PRATT & WHITNEY DEPENDABLE ENGINES

GO BEYOND

Pratt & Whitney – FAA CLEEN II Consortium

November 7, 2018

Washington, D.C.

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

PRATT & WHITNEY DEPENDABLE ENGINES

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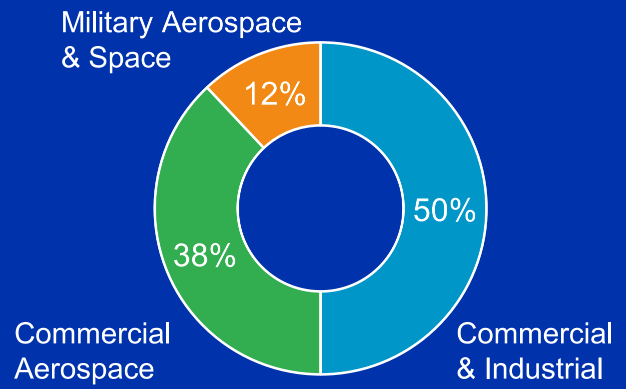
United Technologies Corp.

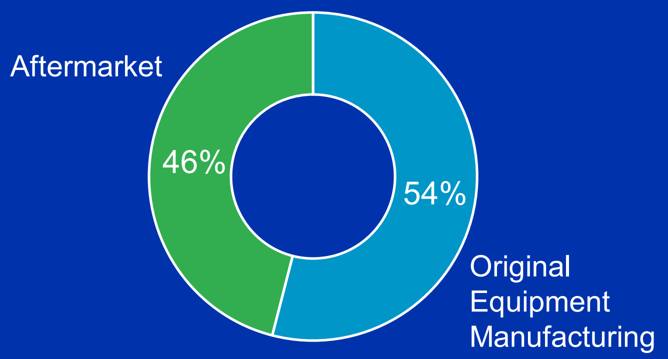
2016 net sales*

$57.4B

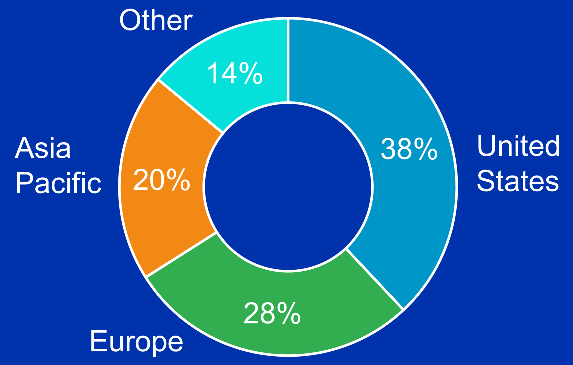
End Markets



Sales By Type



Sales By Geography



Data from 2016 Annual Report * Adjusted net sales and adjusted operating profit are non-GAAP financial measures.

UTC businesses push the limits of innovation

Pratt & Whitney
A United Technologies Company

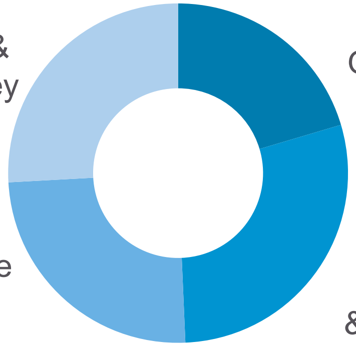
UTC Aerospace Systems

Otis
A United Technologies Company

United Technologies
Climate | Controls | Security

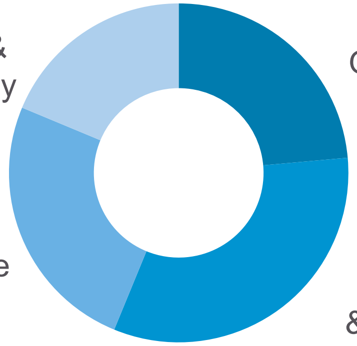
2016 net sales*

$57.4B



Operating profit*

$9.4B



Data from 2016 Annual Report * Adjusted net sales and adjusted operating profit are non-GAAP financial measures.

Pratt & Whitney's history began in 1925…

Frederick Rentschler

PRATT & WHITNEY AIRCRAFT DEPENDABLE ENGINES

…and continues

Pratt & Whitney segments

50%

Commercial Engines

25%

Military Engines

25%

Gas Turbine Engines for Small Aircraft

35,100 Employees | $15.1B Sales | $1.8B EBIT | 11.6% ROS

Pratt & Whitney Commercial Engines

Boeing 757

Airbus 320

Airbus 320neo


Mitsubishi MRJ

Boeing 767

Airbus 330

Bombardier C Series → A220

Embraer 190/195-E2

Boeing 777

Airbus 380


Irkut MC-21

Embraer 175-E2

Mature | Geared Turbofan

Pratt & Whitney GTF^{TM} Engines

Creating the next generation of propulsion

5 AIRCRAFT PLATFORMS

PW1100G-JM A320neo

PW1500G A220

PW1700G & PW1900G E-Jets E2

PW1200G MRJ

PW1400G-JM MC-21

16%
Reduction in Engine Fuel Consumption

75%
Reduction in Noise Footprint

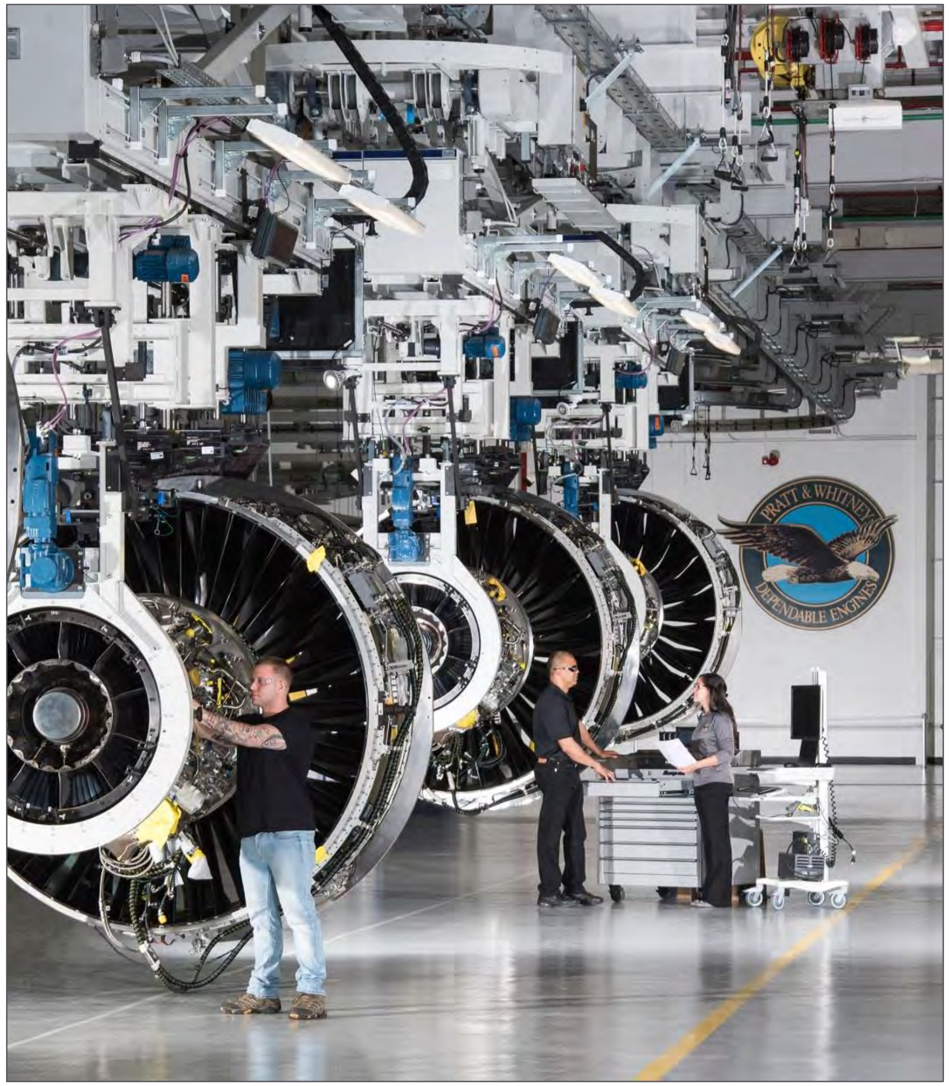
50%
Reduction in Regulated Emissions

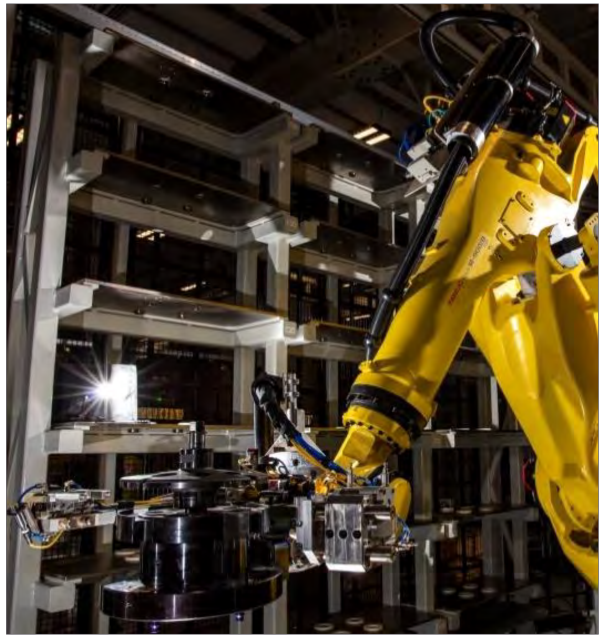
9000+
Orders and Commitments

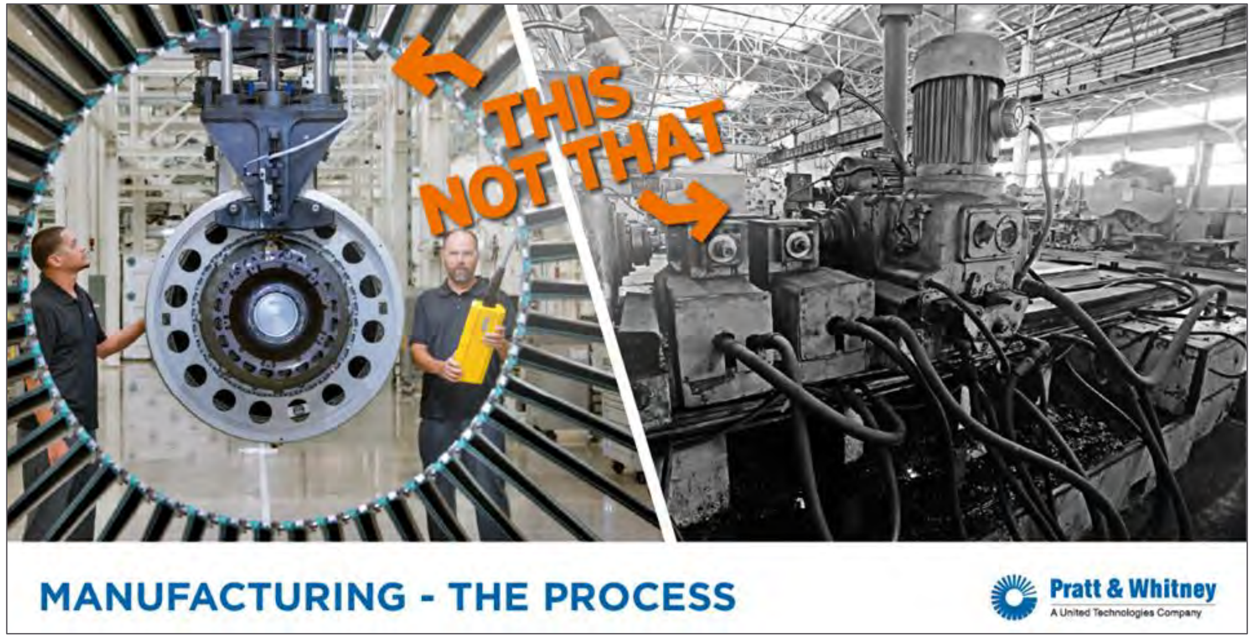
80+
Customers

ANNUAL OPERATOR SAVINGS >1M PER AIRCRAFT

Pratt & Whitney Global Manufacturing







The world's first horizontal assembly lines — up to 50% more productivity

Intelligent manufacturing cells — closed loop machining, robotics, automated inspection

White/blue light quality techniques at sites worldwide — concurrent inspection and manufacturing

State of the art technology to produce advanced aerospace products

Aftermarket and Global Service Network





PRATT & WHITNEY COMMERCIAL ENGINES AFTERMARKET

17 world-class engine overhaul and part repair facilities
5,000 employees with OEM and technical expertise

Upgrades to improve time on wing and fuel efficiency
Maintenance and material solutions — part repair, new spare parts and serviceable parts

PRATT & WHITNEY CANADA GLOBAL SERVICE NETWORK

Over 30 P&WC-owned and designated service facilities
More than 100 field service representatives worldwide

24/7 Customer First Centre for rapid support
MyP&WC Power
ESP® PurePower PW800

The Workforce is changing

Demographics

25k Total global hires by 2026

20k Total anticipated retirements by 2026

50% Paradigm 4 Parity goal by 2030

Development

$1.2b Spent to date on Employee Scholar Program

250 Executives through Thayer Leader Development Group

30+ Workforce training programs P&W has invested in

Skillsets

Job skill portfolio

Automation

Agile culture

Hiring and developing the right people with the skills needed for the jobs of today and the jobs of tomorrow

Pratt & Whitney's CLEEN II Technologies

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Pratt & Whitney's CLEEN II Technologies

Improved propulsive efficiency enabled by Geared Turbofan™ architecture

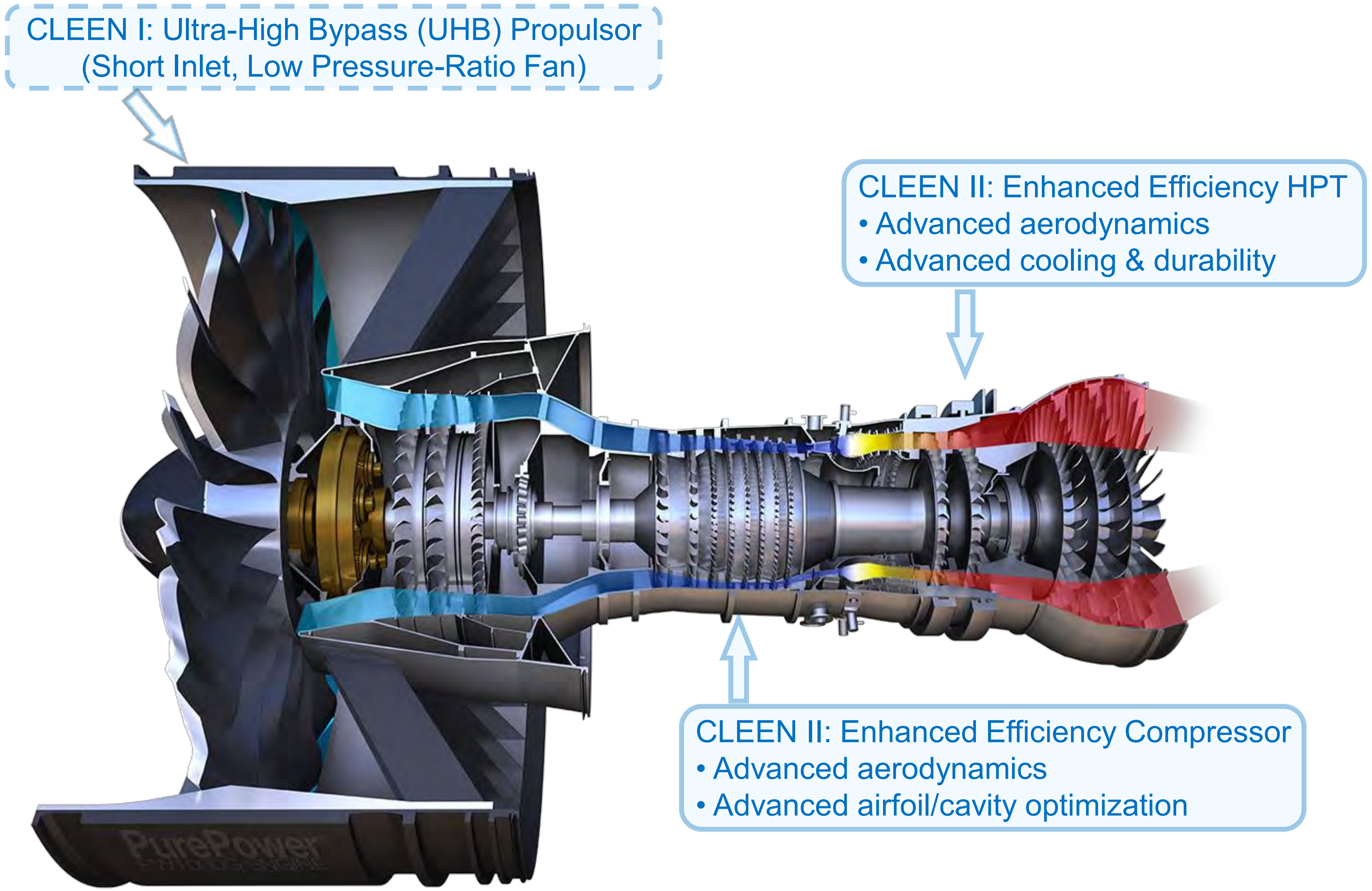
CLEEN II builds upon CLEEN I for overall GTF engine architecture efficiency benefits

Compressor Section – advanced aerodynamics and cavity/airfoil optimization

Turbine Section – advanced aerodynamics and reduced cooling requirements and chargeable flow losses

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

Leads to a 1.6-2.0% total fuel burn reduction



Pratt & Whitney's CLEEN II Technologies

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CLEEN II Progress To-Date

HPC rig scope completed in 2017

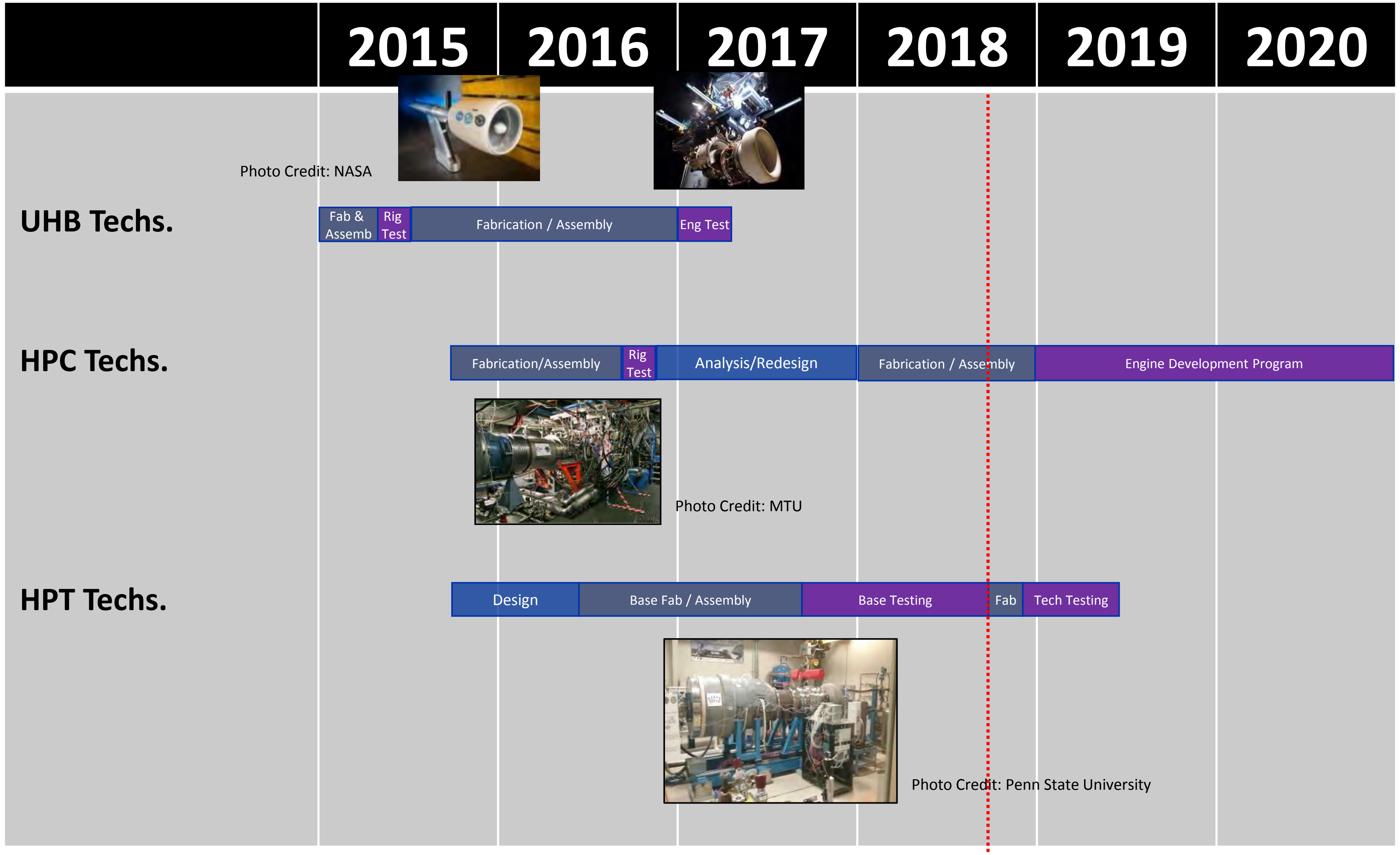
Engine demonstration program picking up momentum

PSU HPT START facility upgrade completed

Baseline turbine testing completed

Technology hardware fabrication in-process

HPT Cascade testing completed



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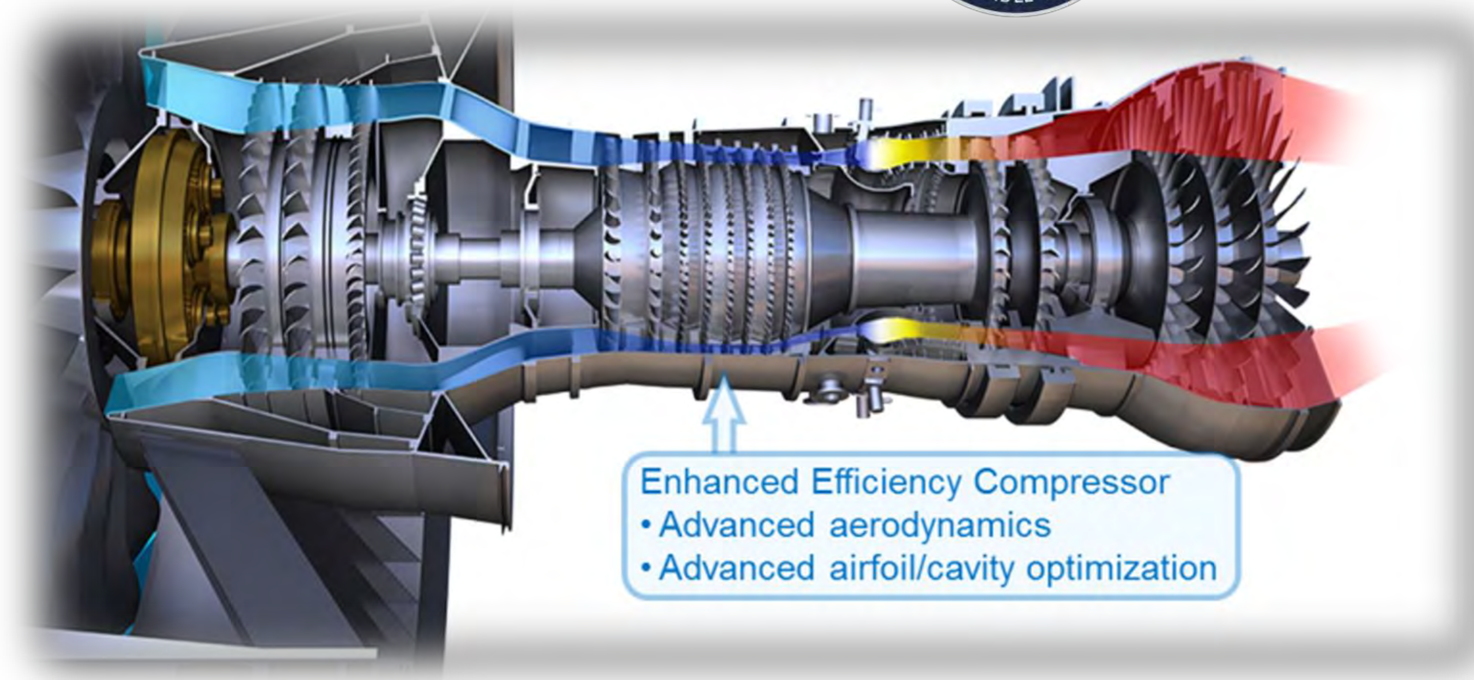
Compressor Aero Efficiency Technologies

Benefits:
Improved thermal efficiency
- ~ 0.8 – 1.0% fuel burn reduction

Risks/Mitigations
Achievement of performance and operability targets
- Utilize multi-stage rigs for early validation
- Execute redesign, if needed, and utilize lower-level rigs for progressive validation before engine demo

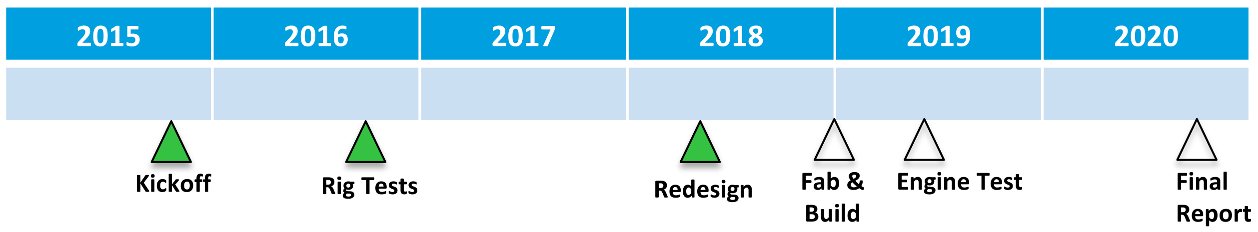


Objectives:
Demonstrate improved high pressure compressor efficiency via advanced aerodynamic airfoil optimization

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

Prior Accomplishments:
- Completed post test technical review
- Redesign Completed and preparing for fabrication and build of the engine test hardware

Schedule & Planned Milestones:



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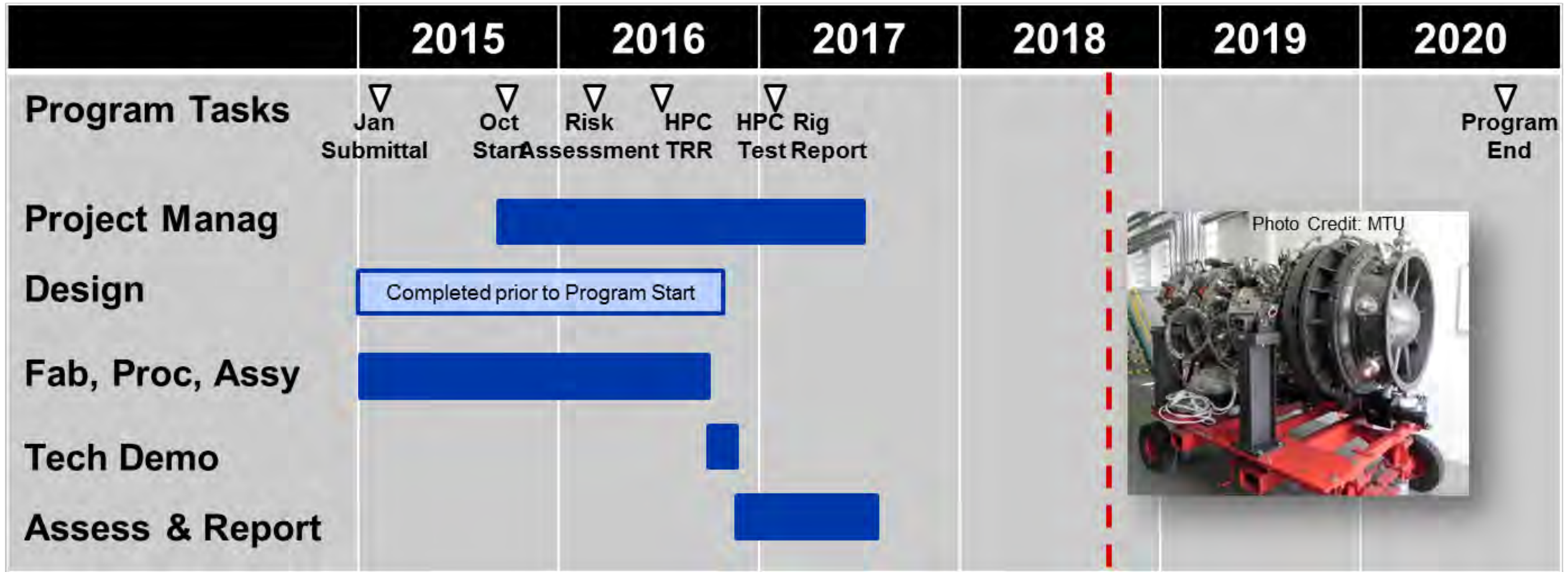
HPC Technology Status - Schedule

High pressure compressor scope was started prior to the start of CLEEN II

With help from FAA, design was fabricated and brought to test in 2016

Test completed in early 2017 and detailed test report submitted



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HPC Technology Maturation Strategy

Previous investment from P&W brought HPC technologies through Technology Readiness Level (TRL) 4

- CFD design and analysis for conceptual design of the technologies
- Cascade rigs for correlation of analytical tools
- Multistage, subscale rigs for further proving out the technologies in a laboratory environment

Under FAA funding, brought HPC technologies to TRL 5 – "component validation in relative environment"

HPC Technology Maturation Process

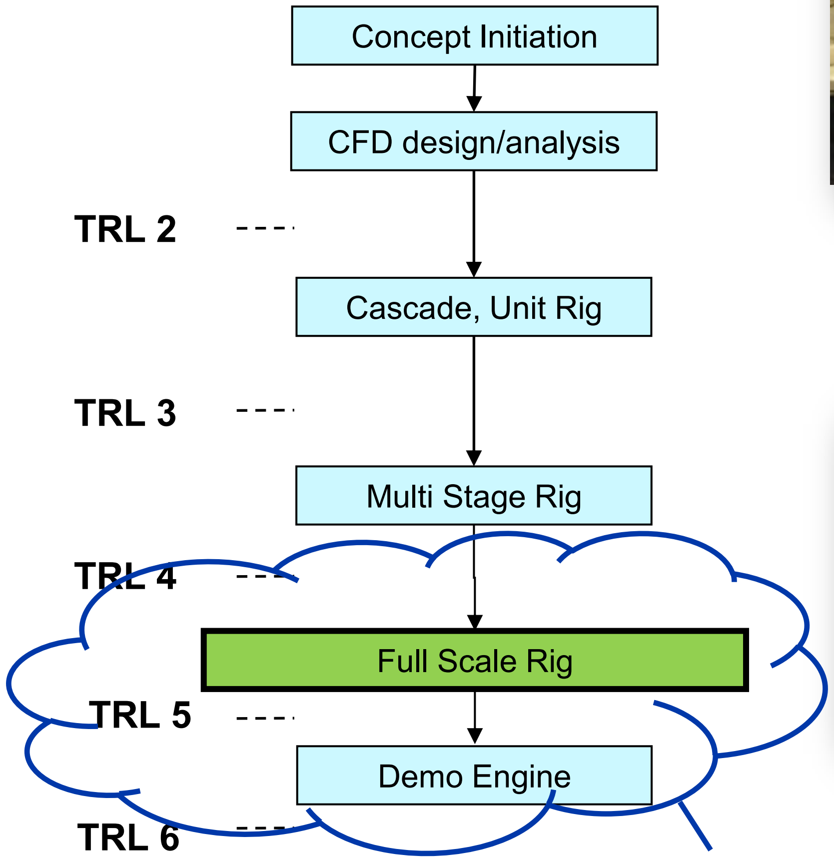

Photo Credit NRC Canada

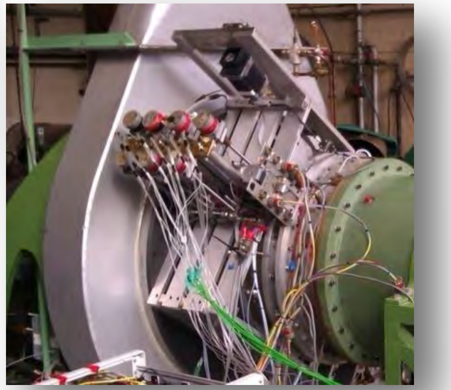

Photo Credit: MTU

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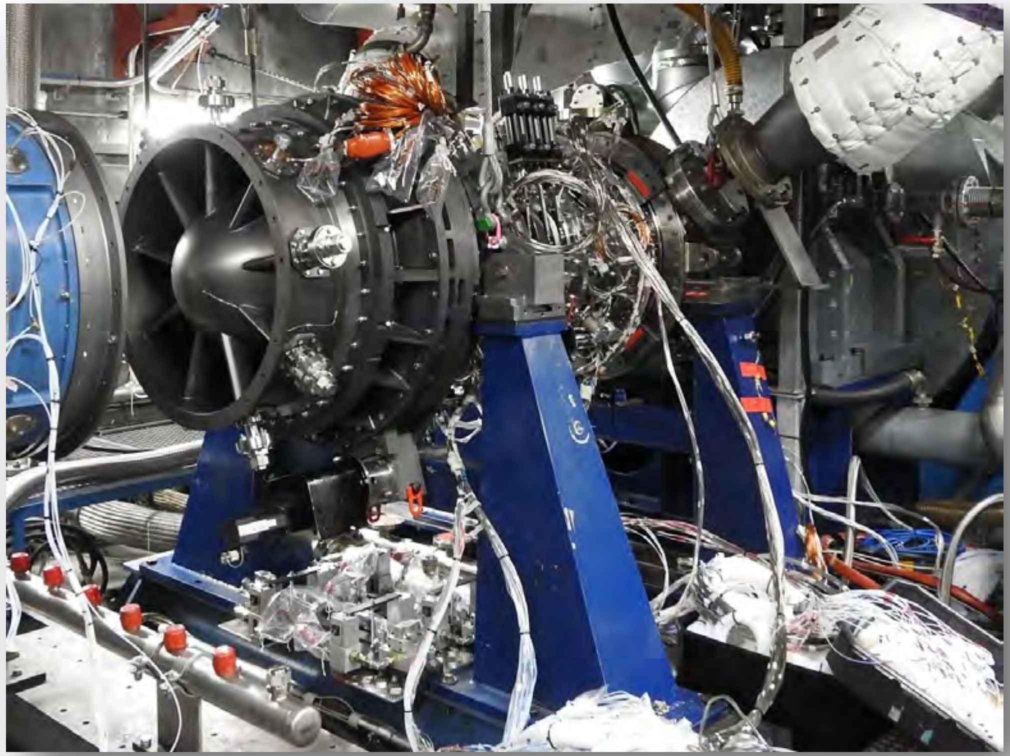
HPC Technology Rig – Build and Installation

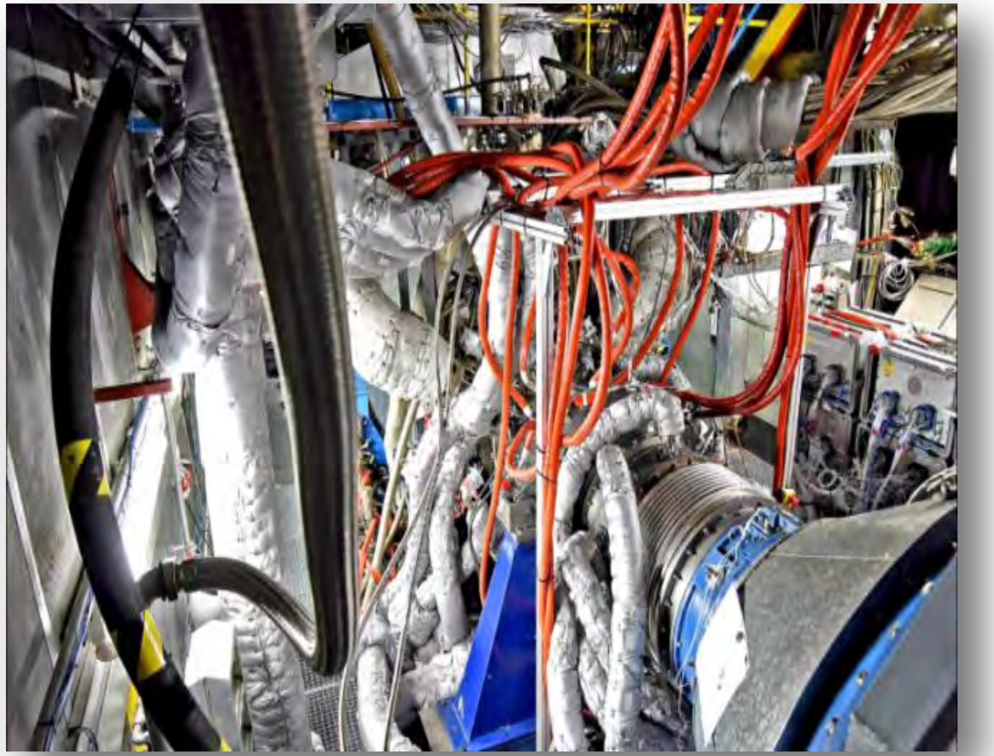
HPC Rig assembly completed and module placed on transport cart on July 21, 2016

Module installed into test cell and final instrumentation completed on August 23, 2016

Can you spot the compressor in that last image?

All Photo Credits: MTU





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HPC Technology Rig – Objectives and Testing

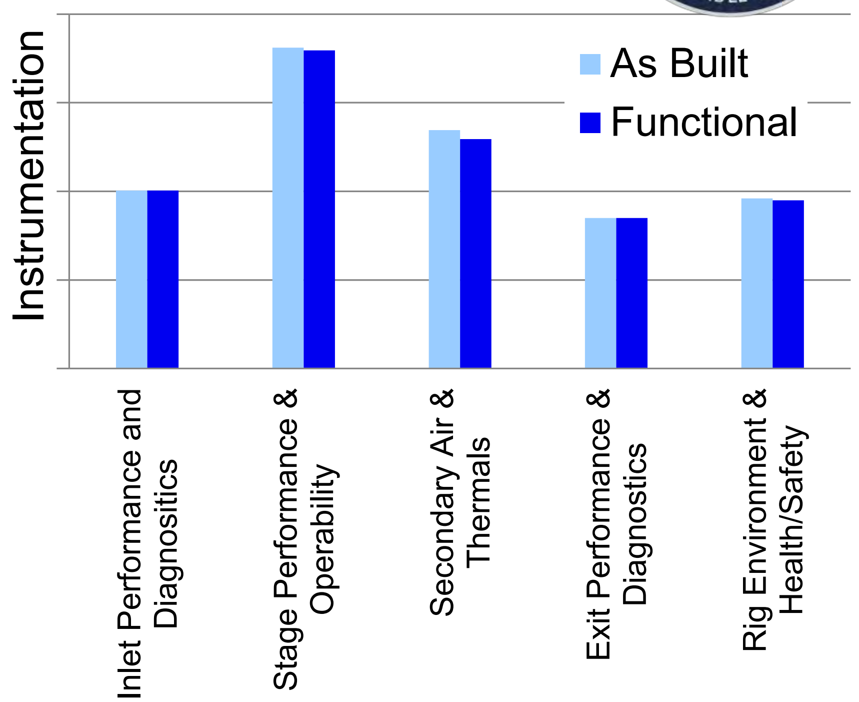
Objective of the rig testing was to validate analytical tools for novel HPC technologies through TRL 5 and to prepare the technologies for engine test

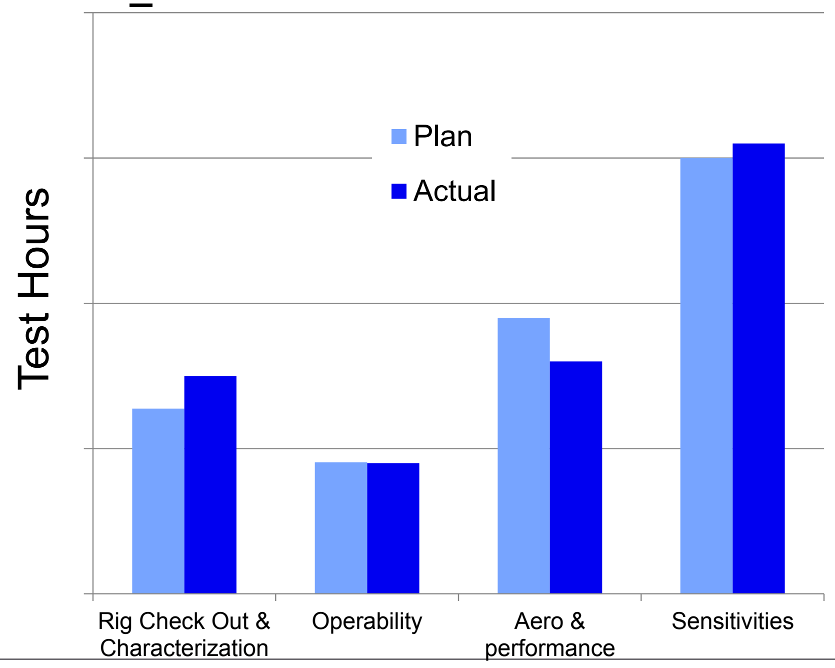
Testing proved out a robust suite of instrumentation

Over 100 hours of testing was conducted

Flexible test schedule allowed for changes to be made on the fly

- Example: Less aero/performance testing was completed in favor of expanding sensitivity testing





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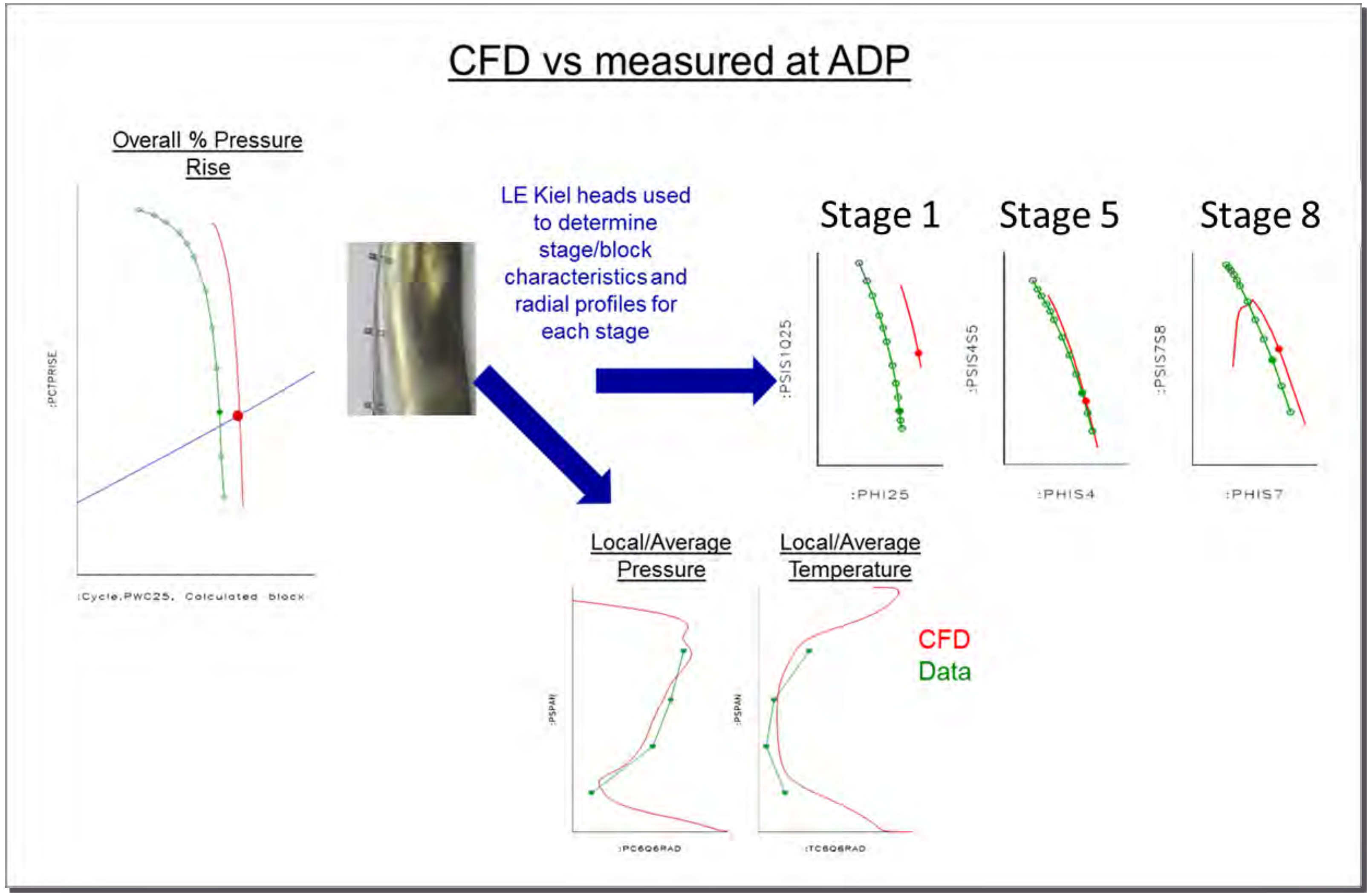
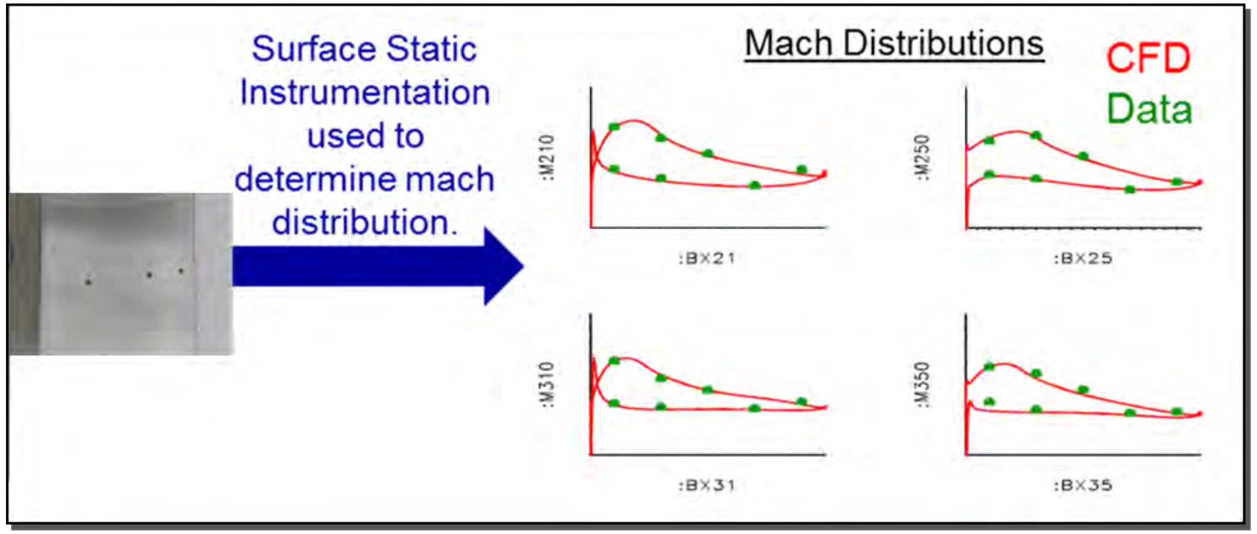
HPC Technology Rig – Initial Results

Results show good correlation to pre-test Mach distributions and radial profiles

Stage sizes close and will be used to improve modelling

Rig learning across compressor operating space will be used to improve modelling capability





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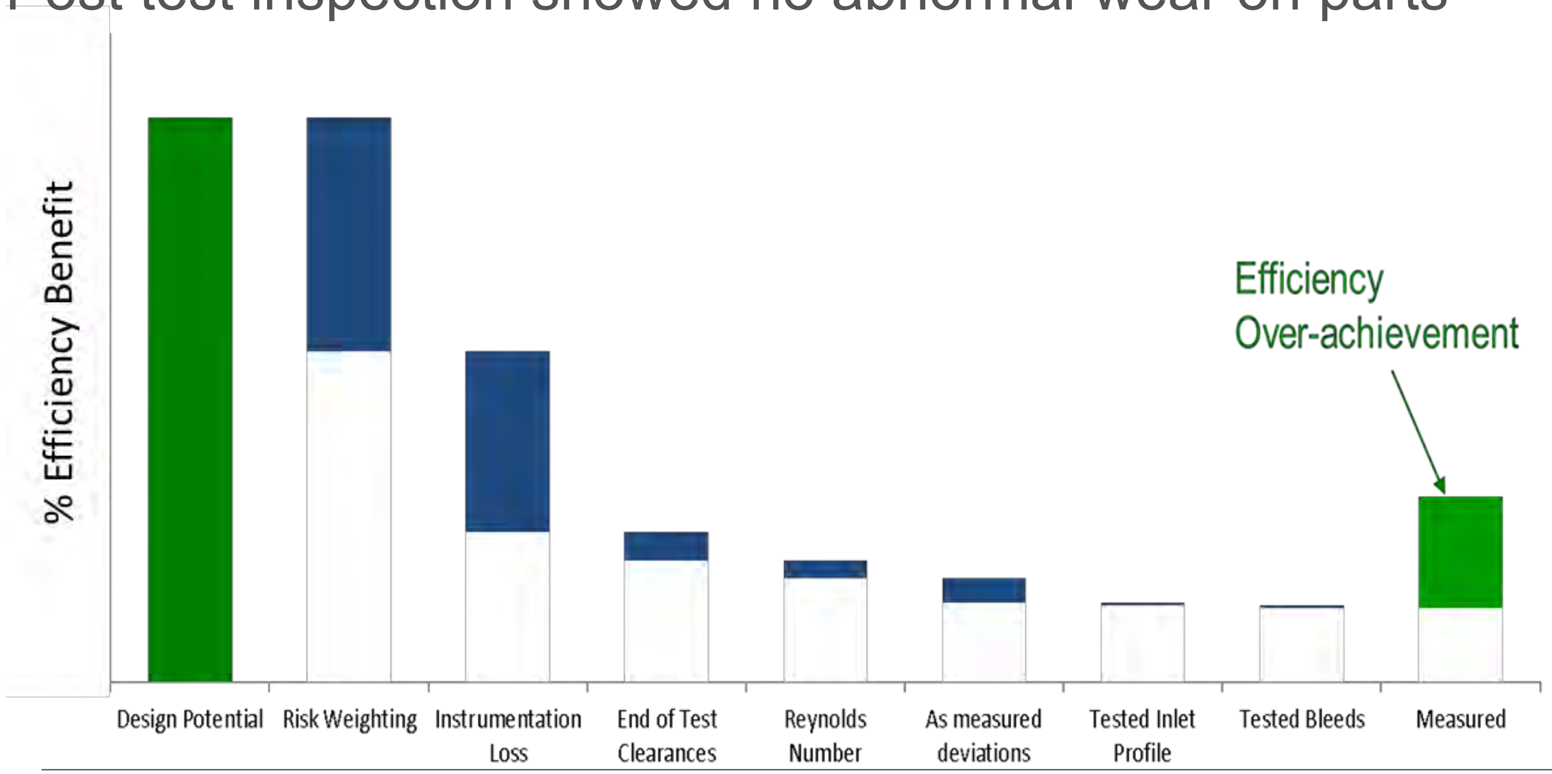
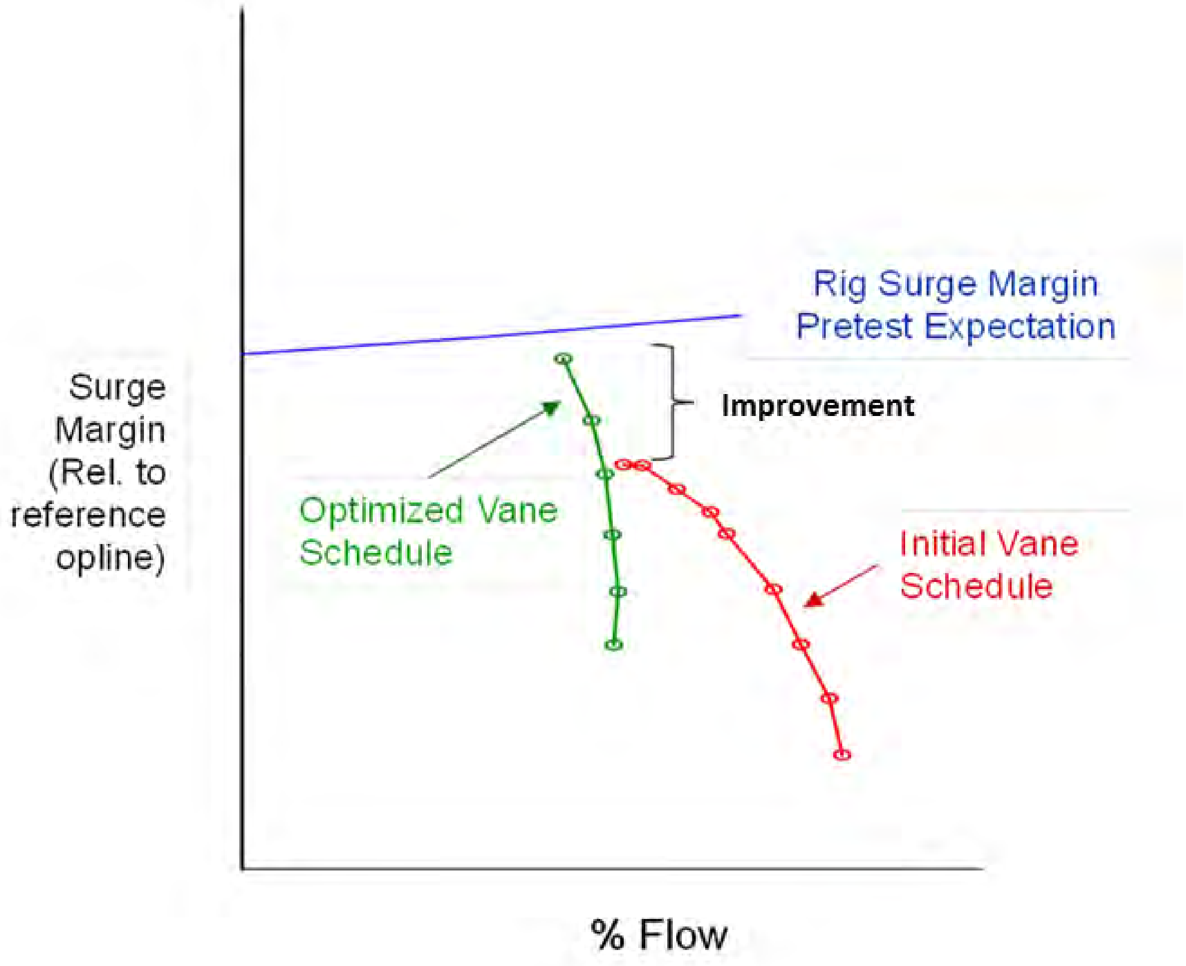
HPC Technology Rig – Final Results and Learning

Optimized vane schedule achieved by running sensitivities during testing. Data to be used to improve scheduling in future products

Overall efficiency of the rig exceeded pretest predictions

Post test inspection showed no abnormal wear on parts





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HPC Technology Rig – What's next?

Same compressor aero design slated to go to ground test shortly to bring HPC technology to TRL 6 – "Subsystem demonstration in a relative environment"

Tools developed and knowledge gained will be utilized for flight test asset sometime in the future and eventual introduction into GTF product line

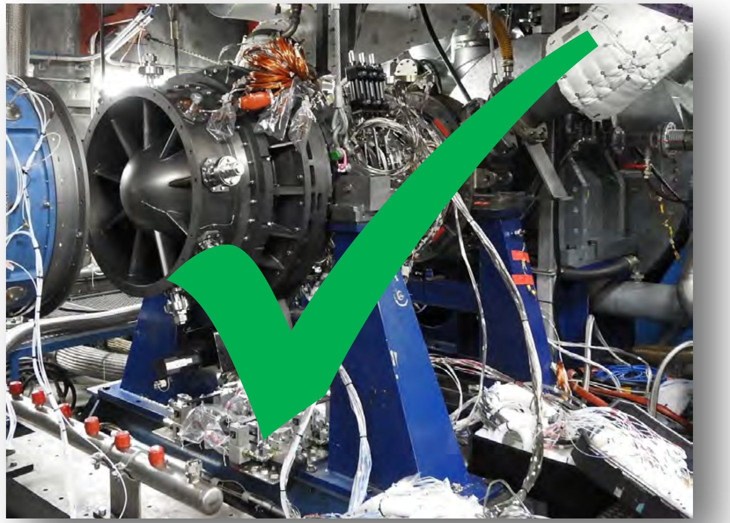

Photo Credit: MTU

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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

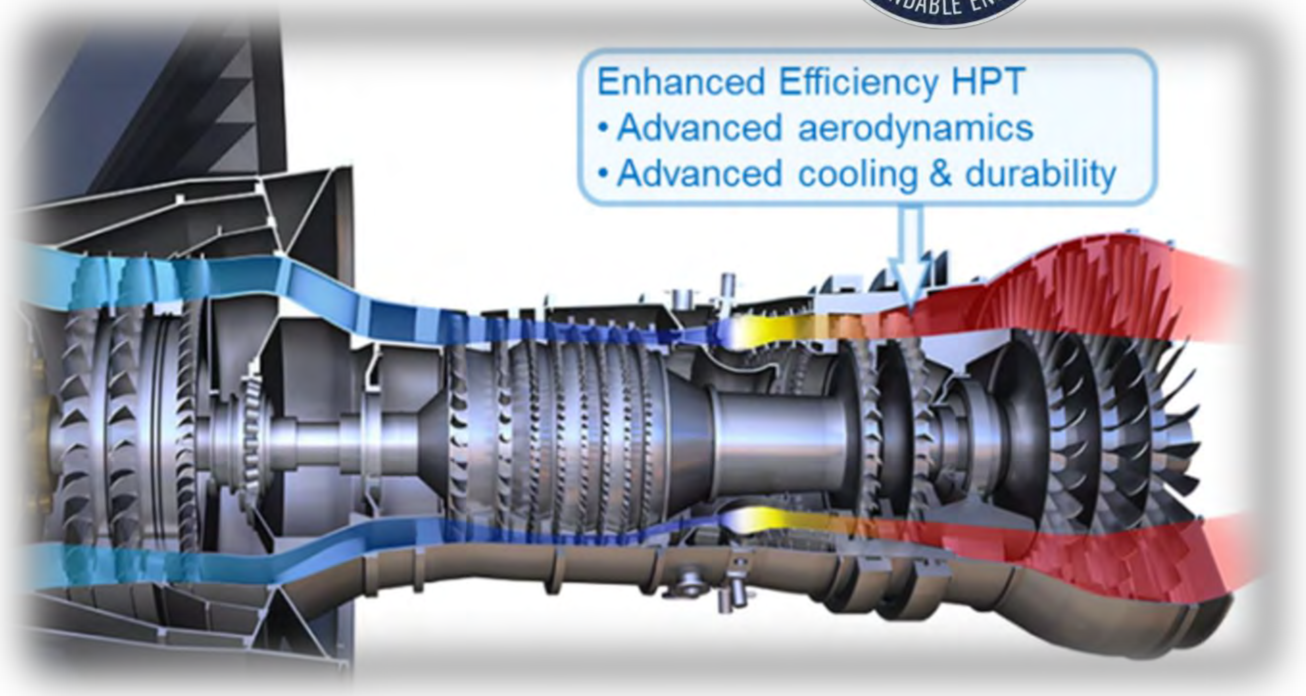
- Execute additional rig trials to isolate

Testing delayed due to linear build schedule

- Procure additional hardware to facilitate parallel build

New facility debugging

- Actively working to understand failure modes and 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
- Kicked off baseline testing

Schedule & Planned Milestones:

2015	2016	2017	2018	2019	2020
			Base Testing	Tech Testing	

Milestones: Kickoff; CFD Studies & Design; Base Fab; Base Test Start; Base Tests Complete; Tech Fab; Tech Test Complete; Final Report

Pratt & Whitney's CLEEN II Technologies

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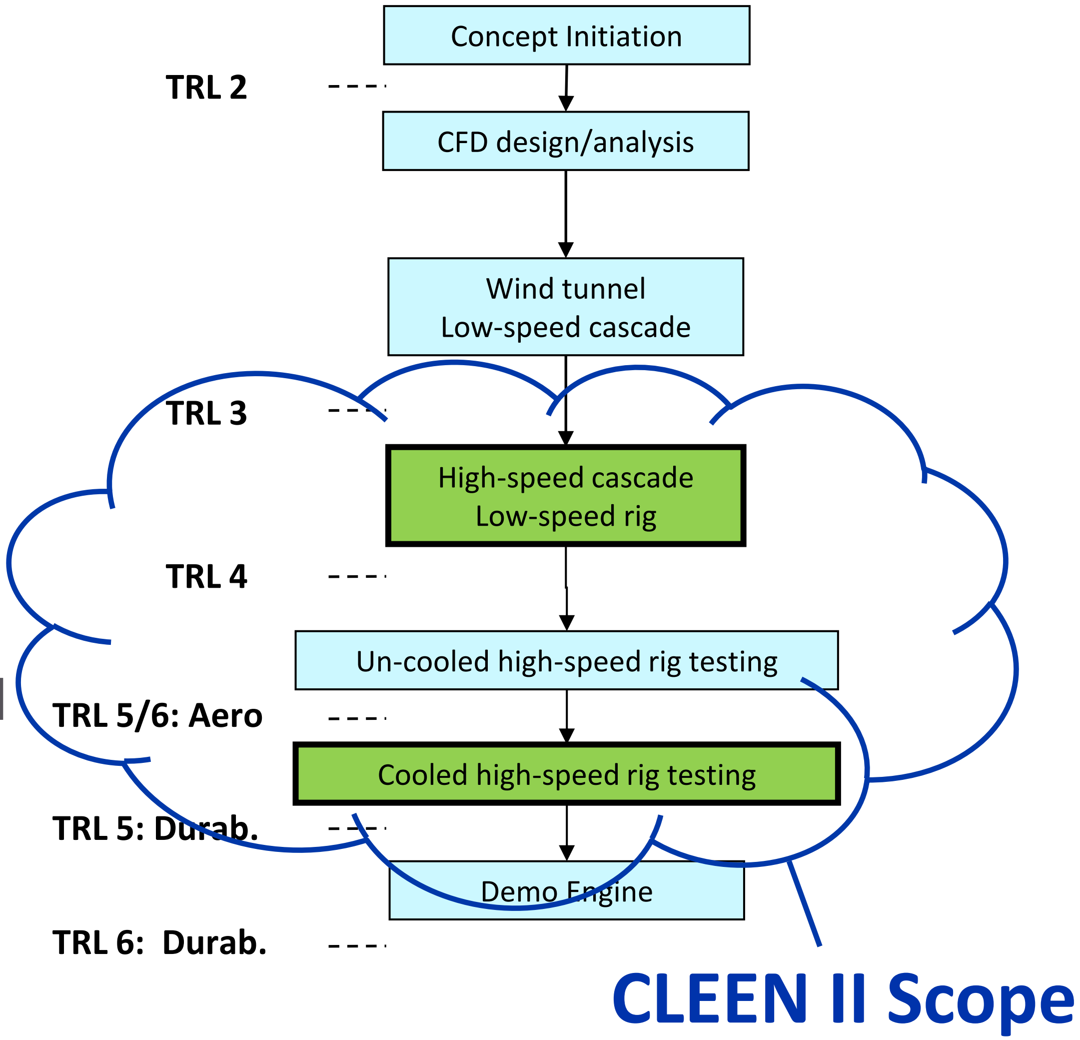
HPT Technology Maturation Strategy

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

HPT Technology Maturation Process



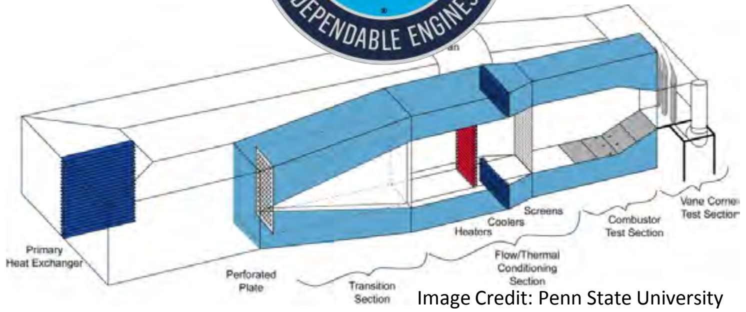


Image Credit: Penn State University

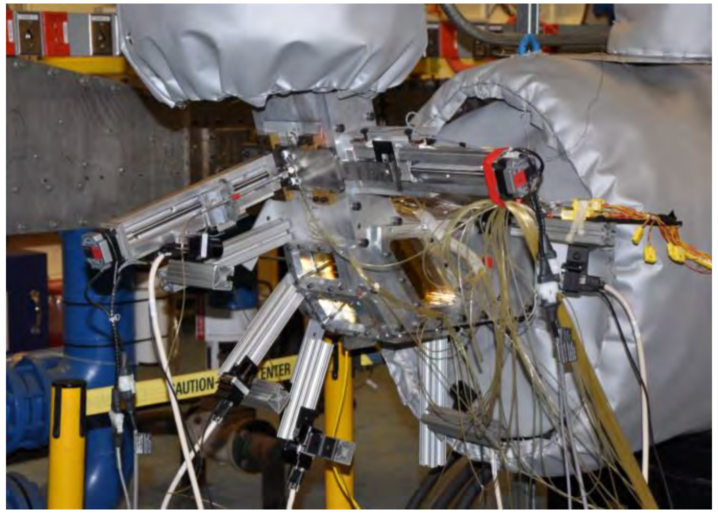


Image Credit: Penn State University

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HPT Technology Status - Schedule

Conceptual design work started prior to CLEEN II contract start

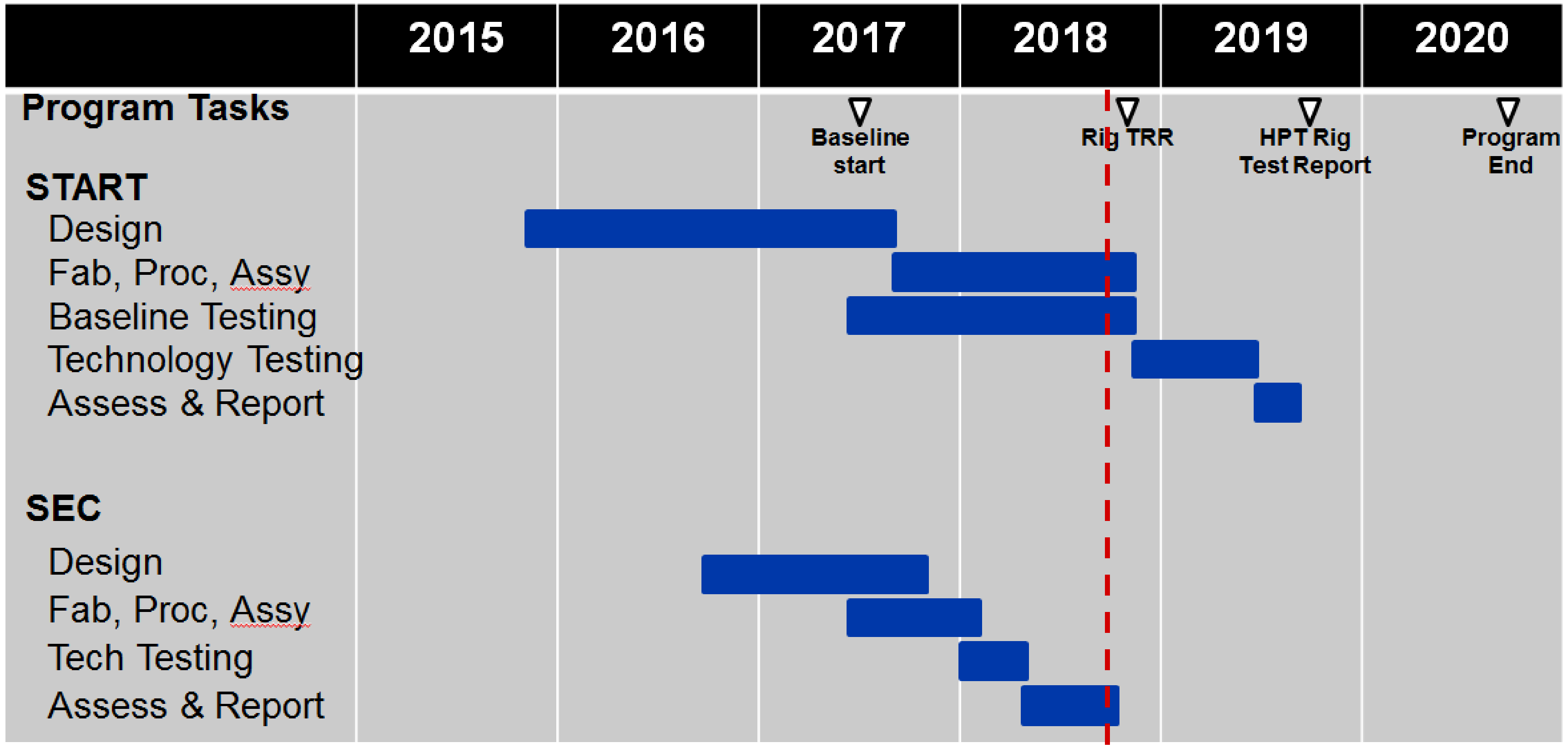
FAA has helped to further mature the HPT technologies beyond TRL 3

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

Single Element Cascade testing complete

Baseline START testing nearly complete

Currently working hardware fabrication and final rig preparation for technology testing



Pratt & Whitney's CLEEN II Technologies

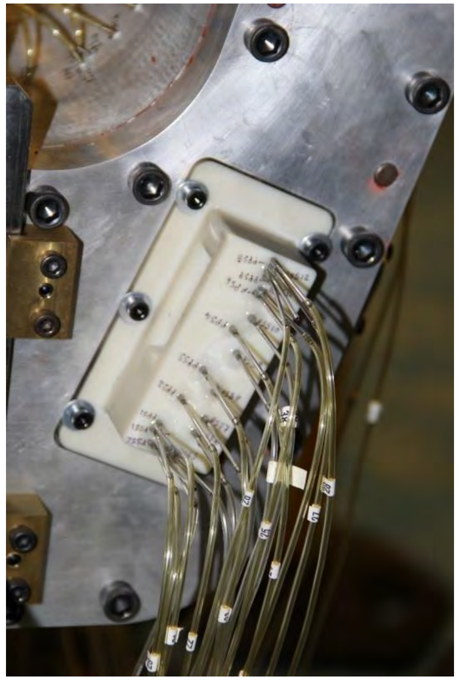
Single Element Cascade (SEC) - Objectives

Test purpose was to measure film cooling effectiveness and aerodynamic loss on high-lift airfoil sections

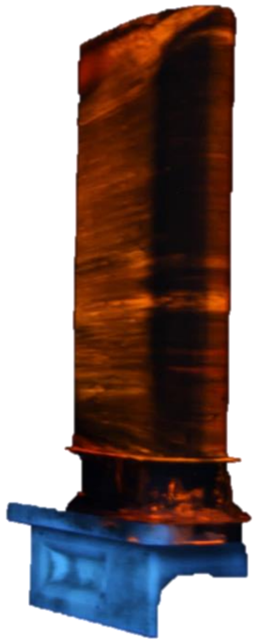
Compare baseline and advanced cooling technology at representative operating conditions

Generate high-quality aero/thermal data to validate Pratt & Whitney's turbine cooling analytical modeling

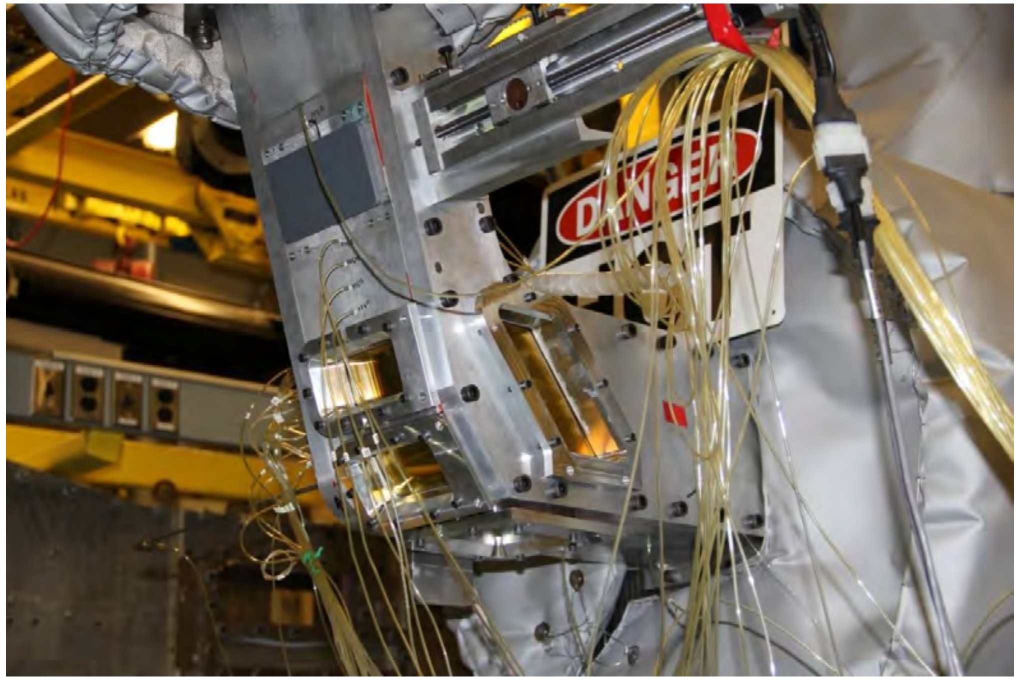
Enhance the understanding of performance losses due to advanced technology cooling architecture



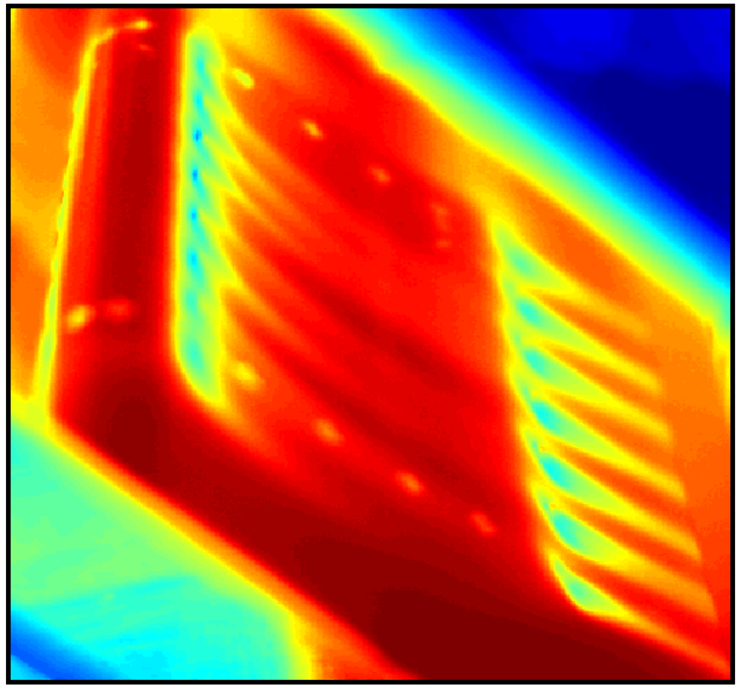
Single Element Cascade Rig Blade



Flow Visualization



Single Element Cascade Rig



Processed IR Image Data

Pratt & Whitney's CLEEN II Technologies

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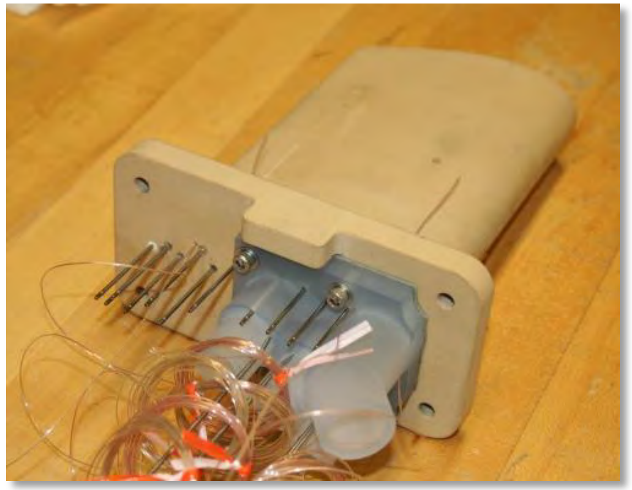
Single Element Cascade (SEC) - Execution

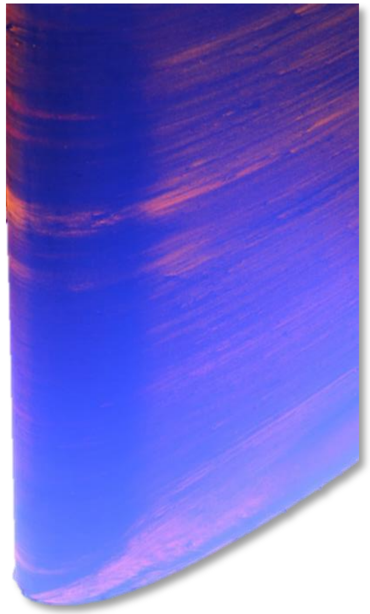
SEC facility and test article assembly was completed at United Technology's Research Center (UTRC) in March 2018

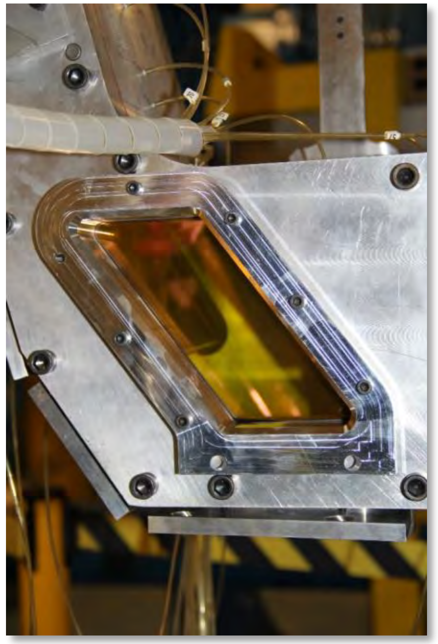


Testing commenced in April and was completed in June 2018

Testing consisted of two major sub-tests:

- Uncooled, baseline testing
- Cooled Aero/thermal testing for the CLEEN II technologies





Data reduction & analysis is currently in-process and expected to be fully complete by the end of the year

Technologies proven-out by the SEC testing allows for future turbine components to reduce cooling air requirements; thus reducing the amount of losses in the engine

Pratt & Whitney's CLEEN II Technologies

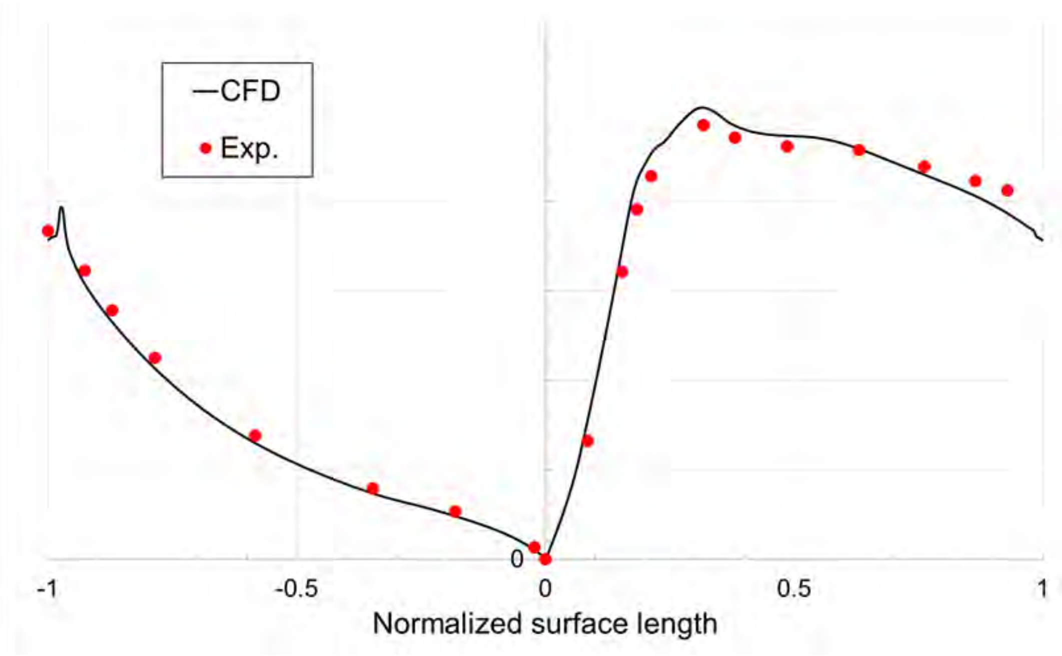
Single Element Cascade (SEC) - Results

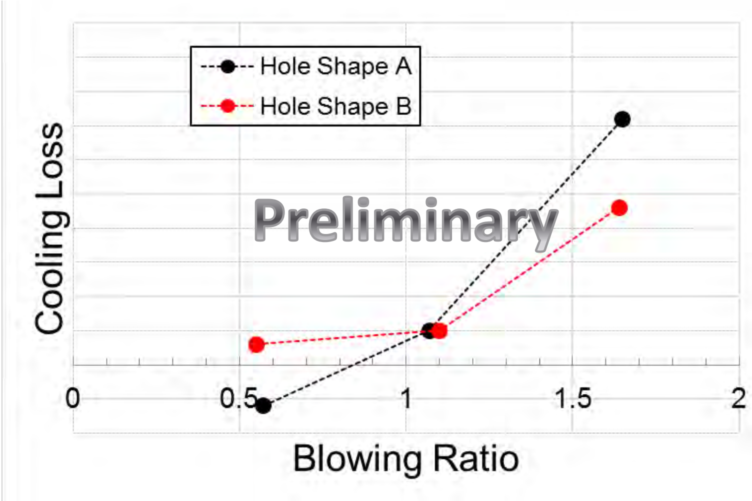
Cascade rig fully instrumented with pressure and temperature probes along with IR camera system

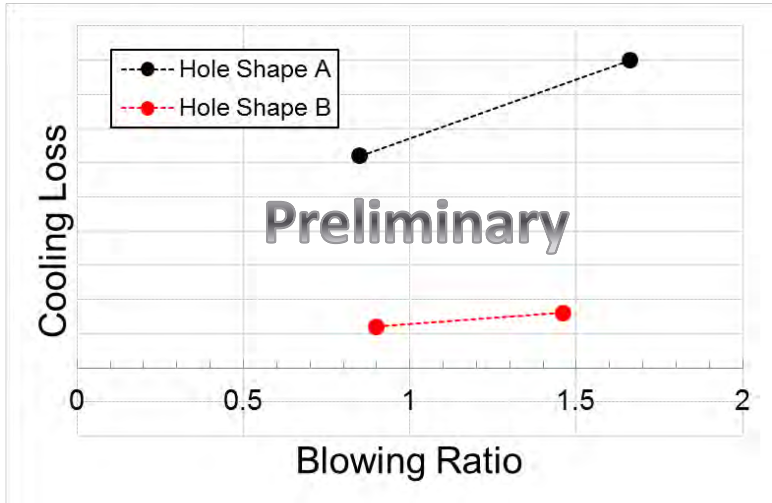
Good correlation of experimental data back to CFD pre-test predictions for surface pressure and Mach number distribution

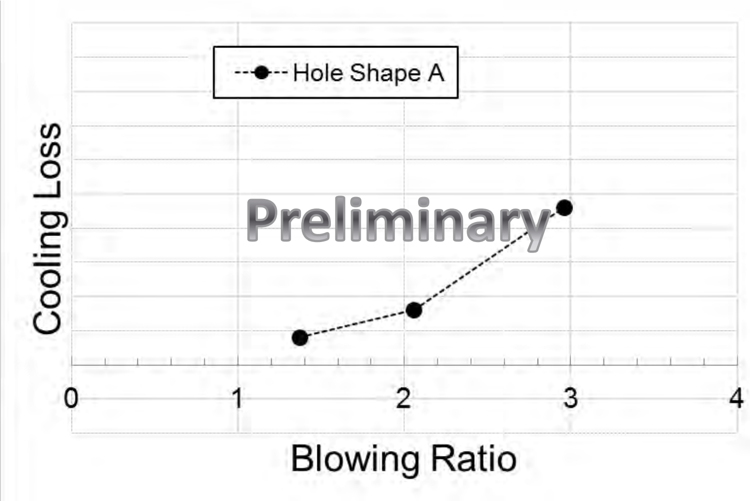
Cooling hole loss data obtained for various cooling hole shapes and blowing ratios on suction side, leading edge, and pressure side

Detailed analysis in-work









Pratt & Whitney's CLEEN II Technologies

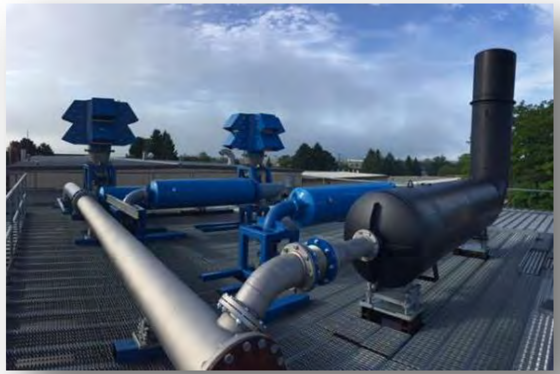
Penn State START Facility – Background

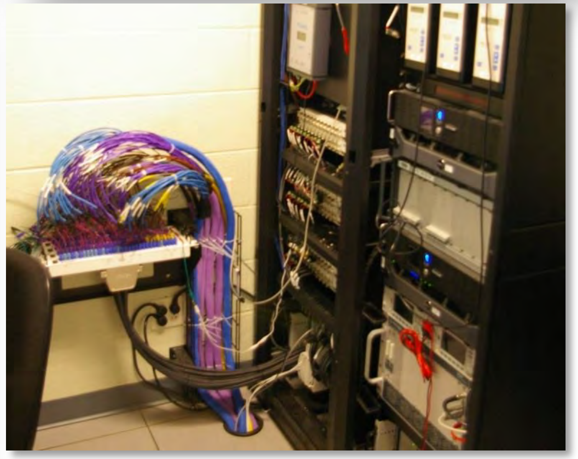
START = Steady Thermal Aero Research Turbine.

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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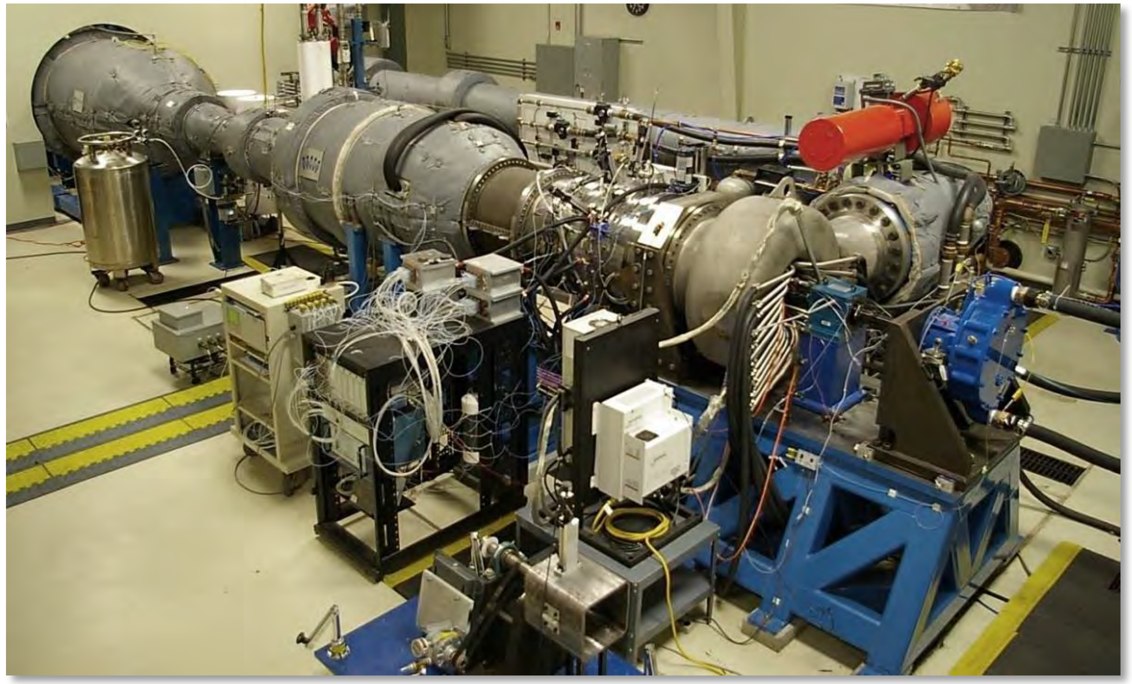
GO BEYOND

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 March 2017

START facility shakedown completed August 2017

Cavity Aero testing completed

Testing of baseline GTF technology anticipated by end of 2018

Analytical aero/thermal pre-test predictions anticipated by end of 2018

CLEEN II advanced technology blade aero/thermal instrumentation fabrication in-process

CLEEN II advanced technology blade fabrication in-process

99% of custom rig hardware for CLEEN II technology has been delivered

On schedule for 2019 test completion

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Penn State START Facility – Pretest Predictions

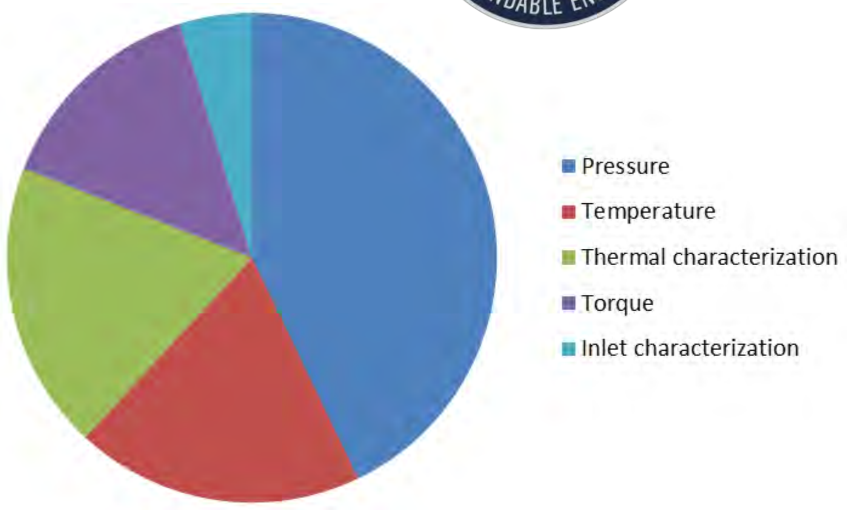
Analytical aero pre-test predictions have been completed and ready for experimental data comparison

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

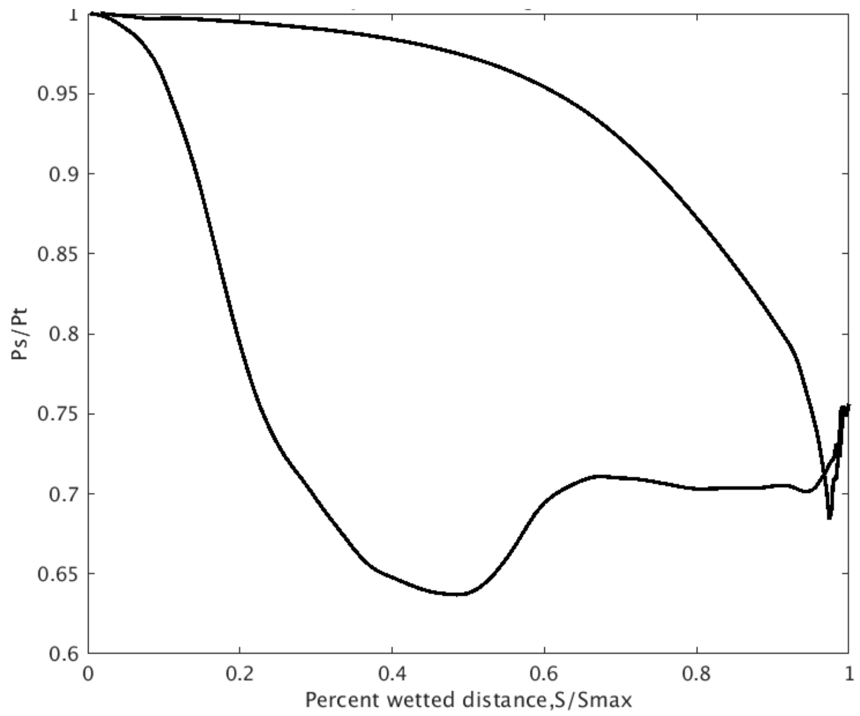
Instrumentation plans are in place for HPT technology testing

80% of the instrumentation required for technology testing has been installed into the START facility

Additional instrumentation specific to technology testing is in-work



CFD Prediction for Pressure Distribution



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

PRATT & WHITNEY DEPENDABLE ENGINES

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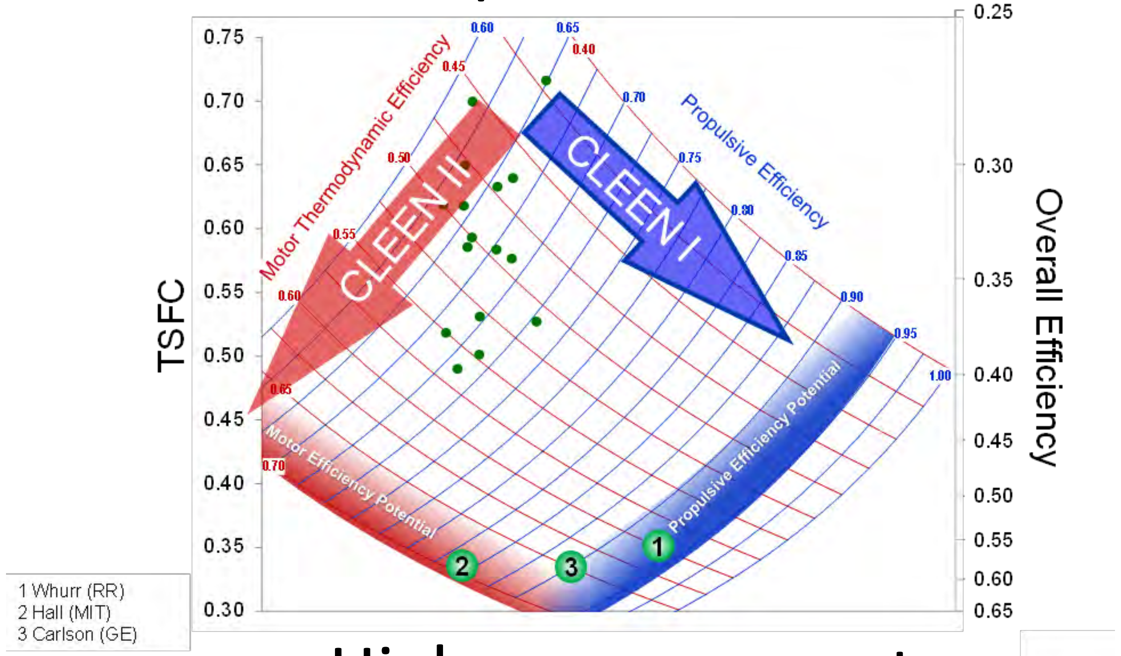
System Level Impact

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 saved 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.

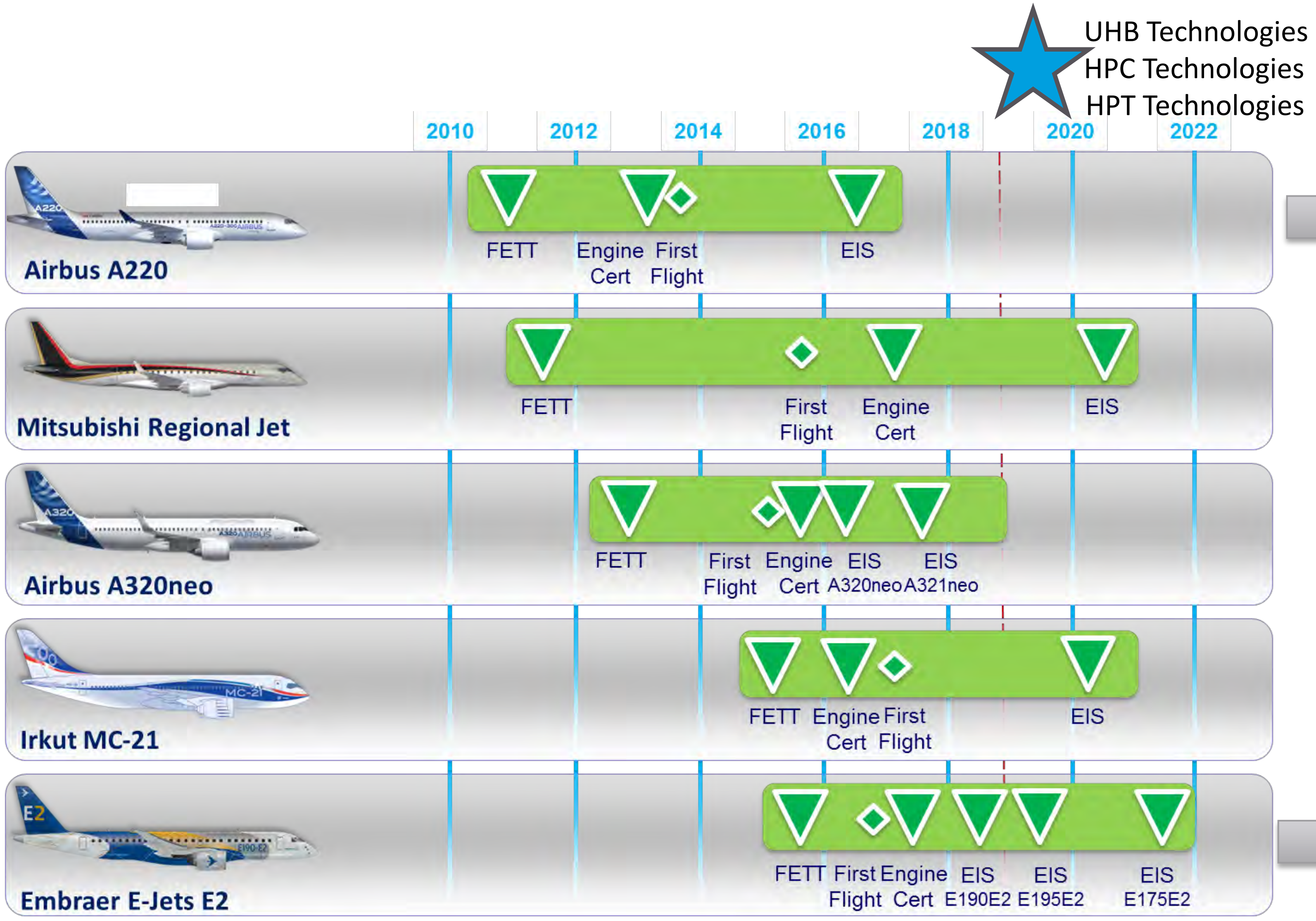

Photo Credit: Airbus

Photo Credit: Widerøe, https://www.wideroe.no/en/E2

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Program Summary

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

High pressure turbine (HPT) Single Element Cascade testing complete, results analysis is underway

HPT START rig baseline testing complete

Industrial phase of CLEEN II technology HPT hardware for START rig continues on-schedule

Queueing-up system level benefits analysis for 2019 and 2020

Future plans are in place for introduction of technologies matured under CLEEN II efforts into Pratt & Whitney's future product offerings

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