Control Architecture for a Concept Aircraft with a Series/Parallel Partial Hybrid Powertrain and Distributed Electric Propulsion

by

Jonathan S. Litt,[1] Jonathan L. Kratz,[1] Santino J. Bianco,[1] Jonah J. Sachs-Wetstone,[1] Timothy P. Dever[1]
Halle E. Buescher[2]
Nicholas C. Ogden,[3] Felipe D. Valdez,[3] Daniel W. Budolak,[3] Matthew J. Boucher[3]
Andrew P. Patterson[4]
Ralph H. Jansen[1]

2023 AIAA SciTech Forum

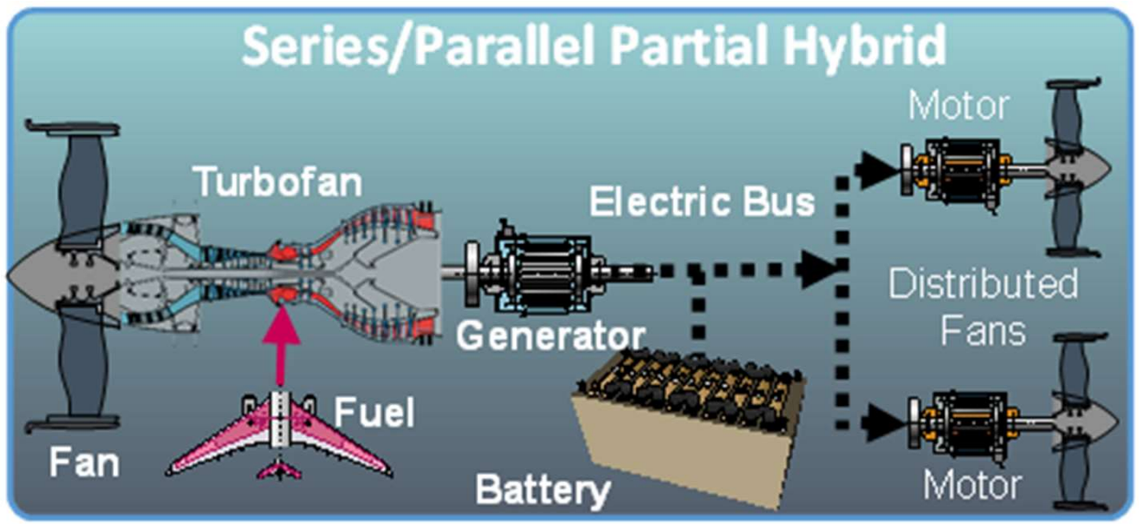
23–27 January 2023

National Harbor, MD & Online

[1] NASA Glenn Research Center
[2] HX5, LLC
[3] NASA Armstrong Flight Research Center
[4] NASA Langley Research Center

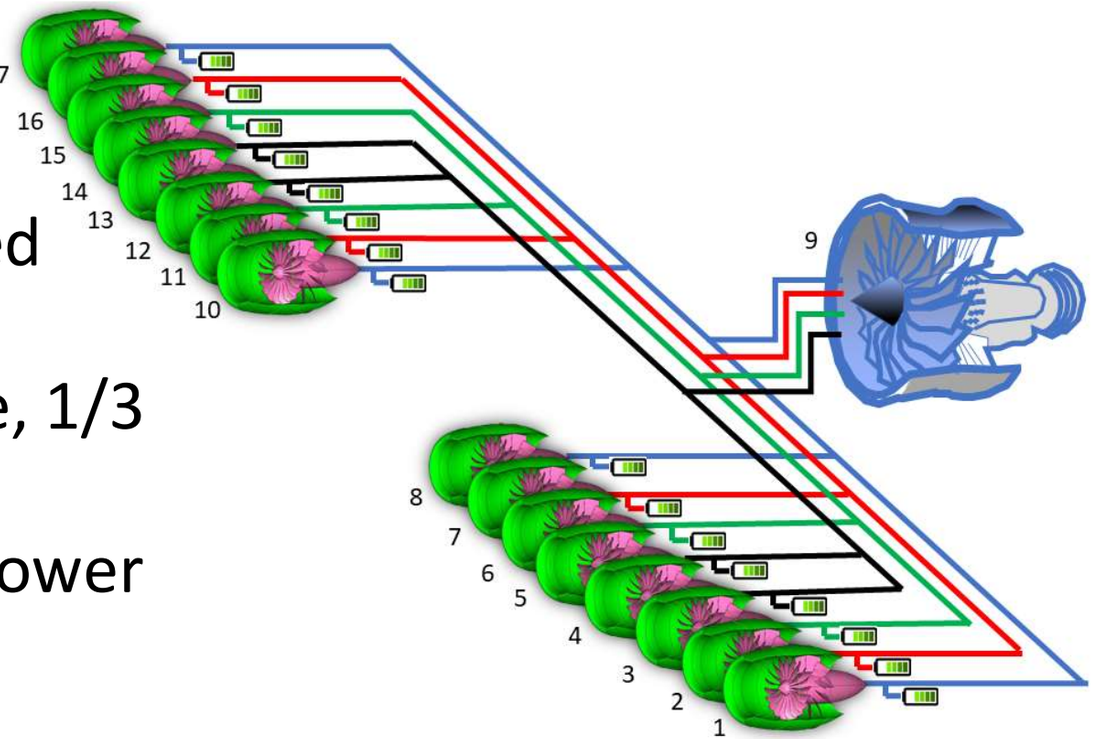
SUsonic Single Aft eNgine (SUSAN) Electrofan

- 2040 entry-into-service concept
- Single aisle 180 PAX regional jet
- Single Turbofan in the Empennage
- 16 Underwing Contrarotating Electric Fans or Electric Engines
- Series/Parallel Partial Hybrid Powertrain
- Small Reusable/Rechargeable (Secondary) Batteries Help Enable Electrification Benefits
- Single-Use (Primary) Batteries Provide Emergency Power, e.g., in the Case of a Turbine Engine Failure



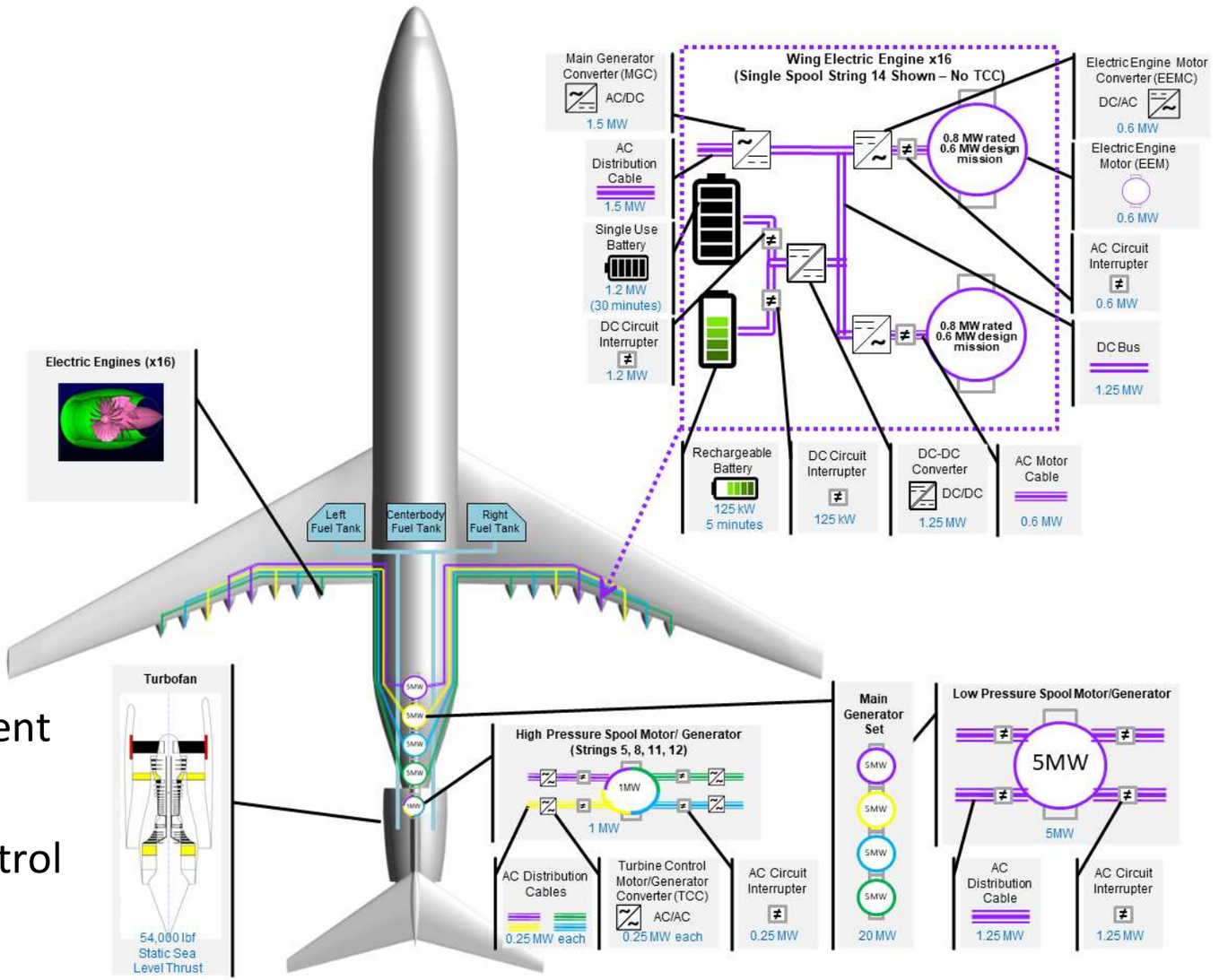
SUSAN's Unique Features and Constraints Require Complex Control Coordination

- 17 Engines, One Turbofan, 16 Electric Engines
- Electric Engines Run on Power Extracted from Turbofan
- Thrust Split Around the Flight Envelope, 1/3 Turbofan, 2/3 Electric Engines
- Turbofan Designed to Accommodate Power Extraction to Achieve Thrust Split
- Turbofan Operates With Only a Small Variation in Power Extraction
- Single Throttle Control for Normal Operation
- Distributed Electric Propulsion



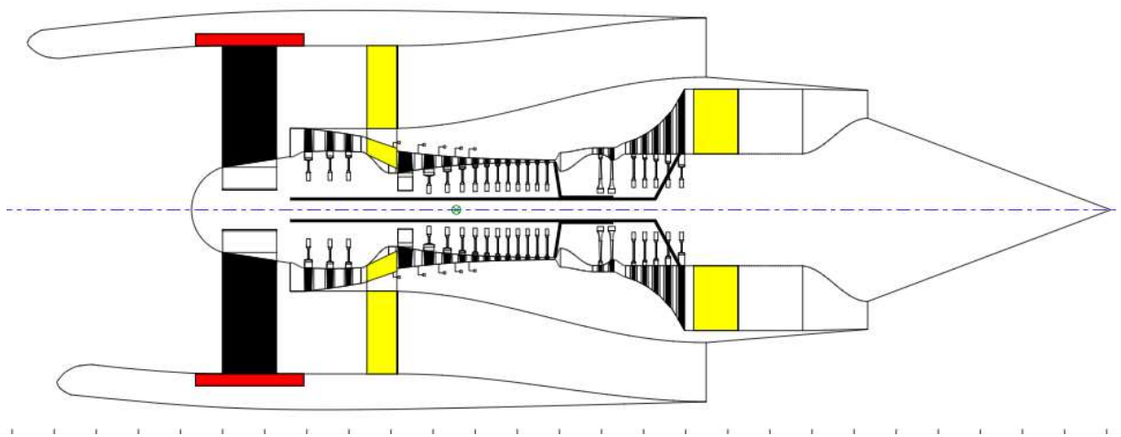
System and Subsystem Control

- Turbine Engine Control
- Power System Control
  - Bus Voltage Control
  - Battery State of Charge Control
- Electric Engine Control
- TEEM Control
- Powertrain Supervisory Control
  - Boost
  - Battery State of Charge Adjustment
  - Integrated Vehicle Health Management
- Flight Control
  - Integrated Flight and Propulsion Control

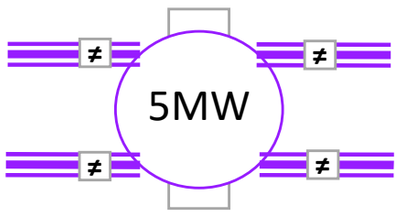


Turbofan Control

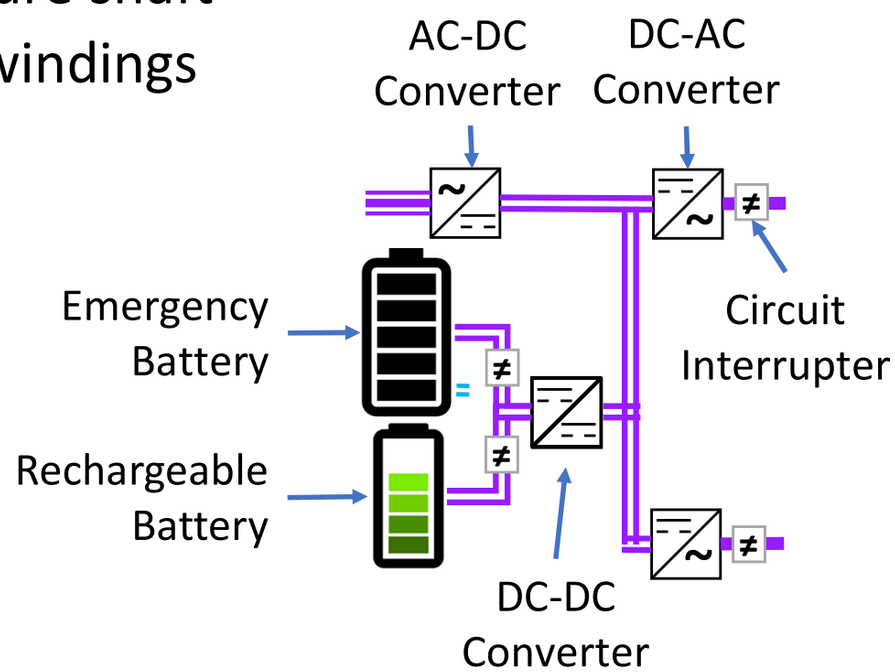
- Fan speed controlled
- Standard Min-Max control system
- Open-loop scheduled Variable Bleed Valve and Variable Area Fan Nozzle



Power System Control

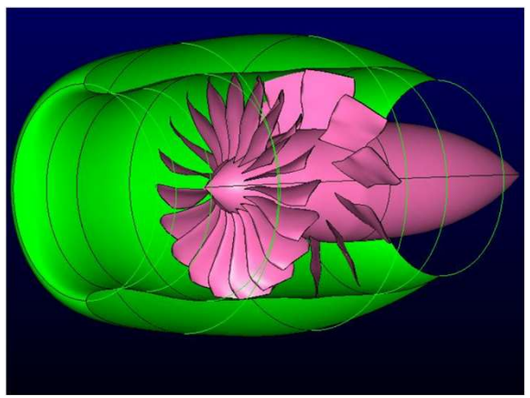


- Power extraction
  - Four 5 MW generators on the turbofan's low-pressure shaft
  - Each 5 MW generator is separated into four 1.25 MW 3-phase windings
  - One 1 MW motor/generator on the high-pressure shaft
  - The 1 MW motor/generator has four 3-phase windings
- Bus Voltage Control
- Battery charging



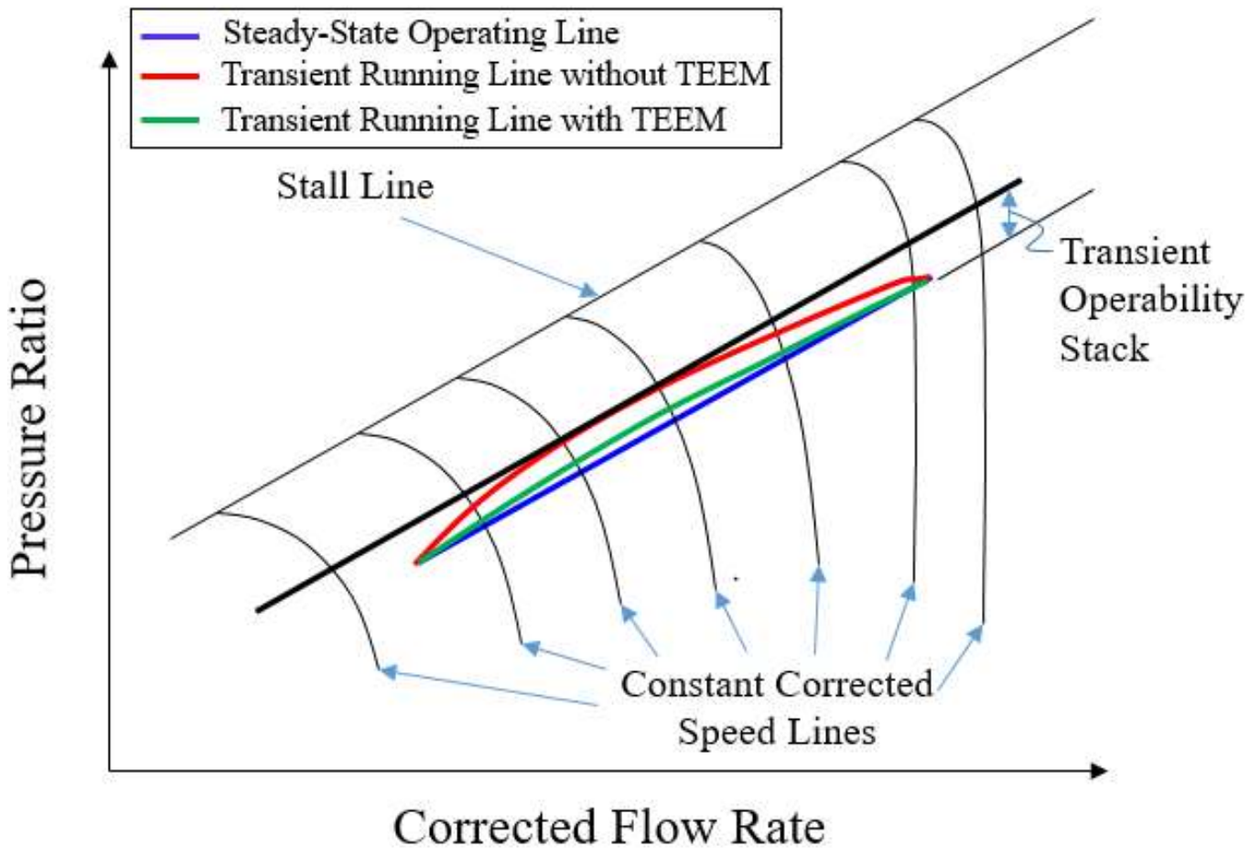
Electric Engine Control

- 16 contrarotating electric engines, eight under each wing, mounted in a mail slot nacelle
- Each electric engine has two fans, each with its own motor
- Each electric engine is individually speed controlled
- Open-loop scheduled Variable Area Fan Nozzle



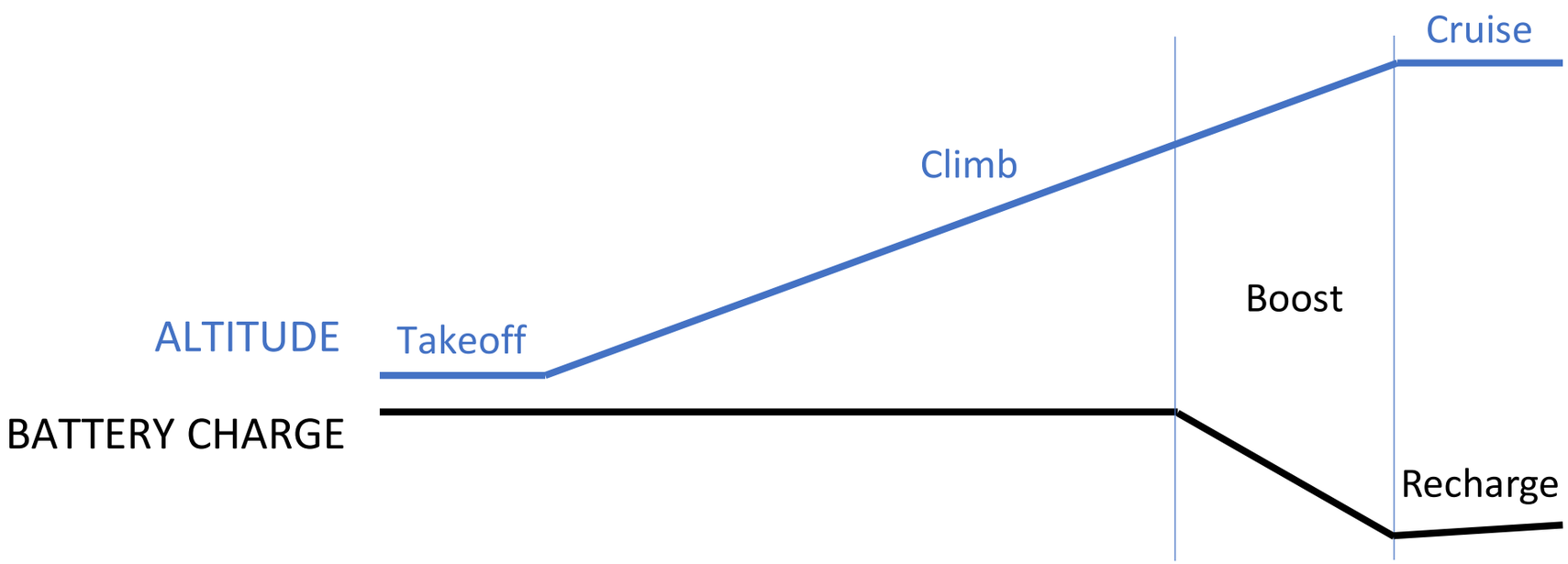
Turbine Electrified Energy Management (TEEM) Control

- TEEM Control takes advantage of the existing motor/generators on the engine shafts to inject or extract power during transient operation, providing an operability benefit
- TEEM Control helps minimize the off-design operation during accelerations and decelerations, maintaining operation close to the steady state operating line



Powertrain Supervisory Control

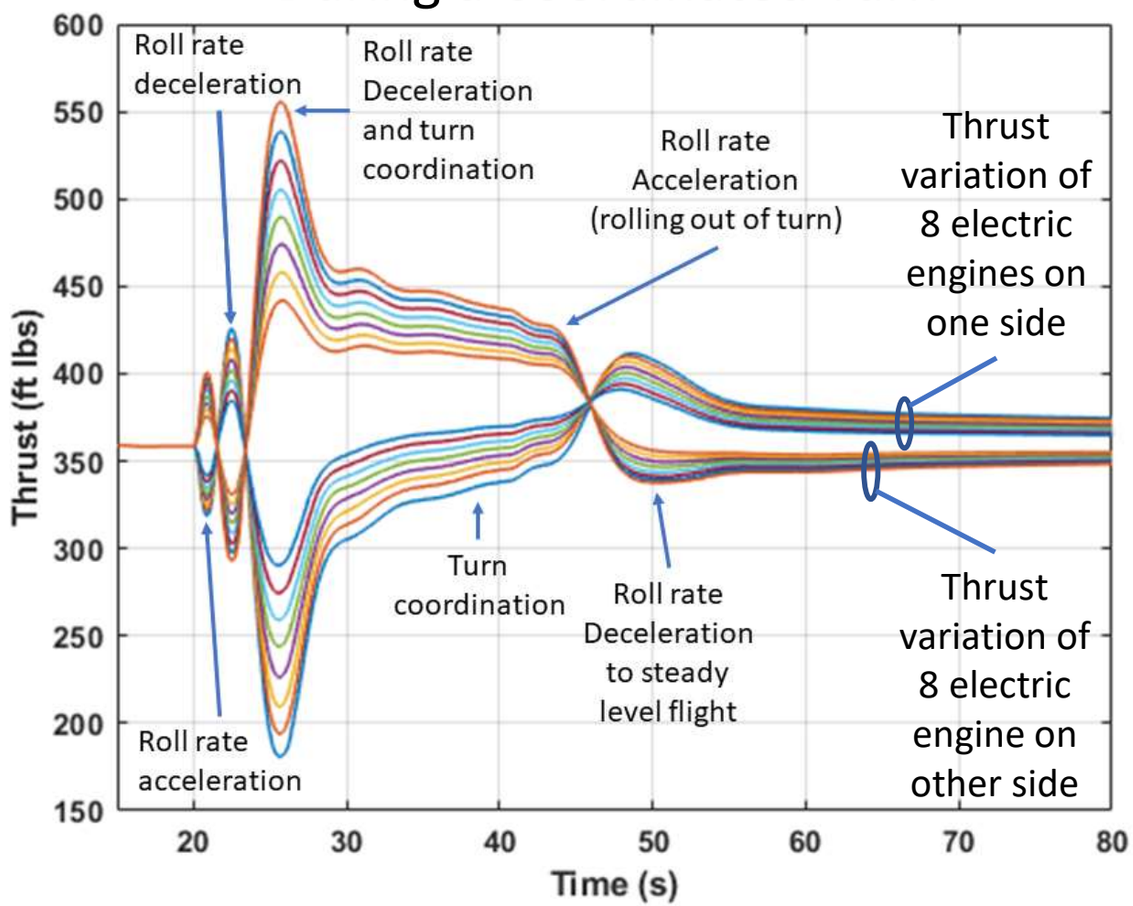
- Boost (electric engine power augmented by battery at top of climb)
- Battery State of Charge Adjustment
- Integrated Vehicle Health Management



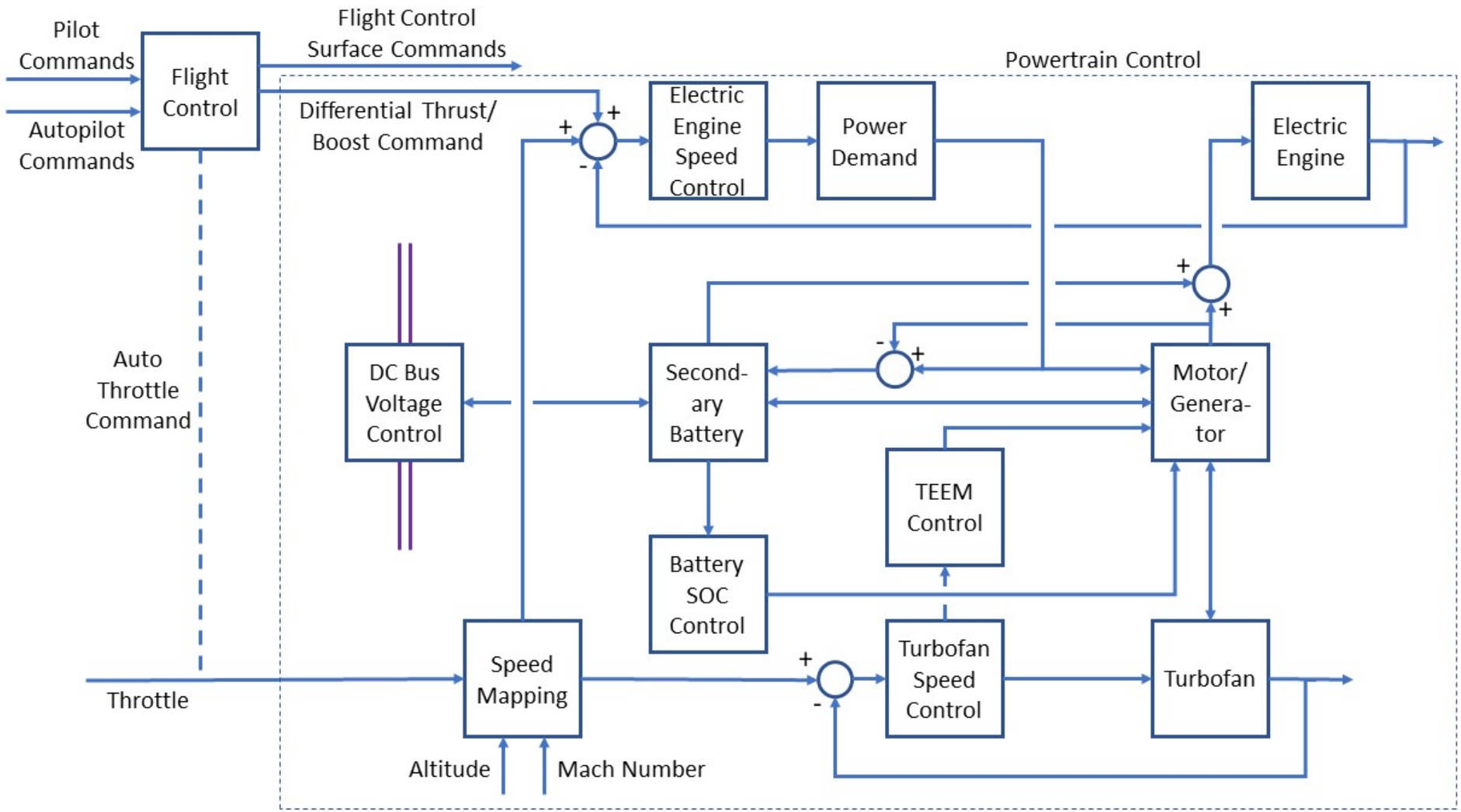
Flight Control

- Standard flight control, including autopilot and an associated auto throttle
- Integrated flight and propulsion control using distributed electric propulsion

Electric Engine Thrust Variation During a Coordinated Turn



High-Level SUSAN Control Structure



Summary

- The control systems of the individual components described are simple
- The overall control scheme to coordinate the various subsystems is relatively complex
- The complexity of the coordination is done automatically, which greatly simplifies the pilot interface
- Any future design updates are not expected to impact the control approach significantly

Acknowledgments

The Convergent Aeronautics Solutions Project sponsors this work with the support of the Transformational Tools and Technologies Project, both of which are part of the Transformative Aeronautics Concepts Program under the NASA Aeronautics Research Mission Directorate.