Pratt & Whitney

A United Technologies Company

CLEEN II: HIGH-PERFORMANCE CORE,ULTRA-HIGH BYPASS RATIO,GEARED DUCTED PROPULSION SYSTEM

HIGH-PERFORMANCE CORE

Topics for Discussion

Program Overview

HPT Technology Status

HPC Technology Status

Technology Impact

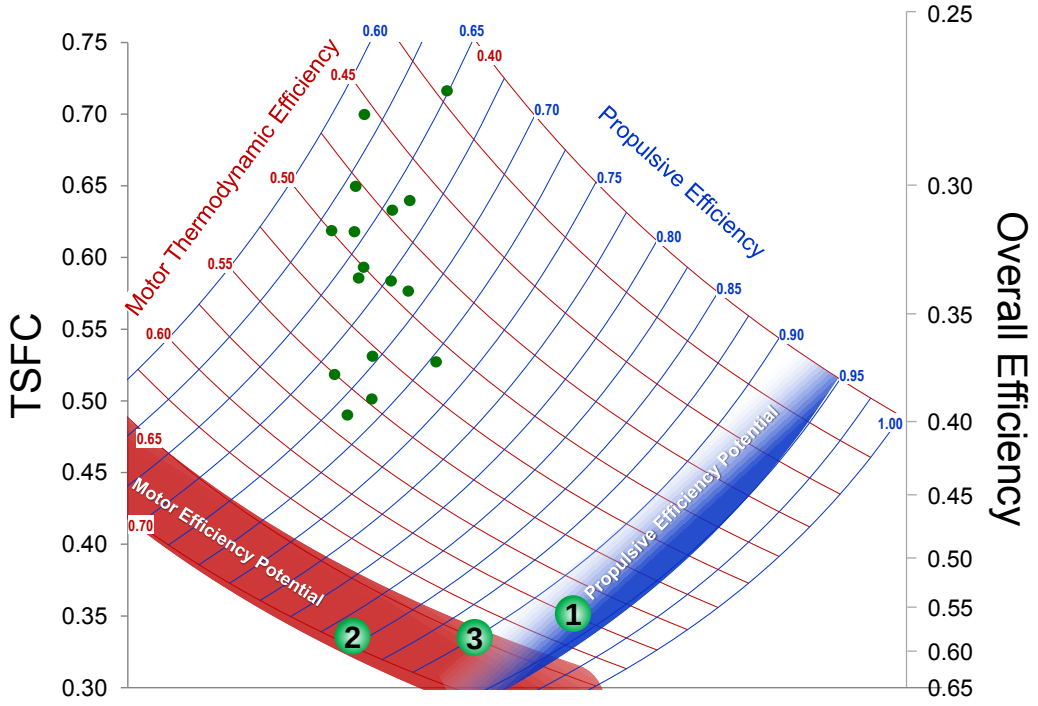
Discussion

HIGH-PERFORMANCE CORE

Entering A New Era of Engine Architecture

Improved propulsive efficiency enabled by PurePower® Geared Turbofan™ architecture

CLEEN II Effort Enhances Performance of GTF System



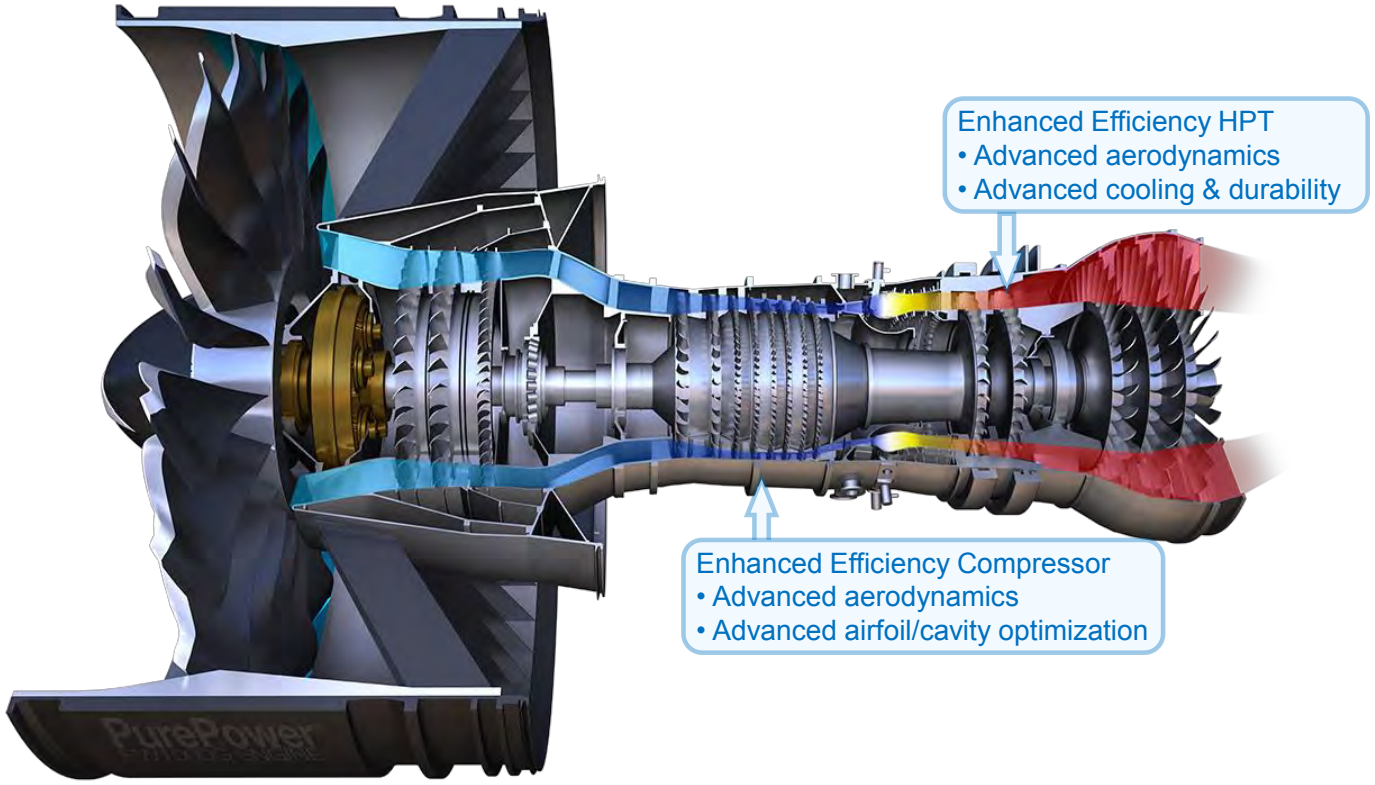
1 Whurr (RR)
2 Hall (MIT)
3 Carlson (GE)

3

HIGH-PERFORMANCE CORE

Program Overview : 1 – 2 % Fuel Burn Improvement

Compressor and Turbine Technology Maturation



Technologies can be transitioned to PurePower® Geared TurboFan™ (GTF) engines

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Program Overview

Compressor and Turbine Technology Maturation

	2015	2016	2017	2018	2019	2020
Program	Jan Submittal; Oct Start	Task Plan; Risk Assessment; HPC TRR	HPC Rig Test Report; HPT Rig PDR; HPT Rig DDR	HPT TRR	HPT Test Report	Final Reports; Prg End
HPC Techs.	Fab/ Assembly; Rig Test	Redesign	Fabrication / Assembly	Engine Development Program		
HPT Techs.	Design	Base Fab	Base Testing	Fab	Testing	

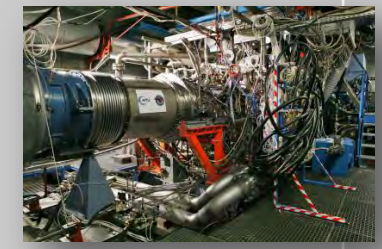


Photo Credit: MTU

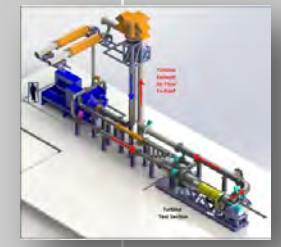


Image Credit: Penn State University

HIGH-PERFORMANCE CORE

Program Overview – Summary Status

Program ramped up & executing

- All key subcontracts in place

HPT aero concept progressed through preliminary design

- Facility upgrades detailed designs completed
- Initial testing planned for Q1 2017

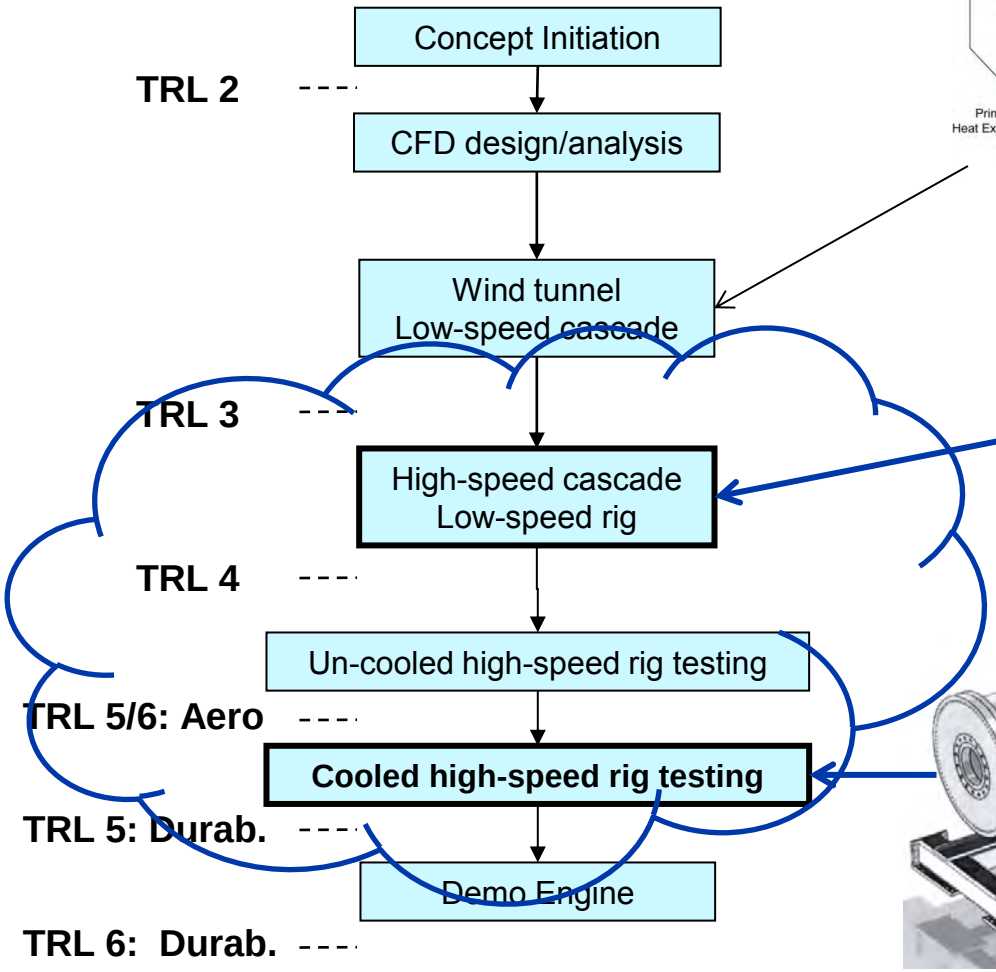
HPC rig testing completed

- Testing initiated August 23rd
- Over 100 hours of testing

HIGH-PERFORMANCE CORE

HPT Technology Status

Maturation Strategy



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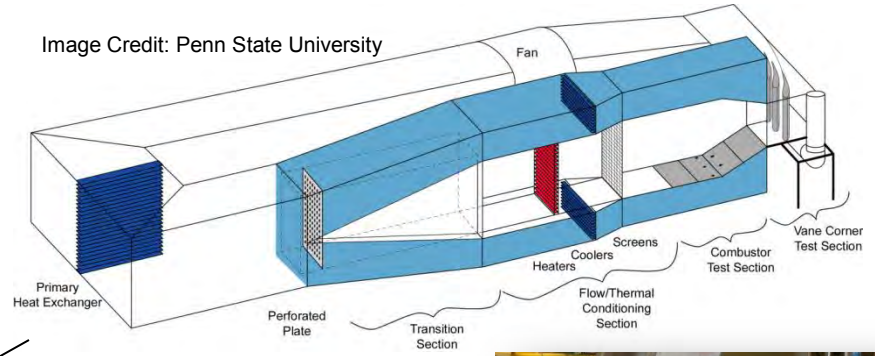

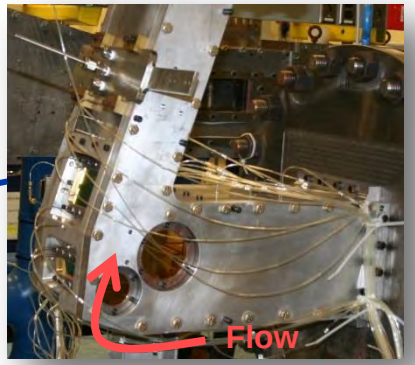

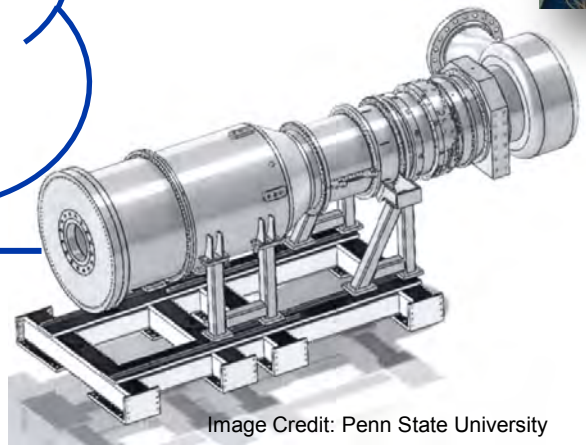

Image Credit: Penn State University

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HPT Technology – Near Term Milestones Achieved

- ✓ Initiate and advance UTRC cascade fabrication
  - Designs released
  - Facility benchmarking CFD assessment complete
- ✓ Delivery majority of PSU START rig hardware for baseline test
  - All hardware delivered
  - On target for Q1 2017 facility shakedown
- ✓ Initiate and progress preliminary design for technology blade for PSU START rig
  - Technology blade successfully passed through PDR

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HPT Technology Status – Cascade Testing

Facility benchmarking assessment completed

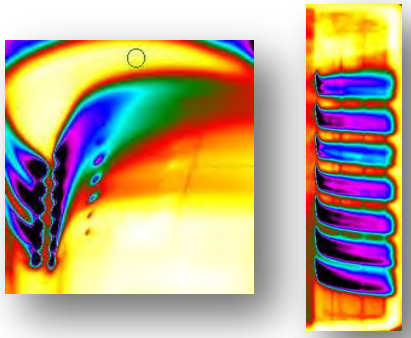
- Excellent agreement with CFD & NASA baseline

Cascade rig special test equipment design completed

- Guidewalls, airfoils, camera integration

Aero / thermal concept progressing through detailed design

- Baseline blade hardware fabrication initiated



Raw IR image processing

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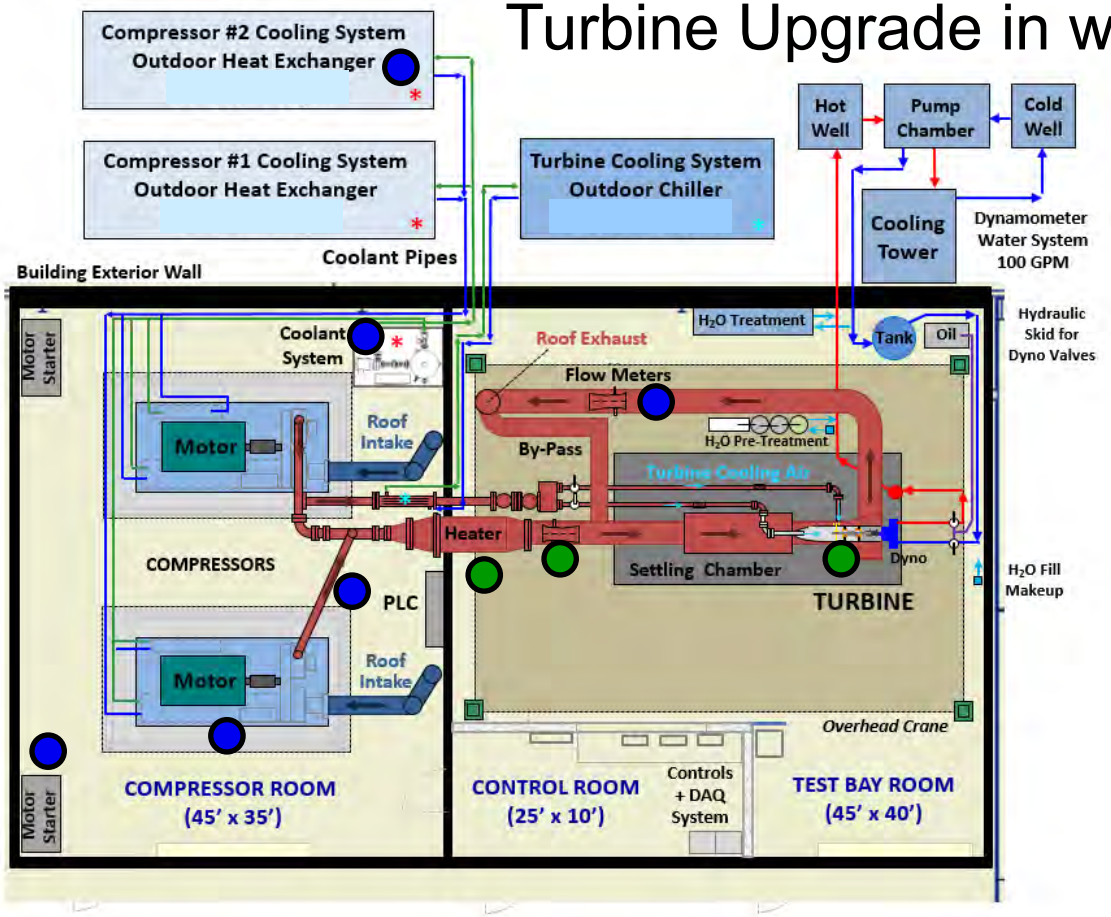
HPT Technology Status – High Speed Rig Testing

Facility upgrade complete – full span, multi-stage, cooling capable Turbine Upgrade in work



All Photo and Image Credits: Penn State University

Two Compressor Setup

Fabricated Combustion Chamber

- Complete/Installed
- Hardware Delivered

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HPT Technology – Near Term Milestones

Complete UTRC cascade fabrication & conduct baseline airfoil testing

Complete PSU START rig hardware fabrication/assembly and initiate facility shakedown

Complete design for technology blade for PSU START rig and release purchase orders

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HPC Technology Status

Maturation Strategy

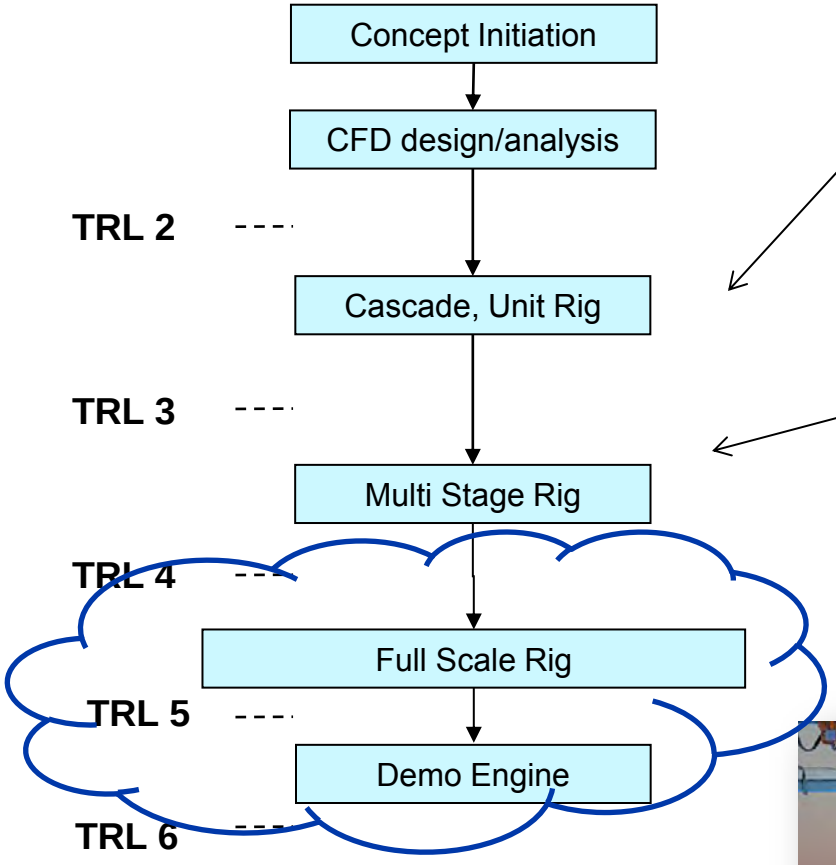
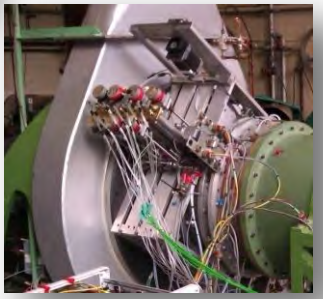


Photo Credit NRC Canada



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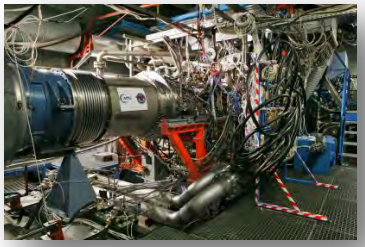

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HPC Technology – Near Term Milestones Achieved

- ✓ Complete instrumentation and module assembly
- ✓ Complete rig assembly and module installation
- ✓ Complete test readiness review
- ✓ Execute rig test program
- ✓ Preliminary data assessment

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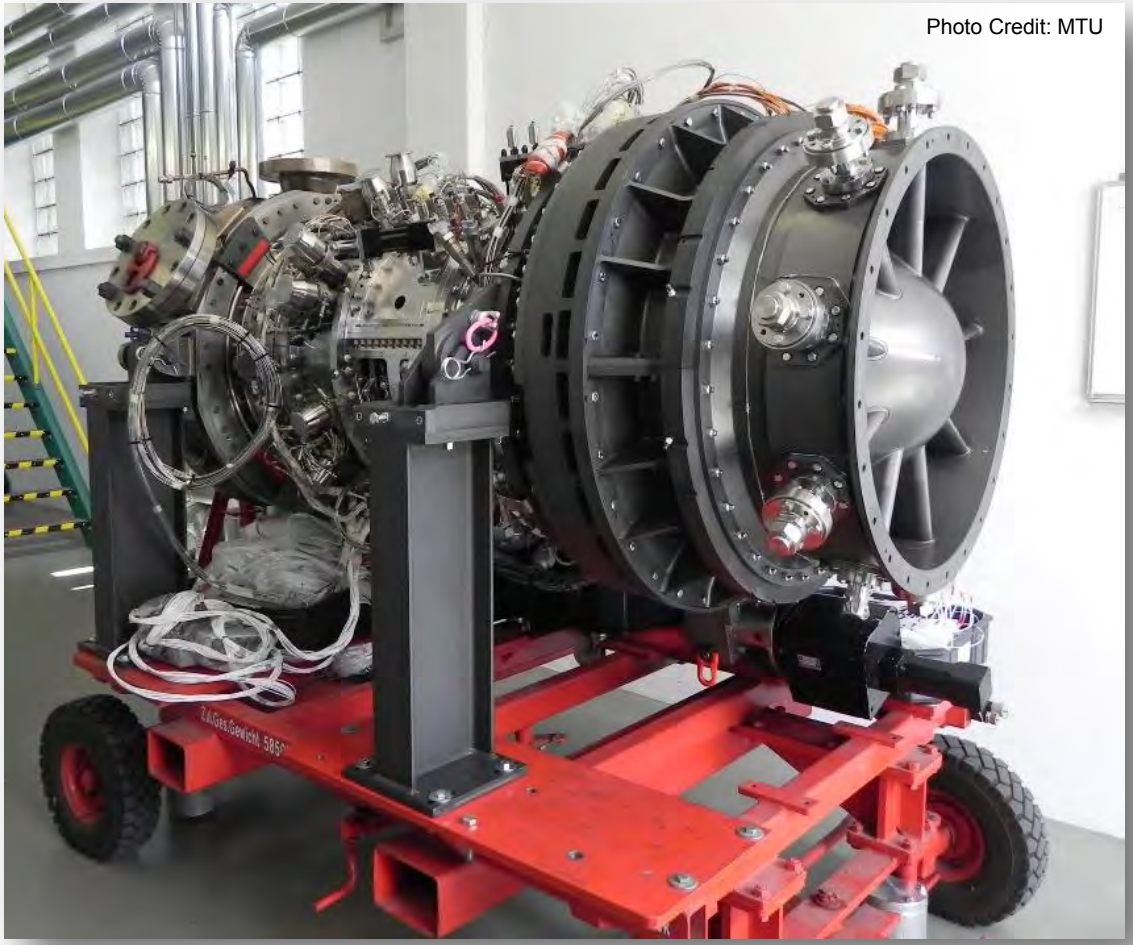
HPC Technology Status – Rig assembly complete

Rig transferred to test cell on July 21



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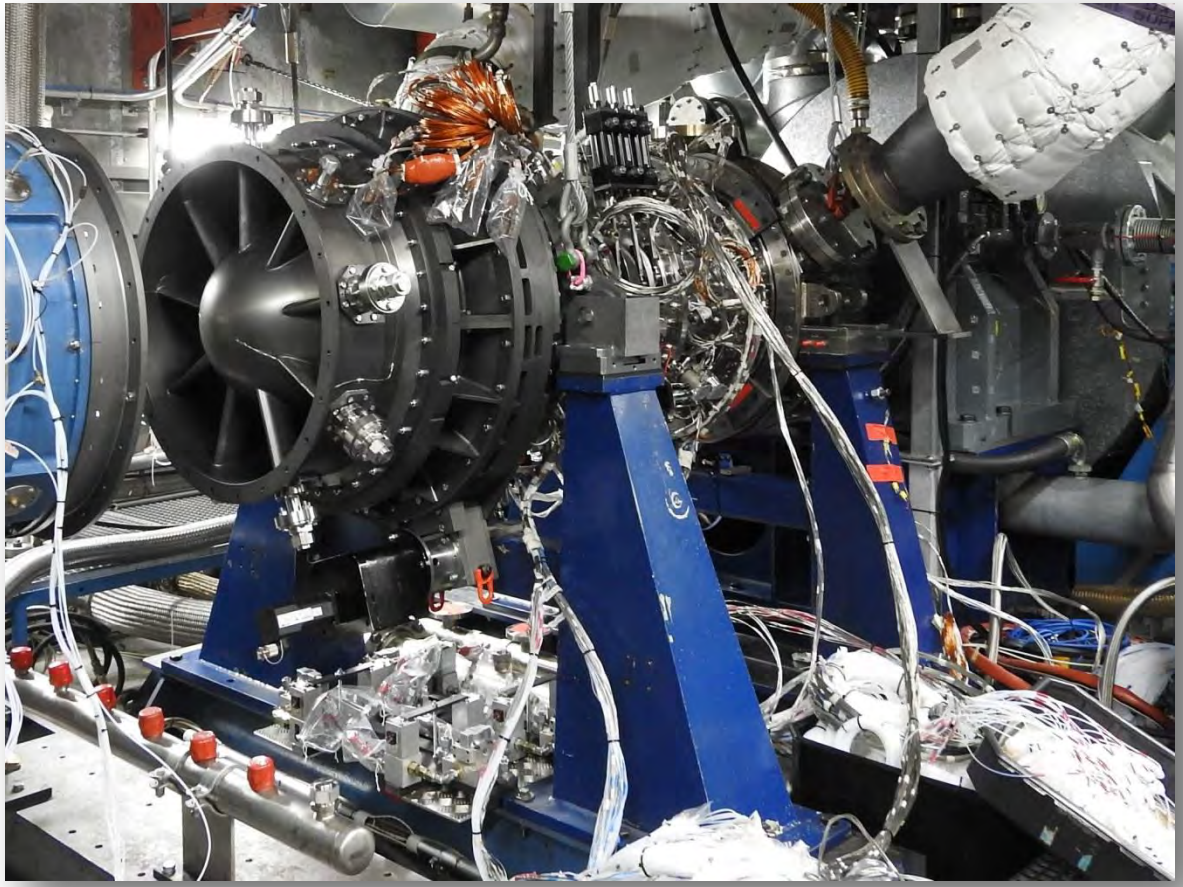
HPC Technology Status – Rig installation complete

Rig installed in test cell and functional check August 23

Photo Credit: MTU



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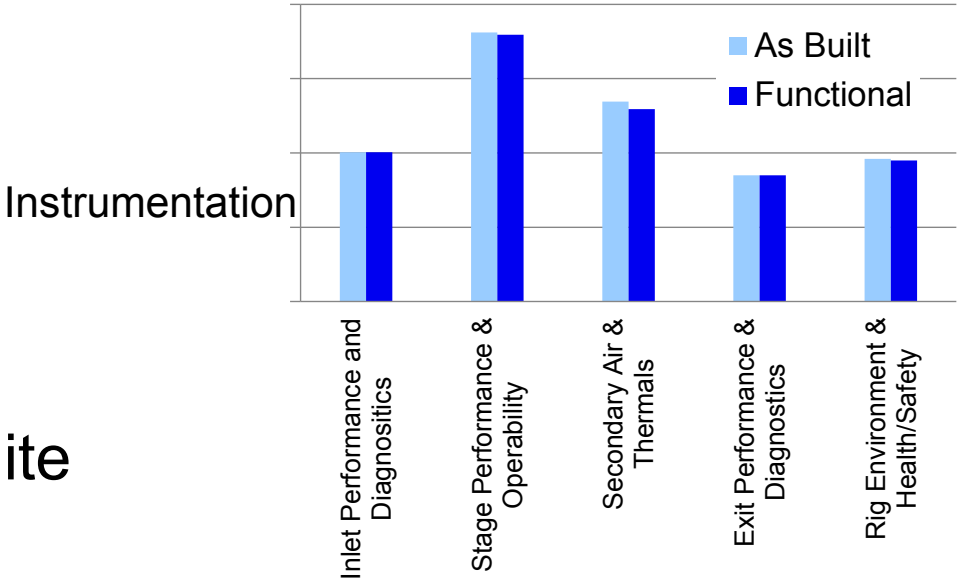
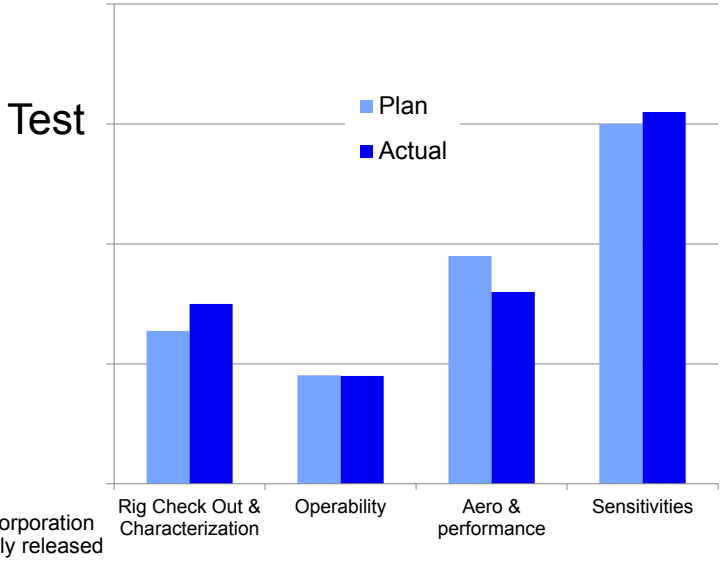
HPC Technology Status – Test and Instrumentation

Over 100 hours of testing conducted

Robust instrumentation suite (> 99% survivability)

Minor adjustments to test plan to react to rig learning





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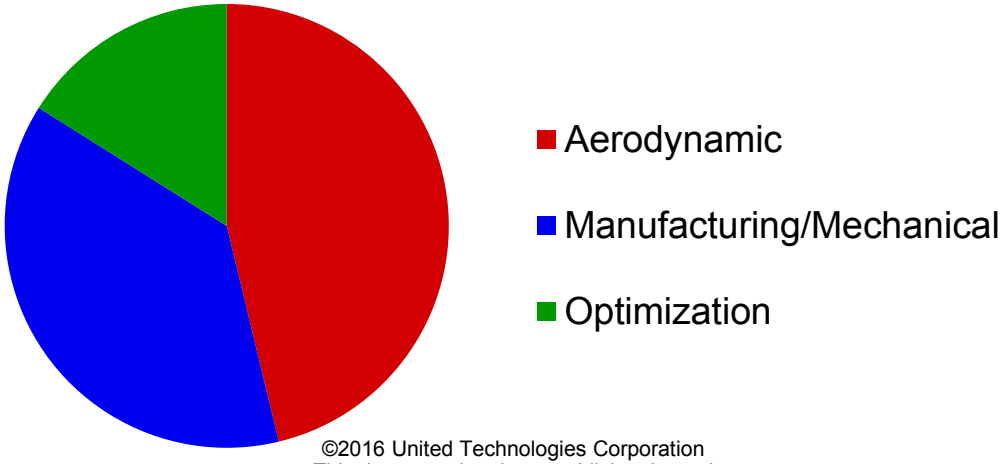
HPC Technology Status – Testing Completed Oct 28th

Technology projections achieved, detailed assessment in process

Performance benefits from both technology maturation and compressor optimization

- Aero technologies
- Manufacturing technologies
- Mechanical design technologies



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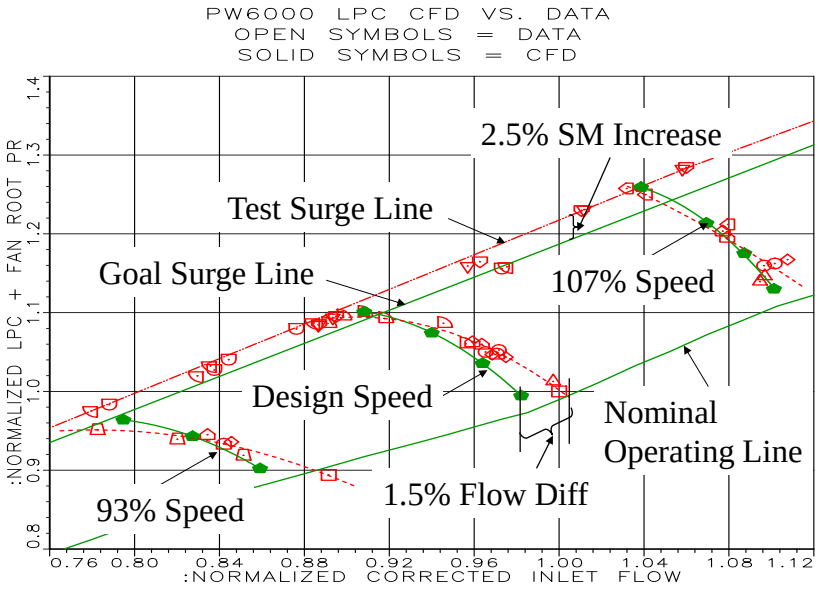
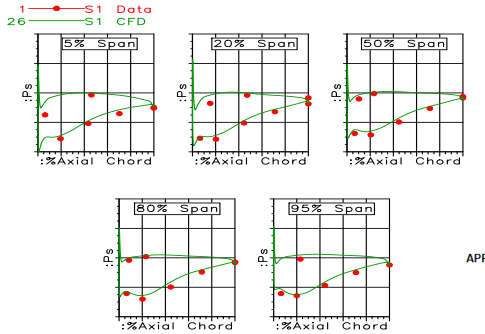
HPC Technology – Near Term Milestones

Complete data assessment and test report

Compressor mapping & characterization (reference - for illustration only)





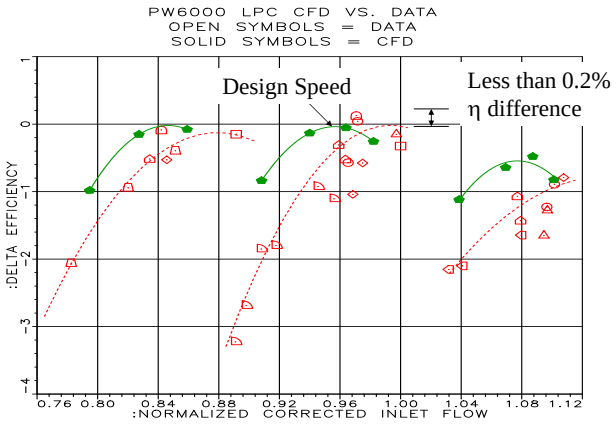
Proceedings of ASME TURBO EXPO 2004:
Power for Land, Sea, and Air
June 14-17, 2004, Vienna, Austria

GT2004-54263

APPLICATION OF MULTISTAGE CFD ANALYSIS TO LOW PRESSURE COMPRESSOR DESIGN

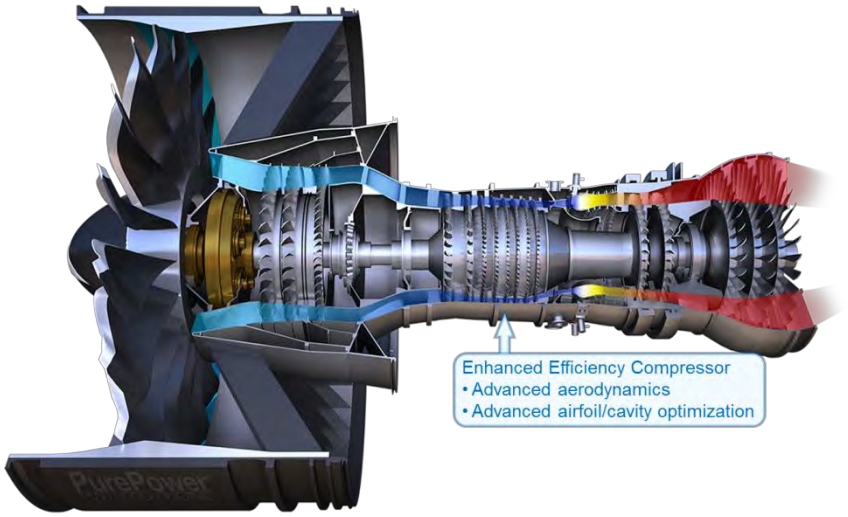
Lisa Brilliant
Pratt and Whitney

Stanley Balamucki
Pratt and Whitney



Clearance and surge behavior

Compressor Aero-Efficiency Techs.



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

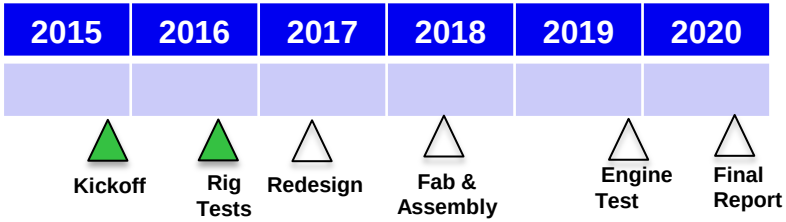
Objectives: *Demonstrate improved high pressure compressor efficiency via advanced aerodynamic airfoil optimization*

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

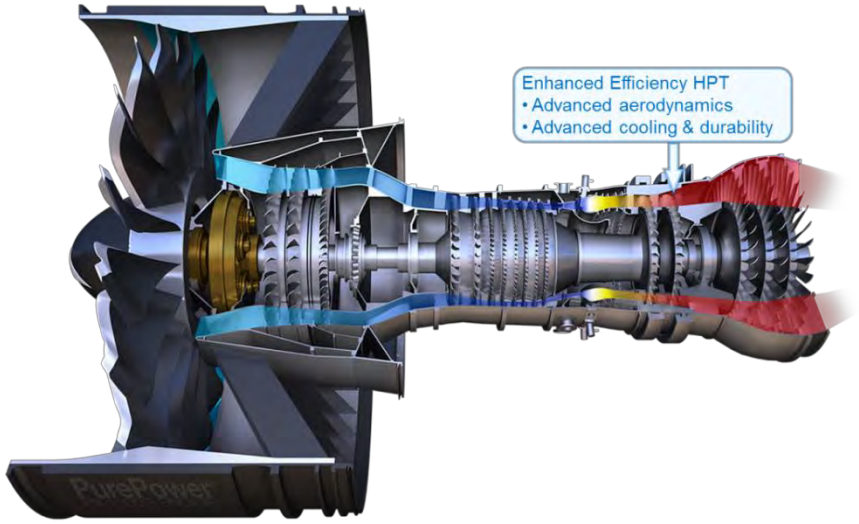
Prior Accomplishments:

- Completed rig testing

Schedule & Planned Milestones:



Turbine Aero-Efficiency & Durability



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 compromised due to assembly delays
  - Procure additional rig hardware for assembly

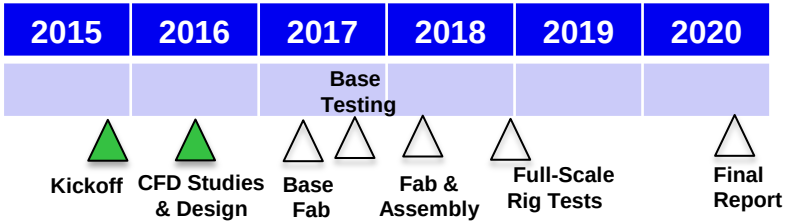
Objectives: *Demonstrate improved high pressure turbine efficiency via advanced aerodynamic airfoil and durability optimization*

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:

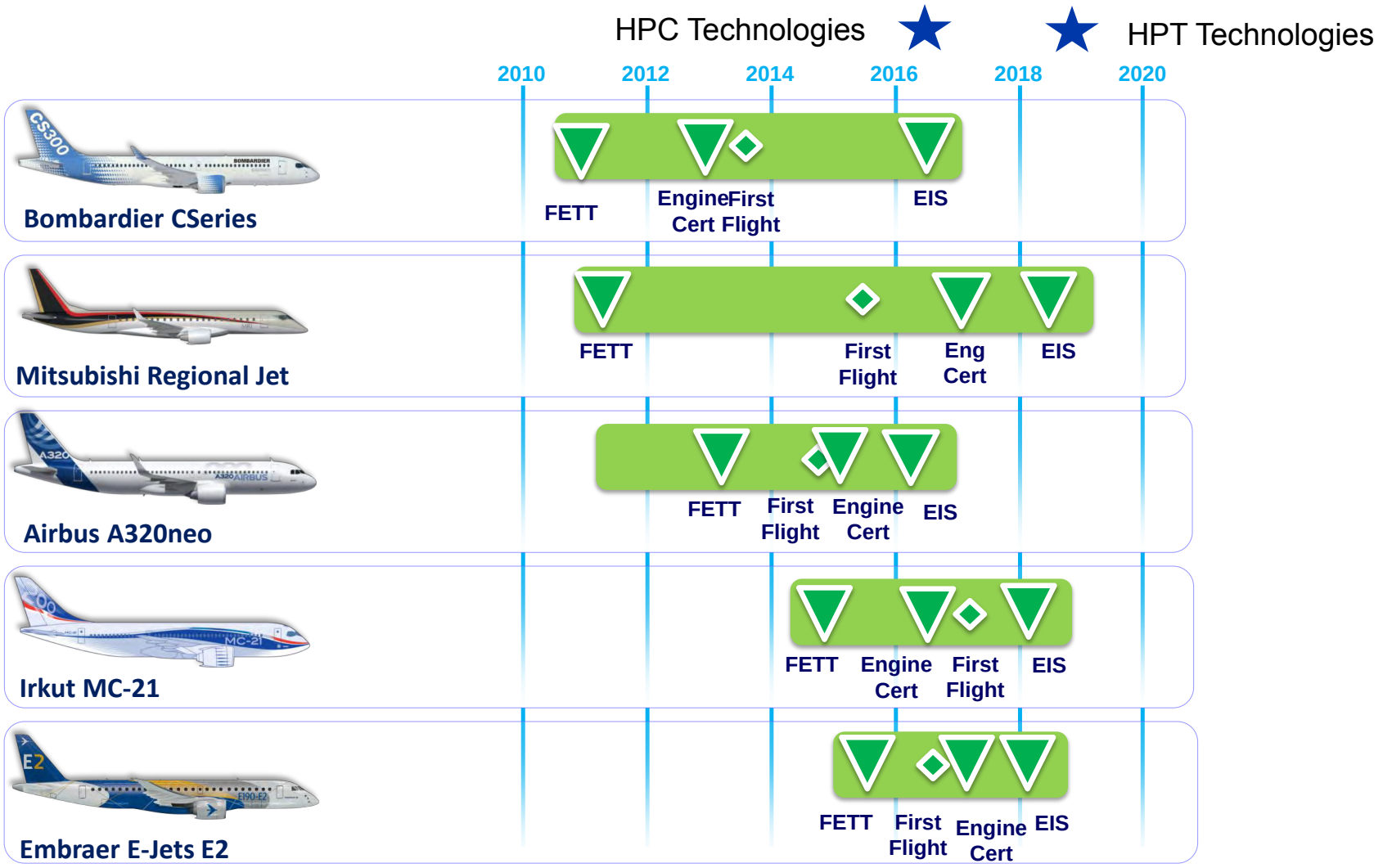
- Completed cascade benchmarking
- Completed PSU START Rig upgrade design
- Technology blade completes preliminary design

Schedule & Planned Milestones:



PUREPOWER® GTF ENGINE APPLICATIONS

80+ Customers/8000+ Engine Orders



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Summary

P&W CLEEN II program progressing to plan

Benefits are achievable

HPT technology facility upgrades on target

HPC technology rig testing successfully completed

THANK YOU