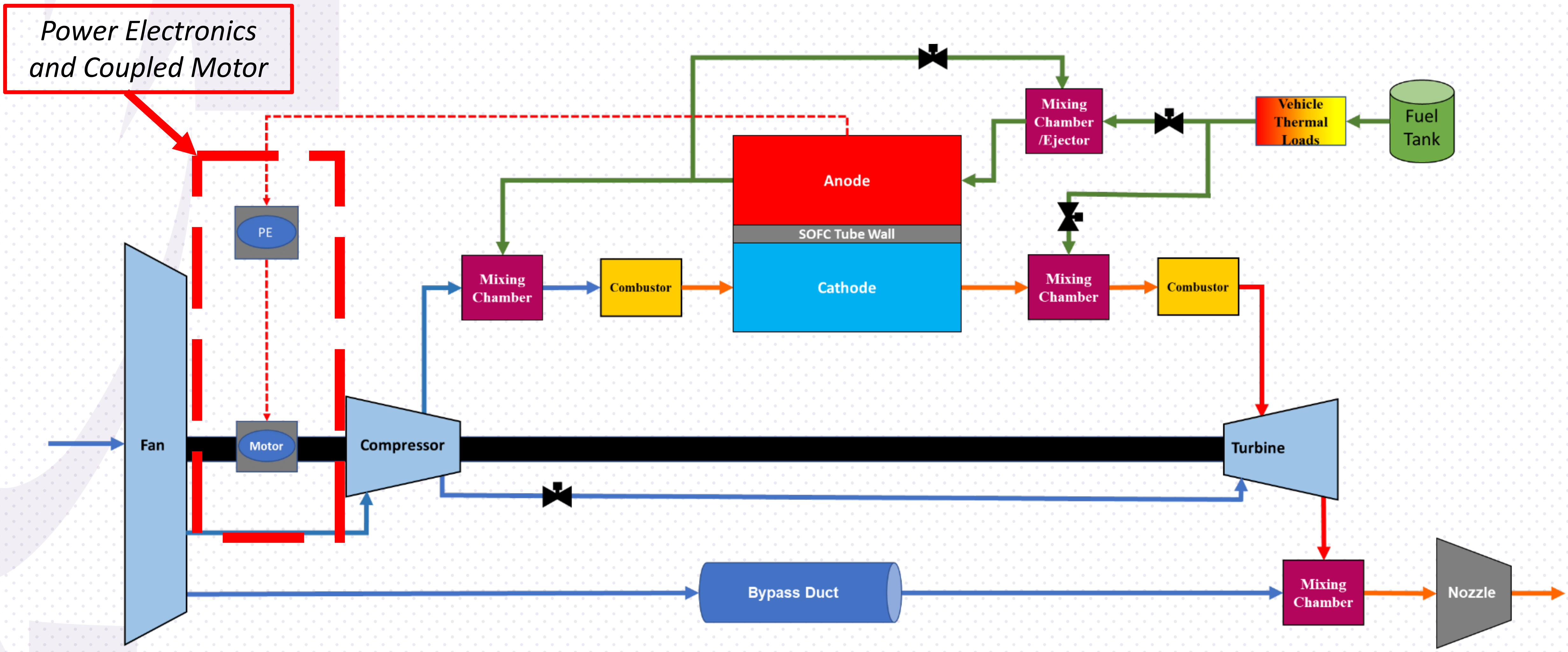


System Overview

Advantages

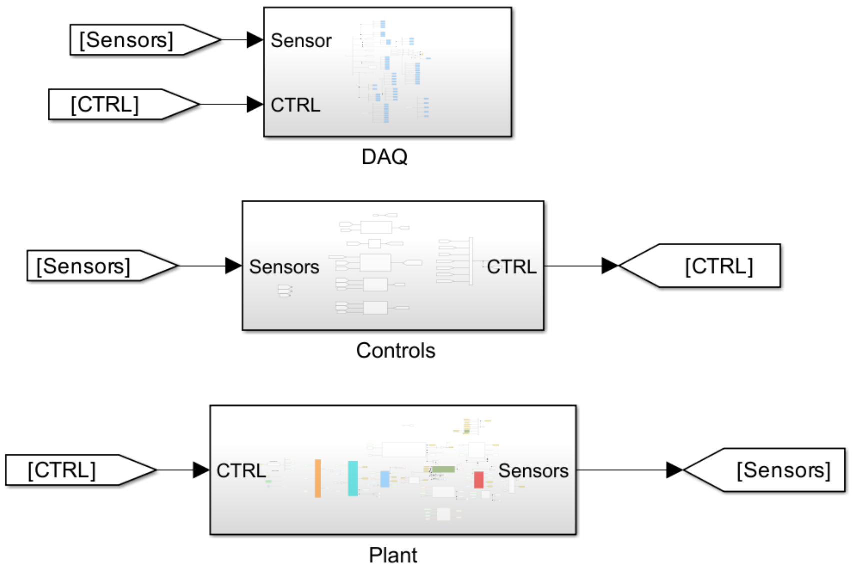
- Increased System Efficiency
- Zero Carbon Emissions
- Lower NOx due to Lower Turbine Inlet Temperature
- Similar to Legacy Equipment

Disadvantages

- Increased System Mass
- Increased Complexity
- New Environmental Concerns
- Fuel Storage Challenges

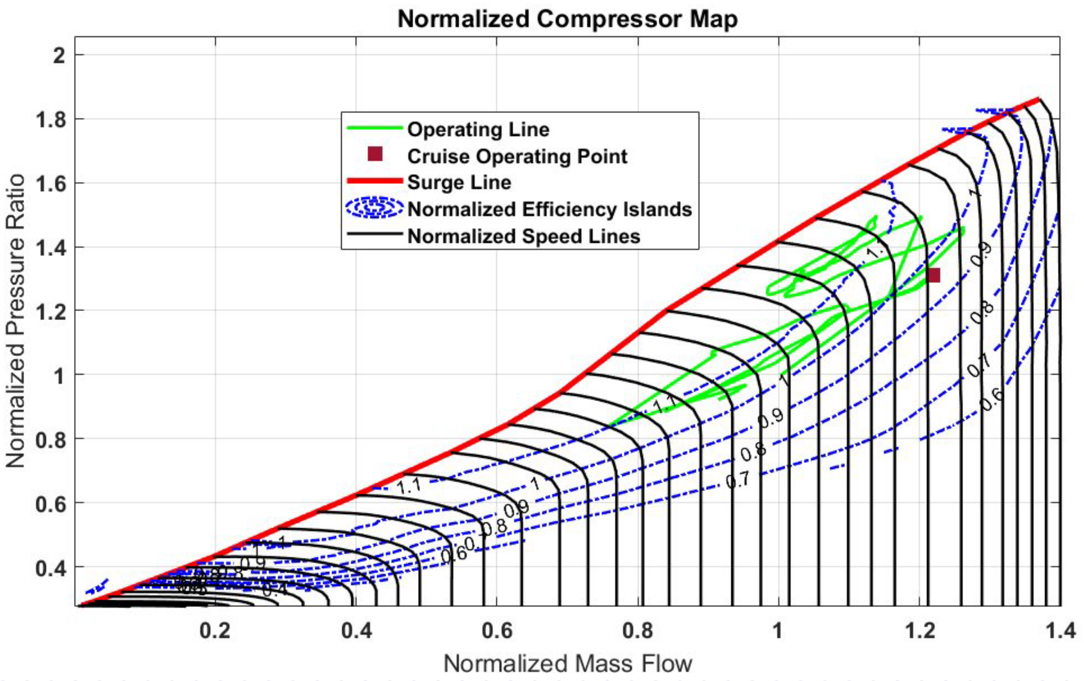
System Modeling

- Dynamic Model created using SIMULINK environment
- Conservation Equations Applied
  - Mass
  - Energy
  - Species
- Controls for warm-up and operation
- Control Loop is to varies TIT to match given Thrust Profile
- Per Wing Basis



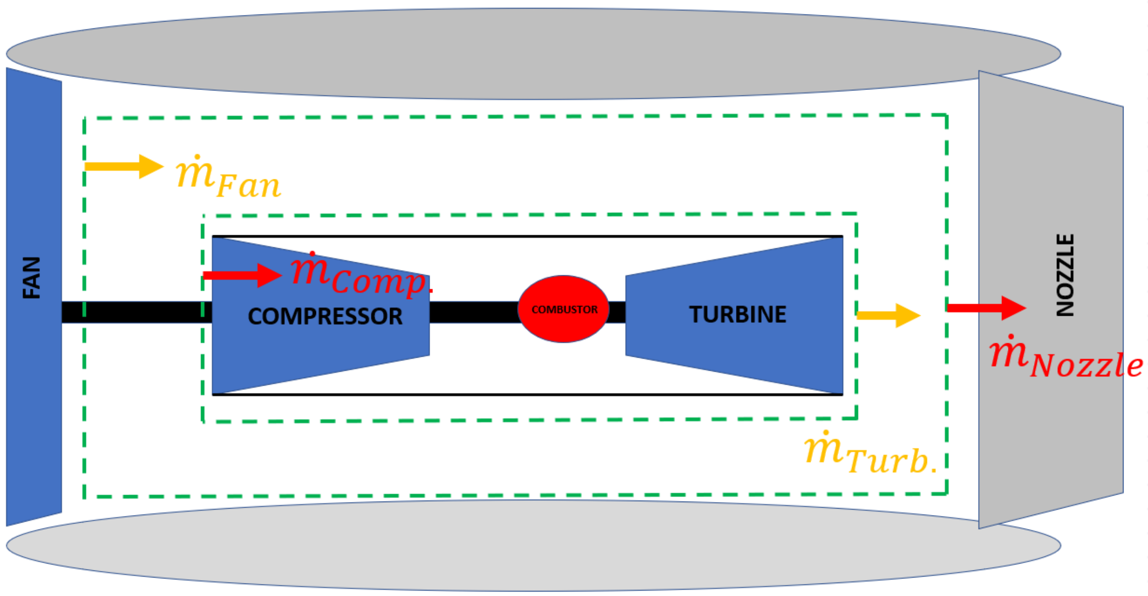
Turbomachinery

- Normalized Maps used for Turbomachinery
- Fan and Compressor Utilize Identical Performance Map
- Isentropic Relations used to Determine Power based on Pressure Ratio



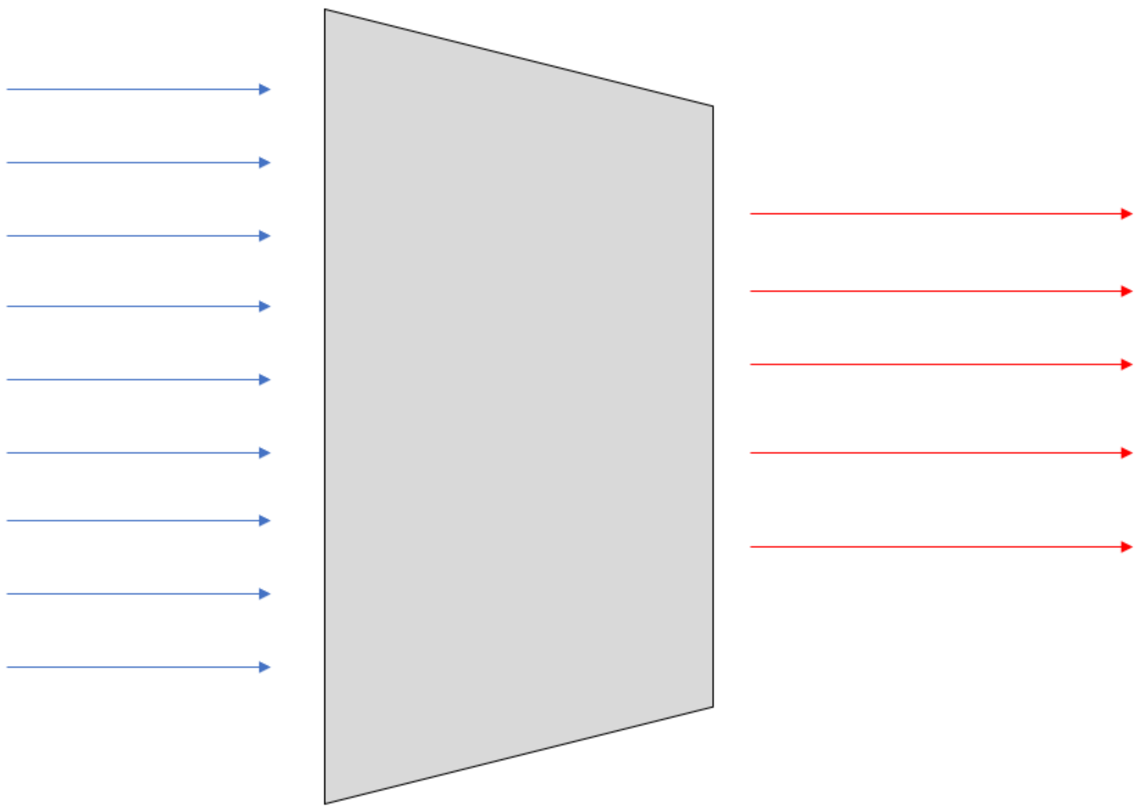
Bypass Duct

- Bypass Duct treated as a Plenum Volume
- Static Pressure Determined using Ideal Gas Law
- Dynamic Pressure found Using Assumed Flow Area



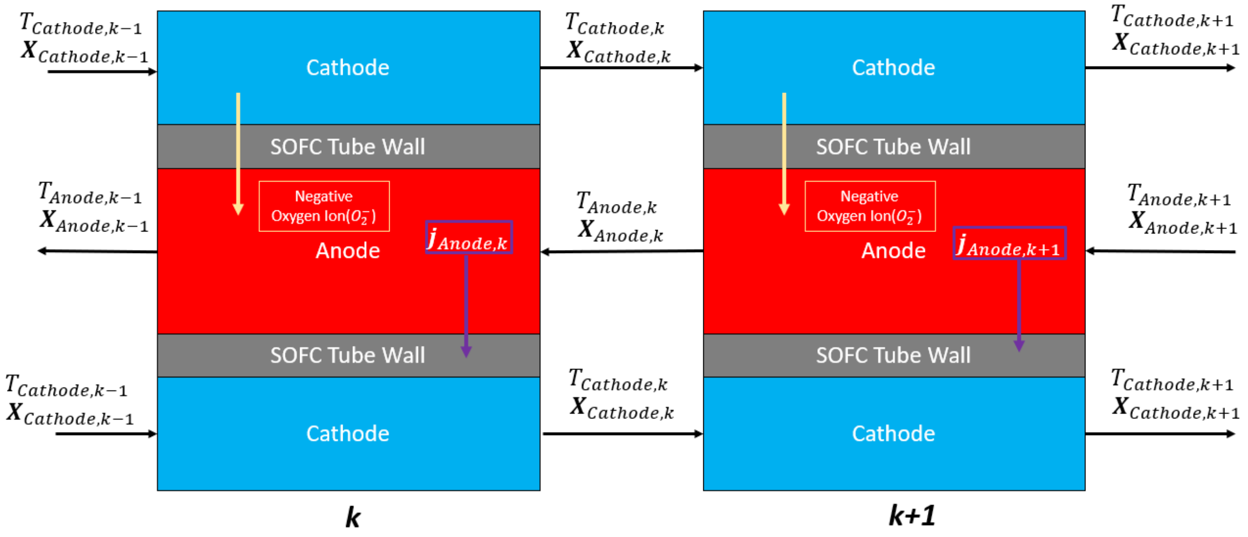
Nozzle

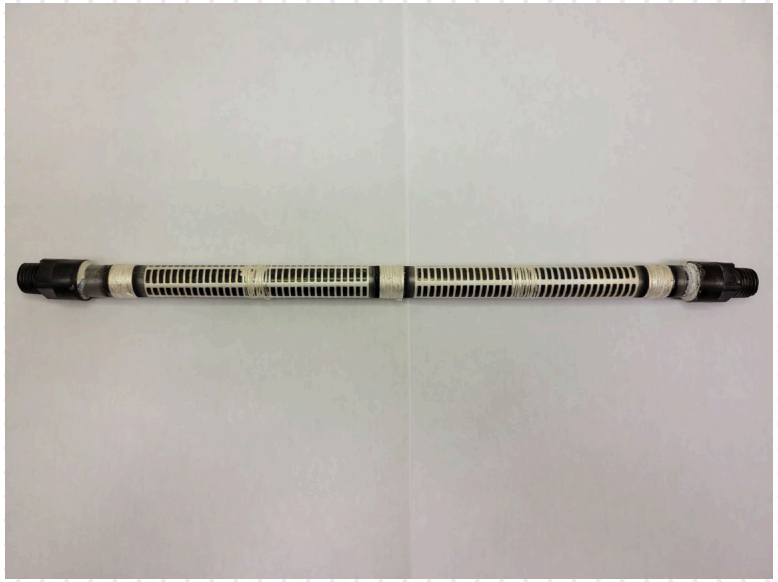
- Converging Nozzle
- Area Design for Mach <= 0.9 at Exit for Noise
- Choked flow condition continuously checked to determine if flow is Choked at Nozzle Exit



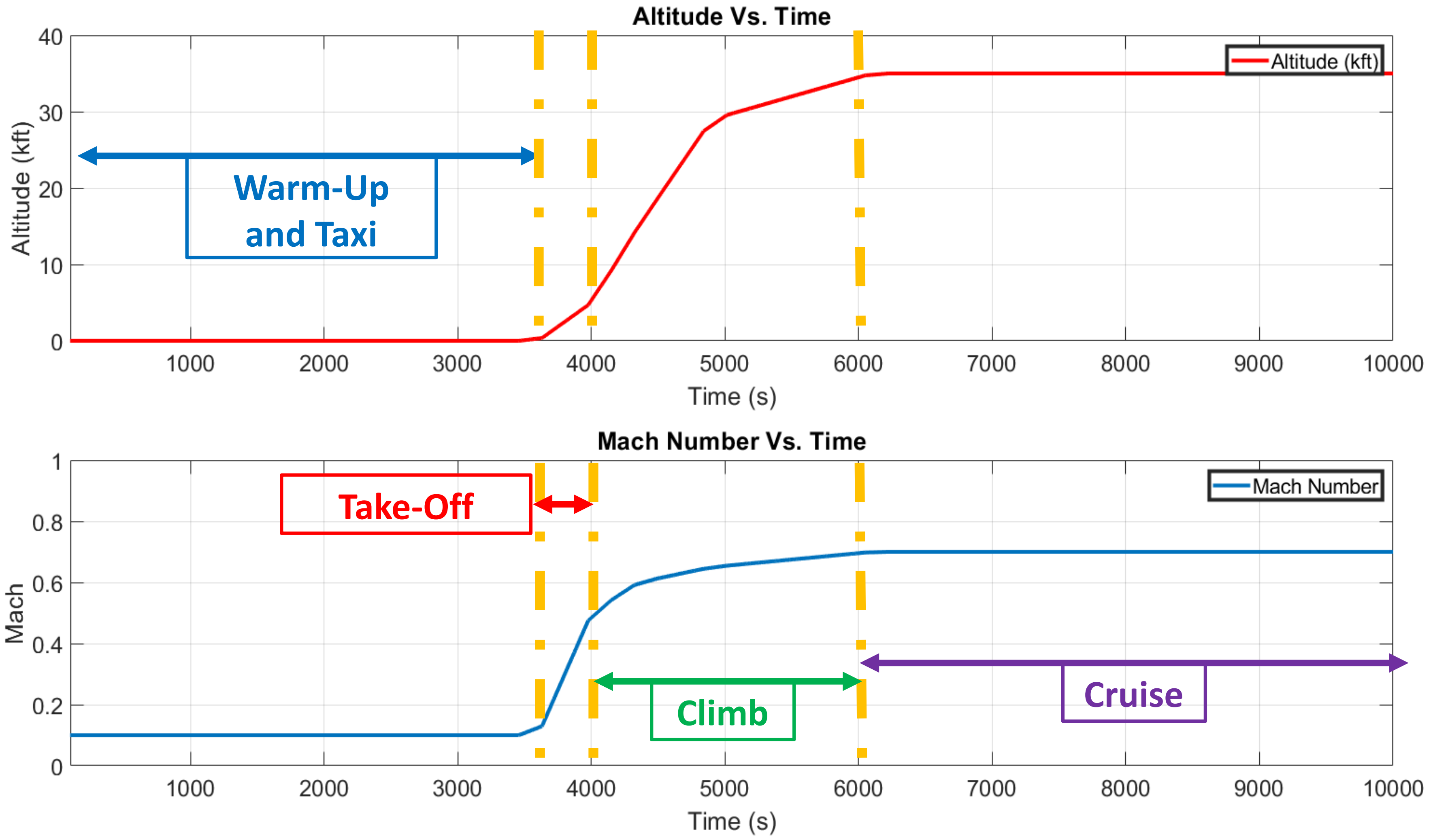
SOFC Tubes

- Tubular SOFC's are discretized into Nodes
- 1-D Conservation Equations applied at each Node
  - Temperature
  - Species
  - Current
- Ammonia Cracked before Entering SOFC to Minimize Thermal Gradients

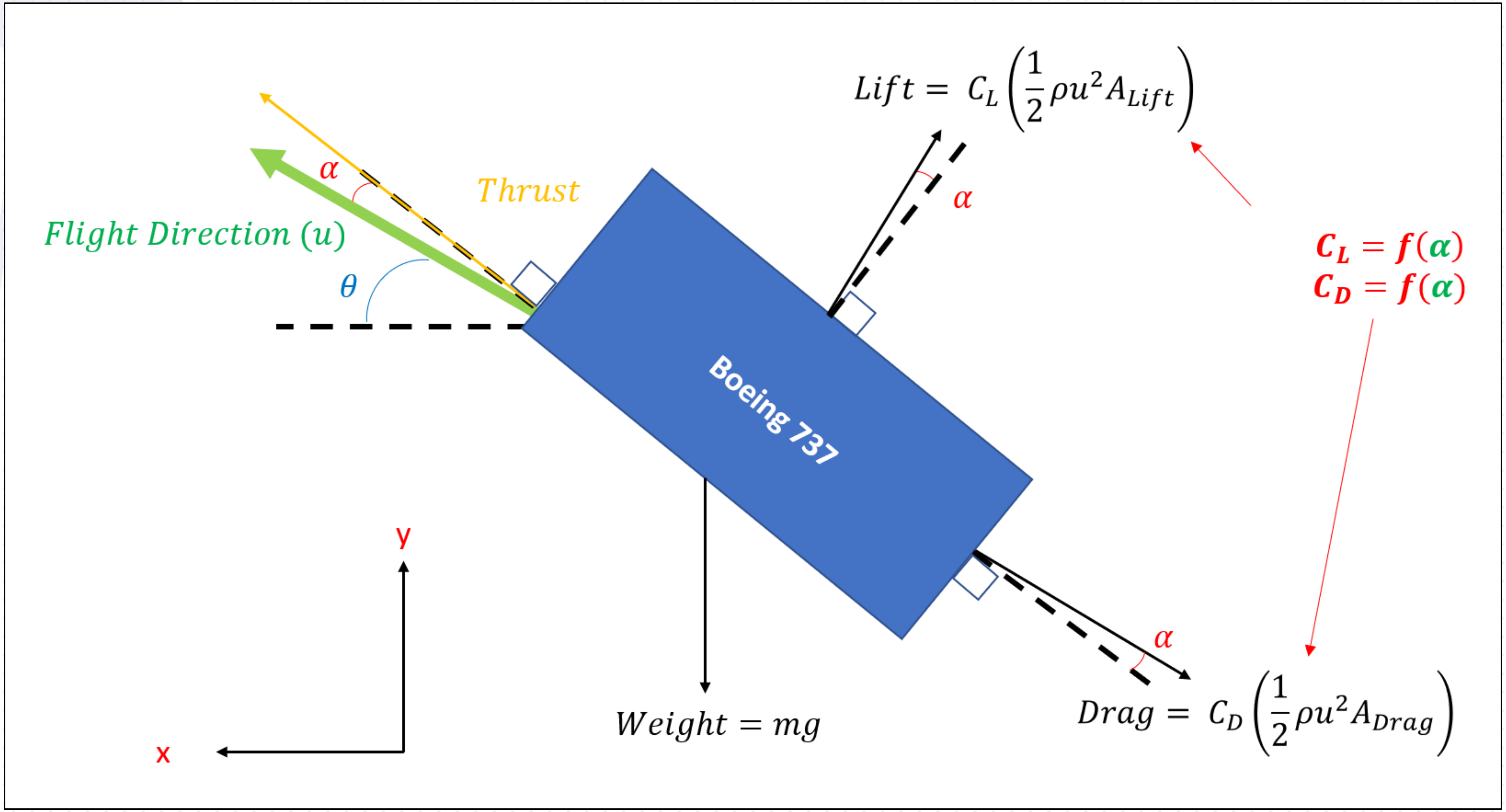




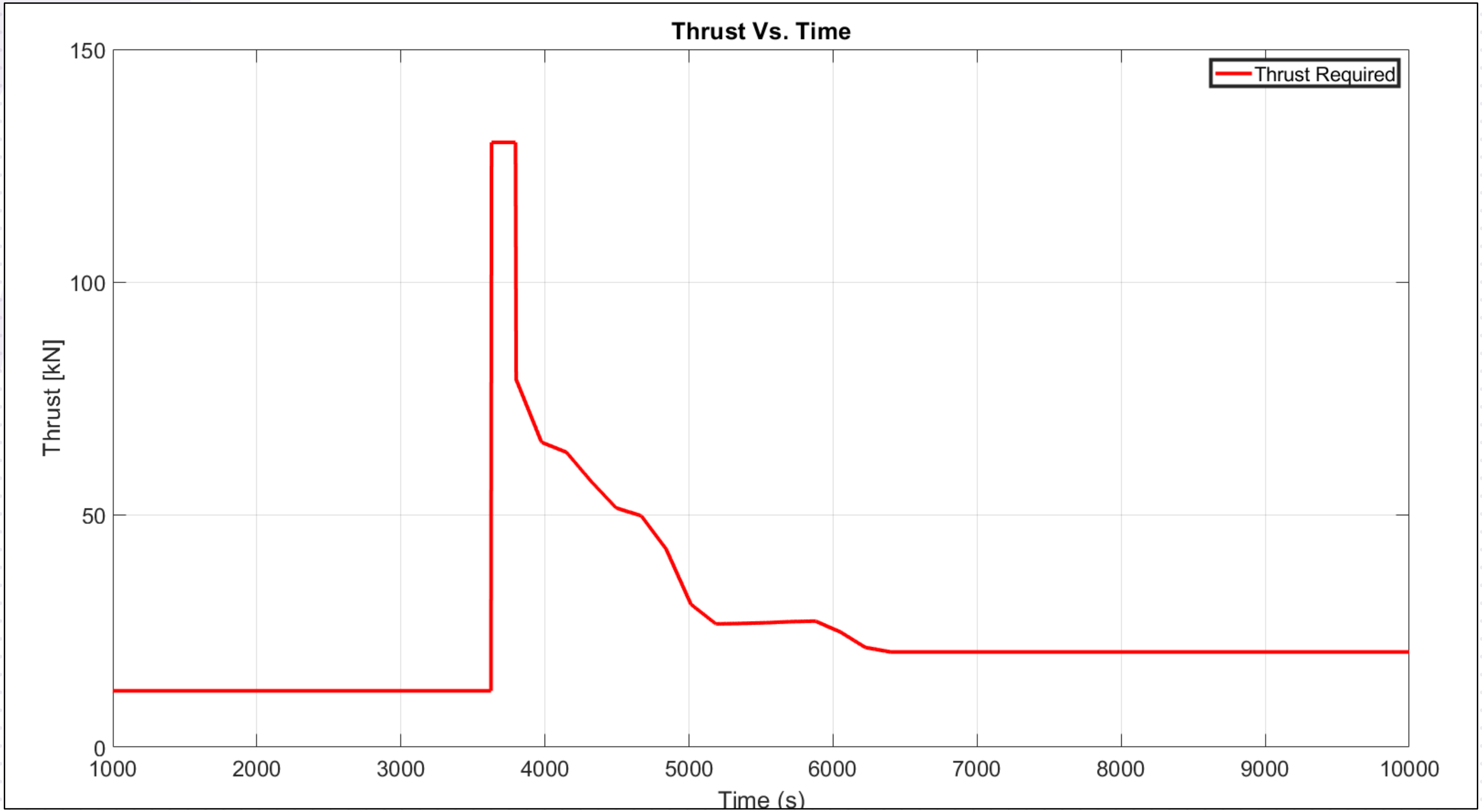
Flight Profile



2DOF Formulation

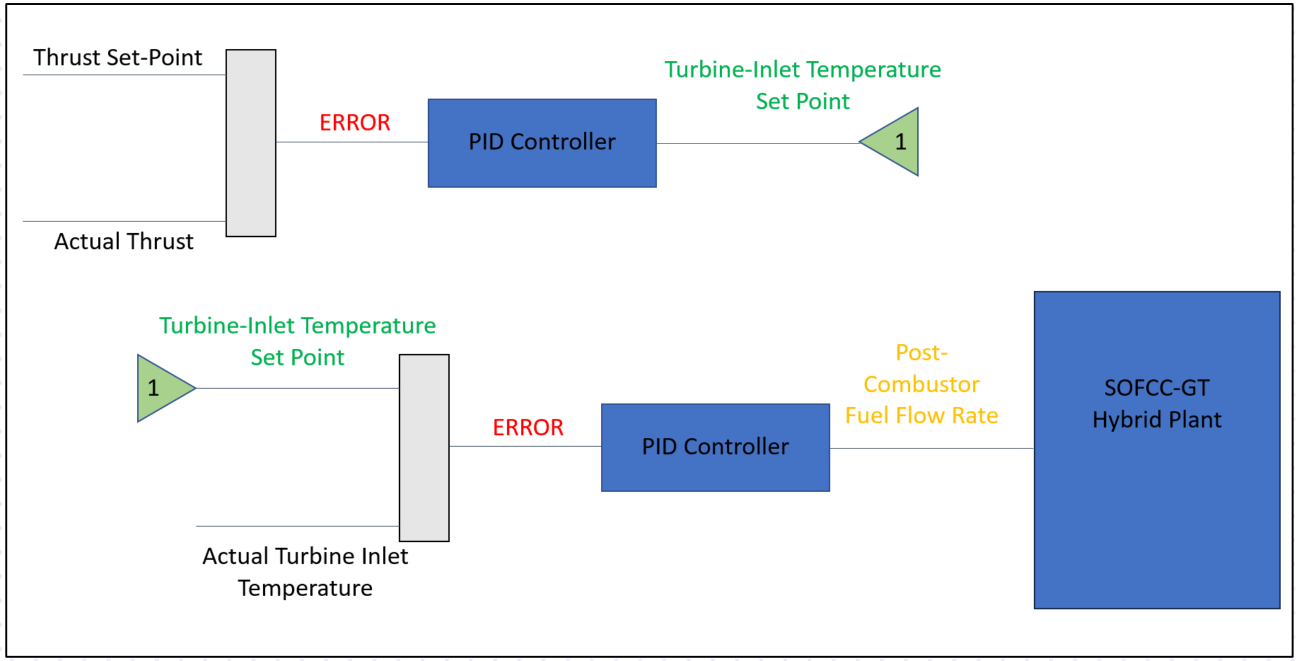


2DOF Formulation

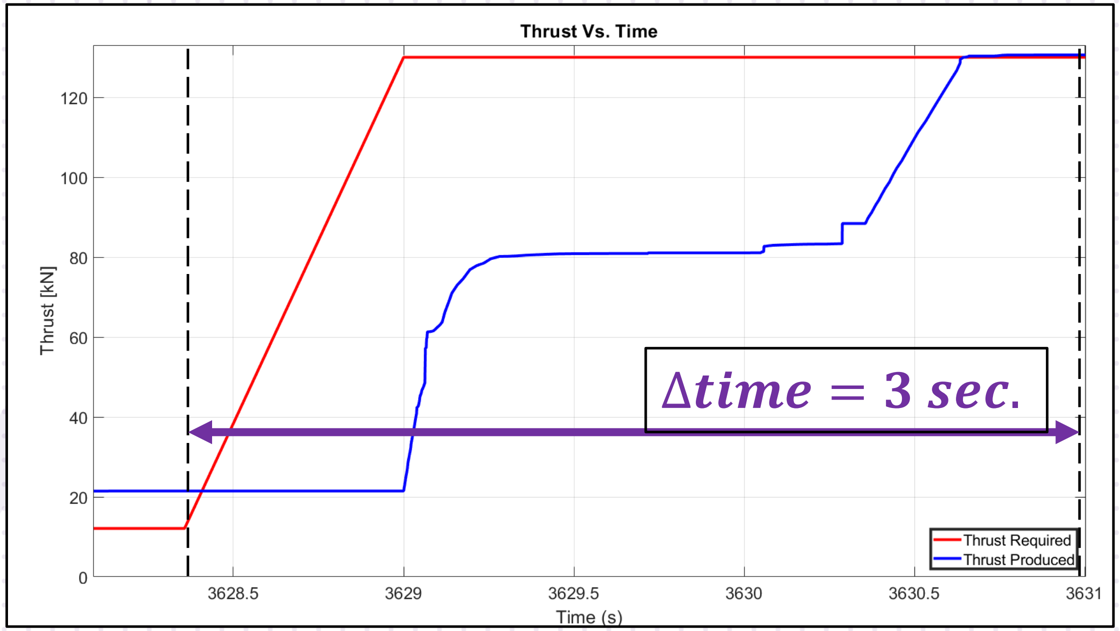


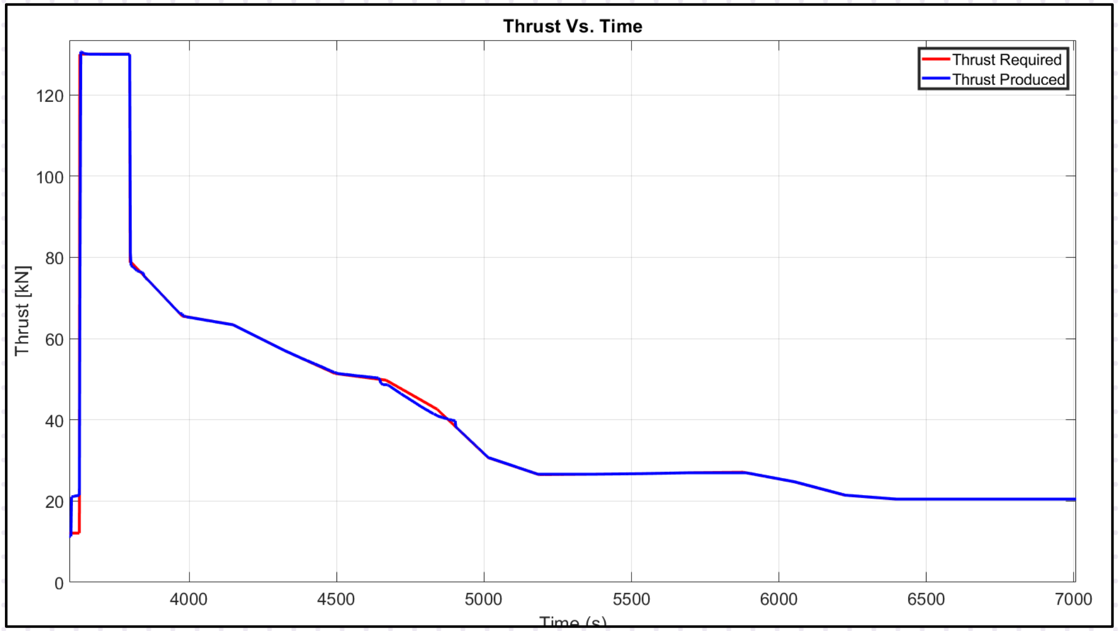
Operational Control Strategy

- SOFC Operated at Maximum Power throughout Flight Profile
- Turbine Inlet Temperature is adjusted via Fuel Flow Rate to Match System Thrust to 2DOF Predicted Thrust



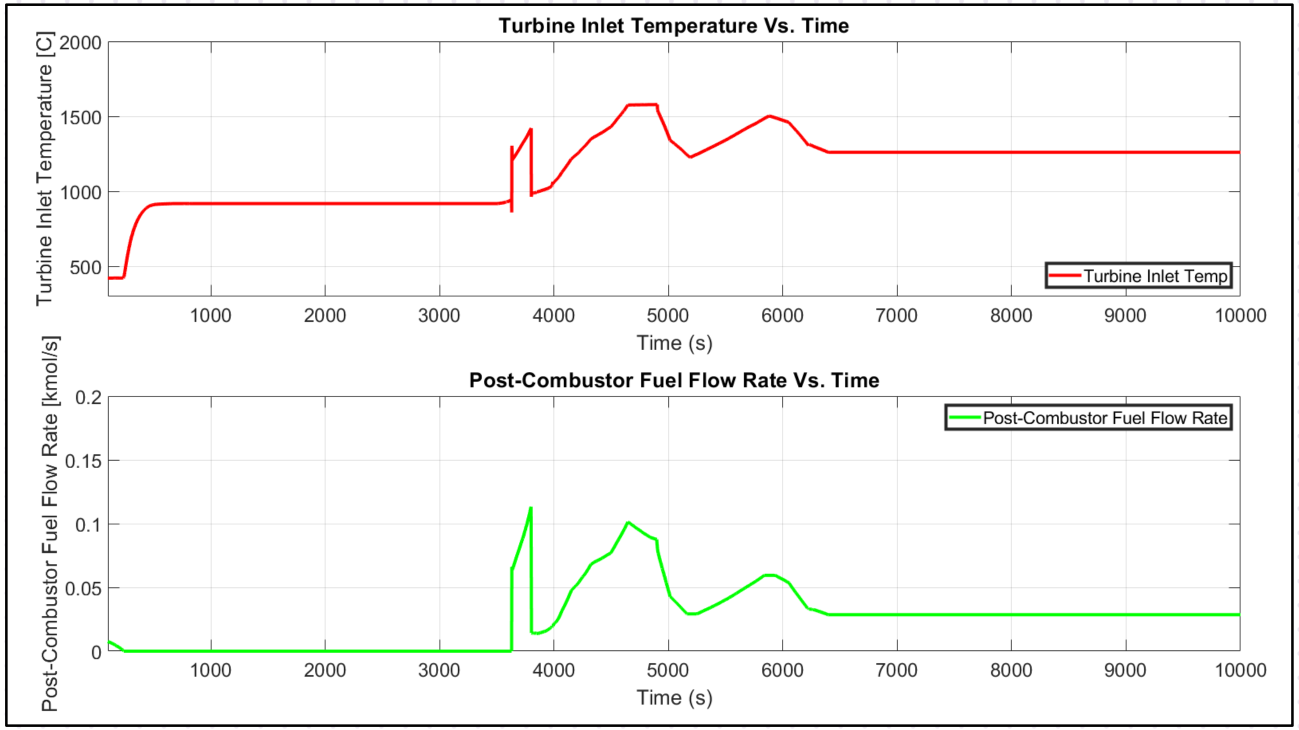
Results (Thrust)





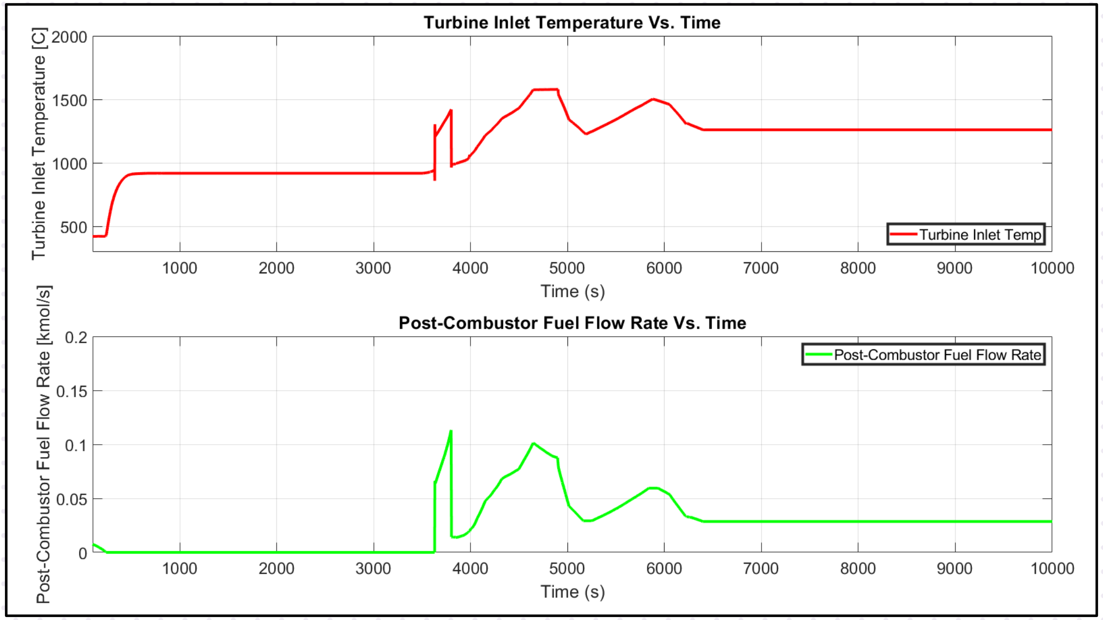
Results (Turbine Inlet Temperature)

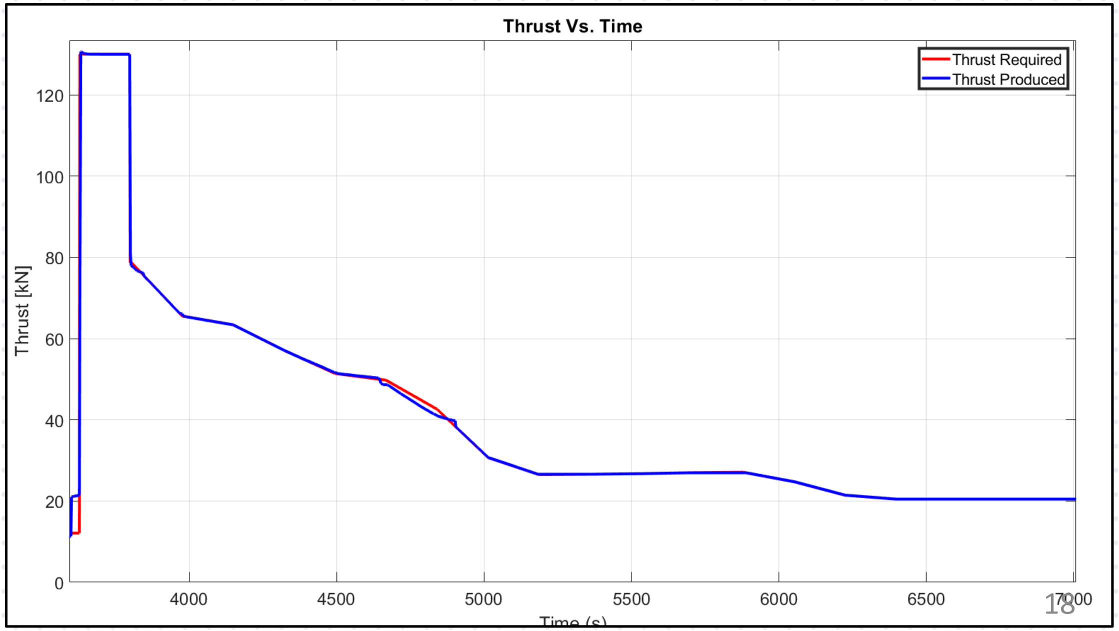
- Turbine Inlet Temperature Reduced Operates at ~1,260˚C at Cruise Condition
- Fuel flow calculated across flight profile with cruise fuel flow being ~0.03 kmol/s



Conclusions

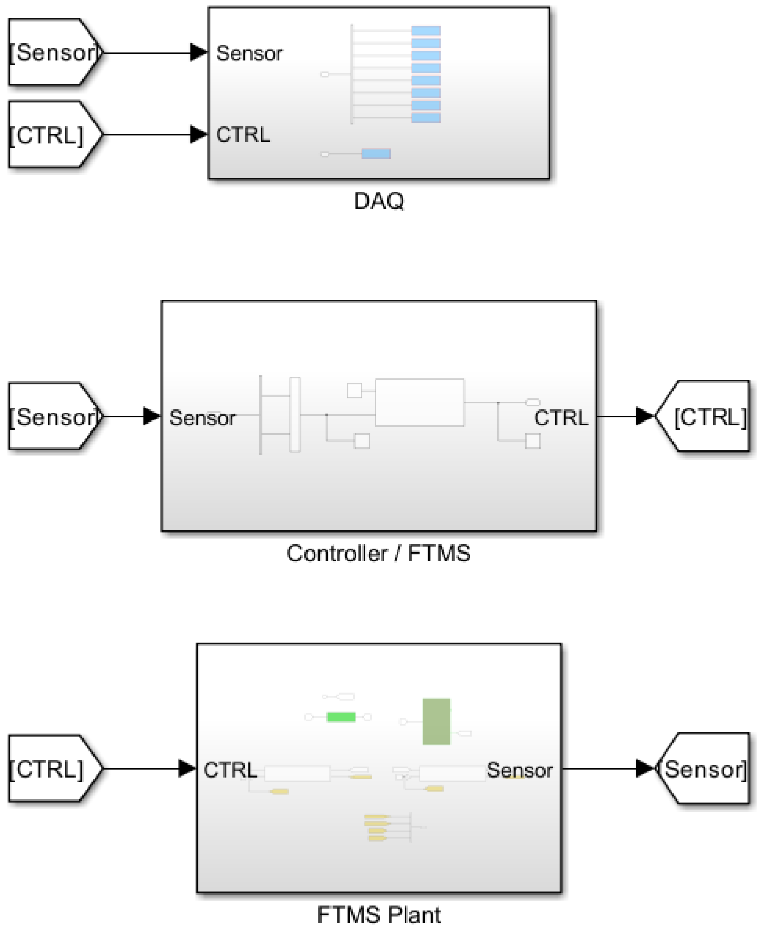
- Hybrid System Using Ammonia Fed SOFC Proposed as a Carbonless Propulsion System
- System was able to Dynamically react and control to match Thrust requirement along flight profile
- Turbine Inlet Temperature was able to be reduced during cruise and take-off, reducing NOx formation





Future Work

- 2DOF incorporation into controls of system model
- Implement Fuel Thermal Management System (FTMS) into system model
- Investigate addition of batteries onboard for high load transients
- Optimize system sizing and controls to maximize range



Acknowledgements

- NASA CLEAN ULI Project
  - This material is based upon work supported by the National Aeronautics and Space Administration under Grant No. 80NSSC23M0060 issued through the University Leadership Initiative Program. Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of NASA.

Thank you!

Are there any questions?

gjlayhew42@tntech.edu

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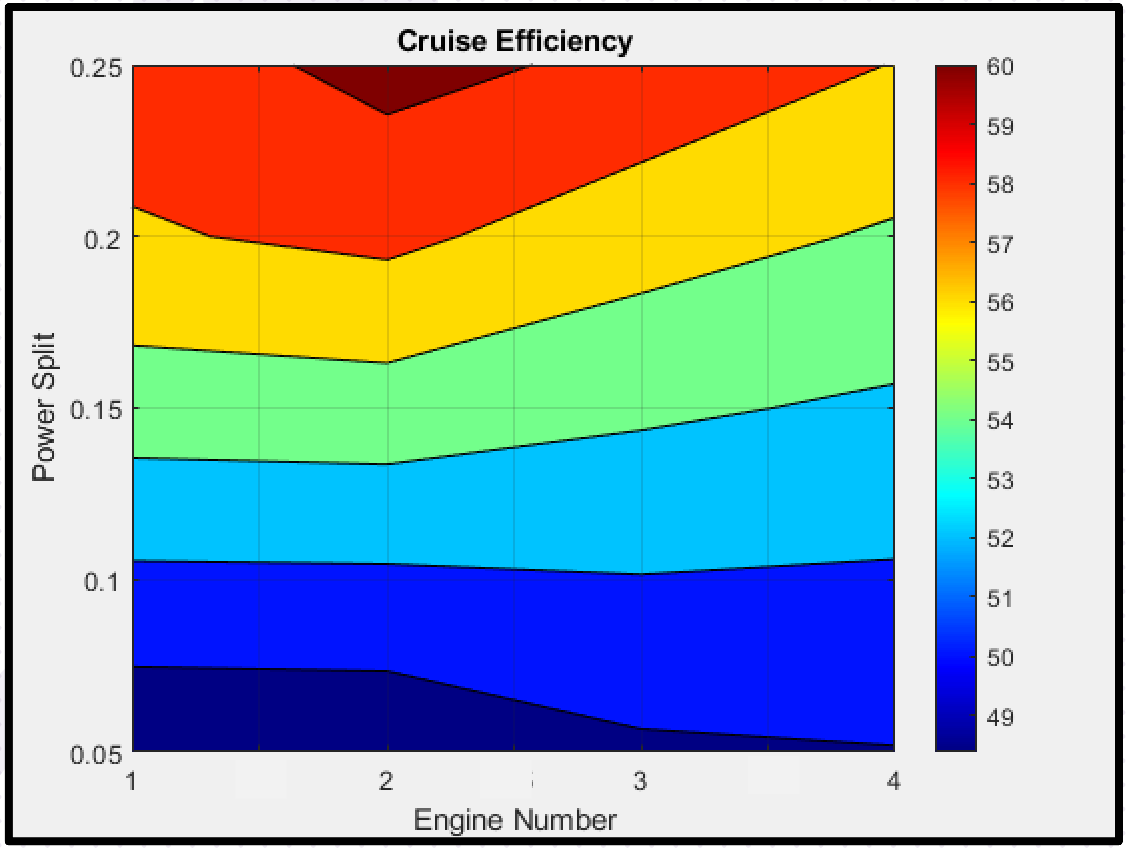
Efficiency

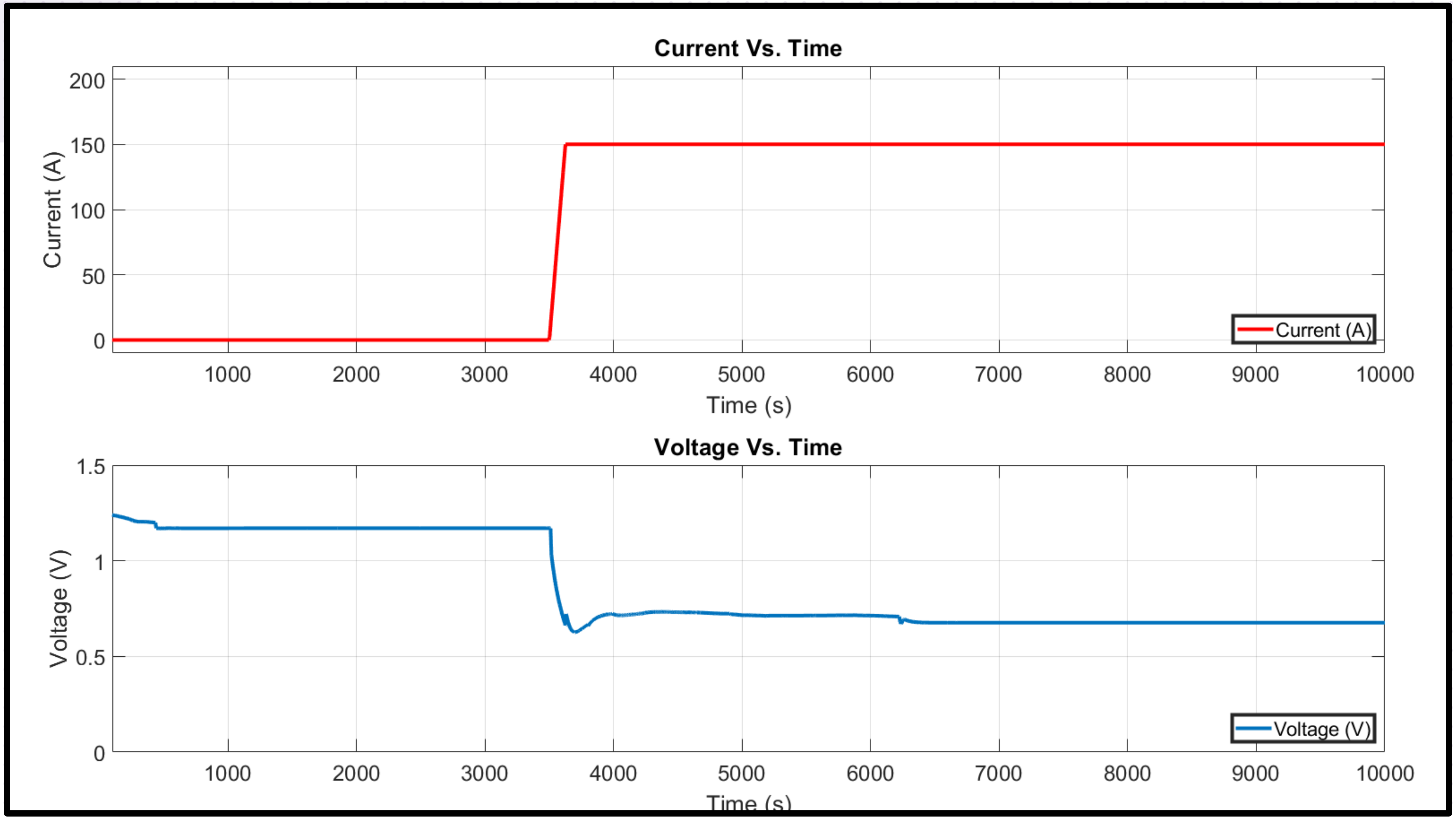


$$Power_{Split} = \frac{\dot{W}_{SOFC}}{\dot{W}_{SOFC} + \dot{W}_{Turbine} - \dot{W}_{Compressor}}$$

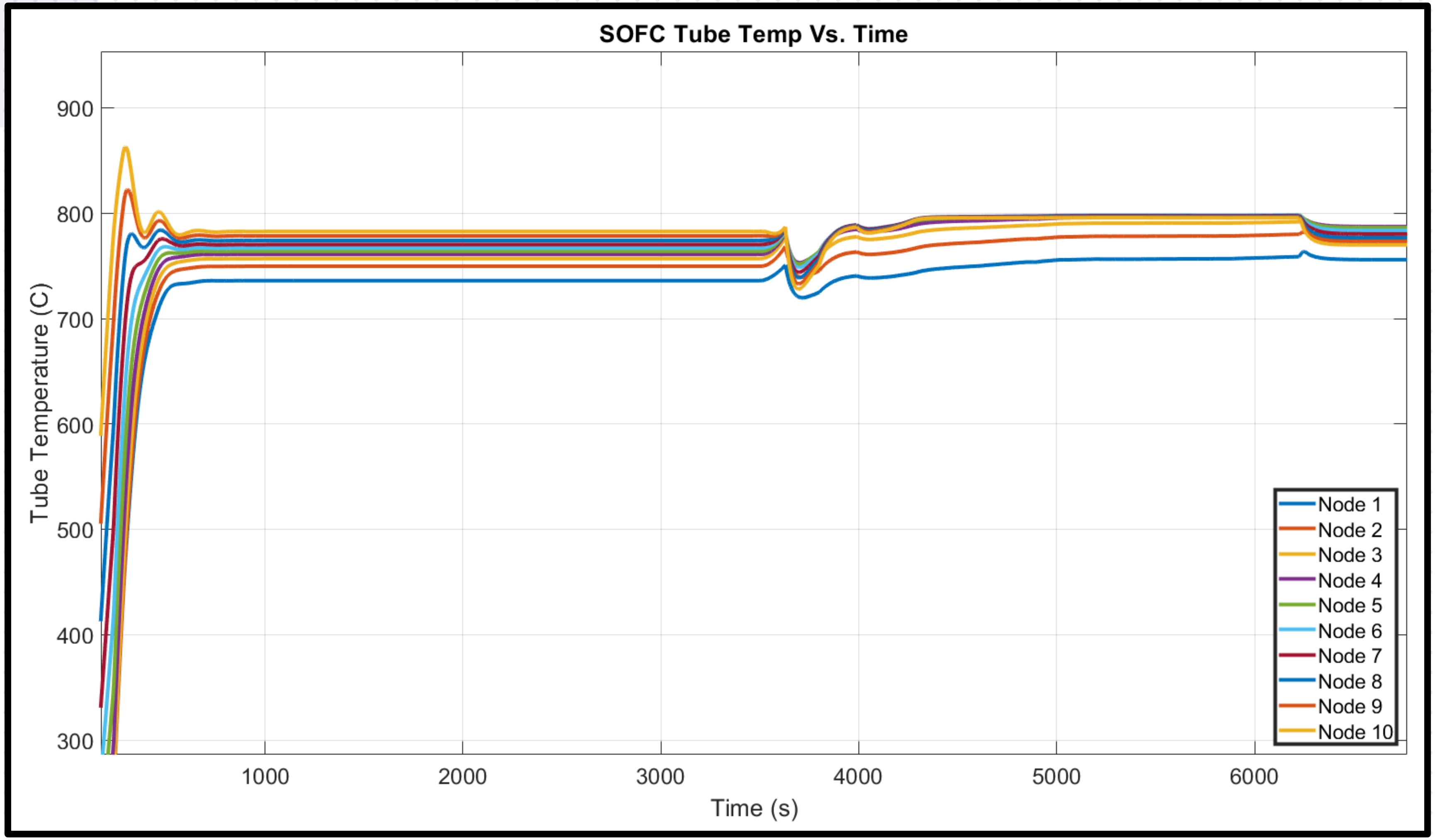
Cruise Propulsive Efficiency	
Leap 1B	**SOFCC-GT**
~36%	>52%

SOFCC ≈ 1.4X Efficient

Voltage and Current

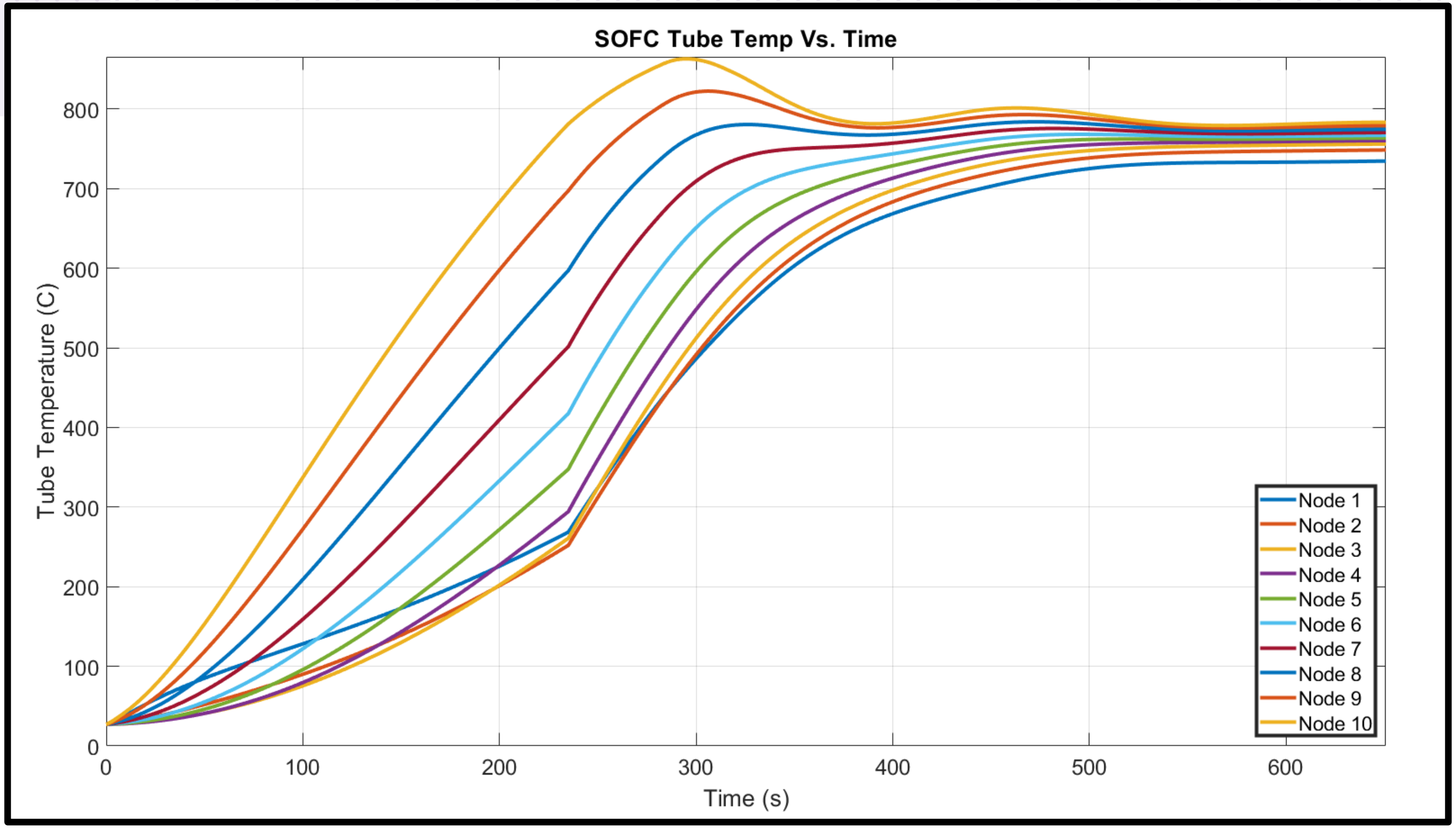


Tube Temps

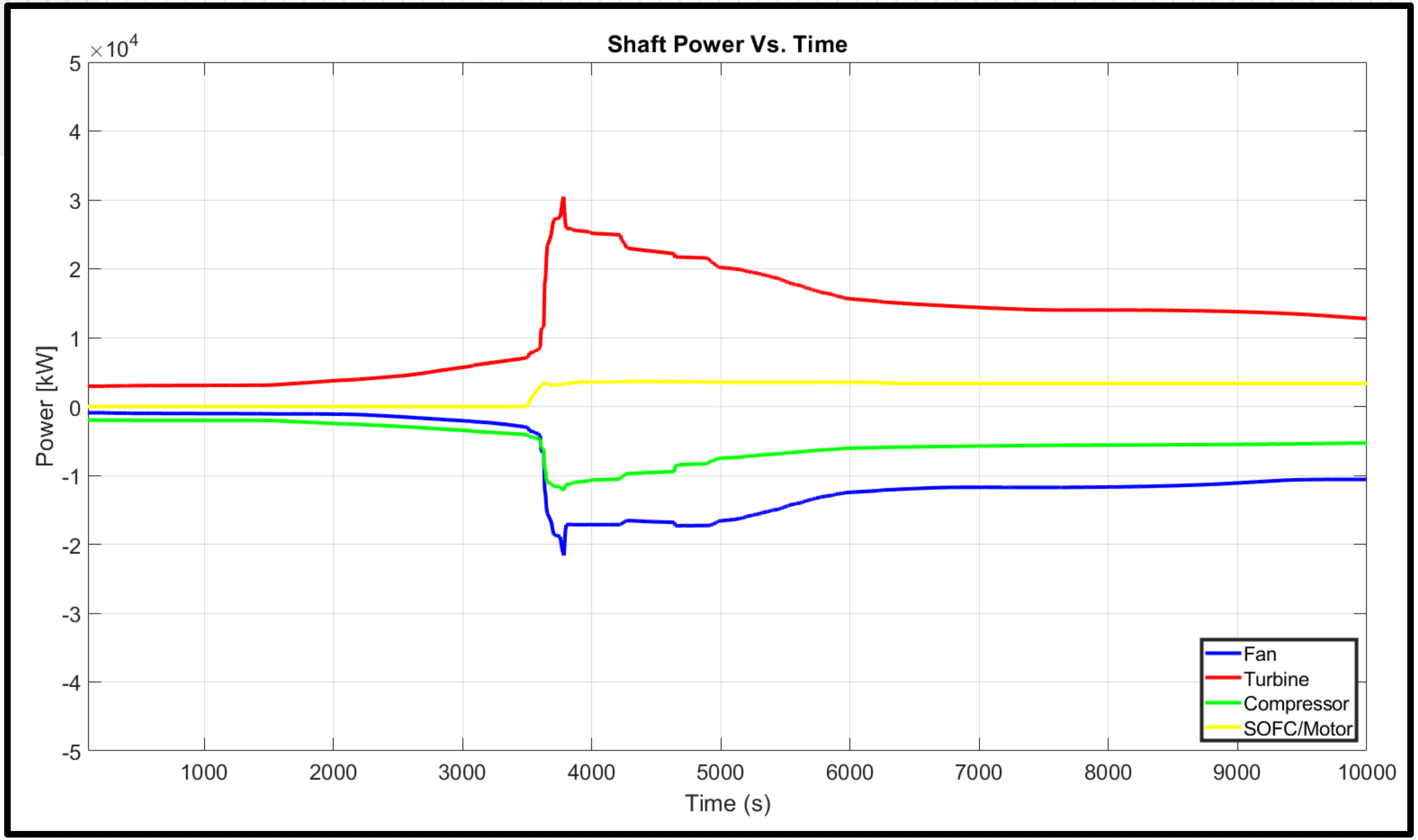


SOFC Tube Temp Vs. Time
900
800
700
600
500
400
300
Tube Temperature (C)
1000
2000
3000
4000
5000
6000
Time (s)
Node 1
Node 2
Node 3
Node 4
Node 5
Node 6
Node 7
Node 8
Node 9
Node 10

Tube Temps (Warm-Up)



Power



Shaft Power Vs. Time
×10^4
5
4
3
2
1
0
-1
-2
-3
-4
-5
Power [kW]
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Time (s)
Fan
Turbine
Compressor
SOFC/Motor