# FACT SHEET

## I. PROJECT PARTICIPANTS

Ames National Laboratory
Oak Ridge National Laboratory (funded separately)

## II. PROJECT DESCRIPTION

**A. Objective(s) –**

The objective of this project is to develop an analysis tool that can be used to examine and explore heat transfer design issues in turbine components to support the development of turbine technologies for advanced FutureGen type coal-based power systems. The tool will consider heat transfer from the hot gases to the thermal-barrier-coating (TBC) system and the superalloy as a function of the cooling strategy, fuel used (e.g., natural gas, syngas, hydrogen fuels, and oxy-fuels), amount of and the nature diluents used to control combustion and formation of nitric oxides, mass flow rate, firing temperature and turbine inlet temperature, and the thermodynamic cycle (e.g., coal-based oxy-fuel Rankine cycles or advanced Brayton cycles).

**B. Relevancy –** Explain how this project advances the body-of-knowledge and/or state-of-the-art in the given field?

This work will advance the state-of-the art in providing an analysis tool for turbine cooling that considers conjugate heat transfer and accounts for the details of internal and film cooling and the details of the TBC system. This work will also advance the body-of-knowledge on turbine cooling.

**C. Project Summary –** Briefly describe the technical approach to achieving the project objective(s).

The analysis tool will be based on the fundamental equations governing fluid flow and heat transfer in the gas phase and conduction heat transfer in the solid phase with temperature and chemical composition dependent material properties.

Validation of the computational tool at various stages of its development will be accomplished by comparing predictions with available experimental data. Also, mathematical methods based on the discrete-error-transport equation will be developed to assess and quantify grid-induced errors.

Simulations will be performed to understand the underlying flow and heat transfer processes, examine the effects of design and operating parameters, and explore and evaluate design concepts to support the development of high performance and durable turbines for advanced coal-based power systems.

**D. Period of Performance – 9/1/05 to 9/30/07**

## III. PROJECT COSTS $ $458,000

**A. DOE Costs** $ 458,000
**B. Prime Cost Sharing** $ 0
**C. Partner Cost Sharing** $ 0

## IV. MAJOR ACCOMPLISHMENTS SINCE THE BEGINNING OF THE PROJECT

- List them in chronological order with approximate dates (month/year). Each accomplishment should be bulleted with a short explanation (short paragraph) of its significance, and benefit/impact. An "accomplishment" is a significant development or finding that advances the state-of-the-art with respect to the technology of interest or significantly contributes to the understanding of a concept or technology.

- 12/31/05
  Incorporated Cantera (an open source code developed at Caltech for computing chemical kinetics and thermodynamic and transport properties) into Syngate (an overarching systems-level software package developed at ORNL to predict hot-gas path flow properties in power-generation gas turbines as a function of fuel composition and combustion operating conditions). This work was with Adrian Sabau and Ian Wright of ORNL.

- 12/31/05
  Edited a special section on turbine science and technology that will appear in the March-April 2006 issue of the AIAA Journal of Propulsion and Power. This special section involves ten review articles, authored by leading authorities on the following topics: internal cooling, film cooling, blade-tip heat transfer, trailing-edge heat transfer, endwall heat transfer, erosion and deposition, seal design, superalloys, thermal barrier-coatings, and high-cycle fatigue. This special section is significant in bringing together thermal management with materials and mechanics of materials to give an integrated view not available before. Further advances in gas turbine efficiency and durability require a synergistic effort

- 12/31/05
  Set up a verification and validation (V&V) database for open critique and assessment of computational fluid dynamics analysis of film cooling in which all input and output files including the grid system used and the solution s generated can be provided. The database now contains solutions generated by Fluent-UNS code (version 6.1.22) for two test problems: (1) film-cooling of a flat plat from a row of inclined circular holes and (2) film-cooling of a leading edge from three rows of compound-angle holes for which experimental data are available for comparison. The details of this database is summarized in an AIAA paper (Na, S., Zhu, B., Bryden, M., and Shih, T.I-P., "CFD Analysis of Film Cooling," AIAA Paper 2006-0022, Aerospace Sciences Meeting, Reno, Nevada, January 2006). This work is significant in providing a place where V&V can be done openly to identify best practices and to provide guidelines on accuracy and reliability of CFD analysis of film cooling.

- 10/31/06
  Developed a preliminary methodology to estimate heat transfer and drag on 3-D surfaces roughened by erosion and/or deposition by performing a series of 2-D CFD analysis. This work would support the modeling

- 10/31/06
  Performed preliminary studies on the capability of the Fluent UNS code to compute conjugate heat transfer and used the Fluent UNS code to explore the coupling of internal and film cooling across the superalloy with and without thermal-barrier coating. The details of this work is summarized in Na, S., Williams, B., Dennis, R.A., Bryden, K.M., and Shih, T. I-P., "Internal and Film Cooling of a Flat Plate with Conjugate Heat Transfer," ASME IGTI Paper GT-2007-27599, IGTI Conference and Expo, Montreal, Canada, May 14-17, 2007, which is currently under review.

- 10/31/06
  Performed preliminary studies on the capability of the Fluent UNS code to compute and understand complicated internal cooling passages with pin fins under rotating and non-rotating conditions. The details of this work is summarized in Zhu, B., Chi, X., Chyu, M.K., and Shih, T. I-P., "Internal Cooling inside an L-Shaped Duct with Pin-Fin Turbulators under Rotating and Non-Rotating Conditions," ASME IGTI Paper GT-2007-27598, IGTI Conference and Expo, Montreal, Canada, May 14-17, 2007, which is currently under review.

## V. MAJOR ACTIVITIES PLANNED DURING THE NEXT 18 MONTHS

- List them in chronological order with approximate anticipated dates of completion (MM/YY). Each planned activity should be bulleted with a short explanation (short paragraph) of its significance, and benefit/impact. An "activity" is a task or sub-task which should directly relate or lead to a desired accomplishment (see IV above).

- 12/31/06
  Perform CFD simulations of conjugate heat transfer in several film-cooling configurations that account for the details of the TBC system and temperature dependent material properties to understand underlying flow and heat transfer process to guide design of effective and efficient film cooling strategies for turbines in FutureGen type power plants.

- 12/31/06
  Initiate studies of conjugate heat transfer that also account for the thermal stresses.

- 12/31/06
  Expand V&V database (see accomplishments under 12/31/05) to include conjugate heat transfer.

- 9/30/07
  Performed preliminary studies of computational tools for analyzing turbine cooling that couple internal and film cooling, conjugate heat transfer, and thermal stresses.

- 9/30/07
  Explore, develop, and evaluate effective and efficient film-cooling strategies for FutureGen turbine operating conditions.

- 9/30/07
  Expand V&V database (see accomplishments under 12/31/05) to include all simulations performed throughout project.

## VI. ISSUES

- Identify any event causing a significant schedule slippage or cost growth; an environmental, safety and health violation; achievement of or problem encountered for an important technical objective.

  Though there are no slippages in schedule or changes in cost, the division of labor between the Ames Lab and the Oak Ridge National Laboratory (ORNL) was made clear in 2006. Basically, ORNL will be developing the 0-D/1-D model for the design and analysis of FutureGen type turbines, whereas the Ames Lab will be performing detailed 3-D CFD analysis to assess 3-D CFD tools, to provide understanding of the flow and heat transfer in FutureGen type turbines, and to guide the development of 0-D and 1-D . Thus, all efforts proposed for 2006 and 2007 to develop 0-D and 1-D models were deleted. In its place was added work on thermal stress to the CFD studies of conjugate heat transfer. Also added was work on CFD studies of surface roughness.