Turbo-Generation Control

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Overview: NEAT Turbine Transient Assessment & Control

Problem

Electrified Aircraft Propulsion (EAP) power systems are being studied at the NASA Electric Aircraft Testbed (NEAT) facility. The electric motors at NEAT have the capability to dynamically respond to commands that would be unrealistic when integrated with turbomachinery. There is a need to provide more realistic turbine transients for future system performance studies.



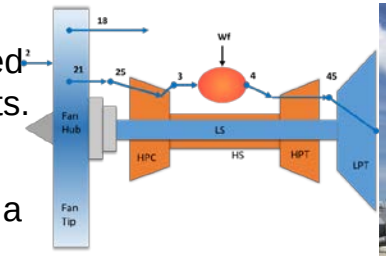
STARC-ABL Aircraft Concept

Objective

Work with the NEAT analysis team to help develop a method to physics based simulations to allow electric motors to provide more realistic turbine transients.

Approach

A dynamic Numeric Propulsion System Simulation (NPSS) generic model of a Turbofan and Tail Fan are combined to be representative of the STARC-ABL configuration. The NPSS models are integrated in MATLAB/Simulink using an S-function with pseudo-real time blocks to allow the simulation to reflect the computer clock. A short flight profile is used that contains altitude, Mach number, fuel flow, and power requirements. The computer is then integrated on the NEAT Ethernet network using User Datagram Protocol (UDP) blocks to pass motor speeds and torques to emulate Turbofan shafts and power extraction.

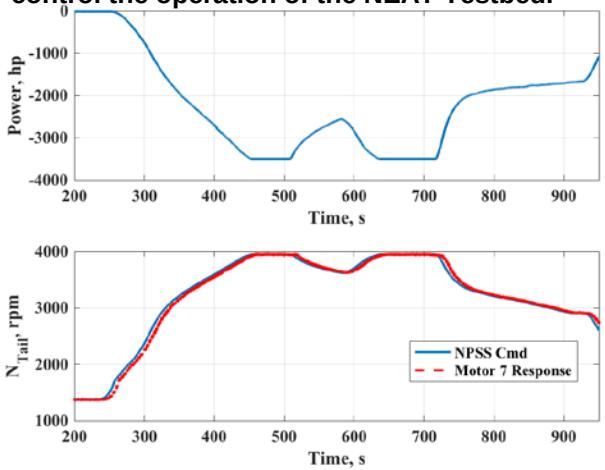




NPSS Turbofan and Tail Fan models used to control the operation of the NEAT Testbed.

Results

The NEAT electric power system has been controlled using a generic NPSS model that is representative of the STARC-ABL configuration. The NPSS model was shown to operate stably during a short flight profile without violating voltage or current limits. Lessons learned have been compiled for future improvements to enable performance and design studies.



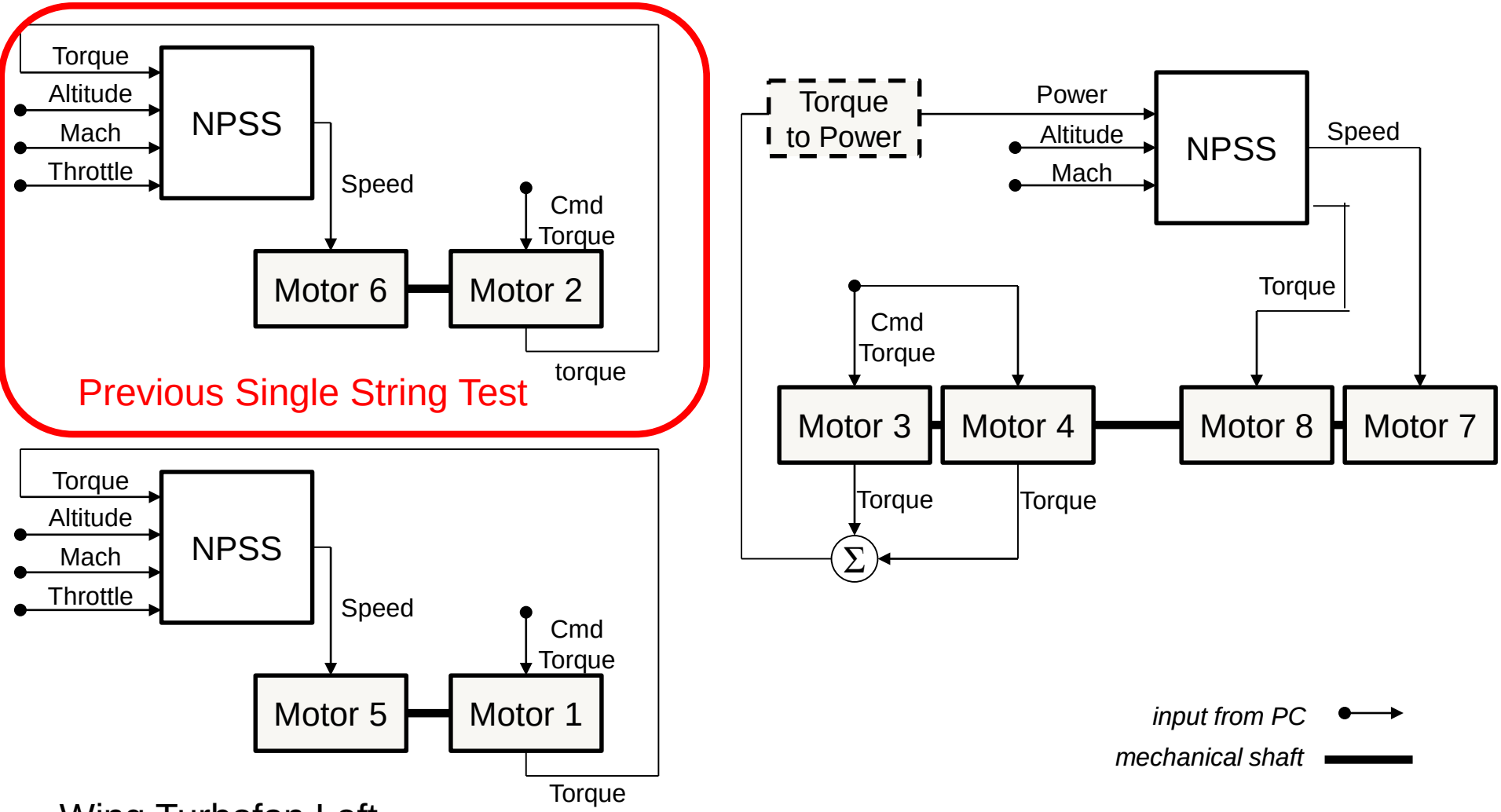
NPSS scaled power input and the resulting NPSS Tail fan shaft speed commanded to electric motor for emulated response.

POC: Joseph Connolly, NASA GRC

Significance

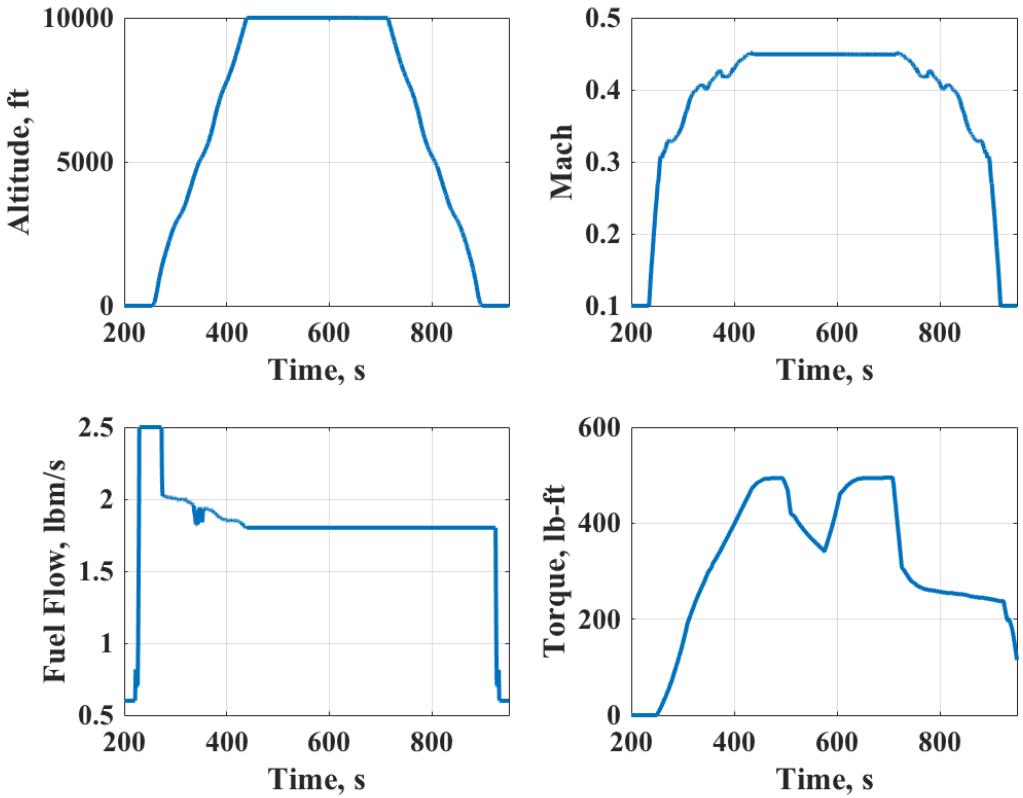
This demonstrates the capability to run turbomachinery models on a networked computer to control the operation of the NEAT electric motors to be more representative of the dynamic response of the system during flight like conditions of takeoff, cruise, and descent.

NEAT STARC-ABL Control Diagram



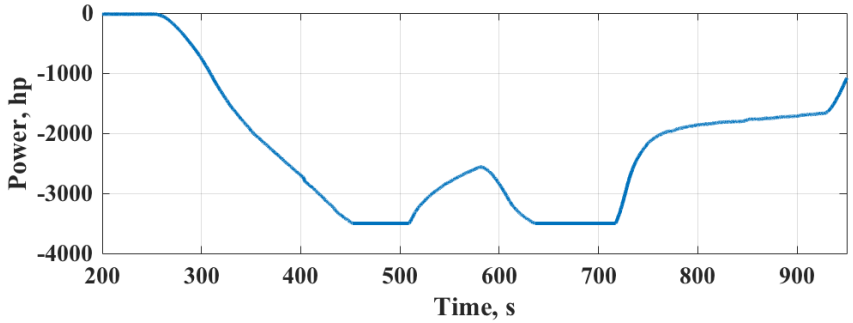
Flight Profile for Transient Turbine Assessment

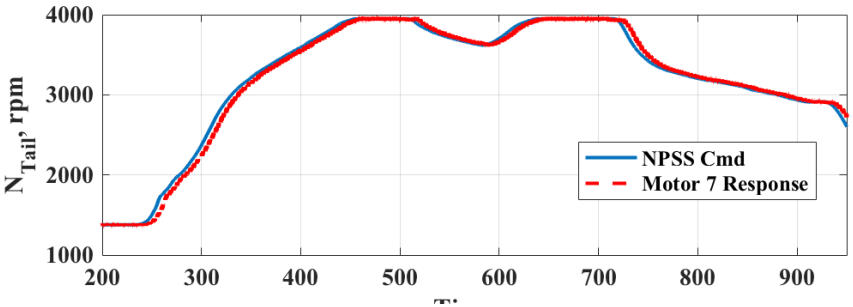
- The flight profile used for this test is a simple takeoff, cruise, and descent, that was limited to about 17min for rapid check out testing.
  - Future studies that will be focused on performance metrics will transition to the N+3 design reference missions
- After the large fuel flow transient for takeoff, the fuel flow is held constant to ensure changes in power extraction are reflected in the NPSS response and NEAT hardware
  - The power extraction used is simply for demonstrating correct communication to hardware and stability

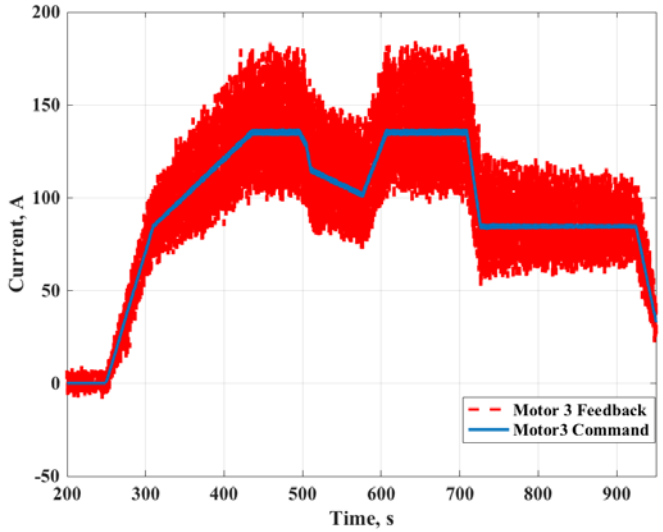


NEAT Hardware Results

- The power to the NPSS Tail Fan motor is shown, starting from zero power at flight idle to the expected 3500 hp at top of climb. Variation in the delivered power is the results of the power extracted from the wing turbofans
- The NPSS model provides a rotational speed to motor 7 that emulates the tail fan shaft.
  - The electric motor track the NPSS command well. There is a slight delay that will need to be understood and possibly filtered when doing future performance studies.
- The current control of the motors appears to behave reasonably in terms of the response following the resulting current commands generated from the NPSS inputs.

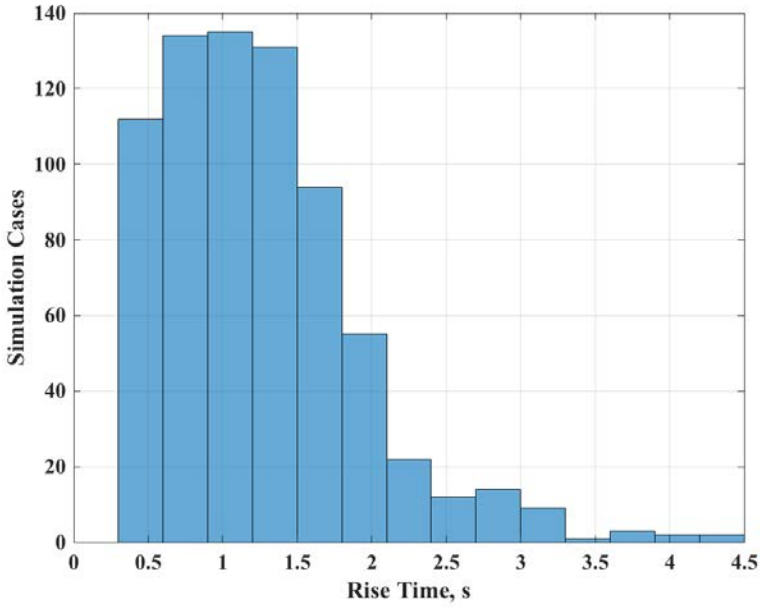




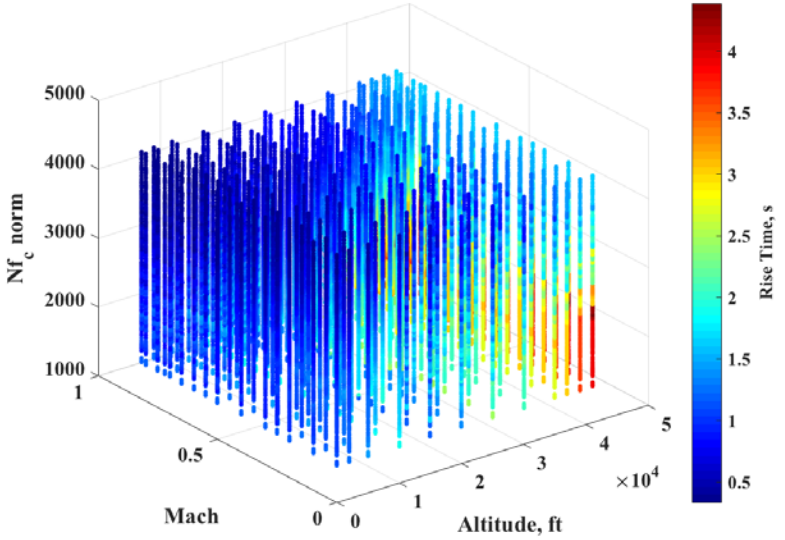


Turbofan Engine Controls Development

- The T-MATS STARC-ABL dynamic system simulation with power flow electrical component modeling was executed at 726 operating points encompassing the full flight envelope.
  - The controller was able to provide the a rise time of less than five seconds meeting the FAA requirement
  - Further analysis is being conducted for operability changes with newly available electrical machines



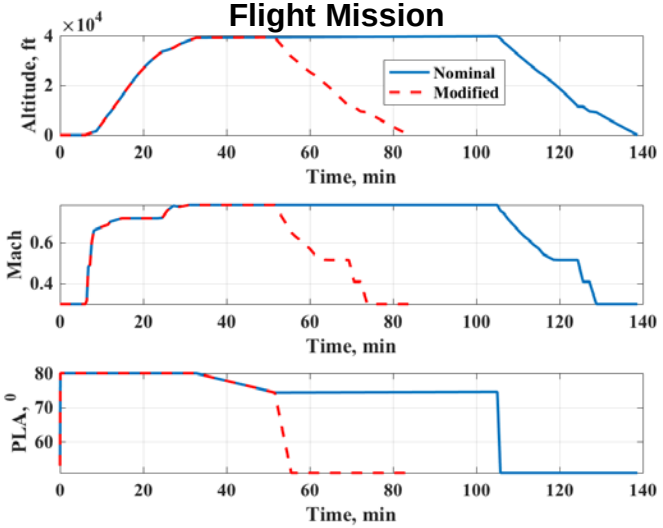
- The turbomachinery controller is required to provide two critical operations
  - It must be able to go from an idle condition to 95% of power within 5 seconds to simulate an emergency takeoff
  - It must be able to operate through out the operational envelope without encountering a stall event that results in a rapid loss of thrust.



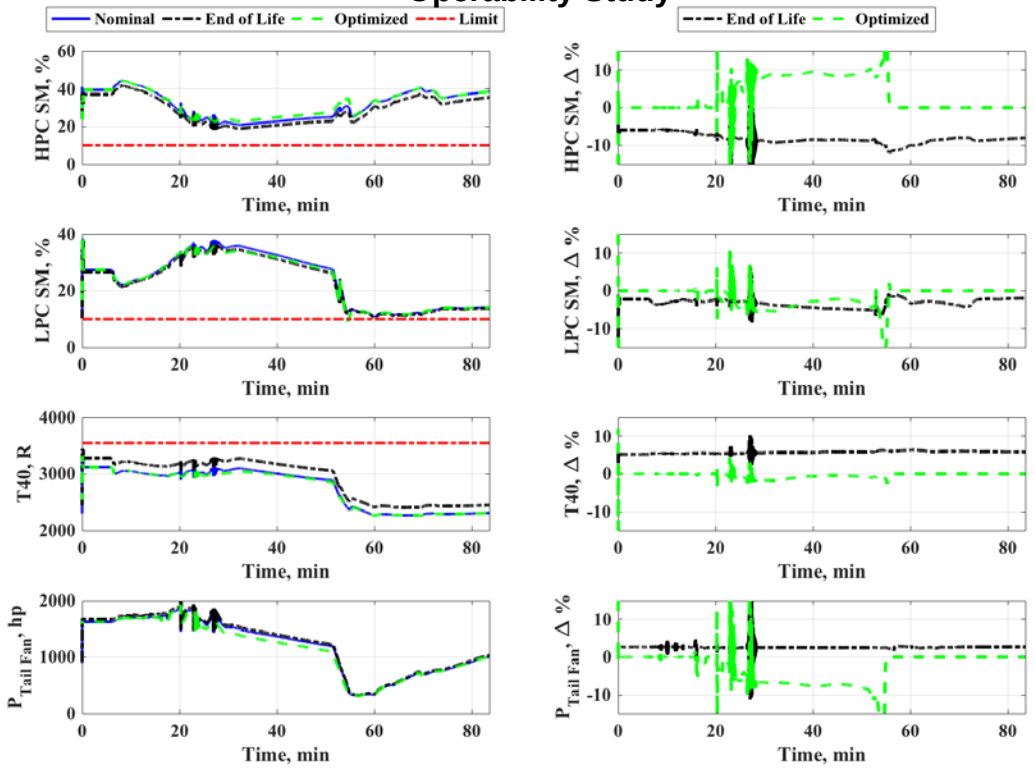
Transient Performance for Flight Mission

- The N+3 expected 900 nmi flight mission profile is provided below, the cruise portion truncated for the interest of time, but the main transient features remain
- Key operability parameters for the STARC-ABL system are shown for a healthy system, end of life, and optimized power split for lower TSFC

Flight Mission



Operability Study



It can be seen that none of the main operability limits are violated for the nominal mission throughout the expected system life cycle

The LPC stall margin is currently the closest to a violation at idle conditions. In general, taking slightly less power form the turbofan improves their operability margins and reduced TSFC by about 0.5%

Summary

- Analysis conducted on N+3 STARC-ABL concept for transient operation and control
  - The simple power flow electrical component modeling neglects the electrical dynamics of switching, but provides a tool for more rapid control system development,
- A transient assessment of the NEAT facility was conducted for a short duration flight profile with the focus on providing realistic transient responses from STARC-ABL representative turbomachinery models to interact with electric motors and generators.
  - A method similar to the the previous single string test of using NPSS MATLAB/Simulink S-function operation with UDP blocks to send and receive data across an Ethernet connection to the 8 electric motors was used.
  - The NPSS models of the STARC-ABL provided the expected transient behavior, however being generic models the performance metrics of the turbomachinery does not reflect the designed STARC-ABL turbomachinery
- A near term goal is to develop and demonstrate critical technologies for hybrid gas-turbine electric propulsion by 2025 to impact the next generation of single aisle aircraft

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Acknowledgments

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