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

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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 x$10^8$ (Engine)
- Turning: 77° 116° 11°
- $M_{exit}$: 0.88 1.30 0.89
- Airfoil Count: 23 46 23
Unsteadiness due to Downstream Interaction is Dominated by First Harmonic of Vane Passing

1B Suction Side, Percent Signal Power

Cross-Passage Shock
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)
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

- 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%.
Small Decrease in 46E Unsteadiness Despite
\approx 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.
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
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, \( \alpha = 90^\circ \)
Reduction in 46E Unsteadiness Increases with Increasing Mass Flow

1B Suction Side, DFT Magnitude, Percent Pt \textsubscript{inlet}

HIT RT

With Steady 2V Blowing

1113 holes, Pt\textsubscript{cool} = 28 psia, 1.7% Flow, \(\alpha = 90^\circ\)
Reduction in 46E Unsteadiness Increases with Increasing Mass Flow

1B Suction Side, DFT Magnitude, Percent Pt\textsubscript{inlet}

HIT RT

With Steady 2V Blowing

450 holes, Pt\textsubscript{cool} = 28 psia, 2.8% Flow, $\alpha = 90^\circ$
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, \( \alpha = 90^\circ \)
A Combination of 2V Pressure-Side Blowing and 2V Bow Looks Promising

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

HIT RT

With Steady 2V Blowing and Bowed 2V

1113 holes, Pt$_{\text{cool}}$ = 28 psia, 1.7% Flow, $\alpha$ = 90°
HIT RT is Intended to Assess 1B-2V Unsteady Interaction in Great Detail

- 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

Full-Scale Testing in Turbine Research Facility, Spring 2010
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.