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Pratt & Whitney – FAA CLEEN II Consortium
November 21, 2019
Egg Harbor Township, NJ

A UNITED TECHNOLOGIES COMPANY

Pratt & Whitney's CLEEN II Technologies

Today's Agenda

- Overview of UTC and Pratt & Whitney
- Summary of P&W's CLEEN II Efforts
- Overview of P&W's CLEEN II Compressor Technologies
- Overview of P&W's CLEEN II Turbine Technologies
- Overall mission performance and fleet impacts (initial estimates)
- Geared Turbofan™ entry into service and applicability of CLEEN II technology to future products

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United Technologies

Note: 2018 Net Sales Shown

Collins Aerospace
A United Technologies Company

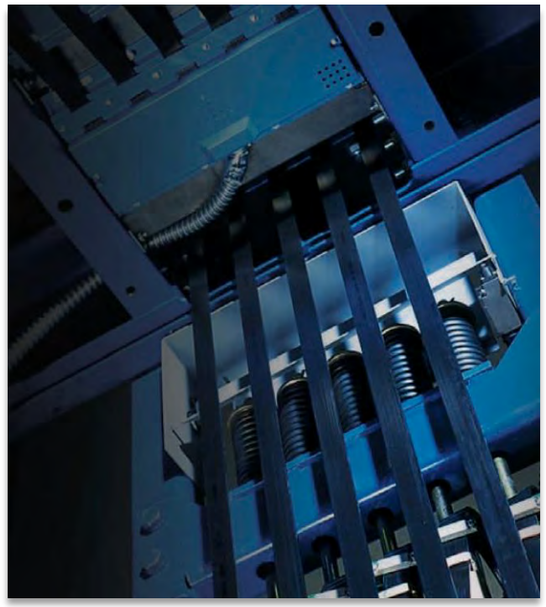
Net Sales $16.6B

Pratt & Whitney

Net Sales $19.4B

Otis
A United Technologies Company

Net Sales $12.9B



Carrier

Net Sales $18.9B

UTC is 240,000 Employees Strong, Four Major Business Units, $66.5B Sales

Raytheon and UTC Merger of Equals

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Combination will create a premier systems provider with advanced technologies to address rapidly growing segments of aerospace and defense

Expanded technology and R&D capabilities to deliver innovative and cost-effective solutions aligned with customer priorities

Significant near- and long-term benefits expected from uniting complementary portfolios of platform-agnostic capabilities, resulting in more than $1 billion of gross annual cost synergies by year four, as well as new revenue opportunities from combined technology

United Technologies' separation into three independent companies remains on track; merger is expected to close in the first half of 2020, following completion of UTC portfolio separation

Legacy

Boeing 757

Airbus A320

Boeing 767

Airbus A330

Boeing 777

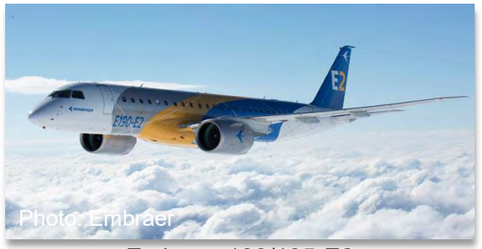
Airbus A380

GTF

Airbus A320neo

Mitsubishi MRJ

Airbus A220



Embraer 190/195-E2

Irkut MC-21

Embraer 175-E2

P&W Powers Commercial Legacy Fleets and the Exclusive Geared Turbofan Fleets

GTF ENGINE FAMILY

FOR LARGE COMMERCIAL AIRCRAFT

AND REGIONAL JETS

17,000 – 33,000
Pounds Thrust Class

16% Improvement in fuel efficiency

50% Reduction in regulated NOx emissions

75% Reduction in noise footprint

GTF Technology Provides Major Benefits

Pratt & Whitney ADVANCED Manufacturing

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Investment in facilities for productivity

Investment in automated manufacturing

Investment in inspection technology for quality

State of the Art Technology to Produce Advanced Aerospace Products

Sustainability goals at Pratt & Whitney

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Strive to be the best aerospace engine company FOR the world

FOR OUR PRODUCTS

Emissions
Reduce the environmental impacts of our products
Work with our customers to reduce in-service impacts

Sustainable Products
Design, manufacture and service products to minimize impacts
Use Ecodesign to drive product innovation

FOR OUR SITES

Zero Waste
All by-products 100% recycled
Increase efficiency and reduce “non-product” output

Carbon Neutral
Use only sustainable energy sources
Lower our footprint to avoid future impacts and costs

FOR OUR PEOPLE

Influence
Be a force for positive change
Support and engage employees and communities in building a better future

Owning Our Future

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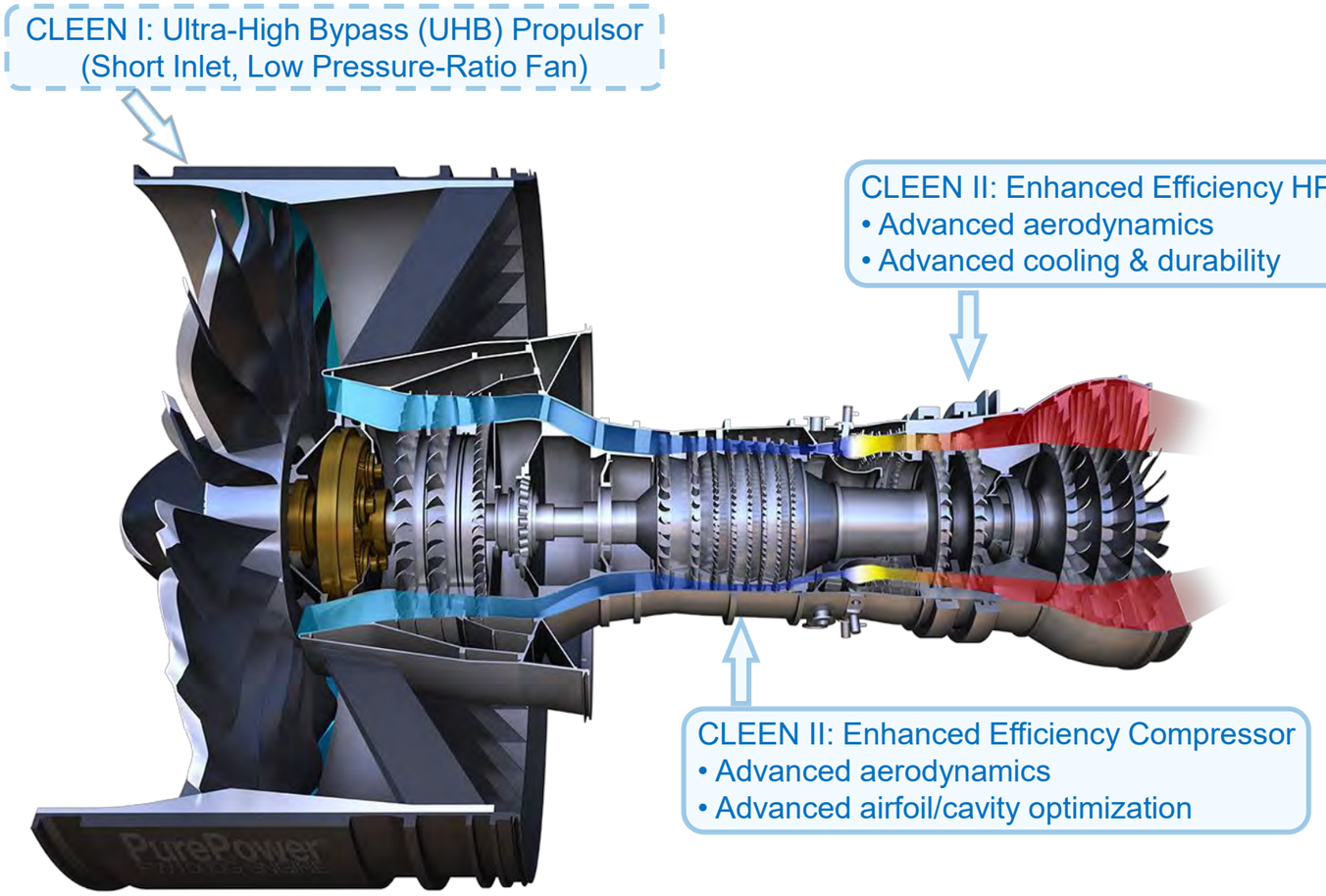
Improved propulsive efficiency enabled by Geared Turbofan™ architecture

CLEEN II builds upon CLEEN I for overall GTF engine architecture efficiency benefits

CLEEN II compressor and turbine technologies together improve the thermodynamic efficiency of the GTF architecture.

Pratt and Whitney is rapidly introducing CLEEN technologies to the GTF fleet

Leads to a 1.6-2.0% total fuel burn reduction



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CLEEN II Progress To-Date

HPC rig scope completed in 2017

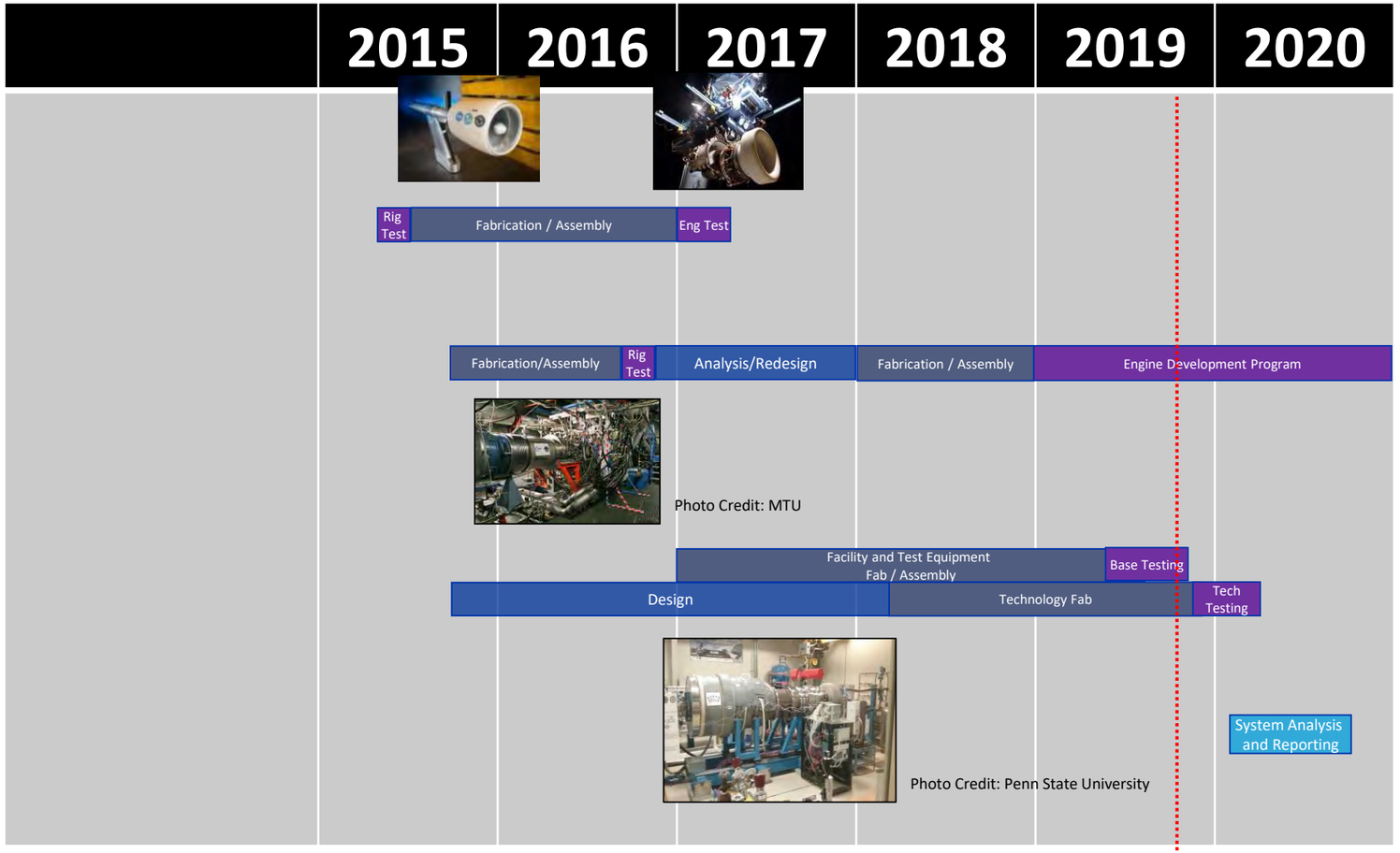
Engine demonstration program in full swing for HPC Technologies

PSU HPT START facility upgrade completed

HPT testing ongoing

Technology hardware fabrication in-process

HPT Cascade testing completed



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Compressor Aero Efficiency Technologies

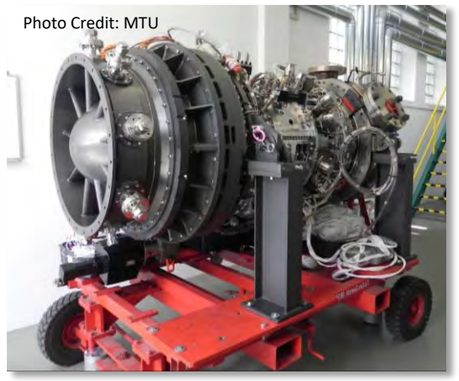
Benefits:

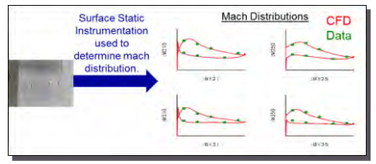
Improved thermal efficiency

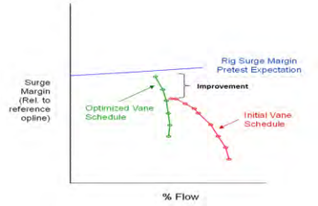
- ~ 0.8 – 1.0% fuel burn reduction

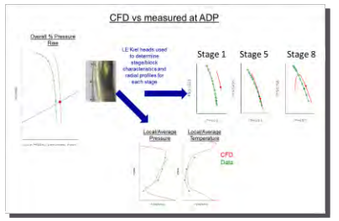
Risks/Mitigations

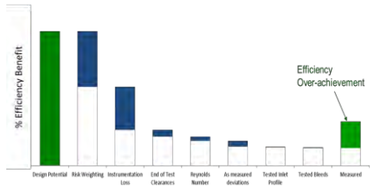
- No risks identified at this time











2016-17 Rig Test → Data Reduction → Module Benefits

Objectives:

Demonstrate improved high pressure compressor efficiency via advanced aerodynamic airfoil optimization

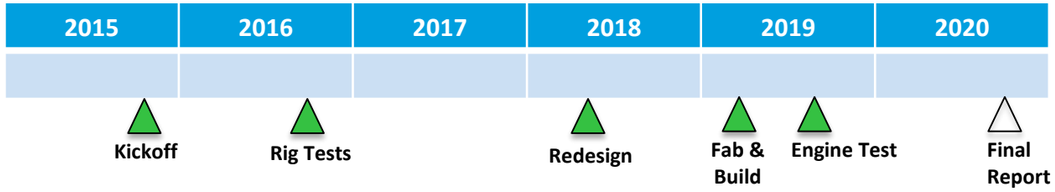
Work Statement:

Continue the TRL advancement of compressor aero-efficiency technologies via detailed design, fabrication, full-scale rig tests, and engine validation.

Prior Accomplishments:

- Redesign completed, component fabrication complete, testing complete

Schedule & Planned Milestones:



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HPC Technology Rig – What's next?

CLEEN II compressor aero design has successfully completed ground and flight test, bringing HPC technology to TRL 6 – "Subsystem demonstration in a relative environment"

Tools developed and knowledge gained on aero performance will be introduced into GTF product line

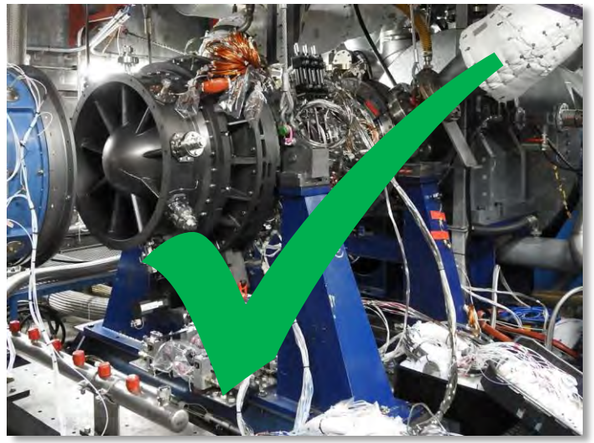

Photo Credit: MTU

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Turbine Aero Efficiency and Durability Technologies

Benefits:

Improved thermal efficiency

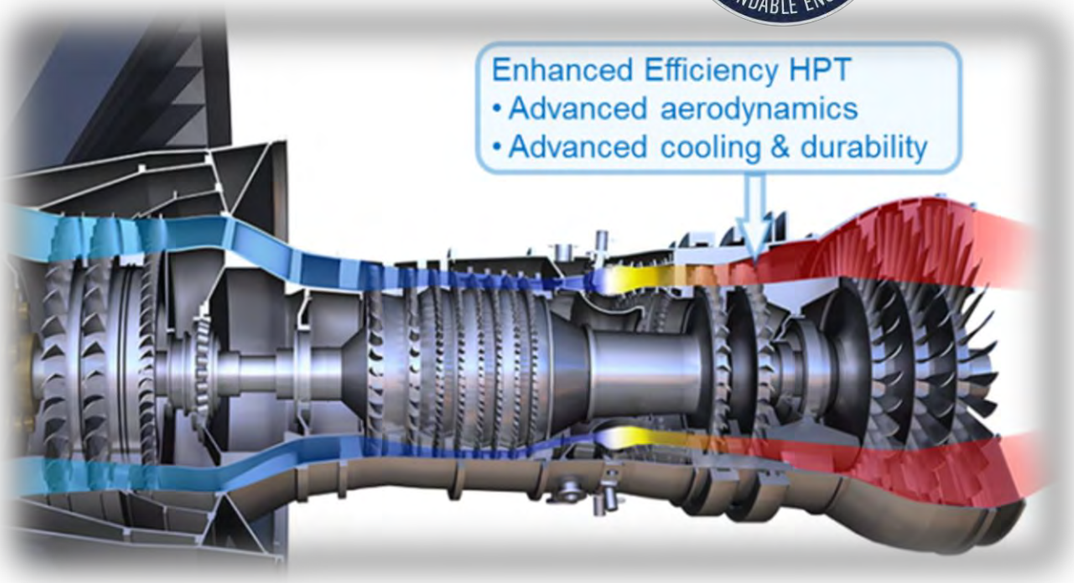
- ~ 0.8 – 1.0% fuel burn reduction

Risks/Mitigations

Technology interaction prevents assessment of contribution of individual items – Execute additional rig trials to isolate

Testing could be delayed due to linear build schedule – Procure additional hardware to facilitate parallel build

New facility debugging – Actively working to understand failure modes and have-ready backup facility hardware



Objectives: *Demonstrate improved high pressure turbine efficiency via advanced aerodynamic airfoil and durability optimization*

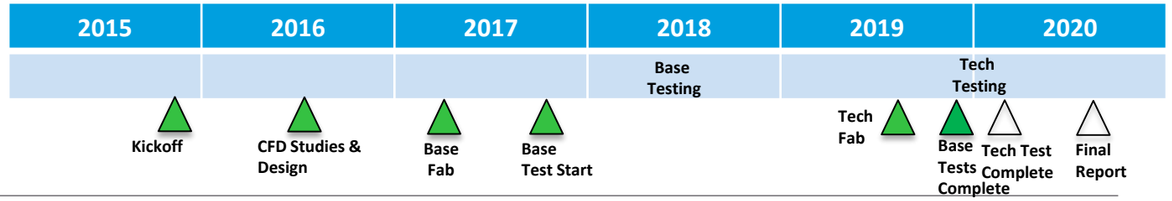
Work Statement:

Continue the TRL advancement of turbine aero-efficiency and durability technologies via CFD studies, detailed design, fabrication, and full-scale rig tests.

Prior Accomplishments:

- Completed cascade rig testing
- Completed START rig traverse assembly
- Completed Baseline Blade Aero testing

Schedule & Planned Milestones:



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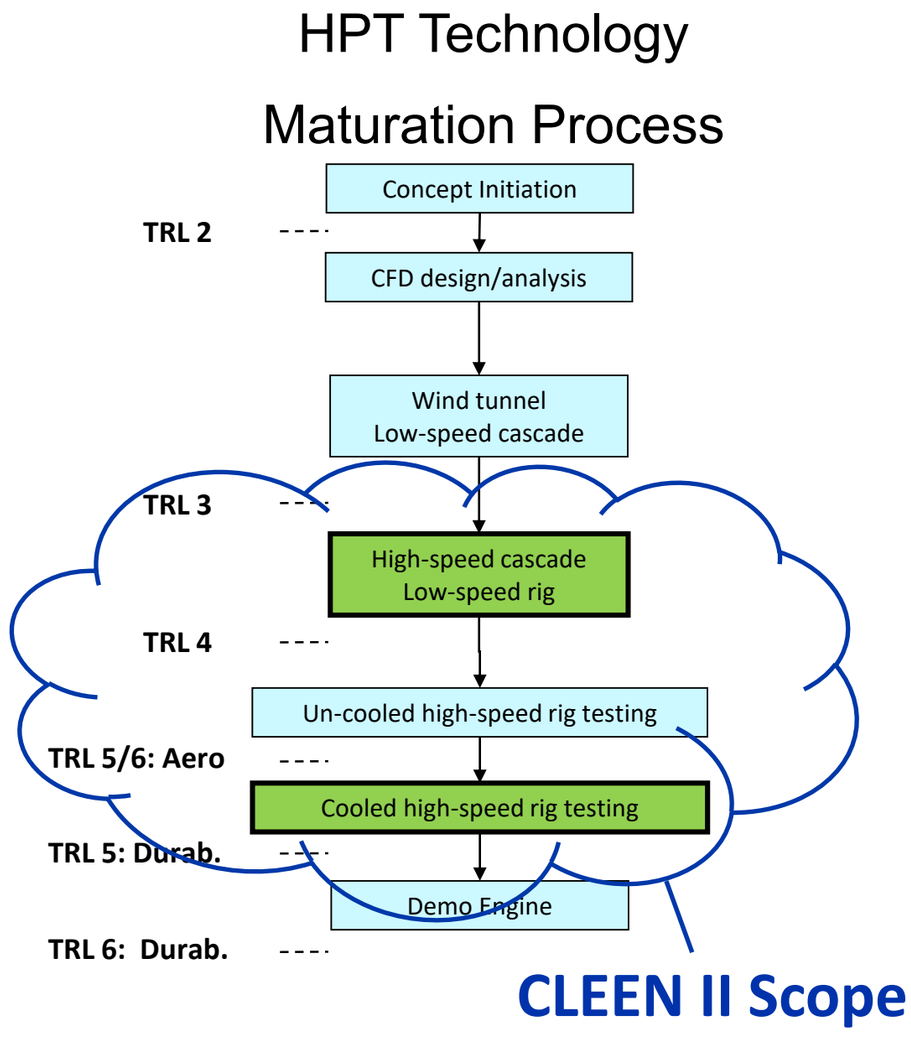
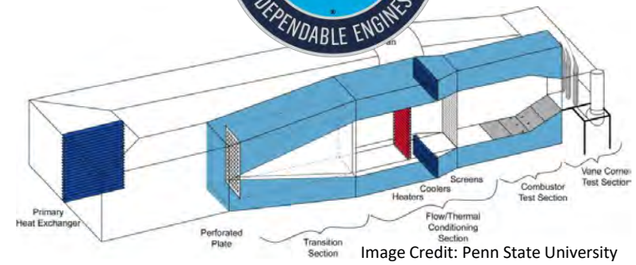
HPT Technology Maturation Strategy

Previous investment from P&W has brought HPT technologies through Technology Readiness Level (TRL) 3

- CFD design and analysis for conceptual design of the technologies
- Low speed wind tunnel testing for initial learning

Under FAA funding, bringing HPT technologies to TRL 5 for durability and TRL6 for aero technologies





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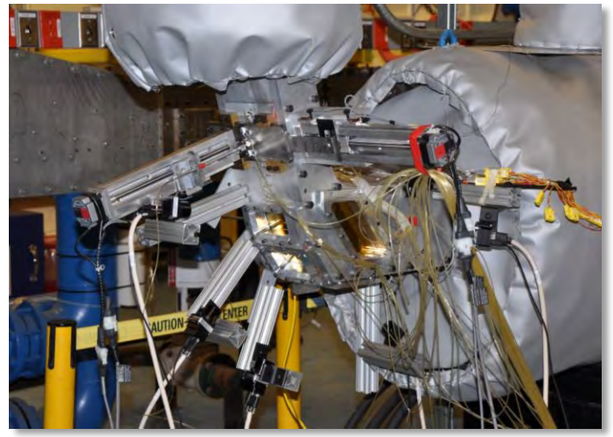

Image Credit: Penn State University

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HPT Technology Status - Schedule

Conceptual design work started prior to CLEEN II contract start

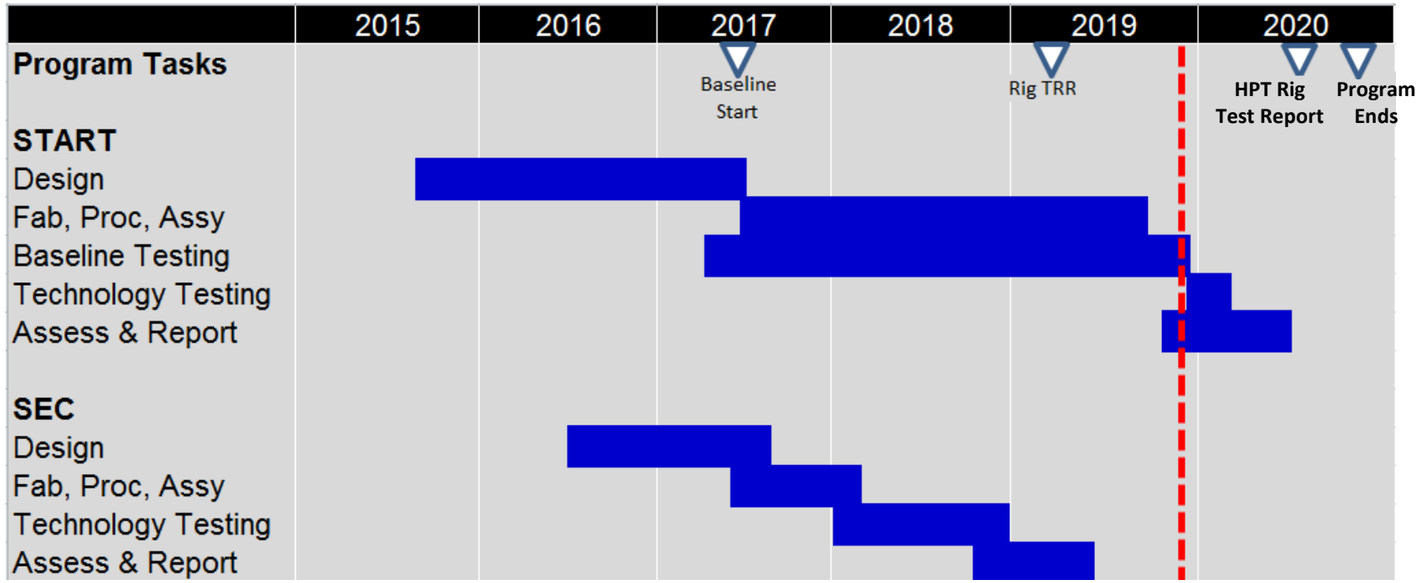
FAA has helped to further mature the HPT technologies beyond TRL 3

HPT scope holding schedule for full-scale hardware Aero/Thermal testing in 2019

Single Element Cascade testing completed

Baseline Blade START rig aero testing completed

Technology Blade START testing begins early Dec.



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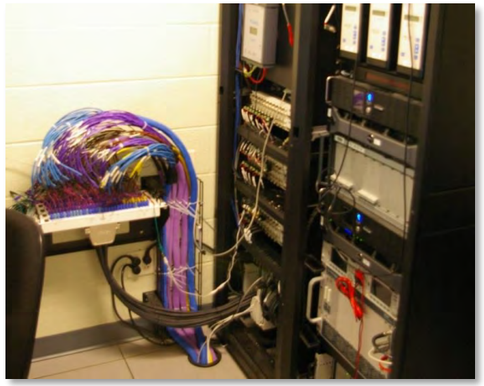
Penn State START Facility – Background

START = Steady Thermal Aero Research Turbine.

Test section is modeled after Pratt & Whitney's GTF high pressure turbine module

~$10M combined investment into the facility over the past 5 years

Pratt & Whitney Center of Excellence, World Class Facility



2013 → **2018**

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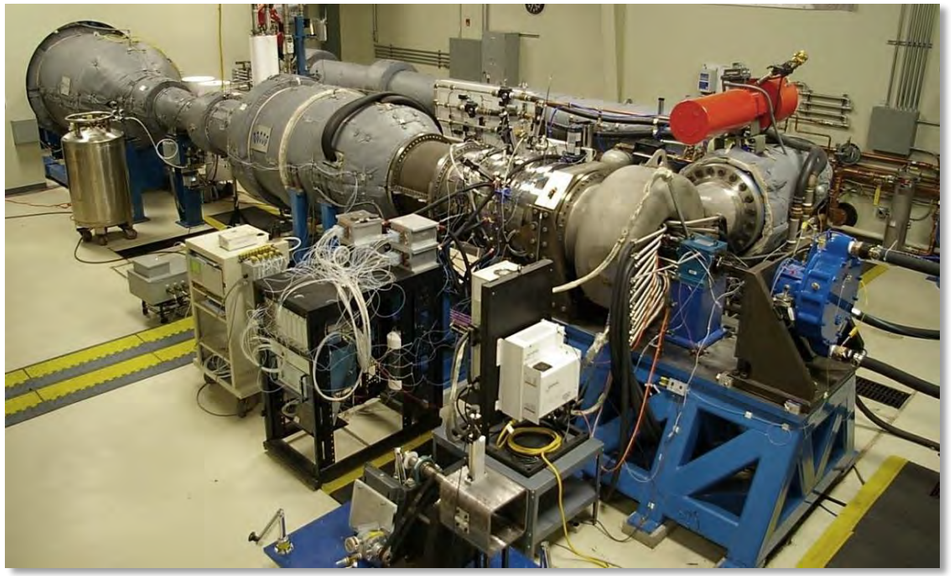
Penn State START Facility – Objectives

Validate predictions for novel aero/thermal component designs in order to correlate analytical tools for CLEEN II technologies

Compare baseline and advanced aero/thermal technologies at representative operating conditions

Build upon completed SEC testing; verifies full-span 3-dimensional aero



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Penn State START Facility – Execution

Procurement and assembly of "Phase II" START rig facility completed

START facility shakedown completed Cavity Aero testing completed

Analytical aero/thermal pre-test predictions completed

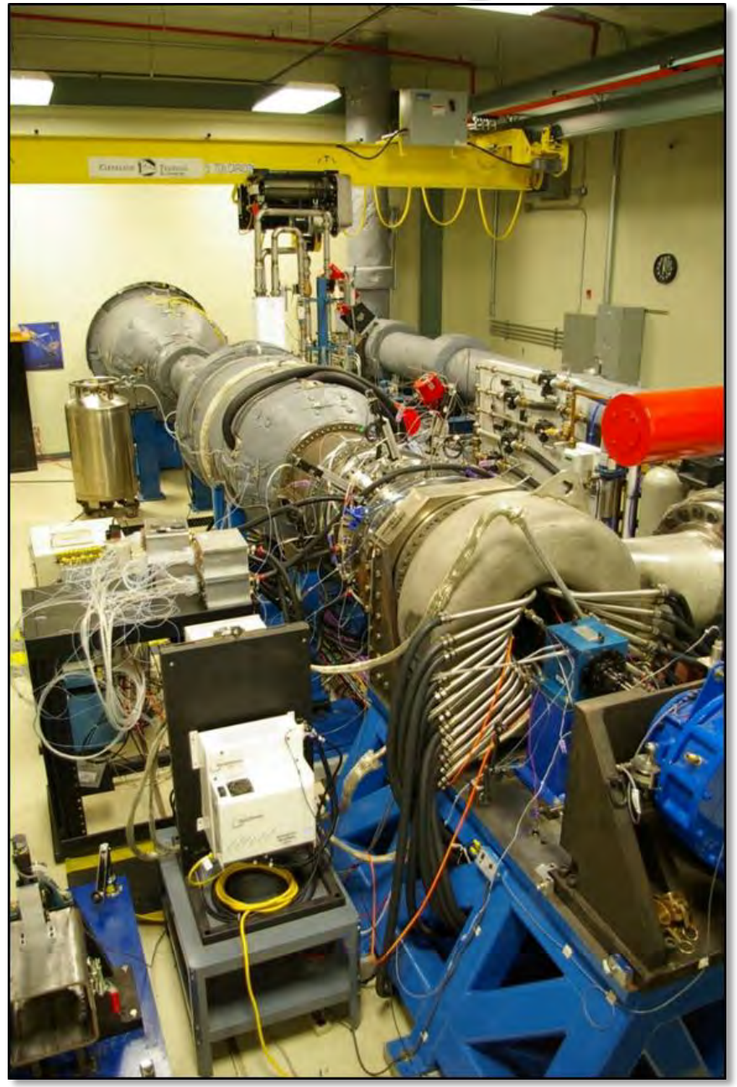
Aero testing of baseline GTF technology completed, data reduction in process

CLEEN II advanced technology blade aero/thermal instrumentation fabrication completed

CLEEN II advanced technology blade fabrication completed

All rig hardware for CLEEN II technology blade delivered

On schedule for Q1CY20 test completion



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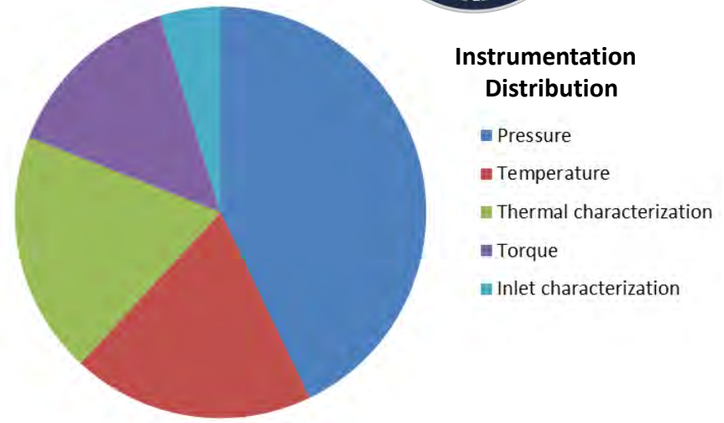
Penn State START Facility – Pretest Predictions

Analytical aero pre-test predictions completed, and are ready for experimental data comparison

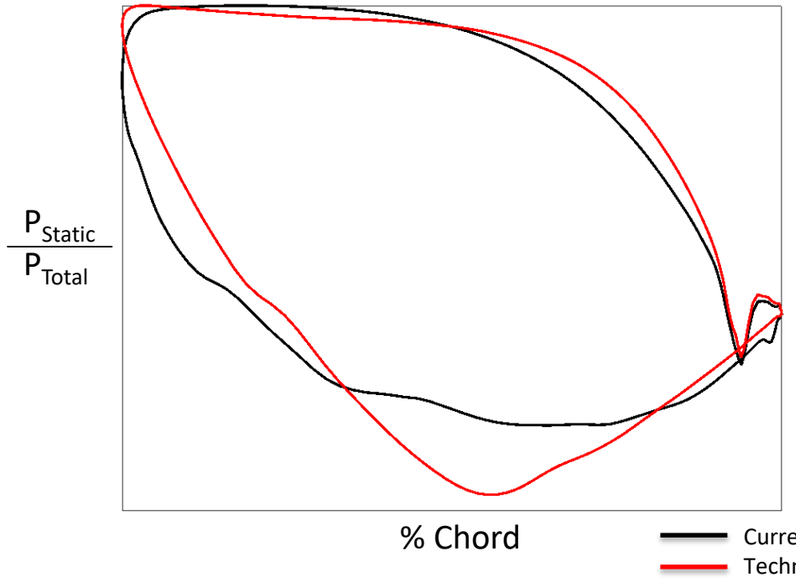
Main gas path CFD has been coupled with secondary flow cavity CFD model for test correlation

Additional instrumentation specific to technology blade testing completed

Effort since May, 2019 has mainly been focusing on manufacturing of the technology blade and START rig special instrumentation



CFD Prediction for Pressure Distribution



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PRATT & WHITNEY DEPENDABLE ENGINES

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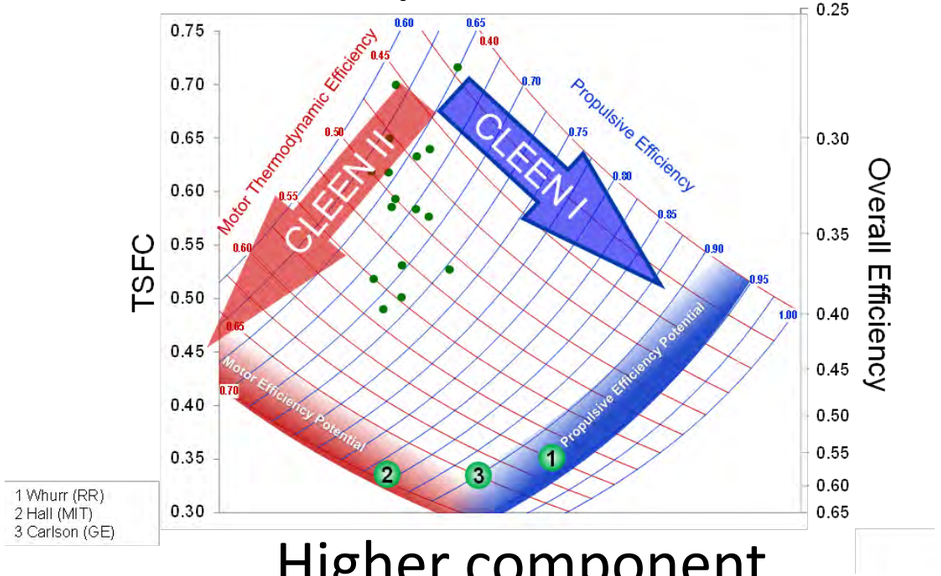
System Level Impact

CLEEN I increased the propulsive efficiency of the GTF engine with fan technologies

CLEEN II technologies continue to push towards more thermodynamically efficient turbofan engines.

Component Level

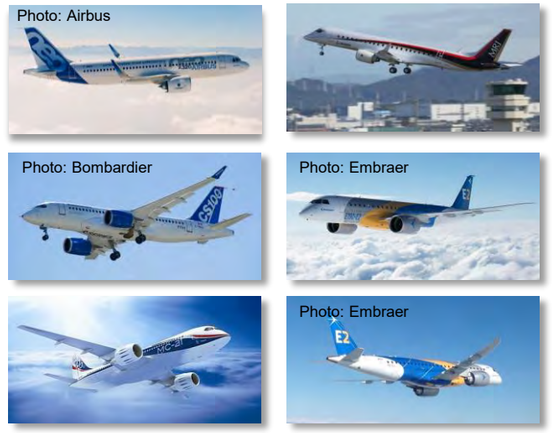


Higher component efficiency

Engine / Airframe Level

1.6-2.0% Fuel Burn Reduction

Fleet Level



34-43K gallons of fuel savings per year per plane

A320NEO, 2.0 hour flights, 3,100 annual flight hours

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80+ Customers/8000+ Engine Orders

Including Firm Orders and Options

CLEEN II HPC and HPT technologies to be infused into GTF fleet.

This Page Contains no Technical Data Subject to the EAR or the ITAR

Pratt & Whitney's CLEEN II Technologies

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Program Summary

High Pressure Compressor (HPC) scope was completed in 2017, ongoing integration of learning into ground test and flight test assets

High Pressure Turbine (HPT) Single Element Cascade (SEC) testing complete, final test complete

START Test Readiness Review (TRR) complete, baseline aero testing completed, durability testing in-process, technology blade testing to commence before the end of the year, to be completed by Q1CY2020

Industrial phase of CLEEN II technology HPT hardware for START rig complete

Queueing-up system level benefits analysis for 2020; working with Georgia Tech

Currently introducing technologies matured under CLEEN II into Pratt & Whitney's product offerings

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