FINAL REPORT

REDUCTION OF TURBINE ENDWALL TOTAL PRESSURE LOSS AND HEAT TRANSFER USING THE ICEFORMATOIN DESIGN METHOD

AGTSR CONTRACT
93-01-SR016

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Project Title: Reduction of Turbine Endwall Total Pressure Loss and Heat Transfer using the Iceformation Design Method

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I. Executive Summary

This project's main goals were to generate endwall geometries using the iceformation method and demonstrate performance improvements by measuring the exit total pressure distribution and endwall heat transfer. The work required the involvement of a team of students and engineers at Clarkson and General Electric. In the first year of the project, General Electric engineers acted in an advisory role to help define trhe experimental test case and guide experimental design decisions. Over the period of the project, General Electric engineers also supported the verification of the experimental set-up by performing 2 and 3-D analyses of the Clarkson Cascade. The team also relied on the advice of a consultant, Professor Lee S. Langston, to develop the cascade model and measurement method.

The Clarkson research team's first year activities were directed toward the adaptation of an existing wind tunnel to form a cascade test section and develop iceformation systems. The primary result was the was the production of specialized cryogenic endwall heat exchangers that would grow and maintain ice layers in the turbine vane air flow that matched or exceeded the engine Reynolds numbers. Details of the apparatus were documented in previous quarterly and semi-annual reports on the project. [1-6]. The second year saw the refinement of the apparatus and development of procedures for operating the iceformatoin and measurement equipment. This lengthy process was concluded and iceformation design experiments were conducted [5,6].

A large number of experiments showed repeatability and the importance of using exit span as a criterion for stopping the experiment and capturing the resulting endwall geometry. Final details of the experimental procedure and experiments were detailed in a Clarkson University Masters of Science thesis [7] by Juan Araujo and a Master's of Engineering report [8] by John Reynolds. They used a four-hole probe. This final

report summarizes the endwall design outcome and additional five-hole probe performance measurements.

This final project report has four main sections addressing the main results of the project: geometric measurements, aerodynamic performance measurements, heat transfer calculations and educational results. Other spin-off results include; 1. the development of a low-error measurement method, 2. four and five hole miniature pressure probe techniques, 3. automated calibration and testing at the rate of 20 time samples per spatial point and between 233-260 spatial points per hour and 4. forging a new direction for three-dimensional (non-rotationally symmetric) endwall geometry design and analysis.

To summarize, regarding the main goals of this project:

Geometry – two new endwall concepts were developed using iceformatoin at two inlet air speeds, 34 and 60 ft/sec. Two baseline geometries were used for comparisons: the flat endwall and the rotationally symmetric tip contour of the Energy Efficiency Engine or what is called the E-cube or E3. The iceformation and E3 geometries simplified the effect of the vane geometry near the endwall. The iceform-34 had the least number of wave features required to fit the endwall shape.

Aerodynamics – The E3 had the lowest total pressure loss but produced a strong exit vortex that is likely to harm rotor performance. Iceformation geometries, iceform-34 and -60, diffused the effect of the passage vortex and produced the least amount of exit vorticity. All geometries under-turned the design exit angle of 20 degrees. Iceform-34 and the flat endwall had the closest exit angles to the design angle. The flat and iceform-60 had the highest passage lift coefficients.

Heat Transfer – As a cooling hole design method, iceformatoin geometries indicated areas where cooling requirements are higher. For lower endwall heat transfer, iceform-34 and 21% lower average heat transfer than the E3 endwall based on an ice-manifold comparison. Iceform-60 has nearly the same average heat transfer as the E3 endwall.

Education – A team of engineering students were exposed to and gained some understanding of the design problems facing the gas turbine industry. This was fruitful for the students and the project. An immediate measure of the impact on the U.S. gas turbine industry is:

3 post-graduates finished their investigations and are working with companies that develop or produce gas turbines in the U.S.

2 undergraduate fellowship students graduated and are known to be working in the U.S. gas turbine field

Bottom Line

The iceform-34 is a new concept endwall that has beneficial features compared to the other endwall geometries. Future directions and activities are detailed in the report.