Advanced Airfoils for Efficient Combined Heat Power Systems

Task 4.3 – Gas Turbine Machinery and Systems

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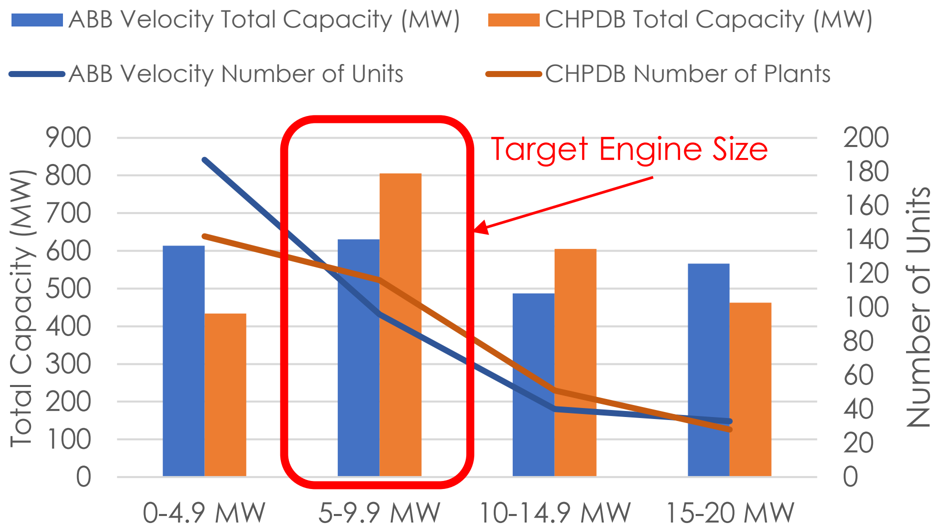
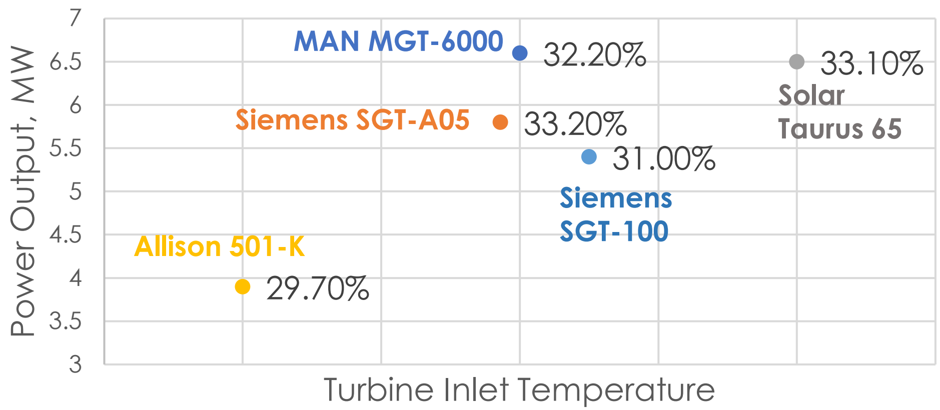
Combined Heat and Power (CHP) Market

Size, Scale, and Baseline Engine Performance

- 2.3 GW of gas turbine CHP <20MW in the U.S.
- NETL market study
  - Cumulative growth of 637 MW GT CHP over 5 years
  - Large growth for universities and hospitals
  - 5-10 MW target market
- NETL baseline engine model[1]

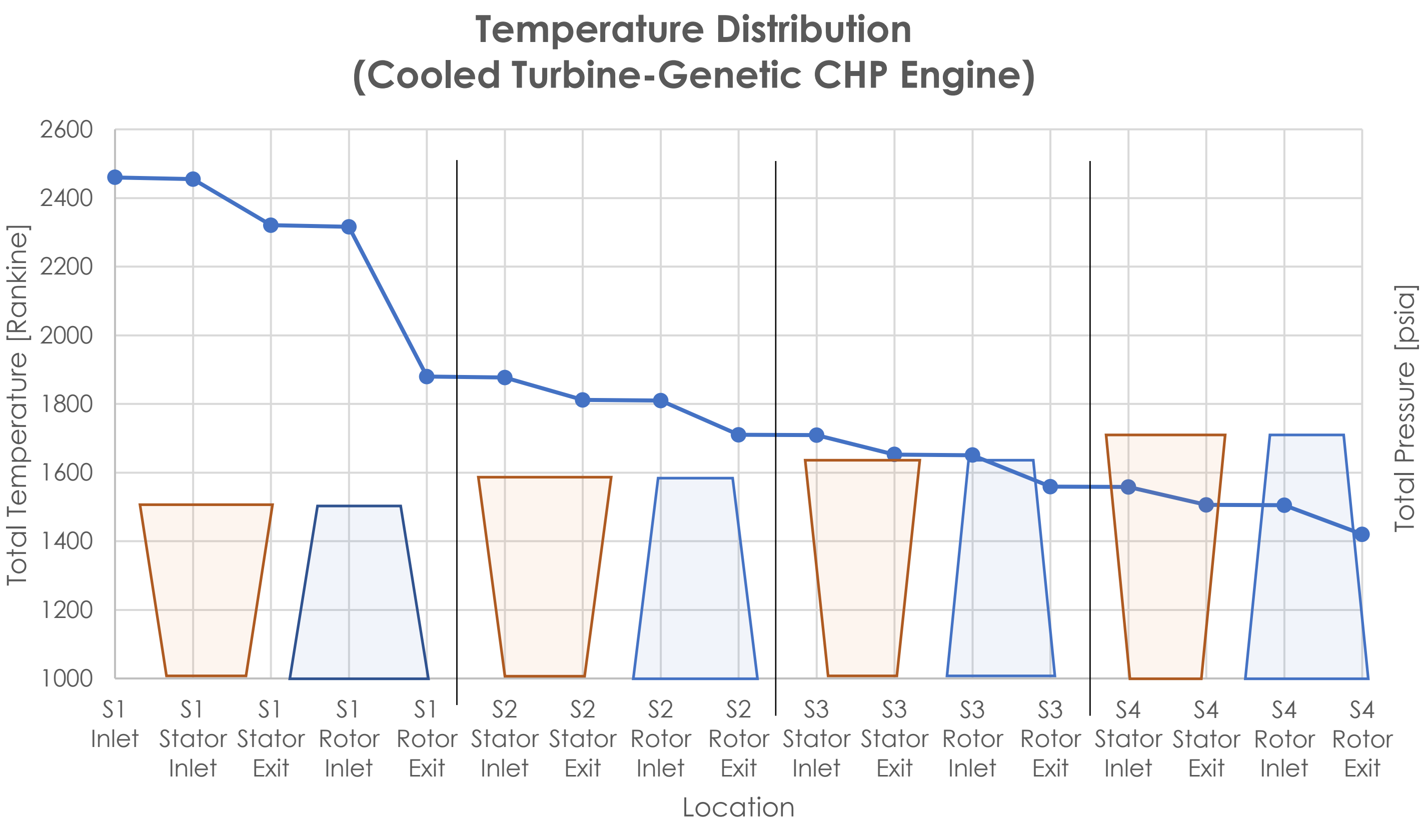
Parameter	Value	Parameter	Value
Power (kW)	6100	Exhaust Temperature (°F)	968
Thermal Efficiency	33.1%	Fuel-to-Air Ratio	0.0172
Heat Rate (Btu/kWh)	10209	Total Coolant Fraction (w.r.t. Turbine Inlet Flow)	9.6%

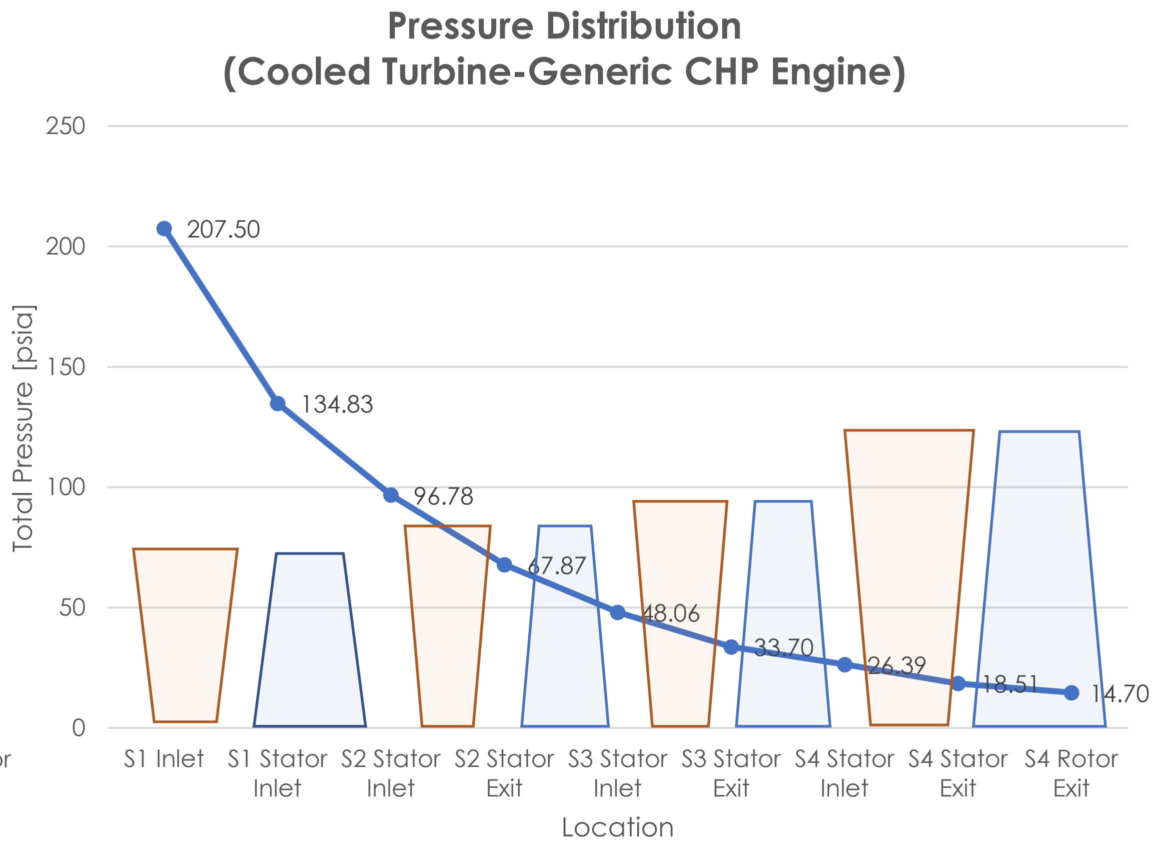




[1] Uysal, et al., 2021, ASME GT2021-58718. https://www.netl.doe.gov/energy-analysis/details?id=7a64f776-2f08-40f3-955d-7f63d42f4a4c

Predicted Turbine Section Temperature and Pressure Distributions – Baseline Engine



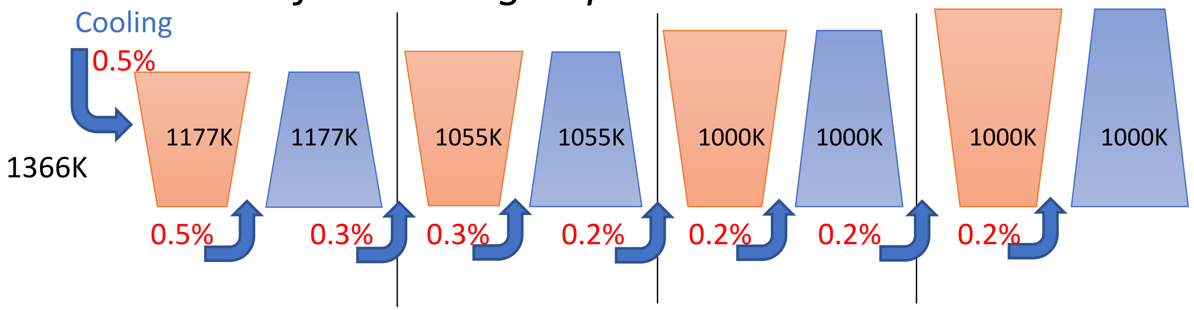


[1] Uysal, et al., 2021, ASME GT2021-58718. https://www.netl.doe.gov/energy-analysis/details?id=7a64f776-2f08-40f3-955d-7f63d42f4a4c

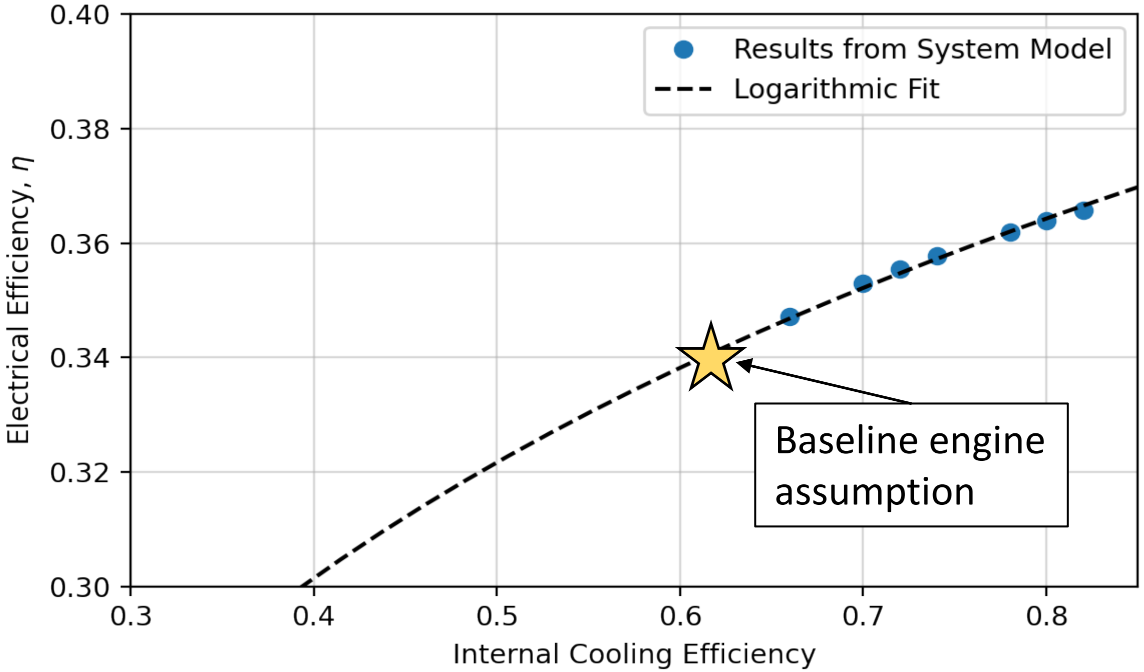
What IF. . . Advanced Cooling Could Increase Turbine Temp. (T_{inlet}) by 100°C?

2-3% point improvement in cycle efficiency[1,2]

No film cooling required



	Baseline Engine	ΔT_{T4}=100C Increase	Int. Cooling Eff. Increase (0.62 → 0.70)
Power (kW)	6100	7214	7592
Thermal Efficiency	33.1%	34.0%	35.3%
Exh. Temp. (K)	793	805	805
Coolant Fraction	9.6%	14.1%	12.9%



Using baseline engine model to define overall cooling effectiveness targets

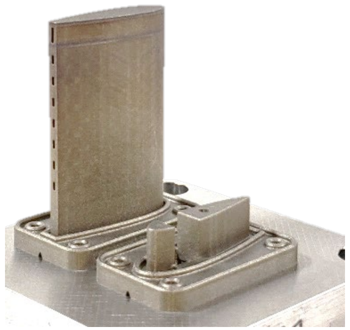
$$\phi = \frac{T_g - T_{w,ext}}{T_g - T_{c,in}}$$

Ref 1: Uysal, et al., 2021, ASME GT2021-58718. https://www.netl.doe.gov/energy-analysis/details?id=7a64f776-2f08-40f3-955d-7f63d42f4a4c
Ref 2: Phase 1 Final Report - DOE.NETL-2023/3822; https://www.netl.doe.gov/energy-analysis/details?id=117dccf6-4fa7-4481-97b5-87894f02fbe7

Screening AM Cooled Airfoils[2,3,4]

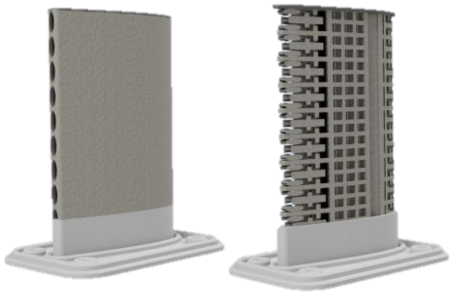
Measure Cooling Performance Curves for Baseline and Advanced Designs

1) Blade (baseline)



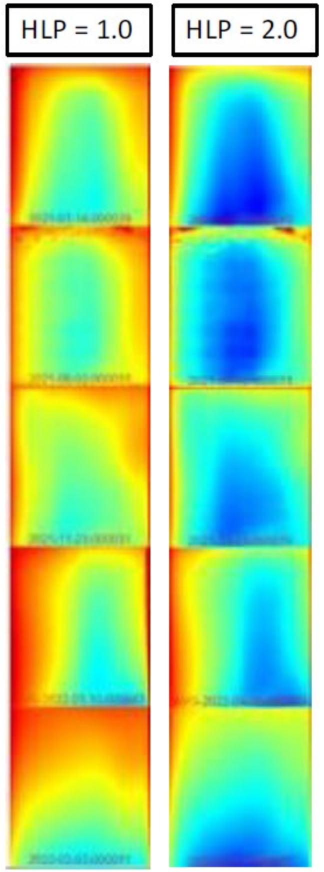
2) Vane (baseline)

3) NETL Double Wall

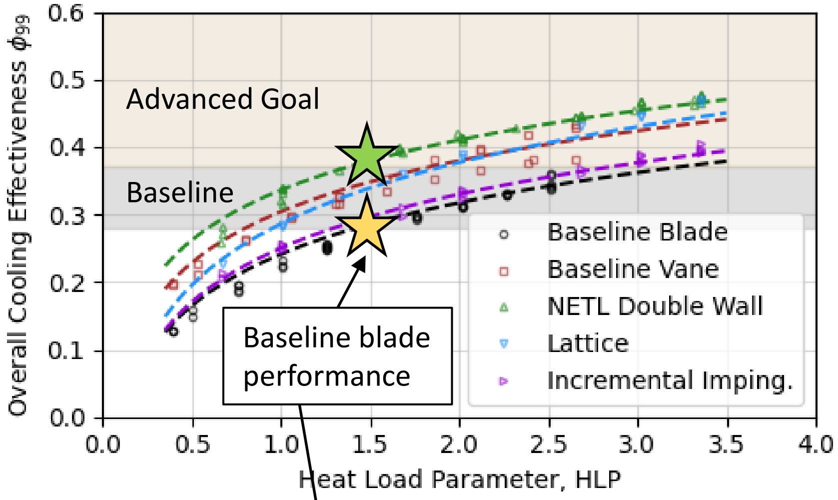


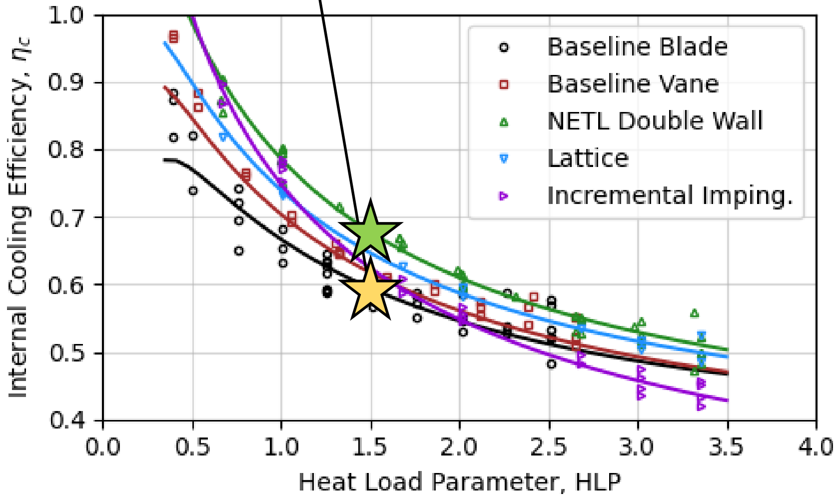
External Surface Removed in CAD

4) Incremental Impingement



Symmetric NACA-0024 shape
Tested airfoil designs at 650K
Re ~ 90k

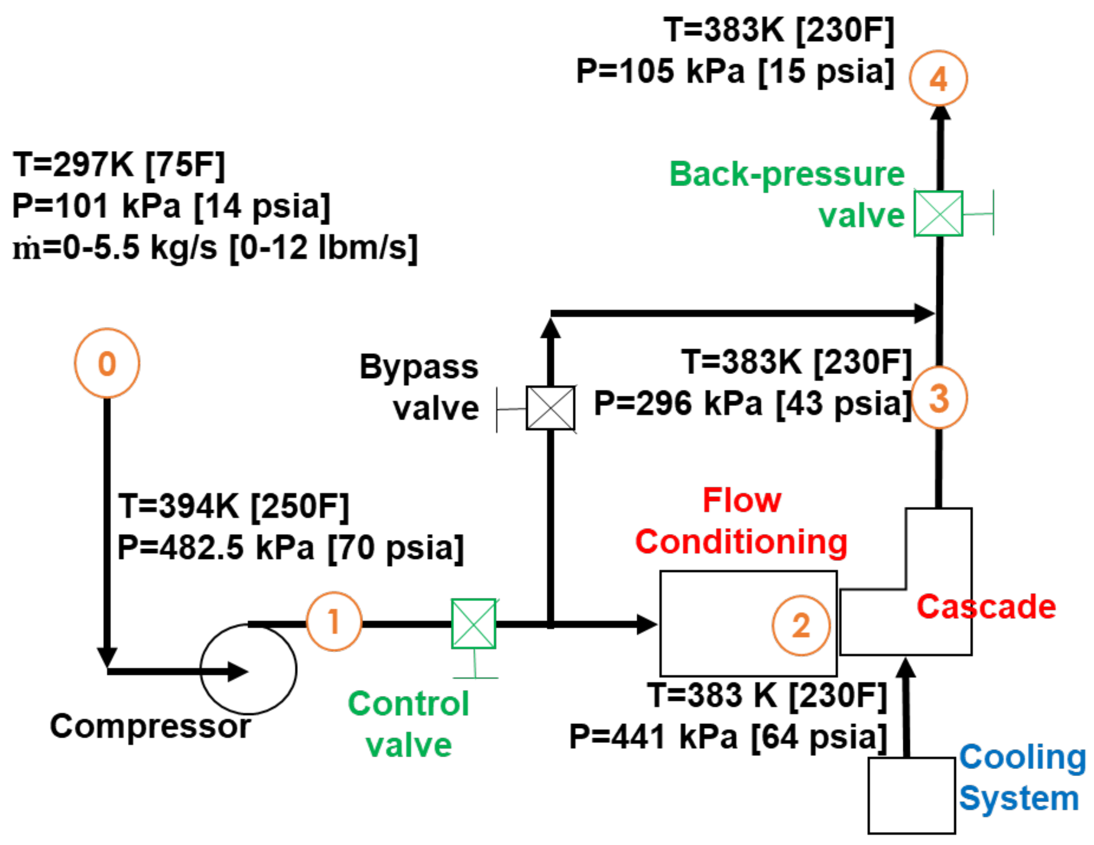


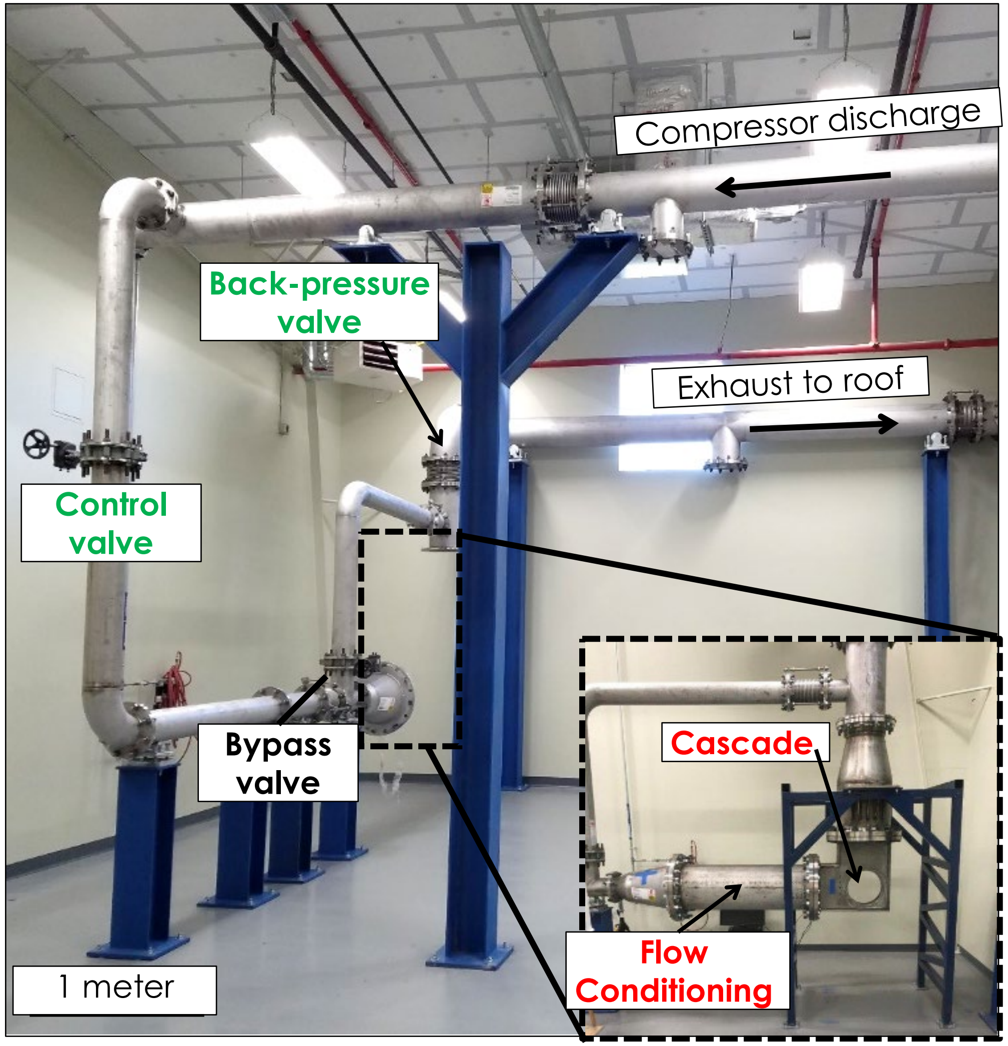


Ref 3: Straub et al., ASME GT2022-83333, https://www.netl.doe.gov/energy-analysis/details?id=6132030e-479b-45f1-beb9-c6b03312ea7d
Ref 4: Searle et al., ASME GT2023-101006, https://www.netl.doe.gov/energy-analysis/details?id=4a6f7b0d-8f02-44ec-b73f-7231caccd11d

Scale Cooling Designs To a Realistic Airfoil Shape and Test at Re_c~1,000,000

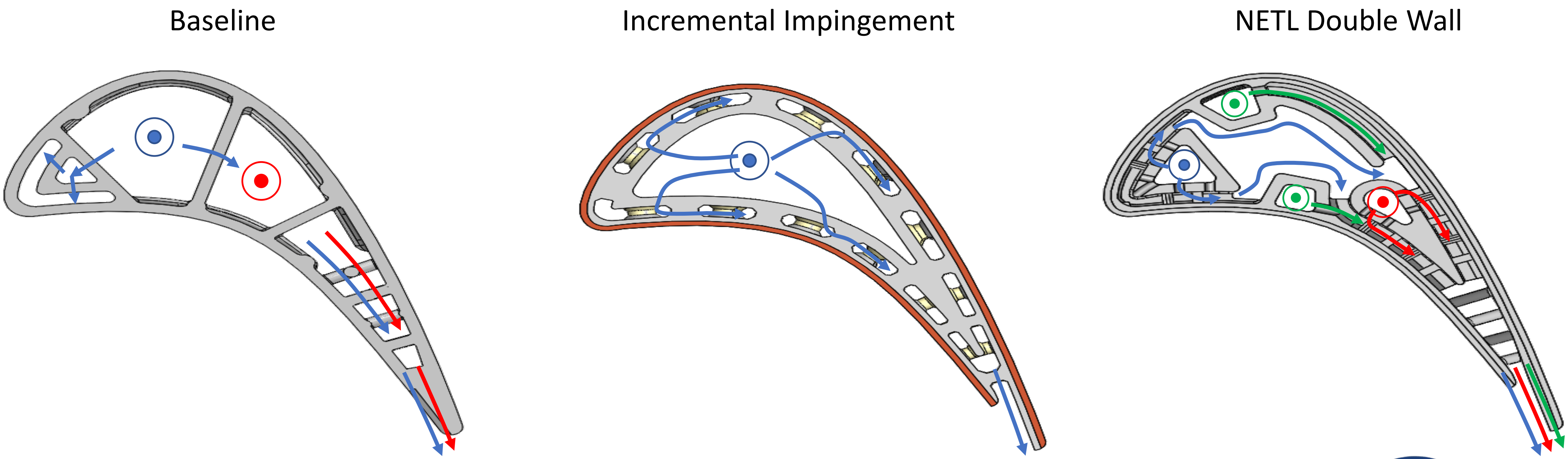
Penn State steady flow cascade facility independently controls Mach & Reynolds number





National Experimental Turbine (NExT) Cooling Designs

Penn State University testing baseline and two advanced AM designs



Summary, Status, and Future Work

Potential benefits of integrating AM internal cooling concepts into airfoils

- Impact of cooling technologies on CHP plant performance is significant
  - ~ 2 percentage points in efficiency
  - GHG reduction
    - 45% reduction relative to separate boiler/power generation configuration
    - ~10% reduction relative to conventional state-of-the-art GT CHP in 5-10 MW size range
- Additively manufactured (AM) internal cooled airfoil designs are promising
  - Screening tests → 50% reduction in coolant flow
- Current Status/Future work
  - AM designs have been scaled to NExT airfoil shape
  - Testing in progress at Penn State University's high-speed cascade test facility

Disclaimer

Questions

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