



the **ENERGY** lab

PROJECT FACTS

Hydrogen Turbines

Analysis of Gas Turbine Performance— Ames Laboratory

Background

Developing turbine technologies to operate on coal-derived synthesis gas (syngas), hydrogen fuels, and oxy-fuels is critical to the development of advanced power generation technologies such as integrated gasification combined cycle and the deployment of near-zero-emission type power plants with capture and separation of carbon dioxide (CO₂). Turbine efficiency and service life are strongly affected by the turbine expansion process, where the working fluid's high thermal energy gas is converted into mechanical energy to drive the compressor and the electric generator. The most effective way to increase the efficiency of the expansion process is to raise the temperature of the turbine's working fluid. However, the higher temperatures exceed the maximum temperature the state-of-the-art turbine material systems can withstand while maintaining structural integrity and operational reliability. Thus, cooling—such as internal, film, and impingement—is essential for all parts of the turbine whose surfaces contact the hot gases.

Ames Laboratory (Ames Lab) and Purdue University are exploring advanced cooling strategies to respond to the challenging nature of turbine hot gas path component design. Today's turbines are designed to operate very close to the maximum allowable temperatures of their materials of construction and must meet current industry goals to greatly reduce cooling flows to further increase system efficiency. These cooling component designs are further challenged by the combustion of high-hydrogen fuels and oxy-fuels, which increase turbine heat transfer characteristics due to the increase water vapor content, elevated erosion and deposition tendencies, and much higher hot-gas mass flow rates. These combined aero-thermal challenges illustrate the importance of maximizing the available cooling within the application of advanced cooling strategies.

This project is 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 CO₂ emissions, and will help maintain the nation's leadership in the export of gas turbine equipment.

Project Description

Ames Lab and Purdue University are developing cooling strategies through the following tasks:

- Develop and evaluate computational fluid dynamics (CFD)-based analysis tools that can be used to study heat transfer issues in the design of turbine components and develop guidelines and best practices for their use.
- Examine the basis of the experimental methods used to validate CFD design and analysis tools.

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PROJECT DURATION

Start Date	End Date
10/01/2004	09/30/2011

(annual continuations)

COST

Total Project Value
\$995,000

DOE/Non-DOE Share
\$995,000/\$0

AWARD NUMBER

AL05205018



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- Apply CFD analysis tools to support the development of turbine technologies for advanced, near-zero emission-type coal-based power systems. The analysis tools of interest are those that can properly account for the steady and unsteady three-dimensional heat transfer from the hot gas in the turbine blade/vane passages through the turbine material system (thermal barrier coating and superalloy) to the internal cooling passages as a function of the cooling strategy as well as a function of the hot-gas and coolant compositions, mass flow rates, and temperatures.

Goals and Objectives

The goal is to develop an analysis tool that can be used to examine and explore heat transfer design issues of turbine components to support the development of turbine technologies for advanced coal-based power systems. The tool will consider heat transfer from the hot gases to the turbine material system as a function of the cooling strategy, fuel used, amount and nature of diluents used to control combustion and formation of nitric oxides, mass flow rate, firing and turbine inlet temperatures, and the thermodynamic cycle. Objectives for fiscal year 2011 are as follows:

- Demonstrate the utility of the Biot number analogy in exploring turbine cooling designs under laboratory conditions.
- Quantify the effects of different approximations of the bulk temperature in computing the heat-transfer coefficient.
- Assess turbulence models in predicting flow and heat transfer in ducts lined with pin fins.

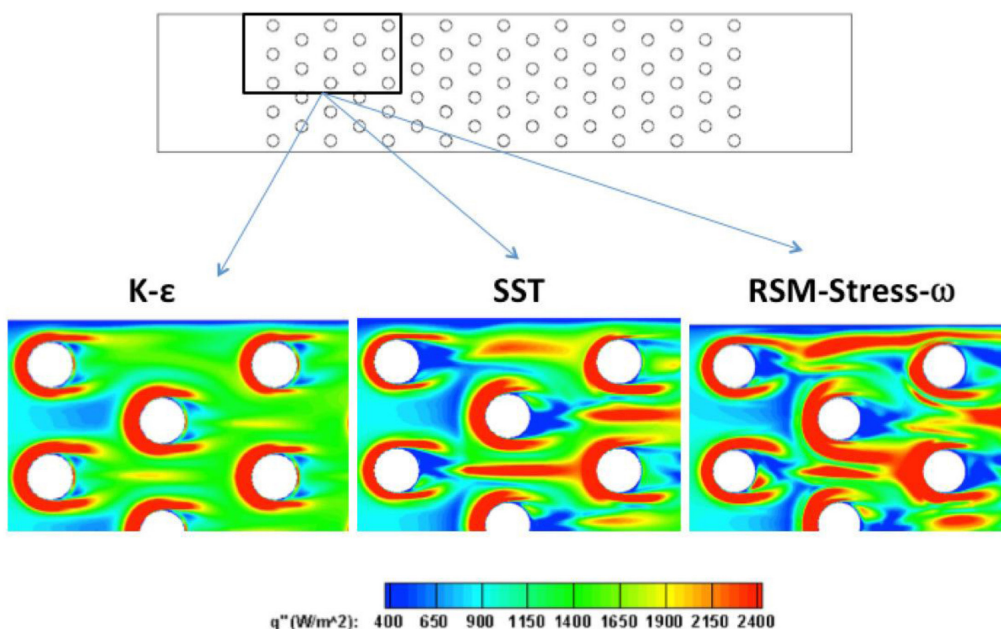
Accomplishments

Ames Lab and Purdue University have demonstrated numerous accomplishments under this DOE project in the last year:

- Performed CFD simulations that showed that if the Biot numbers of two geometrically similar configurations are nearly the same in magnitude and distribution on both the hot and cold sides of a turbine material, then the magnitude and contours of the normalized temperature and heat flux within the turbine material would be nearly the same. This analogy enables experimental studies of turbine cooling designs at near room temperatures and pressures with greatly scaled-up geometries to allow for more detailed interrogations that provide information about how well turbines are cooled (as if the experiment was conducted under realistic turbine operating conditions with high temperatures, high pressures, and the correct dimensions).
- Examined three approximations of the bulk temperature that are widely used in experimental measurements of the heat transfer coefficient and showed that linear interpolation gives accurate results in straight ducts with an error of less than 3 percent if the flow is turbulent, the two planes where the bulk temperatures are measured are taken in the fully-developed region (i.e., not in the entrance transition region), and the distance between the two planes where linear interpolation is employed is 20 duct hydraulic diameters (D) or less. Other approximations based on the inlet temperature or an averaged bulk temperature give grossly inaccurate results.
- Performed initial CFD studies to understand how 'pin fins' clearance height-to-diameter ratio (C/D) and height-to-diameter ratio (H/D) affect surface heat transfer and stagnation pressure.

Benefits

This 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. Studies by Ames Lab and Purdue University will increase the reliability of CFD-based analysis tools and thereby allow designers to minimize the critical heat transfer issues in the design of their turbine components.



Heat Flux on the Wall Induced by Pin Fins as obtained by using the following turbulence models: realizable $k-\epsilon$, shear-stress transport (SST), and full Reynolds stress model (RSM) with stress-omega in the near-wall region.