GT2022-81587

GO BEYOND

CLEARANCE SENSITIVITY MITIGATION IN SMALL CORE COMPRESSORS

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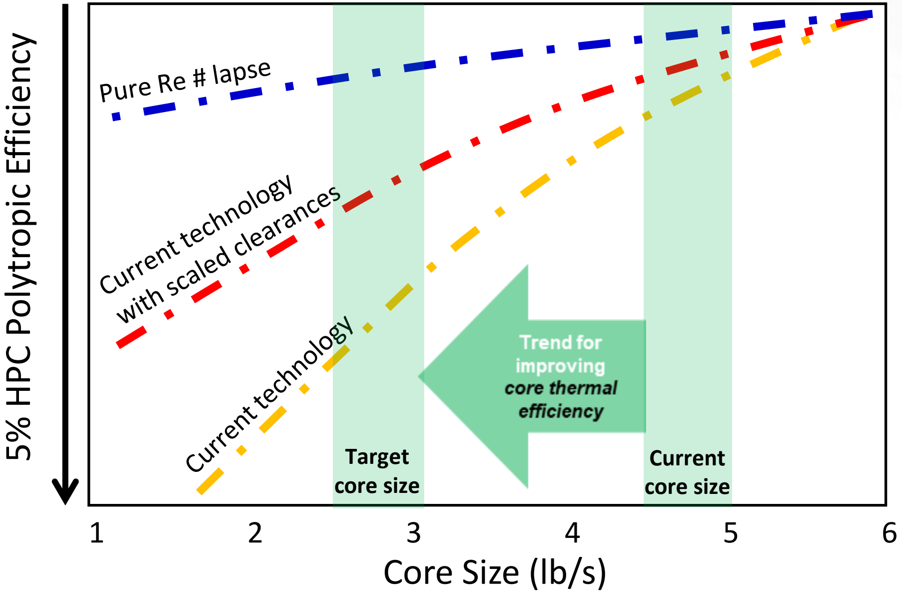
JUNE 13-17, 2022

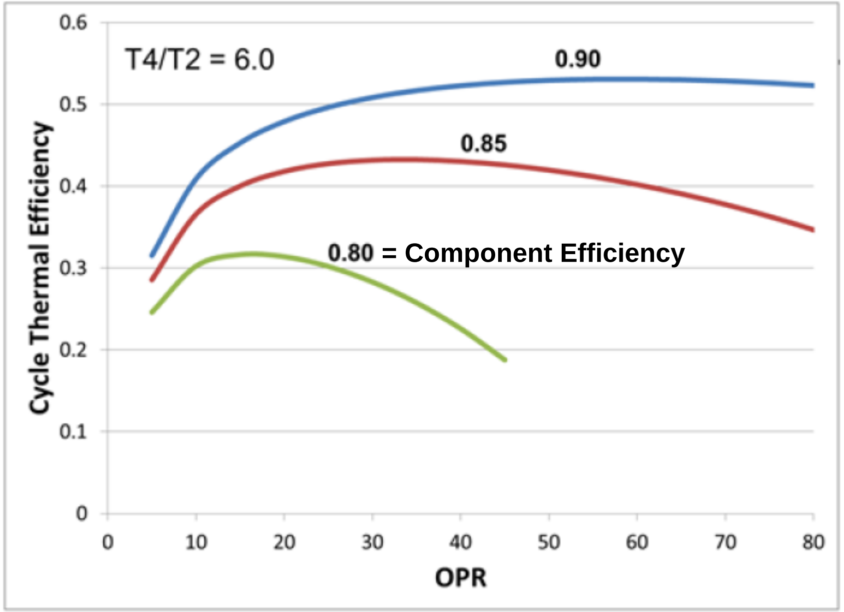
MOTIVATION

REDUCED CORE SIZES ASSOCIATED WITH INDUSTRY TRENDS WILL CAUSE AN EFFICIENCY PENALTY IF NOT ADDRESSED



MOTIVATION

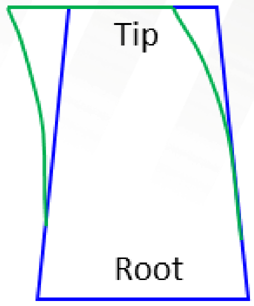
EFFICIENCY LOSS WITH CORE SIZE NEGATES BENEFIT OF HIGH OPR CYCLE



TECHNOLOGY STUDIED

TECHNOLOGY WAS INSERTED INTO THE COMPRESSOR TO RECOVER THE SMALL CORE EFFICIENCY FALL-OFF

- Advanced forward sweep
  – Unloads the leading edge at the tip [1]
  – Increases meridional momentum in the tip [2]
  – Increases range & reduces sensitivity to clearance [3-5]
  – Aero benefits balanced with real-world constraints, incl. stress & radial momentum balance
- Tip-strong total pressure profile
  – Creates a tip-strong meridional velocity profile
  – Reduces clearance sensitivity [2]
- Airfoil counts reduced to optimize efficiency while maintaining required stall margin

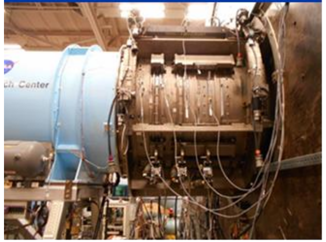


[1] Potts, I, 1987, "The importance of S1 stream surface twisting in the analysis of inviscid flow through swept, linear turbine cascade," *I Mech. E* Paper No C 258/87.
[2] Erler, E., Vo, H.D., and Yu, H., 2015, "Desensitization of Axial Compressor Performance and Stability to Tip Clearance Size," GT2015-42746, *Proceedings of the ASME Turbo Expo*, Montreal, Canada, 2015.
[3] Ramakrishna, P. and Govardhan, M., 2010, "Study of Sweep and Induced Dihedral Effects in Subsonic Axial Flow Compressor Passages, Part II: Detailed Study of the Effects on Tip Leakage Phenomena," *International Journal of Rotating Machinery*, 491413.
[4] McNulty, G. and Decker, J., 2004, "The Impact of Forward Swept Rotors on Tip Clearance Flows in Subsonic Axial Compressors," *Journal of Turbomachinery*, 126, pp. 445.
[5] Wadia, A., Hah, C. and Rabe, D., 2004, "The Impact of Forward Sweep on Tip Clearance Flows in Transonic Compressors", *Proceedings of the 24th International Congress of the Aeronautical Sciences*, Yokohama, Japan, ICAS2004-6.2.1

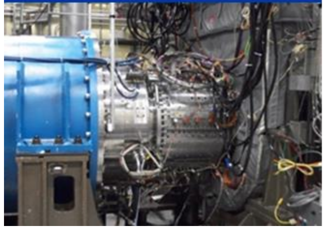
RIG PROGRAM

3 RIGS RUN TO DEMONSTRATE TECHNOLOGY

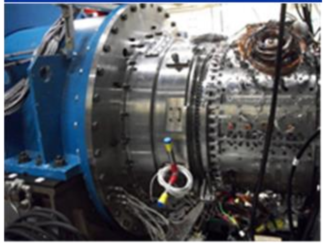
Low Speed Rig
Validate Models
Vet technology



High Speed Rig 1
Baseline

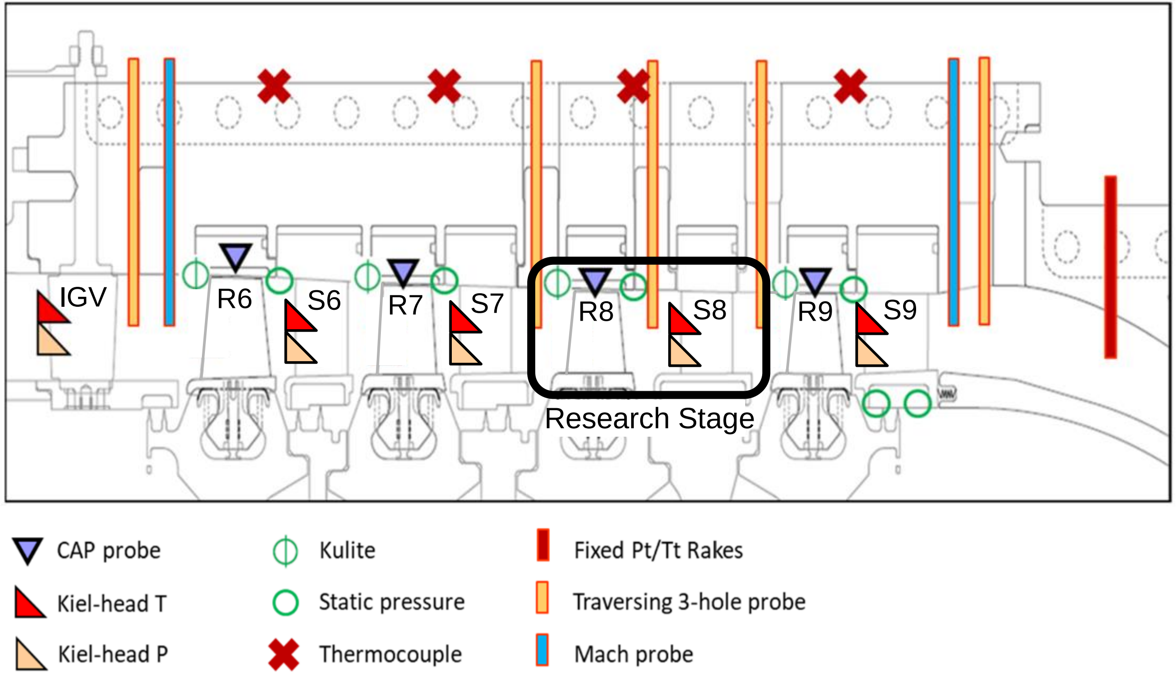


High Speed Rig 2
Demonstrate technologies



HIGH SPEED MULTISTAGE COMPRESSOR RIG

4.5-STAGE HIGH-SPEED RIG REPRESENTING REAR STAGES OF A 9-STAGE SMALL CORE COMPRESSOR

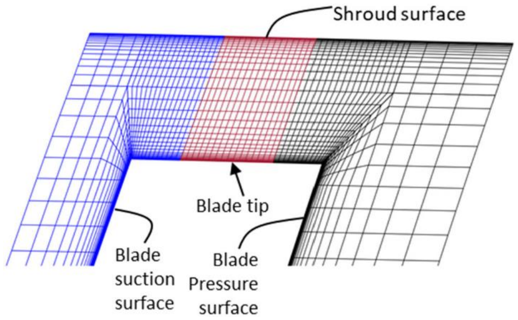


- Two clearances tested in Rotor 8
  – Nominal, representing new
  – Open, representing end-of-life

MODELING APPROACH

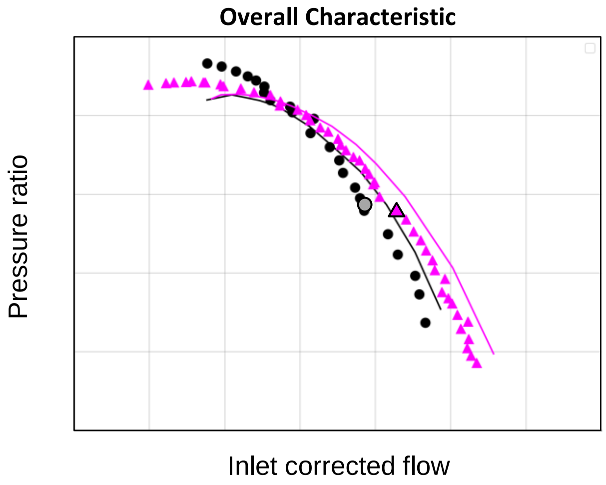
CFD VALIDATED WITH LOW-SPEED RIG AND HIGH-SPEED RIG 1, USED TO DESIGN RIG 2

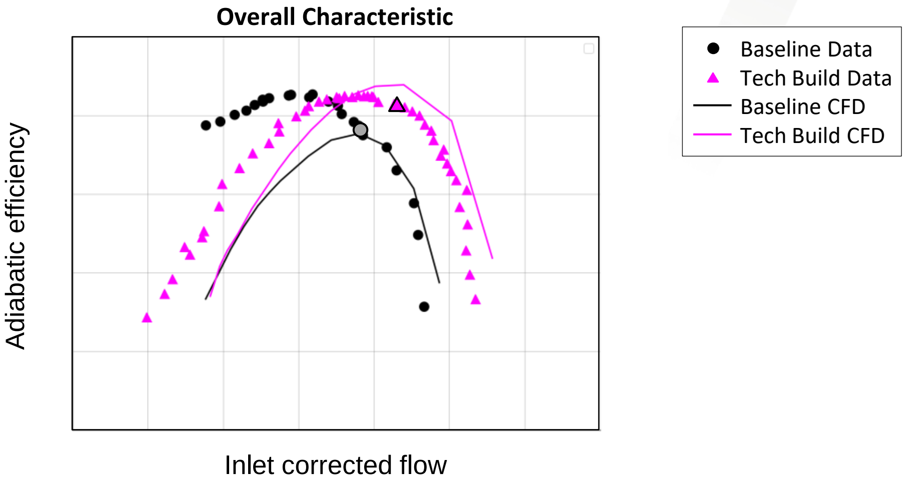
- In-house Pratt & Whitney / Raytheon Technologies Research Center solver, UTCFD
  - Density based, 3-D, structured RANS flow solver
  - Validated for small core compressors
- Approach
  - Unsteady RANS used here
  - Modified k-ω turbulence model used here
  - Scaled interface model
  - Number of passages modeled based on airfoil counts, keeping ratio between rows ~1
  - Leakages modeled with flowpath patches
  - 4 revolutions run
  - Quoted solutions averaged over last revolution
  - Solution extracted at measurement locations and post-processed like data
- Mesh
  - C-type around-blade tip mesh
  - 2.4M grid points
  - y+ < 2



CHARACTERISTICS AT NOMINAL CLEARANCE

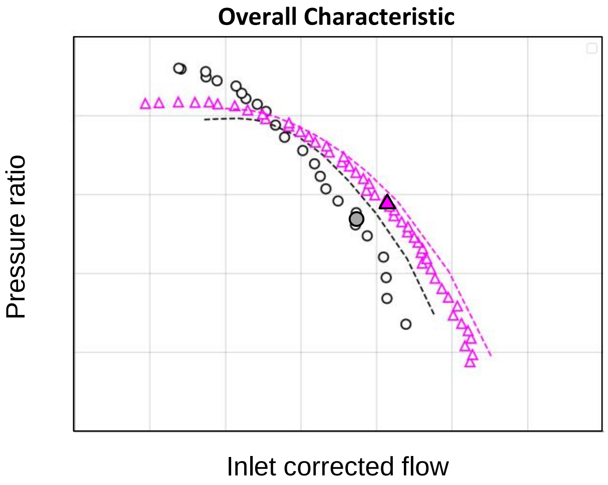
TECHNOLOGY ALLOWS CHOKE BIAS OF BASELINE BUILD TO BE ELIMINATED, ENABLING AN EFFICIENCY INCREASE

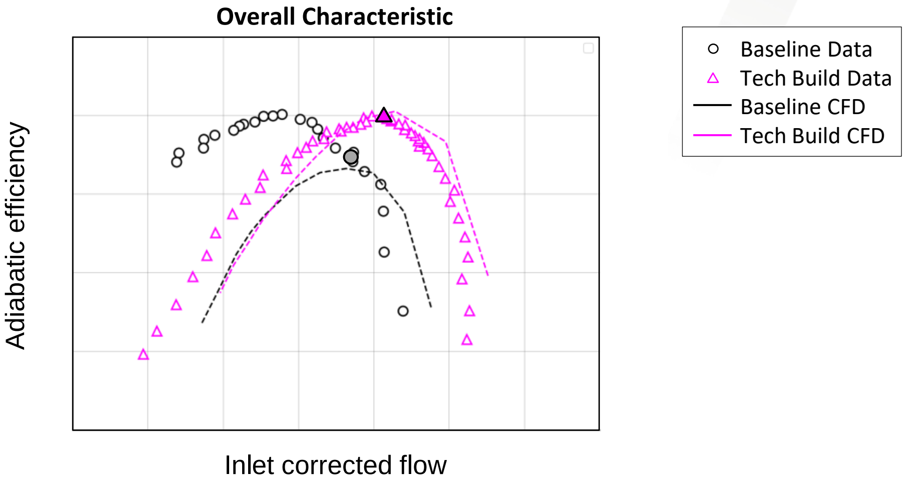




CHARACTERISTICS AT OPEN CLEARANCE

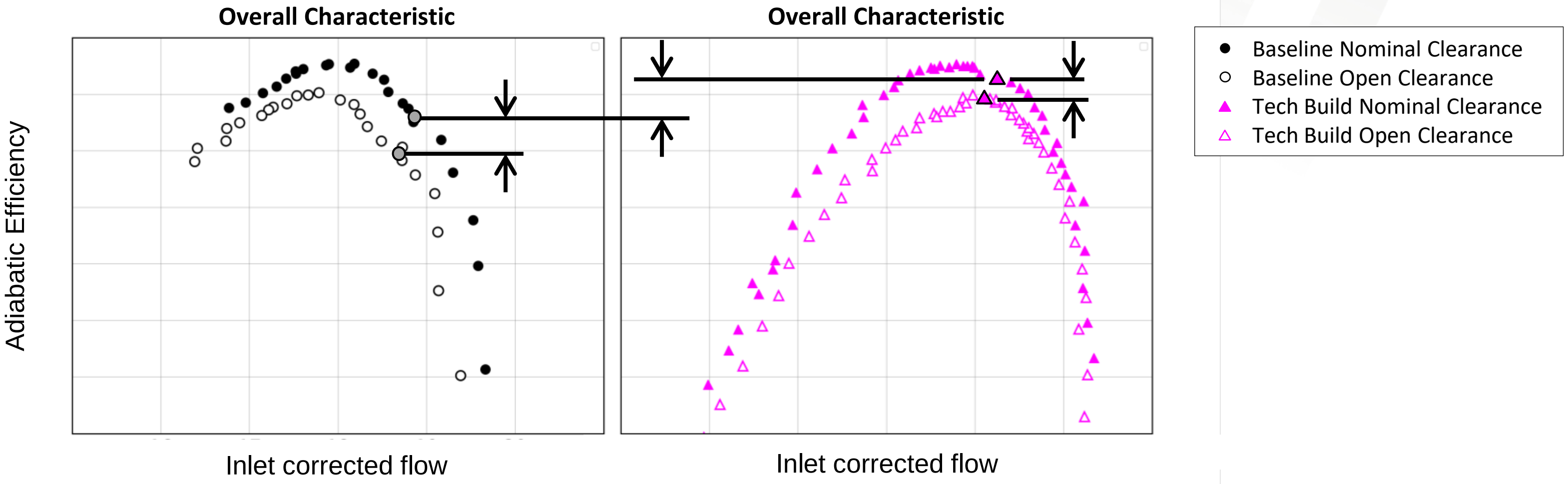
EFFICIENCY IMPROVEMENT AT OPEN CLEARANCE IS EVEN GREATER





CLEARANCE SENSITIVITY

CLEARANCE SENSITIVITY IS REDUCED WITH INCLUSION OF TECHNOLOGY

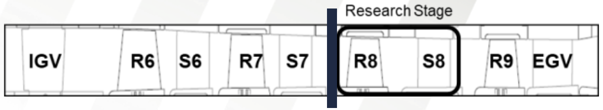


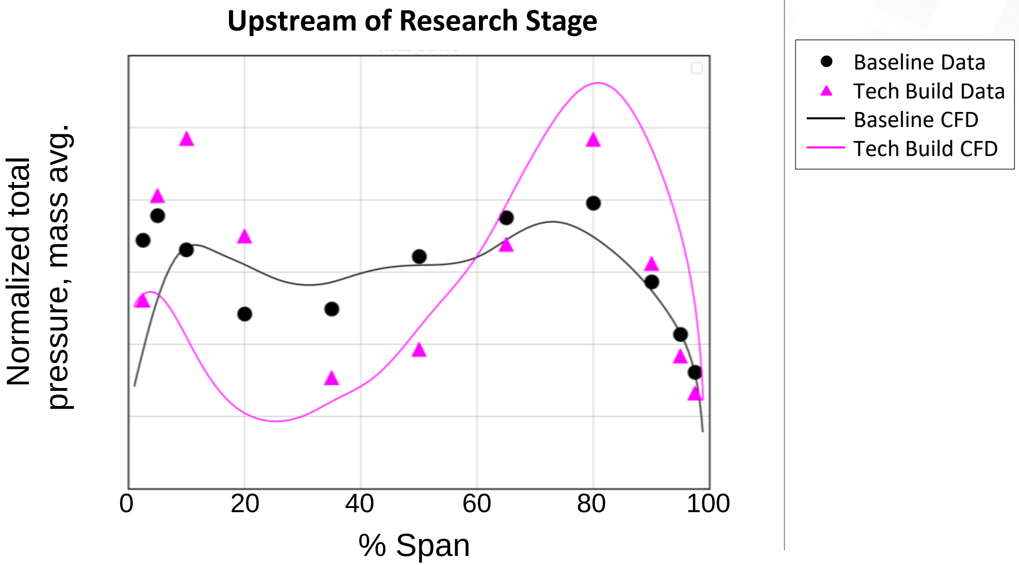
Baseline Build

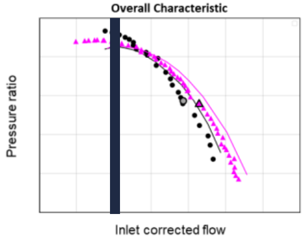
Technology Build

RADIAL PROFILES UPSTREAM OF ROTOR 8, NEAR STALL

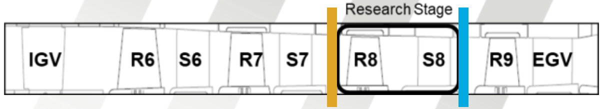
PROFILES SHOW STRONGER TIP PROFILE CREATED BY TECHNOLOGY INTRODUCED INTO STAGES 6 & 7



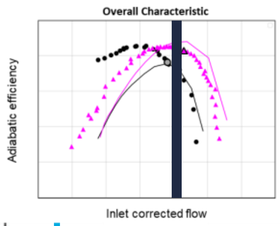


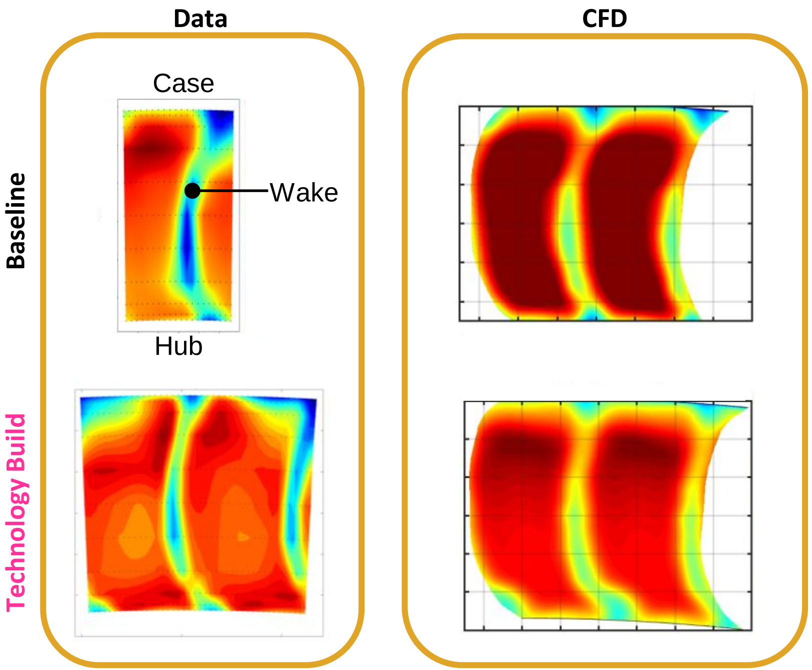


CONTOURS OF PT AT OPLINE, NOMINAL CLR

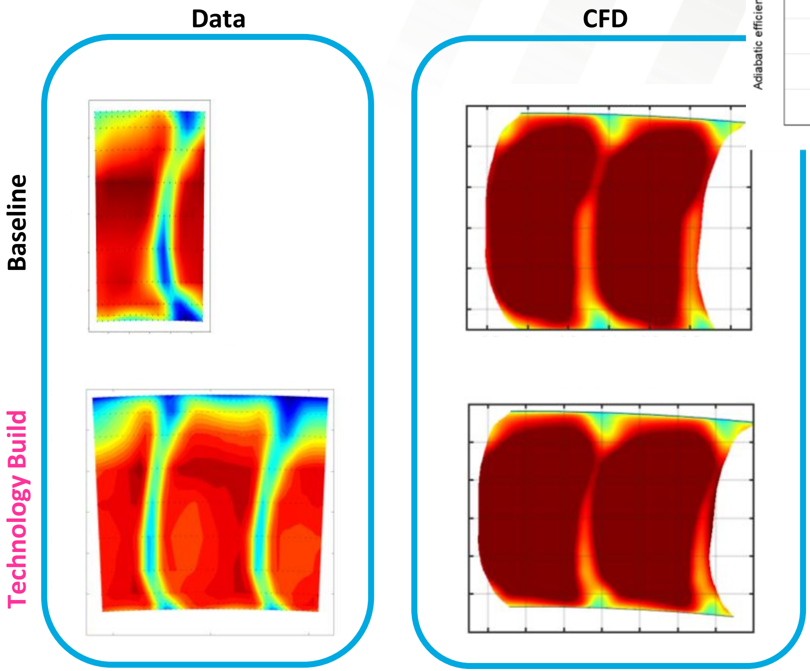


THINNER WAKES IN TECHNOLOGY BUILD CONSISTENT WITH OPERATION AT PEAK EFFICIENCY POINT



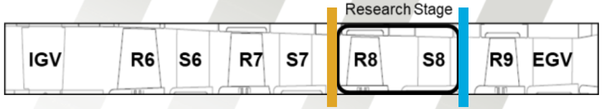


Upstream of R8

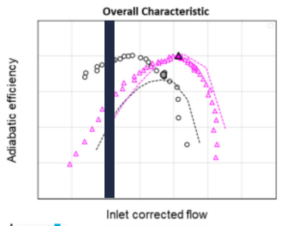


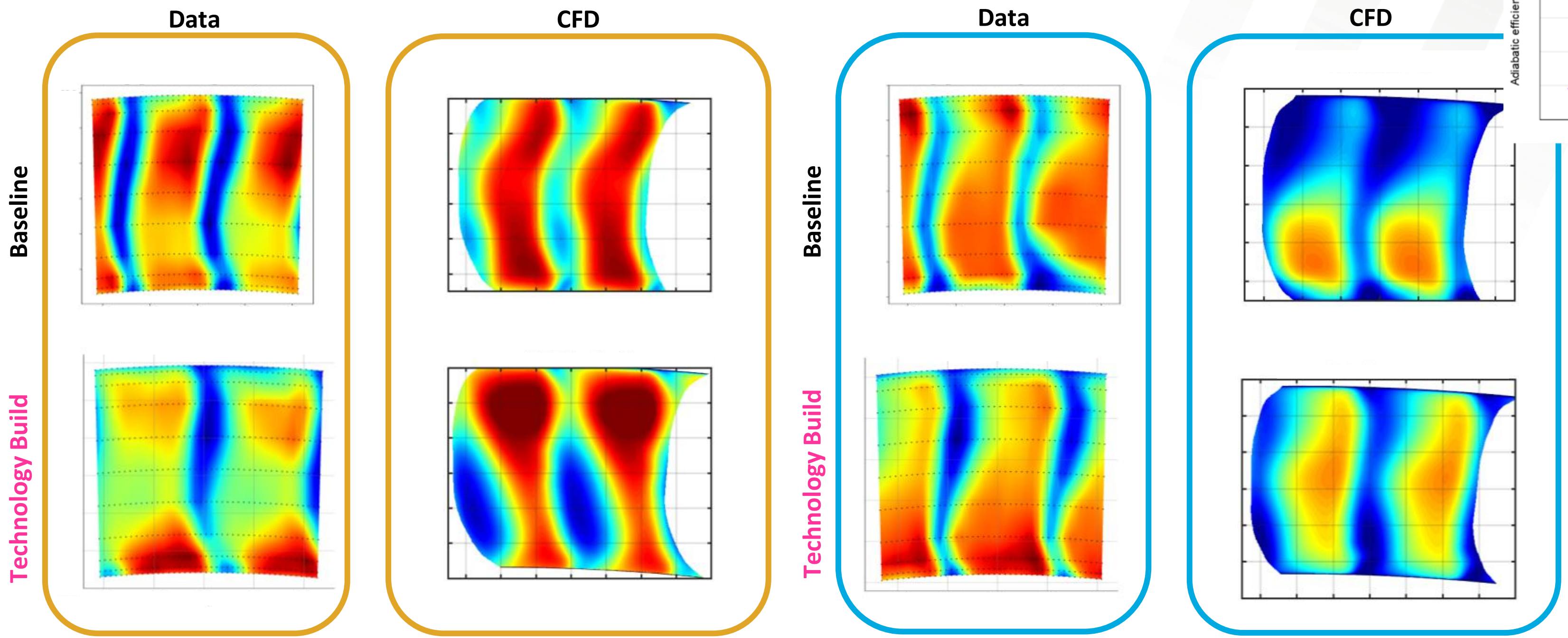
Upstream of R9

CONTOURS OF PT NEAR STALL, OPEN CLR



THICKER MIDSPAN WAKES IN TECHNOLOGY BUILD CONSISTENT WITH HIGHER INCIDENCE, BUT STABILITY MAINTAINED





Upstream of R8

Upstream of R9

CONCLUSIONS

TECHNOLOGY ENABLES RECOVERY OF EFFICIENCY LOST TO CORE SIZE REDUCTION

- A modeling methodology for multi-stage compressors was evaluated at small core clearance-to-span ratios
  - Trends in clearance sensitivity and technology benefit are accurately captured
  - Opportunities exist to improve absolute efficiency and stall margin

- Sweep and tip-strong total pressure profiles shown to enable an efficiency increase without compromising stall margin
  - Clearance sensitivity reduced by technology inserted
  - Efficiency gain amplified at open clearance
  - Technology enables compressor to be designed close to peak efficiency without compromising stall margin

GO BEYOND

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