Progress Summary for FAA ASCENT #68:

Combustor Wall Cooling with Dirt Mitigation and Combustor Simulator

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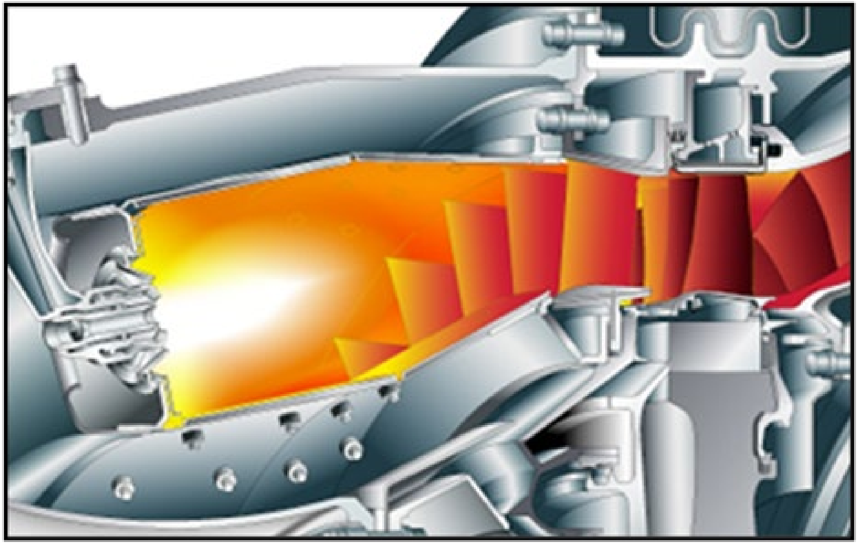
The objective is to understand durability impacts related to the combustor

Focus 1

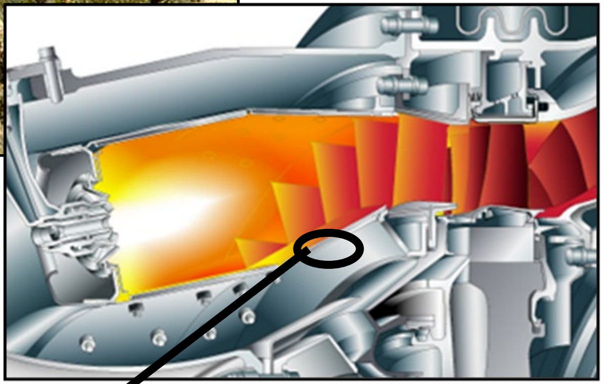
Ingestion of dirt diminishes combustor wall cooling. We will explore how cooling features can be made insensitive to dirt.

Focus 2

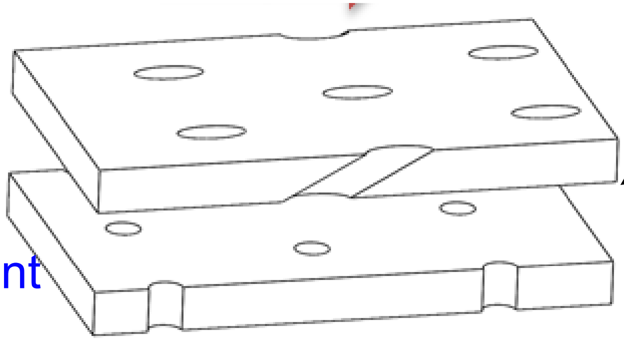
Temperature and pressure profiles exiting the combustor affect efficiency and durability of the high pressure turbine. We will explore developing a non-reacting profile simulator to produce a range of profiles entering the turbine.



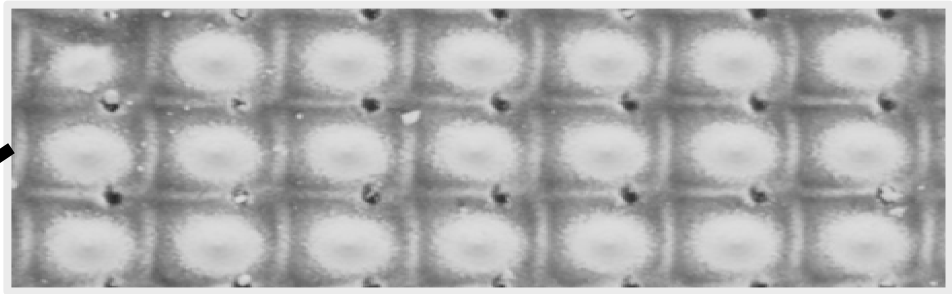
The motivation for this research is degradation of combustor wall cooling with dirty air



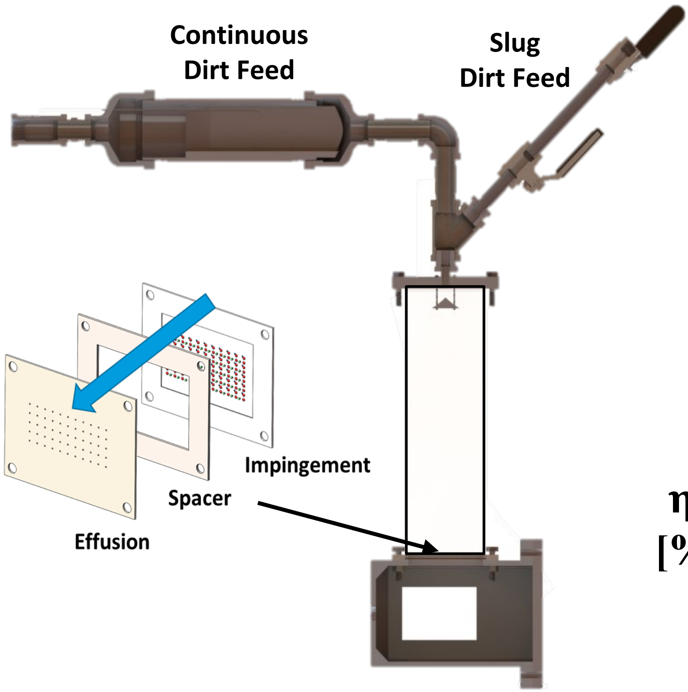
Double-Wall Cooling Design

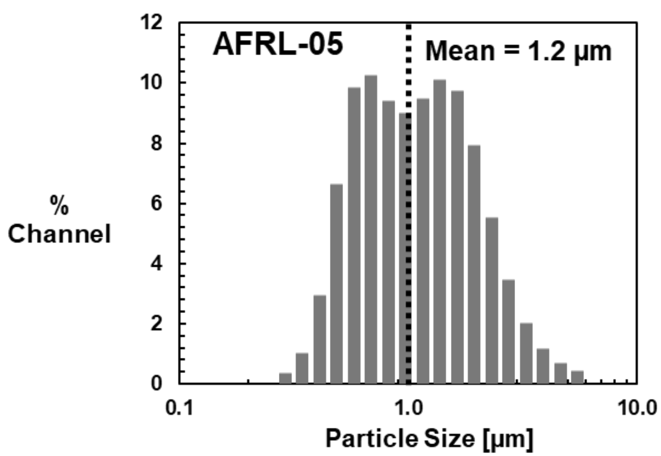


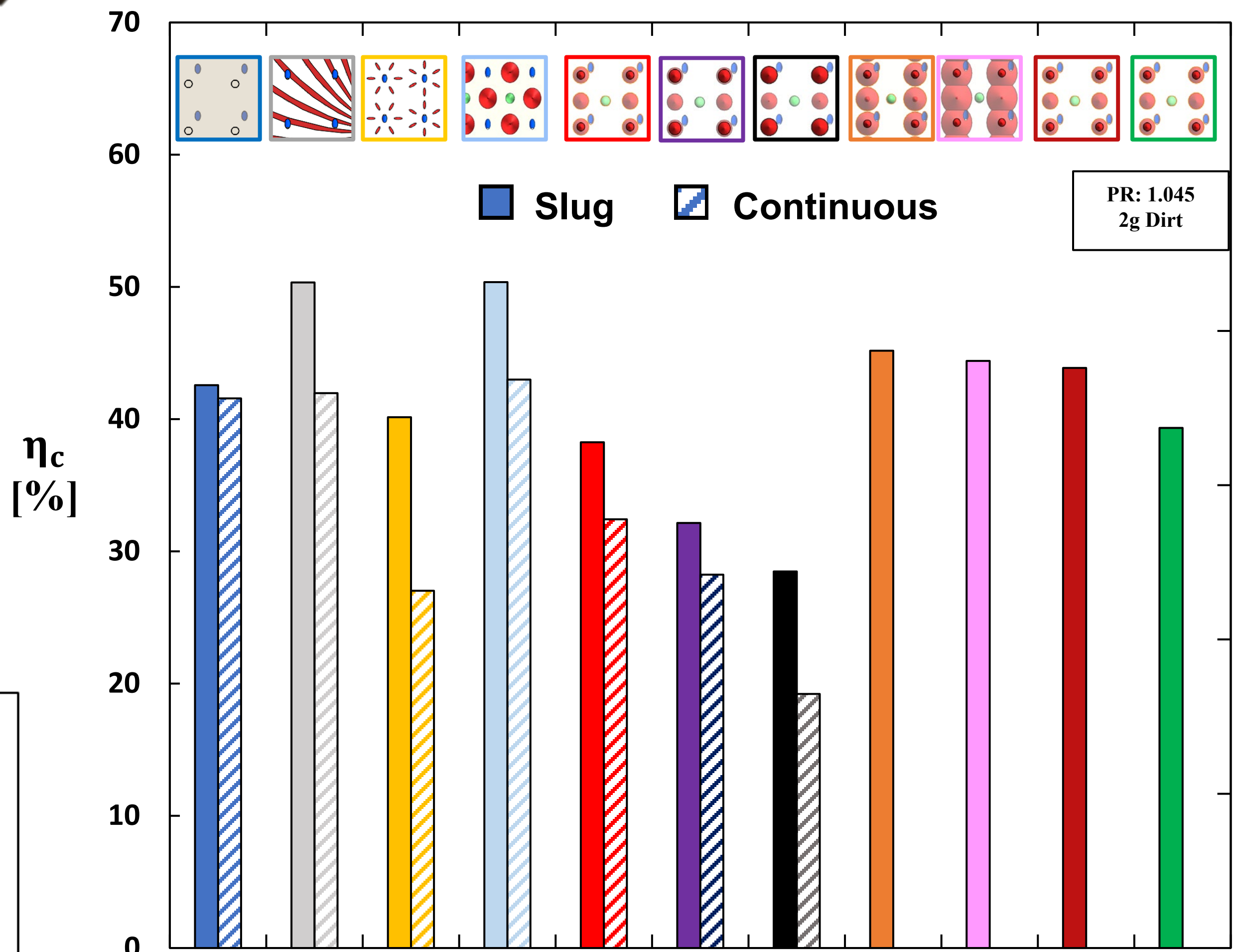
Cold Side of Effusion



Previous results indicate capture efficiencies depend on geometric features on the cold-side of an effusion plate

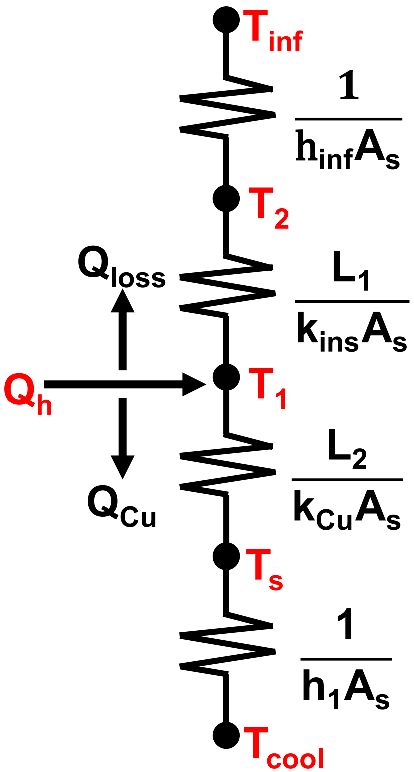


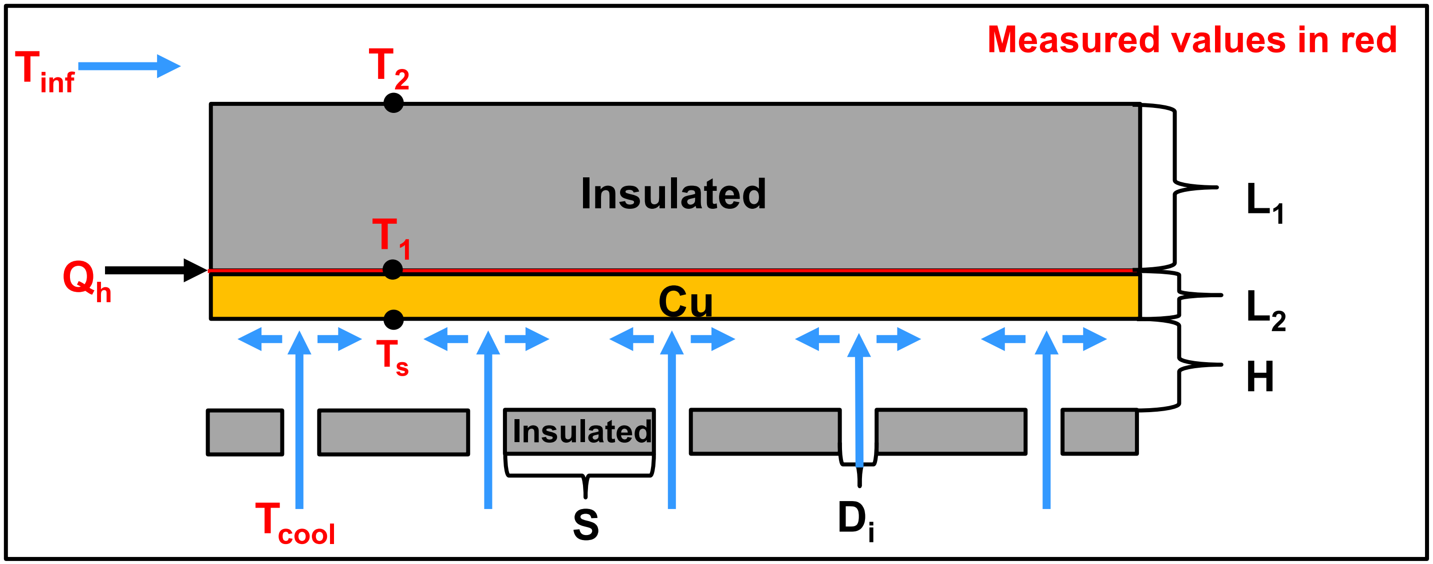




$$\eta_c (\%) = \frac{\text{Dirt Captured on Effusion Plate}}{\text{Dirt Injected}}$$

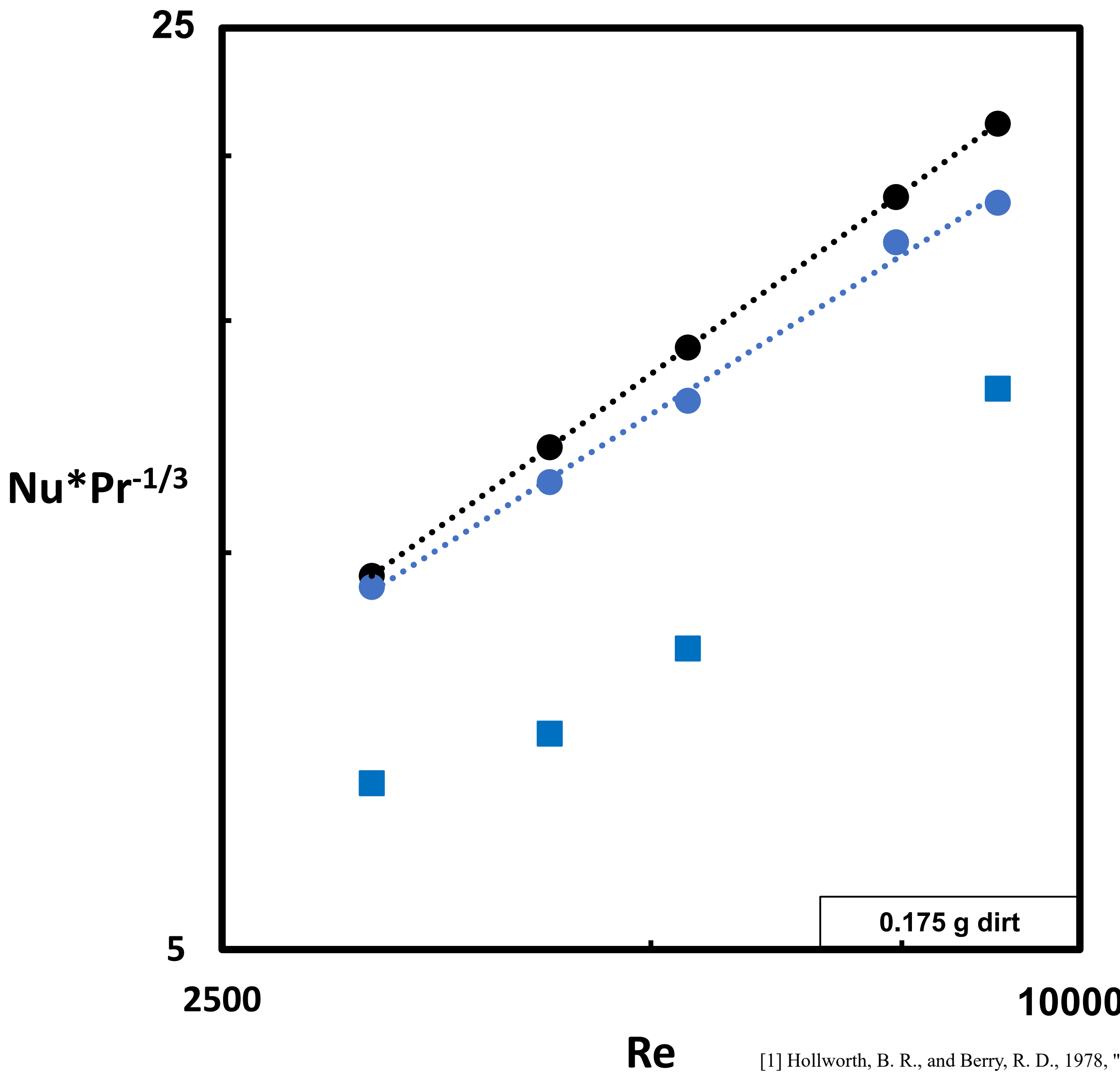
To determine the cooling impacts of the dirt deposition a method for measuring heat transfer is being developed



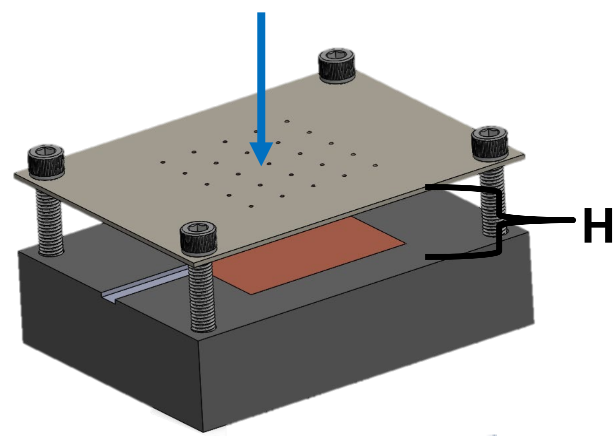


Impingement Plate			Effusion Plate	
D_i [mm]	S/D_i	A_f [mm^2]	D_e [mm]	H/D_i
1.02	10	20.43	0	10

The accumulation of AFRL-05 dirt resulted in diminished cooling capabilities of the effusion plate

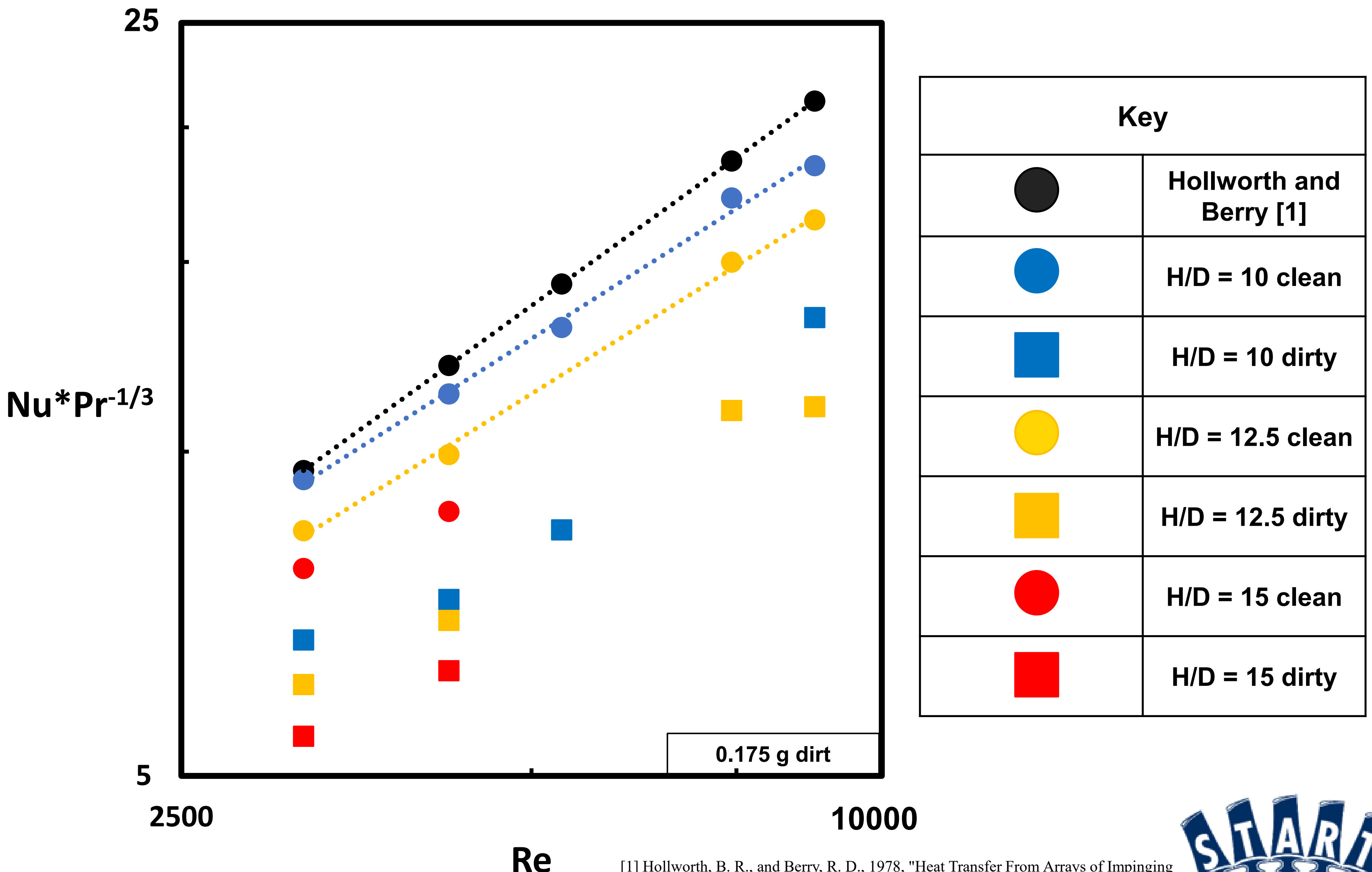


Key	
●	Hollworth and Berry [1]
●	H/D = 10 clean
■	H/D = 10 dirty



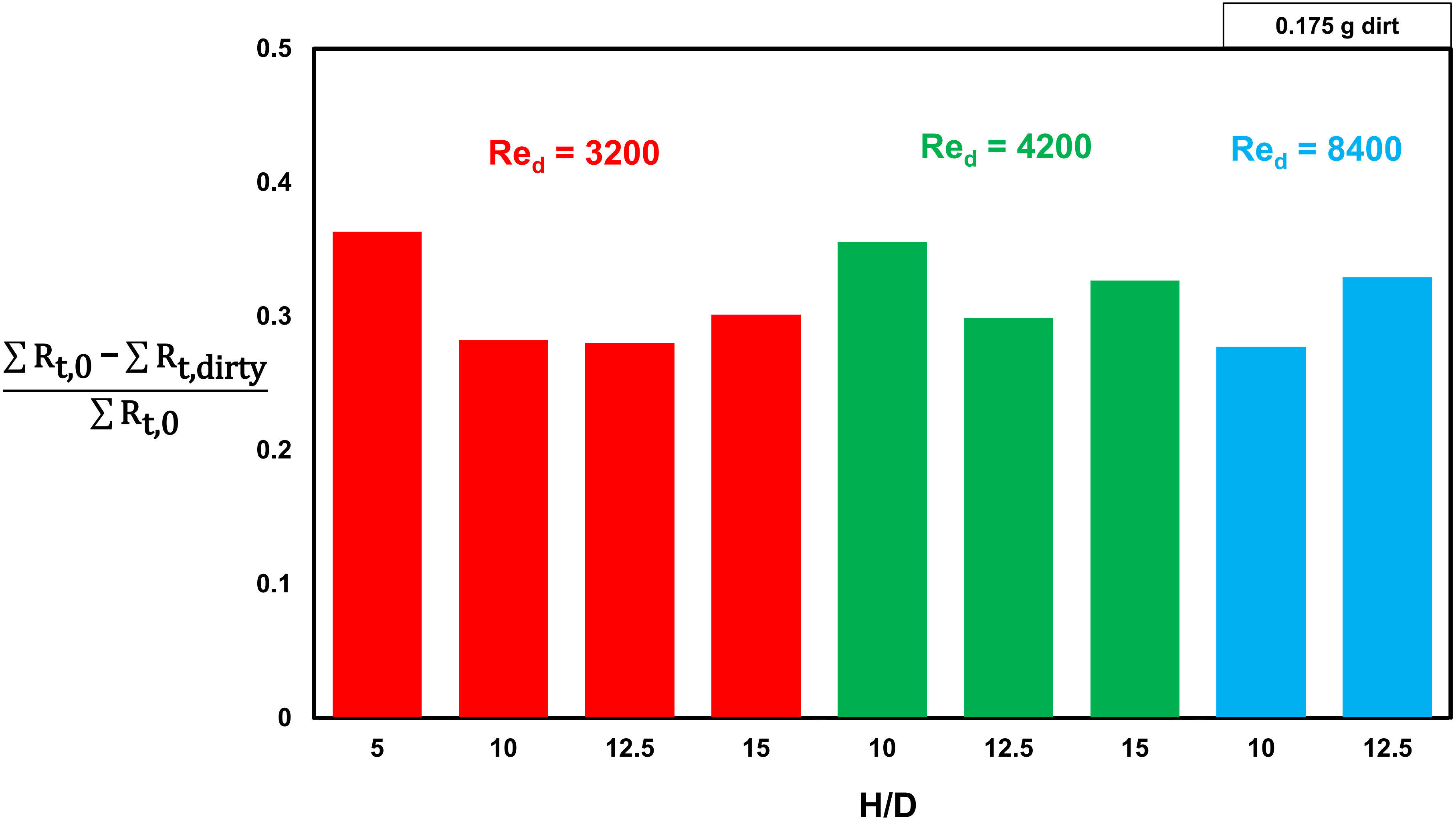
[1] Hollworth, B. R., and Berry, R. D., 1978, "Heat Transfer From Arrays of Impinging Jets with Large Jet-to-Jet Spacing," *ASME J. Heat Transfer*, 100(2), pp. 352–357.

Increasing H/D or increasing dirt deposition resulted in decreased heat transfer (ability to cool)



[1] Hollworth, B. R., and Berry, R. D., 1978, "Heat Transfer From Arrays of Impinging Jets with Large Jet-to-Jet Spacing," *ASME J. Heat Transfer*, 100(2), pp. 352–357.

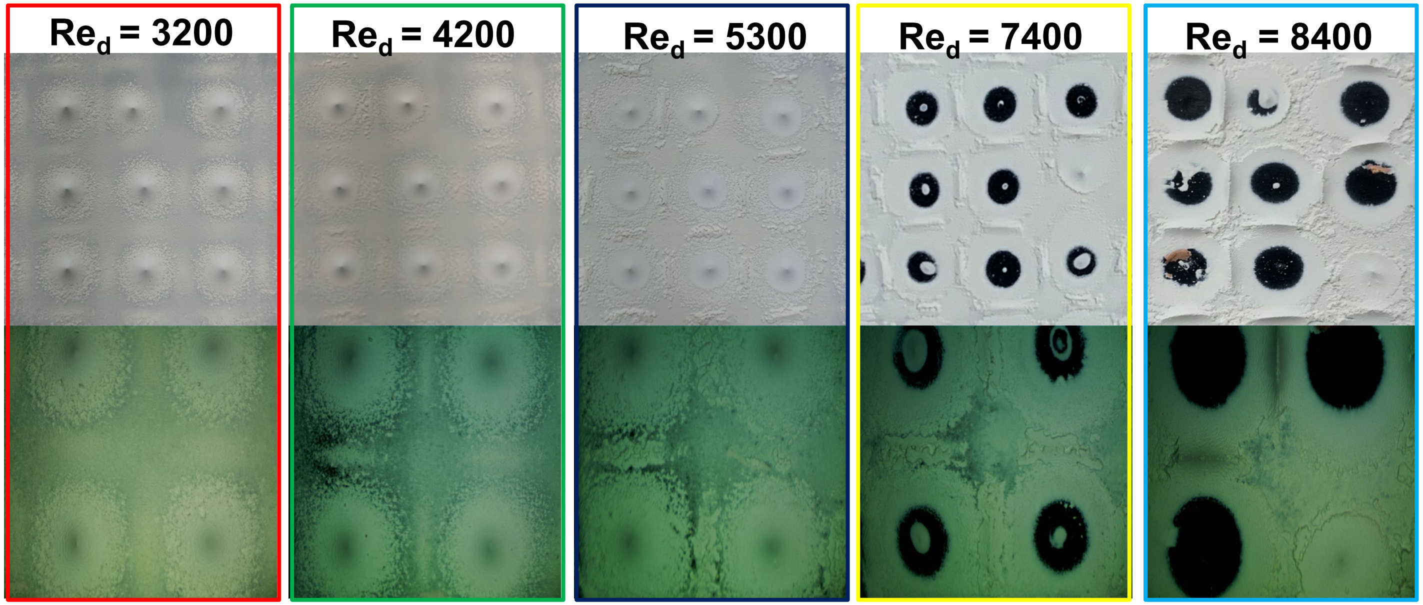
Reductions in heat transfer (cooling) between 30-40% occurred for all H/D ratios and Reynolds numbers



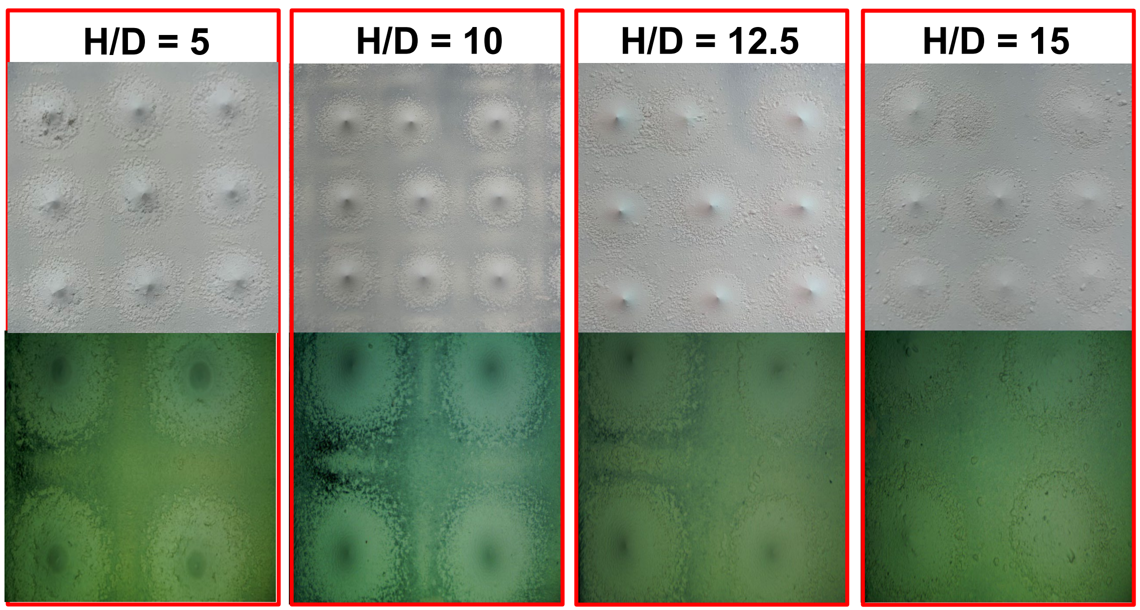
$$\sum R_{t,0} = R_{t,cond} + R_{t,conv} = \frac{L}{kA} + \frac{1}{h_0 A} = \frac{T_1 - T_{cool}}{Q_{Cu}}$$

Changes in the impinging flow rate and H/D spacing impact the areas of heightened dirt deposition

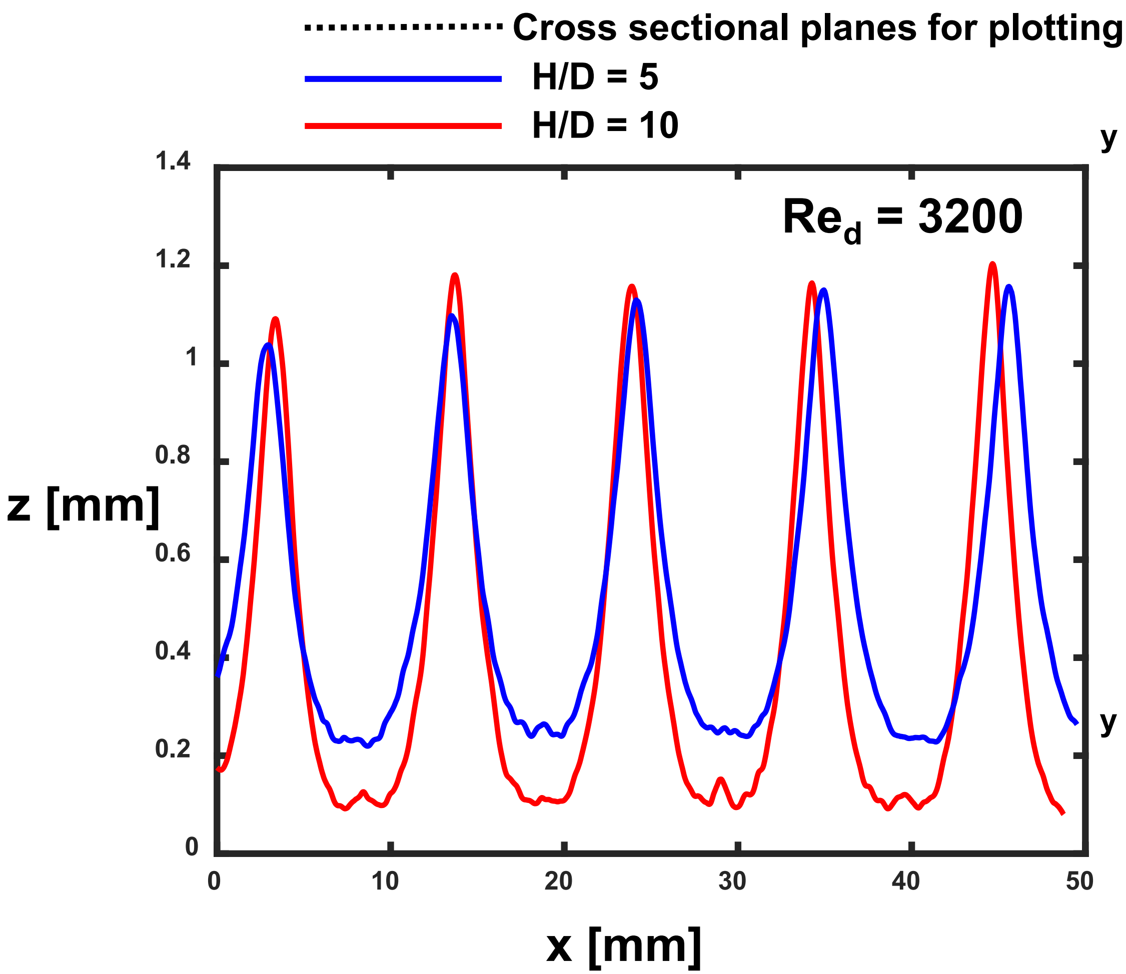
H/D = 10

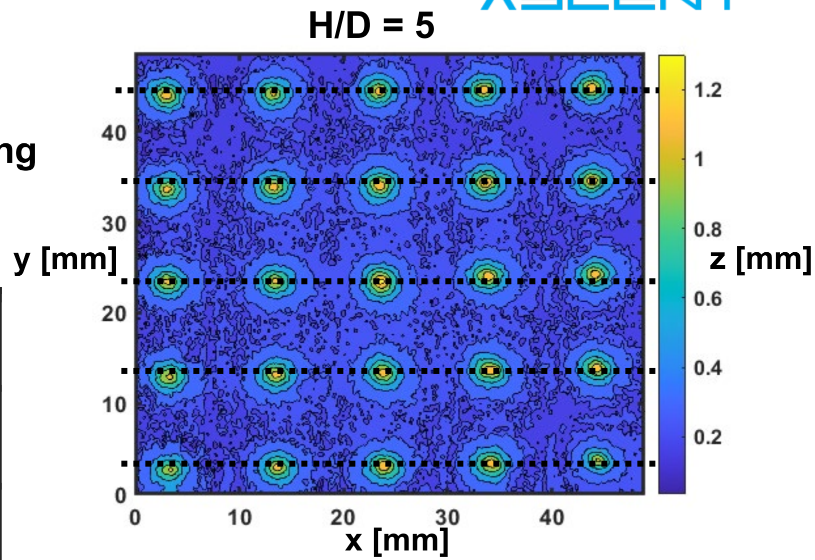


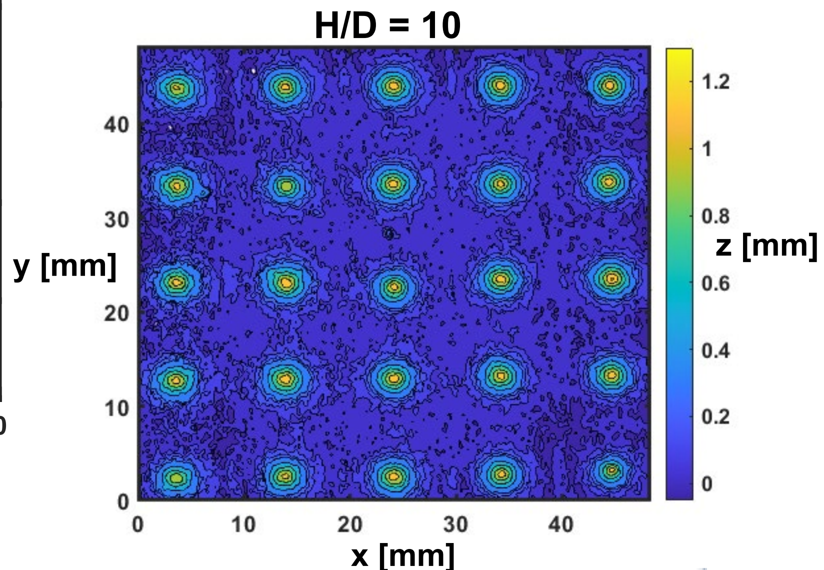
$Re_d = 3200$



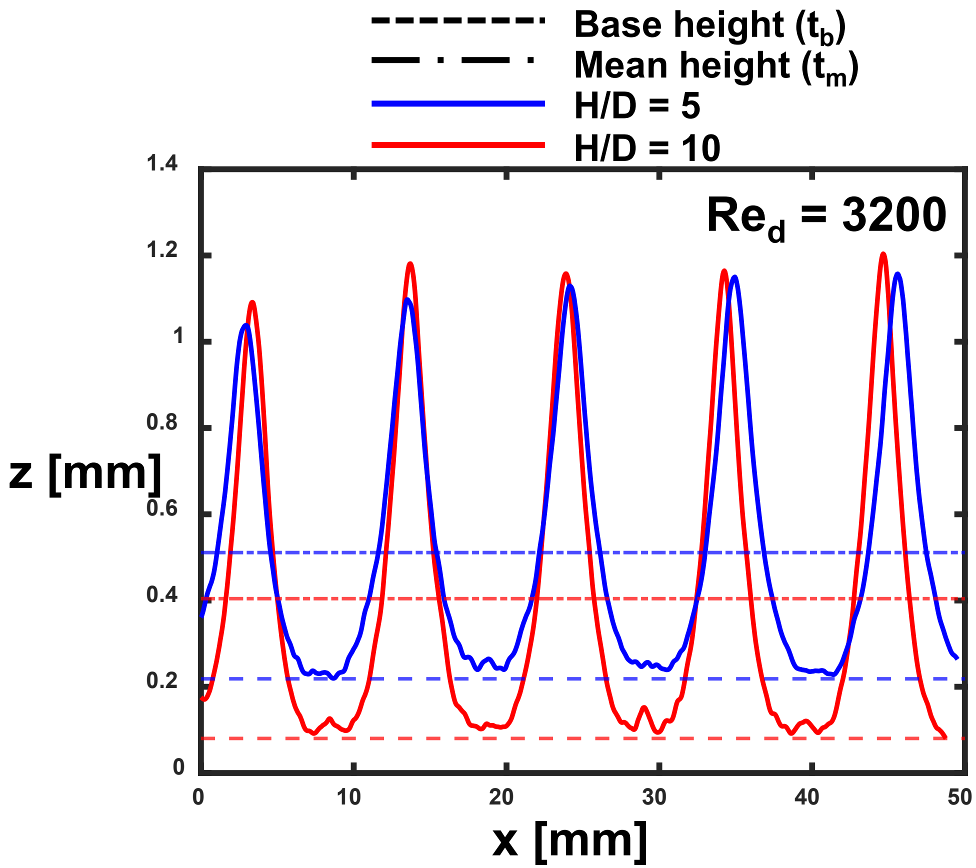
Similar peak heights in the dirt occurred but a lower H/D had greater spreading of the dirt

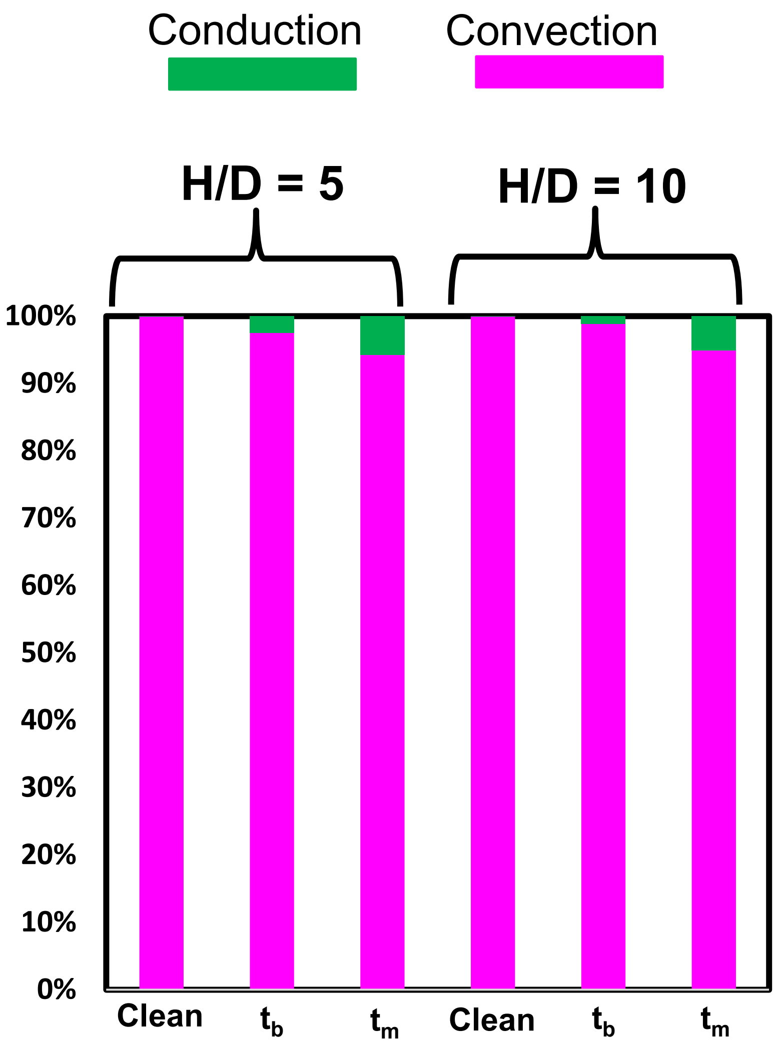




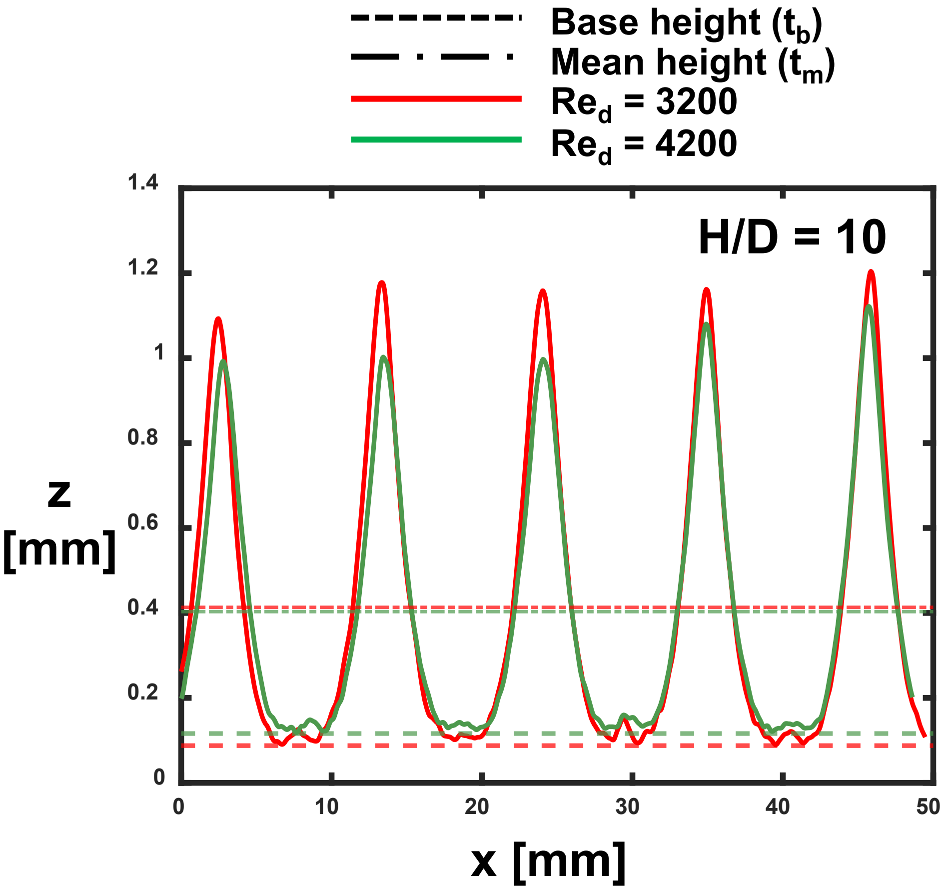


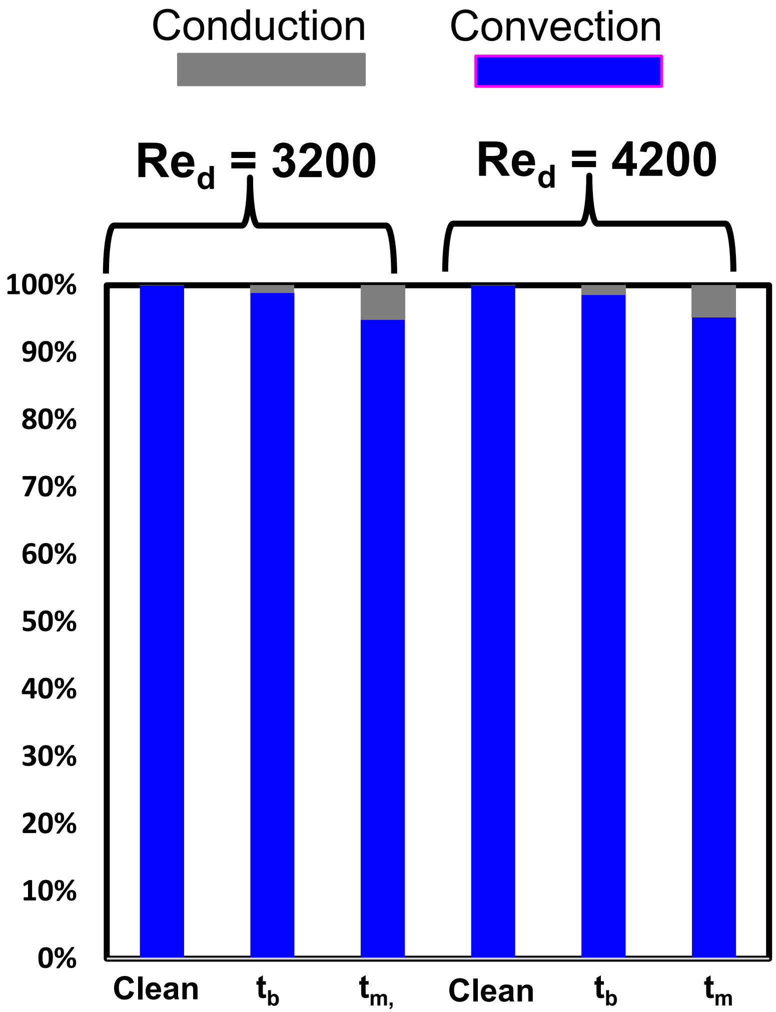
Extra dirt thickness contributes only a small amount to the thermal resistance



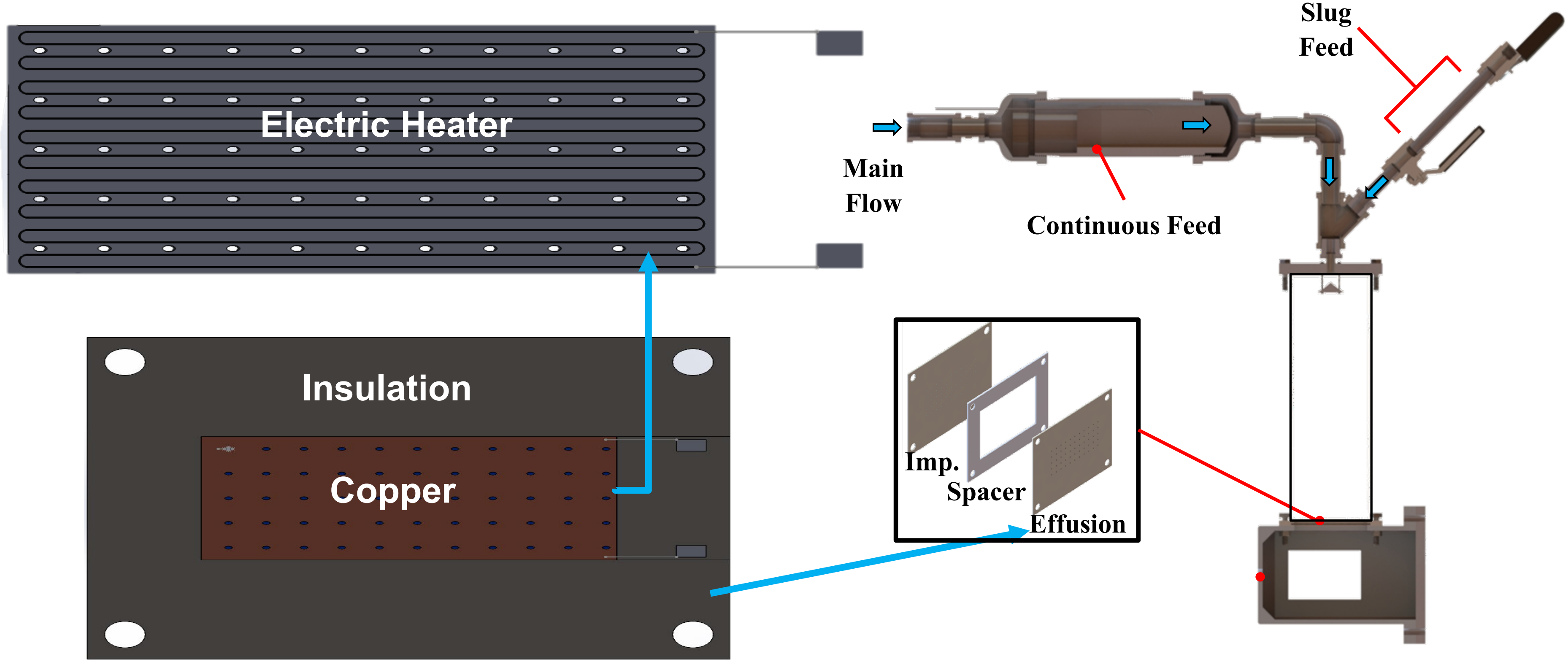


Increasing Reynolds number decreased the peak heights but conductive resistance stayed the same



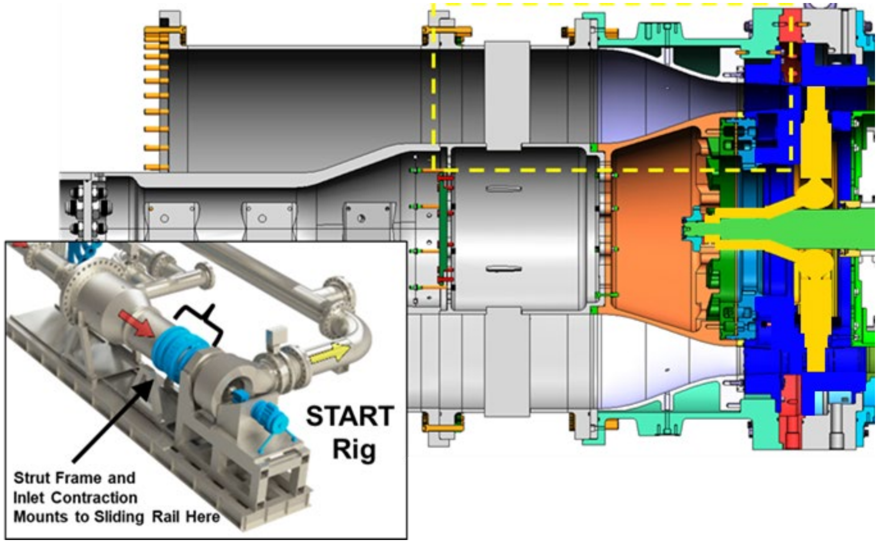


Future heat transfer testing will be done on an effusion plate with cooling holes



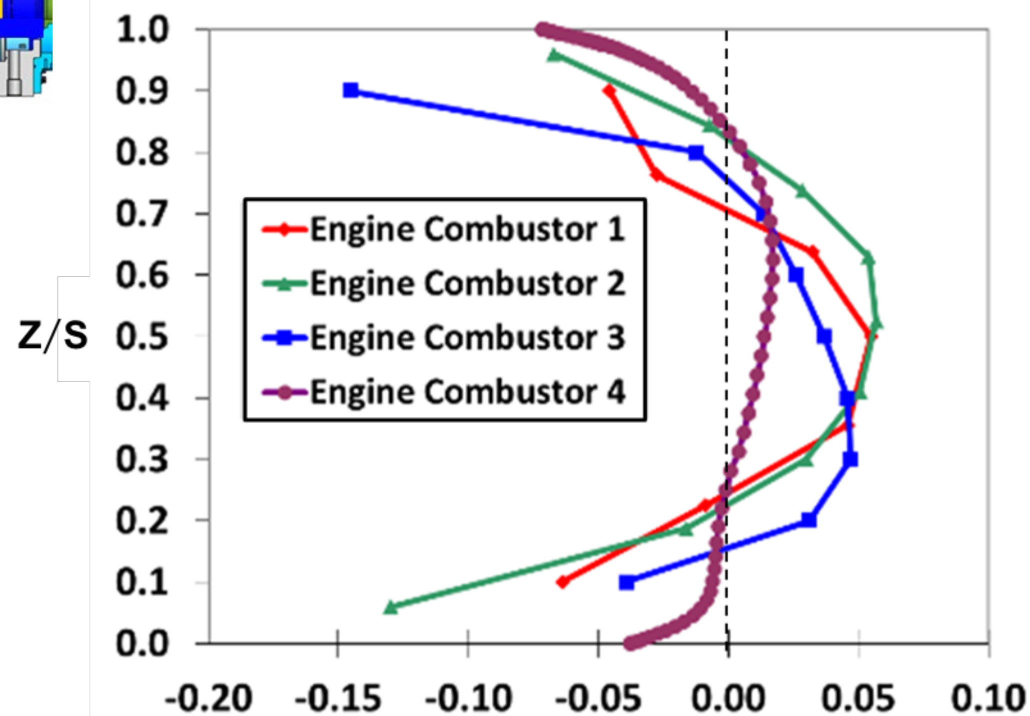
Effusion plate

Temperature and pressure profiles exiting the combustor impact the turbine durability and efficiency



Target Profile Shapes

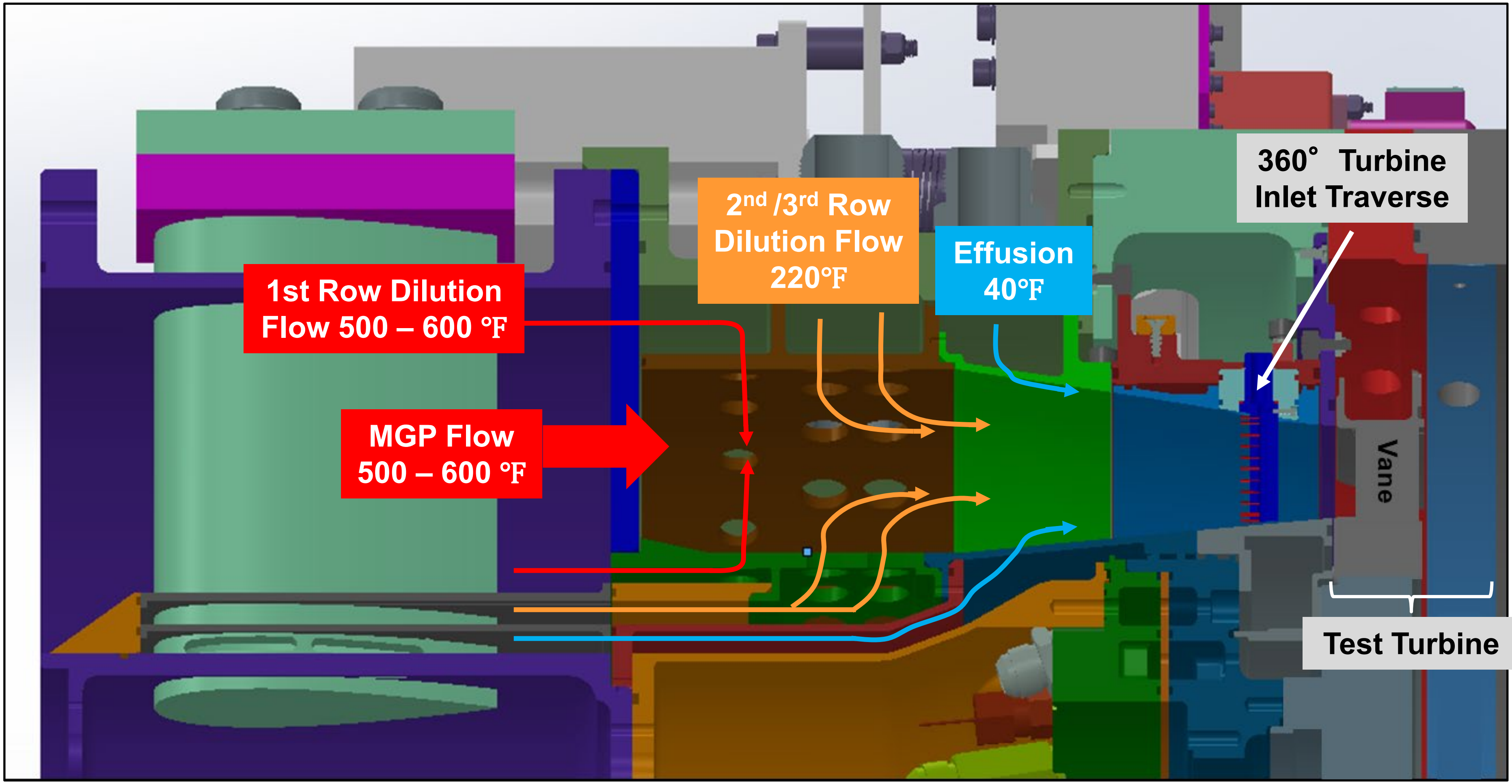
- OD Peaked
- Center Peaked
- ID Peaked
- Uniform



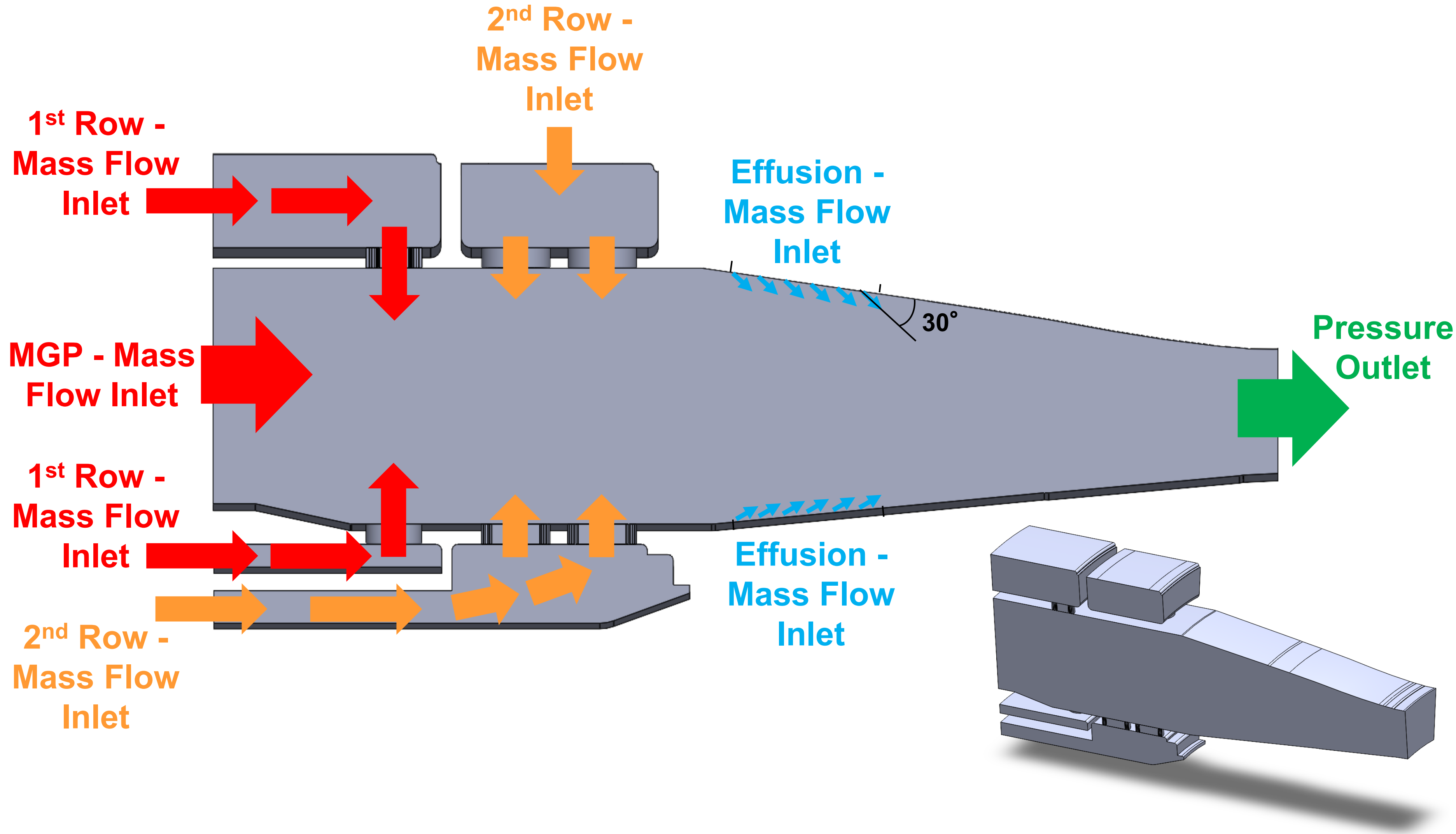
$$\theta = \frac{T - T_{AVG}}{T_{AVG}}$$

[Barringer, 2004]

A design has been developed upstream of the START test turbine to simulate different profiles

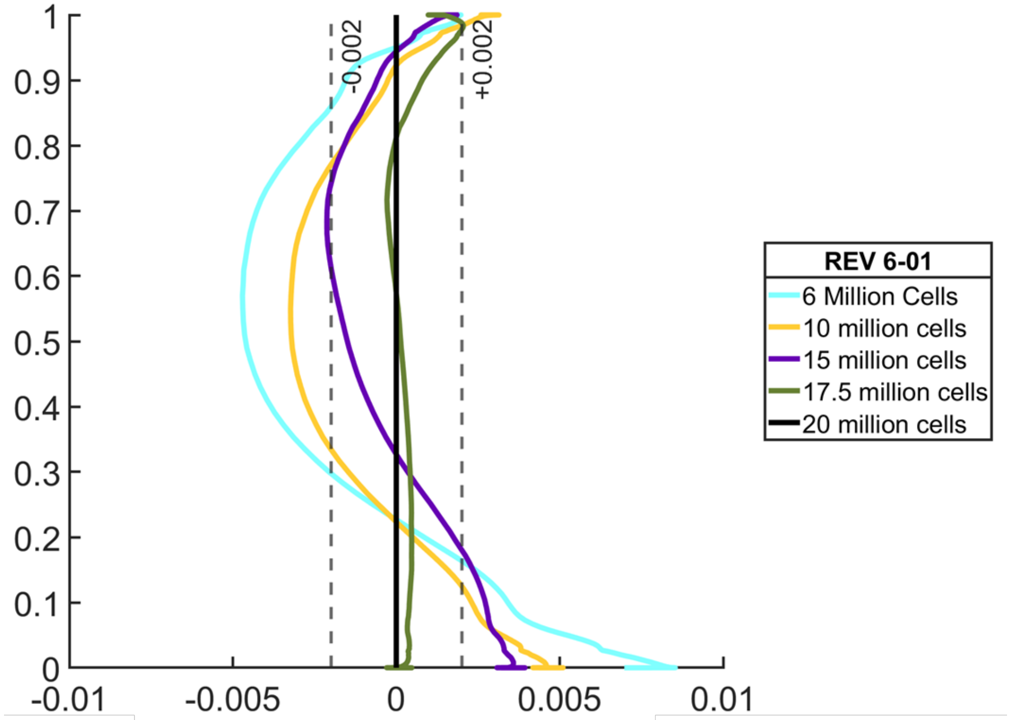


Computational simulations are being completed to evaluate the profiles possible during the design phase

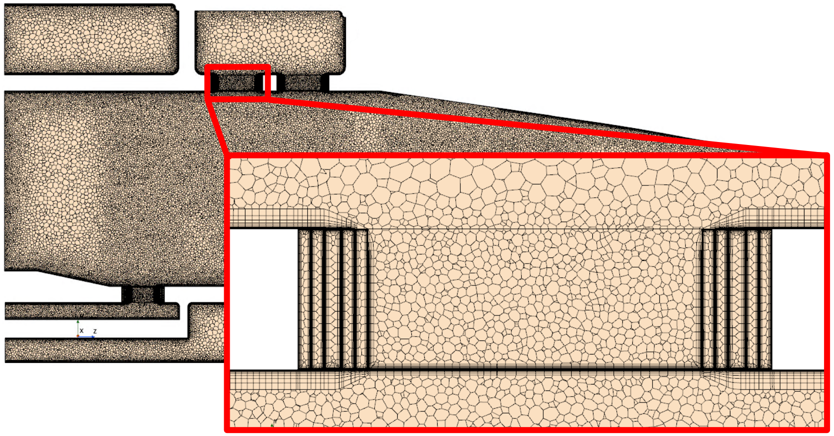


Grid independence was determined by the difference of circumferentially-averaged radial total temperature profiles

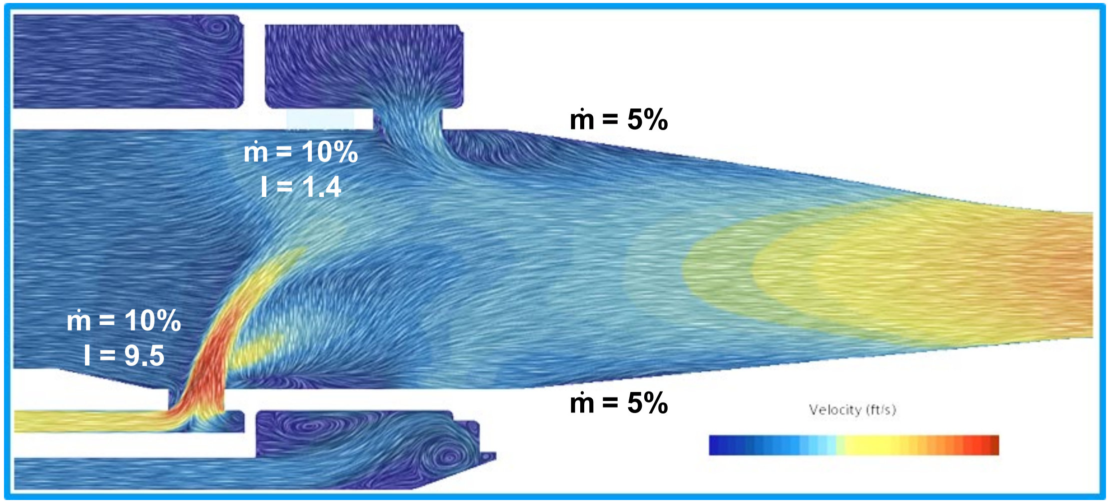
Radial Span
At
Simulator Exit

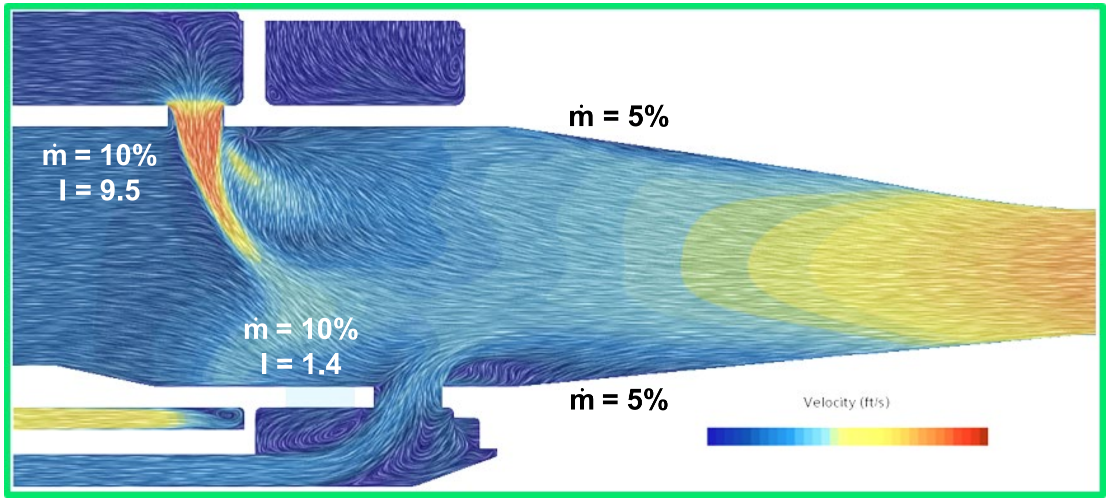


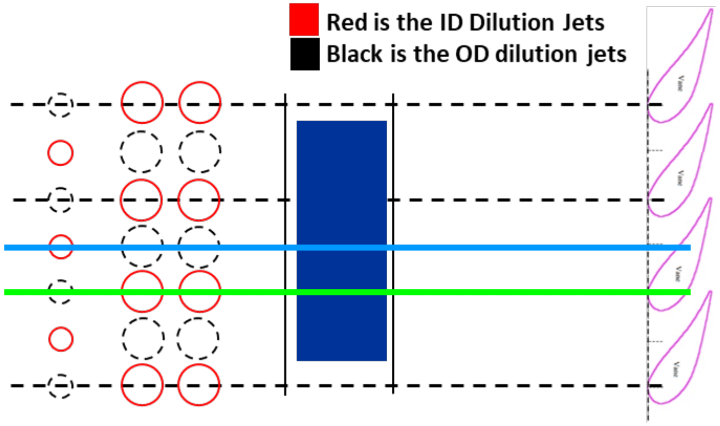
$$\frac{T_0 - T_{0_{finest}}}{T_{0_{finest}}}$$



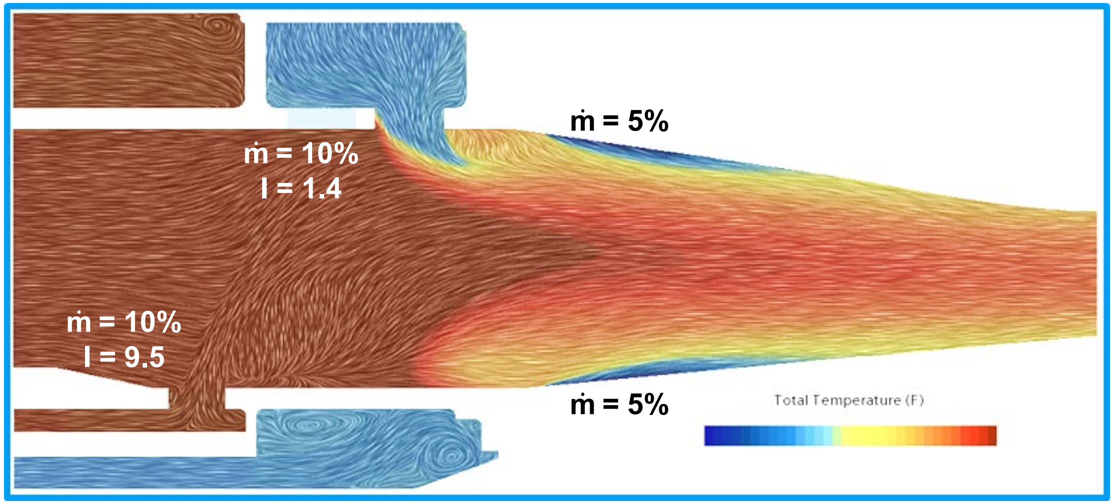
Velocity streamlines show the penetration depth of the first and second row dilution jets

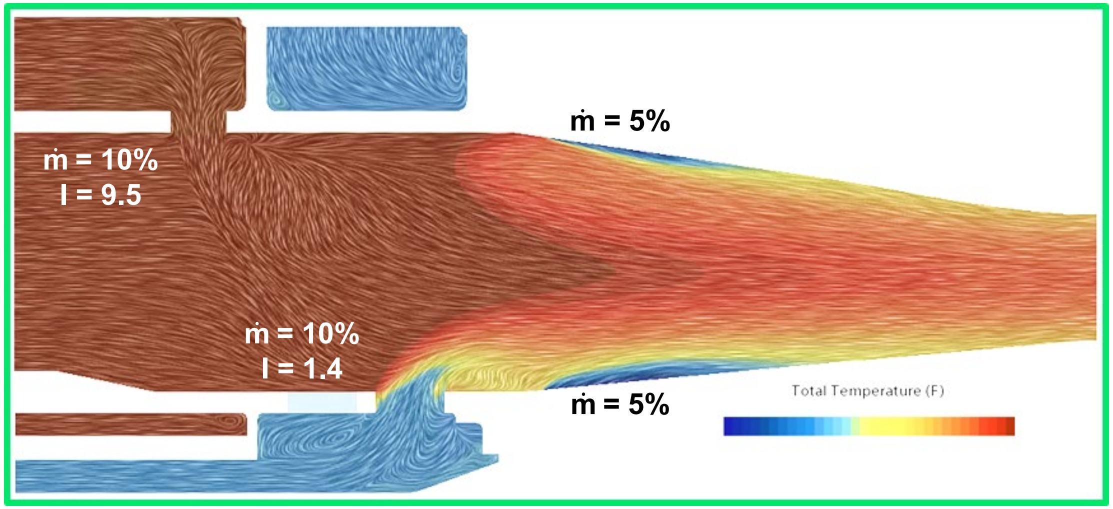


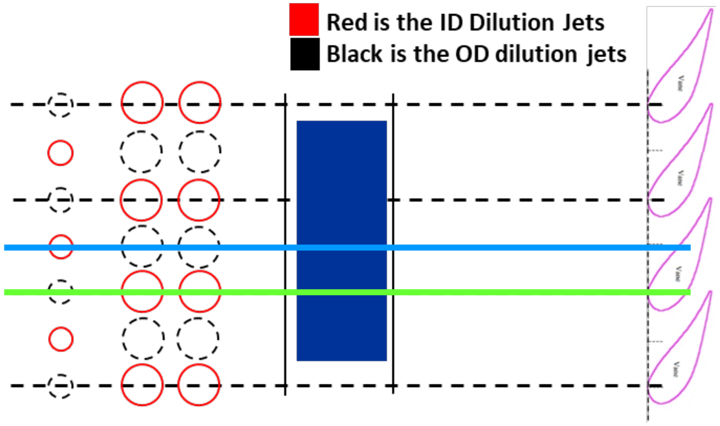




The mixing of cooler 2nd row dilution jet and effusion flow is seen in the contours of total temperature

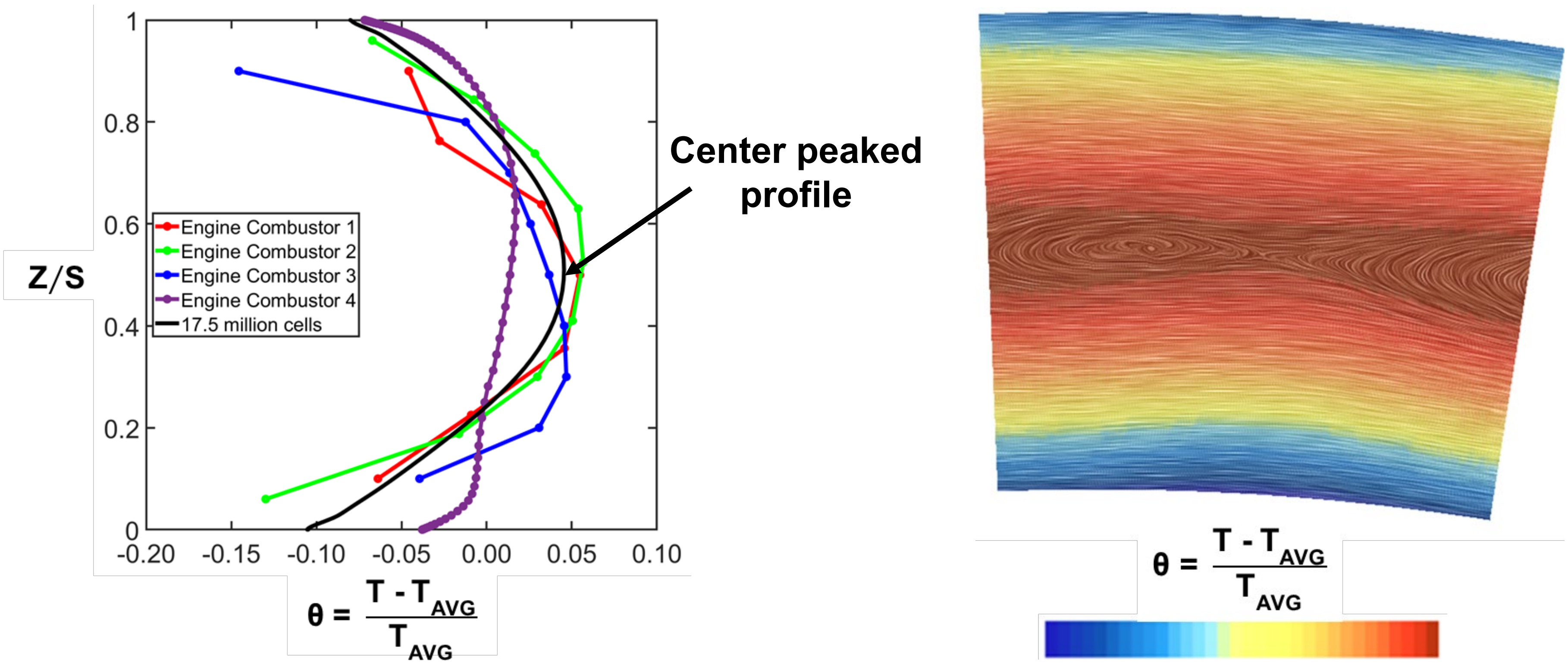






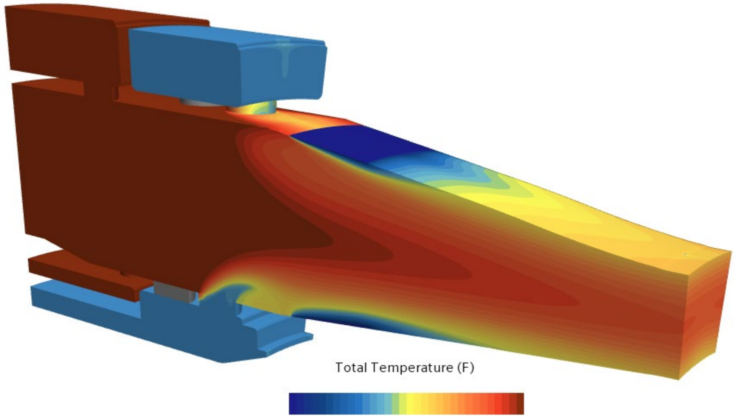
A center peaked profile at the simulator exit plane was generated by using specified flow areas and mass flow rates

	MGP	Row 1	Row 3	Effusion
Diameter	--	0.68"	0.84"	--
$\dot{m}$	50%	20%	20%	10%
Momentum Flux Ratio	--	9.4	1.4	--



Studies are continuing to determine the impacts of dirt and combustor-turbine interactions

Heat transfer of a double-walled combustor liner showed that dirt negatively impacts the cooling



A temperature profile simulator will provide a good understanding on turbine durability and performance

Backup

ASCENT Project 068

Combustor Wall Cooling with Dirt Mitigation and Combustor Simulator

The Pennsylvania State University

PI: Karen A. Thole / co-PI: Stephen P. Lynch

PM: Joshua Glottmann

Cost Share Partner(s): Pratt & Whitney

Objective:

Combustor Wall Cooling: Ingestion of dirt and other fine particles lead to blockages of cooling holes which ultimately diminishes the effectiveness of combustor wall cooling. The objective of this part of the study is to explore how cooling capabilities are impacted for new liner designs through detailed heat transfer measurements with and without dirt accumulation.

Combustor Simulator: Elevated temperatures and pressures exiting the combustor can affect the efficiency and durability of the high pressure turbine. The research objective is to design a non-reacting combustor profile simulator that produces total temperature and pressure profiles representative of those entering high pressure turbines using computational fluid dynamics (CFD) simulations.

Project Benefits:

Combustor Wall Cooling: The expected benefit from the dirt study is to better understand the effects of dirt accumulation on heat transfer rates across double-walled combustor liners. Combining this increased understanding of heat transfer with the use of prior dirt mitigation designs will lead to reduced turbine maintenance.

Combustor Simulator: The expected benefit from the combustor profile simulator is to understand how the different temperature and pressure profiles affect the efficiency and durability of hot turbine section components.

Research Approach:

The research approach for obtaining accurate heat transfer measurements within double-walled liners:

i. Design heater coupons with accurate temperature reading capabilities;
ii. Compare baseline (no dirt) heat transfer results of different heater coupons to relevant literature;
iii. Tests each heater coupon with and without dirt buildup.

The research approach for designing and manufacturing the combustor profile simulator:

i. Work in conjunction with Agilis (contracted design firm) to design the combustor simulator chamber shape and other rig components needed to install the combustor simulator into the START rig.
ii. Use CFD simulations to tailor specific profile shapes to certain targeted profiles.
iii. Benchmark the CFD simulations using a low speed linear cascade.
iv. Install and benchmark the complete combustor profile simulator in the START rig.

Major Accomplishments (to date):

Combustor Wall Cooling: Two different heater coupons have been tested with dirt and no dirt. Both designs have shown that dirt negatively impacts the rate of heat transfer.

Combustor Simulator: A number of CFD simulations using both Reynold's-averaged Navier-Stokes (RANS) and large eddy simulation (LES) models have been run. Currently, both models are being used to tailor the temperature and pressure profiles to the shapes desired.

Future Work / Schedule:

Combustor Wall Cooling: While continuing to validate the experimental dirt testing procedure, heat transfer measurements will be made on heater coupons with different dimensions and surface features.

Combustor Simulator: CFD simulations will continue to focus on generating profiles representative of real engine combustors. A range of profiles is generated by varying the dilution hole diameters, the mass flow rate through the dilution and effusion holes, and the supply temperatures.

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Increasing the Reynolds number decreased the peak height