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
- $A_N^2 \text{ (in}^2 \text{ rpm}^2\text{)}$: $573 \times 10^8$ (Engine)
- Turning: 77° 116° 11°
- $M_{\text{exit}}$: 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\(_{\text{inlet}}\)

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 in

HIT RT

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

1B Suction Side, DFT Magnitude, Percent Pt<sub>inlet</sub>

HIT RT

With Steady 2V Blowing

1113 holes, Pt<sub>cool</sub> = 28 psia, 0.8% Flow, α = 90°
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, P_{cool} = 28 psia, 1.7% Flow, α = 90°
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, \(\alpha = 90^\circ\)
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, 6.8\% Flow, \alpha = 90\degree
A Combination of 2V Pressure-Side Blowing and 2V Bow Looks Promising

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

With Steady 2V Blowing

HIT RT

With Steady 2V Blowing and Bowed 2V

1113 holes, Pt_{cool} = 28 psia, 1.7% Flow, \( \alpha = 90^\circ \)
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.