the ENERGY lab

PROJECT FACTS

Hydrogen Turbines

Effects of Hot Streak and Phantom Cooling on Heat Transfer in a Cooled Turbine Stage Including Particulate Deposition—The Ohio State University

Background

Sophisticated computational modeling and simulation play a crucial role in the design, analysis, and optimization of next-generation gas turbines for power generation. For example, accurate prediction of first stage heat loads and blade temperatures is critical as manufacturers increase turbine inlet temperatures and reduce cooling flows in pursuit of increased turbine efficiency. In this project, The Ohio State University (OSU) will develop a validated computational modeling capability for characterizing the effects of hot streaks (spatial variations in the working fluid temperature upon combustor exit) and particulate (e.g., fly ash) deposition on the heat load and blade temperatures in a cooled turbine stage (vane and rotor). Experimental data from OSU's Turbine Reacting Flow Facility (TuRFR) deposition cascade facility and transient turbine test rig will be used to validate the models.

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

Project Description

The particulate deposition model developed by OSU in prior UTSR work will be modified to better account for the fundamental physics of particle impact and sticking, including particle and surface properties. Experimental data from OSU's TuRFR deposition cascade facility will be used to validate the revised model.

The TuRFR facility will be modified to provide for the generation of inlet temperature profile non-uniformities (hot streaks), which will be tracked through the turbine nozzle passage using surface temperature infrared imagery and exit plane temperature measurements. Hot streak evolution and the effect of the hot streaks on deposition will be evaluated. Film cooling will then be added to both the experiments and the computation to evaluate its effect on hot streak migration and deposition. Finally, the model's ability to track hot streak migration will be exercised on a full turbine stage

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PROJECT DURATION

Start Date	End Date
10/01/2011	09/30/2014

COST

Total Project Value
$621,758

DOE/Non-DOE Share
$497,223/$124,535

AWARD NUMBER

FE0007156

(vane and rotor) using data acquired in the OSU Gas Turbine Laboratory transient turbine test rig. The model will also be used to predict deposition in the rotating configuration, although there will be no experimental validation of deposition in the rotating frame.

Goals and Objectives

The objective of this project is to develop a validated computational modeling capability for the characterization of the effects of hot streaks and particulate deposition on the heat load of modern gas turbines. In its final form, the model will be able to accurately predict the heat load and deposition rates in a cooled turbine stage. The research effort will include model validation with data obtained from the unique deposition and rotating turbine test facilities at OSU.

Accomplishments

- Incorporated elastoviscoplasticity (EVP) model which incorporates both elastic and plastic particle deformation. Previous models accounted for either elastic (critical velocity model) or plastic (critical viscosity model) deformation only.
- Conducted preliminary hot streak clocking study to determine dependency of deposition on hot streak location, particle size, and hot streak severity.
- Generated hot streaks in TuRFR.
- Conducted hot streak deposition test with uncooled nozzle guide vanes.
- Conducted flow simulation of TuRFR test conditions to produce first-ever corroborating computational and experimental data with hot streaks and deposition.
- Designed and constructed a new high temperature particle impingement test facility for the study of rebound/deposit mechanics of micron-sized particles.
- Fundamental rebound studies show trends in coefficient of restitution and deposition rate with temperature and velocity. Results will enhance modeling capabilities.
- Designed and fabricated film slot into existing vane set.
- Conducted tests with deposition and slot cooling with uniform freestream temperature as baseline.
- Developed flow model in Fluent for cooled vane.

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. This project will providethe U.S. gas turbine industry with valuable insights into factors affecting the operation of state-of-the-art gas turbines and the tools for the development of new, innovative airfoil cooling designs.

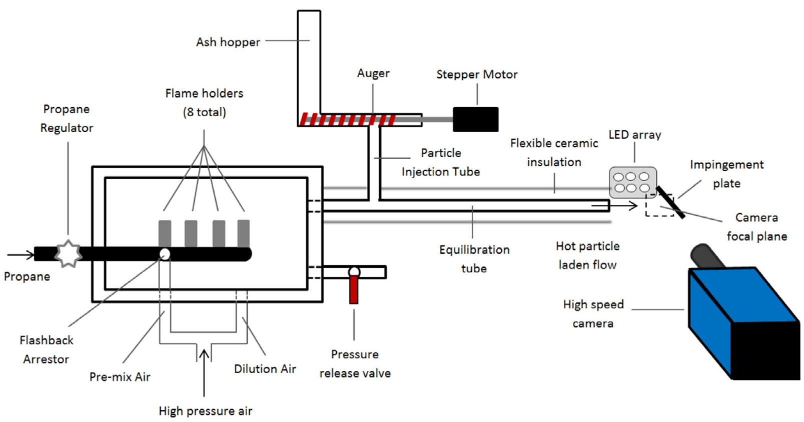

Figure 1. New high temperature fundamental particle impact testing facility showing particle shadow velocimetry arrangement.

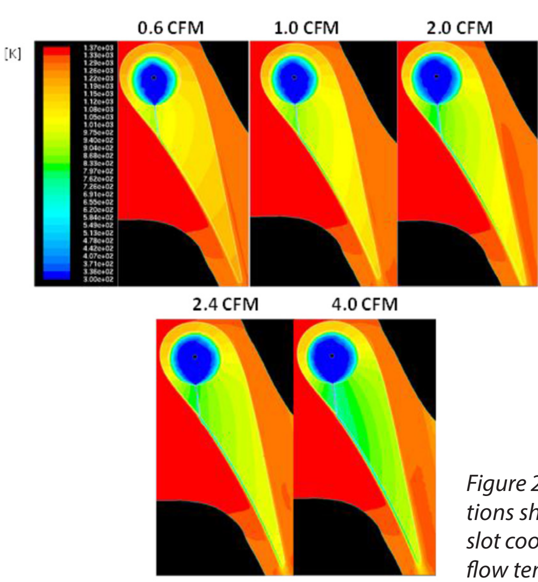

Figure 2. Fluent simulations showing effect of slot cooling on vane and flow temperatures.

Figure 3. OSU turbine reacting flow rig (TuRFR) showing upper and lower sections assembled.