Evaluating the Effect of Vane Trailing Edge Flow on Turbine Rim Sealing

Iván Monge-Concepción

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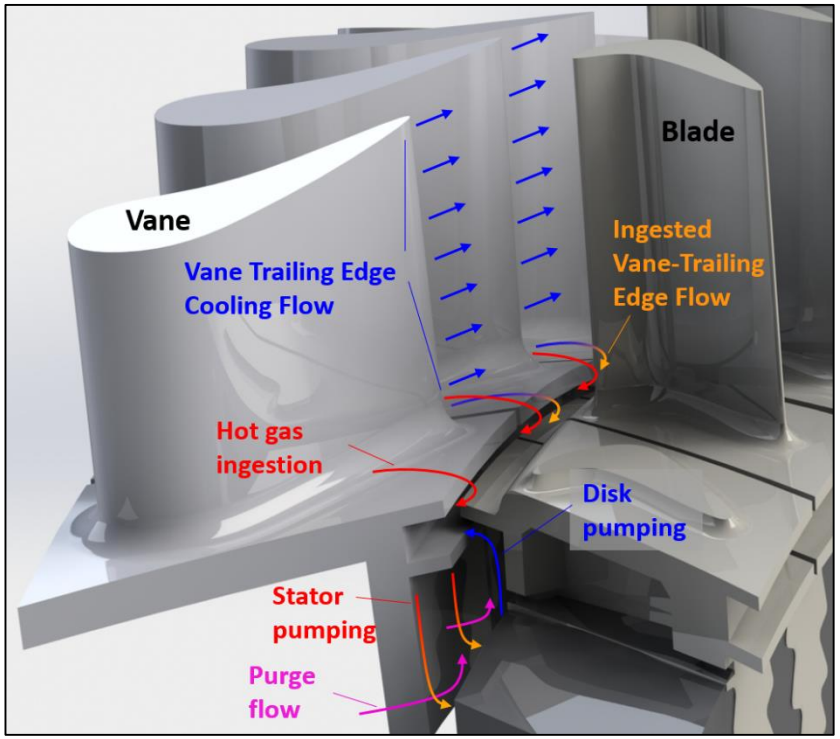
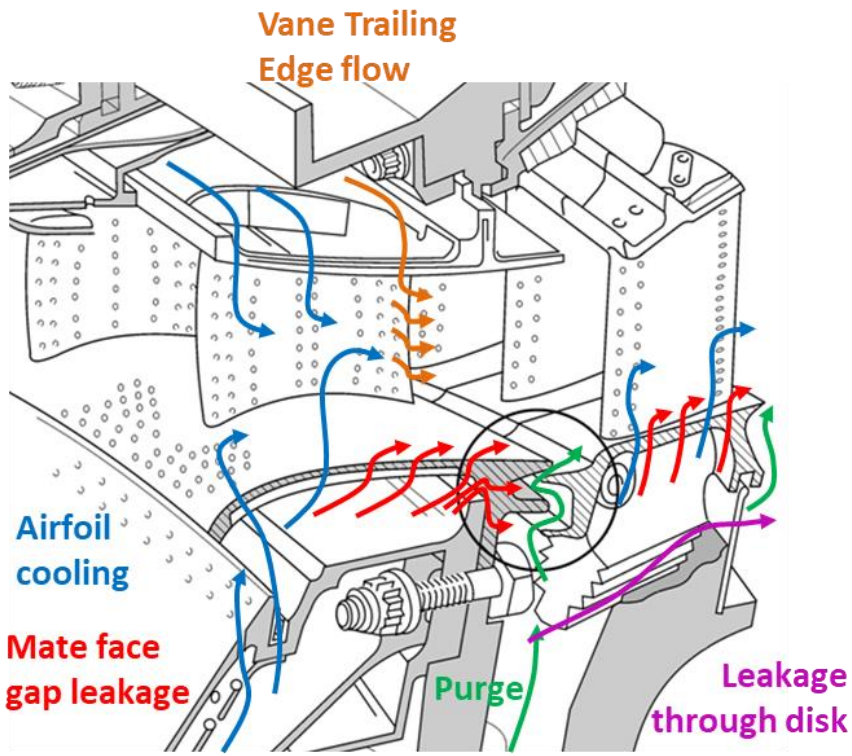
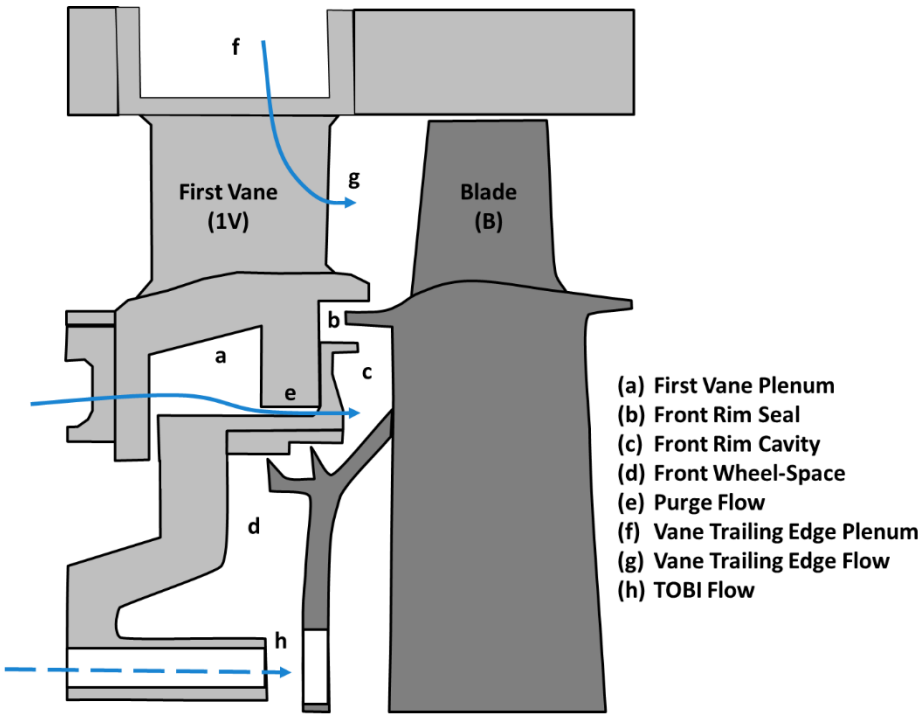


GT2019-91576

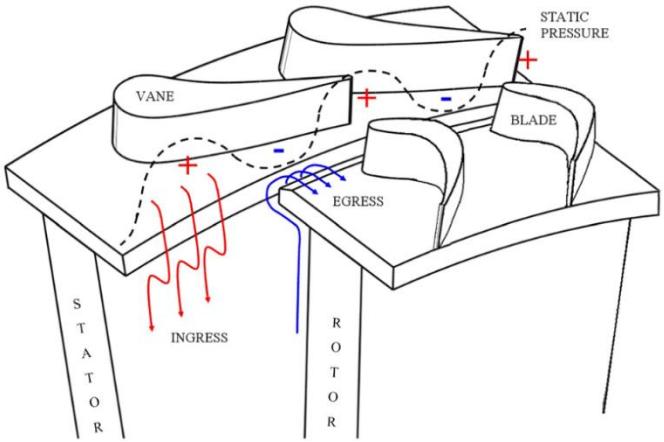
Turbine cooling flows are used to improve engine hardware durability, but at the cost of reduced engine efficiency

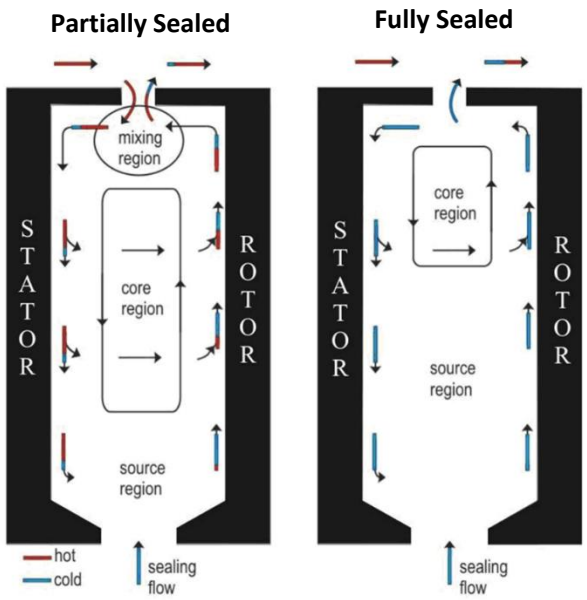


Sangan et. al, 2013

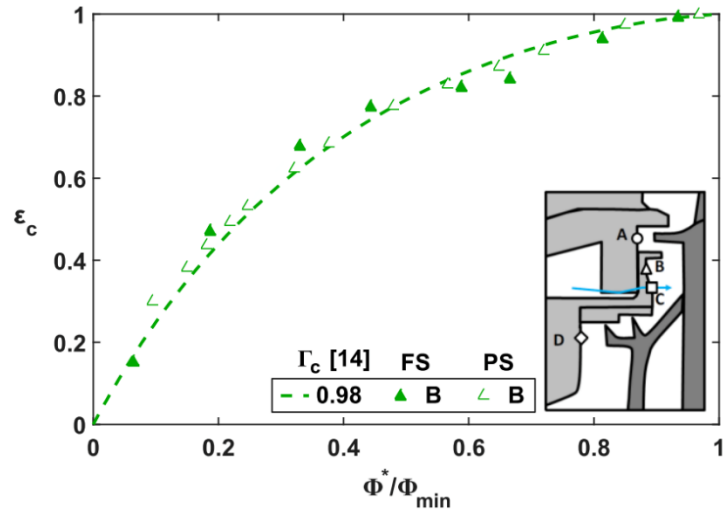


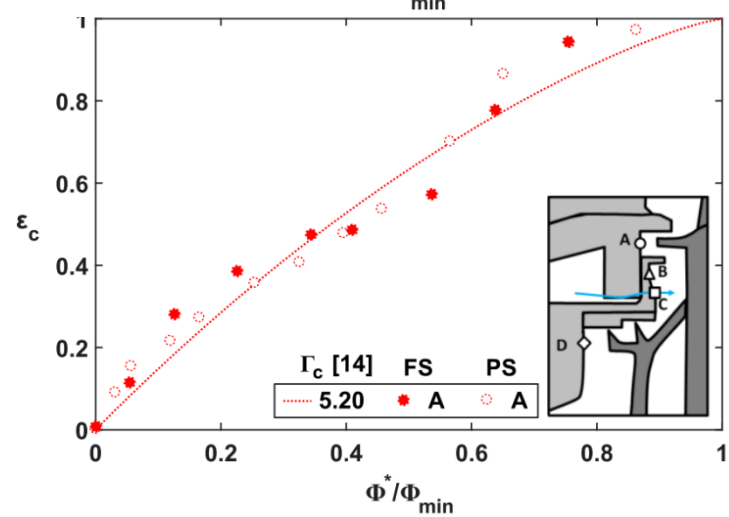
Previous research on rim sealing performance shows that externally induced ingestion is complex to model





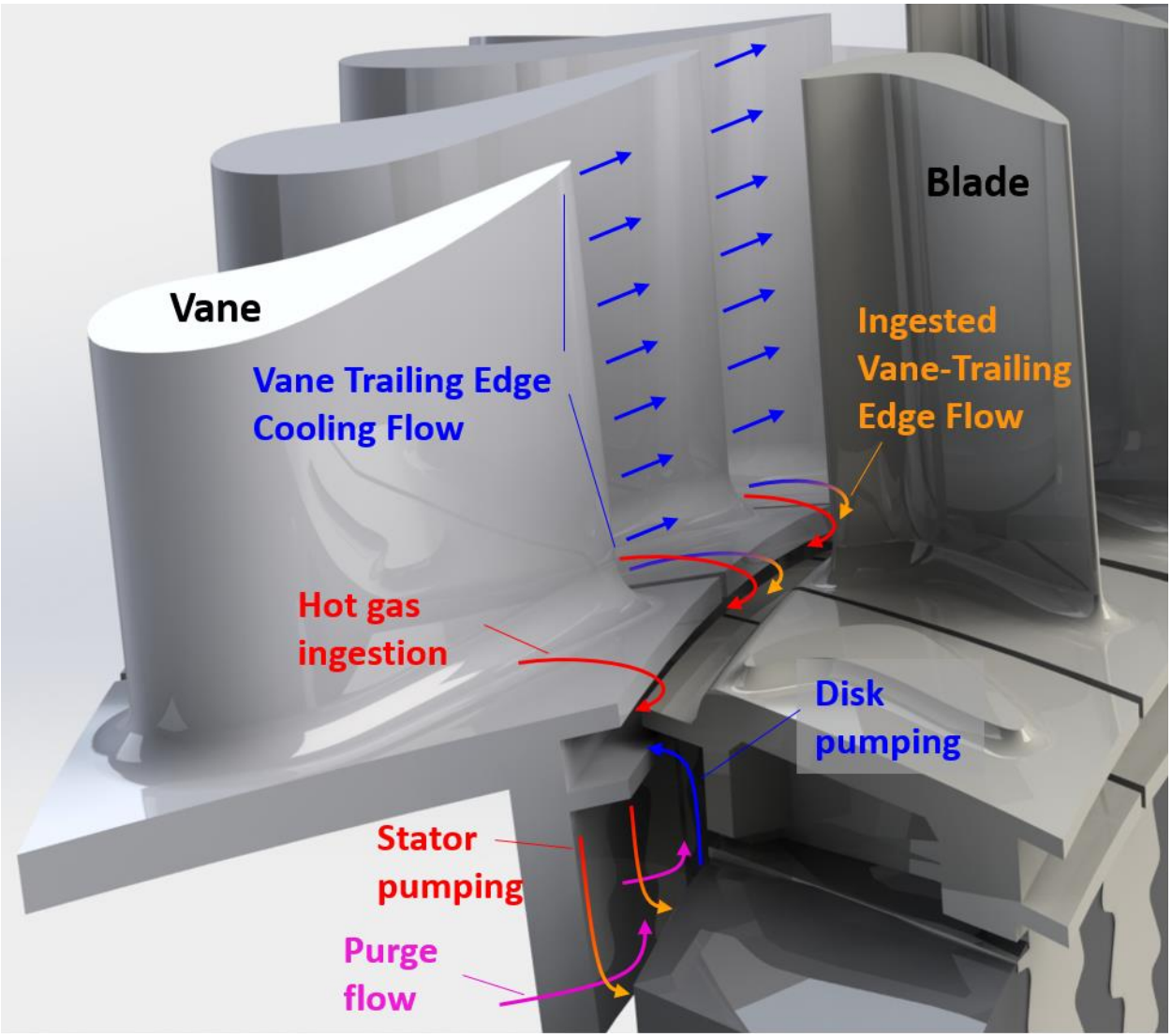
Sangan et. al, 2013



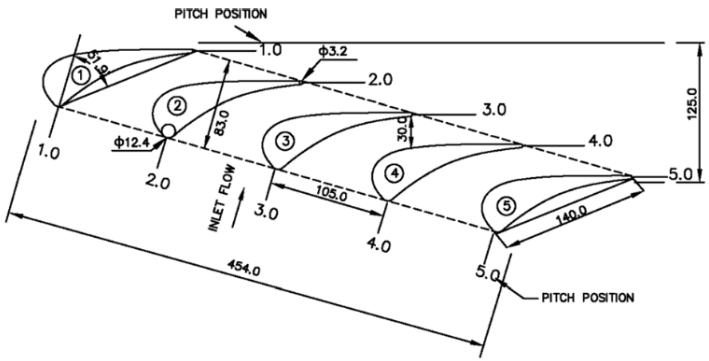


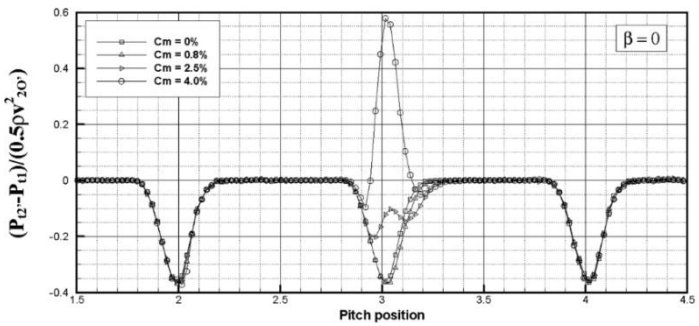
Berdanier et. al, 2018

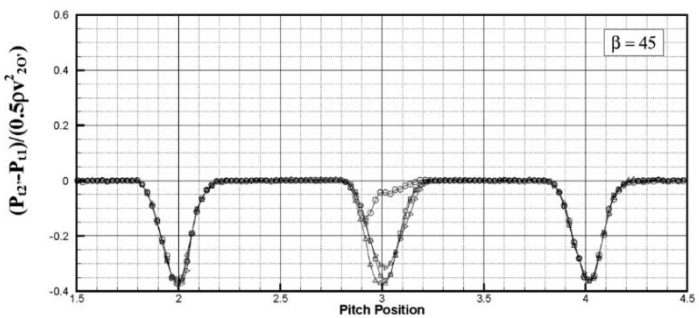
It is hypothesized that vane trailing edge (VTE) flow will have an effect on turbine rim cooling effectiveness



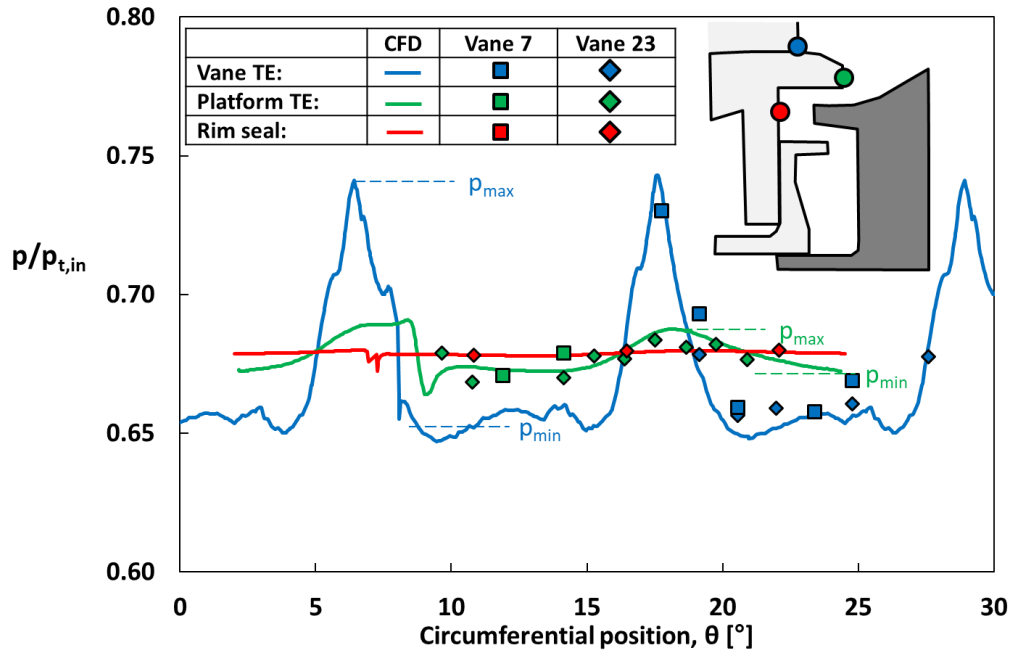
VTE flow is used to increase the total pressure loss caused by the vane wake





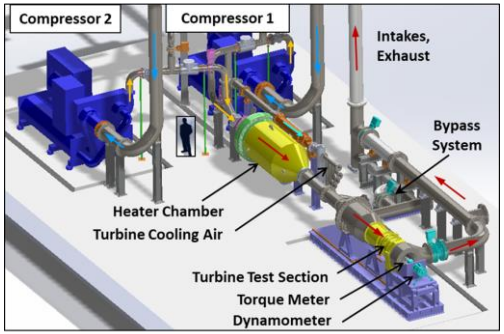


Aminossadati et. al, 2013

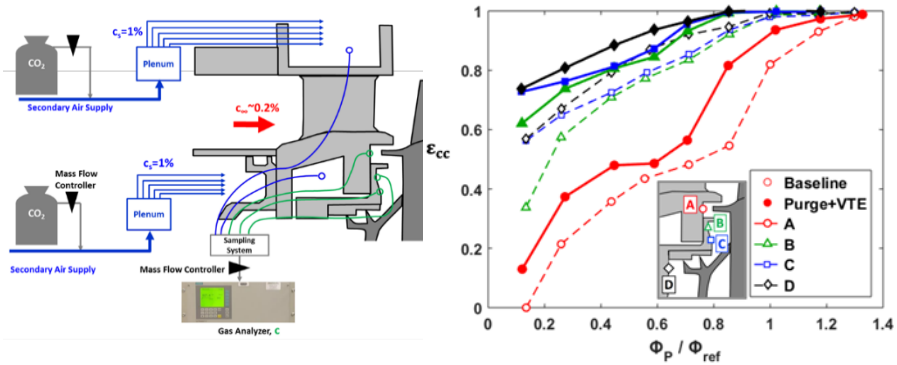


Clark et. al, 2017

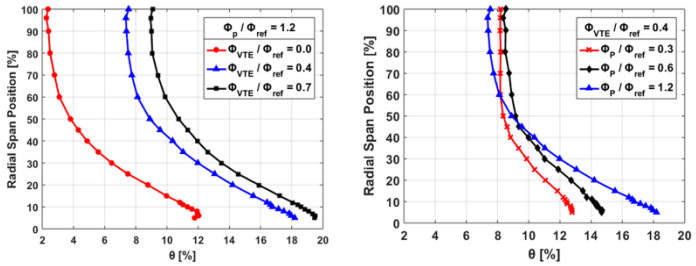
This presentation outlines motivation and results for the influence of VTE flow on rim cooling effectiveness



PSU-START facility description

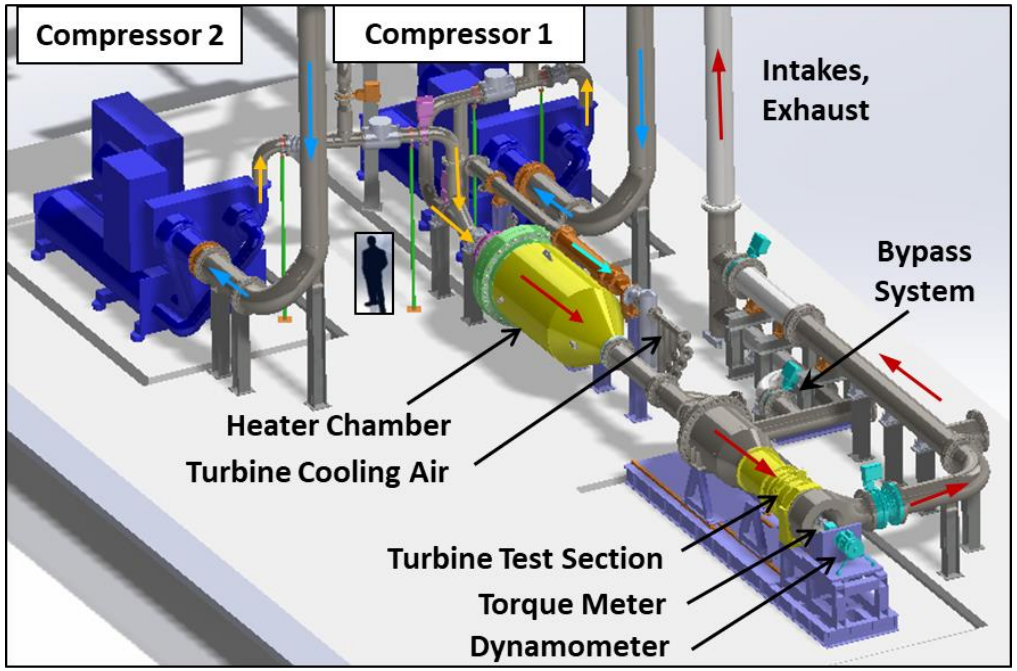


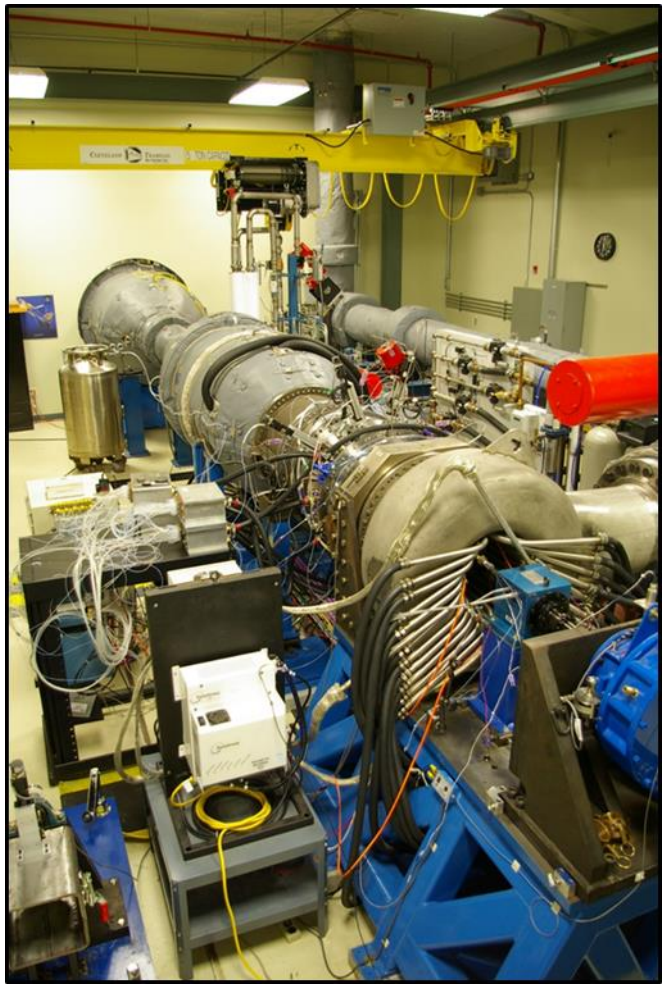
Influence of vane trailing edge (VTE) flow on rim cooling effectiveness



Cooling flow migration from the wheelspace cavity to main gas path

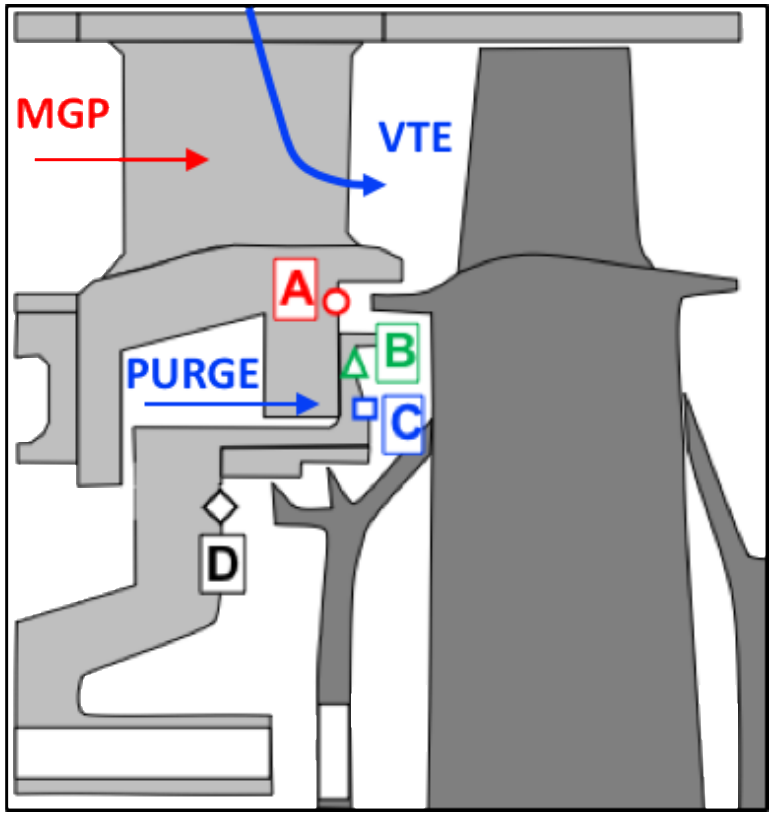
START is a continuous-duration turbine facility capable of replicating relevant turbine conditions and test parameters





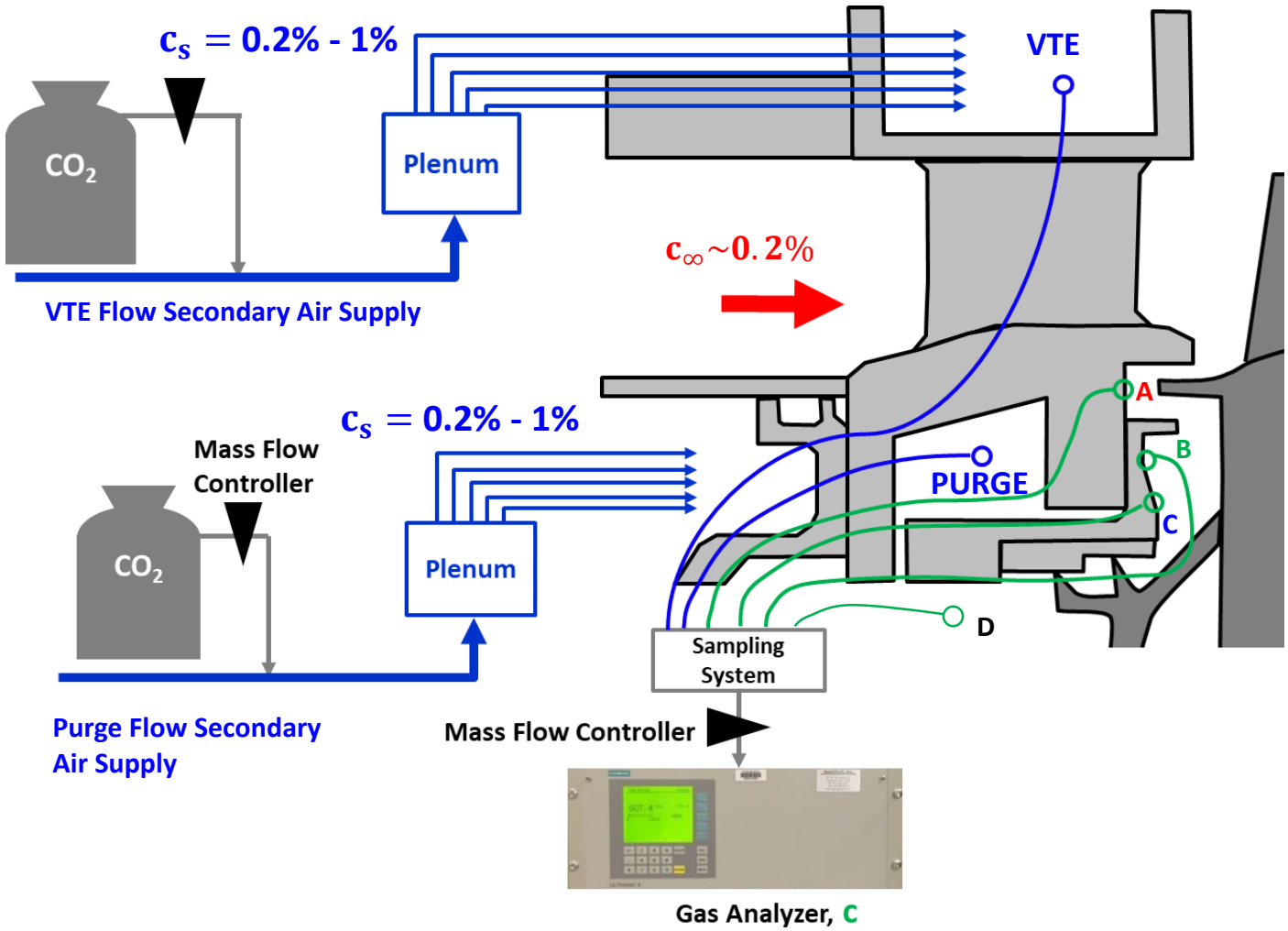
Turbine Conditions	Main Gas Path	Cooling Air
Pressure	2.5 - 5.5 bar (36 – 80 psia)	2.5 - 5.5 bar (36 – 80 psia)
Temperature	100 – 400 °C (212 – 750 °F)	> 0 °C (> 32 °F)
Mass Flow Rate	≤ 11.4 kg/s (≤ 25.1 lb_m/s)	< 1.4 kg/s (< 3.1 lb_m/s)

Rim cooling effectiveness was studied at four radial locations using different cooling flow and CO_2 combinations

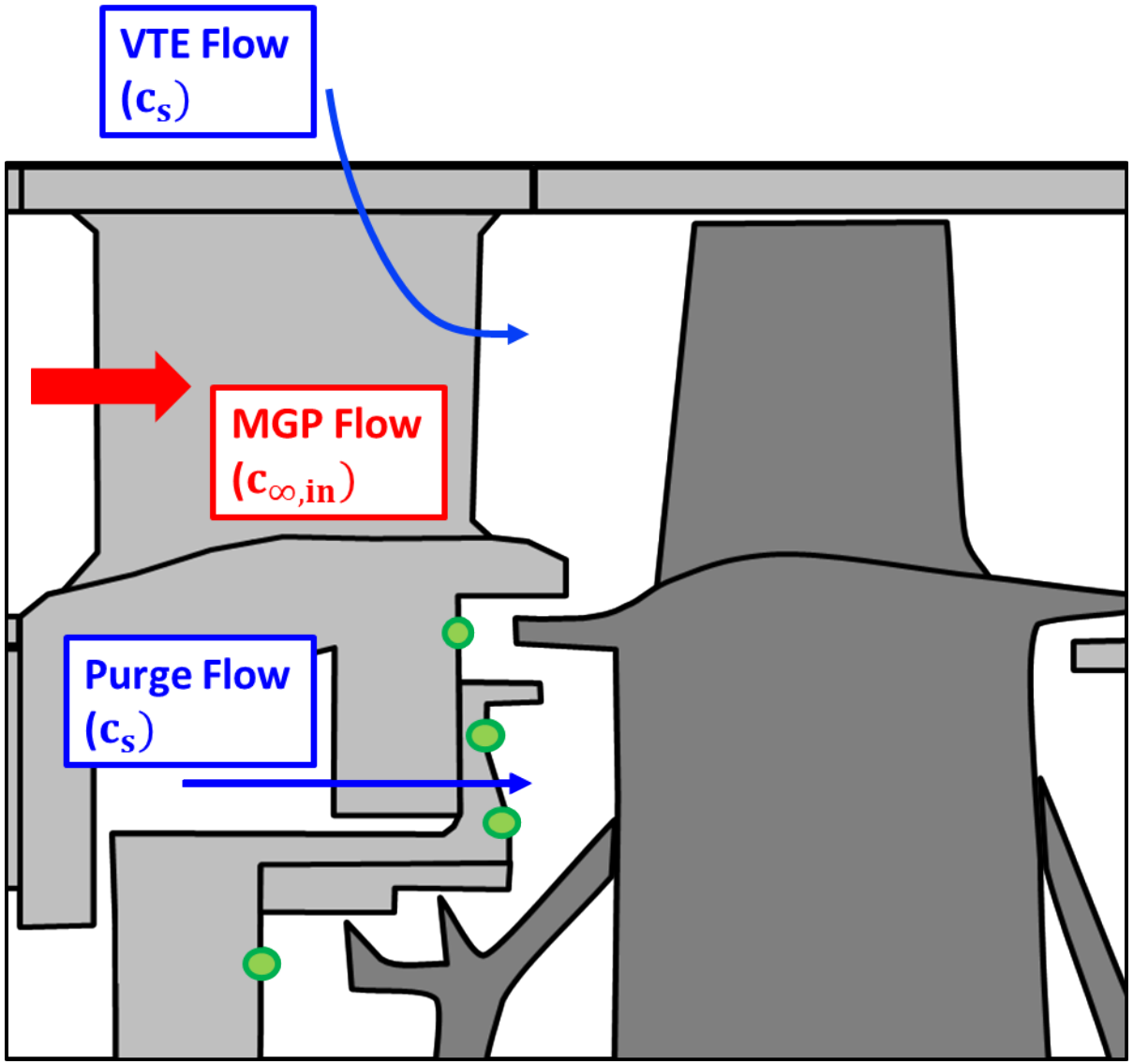


Location	Name
A	Front Rim Seal (FRS)
B	Front Rim Cavity A (FRCA)
C	Front Rim Cavity B (FRCB)
D	Front Wheelspace Cavity (FWSC)

Measurement taps were used to study the VTE and purge contributions to the CO_2 concentration at the four locations



Rim cooling effectiveness was defined to take into account that the VTE cooling flow originates from the main gas path

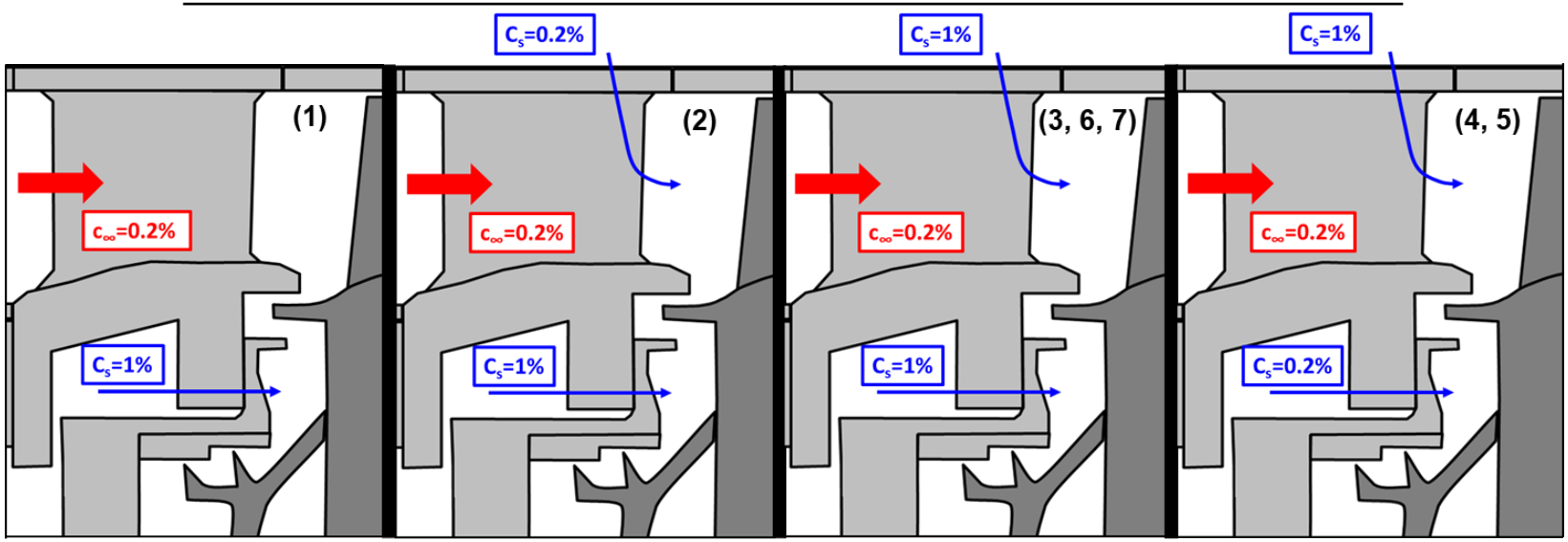


Rim Sealing Effectiveness

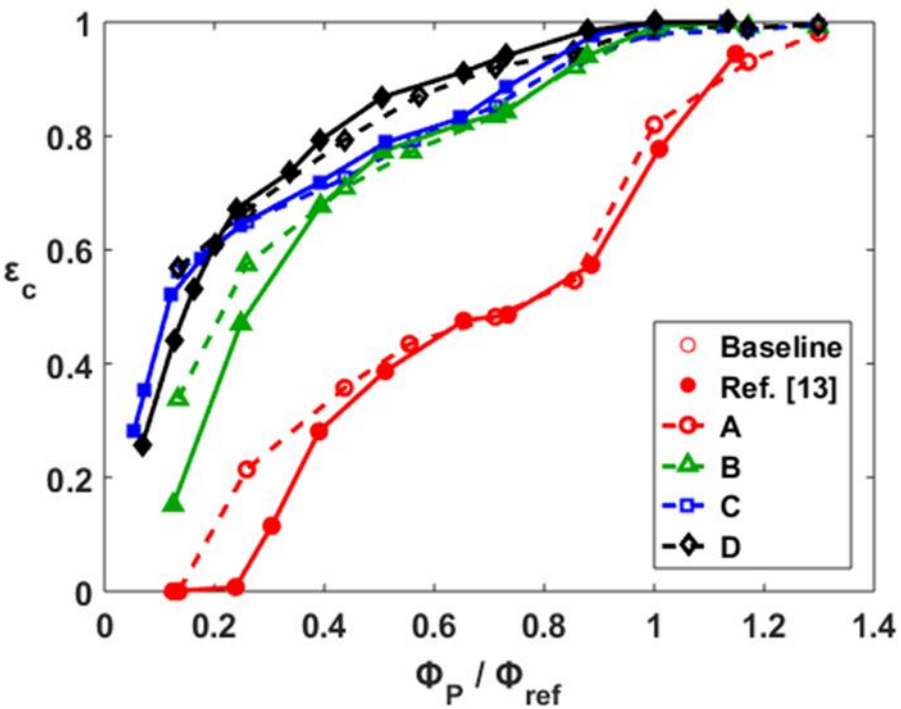
$$\varepsilon_c = \frac{c - c_{\infty,in}}{c_s - c_{\infty,in}}$$

Various CO_2 seeding configurations were used to study the independent contributions of purge and VTE flow

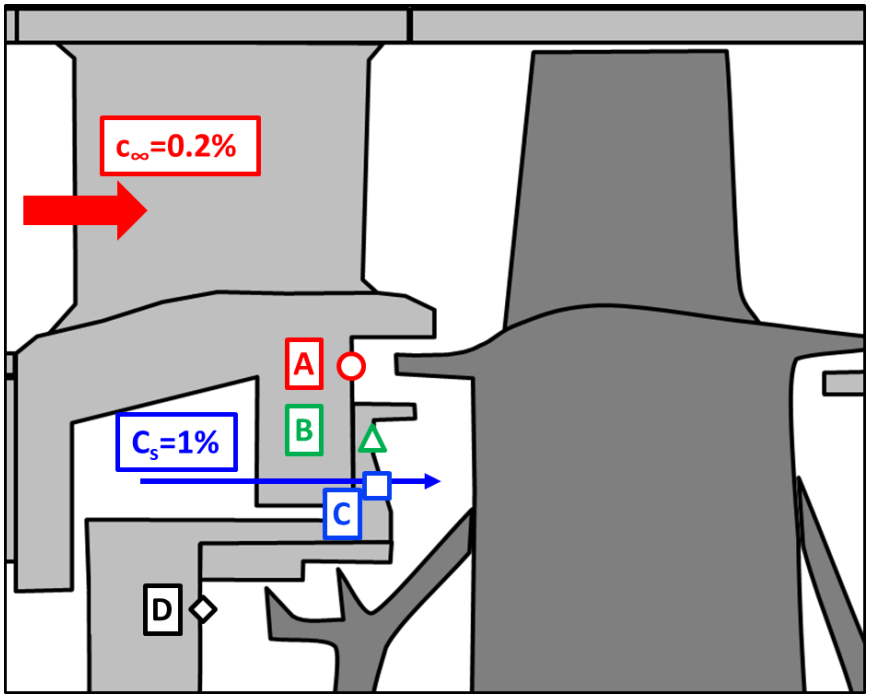
CO_2 Seed Configuration	MGP Background CO_2 Level	Purge Flow CO_2 Level	VTE CO_2 Level	Φ_P/Φ_{ref}	Φ_{VTE}/Φ_{ref}
(1) Baseline	0.2%	1.0%	No Flow	0.1 – 1.3	No Flow
(2) Purge	0.2%	1.0%	0.2%	0.1 – 1.3	0.4
(3) Purge+VTE	0.2%	1.0%	1.0%	0.1 – 1.3	0.4
(4) VTE1	0.2%	0.2%	1.0%	0.1 – 1.3	0.4
(5) VTE2	0.2%	0.2%	1.0%	0.4	0.1 – 0.7
(6) VTEMigration	0.2%	1.0%	1.0%	1.2	0 – 0.7
(7) PurgeMigration	0.2%	1.0%	1.0%	0.3 – 1.2	0.4



A baseline study without VTE flow present shows that rim sealing effectiveness data is repeatable to previous studies



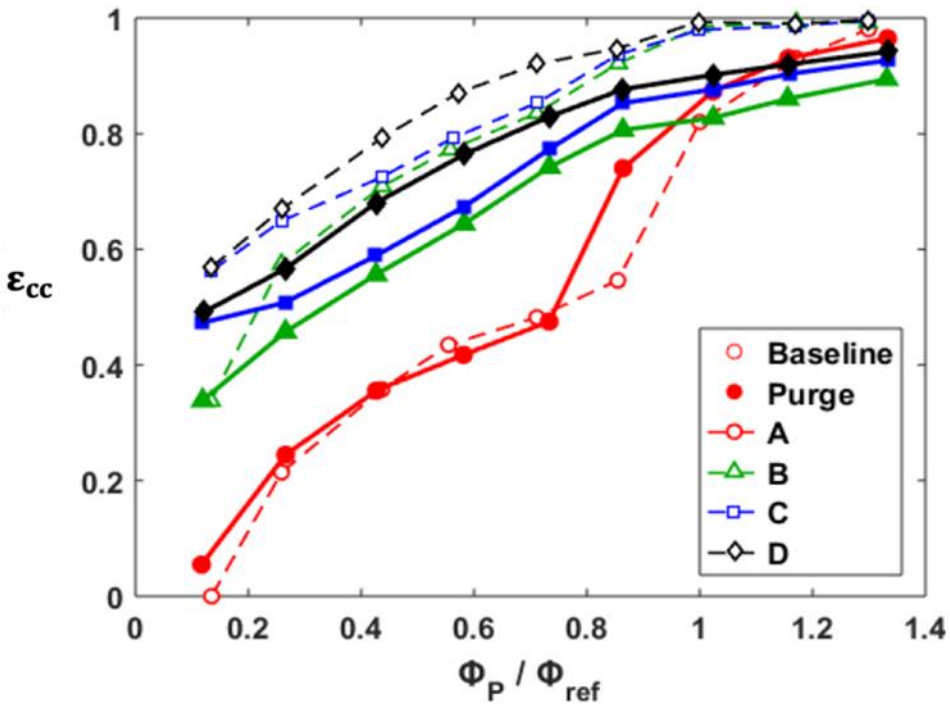
Berdanier et. al, 2019

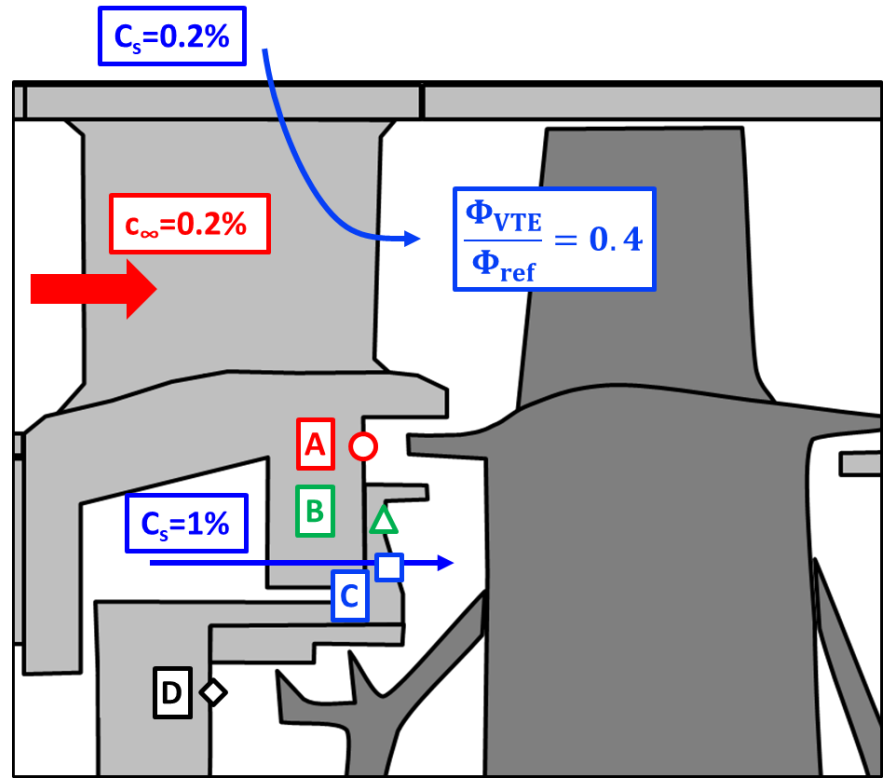


$$\Phi = \frac{\dot{m}}{2\pi s_c \rho \Omega b^2}$$

Φ_{ref} is the reference purge flow rate for a fully sealed condition at Location B

With VTE flow present there was a surprisingly small effect found at the rim seal, but a larger effect at inboard locations

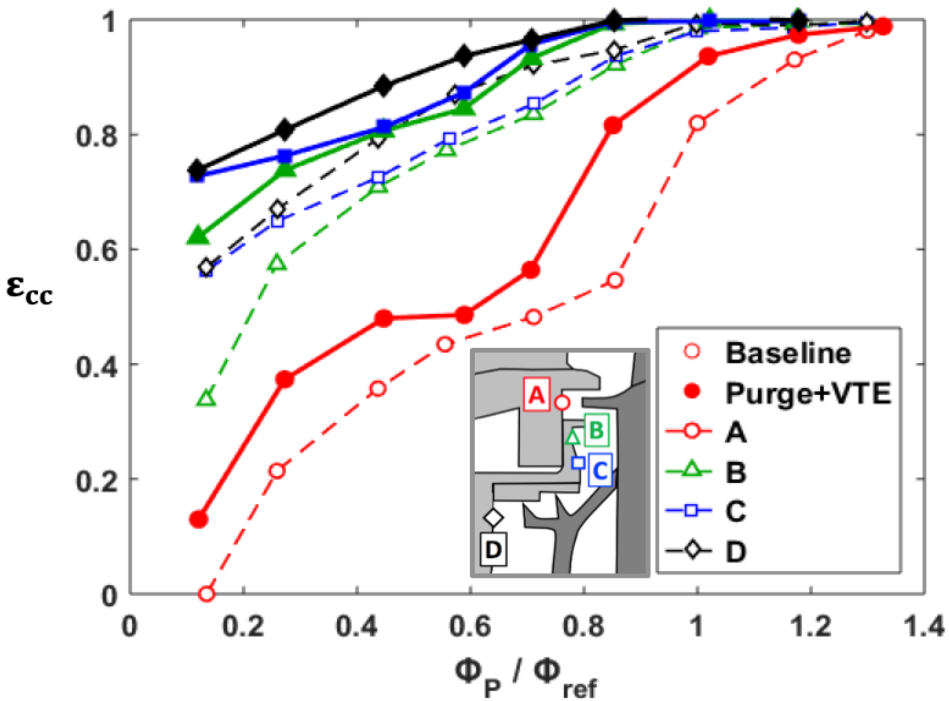


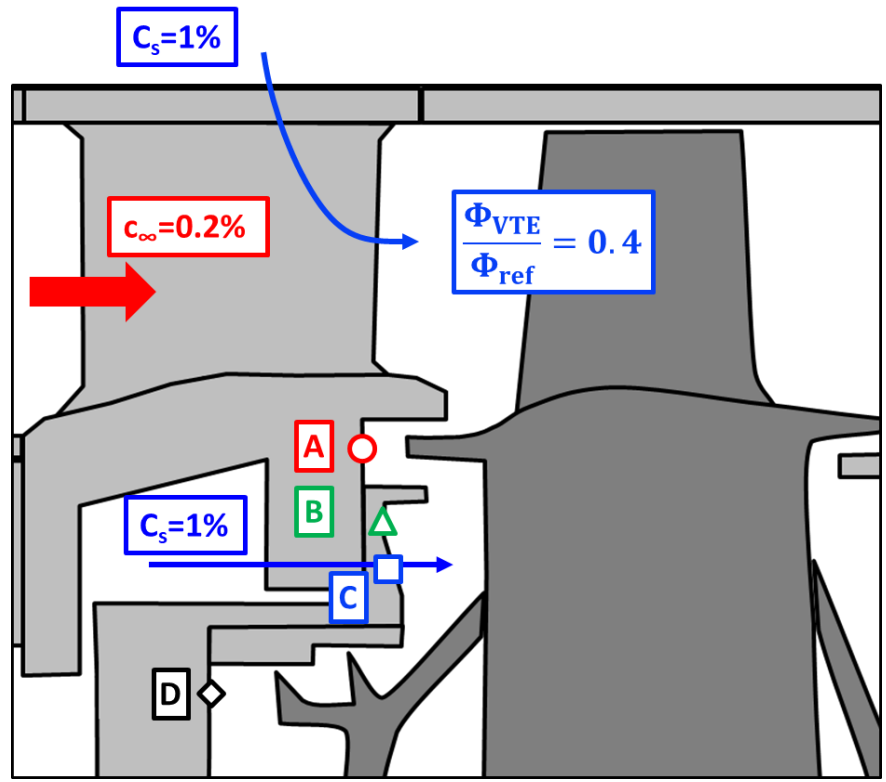


$$\Phi = \frac{\dot{m}}{2\pi s_c \rho \Omega b^2}$$

Φ_{ref} is the reference purge flow rate for a fully sealed condition at Location B

VTE flow has a positive overall effect in combination with the purge flow on rim cooling effectiveness

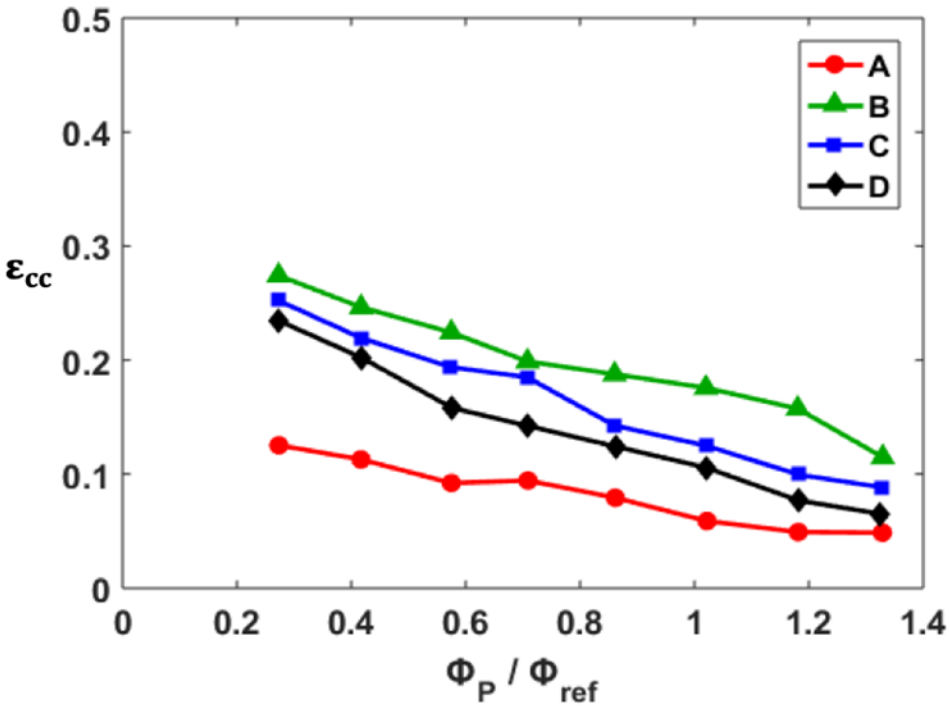


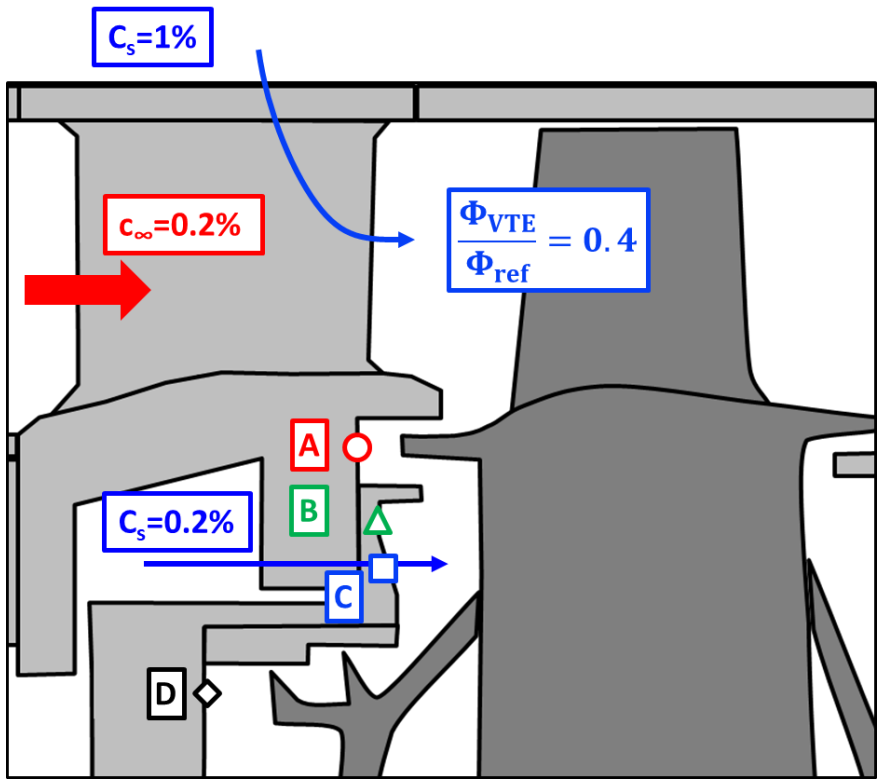


$$\Phi = \frac{\dot{m}}{2\pi s_c \rho \Omega b^2}$$

Φ_{ref} is the reference purge flow rate for a fully sealed condition at Location B

Increasing the purge flow decreases the influence of VTE flow due increased wheelspace cavity pressure



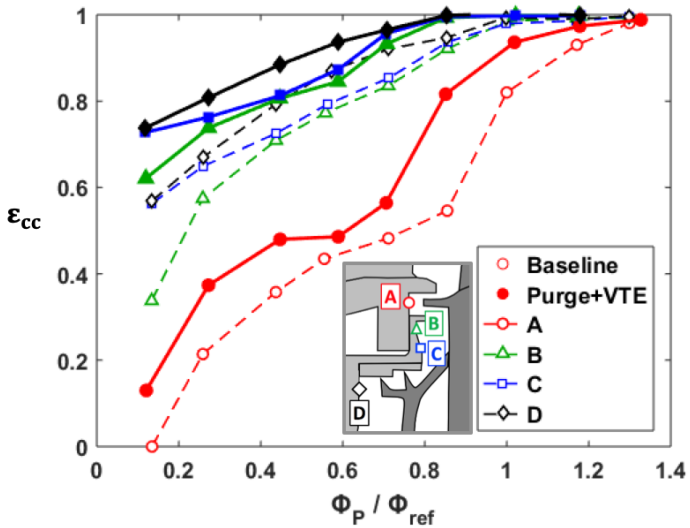


$$\Phi = \frac{\dot{m}}{2\pi s_c \rho \Omega b^2}$$

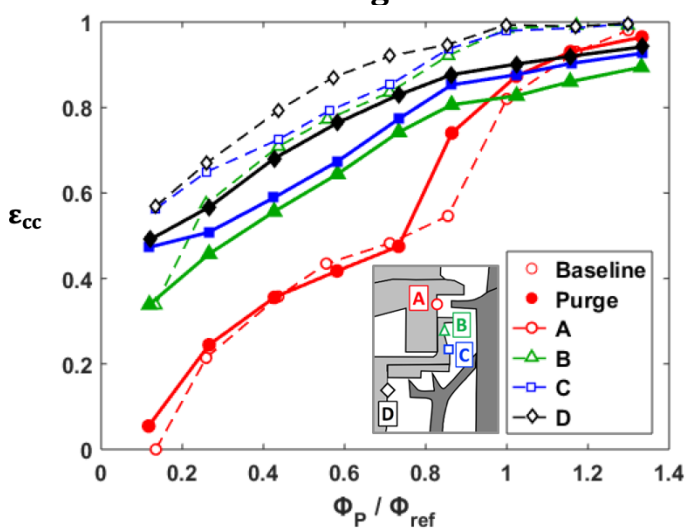
Φ_{ref} is the reference purge flow rate for a fully sealed condition at Location B

With VTE and purge flows present, linear superposition can be used to predict rim cooling effectiveness

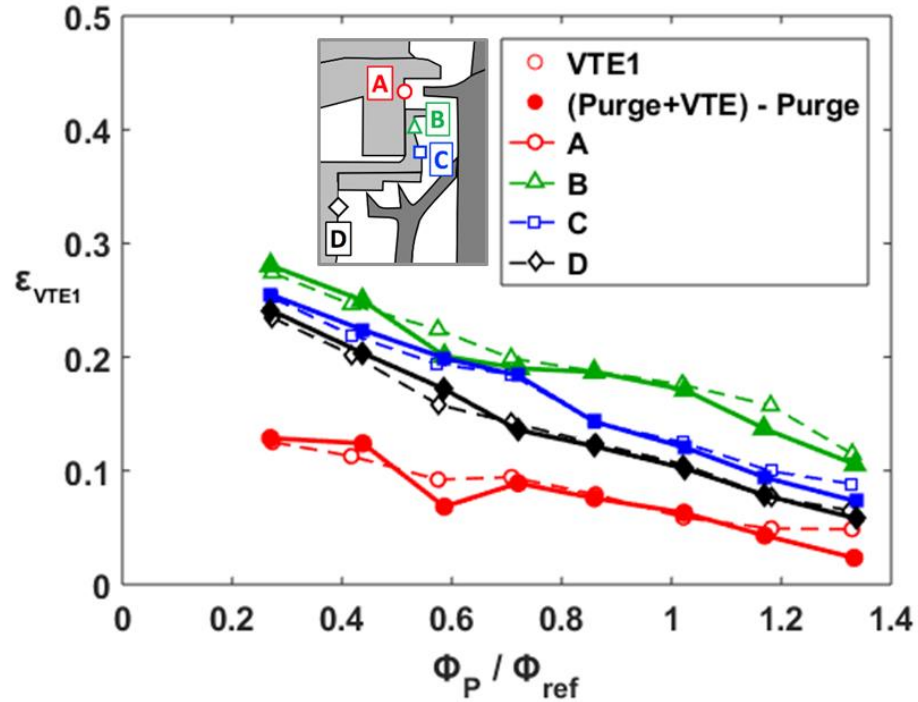
$\varepsilon_{Purge+VTE}$



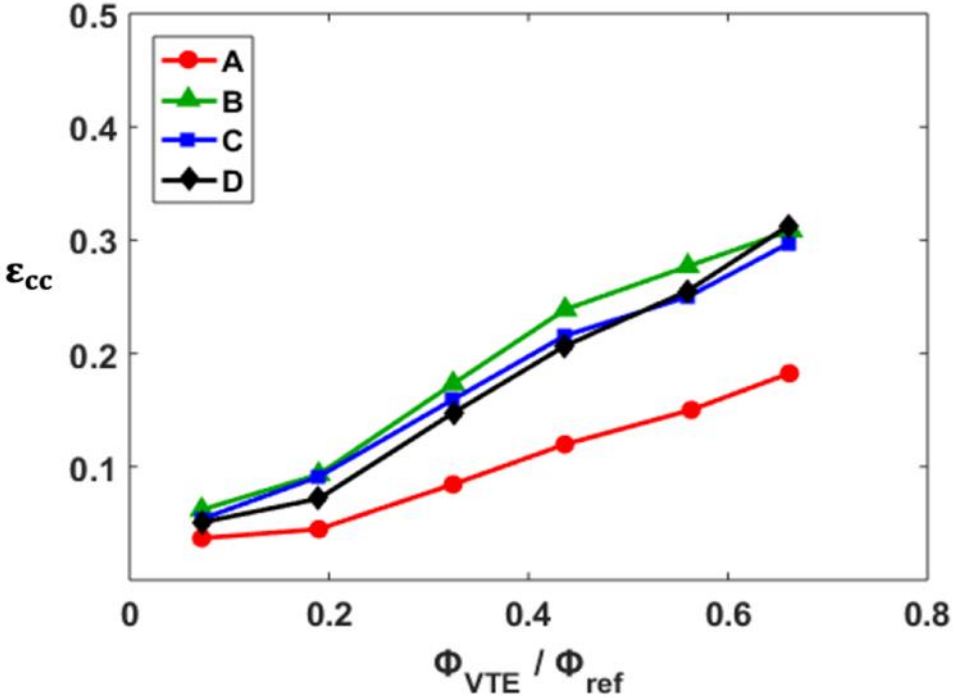
ε_{Purge}

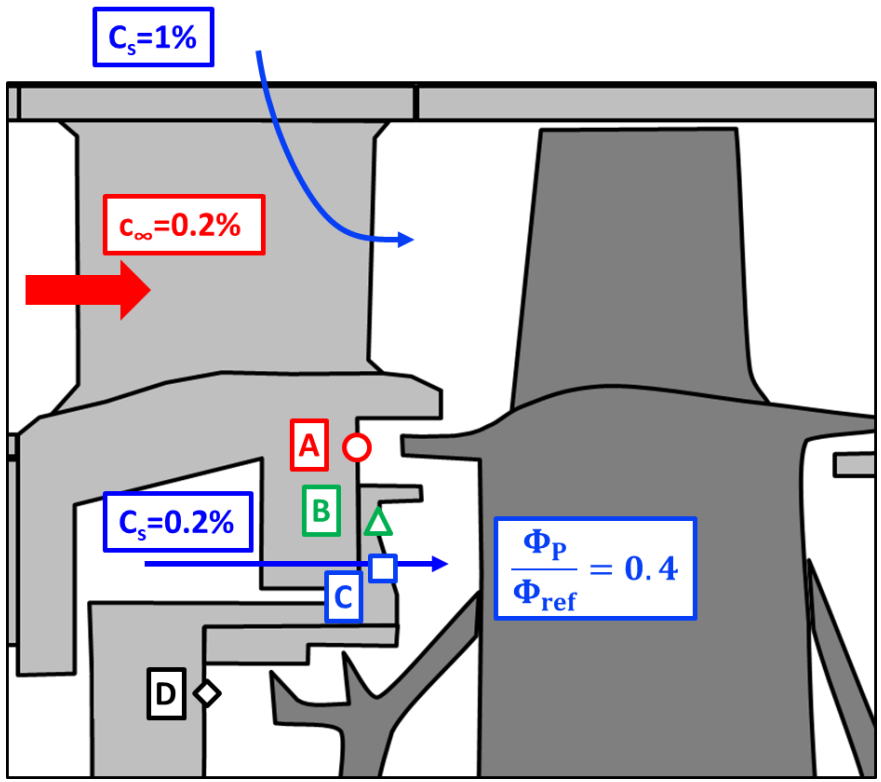


$\varepsilon_{Purge+VTE} = \varepsilon_{Purge} + \varepsilon_{VTE1}$



When purge flow is fixed and VTE flow is varied, cooling effectiveness in the rim seal is affected less than inboard

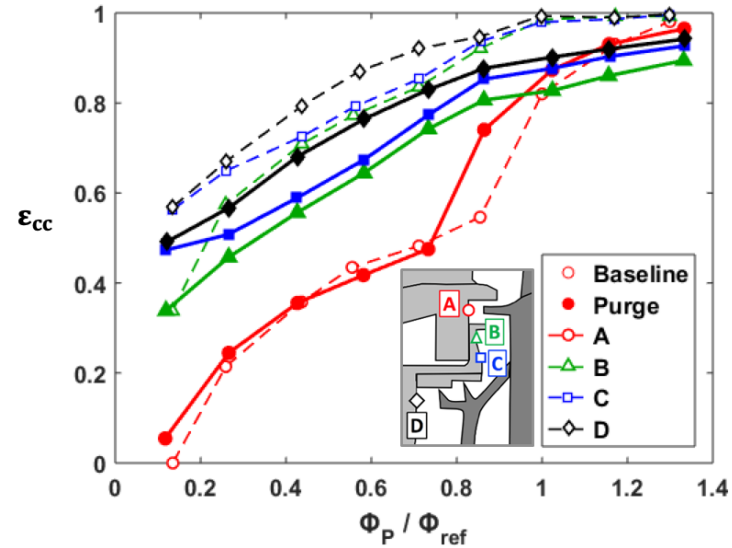


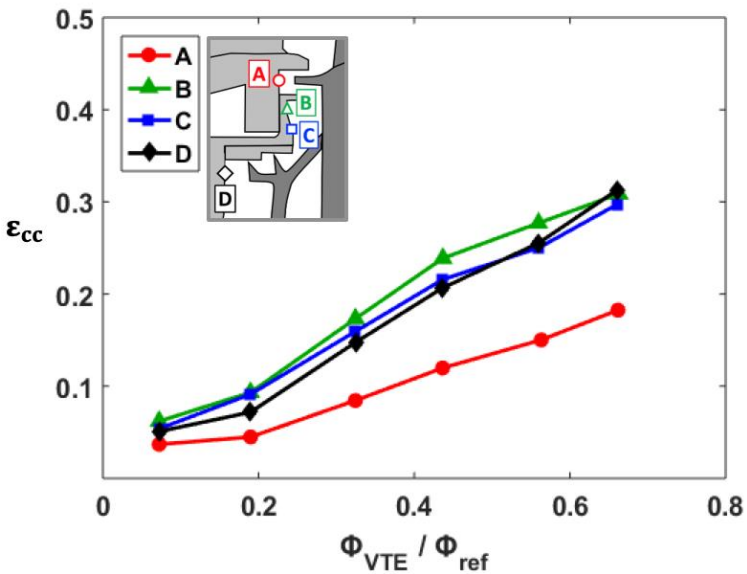


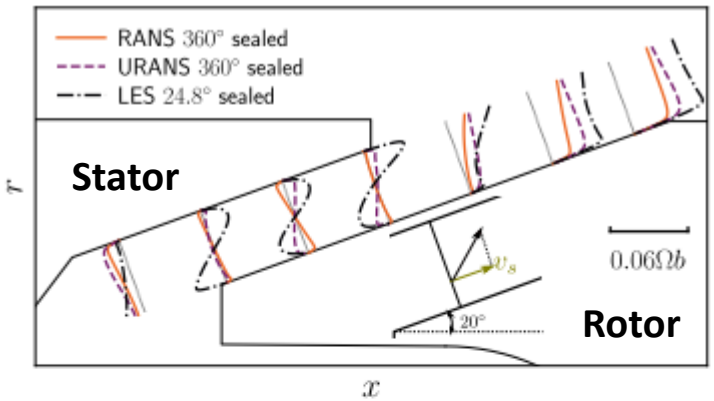
$$\Phi = \frac{\dot{m}}{2\pi s_c \rho \Omega b^2}$$

Φ_{ref} is the reference purge flow rate for a fully sealed condition at Location B

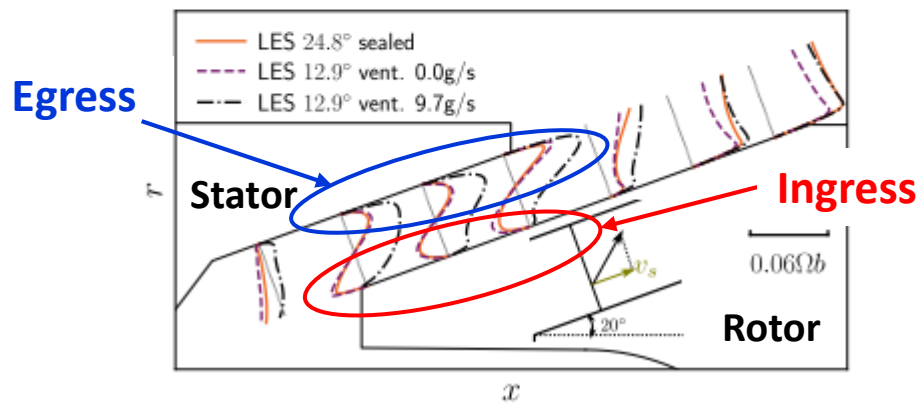
Recent literature has reported that high fidelity CFD models such as URANS and LES show ingress on the rotor side







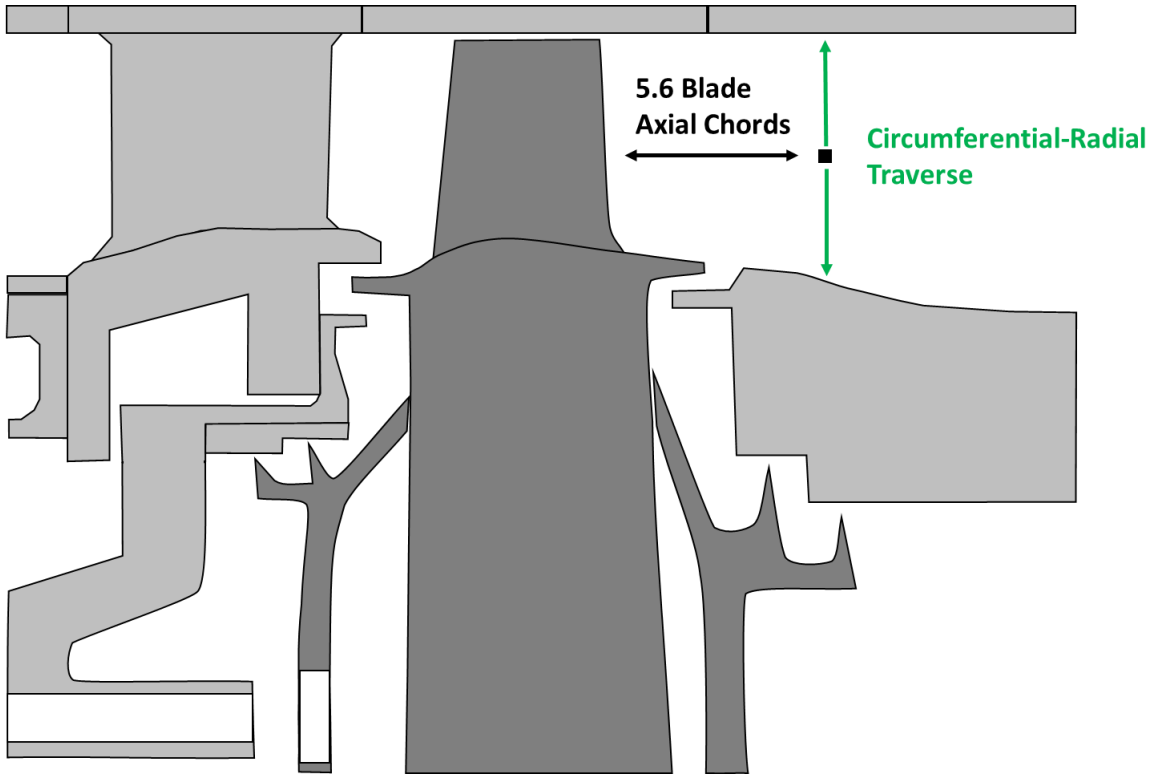
(a) RANS, URANS, and LES

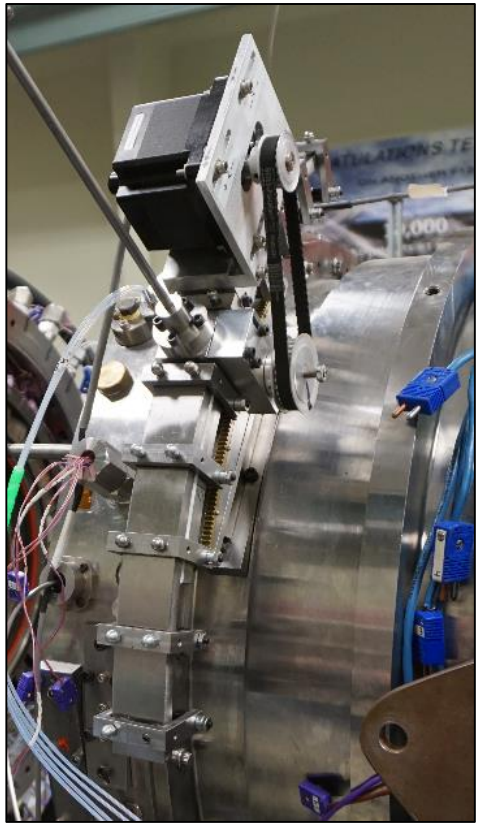


(b) LES

Gao et. al, 2018

A circumferential sector traverse was installed aft of the rotor to study cooling flow migration into the main gas path



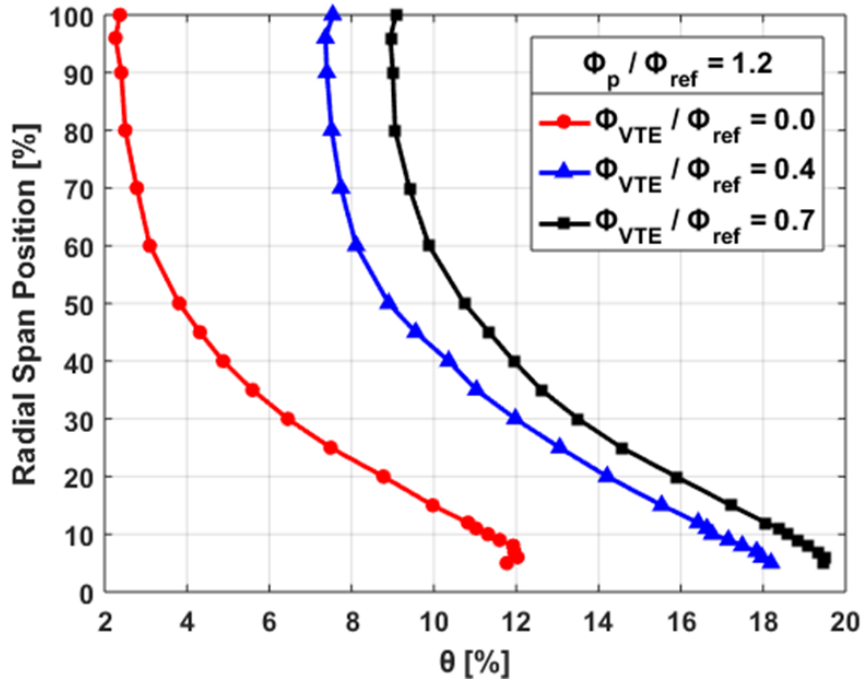


CO_2 tracing was performed in the main gas path with the use of a circumferential traverse to trace cooling flow migration

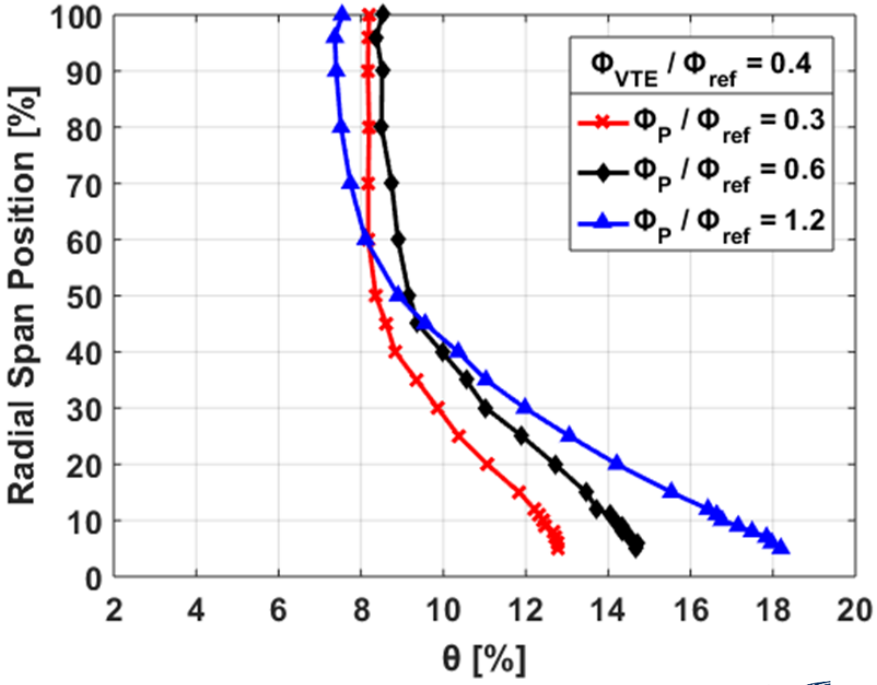
$$\theta = \frac{c - c_\infty}{c_s - c_\infty} \approx \varepsilon_{cc}$$

Blue = Same Flow Conditions

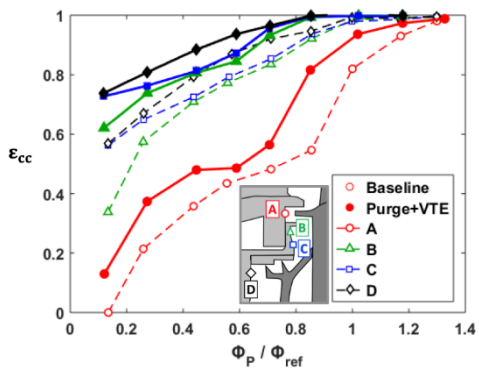
Constant Purge Flow
Varying VTE Flow



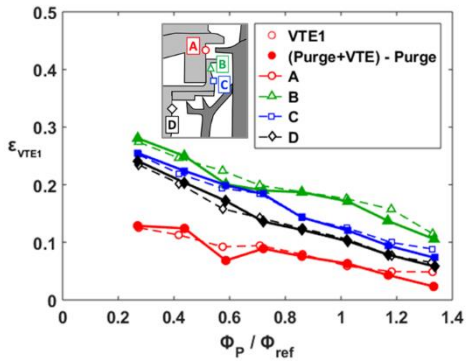
Varying Purge Flow
Constant VTE Flow



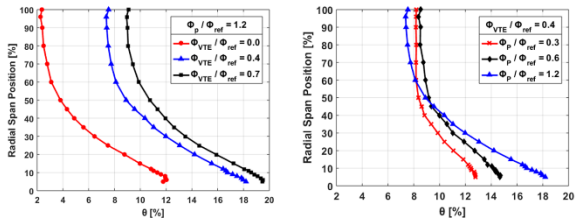
This study identified that vane trailing edge flow is ingested into the wheelspace and affects rim cooling effectiveness



Vane Trailing Edge flow has an impact on rim cooling effectiveness

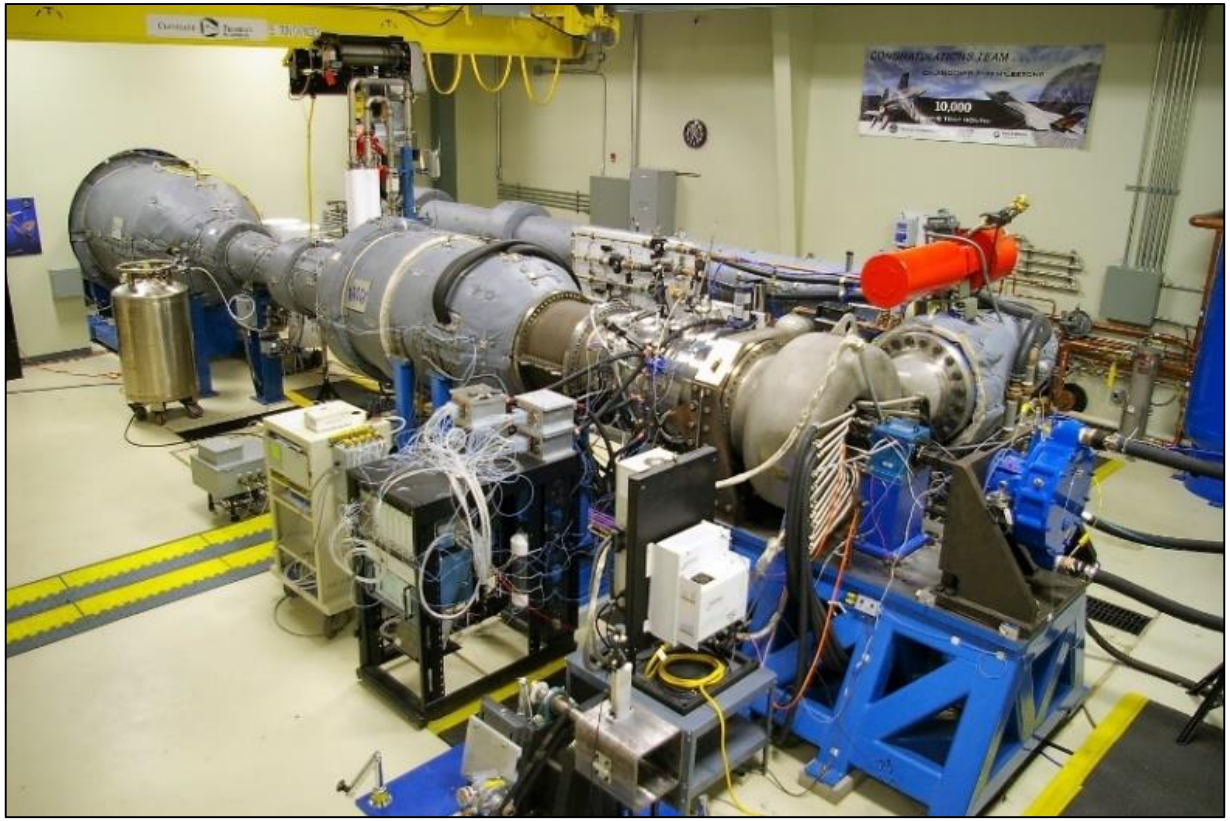


Superposition can be used to predict cooling effectiveness across seeding configurations



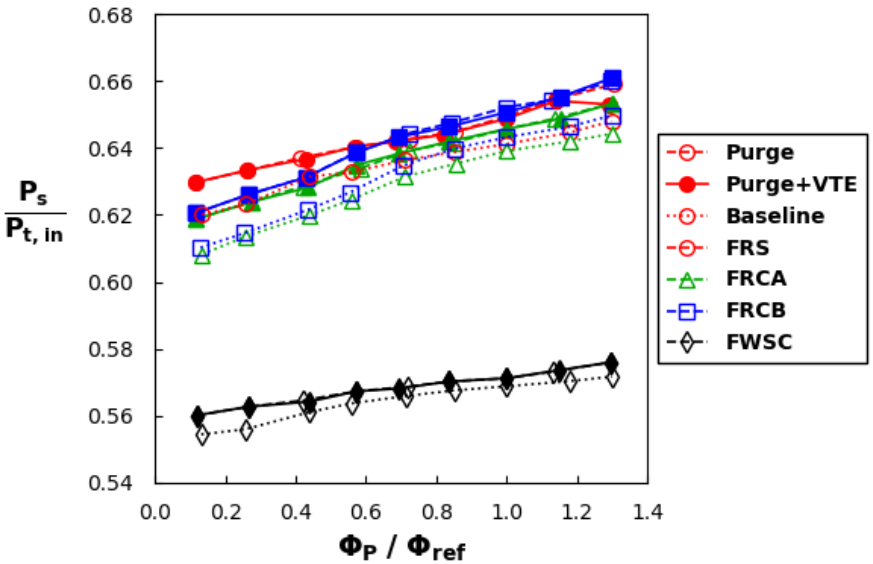
Circumferential traverse surveys confirm VTE ingestion into the wheelspace cavity

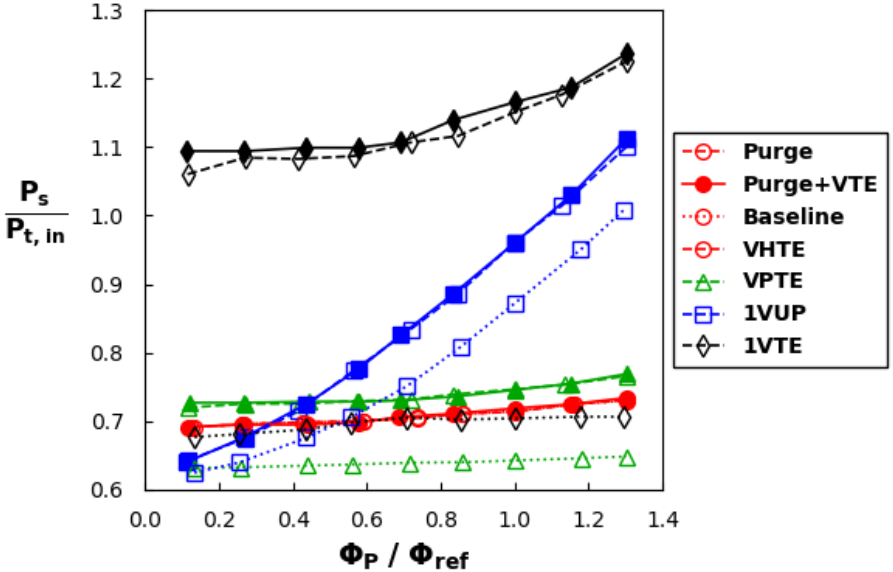
Thank you for your attention.



Backup Slides

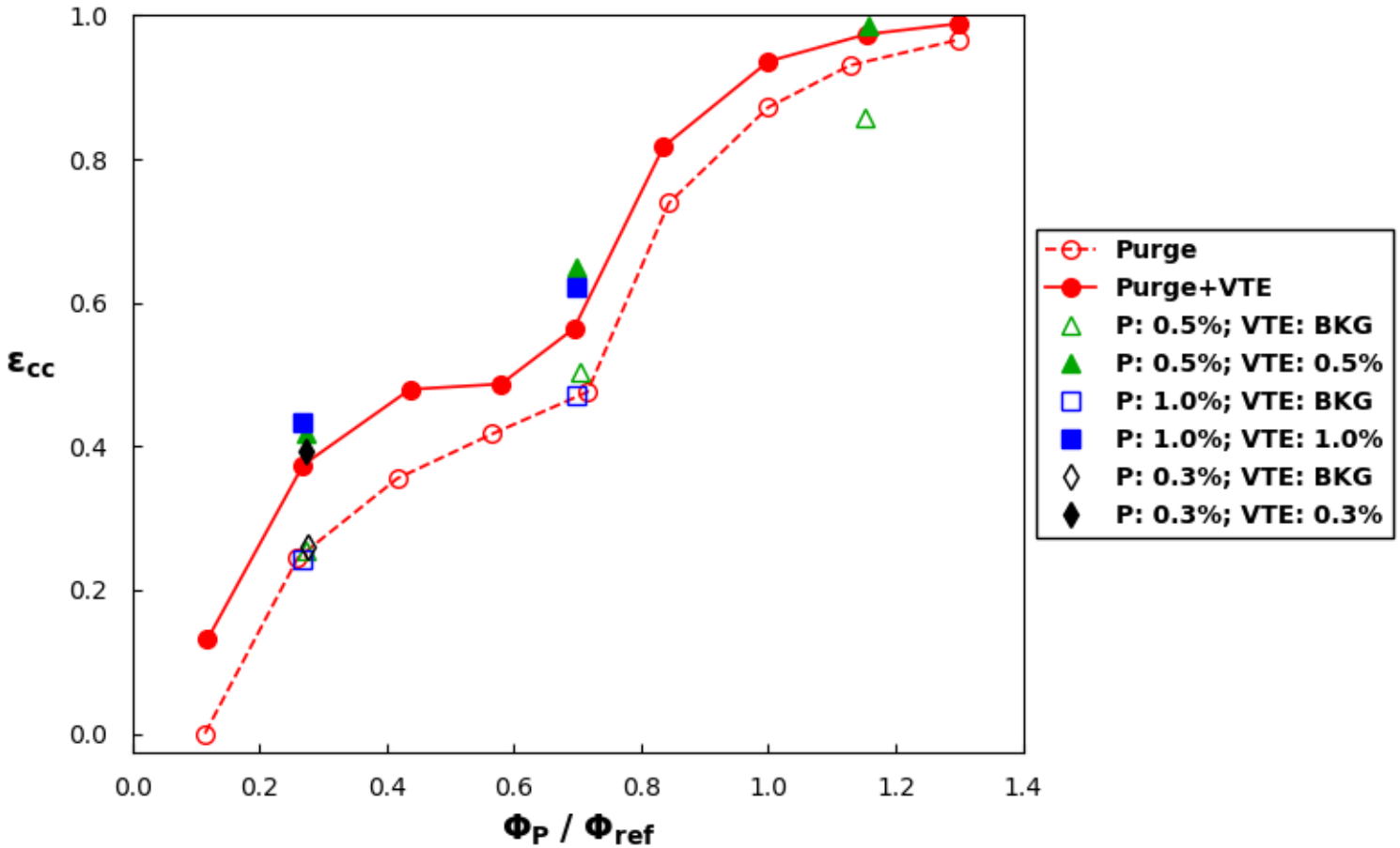
Pressure studies show that from Purge to Purge+VTE, there is no difference in flow field.





The addition of VTE flow increases the pressures inside the wheelspace cavity when comparing with Baseline.

Using different CO_2 configurations yield the same results as the ones presented in the paper.



This confirms that the effectiveness ratio holds on a day to day operation.