Update on ScreenVane Testing in W8

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AATT VSI BLITS project

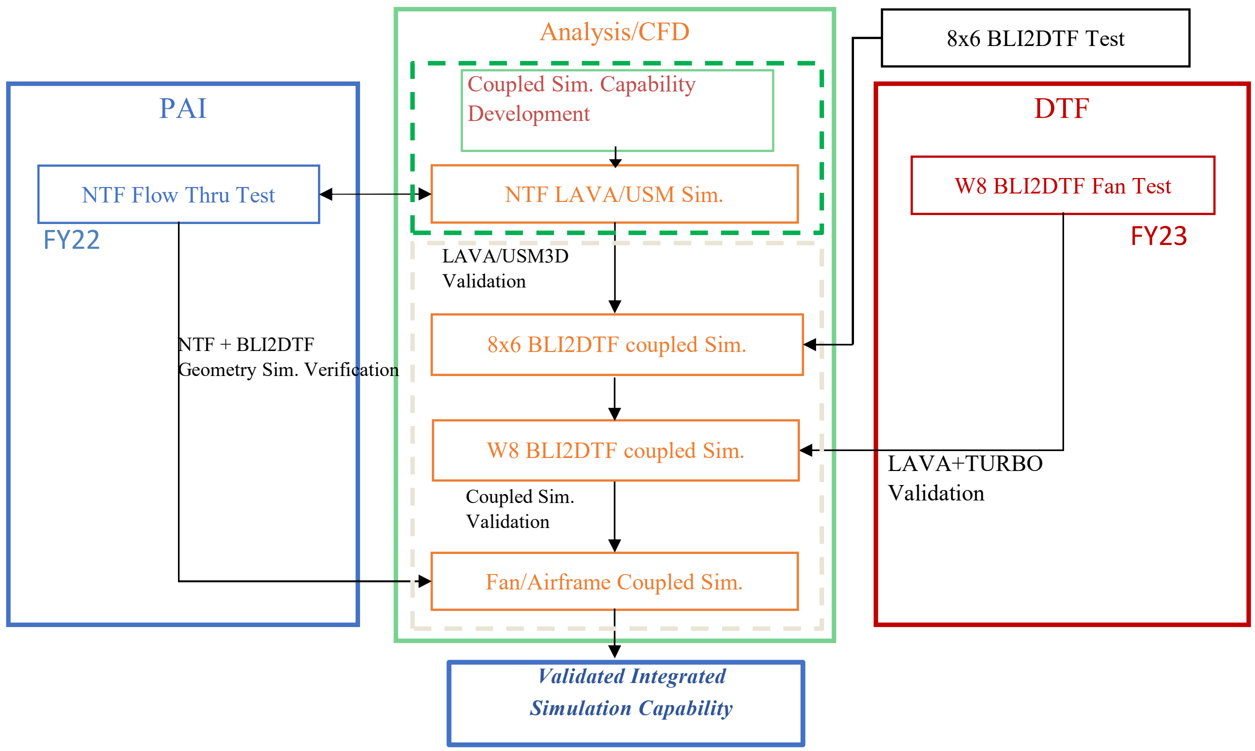
National Aeronautics and Space Administration
Advanced Air Transport Technology Project
Advanced Air Vehicles Program

Boundary Layer Ingestion

"Type 1": BLI2DTF

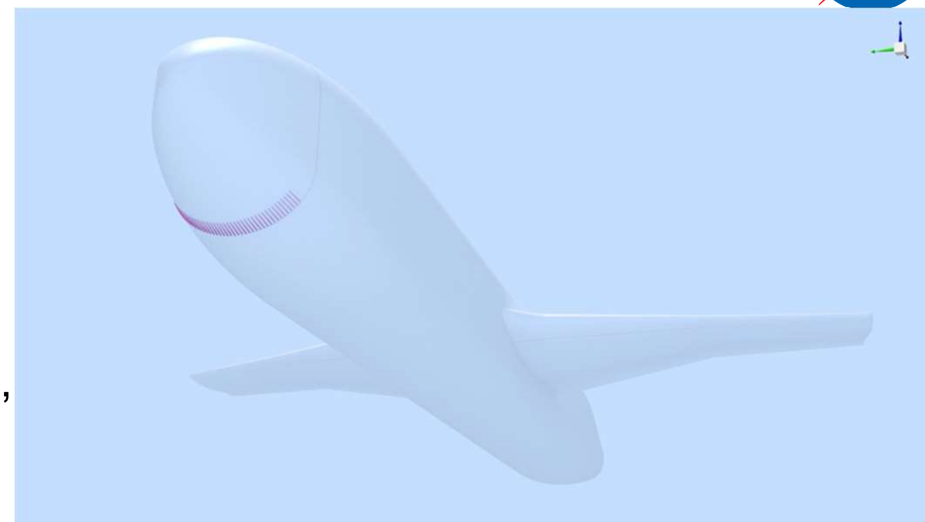
"Type 2": STARC-ABL

Introduction to BLITS Project



LAVA Curvilinear

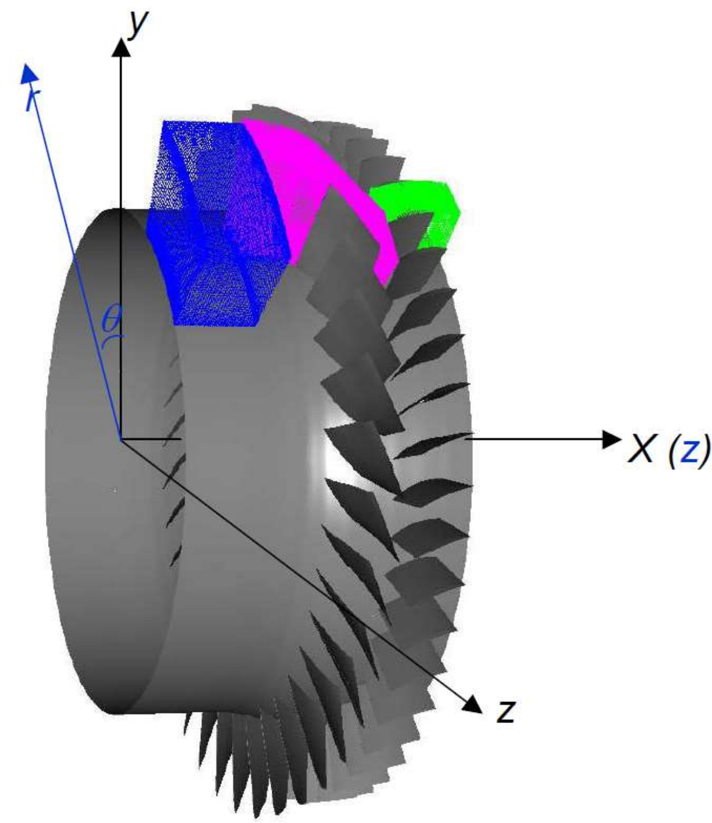
- LAVA Curvilinear is a multi-block/overset CFD solver
- It is used for steady RANS, URANS, (Z)DDES, LES and WMLES
- Extremely high computational performance on CPU architectures (MPI + OpenMP Hybrid)
- Various discretizations including central schemes, upwind schemes and HWCNS schemes
- Primitive are used in the code
- Strong non-linear and linear solvers (Inexact Newton's Method + GMRES + ILU(p)
- SA turbulence model + variants
- General equation of state
- Sutherland's Law for viscosity



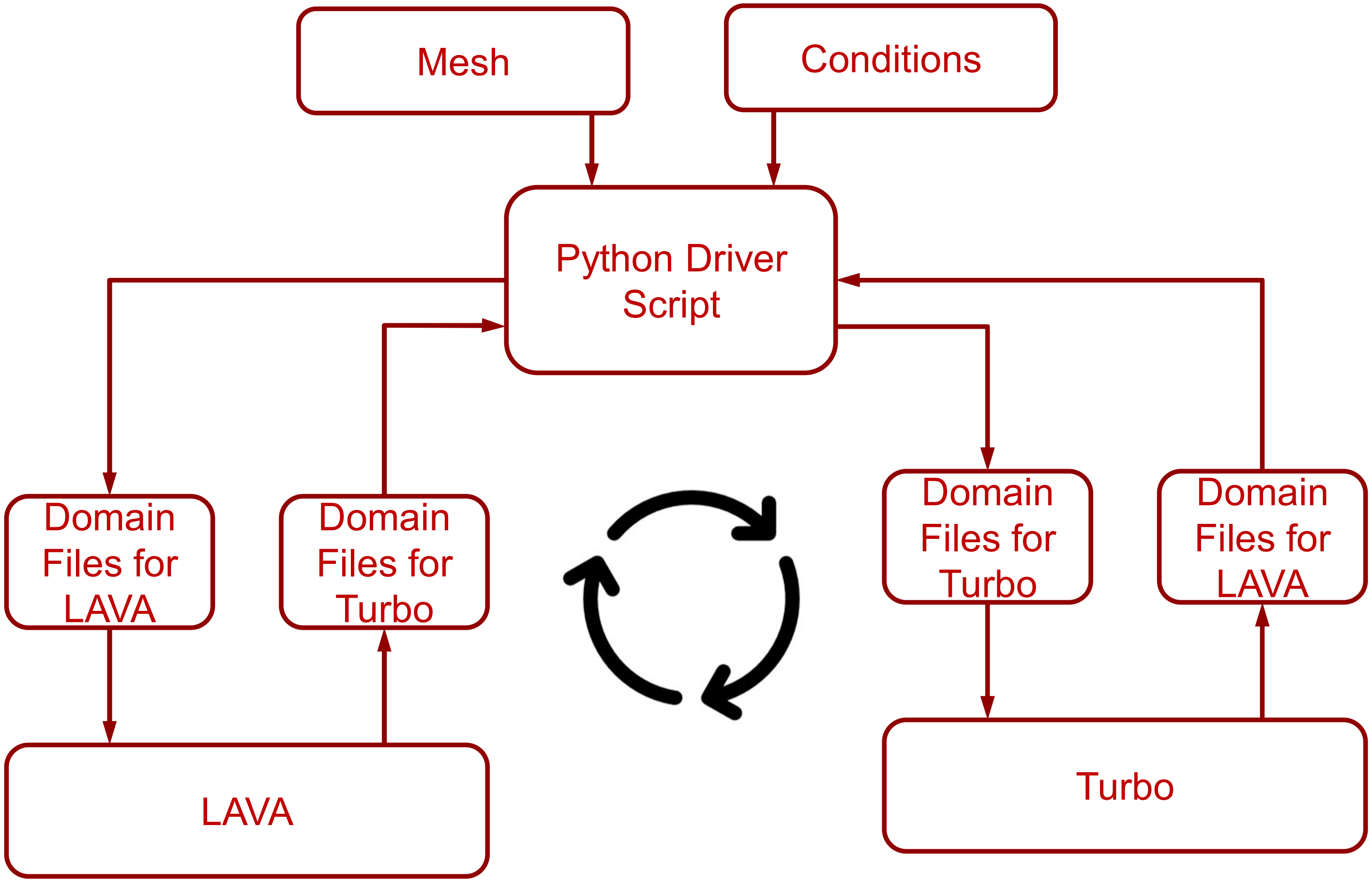
Scale resolving simulation of the NASA Juncture Flow Model computed using LAVA Curvilinear. Passive particles colored by stream-wise velocity

Turbo

- The main function of TURBO is to perform high fidelity CFD simulations of rotating turbomachinery
  - Multistage capability allows rotating and stationary blade rows
- TURBO is a URANS based CFD solver
  - Equations formulated in the relative frame
- Numerical features
  - Structured multi-block grid capability
  - Finite volume discretization utilizing conservative variables
  - Constructed with non-dimensional variables
  - Fluxes based on a Roe scheme
  - Implicit time marching
  - Newton and Gauss-Seidel relaxation
  - k-ε turbulence model

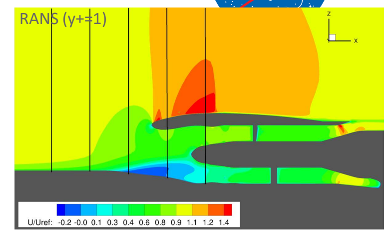


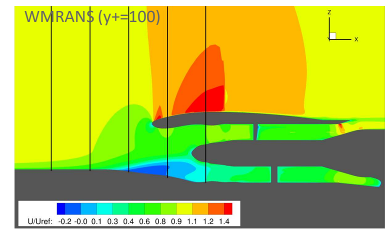
LAVA+Turbo Coupling

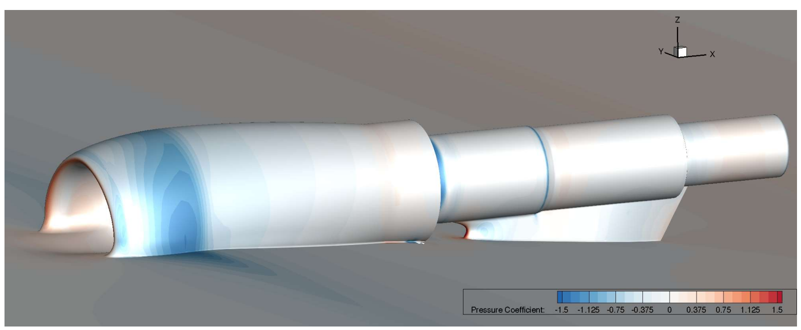


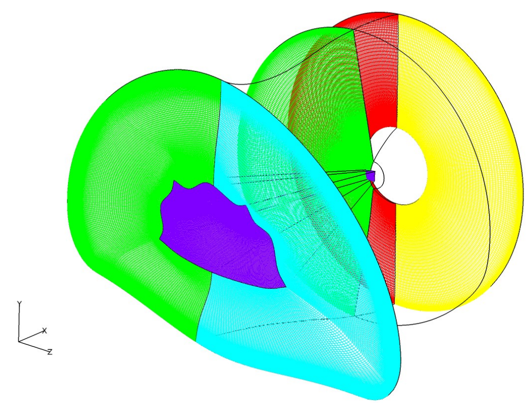
LAVA+Turbo Coupling

1. Coupled LAVA-TURBO tests:
   1. Coupling mechanics have been tested on sandbox problems.
      - Wall-resolved (y+≈1) LAVA simulation compared with wall-modeled (y+≈100) RANS.
      - Both codes will use wall-modeled RANS for efficient, low-error coupling.
      - Coupling process testing completed, including data-exchange frequency testing.
   2. 8x6 BLI2DTF coupling build-up:
      - Bladeless propulsor tests being conducted.
      - Rotor only propulsor tests are next.
      - Validation: 8x6 BLI2DTF wind tunnel test.





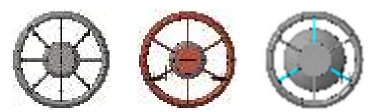


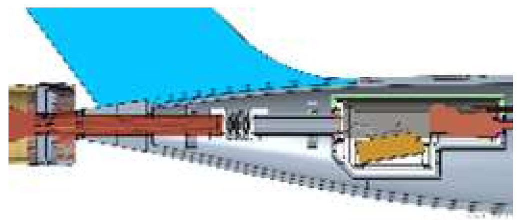


NTF Test

- NTF Common Research Model Tail Cone Thruster (CRM-TCT) Flow Thru Test (2022)
  - Evaluate tail cone thruster configuration airframe performance
  - Simulate propulsor with mass flow plugs to get a prediction of inlet conditions at TCT highlight
  - Evaluate sensitivity of measured quantities to Mach number, Reynolds number, and angle of attack
  - Data will be used to validate the airframe CFD and verify the coupled airframe/propulsor CFD

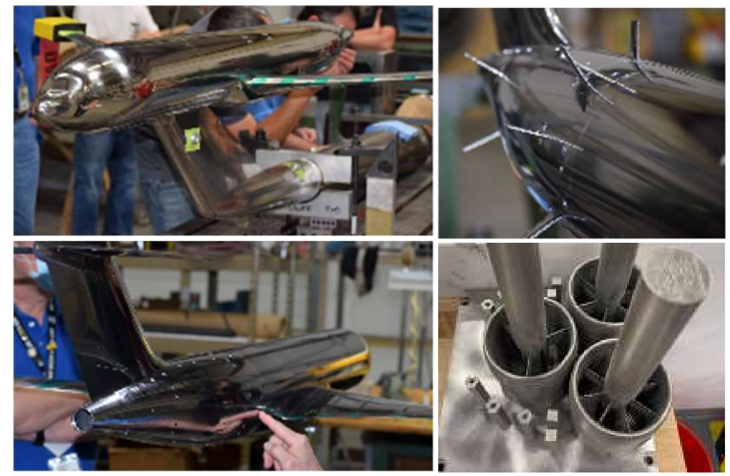
ARP1420 Rotary 5-hole Probes

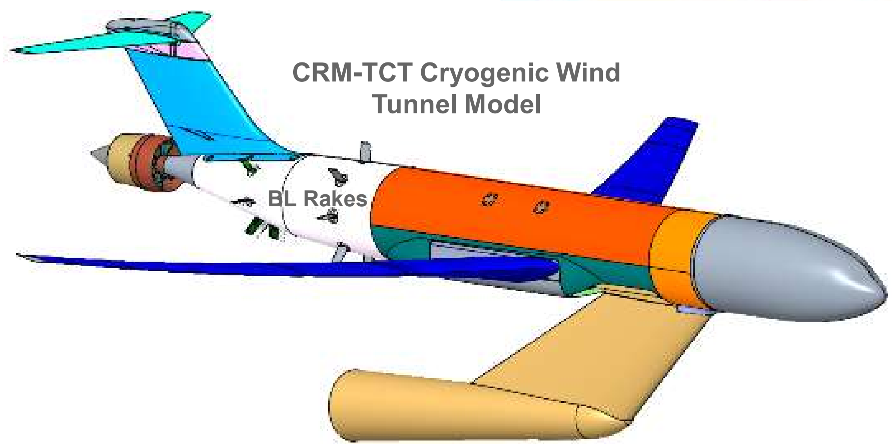




Rotating Mechanism for Nacelles

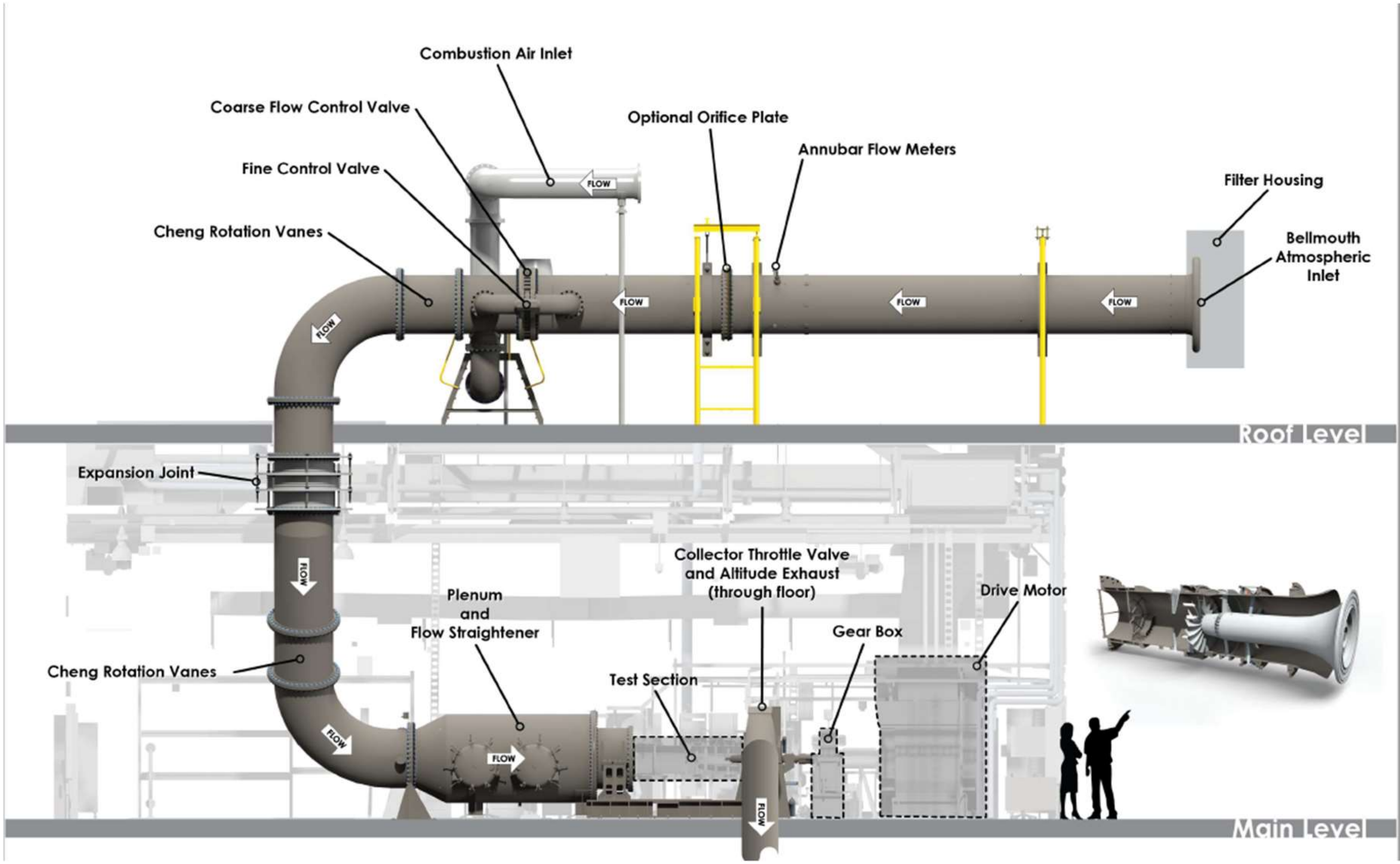
Fabrication Photos





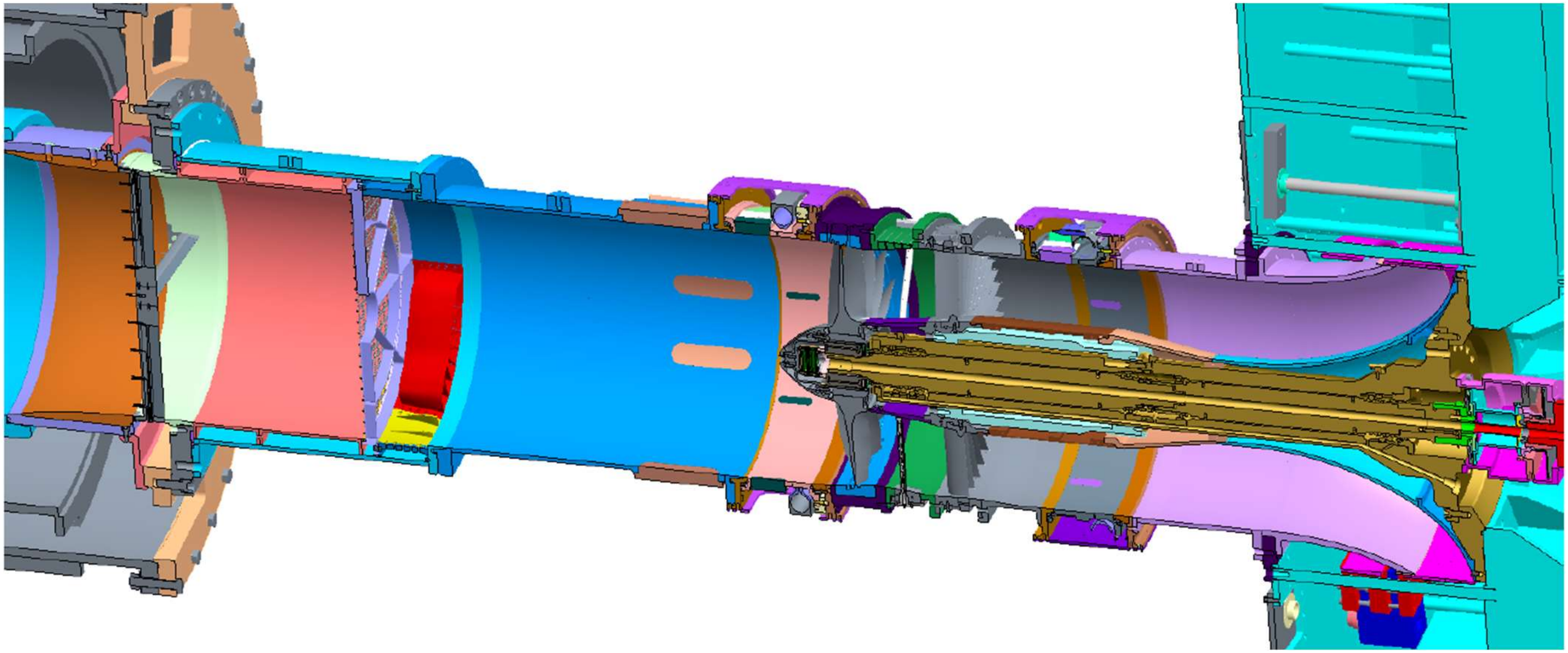
CRM-TCT Cryogenic Wind Tunnel Model

W8



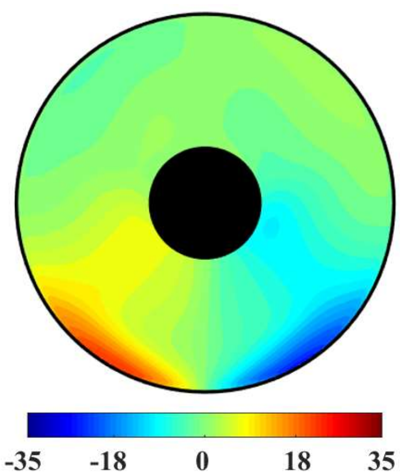
Combustion Air Inlet
Coarse Flow Control Valve
Optional Orifice Plate
Annubar Flow Meters
Fine Control Valve
Filter Housing
Cheng Rotation Vanes
Bellmouth Atmospheric Inlet
FLOW
Roof Level
Expansion Joint
Collector Throttle Valve and Altitude Exhaust (through floor)
Plenum and Flow Straightener
Drive Motor
Gear Box
Cheng Rotation Vanes
Test Section
Main Level

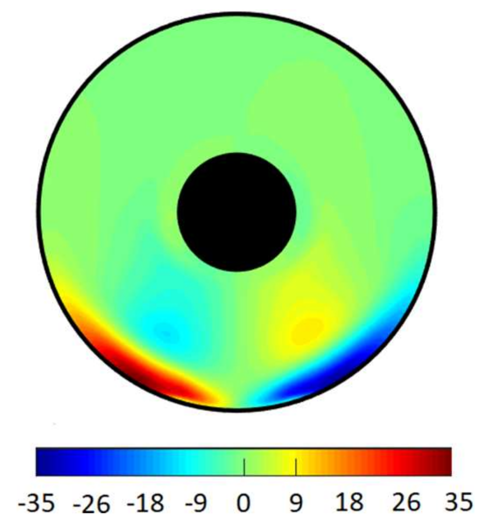
Test Section



StreamVane Design Process

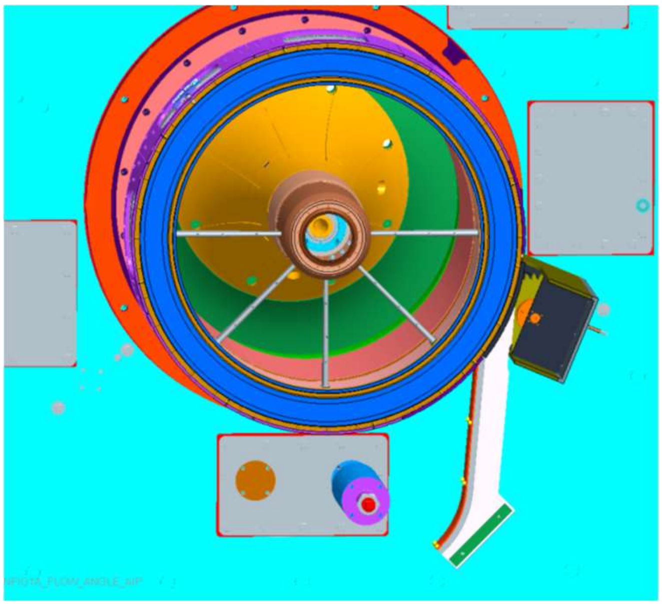
Define desired downstream swirl profile → Use StreamFlow based on vorticity transport equation to design structures at StreamVane Location → Validate using ANSYS CFX

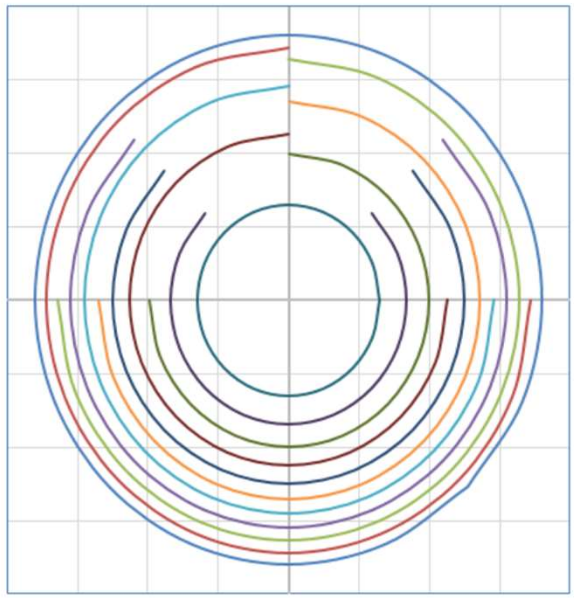


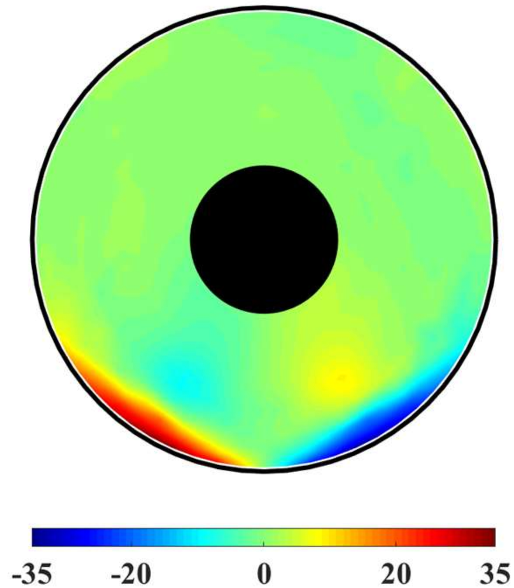


AIAA-2017-1622, Scheck et al

Swirl Measurement



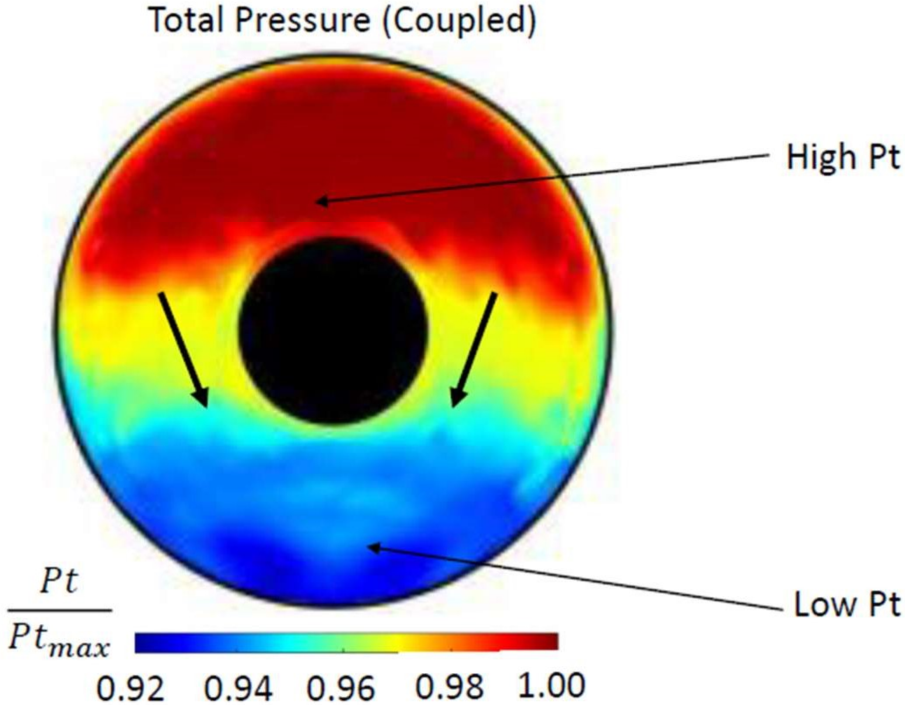


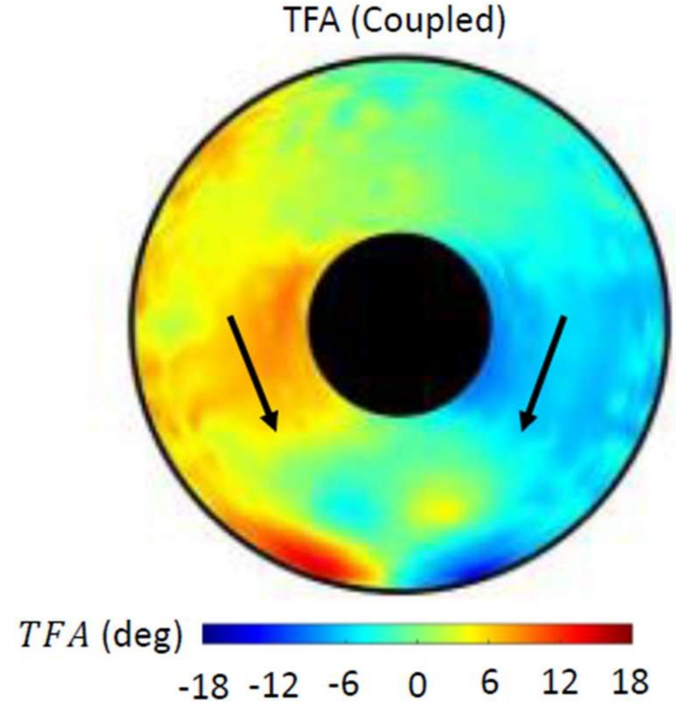


Measured
(Mach 0.41)

Fan-Induced Swirl

- Fan interaction drives a swirl from high total pressure region to low total pressure

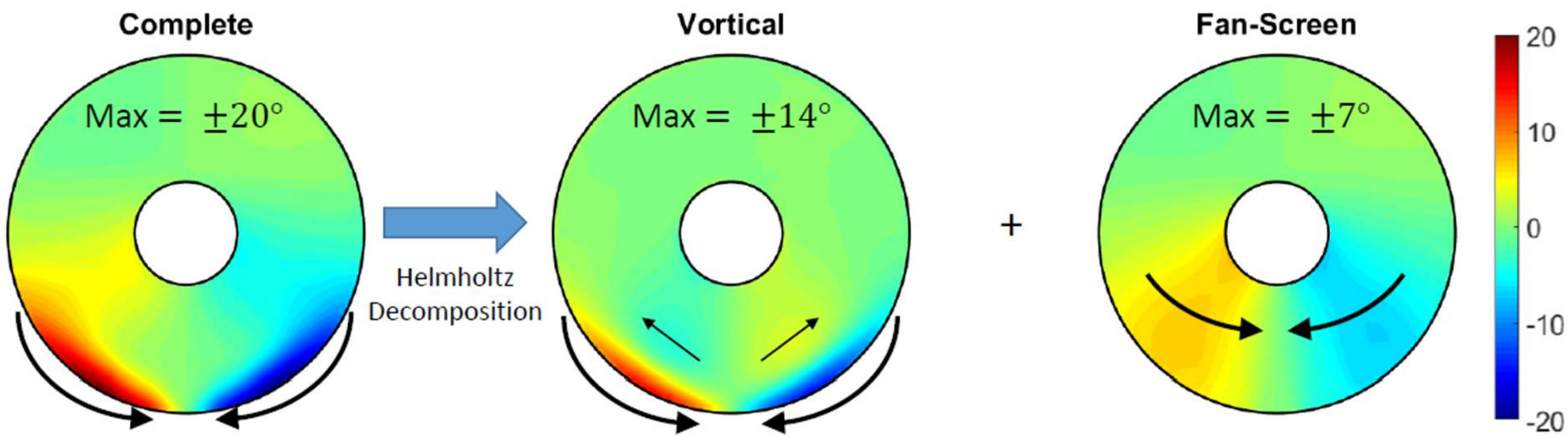




Frohnapfel, Dustin Joseph. *Methodology Development and Investigation of Turbofan Engine Response to Simultaneous Inlet Total Pressure and Swirl Distortion*. Diss. Virginia Tech, 2019

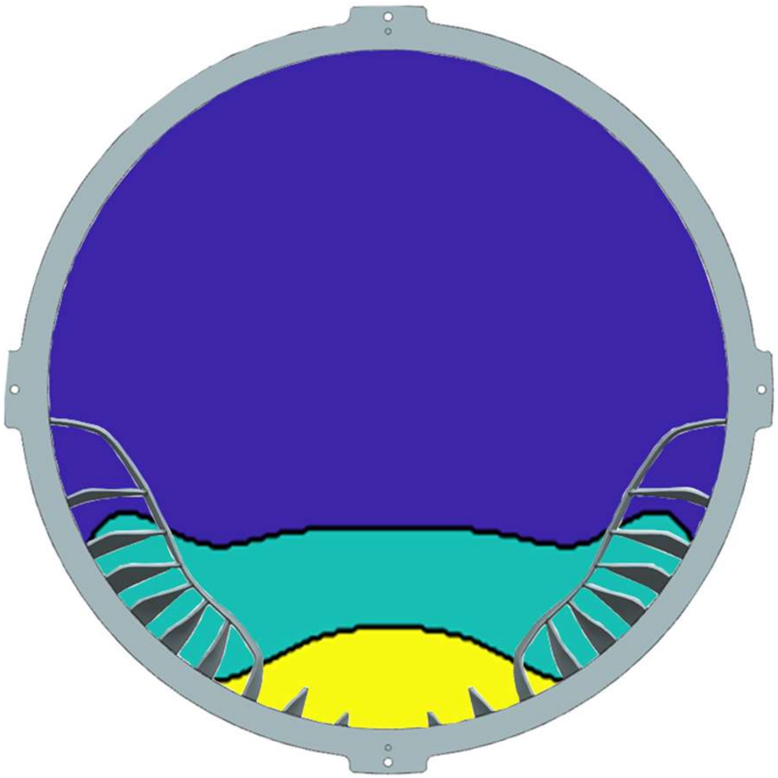
Helmholtz Decomposition

- It is possible to separate out the two types of swirl mathematically
  - Helmholtz decomposition separates a general vector field (here, the transverse velocity field) into a solenoidal (divergence free) component and an irrotational (vorticity-free) component*
  - The solenoidal component is described completely by streamwise vorticity
    - This is what can be generated by a StreamVane
  - The irrotational component is described by the in-plane divergence (or axial gradient of axial velocity)
    - This is generated by the fan-screen interaction



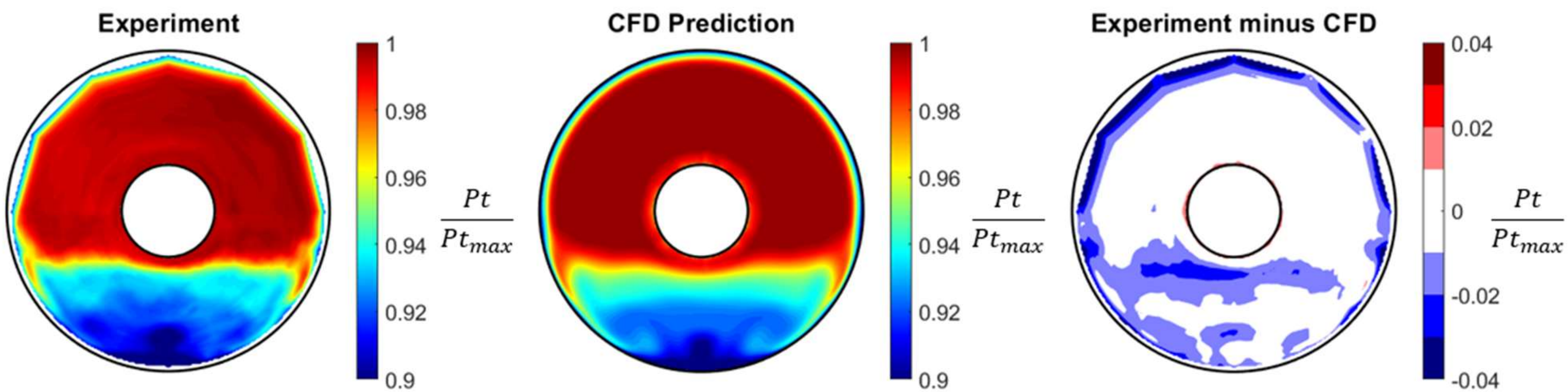
*Assuming certain well-behaved properties of the vector field that generally apply here

Second Iteration: ScreenVane



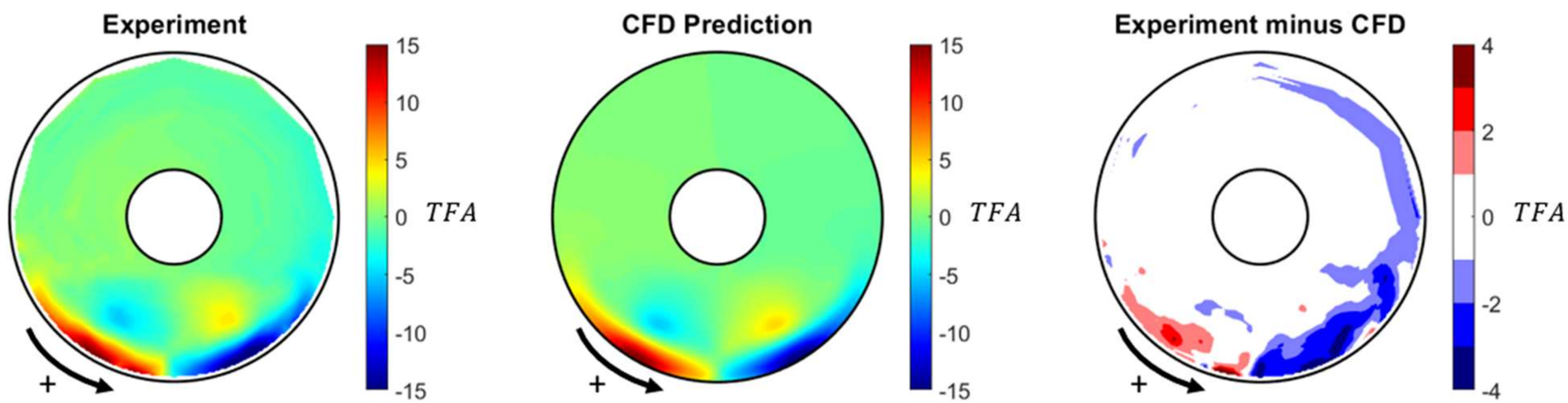
ScreenVane Off-Design Prediction

- Subscale ScreenVane matches CFD prediction quite well
  - Slightly more loss, attributed to the slightly less porous backer screen used in the experiment (vs. predictions)
  - Experiment boundary layer is somewhat thicker than CFD prediction of boundary layer (not all upstream duct is included)



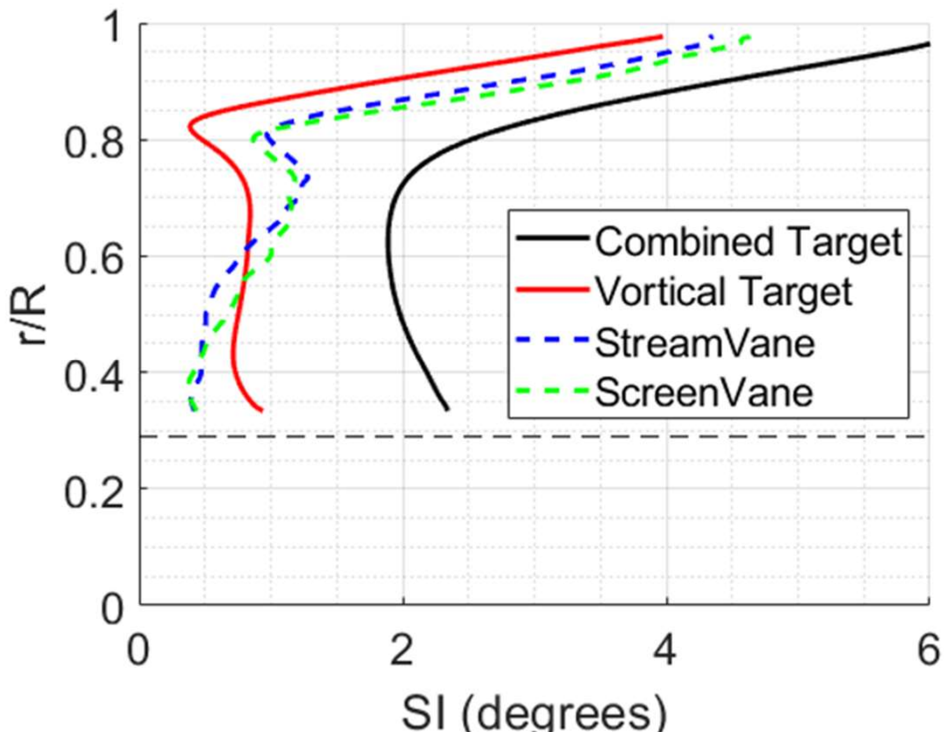
ScreenVane Off-Design Prediction

- CFD prediction matches experiment well
  - The ~2° discrepancy may be due to the total pressure gradient tricking the five hole probe



Swirl Intensity

- Swirl intensity matches the vortical target fairly well, as expected



To re-iterate:

- Combined target is the profile we truly want
- Vortical target seeks to eliminate fan effects
- By matching the vortical target without a fan, we believe that we will match the combined target with a fan
- This division is slightly imperfect (ScreenVane with the centerbody seems to pick up some small "fan" effects)

Conclusions

- Coupling of the LAVA and TURBO codes will enable modeling of systems with complex PAI
- The NTF test will provide drag estimates and BLI flow measurements
- W8 testing of the BLI2DTF fan will enable better understanding of the BLI2DTF Fan performance and understanding of simulated BLI flows using ScreenVanes

Telemetry

- An integrated source and sampling instrument capable of powering 24 blade strain gauges, 4 force bridges, 2 Kulites, and 8 RTD's.
- Strain gauge, Kulite, and force bridge measurement are synchronous
- Data link is 100Mb Ethernet, time stamped frames, 32bit CRC
- System powered by 2 DC channels
- Rotation not to exceed 18,500 RPMs
- Operational temperature range: -40° to 125° C, duty cycle: 100%

Balance

COMPONENT	LOAD ABOUT MOMENT CENTER	GAGE STRESS (PSI)	EST. OUTPUT uV/V
TORQUE	28,560 in-lbs	20,035	1,603
THRUST	2,200 lbs	7,523	602