the ENERGY lab

PROJECT FACTS

Hydrogen Turbines

Aerodynamics and Heat Transfer Studies of Parameters Specific to the IGCC-Requirements: High Mass Flow Endwall Contouring, Leading Edge Filleting and Blade Tip Ejection under Rotating Turbine Conditions—Texas A&M University

Background

The efficiency of gas turbines is affected by a number of parameters, including turbine inlet temperature (TIT) and individual component efficiencies. By utilizing the current high level of TIT, efforts are concentrated on improving the component efficiencies. This project with Texas A&M University (TAMU) introduces two different methods for turbine efficiency improvement: (1) a physics-based turbine endwall contouring and (2) blade tip cooling ejection to reduce the tip leakage and to improve the blade tip film cooling effectiveness.

This project was competitively selected under the University Turbine Systems Research (UTSR) Program that permits academic research and student fellowships between participating universities and gas turbine manufacturers. Both are managed by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL). NETL is researching advanced turbine technology with the goal of producing reliable, affordable, and environmentally friendly electric power in response to the nation's increasing energy challenges. With the Hydrogen Turbine Program, NETL is leading the research, development, and demonstration of these technologies to achieve power production from high hydrogen content fuels derived from coal that is clean, efficient, and cost-effective; minimizes carbon dioxide (CO_2) emissions; and will help maintain the nation's leadership in the export of gas turbine equipment. This project was competitively selected under the University Turbine Systems Research (UTSR) Program that permits academic research and student fellowships between participating universities and gas turbine manufacturers.

Project Description

This work is designed to provide the gas turbine industry with quantitative aerodynamic and film cooling effectiveness data essential to understanding the basic physics of complex secondary flows. This includes their influence on the efficiency and performance of gas turbines and the impact that different film cooling ejection

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PARTNERS

None

PROJECT DURATION

Start Date	End Date
10/01/2009	09/30/2013

COST

Total Project Value
$499,969

DOE/Non-DOE Share
$399,891/$100,078

AWARD NUMBER

FE0000753

U.S. DEPARTMENT OF ENERGY

arrangements have on suppressing the detrimental effects of these secondary flows. TAMU is developing a new non-axisymmetric endwall contouring technology and applying it to a three stage, rotating research turbine test facility. Detailed experimental results presented below document the turbine efficiency improvement. Extensive experimental investigations relative to the blade tip ejection presented have shown the effect of different cooling injection arrangements. Both research topics treated in the current research support the gas turbine community in designing high efficiency gas turbines

Goals and Objectives

The main goal of this research is to provide the gas turbine engine designer with fundamental information pertaining to the physics of secondary flow, its influence on the efficiency and performance of gas turbines, and the impact of film cooling ejection arrangements on suppressing the detrimental effect of secondary flows. Project objectives are as follows:

- Establish a physics-based wall contouring method for turbine blades with high, medium, and low deflection.
- Investigate the aerodynamic and performance behavior of the three-stage turbine with and without endwall contouring.
- Generate detailed computer-aided design and computer-aided manufacturing (CAD-CAM) design for the final endwall contours of the second stage rotor.
- Perform an extensive optimization process for first stage contouring. The step is necessary because of the presence of a purge air slot posing a hardware constraint.
- Manufacture a new turbine hub with non-axisymmetric endwall contourings for first and second rotor row.
- Design of four pairs of blades with blade tip film cooling holes.
- Detailed experimental investigation of endwall contouring on purge flow film cooling.
- Detailed experimental investigation of four different blade tip geometries on blade tip film cooling.

Accomplishments

- Applied a new physics-based wall contouring method to the hub section of the second rotor row of an existing three-stage research turbine. A detailed numerical investigation with the new contouring revealed an efficiency improvement of 0.51 percent. The following performance measurement, however, revealed an efficiency of more than 1 percent above the one for reference non-contoured cases. The implied benefits could result in a substantial efficiency improvement for a typical four-stage gas turbine engine with four stator and four rotor rows.
- Numerical investigations highlighted a critical flow regime above which the geometry of the blade pressure side close to the hub needs to be contoured. Two alternative continuous diffusion contouring methods were applied, which reduced the pressure distributions on the blade pressure side, thus accelerating the flow in that region. While the first contouring requires a redesign of the blade geometry close to the hub, the second contouring, which introduced a sequential positive-negative contouring, is confined to the hub surface between the blade suction and pressure surface.
- Generated a detailed CAD-CAM design for the final endwall contours of the second turbine stage. The research turbine was disassembled and sent to a machine shop for modification necessary to perform endwall contour performance testing. Detailed film cooling experiments were also performed to document the impact of non-axisymmetric endwall contouring on film cooling effectiveness of the endwall exposed to purge flow.
- Performed an extensive optimization process for first stage contouring. This step was necessary due to the presence of purge air slot which posed a hardware constraint.
- Designed, manufactured and installed four pairs of blades with different tip ejection film cooling holes onto the research turbine. These configurations were used in detailed film cooling experiments to document the impact of different film cooling hole arrangements on film cooling effectiveness of the blade tips.

Benefits

This UTSR project supports DOE's Hydrogen Turbine Program that is striving to show that gas turbines can operate on coal-based hydrogen fuels, increase combined cycle efficiency by three to five percentage points over baseline, and reduce emissions. The new method for designing non-axisymmetric endwall contours presented in this project could eventually increase the efficiency of gas turbines.

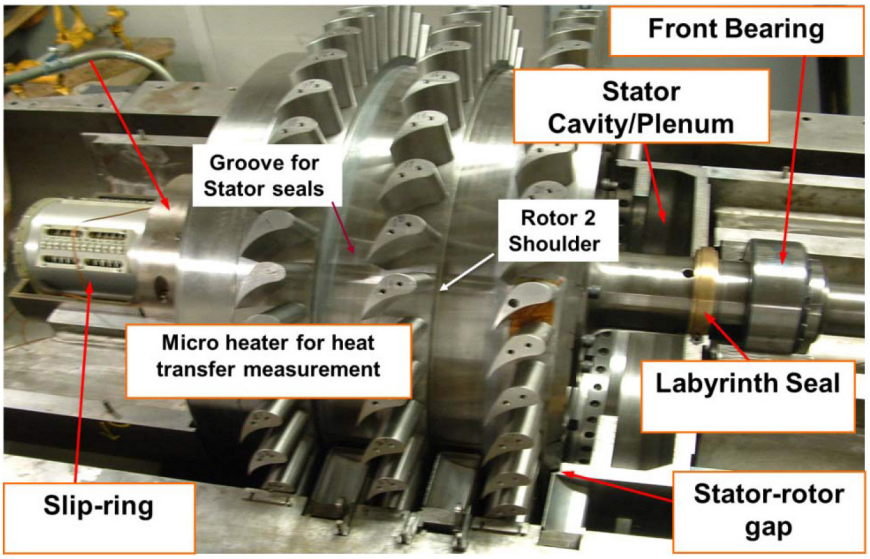
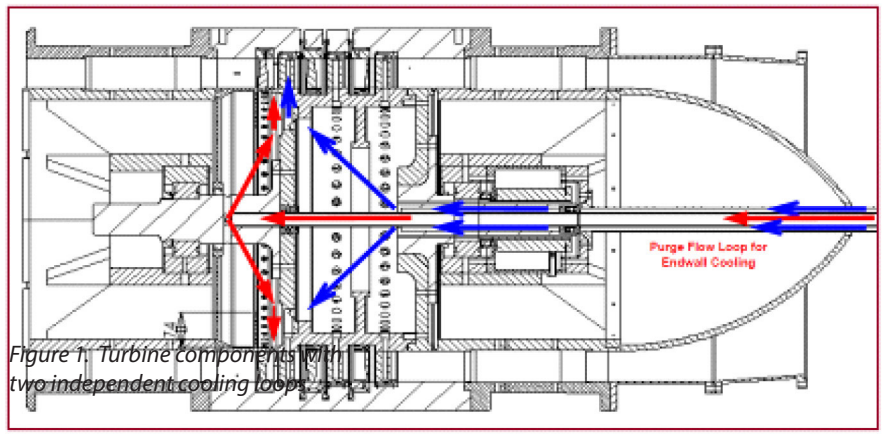


Figure 1. Turbine components with two independent cooling loops.



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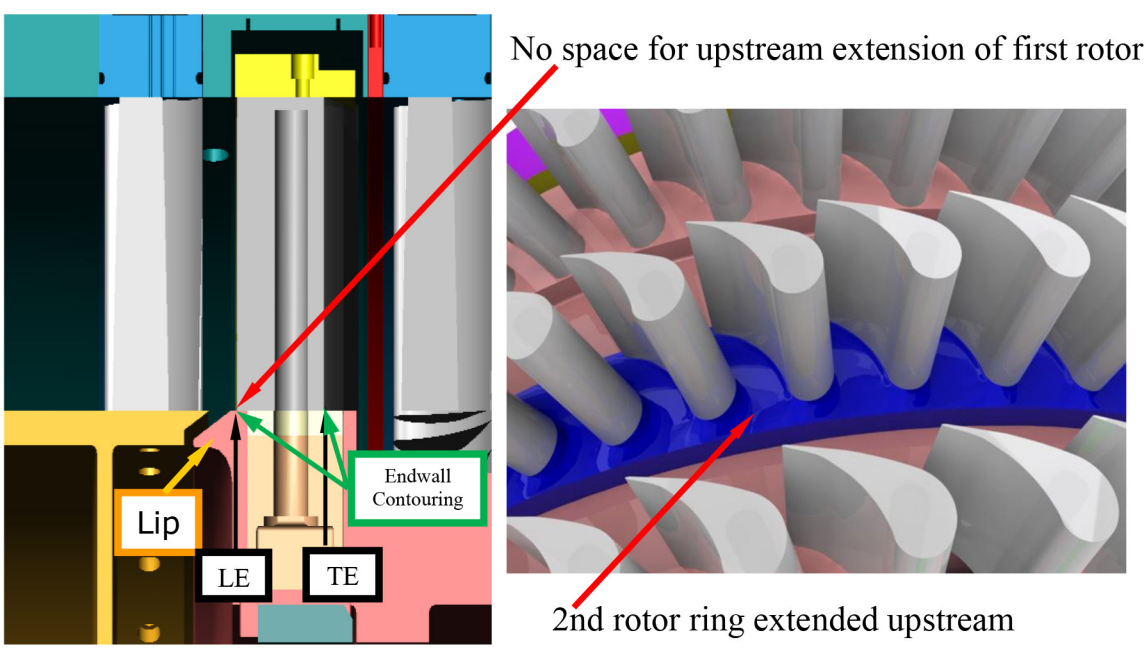

Figure 2. Details of purge flow injection (left), Contouring on second turbine row (blue) right.

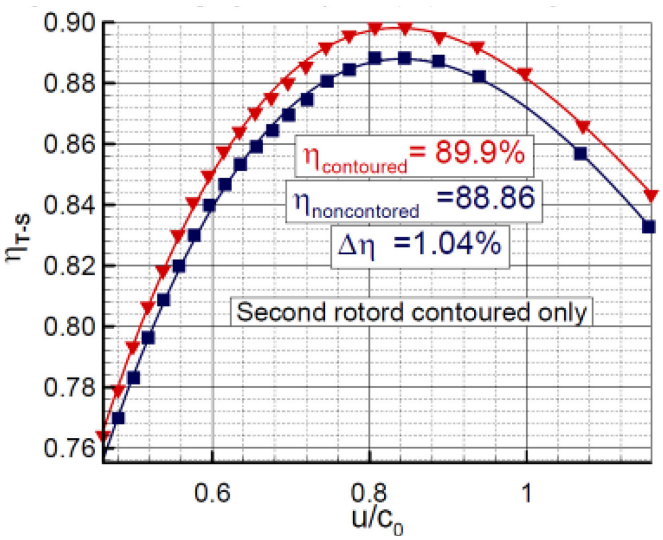

Figure 3. Measured total-to-static efficiency distribution as a function of u/co for the three-stage TPFL-research turbine. Efficiency of the non-contoured reference case is marked by solid squares, whereas the triangles designate the efficiency distribution of the contoured case.

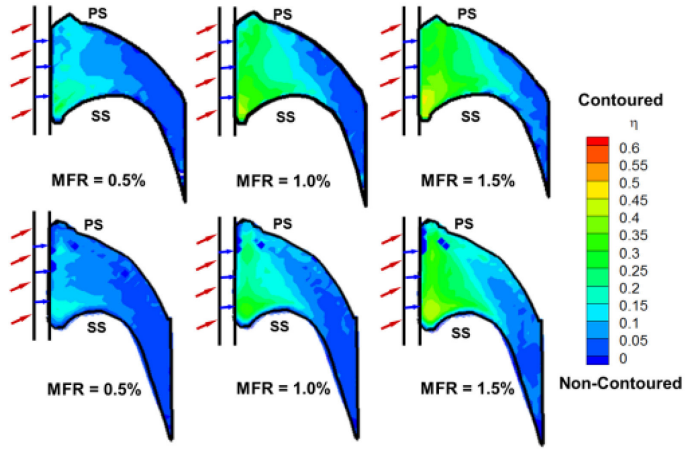

Figure 4. Comparison of film cooling effectiveness distribution on the contoured and non-contoured rotating platform for 3000 rpm.

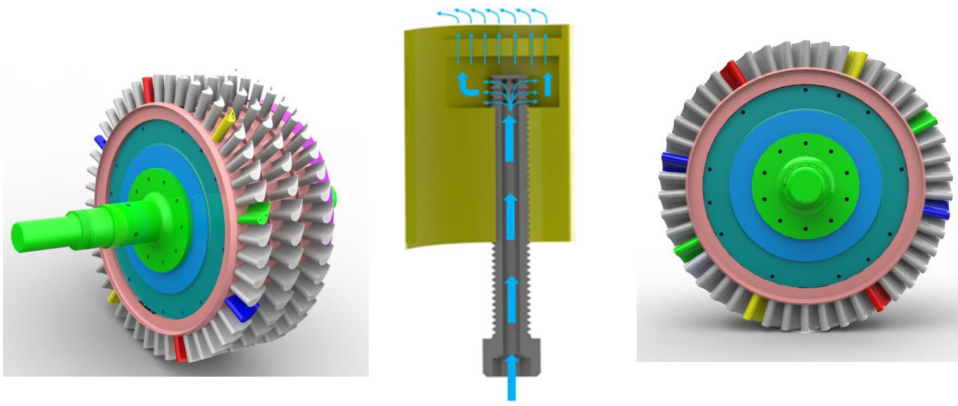

Figure 5. Comparison of film cooling effectiveness distribution on the contoured and non-contoured rotating platform for 3000 rpm.

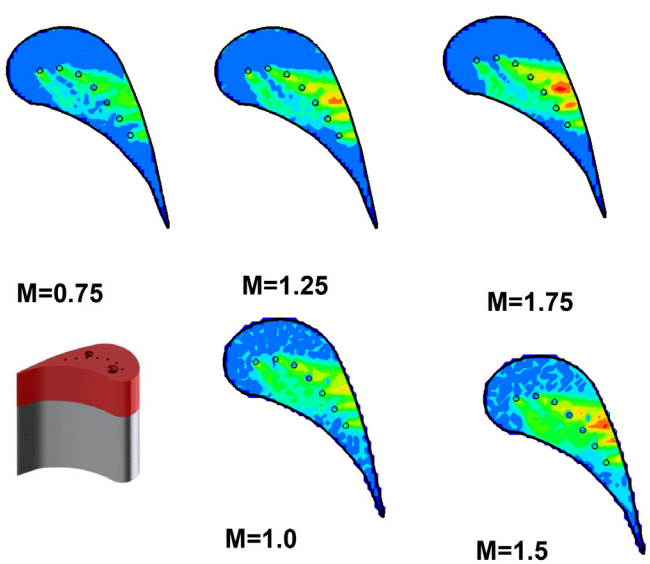

Figure 6. Blade tip film cooling effectiveness distribution on a flat tip at different blowing ratios for 3000 rpm.