NASA/CP—2010-216112

THE AIR FORCE RESEARCH LABORATORY

LEAD | DISCOVER | DEVELOP | DELIVER

Reduction of Unsteady Forcing in a Vaned, Contra-Rotating Transonic Turbine Configuration

Minnowbrook VI
Workshop on Flow Physics and Control for Internal and External Aerodynamics
23-26 August 2009

John Clark, D Phil, PE
Turbine Engine Division
Propulsion Directorate
Air Force Research Laboratory

Acknowledgements and Collaborations

AFRL

Peter Koch
Michael Ooten
Richard Anthony
Andrew Lethander
Michael Flanagan
Greg Minkiewicz
John Finnegan
Mike Kobelak
Capt Abram Claycomb
Capt Ryan Lemaire
Capt Adam Opava
2Lt Kat Lyons
2Lt Stephen Kennedy

Florida Turbine Technologies, Inc.

Dean Johnson
Frank Huber
Jim Hendershot
Jim Downs

UC Davis

Roger Davis
Ronnie Bozinoski

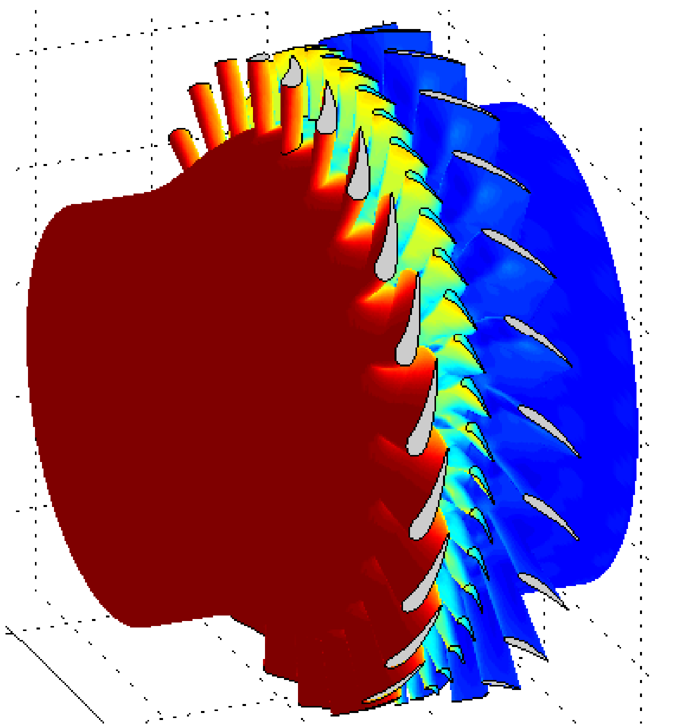
Aerodynamic Solutions, Inc.

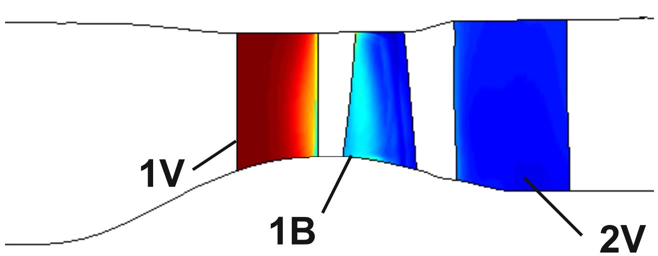
Bob Ni

NASA MSFC

Dan Dorney

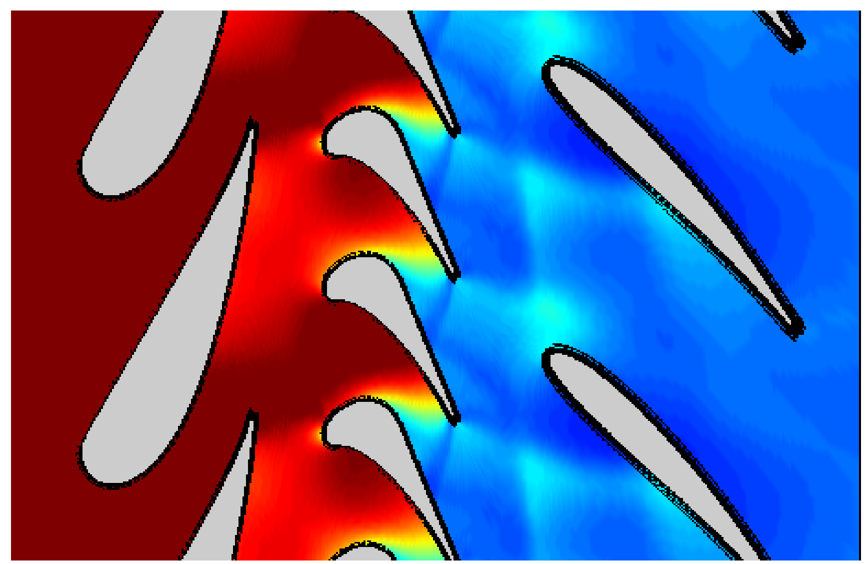
The AFRL High Impact Technologies Research Turbine (HIT RT)





Meanline Design Parameters: HIT RT

PR	3.75 total-total		
Reaction	49.5%		
Flow Coefficient	0.71		
Work Coefficient	2.11		
AN^2 (in^2 rpm^2)	573 $x10^8$ (Engine)		
	1V	1B	2V
Turning	77°	116°	11°
M_{exit}	0.88	1.30	0.89
Airfoil Count:	23	46	23

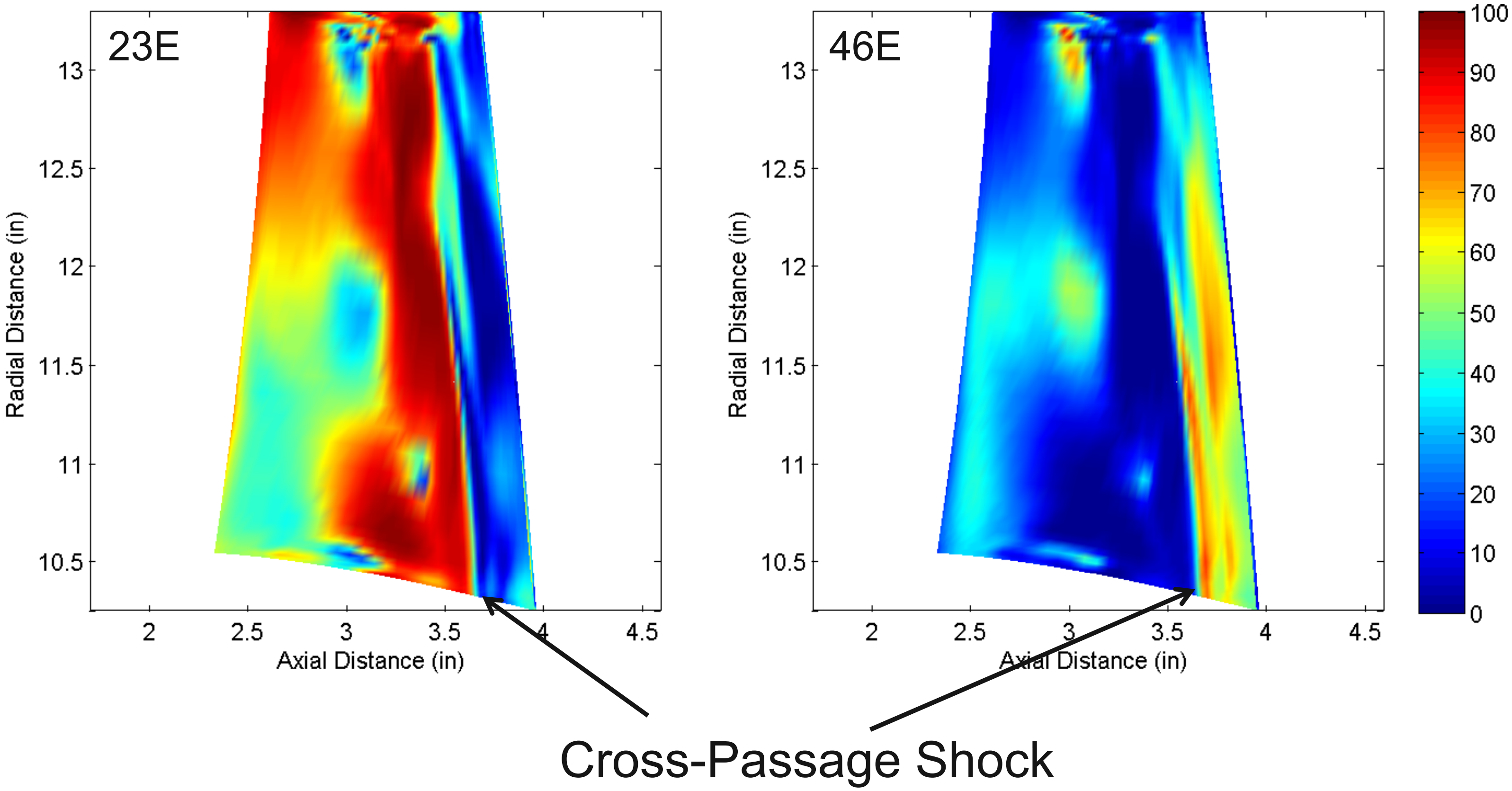


NASA/CP—2010-216112

402

Unsteadiness due to Downstream Interaction is Dominated by First Harmonic of Vane Passing

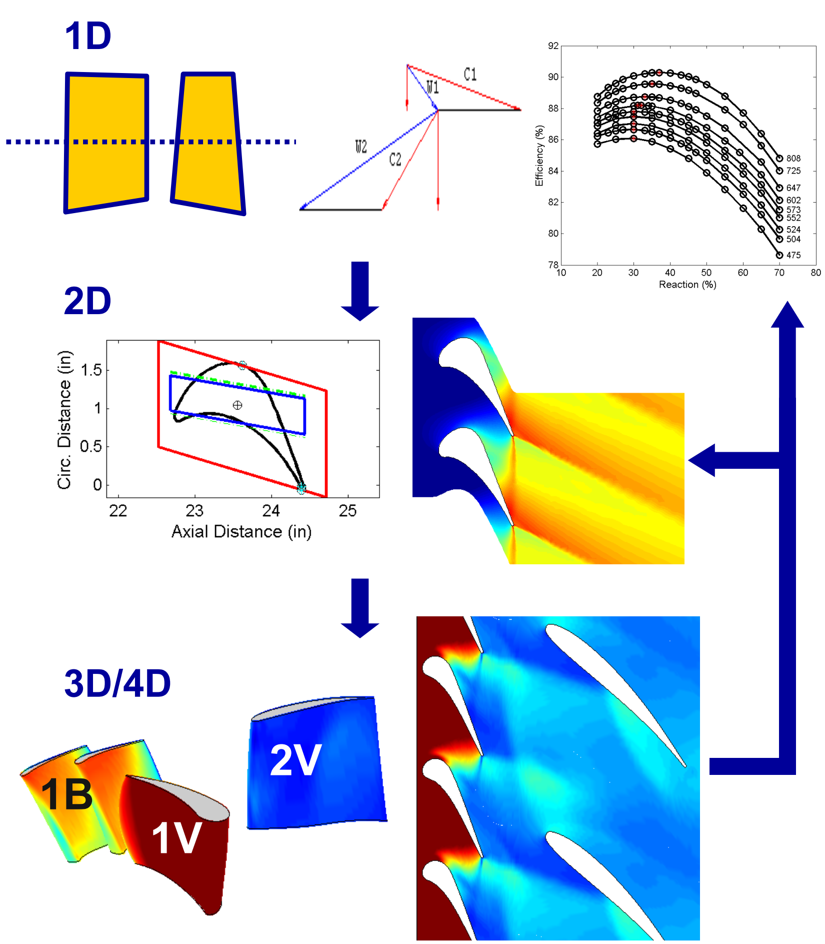
1B Suction Side, Percent Signal Power



NASA/CP—2010-216112

Turbine Design And Analysis System : Created to Enable Design of the HIT Research Turbine

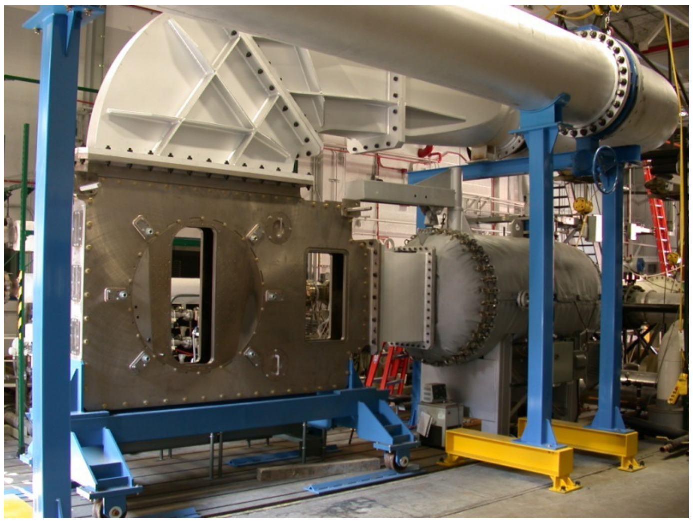
Iterative Turbine-Design Loop

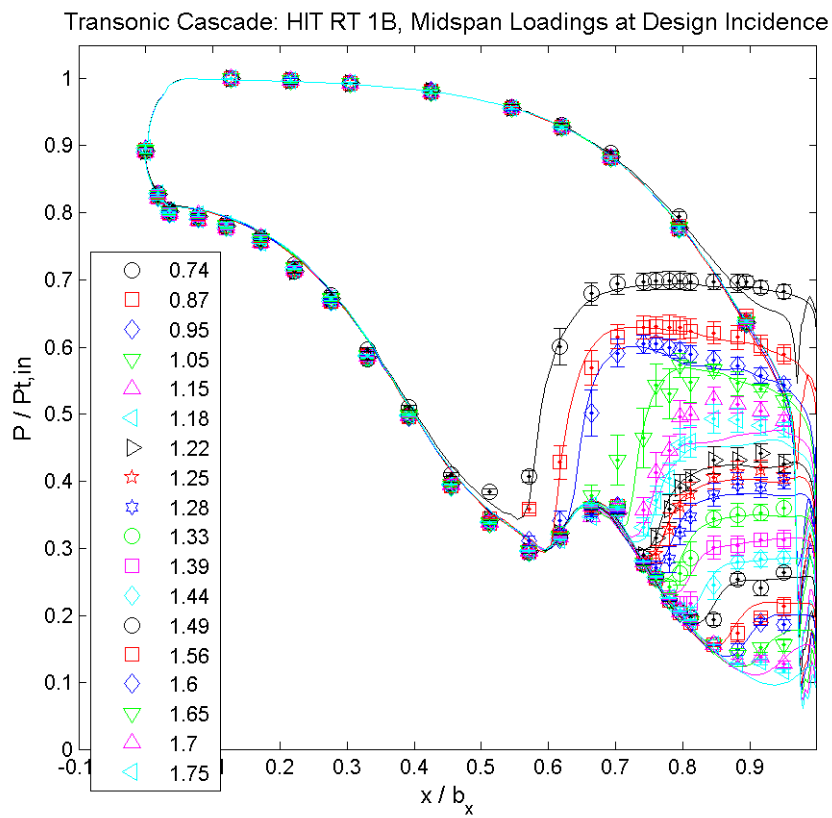


- 1D: Turbine size and velocity triangles were set with a 1D meanline code (HuberLine, FTT)
- 2D: Airfoil-section design, analysis, and optimization was conducted in MATLAB
  - HuberFoil (FTT) profile algorithm
  - GUI-based flowfield interrogation
  - Optimization via SQP, genetic algorithms, and DoE
- 4D: Time-resolved 3D analysis
  - DSP-based convergence-monitoring and unsteady post-processing
  - Enables investigation of unsteady shock interactions and instrumentation design for code validation
- A range of solvers are integrated with the system:
  - Corsair (Dorney, NASA MSFC)
  - LEO (Ni, Aerodynamic Solutions, Inc.)
  - MBFLO (Davis, UCDavis)

NASA/CP—2010-216112

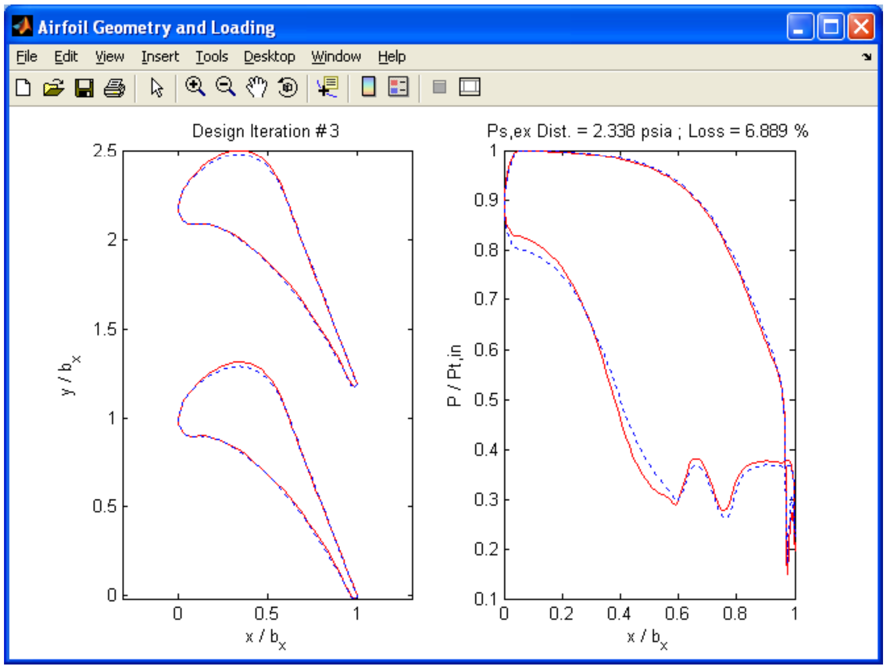
Cascade Experiments are Underway to Validate Design and Analysis Tools



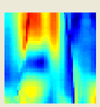


- Match to predictions gives confidence that the source of 1B-2V interaction is controllable via aerodynamic shaping.

HIT RT Blade was Re-Designed in an Attempt to Reduce Levels of Unsteadiness at 46E



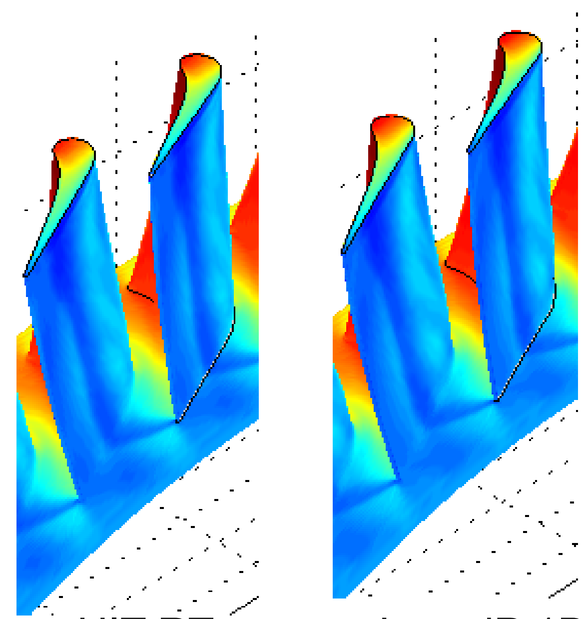
Parameter Comparison



Iteration :	1	3
TED :	0.0450	0.0431
TEW :	5.1562	3.3191
TEWF :	0.4516	0.5951
uncvrtrn :	0.0440	-2.0191
L3F :	0.4706	0.5080
L3R :	0.1506	0.2373
L4 :	0.1000	0.1445

OK

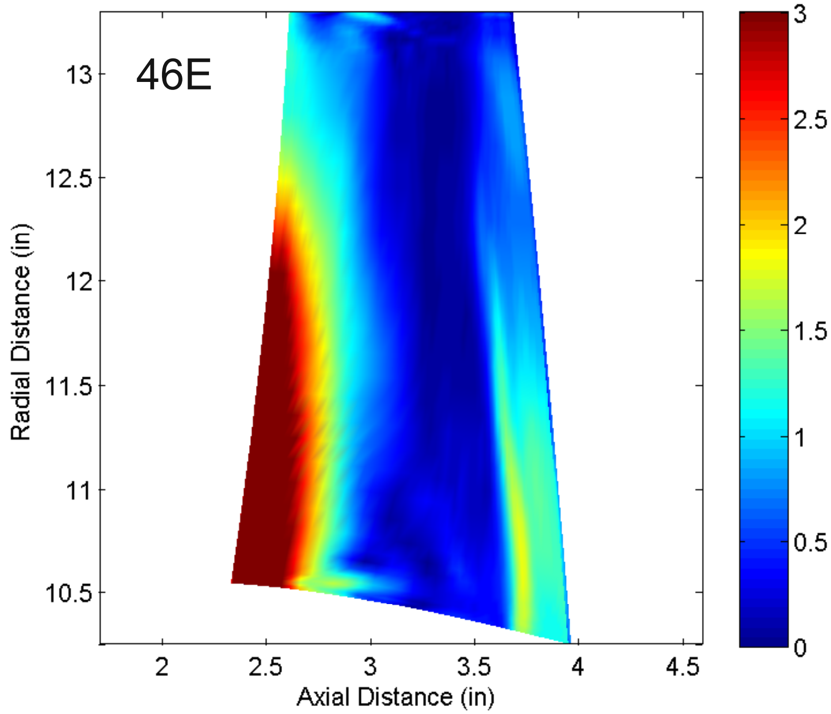
- Design-space exploration was performed to equalize strengths of the double-shock pair.
- Peak-to-peak circumferential distortion in exit static pressure was reduced of order 25%.



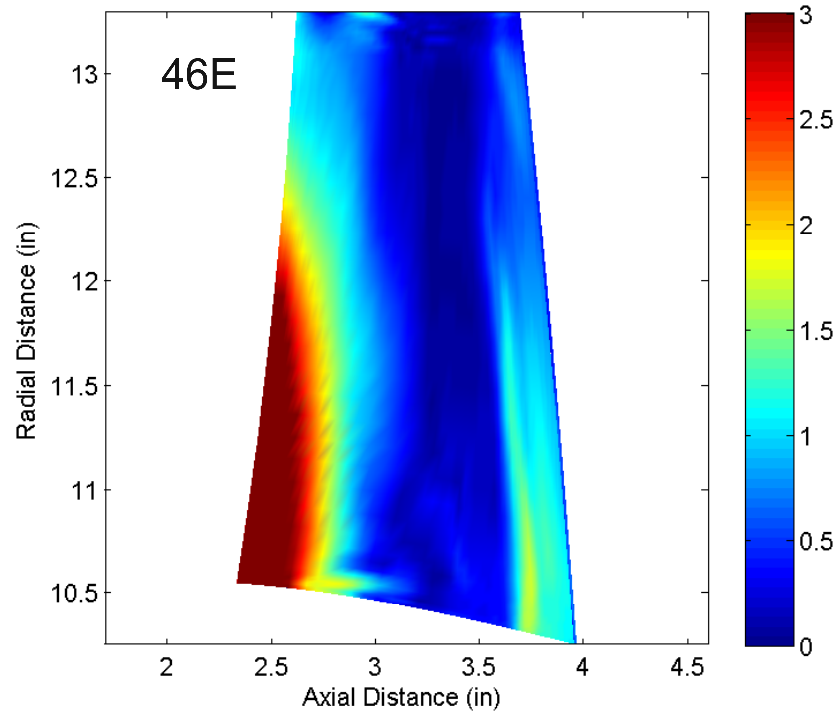
HIT RT Low dP 1B

Small Decrease in 46E Unsteadiness Despite ≈25% Reduction in Peak-to-Peak Ps Variation

1B Suction Side, DFT Magnitude, Percent Pt $_{inlet}$



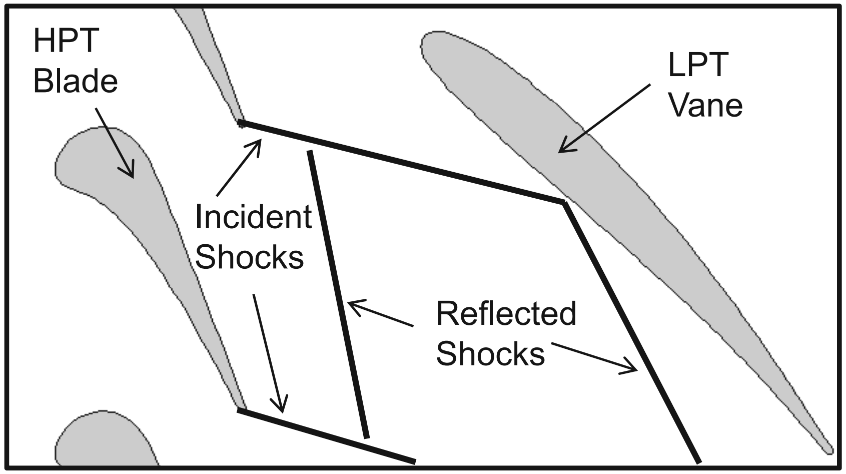
HIT RT



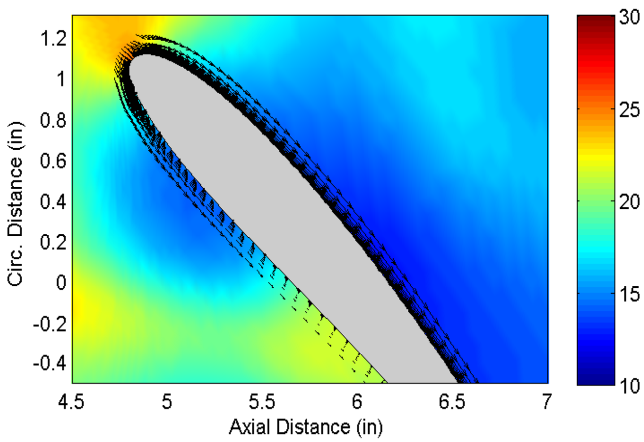
With Low dP 1B

Additional Means to Reduce 1B-2V Interaction: Steady 2V Blowing and 3D Vane Shaping

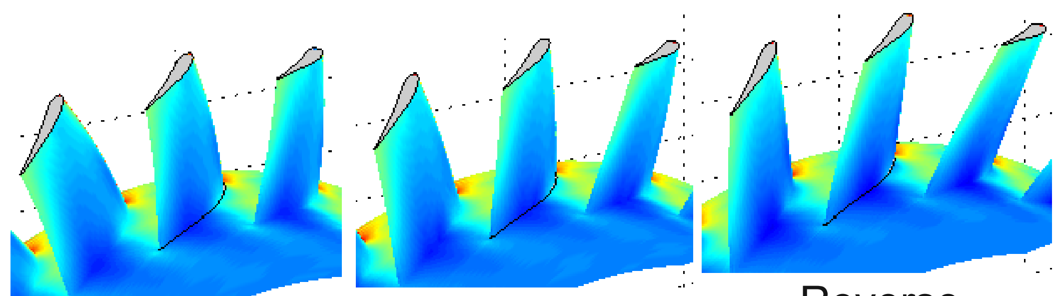
Present Situation



- 2V geometry leads to shock reflections for vaned contra-rotating turbines.
- These arise because induced-flow components due to moving shocks must be cancelled at no-slip surfaces.
- Injection of a small amount of flow equal and opposite the induced velocity should reduce the strength of reflected shocks.
- Bowing of the 2V should affect unsteadiness levels on the 1B surface.



2V With Blowing



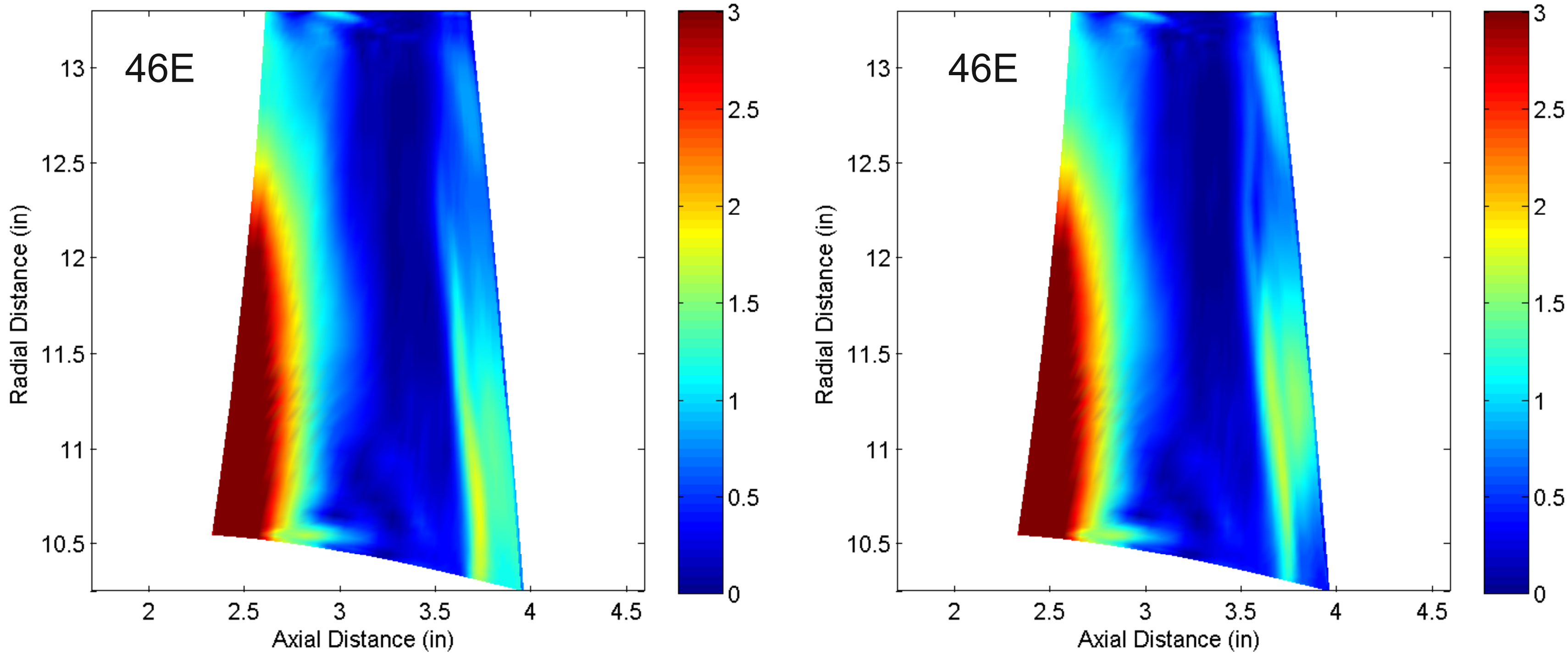
Bowed 2V

HIT RT 2V

Reverse-Bowed 2V

Reverse-Bowed 2V Leads to a Significant Change in Distribution of 46E Unsteadiness

1B Suction Side, DFT Magnitude, Percent Pt $_{inlet}$

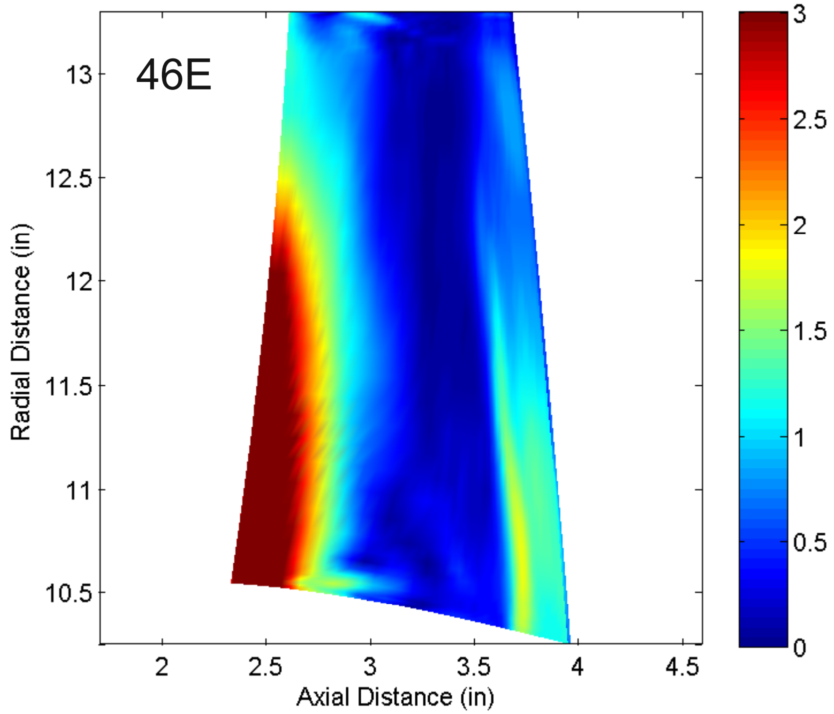


HIT RT | Reverse-Bowed 2V

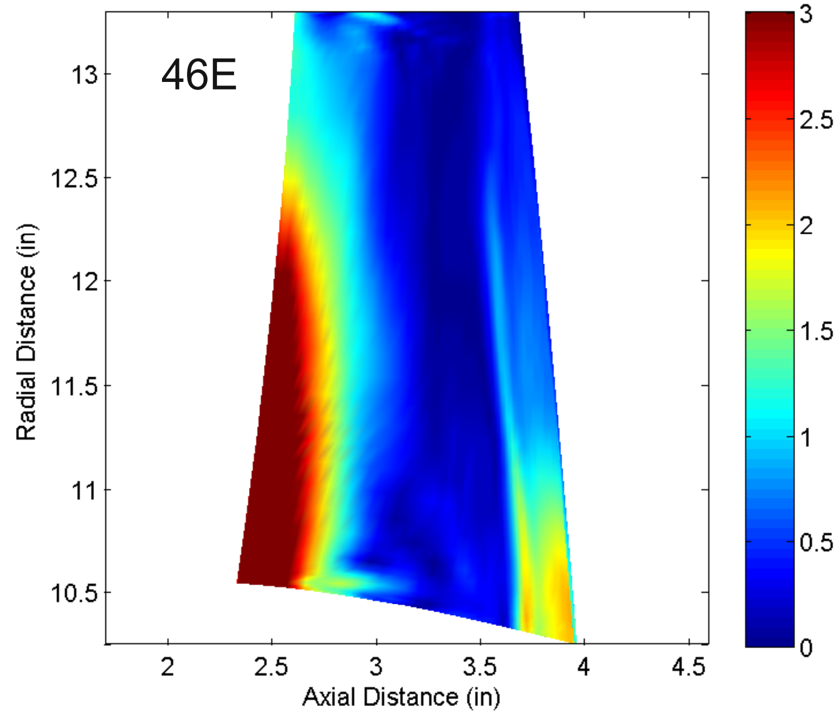
NASA/CP—2010-216112

Bowed 2V Also Leads to a Significant Change in Distribution of 46E Unsteadiness

1B Suction Side, DFT Magnitude, Percent Pt $_{inlet}$



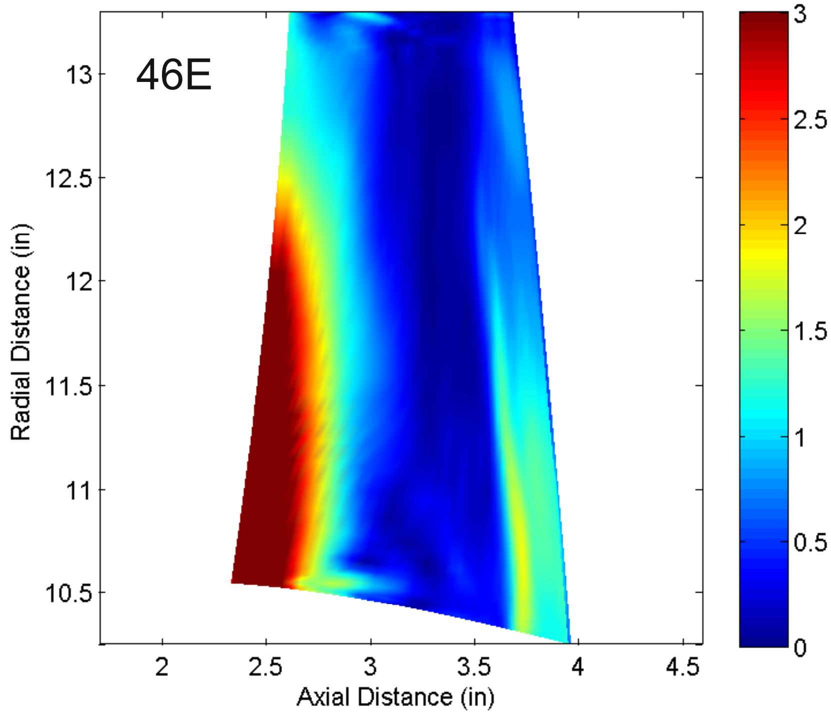
HIT RT



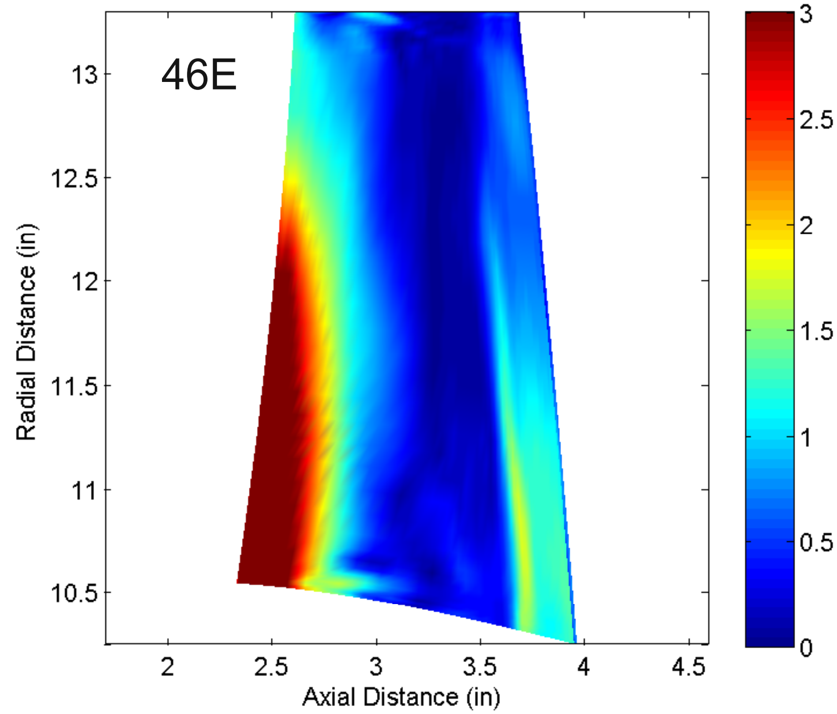
Bowed 2V

Small Decrease in 46E Unsteadiness Due to Steady Blowing on 2V Pressure Side

1B Suction Side, DFT Magnitude, Percent Pt_{inlet}



HIT RT

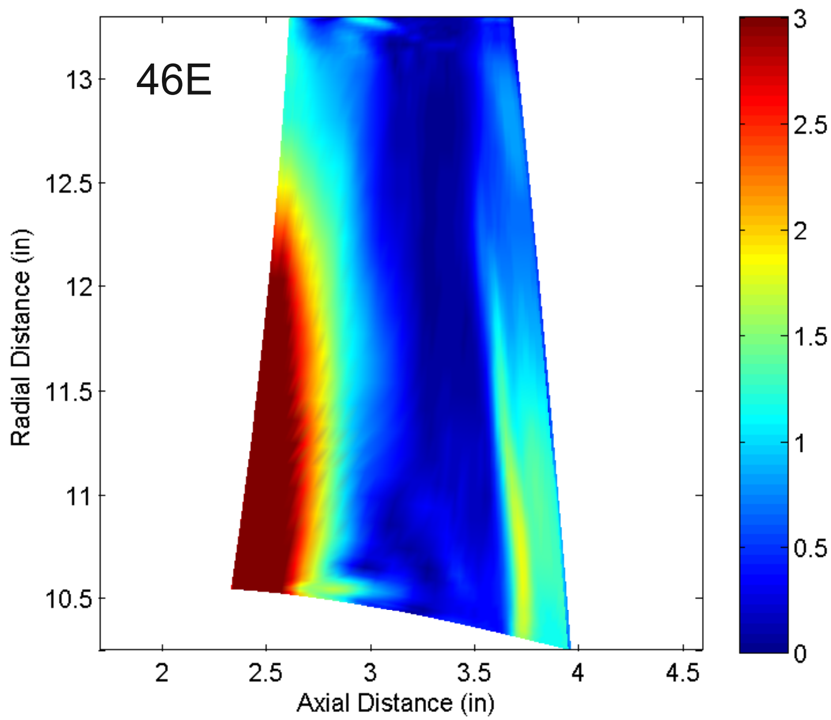


With Steady 2V Blowing

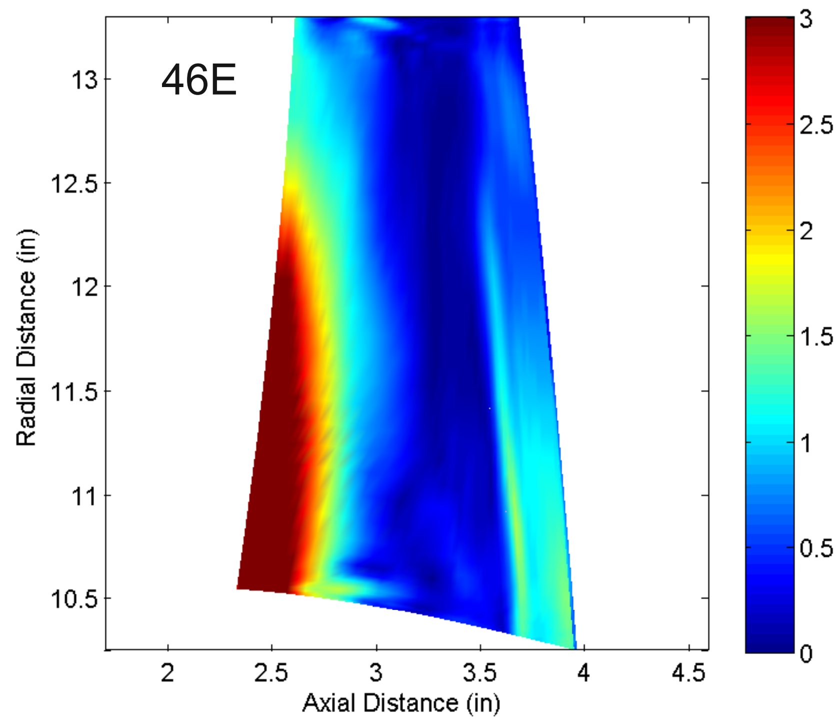
1113 holes, Pt_{cool} = 28 psia, 0.8% Flow, α = 90º

Reduction in 46E Unsteadiness Increases with Increasing Mass Flow

1B Suction Side, DFT Magnitude, Percent Pt $_{inlet}$



HIT RT

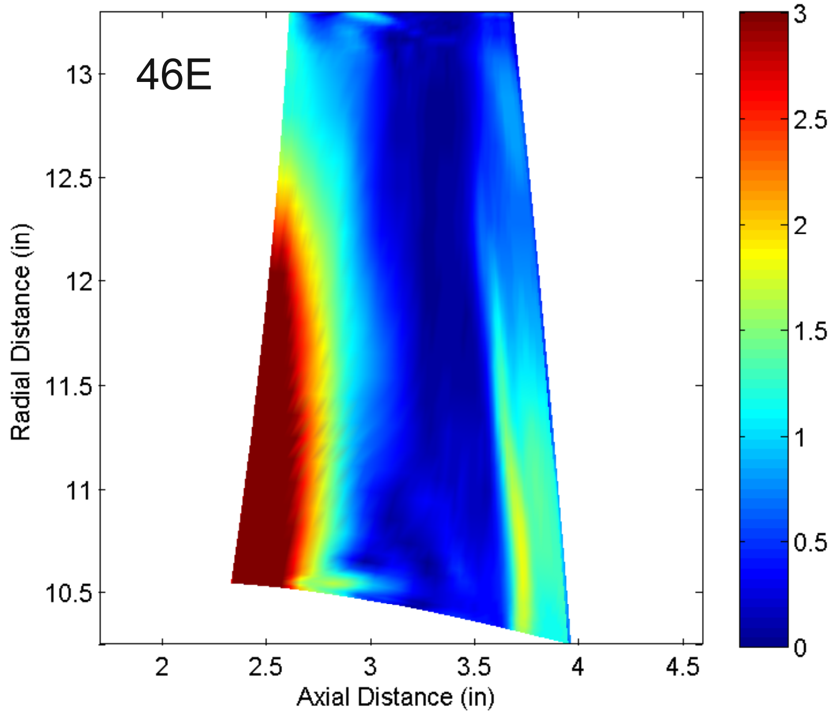


With Steady 2V Blowing

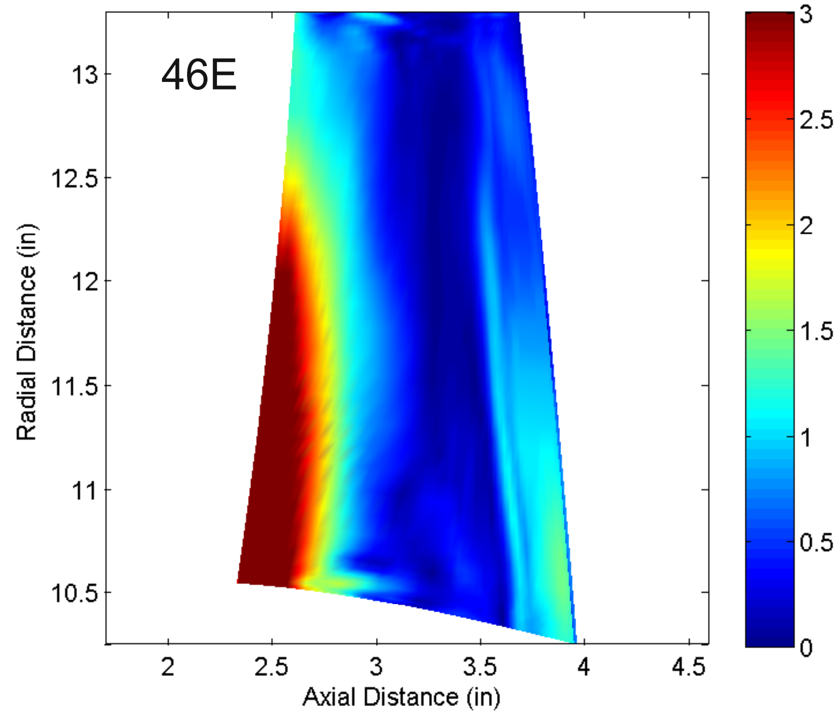
1113 holes, Pt_{cool} = 28 psia, 1.7% Flow, α = 90º

Reduction in 46E Unsteadiness Increases with Increasing Mass Flow

1B Suction Side, DFT Magnitude, Percent Pt_{inlet}



HIT RT

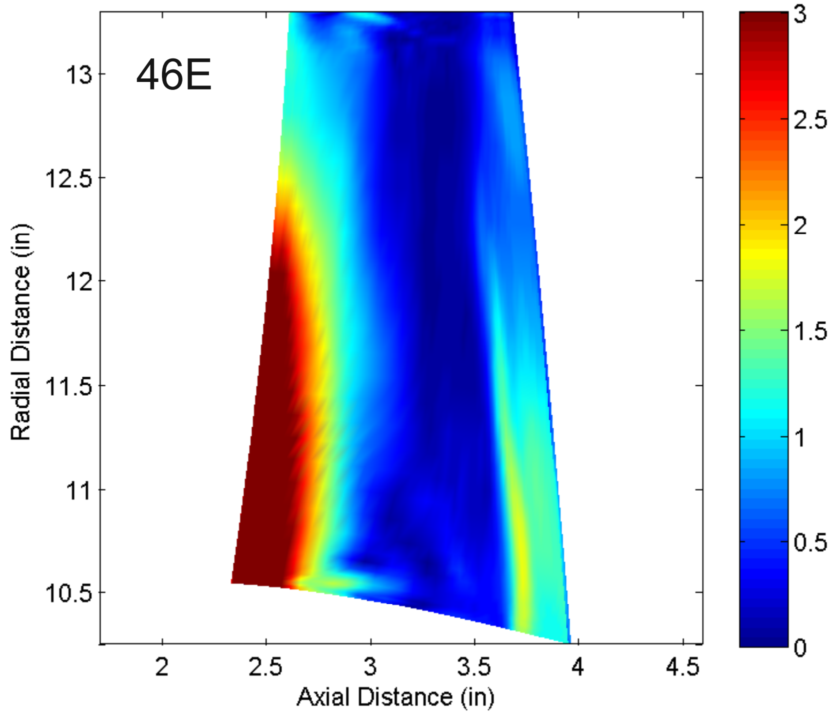


With Steady 2V Blowing

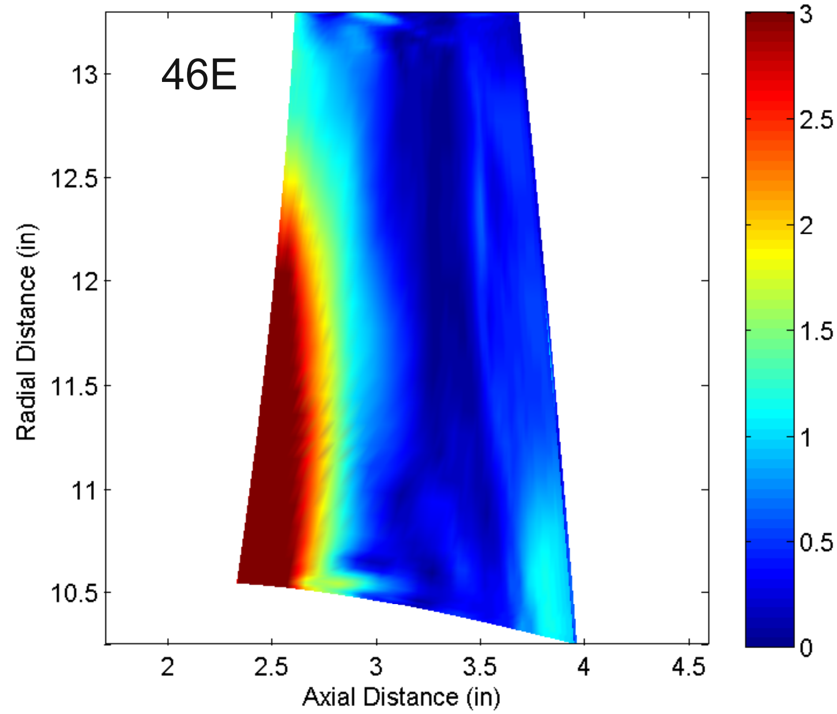
450 holes, Pt_{cool} = 28 psia, 2.8% Flow, α = 90º

Reduction in 46E Unsteadiness Increases with Increasing Mass Flow

1B Suction Side, DFT Magnitude, Percent Pt_{inlet}



HIT RT



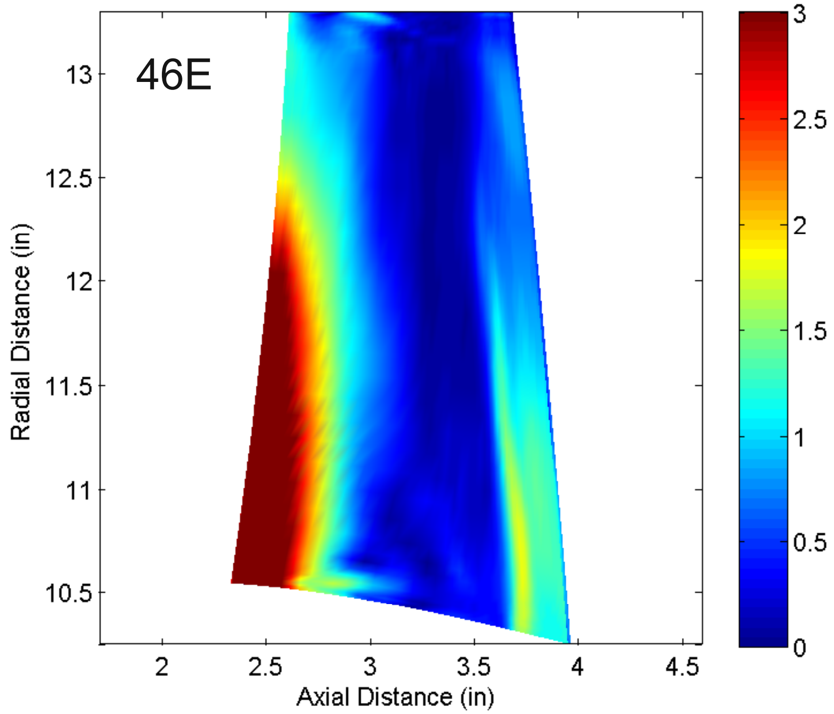
With Steady 2V Blowing

1113 holes, Pt_{cool} = 28 psia, 6.8% Flow, α = 90º

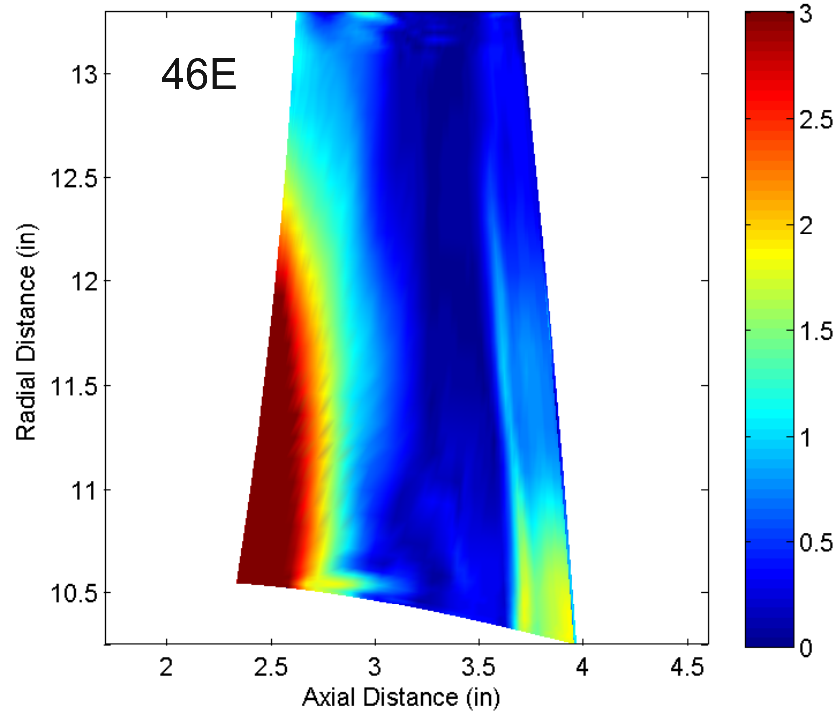
NASA/CP—2010-216112

A Combination of 2V Pressure-Side Blowing and 2V Bow Looks Promising

1B Suction Side, DFT Magnitude, Percent Pt $_{inlet}$



HIT RT

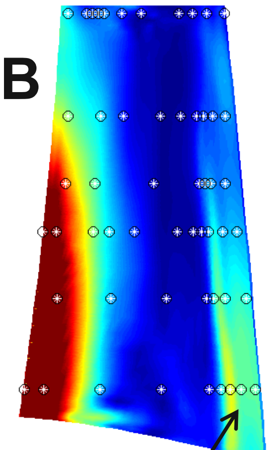


With Steady 2V Blowing and Bowed 2V

1113 holes, Pt_{cool} = 28 psia, 1.7% Flow, $\alpha = 90^o$

HIT RT is Intended to Assess 1B-2V Unsteady Interaction in Great Detail

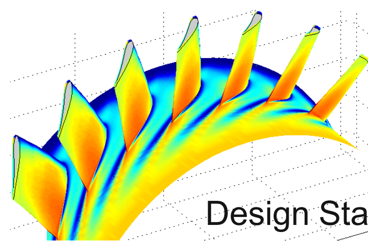
1B



1B

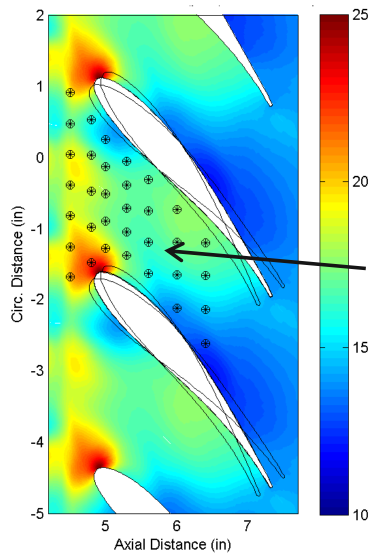
Airfoils :

75 Kulites



2V

Design Stagger



2V

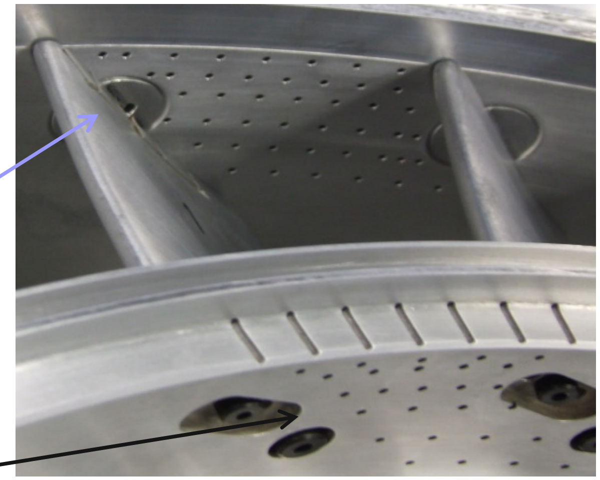
Endwalls :

80 Kulites

Airfoils :

100 Kulites

"Buttons" for Airfoil Re-Stagger



Full-Scale Testing in Turbine Research Facility, Spring 2010

- Variable Stagger 2V (±10% A45 variation)
  - Also enables the investigation of vane asymmetry and re-stagger to reduce unsteady loading
- Vane-row clocking to affect phase of unsteadiness

Summary

- HPT blade unsteadiness in the presence of a downstream vane consistent with contra-rotation is characterized by strong interaction at the first harmonic of downstream vane passing.
- An existing stage-and-one-half transonic turbine rig design was used as a baseline to investigate means of reducing such a blade-vane interaction.
- Methods assessed included:
  - Aerodynamic shaping of HPT blades
  - 3D stacking of the downstream vane
  - Steady pressure-side blowing
- Of the methods assessed, a combination of vane bowing and steady pressure-side blowing produced the most favorable result.
- Transonic turbine experiments are planned to assess predictive accuracy for the baseline turbine and any design improvements.