Overview of a Ground Test of a Hybrid Electric Turbofan Engine

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Presentation Outline

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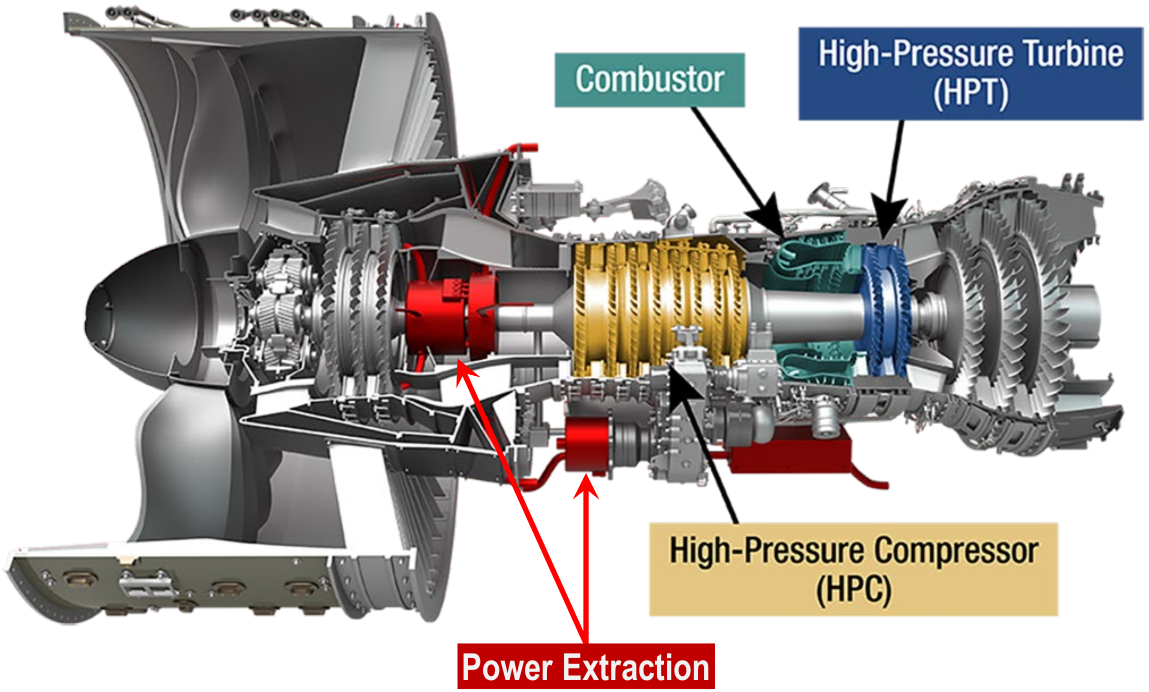
Background and Overview

- NASA's Hybrid Thermally Efficient Core (HyTEC)[1] project aims to develop small core turbofan engine technologies, including hybrid electric technology. HyTEC aims to achieve:
  - Fuel burn reduction of 5-10% compared to 2020 best-in-class turbofan engines
  - Up to 20% power extraction at altitude, which is 2-4 times current state of the art
  - Advanced design capabilities for small core combustors to operate effectively and efficiently on high blend (80-100%) synthetic aviation fuels
- Hybrid electric engines offer potentially significant performance improvements for transport aircraft
  - Enabling increased power extraction to power downstream loads such as electric propulsors
  - Optimizing engine performance through turbine electrified energy management (TEEM)
  - Hybrid electric systems can function with and without energy storage such as batteries
- The HyTEC Power Extraction (PEx) Demonstration is a partnership between GE Aerospace and NASA to advance the state of the art of hybrid electric engines for commercial transport aircraft



1. Work in the HyTEC project is currently being transferred to the Subsonic Vehicles Technologies and Tools (SVTT) Project

Hybrid Electric Turbofan Test Overview

Hybrid architecture informed by GE Aerospace future product requirements

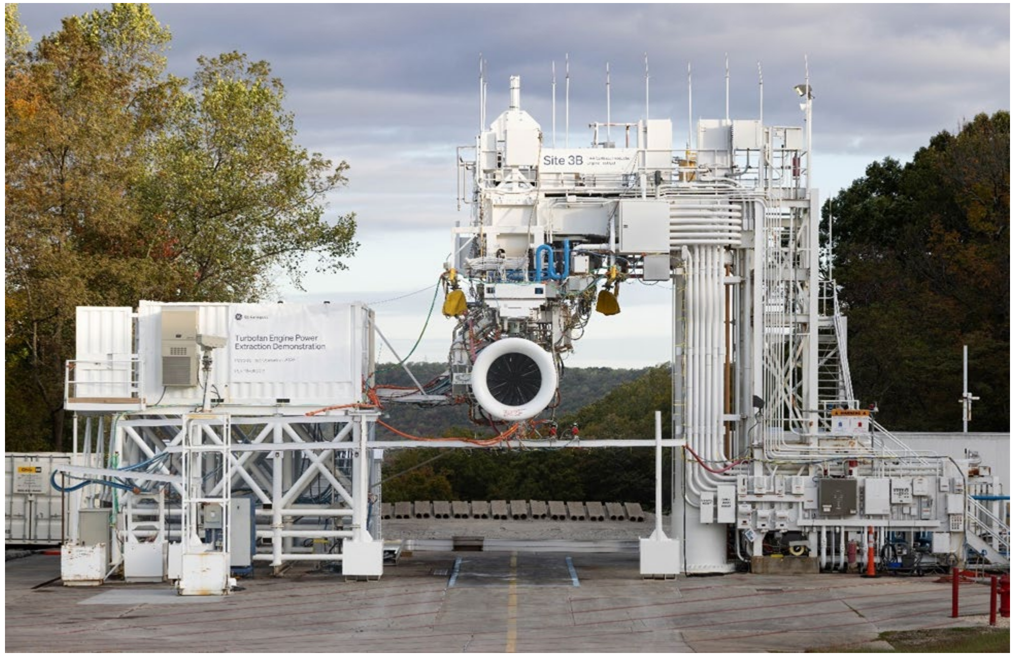
- Passport turbofan with test-specific engine control software
- High Pressure (HP) spool motor/generator (M/G) attached through accessory gearbox
- Low Pressure (LP) spool motor/generator attached through test-enabling drivetrain
- MW-class power converters, test-enabling power supplies and load bank
- Test-enabling exhaust flowpath, thermal management system, facility controllers
- Highly instrumented turbomachinery and electrical system

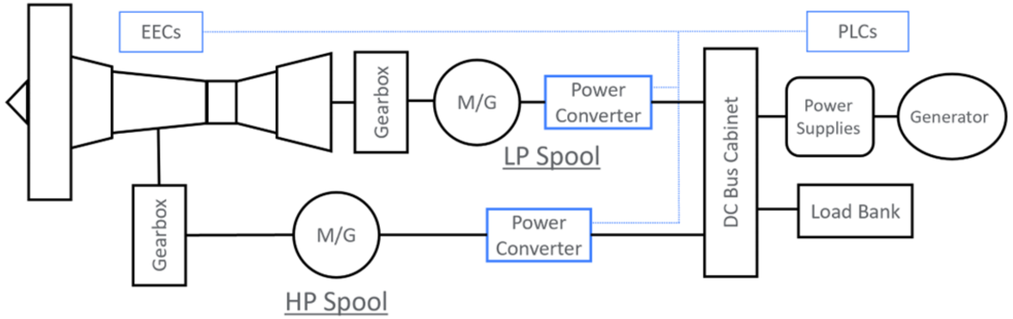
Test objectives advance TRL in key demonstration areas

- Mechanically integrate hybrid electric capability into a commercial turbofan
- Integrate electric machine and turbofan controls for advanced power management
- De-risk performance modeling of future hybrid electric architectures

Testing completed in 2025 at GE Aerospace's Peebles Test Operation

- Steady state performance across all combinations of extraction/injection/standby
- Demonstrations with transient engine and electrical conditions
- Controls demonstrations, including load drops on both spools
- Zero test safety incidents





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Test Results

Hybrid-electric capability assessed against four Technical Performance Measures (TPM's)

- All aligned with HyTEC Key Performance Parameter (KPP) 5, “degree of hybridization measured by level of power extraction from the turbine engine"
- Selected to demonstrate capability with engine operating conditions representative of different phases of flight
- Minimum Success and Full Success criteria determined for each TPM
- All testing performed back-to-back with representative baseline condition (without use of electric machines)
- Test cards performed multiple times to ensure repeatability

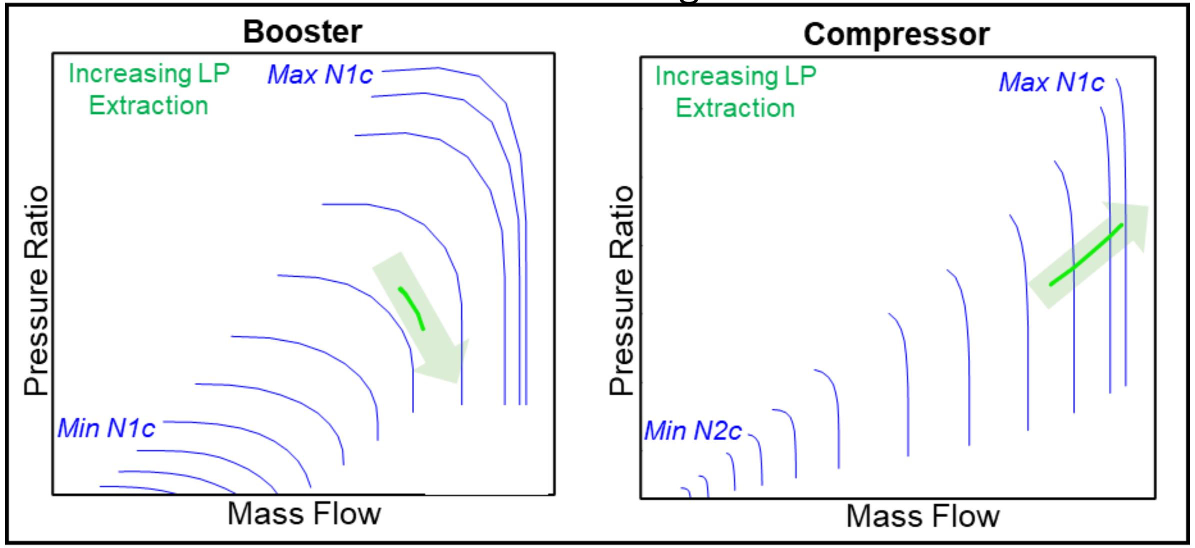
TPM	Description	Result
1	MW-class power extraction demonstration at sea level static conditions, with a projection to cruise conditions	Exceeded TPM Full Success Criteria • >20% LP extraction at cruise
2	EGT reduction at takeoff	Exceeded TPM Full Success Criteria • Significant EGT reduction
3	Electric taxi (dual spool electric injection with fuel cut)	Exceeded TPM Full Success Criteria • Maintained ground idle fan speed
4	Ground idle representative power transfer	Exceeded TPM Full Success Criteria • Achieved HP injection representative of future product requirements

All TPM's exceeded full success criteria, confirming that 10-20% power extraction from a next generation single aisle engine as defined in KPP-5 is achievable.

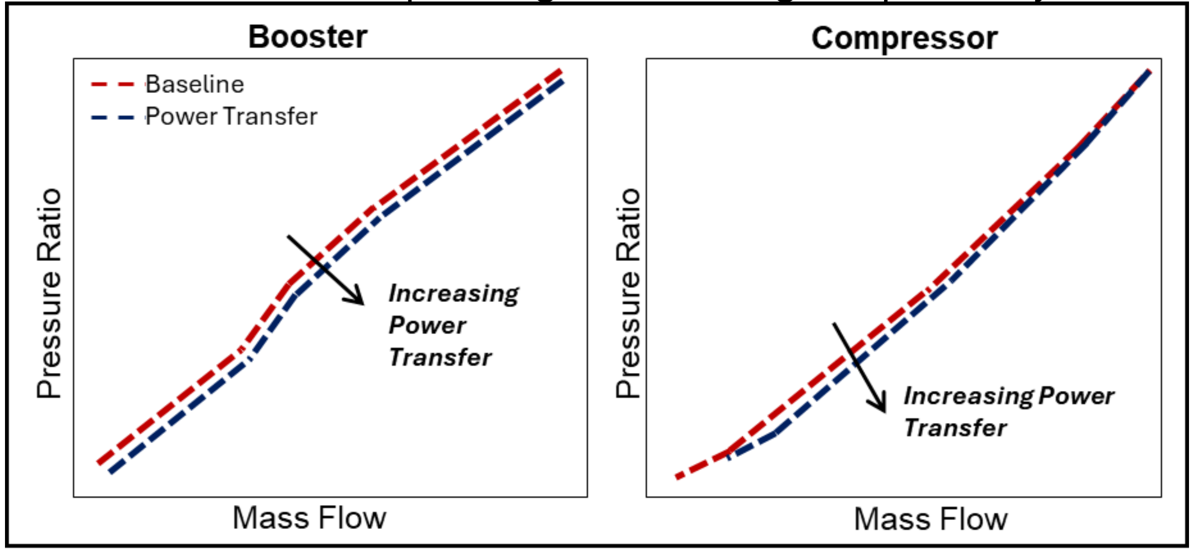
Modeling and Analysis

- NASA modeling tools* are used to assess the impact of the hybrid electric system on the engine performance
  - Upper image illustrates changes in operating point for 20% LP power extraction at cruise
  - Lower image shows changes to steady-state operating line for 2% LP-to-HP shaft power transfer at sea level
- Test data from the PEx Demonstration enables the validation of modeling tools and methods for hybrid electric turbine engine systems
  - Steady-state models used for cycle analysis and projecting system performance to altitude conditions
  - NASA transient models and subscale hardware-in-the-loop testing enables insight into system performance and control design

Migration of Operating Point on Component Maps for Constant N1c with LP Power Extraction Increasing from 0 to 20% at Cruise.



Sweep from Idle to Takeoff N1c with Direct Power Transfer At Sea Level Shows Reduction in Operating Line Leading to Operability Benefit



*Toolbox for the Modeling and Analysis of Thermodynamic Systems (T-MATS), and Electrical Modeling and Thermal Analysis Toolbox (EMTAT)

NASA Hybrid Performance and Trade Studies

- Trade studies indicate fuel burn reduction on the order of 0.5% and significant (>10 °C) EGT reduction associated with mild hybrid systems at fixed operating conditions
  - Reduction associated with increased efficiency of electrical power extraction over compressor bleed for auxiliary systems (estimated at 30% more efficient)
  - Comparing hybrid system power extraction (mechanical power) to total enthalpy of bleed flow
  - Benefits increase when trade space is expanded to full engine operating envelope
- ***Fuel burn and other benefits of hybrid systems cannot be fully realized without an engine and cycle designed with hybrid capability from the conceptual phase***

Study performed at a fixed cruise condition (35kft, 0.8M) with nominal cruise thrust. M/G extracts 100kW power from the engine spools, replacing 2% mass fraction bleed of the 50% worked flow from the compressor.

Test Case	Thrust Setting[3]	% TSFC Improvement	% EGT Improvement
Compressor Bleed (Baseline)[1]	90.4%	0 %	0 %
LP M/G Extraction[2]	90.4%	0.5%	0.9%
HP M/G Extraction[2]	90.4%	0.6%	0.7%
LP/HP Split Extraction[2]	90.4%	0.5%	0.8%

*1: Power = W*ht*
*2: Power = N*Trq*
3: % of max thrust at cruise condition

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Technology Readiness and Adoption Barriers

Technologies advanced to TRL 6 for a future potential narrowbody product architecture:

- Integration of large electric machines with a production engine control system
- Transient benefits of hybrid electric technologies (e.g., improving operability margin and managing accel/decel times)
- All-electric taxi
- Capability for optimal power balance between the HP and LP spools
- Operation with multiple power converters on high voltage direct current bus

Technologies advanced to TRL 4 for a future potential narrowbody product architecture:

- Embedded motor/generators, including in the exhaust flowpath
- Engine controller acting as supervisory control for electric machines

Key technology maturation remaining for a notional product:

- Electrical component design
- Control system design / Fault mitigation within an aircraft system
- Mechanical integration, packaging, thermal management

Final Hybrid Electric Turbofan Engine Assembly

The PEx program represents a significant step forward in support of a notional product: the integration of the electric power system with the engine control system, and the ability to both share and transfer power between the HP and LP spools provide key information to the value story for such architectures going forward.

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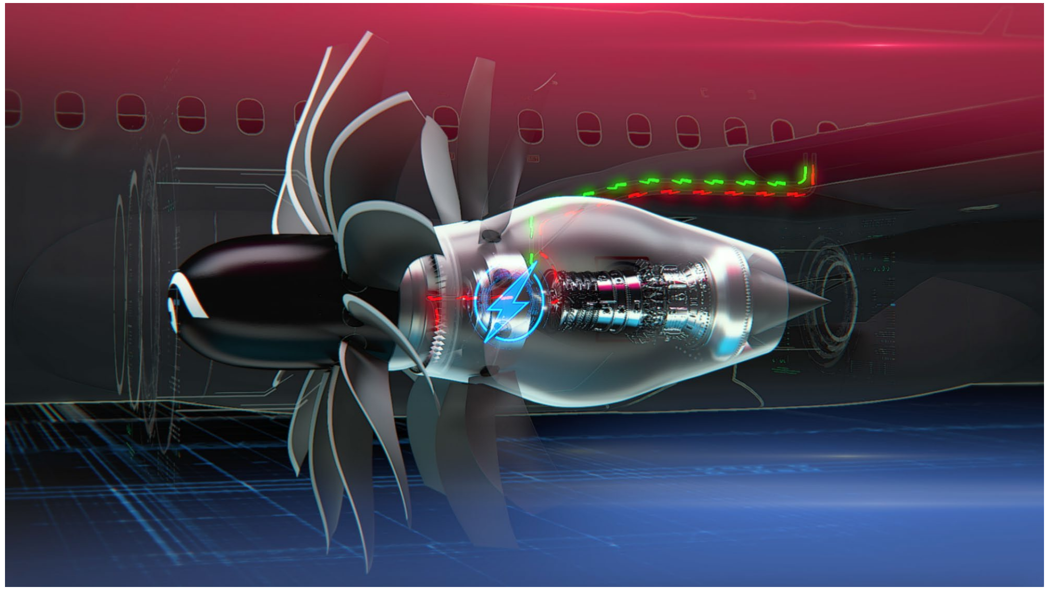
Next Steps

- NASA and GE Aerospace are partnering to develop and demonstrate a hybrid electric compact engine core
  - The Advanced Core Demonstration (ACD) will be the first example of a truly hybrid electric engine system for commercial single-aisle transports and larger aircraft entering into service after 2030
- NASA's SVTT project will focus on long-term (2050) technology development for commercial transport aircraft
  - Includes hybrid electric aircraft propulsion systems for large-scale commercial transports (narrowbody and widebody)
  - Hybrid electric systems feed into multiple advanced technologies such as distributed propulsion, propulsion/airframe integration, and advanced engine cycles



This artist concept shows a NASA- and industry-developed small-core jet engine installed in GE Aerospace's CFM RISE jet engine design (GE Aerospace)

The N3-X concept aircraft illustrates focus for long-term development of hybrid electric technology (NASA)

Thank You!
Questions?

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