Leveraging Additive Manufacturing and Coatings for Turbine Thermal Management

Matthew Searle
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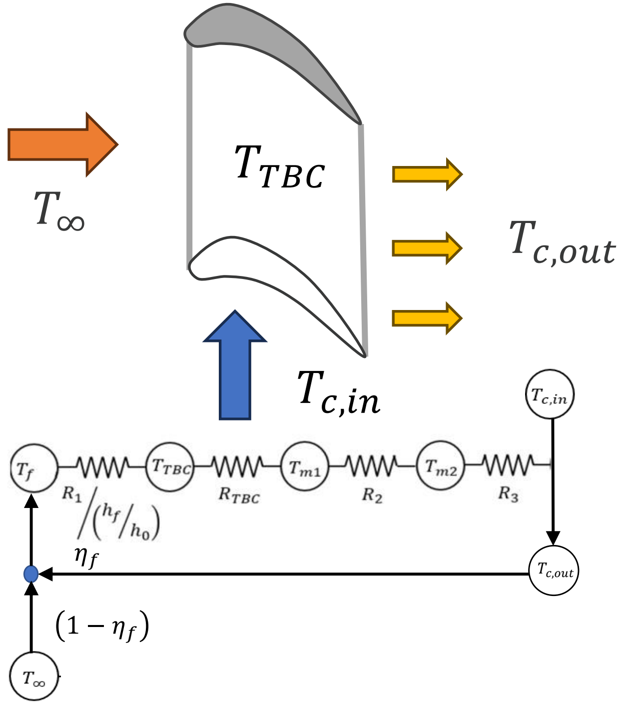

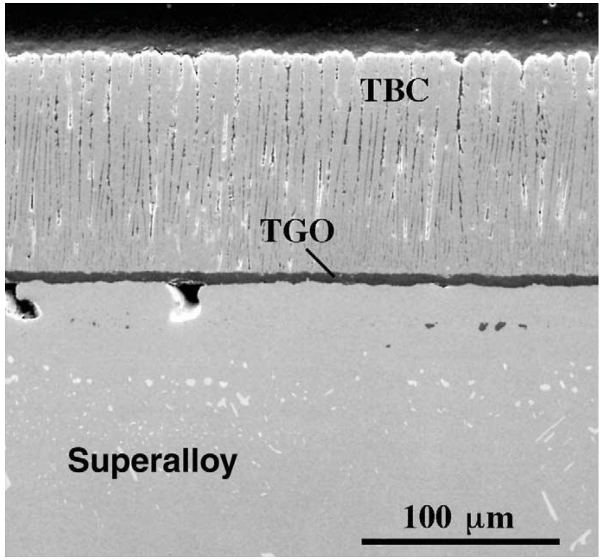

Clarke and Phillpot, 2005

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University Turbine Systems Research and Advanced Turbines Program Review
Sept. 24, 2024

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Outline

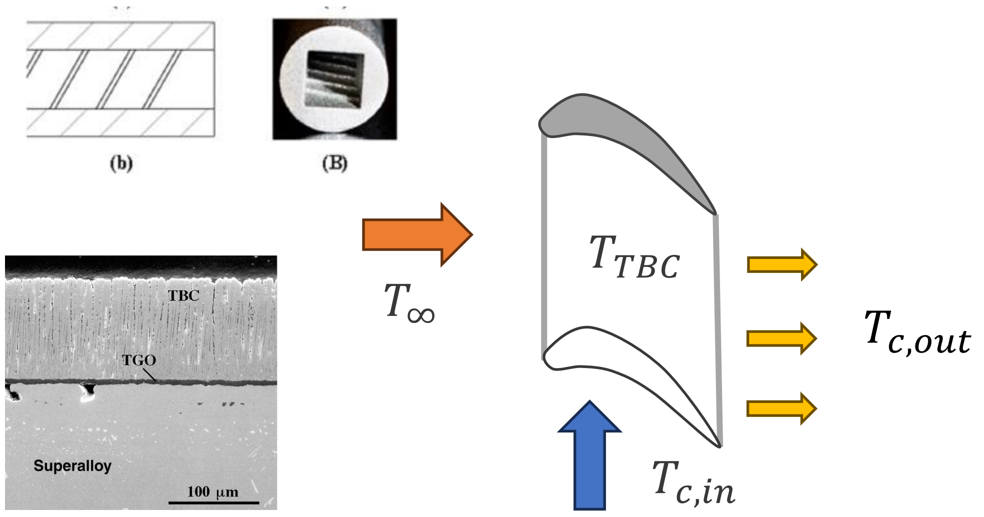
sCO_2 Field Work Proposal (FWP) Task 2

- Background
- Cooling model for direct supercritical carbon dioxide (sCO_2) turbines
- Performance of thermal barrier coating in flowing sCO_2

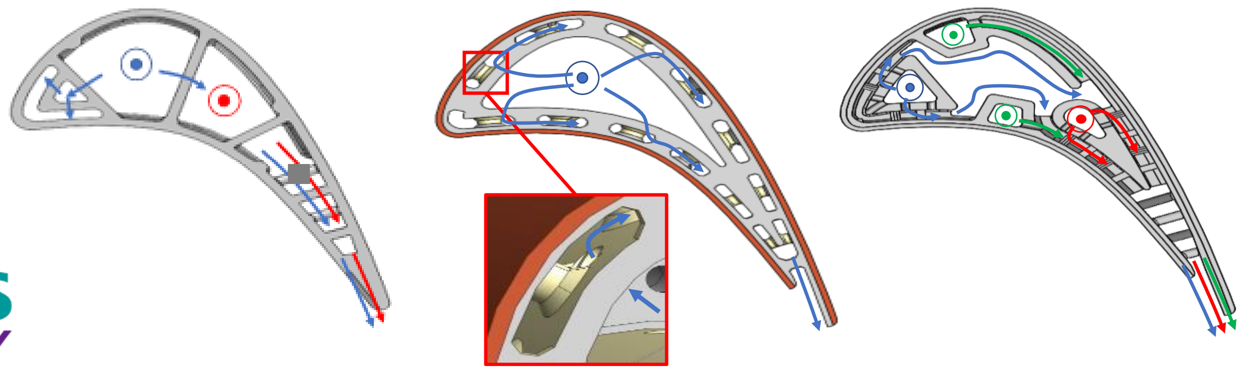
Turbines Multi-Year Research Plan (MYRP) Goal 4

- Background
- Design of additively manufactured (AM) cascade airfoils
- Test of AM cascade airfoils

Summary/Conclusions



Clarke and Phillpot, 2005



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NExT PENN STATE ExCCL SIEMENS energy

sCO$_2$ FWP Heat Transfer (Task 2)

Background

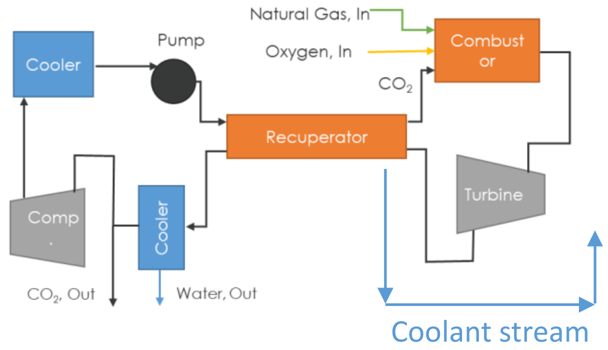
Objective

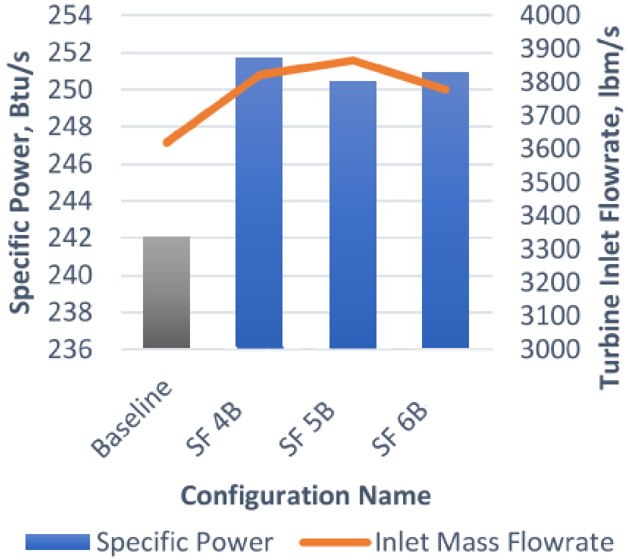
- Advance understanding of sCO$_2$ heat transfer for net-zero power cycles
- Design and test novel concepts for cycle and turbomachinery components

Benefits

- **Increased efficiency**
  - Up to 3% pt increase (Uysal et al., 2022)*
  - Reduced sequestration requirements (fossil fuel systems)
- **Decreased payback period**

* Optimal sourcing of coolant contributes to performance improvement



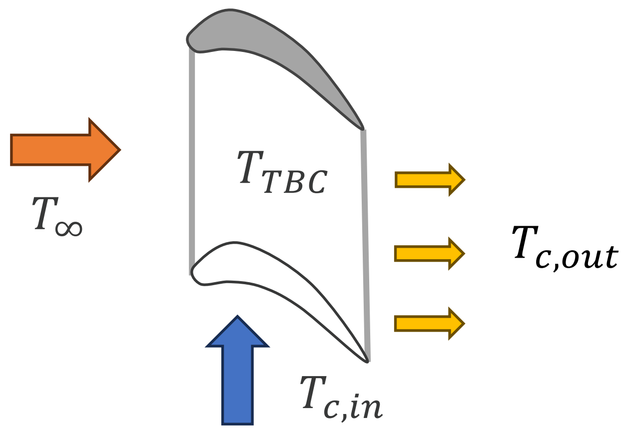


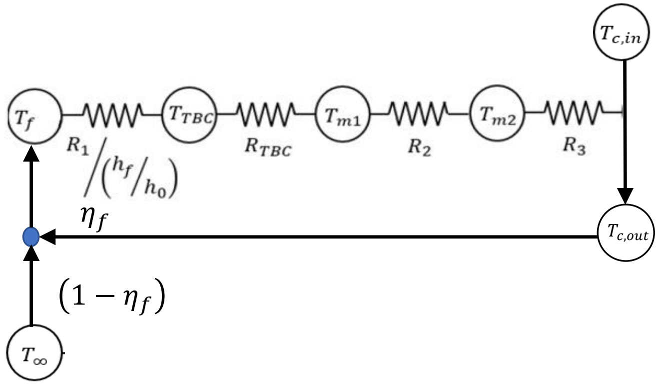
Single Flow Turbine (SF)
4B and 6B: Two high-temperature recuperator (HTR) streams
5B: One HTR stream and one inlet HTR stream

Uysal et al., 2022

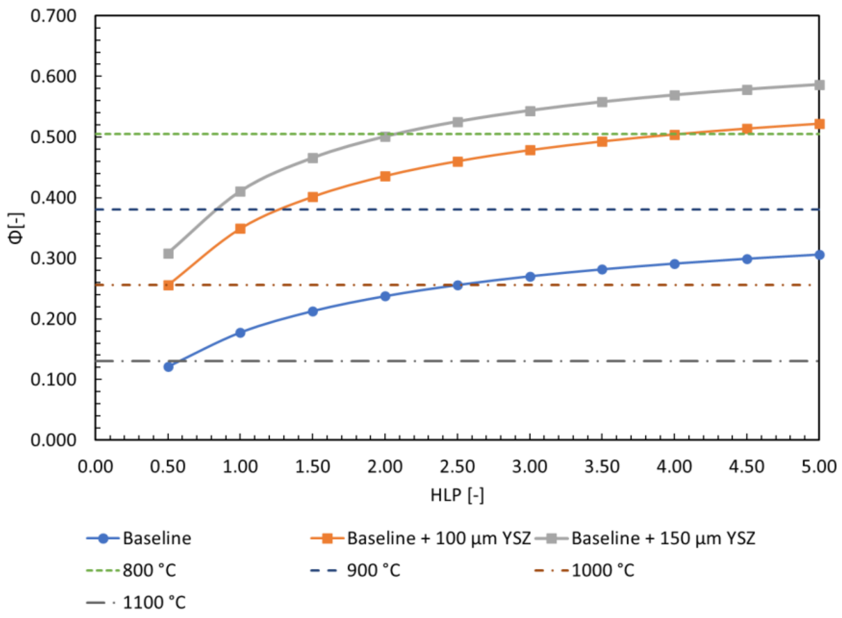
sCO_2 FWP Heat Transfer

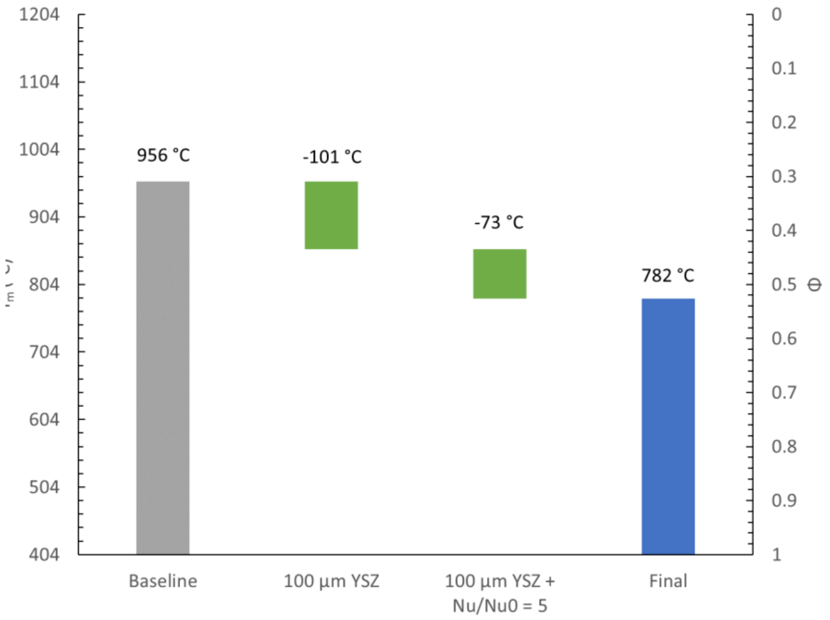
Direct sCO_2 Cooling Model





$$\phi = \frac{T_\infty - T_{m1}}{T_\infty - T_{c,in}} \qquad HLP = \dot{m}_{cool} c_p R_1$$





Searle et al., 2024 (all figures)

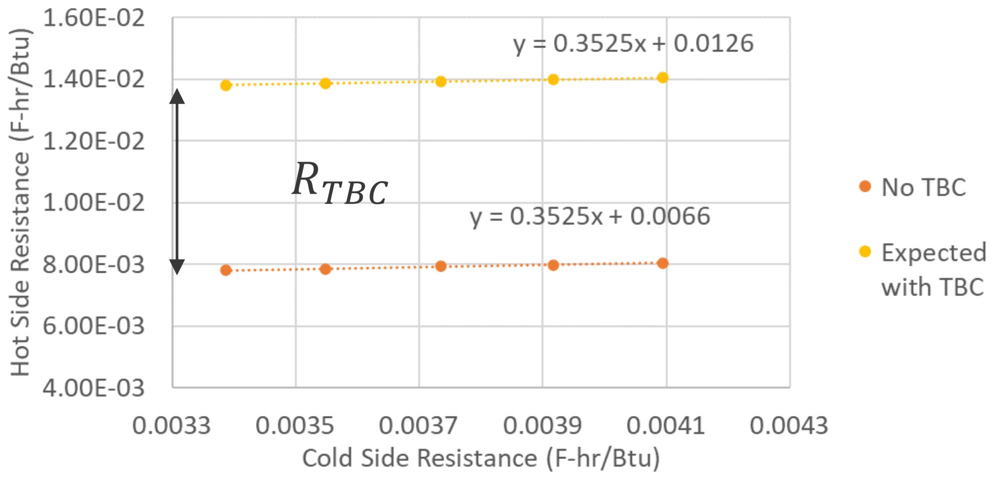
- Screened internal cooling (Nu/Nu_0 up to 10), thermal barrier coating (up to 150 µm), and film cooling (up to $\eta_f = 0.2$)
- Advanced internal cooling (Nu/Nu_0= 5) results in a 31% increase in ϕ
- Applying a durable thermal barrier coating (100 µm yttria-stabilized zirconia(YSZ)) yields an 83% increase
- Current research should advance thermal barrier coating and internal heat transfer enhancement

sCO_2 Turbine Cooling

Thermal Barrier Coating Test

- Measure thermal barrier coating (TBC) resistance in-situ
- Use Wilson plot technique
- Explore performance of "as received" and aged TBC

Test Articles	Description
1	No TBC
2	"As received" TBC
3	Aged TBC



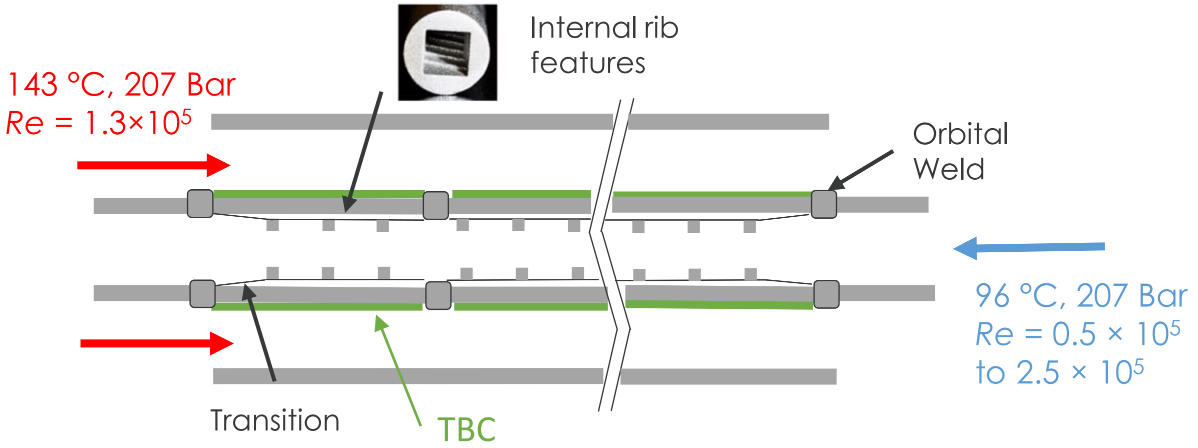
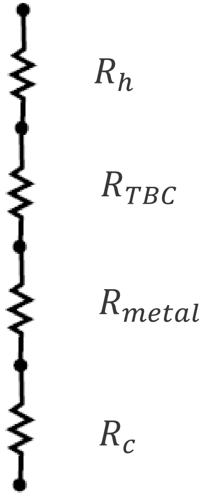
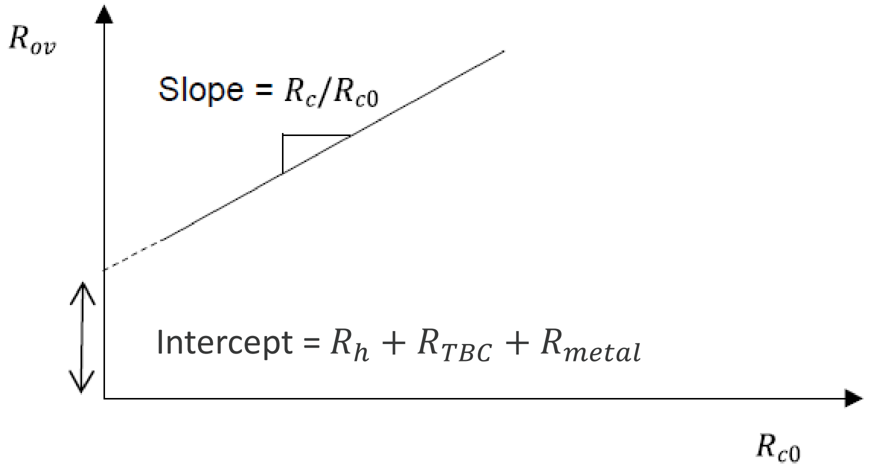


Figure not to scale.





Turbines MYRP Small Turbines (Goal 4)

Background

Objective

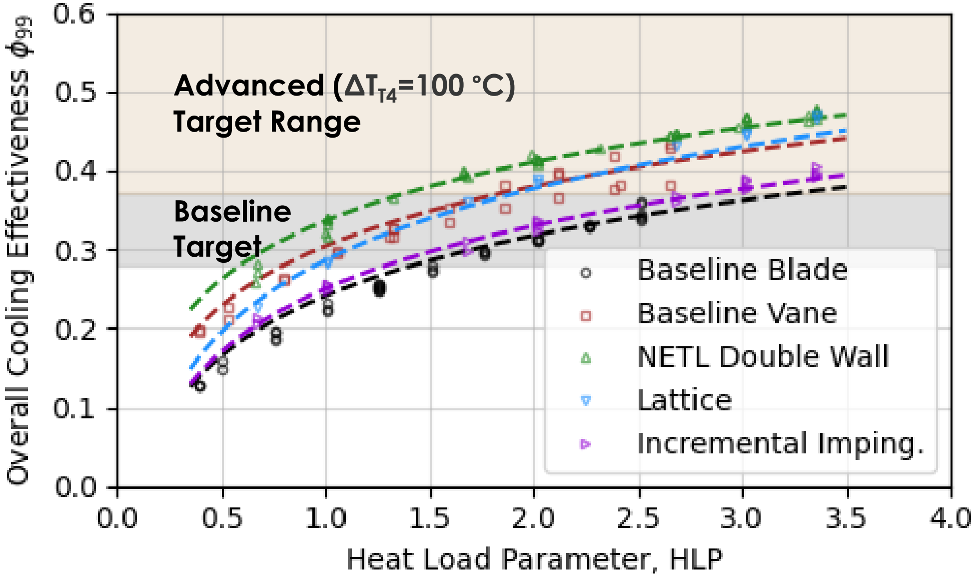
Improve efficiency and emissions of small-scale turbines and combined heat and power (CHP) systems to reduce impact of industry on disadvantaged communities

Approach

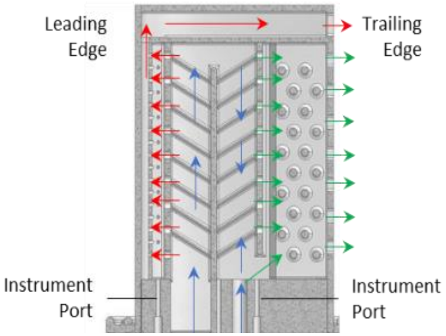
Utilize advanced materials, AM, and advanced cooling designs to increase firing temperature by 100 °C

Benefits

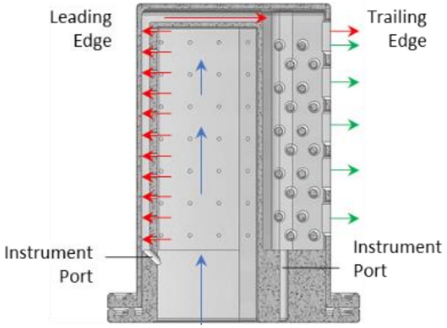
- Reduce payback period for CHP plants
- Reduce sequestered CO_2 and fuel consumption



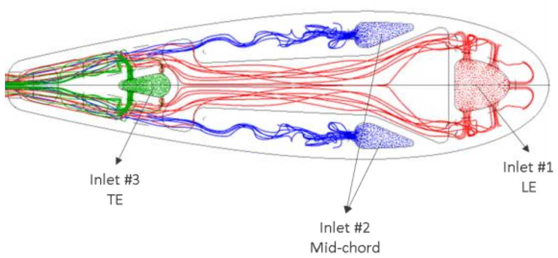
1) Blade (baseline)



2) Vane (baseline)



3) NETL Double Wall



4) Incremental Impingement

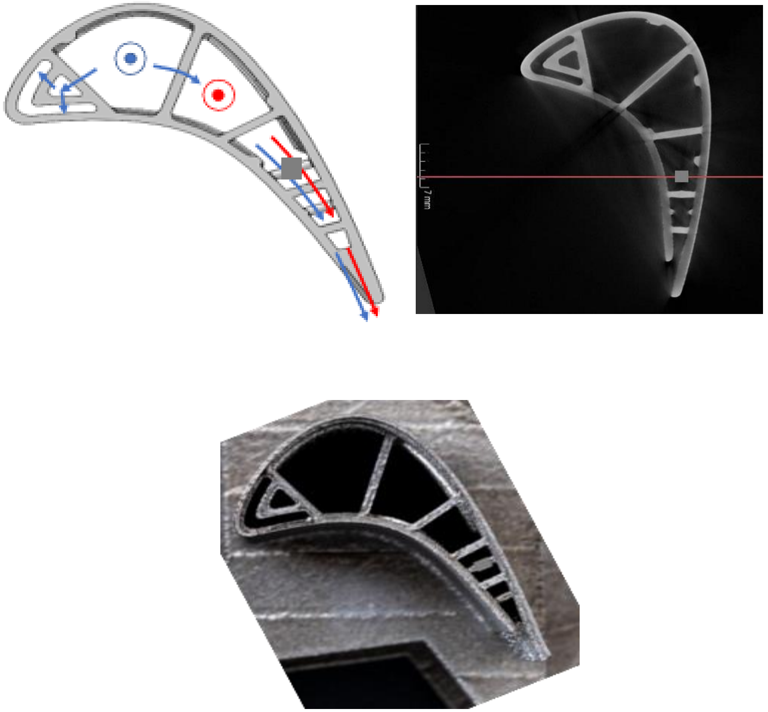
Straub et al., 2023 (all figures)

Turbines MYRP Small Turbines

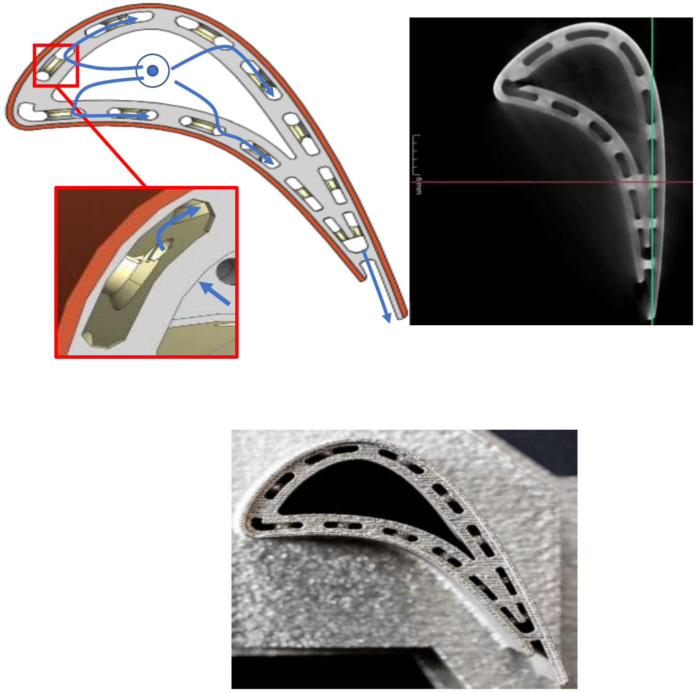
Design and Manufacture of High-Speed Cascade Test Airfoils

- Integrate symmetric designs in National Experimental Turbine (NExT) profile
- Conduct numerical modeling to understand performance
- Develop design for AM guidelines

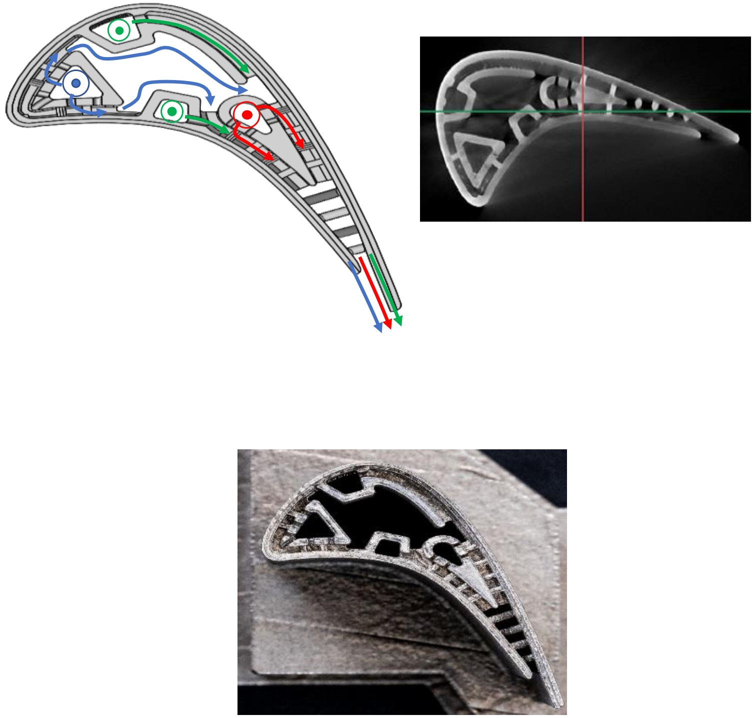
Baseline Blade



Incremental Impingement



Double Wall



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Turbines MYRP Small Turbines

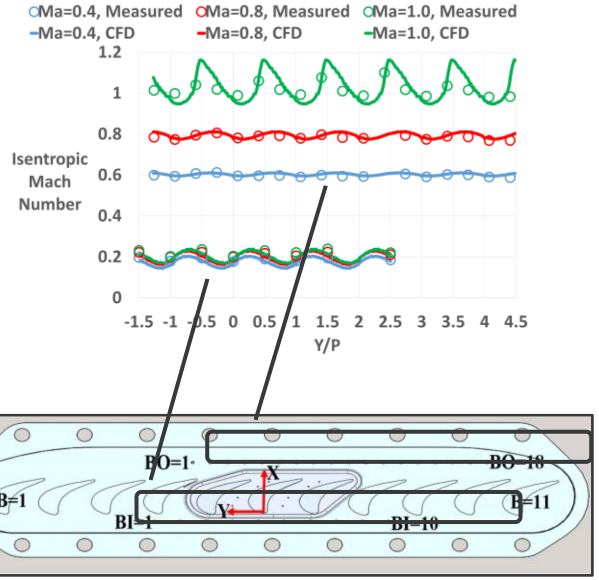
NATIONAL ENERGY TECHNOLOGY LABORATORY

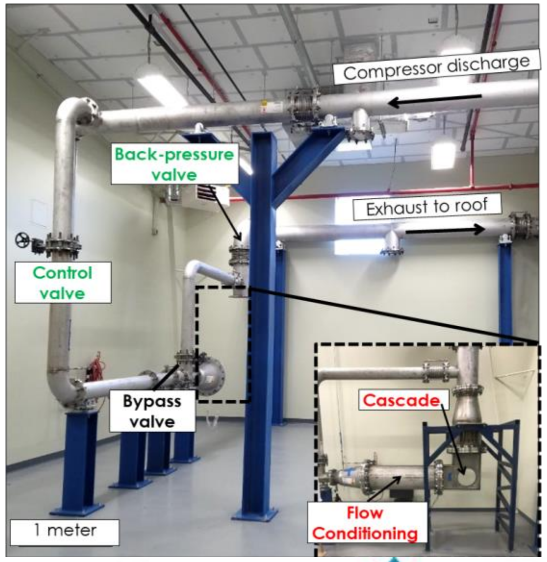
High-Speed Cascade Test

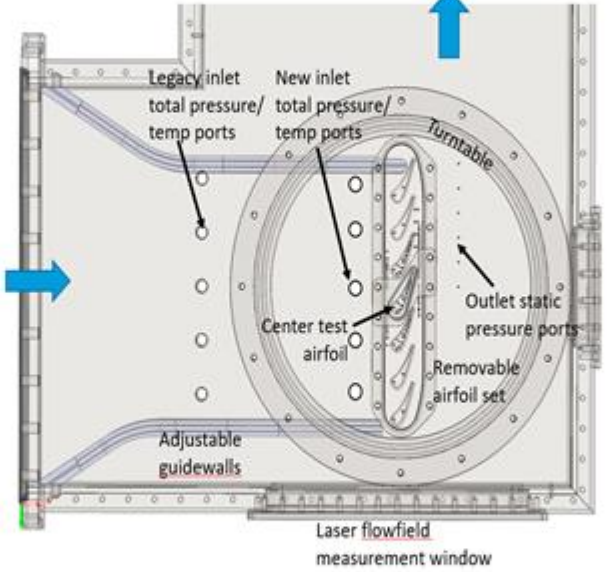
PSU ExCCL High-Speed Cascade

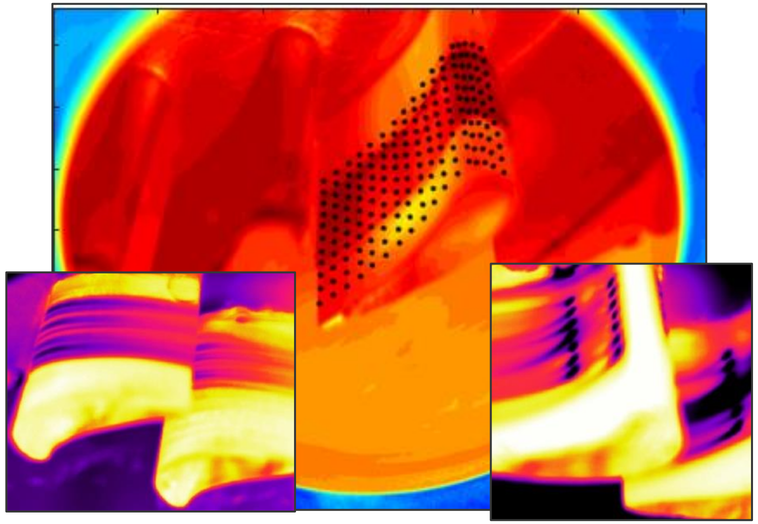
PENN STATE ExCCL

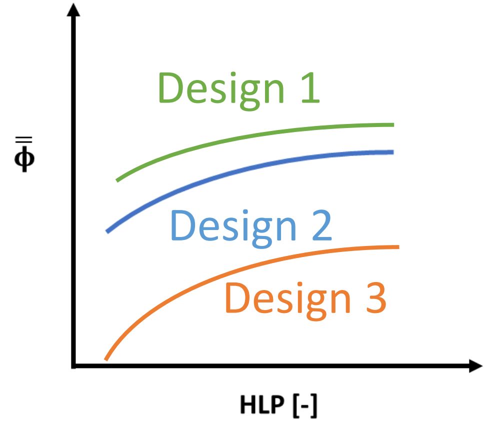
Test conditions:
Hot gas: up to T = 250 °F and P = 70 psia
Re: 7 × 10^5 to 1.4 × 10^6
Heat Load Parameter (HLP): 0.5 to 2











$$\phi = \frac{T_H - T}{T_H - T_C}$$

$$HLP = \frac{\dot{m}_c c_{p,c}}{h_{ext} A_s}$$

Technology map.

Test campaign is ongoing. Periodicity plots and infrared images shown here are prior work provided by PSU.

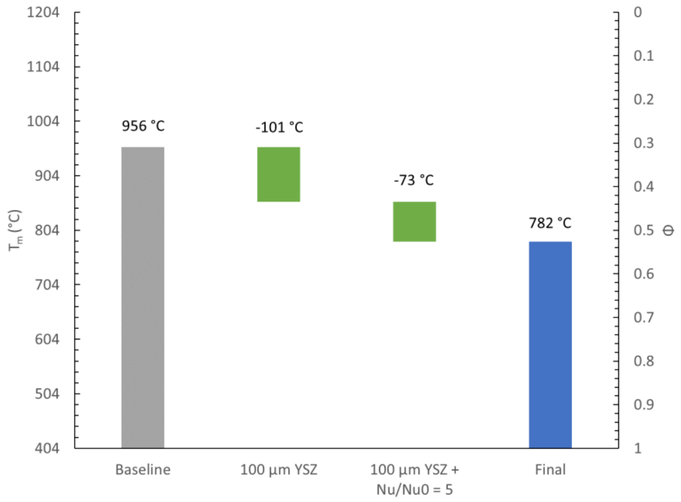
Conclusions

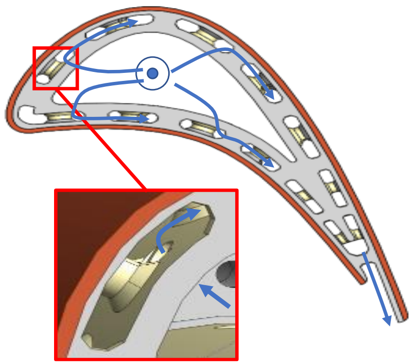
sCO_2 Heat Transfer

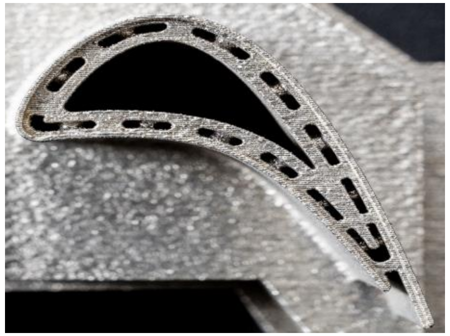
- Pathway to direct sCO_2 turbine thermal management
- Novel approach to evaluate TBC performance in sCO_2 environment
- Pathway toward enhanced condensation through AM

Small Turbines Heat Transfer

- Design for AM guidelines and flow data
- Approaches to model conjugate heat transfer in complex AM geometries
- Spatially resolved overall cooling effectiveness in scaled thermal environment across range of HLP and novel integrated cooling strategies







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