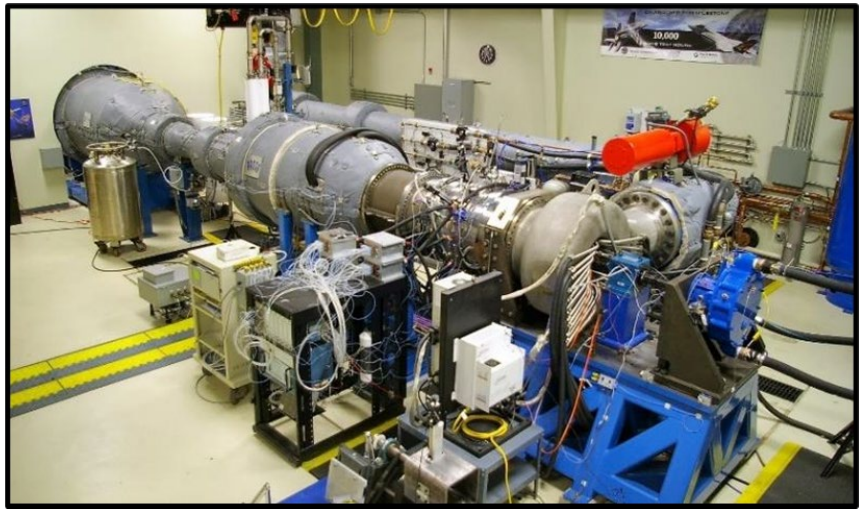
Advanced Two-Stage Turbine Rig Development



START PennState Steady Thermal Aero Research Turbine

NExT

START+ PennState Steady Thermal Aero Research Turbine

Research Staff

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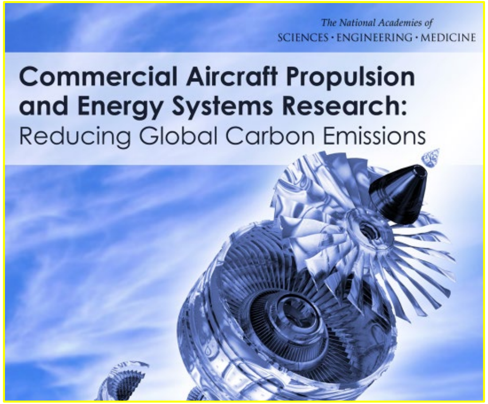
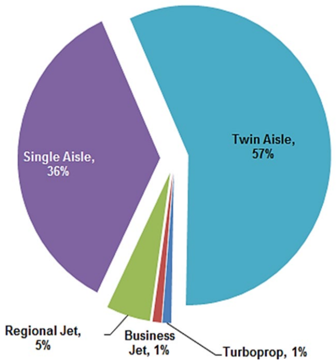
Chad Schaeffer	

Two National Academy of Engineering studies have identified important technologies to reduce the CO_2 emissions



90% of CO_2 emissions is from large aircraft



Four solutions being discussed for sustainable aviation:

- Sustainable aviation (jet) fuels (small efficient turbine)
- Hydrogen fuels (small efficient turbine)
- Hybrid electric (small efficient turbine)
- Fully electric

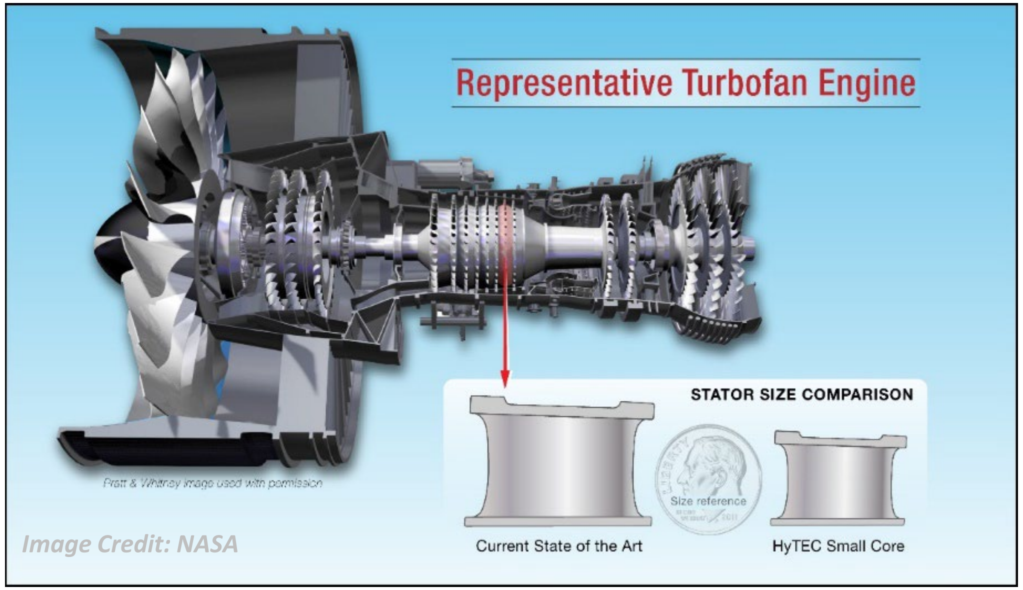
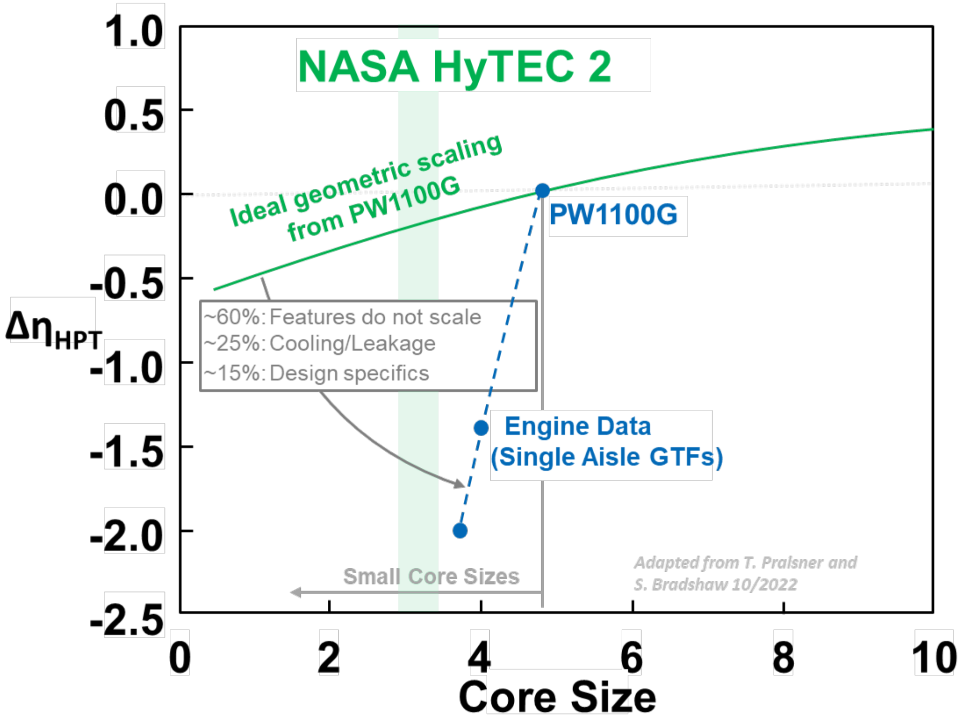
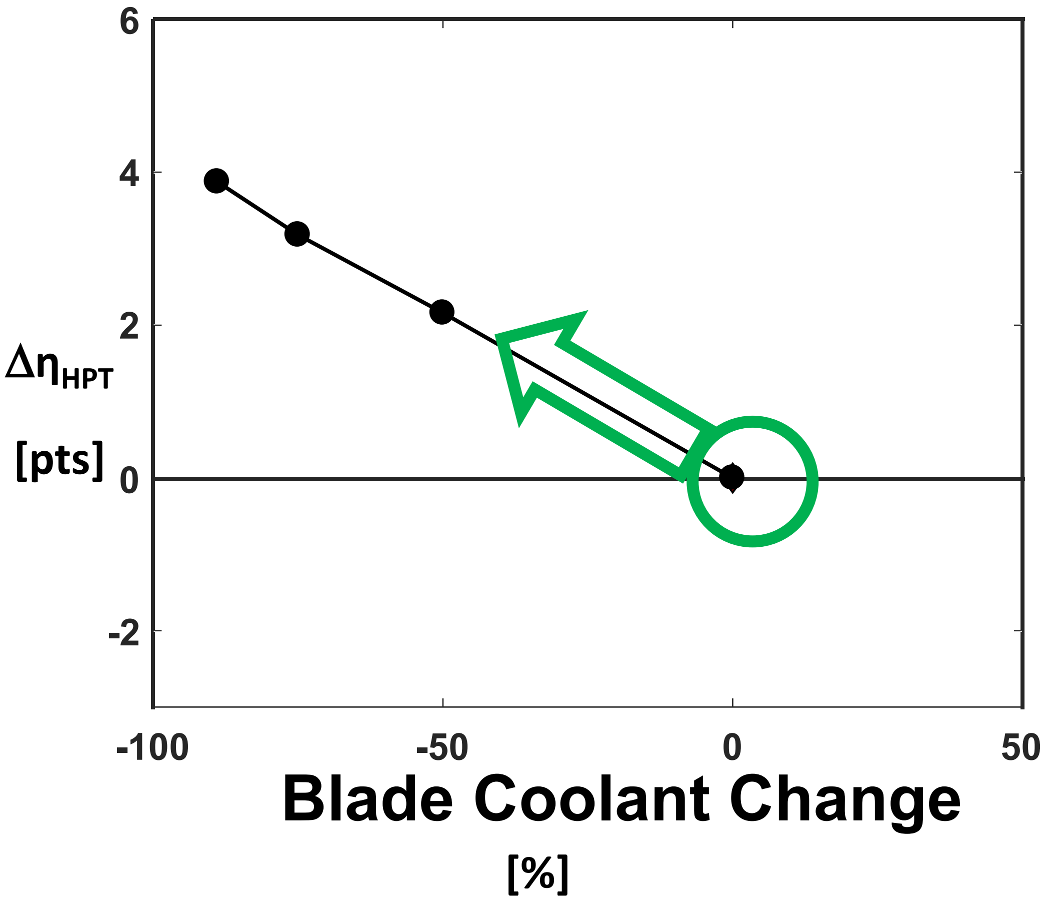


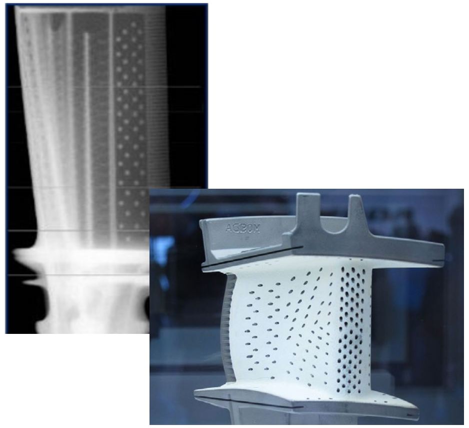
Image Credit: NASA



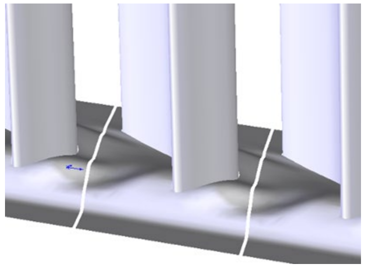
Cooling methods can be improved through optimization tools and advanced manufacturing methods



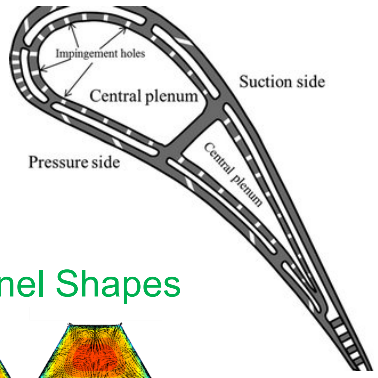
Internal and External Cooling



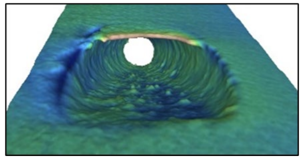
Airfoil and Endwall Shaping



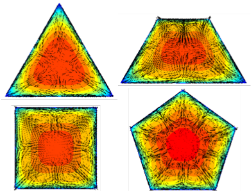
Double-Wall Cooling



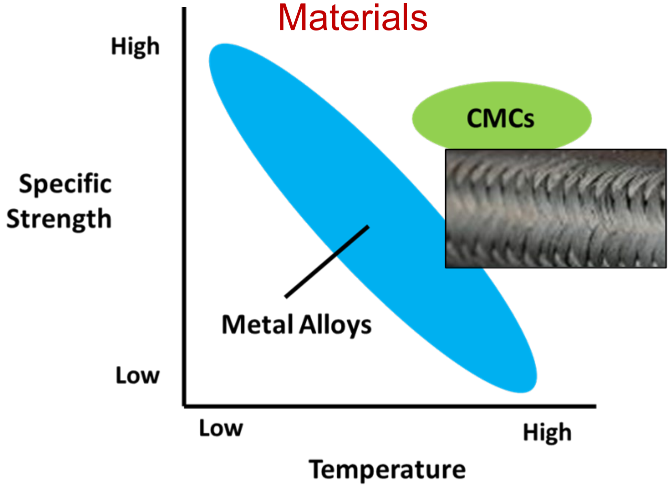
Cooling Hole Shape



Channel Shapes



High Temperature Materials



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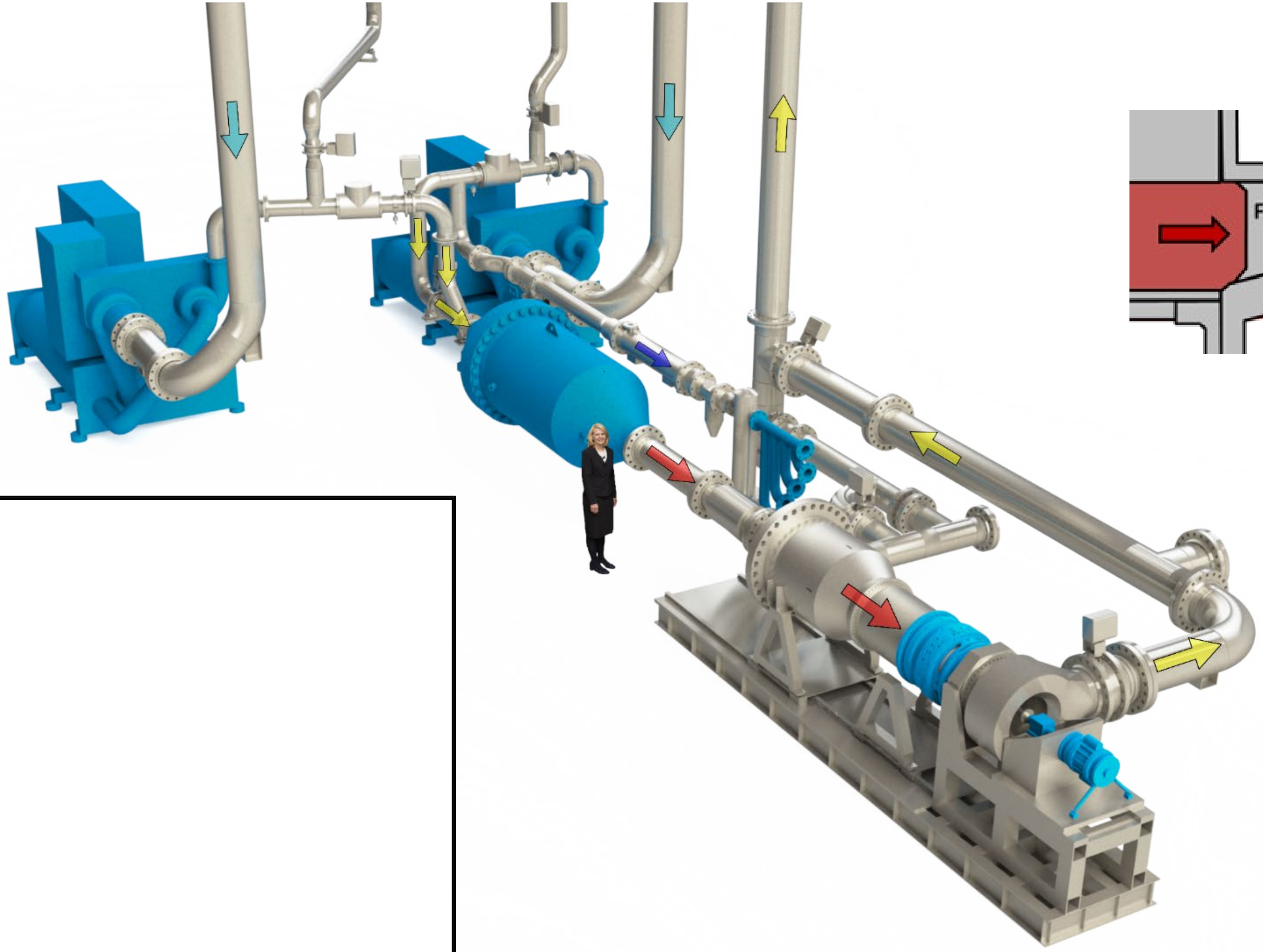
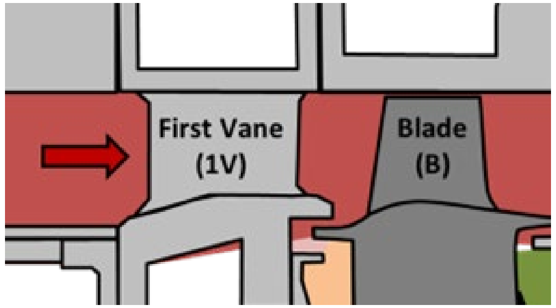
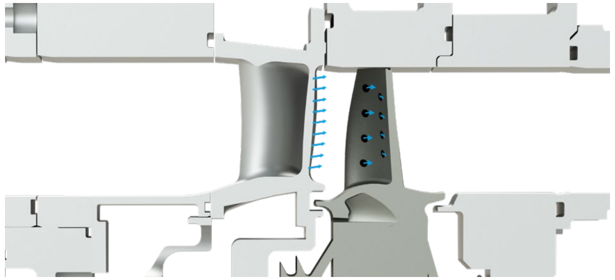
The existing test turbine in START is a single stage

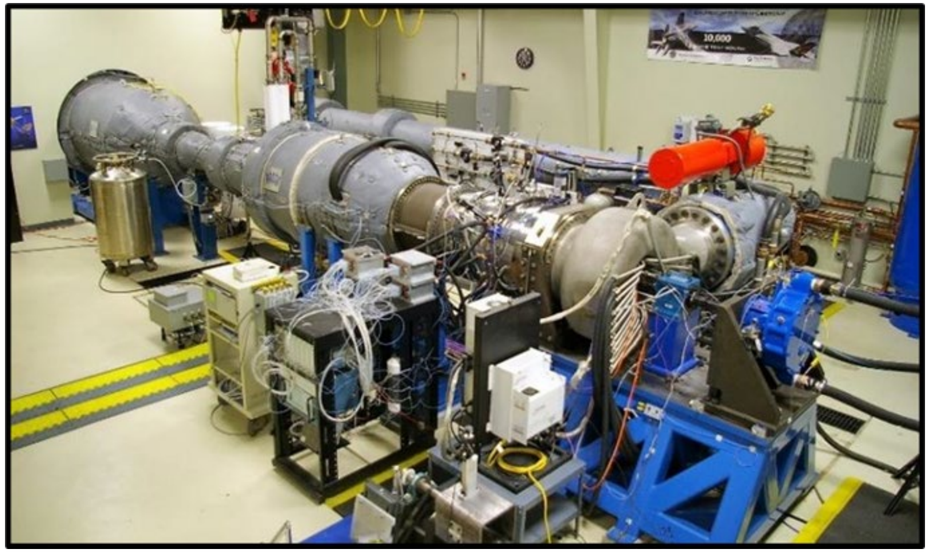




START is founded on four pillars of research

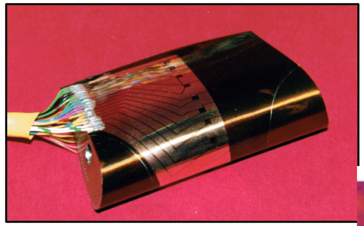
Increase turbine efficiencies and durability for propulsion and power

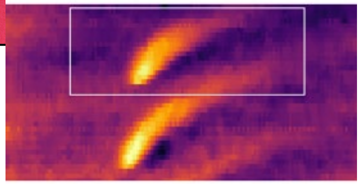




Engine hardware to generate data for a cooled turbine stage

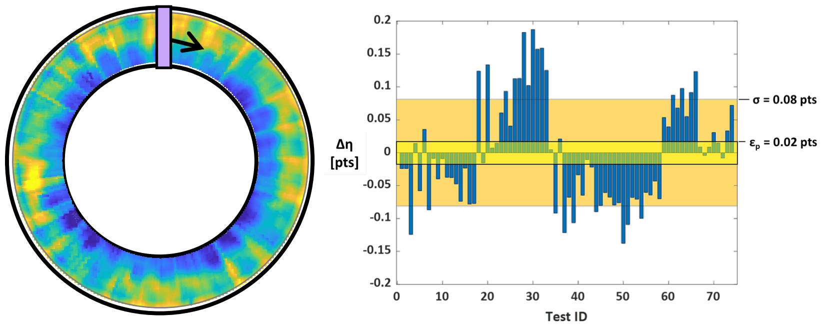
Testbed for sensor development



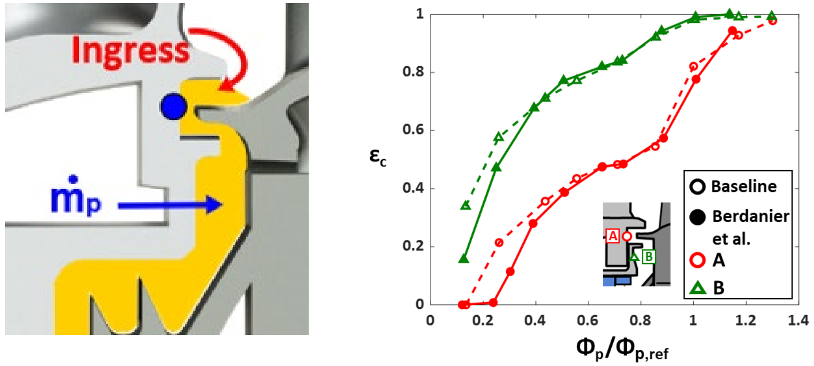


Advanced manufacturing testbed for turbine components

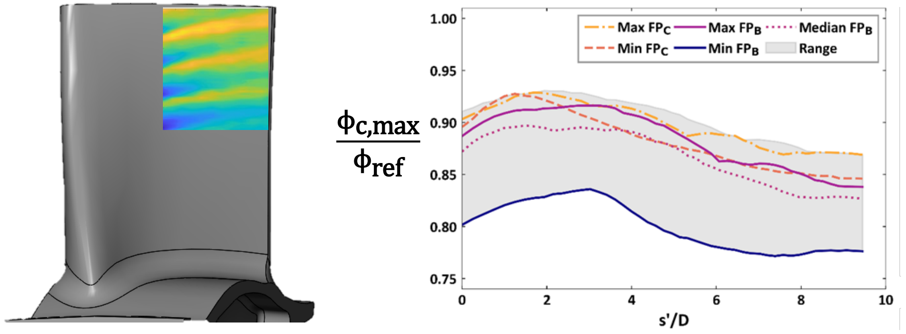
Three key measurements have been developed to set START apart



Efficiency of Cooled Turbine Stages

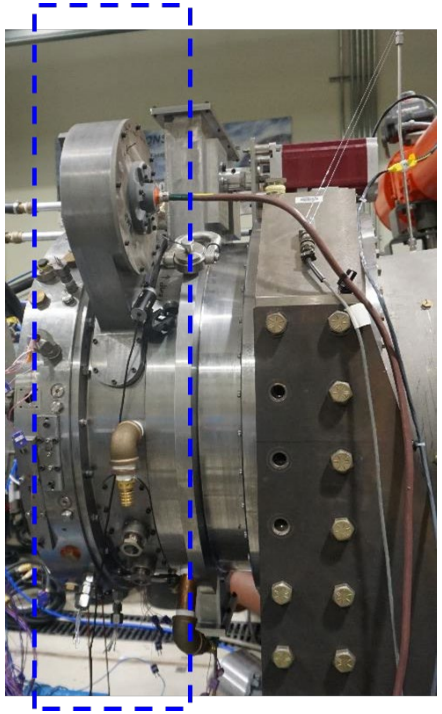


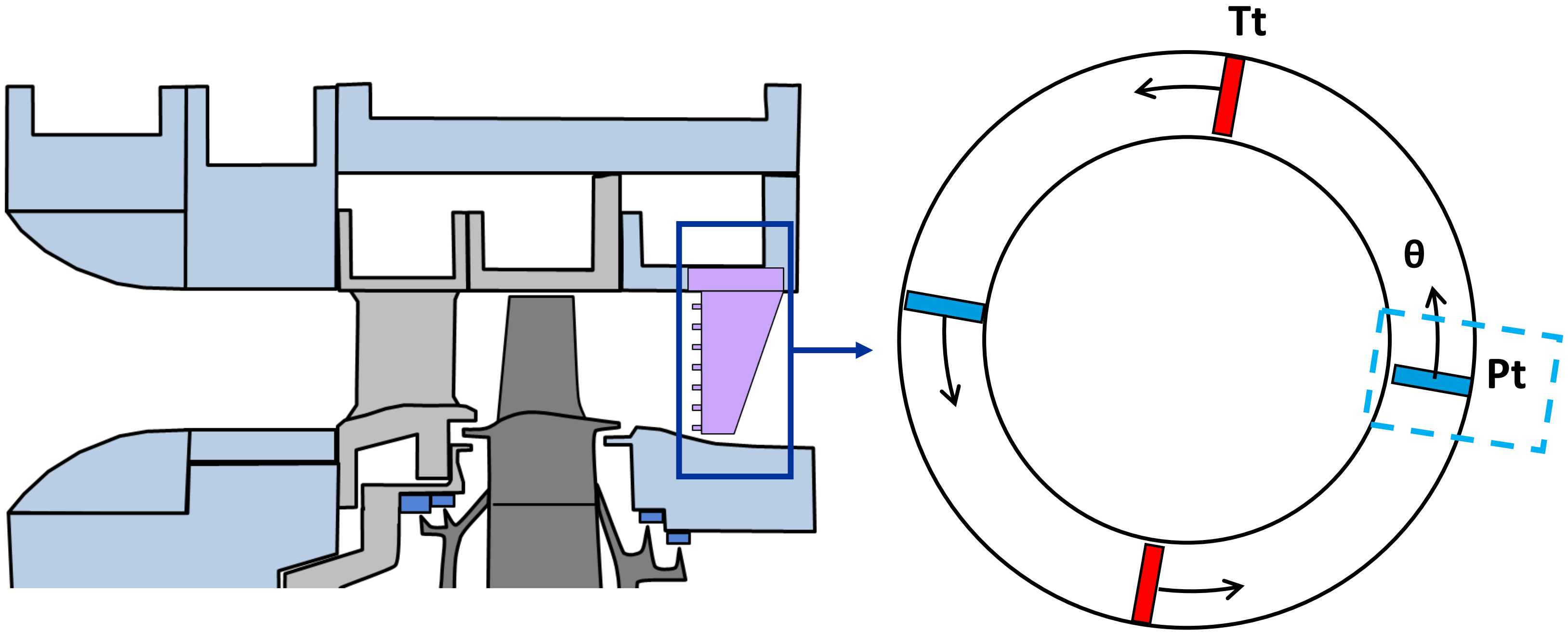
Rim Sealing Effectiveness

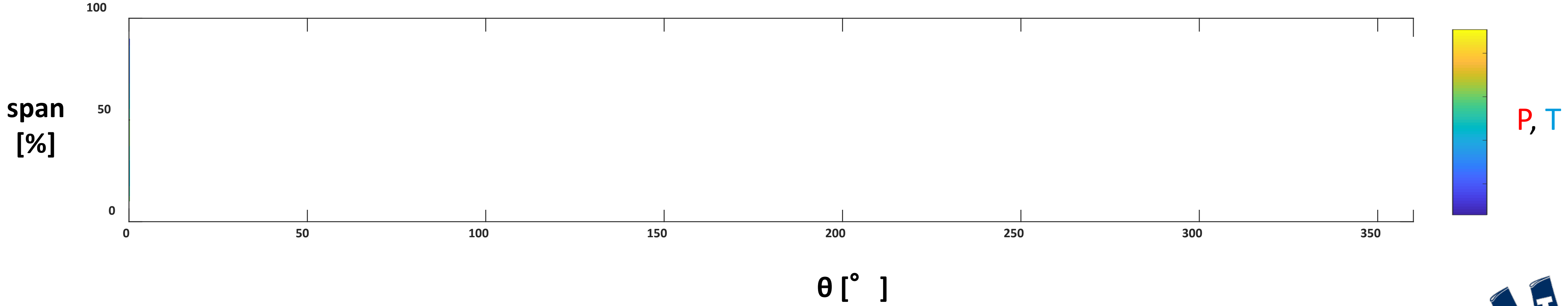


Durability

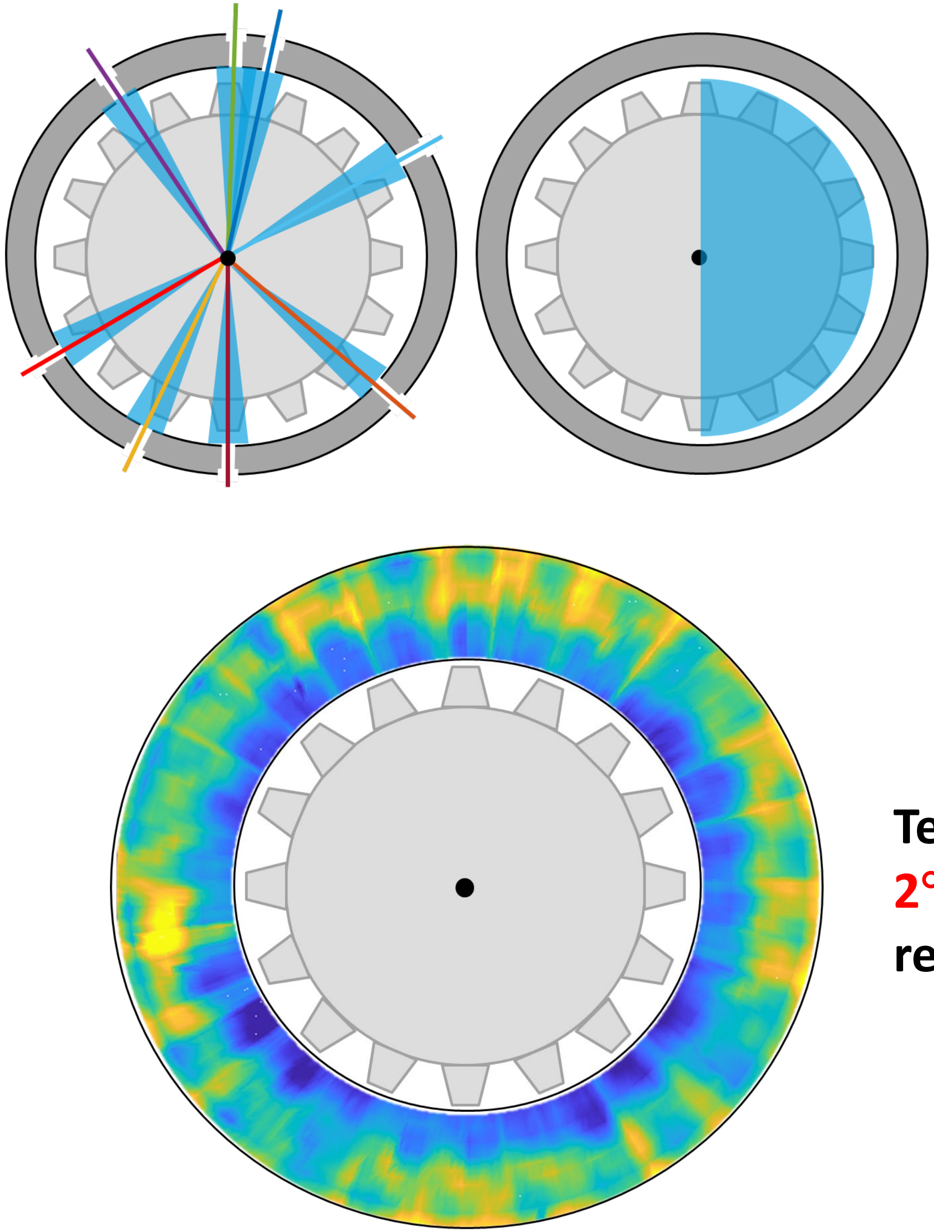
The test turbine facility includes a 360° probe traverse for full-annulus calculations of aero efficiency







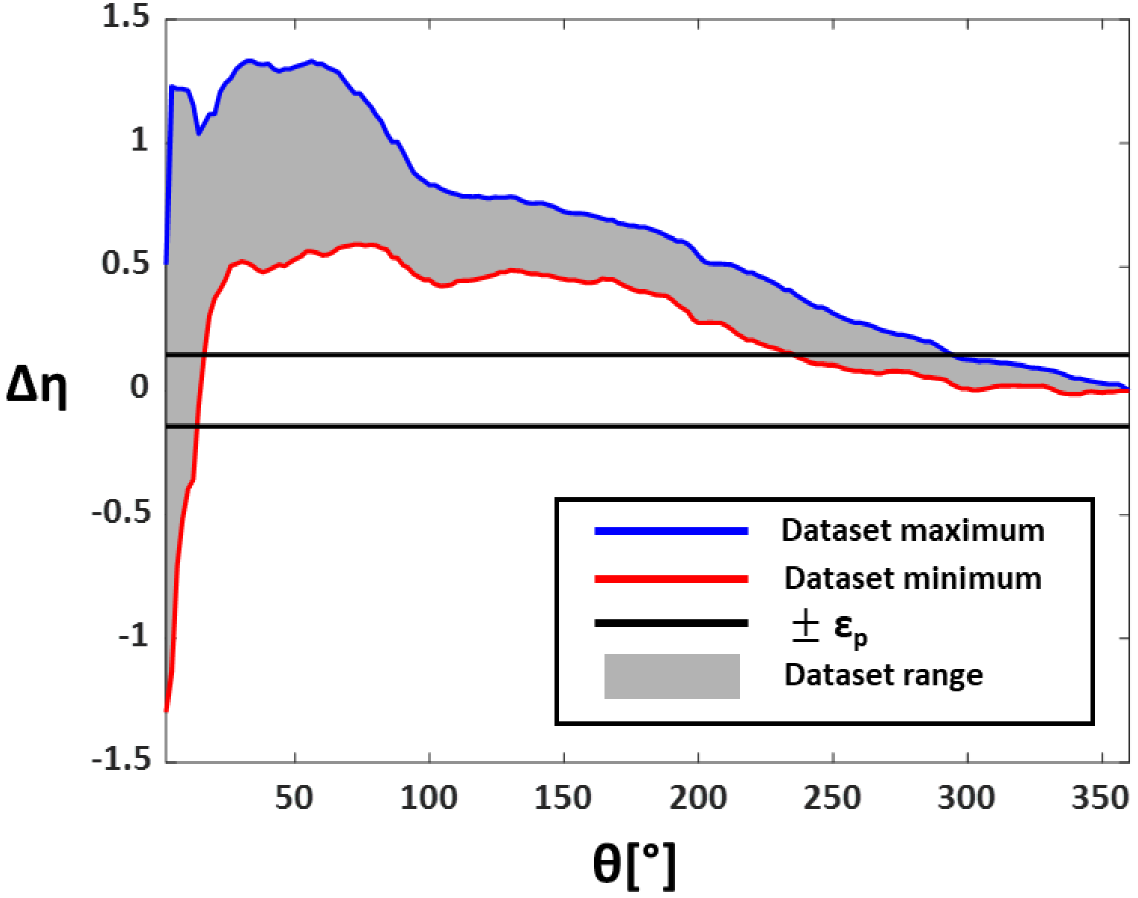
Spatial variations require full 360° measurements based to give accurate thermal efficiencies

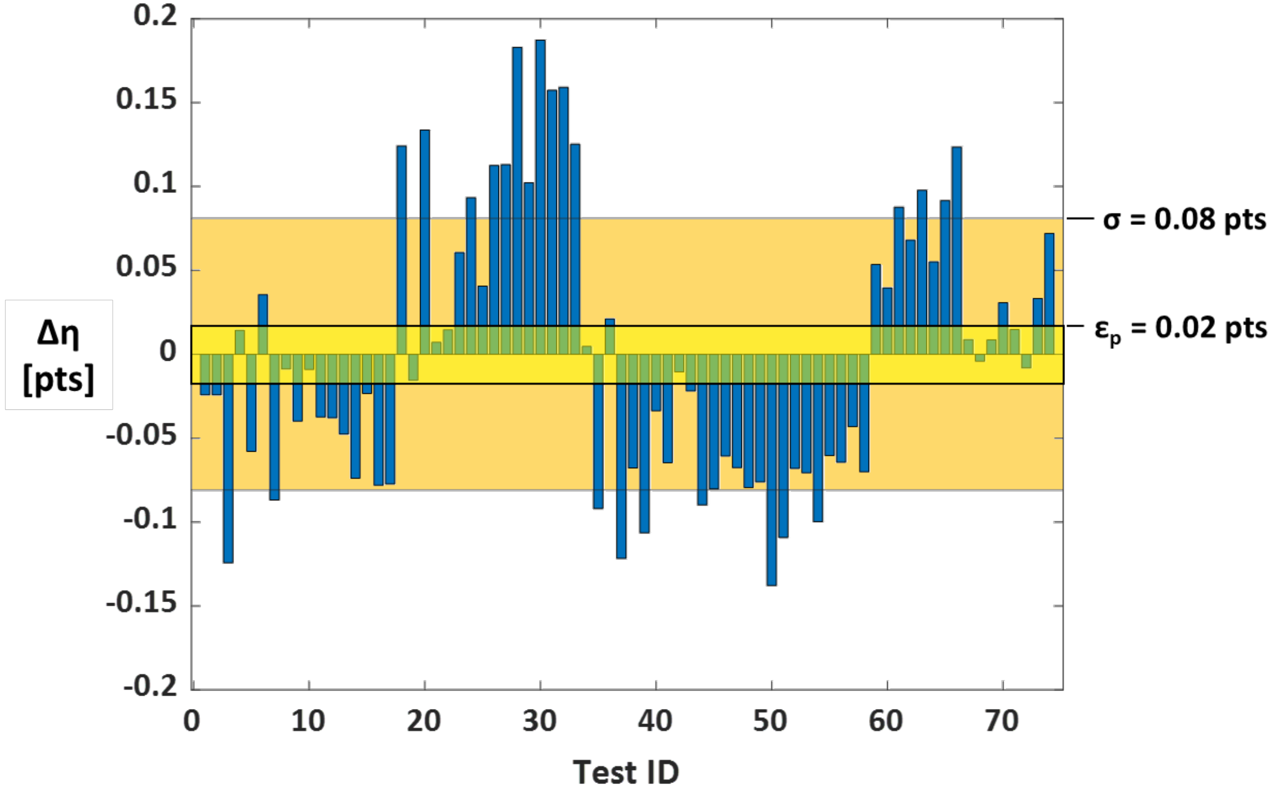


Temperature differences of only 2°F at the turbine exit plane can result in stage efficiency of > 1pt

These figures show the efficiency range as a function of sector size centered at BDC as it approaches the 360° values

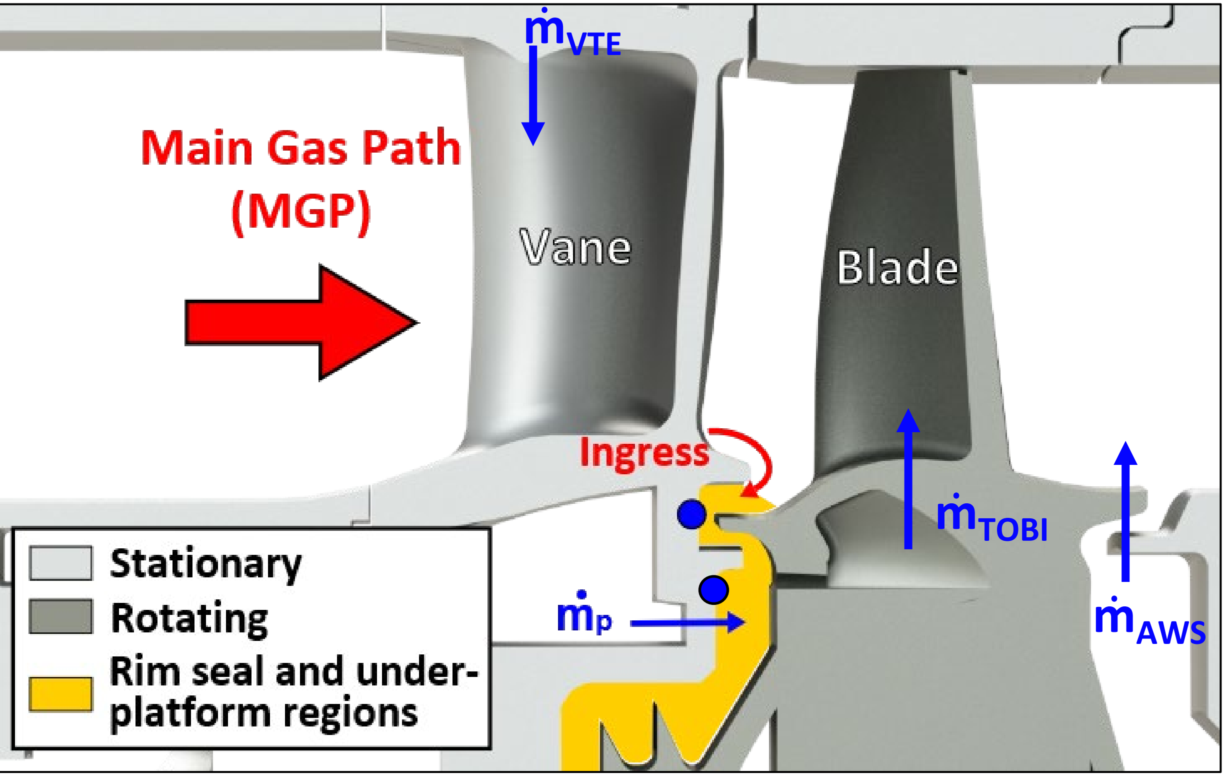
$$\Delta\eta = \eta - \eta_{360°}$$

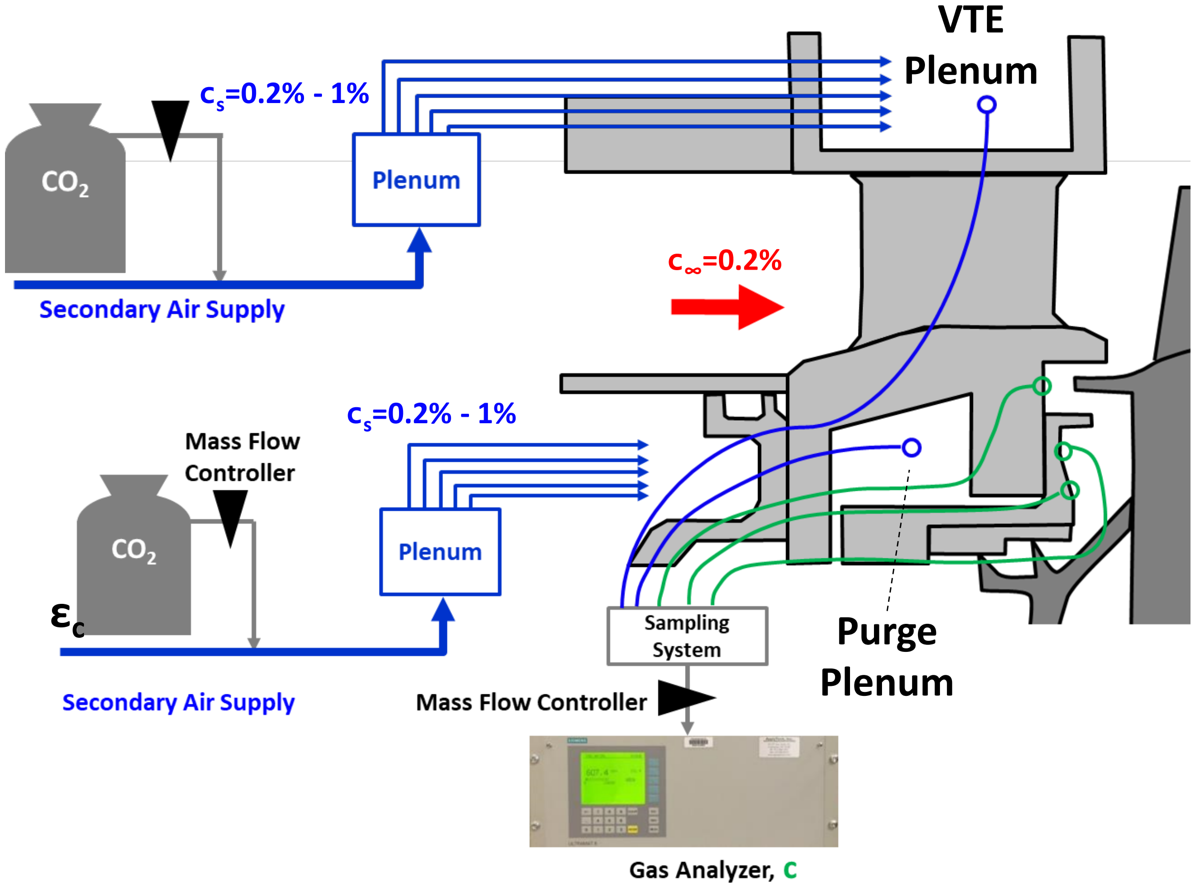




Tracer gases in several configurations are used to measure hot main gas path flow migration into the rim seal cavity

$$\varepsilon_c = \frac{c - c_\infty}{c_s - c_\infty}$$





Spatial measurements in START is presented non-dimensionally so it can be directly related to engine blade temperatures

Requirements: Matched Re, Ma, and Biot

$$\phi = \frac{T_{MGP} - T_s}{T_{MGP} - T_c}$$

START Conditions:

T_{mgp} 450° F
T_c 70 ° F

IR Blade Surface Measurements: T_s

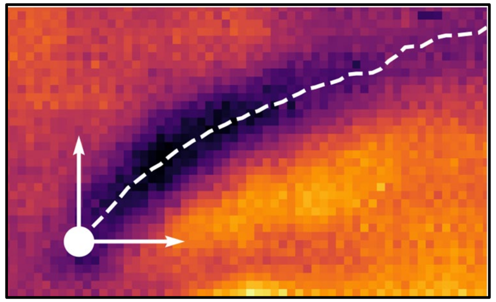
→ ϕ →

Engine Conditions:

T_{mgp} XXX° F
T_c XX ° F

Engine Blade Surface Temperatures: T_s

Feature to Entire Blade



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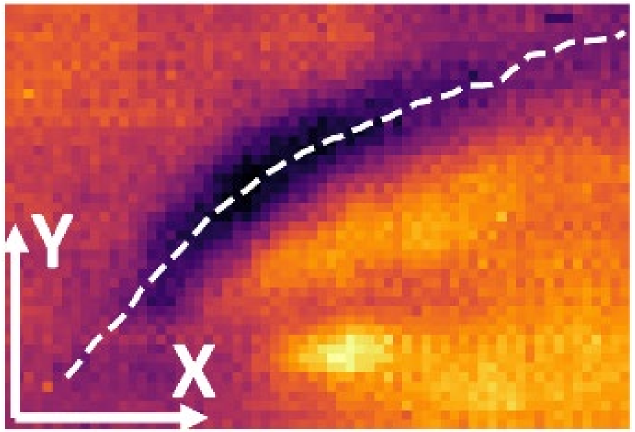
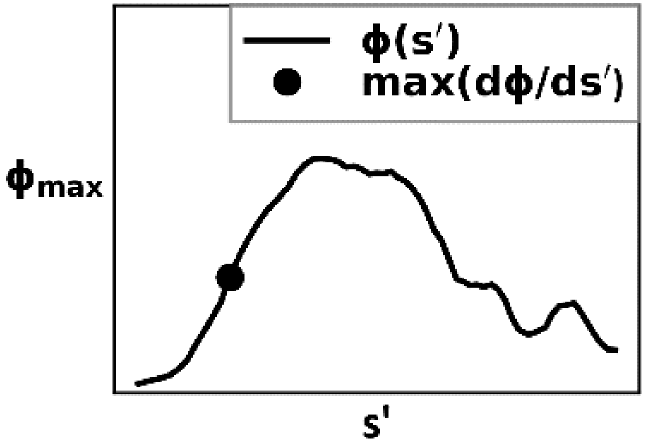
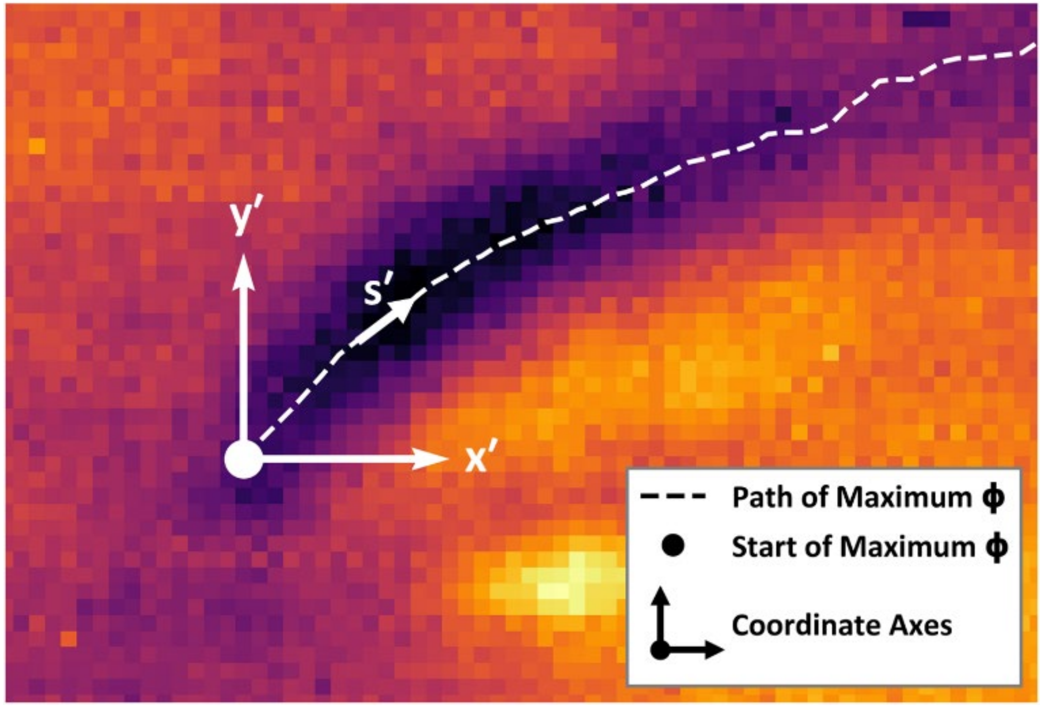
To compare effectiveness results between blades, an method was used to establish a coordinate system for each blade for a single hole



Determine path of maximum effectiveness

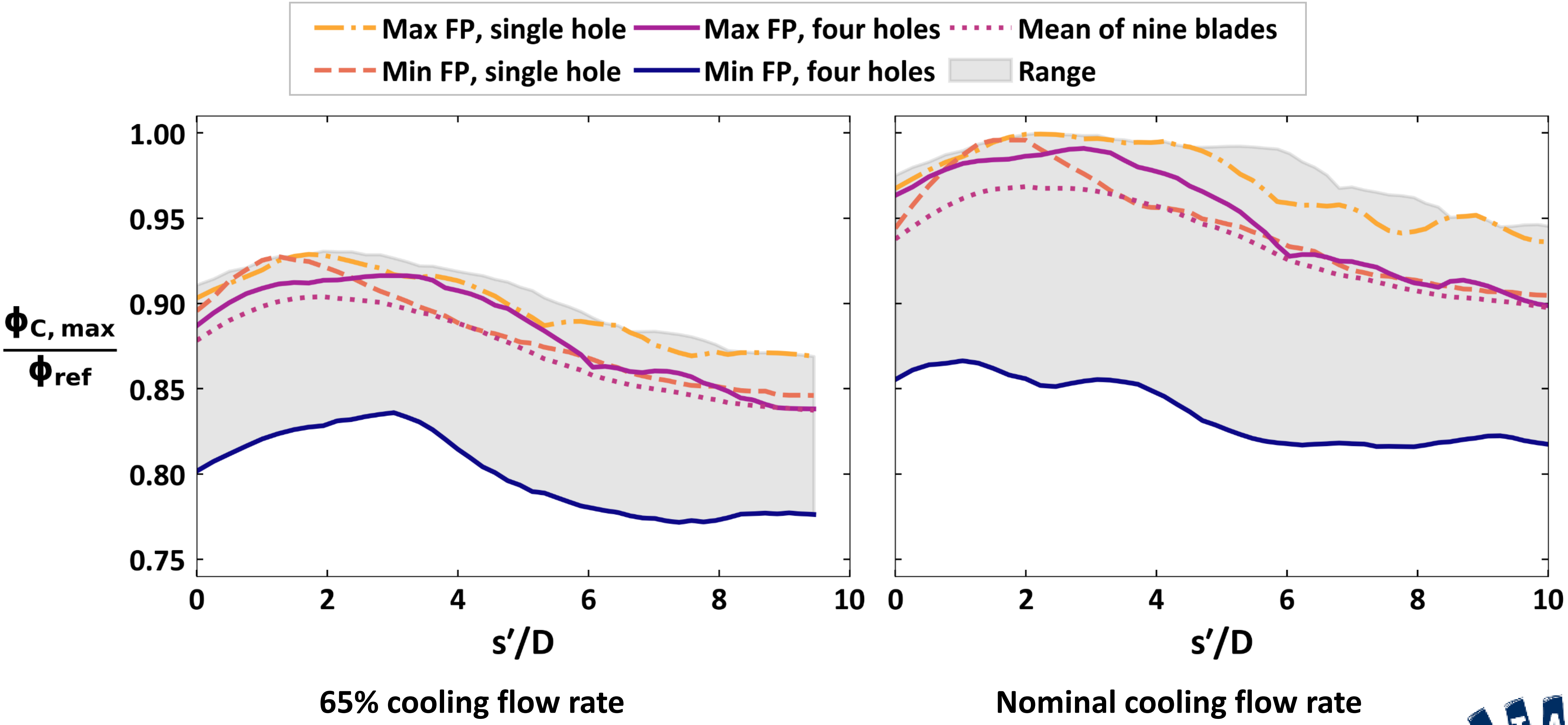


Find location of maximum slope dϕ/ds′

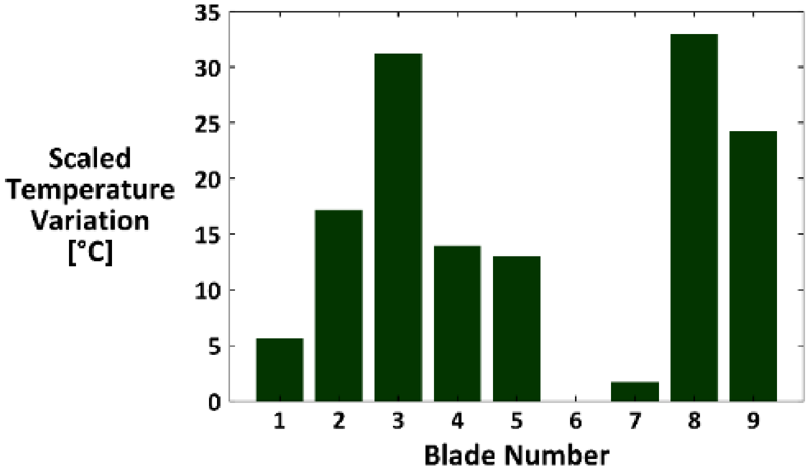


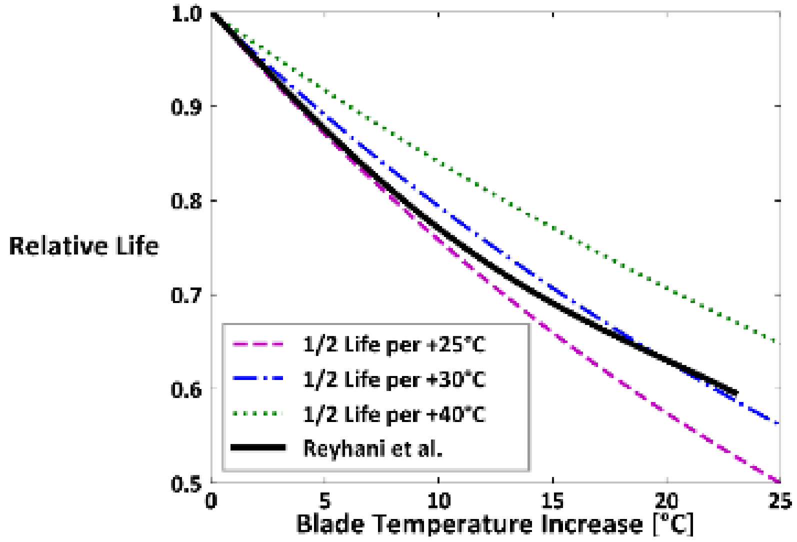
Use location of maximum slope as origin of (x′, y′) coordinates

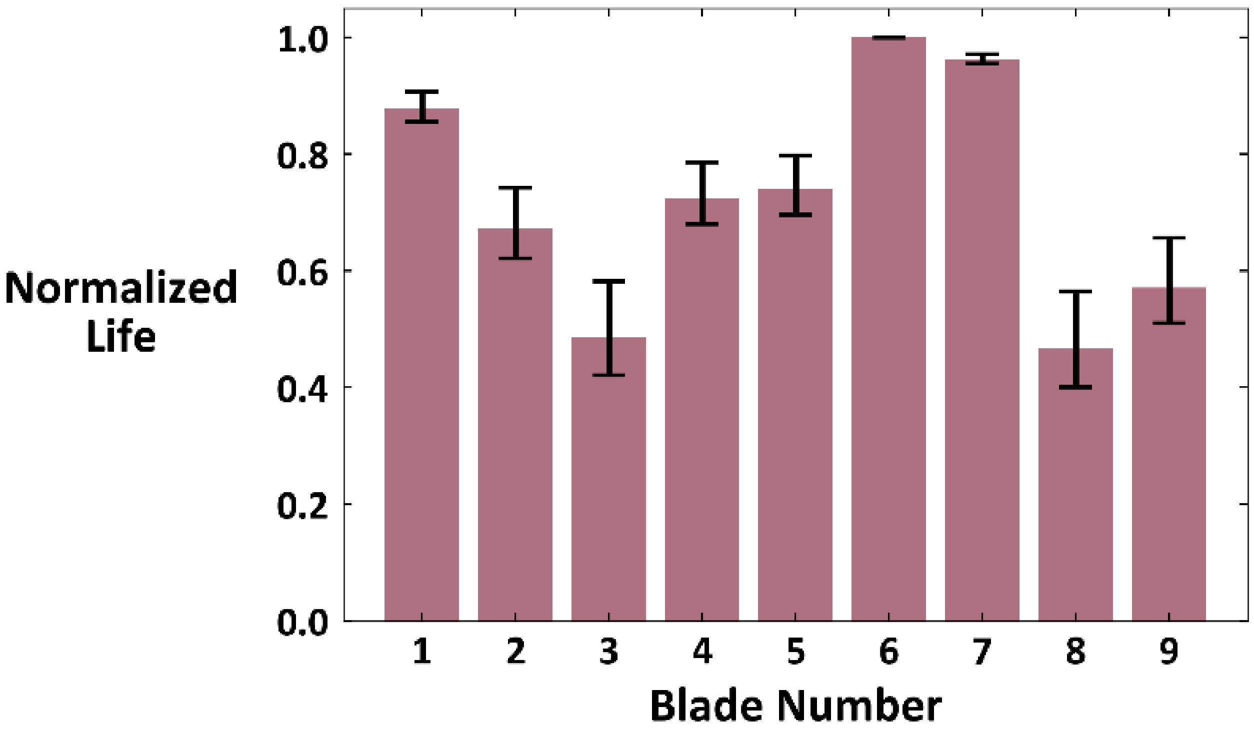
Blade-to-blade variations can exist for those operated in the field



Variations in normalized effectiveness can be scaled to engine conditions to show the expected variations in temperature and life







We have worked with DOE, FAA, and Pratt to identify research needed for an expansion of START

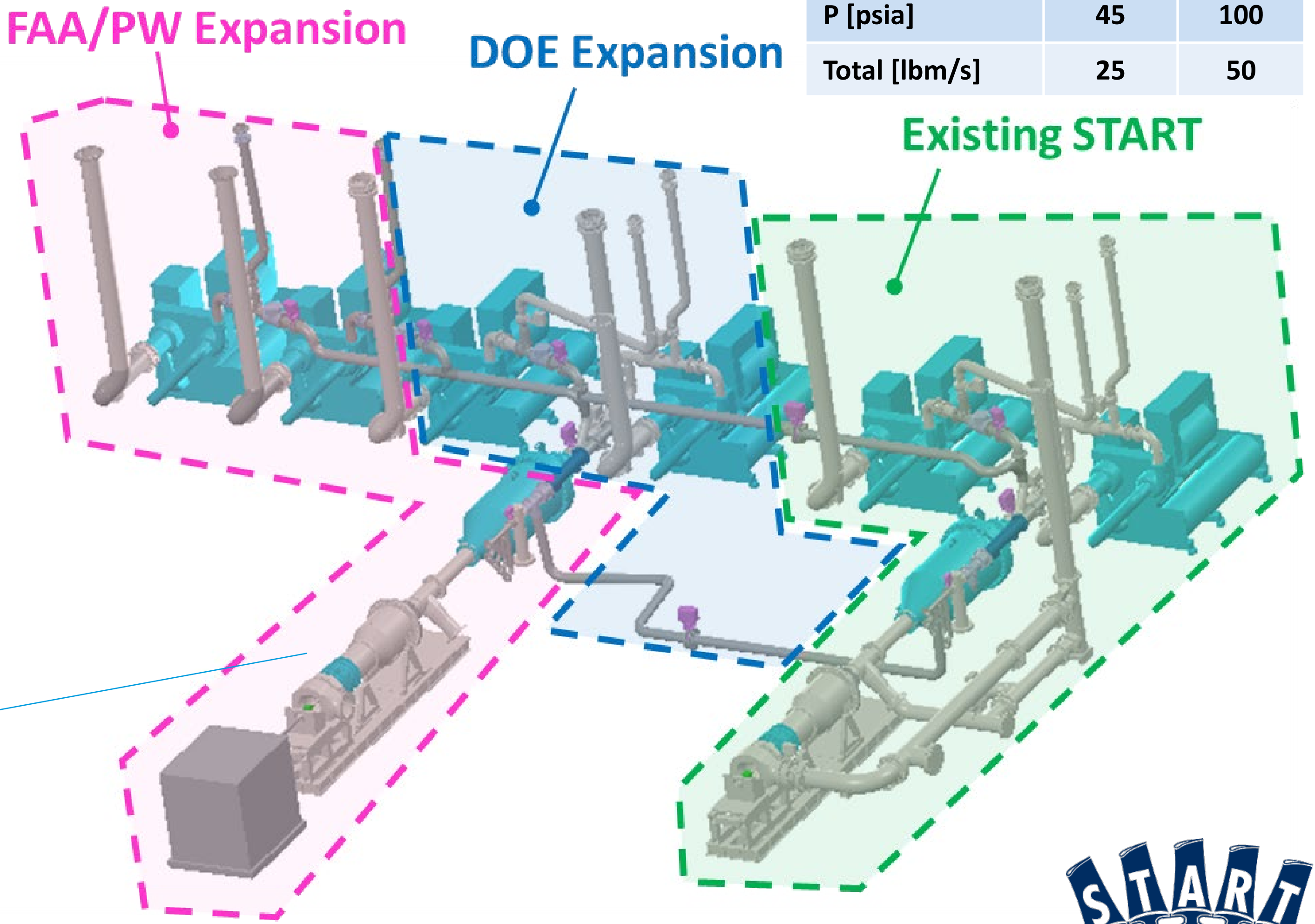
DOE Program Goals:

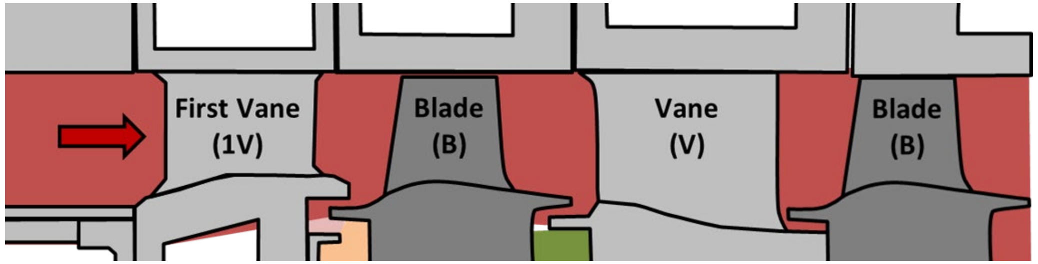
- Evaluate non-combusting profiles associated with hydrogen fuels
- Evaluate advanced materials for airfoils
  - ✓ Ceramic matrix composites

FAA Program Goals:

- Install a small core 2-stage turbine
- Evaluate impacts of working cycles
- Evaluate manufacturing impacts

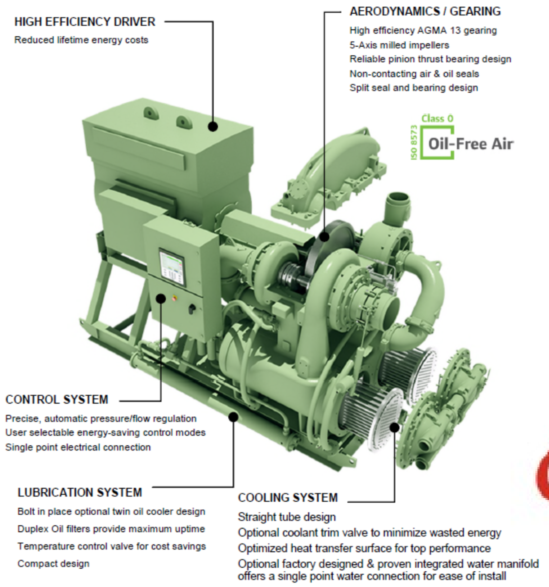
	Existing	New
P [psia]	45	100
Total [lbm/s]	25	50





The first step for START+ is to purchase the four new compressors

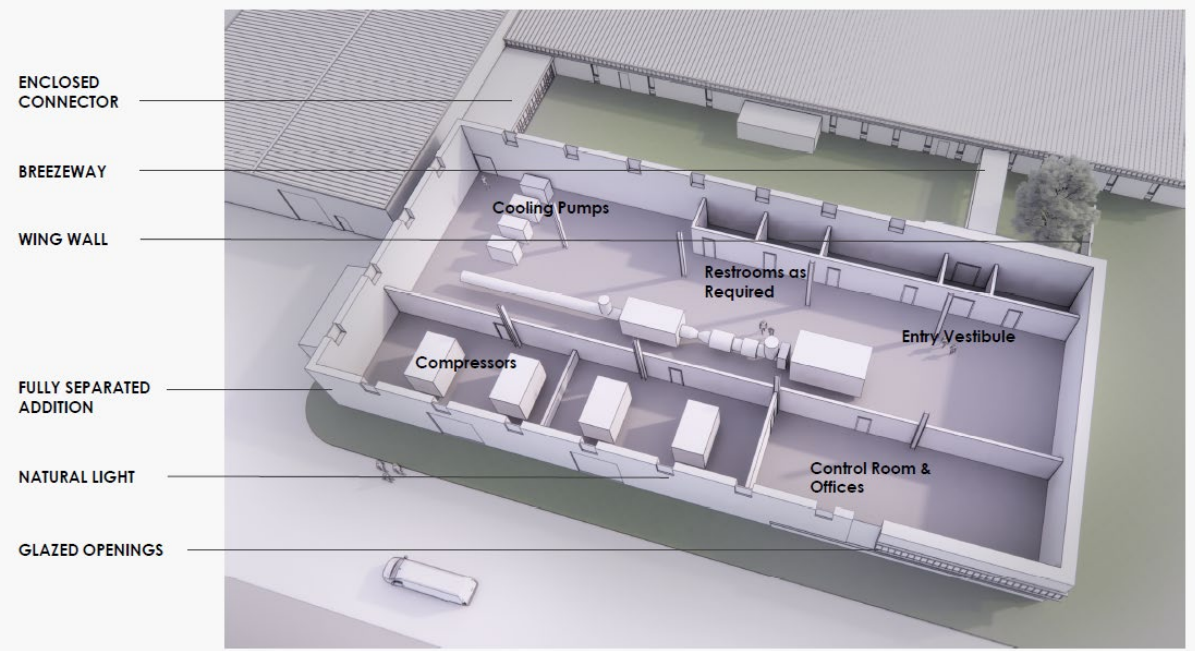
START Lab Compressor Sizing			
Parameter	Symbol, Units	Design Value	Acceptable Range of Parameter / Notes
Compressor Discharge Pressure	PSIA	100-125	Compressor vendor to provide max/min based on flow rate. We would like to achieve 125 PSIA but will accept anything over the nominal design of 100 PSIA with a safety margin.
Compressor Discharge Flow Rate	lbm/s (SCFM)	40-45 (35-40K)	Flow tolerance = +/- 5%.
Maximum Ambient Temperature	ºF	90	Compressor unit will draw air into its inlet from outdoor ambient air (summer time = 90 deg F).
Minimum Ambient Temperature	ºF	0	Compressor unit will draw air into its inlet from outdoor ambient air (winter time = 0 deg F).
Unloading Silencer	dBA	80	At three feet. Mounted on building roof.
Design Elevation	feet	1200	Outdoor local ground elevation.
Motor	V	TBD	To be determined by air compressor vendor. Available 46 kV dedicated power line on property, can be transformed down to proper motor voltage.
Motor Starter	N/A	VFD	The motor starter will be as soft as possible. Note VFD would only be used during startup, and normal running operation would include design single fixed speed.

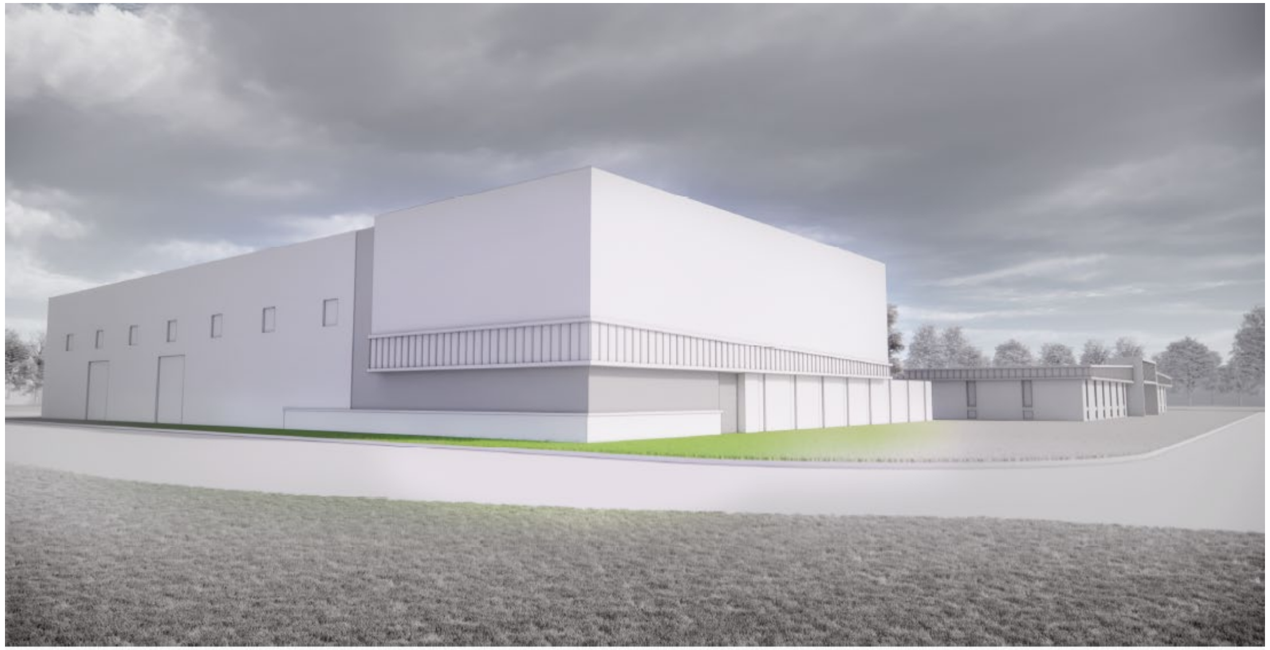


Ingersoll Rand

FS-ELLIOTT

Penn State selected a design firm after a competition of more than 20 interested companies

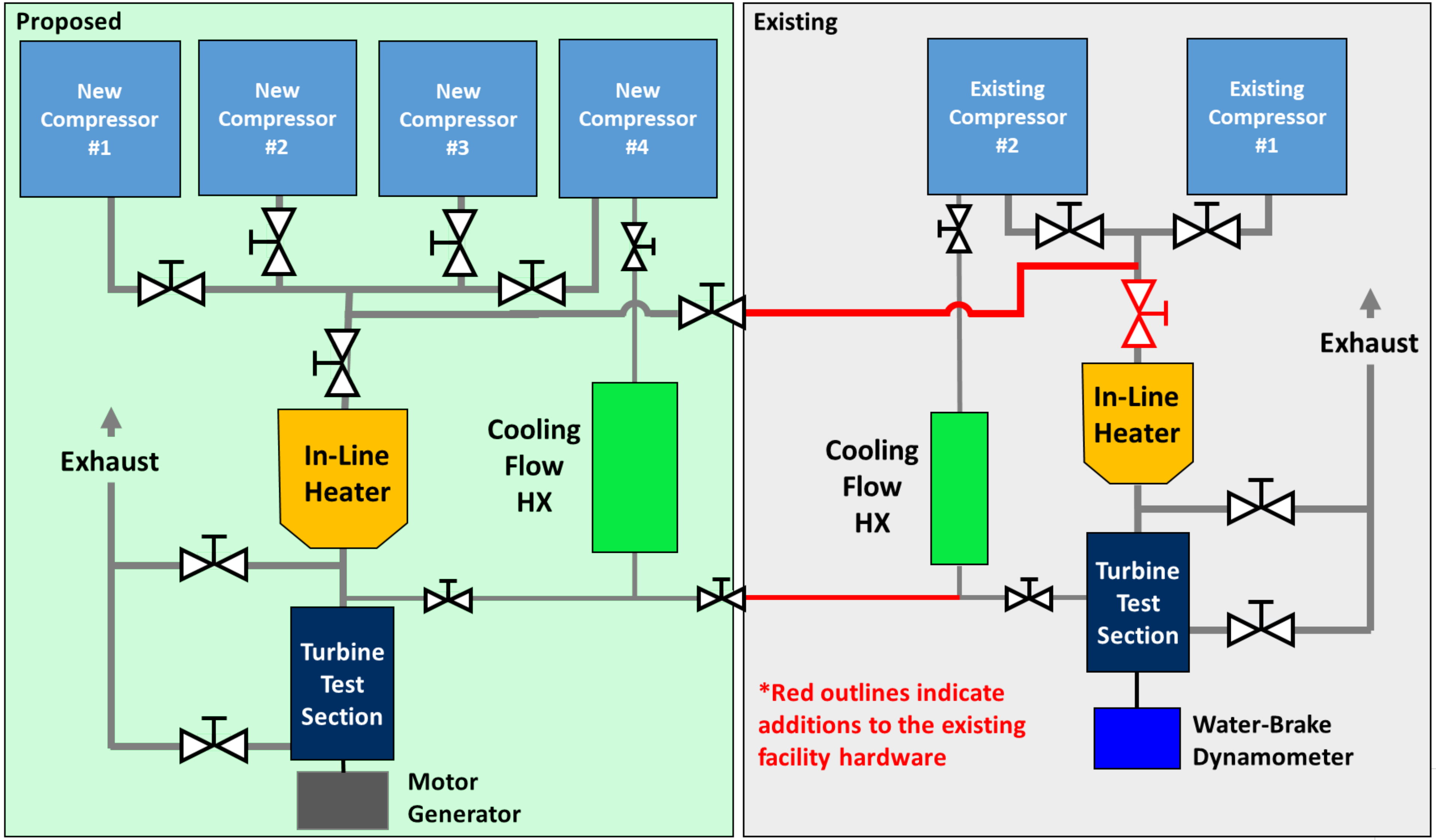




Stantec

ALEXANDER
A BUTZ FAMILY COMPANY

START enlisted the process design team of Burns and McDonnell to leverage extensive experience in gas turbine facility design



The building completion will be done by mid-2025 to allow for the ASCENT #92 rig to be operational in 2026

Year	2023				2024				2025				2026				2027			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Design Build Firm Selection	■	■																		
Mechanical / Electrical Design		■	■	■	■	■														
Permit Submittal and Review			■	■	■	■														
Building Construction						■	■	■	■	■										
Long Lead Item Procurement (Transformer First)			■	■	■	■	■	■												
Rig Mechanical and Electrical Installation									■	■	■	■	■	■						
Start Up and Commissioning														■	■	■	■			
Testing of Turbine Rig																	■	■	■	■

Project Risks and Mitigations:

1. Risk: Electrical grid updates
   Mitigation: Already engaging electrical utility with an ongoing study

2. Risk: Supply chain issues continue to plague the industry
   Mitigation: Continue to increase number of suppliers

3. Risk: Manufacturing challenges on turbine components
   Mitigation: Continue to advance manufacturing methods