An Investigation into the Mechanics of Single Crystal Turbine Blades
with a View Toward Enhancing Turbine Efficiency

FACT SHEET

I. PROJECT PARTICIPANTS

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II. PROJECT DESCRIPTION

A. Objective(s)

To model the behavior of single crystal turbine blades within a full thermodynamic framework, accounting for the evolving anisotropy of the material as it deforms and the creep behavior at different temperatures.

B. Background/Relevancy

The preferred solution to the generation of electric power is by means of gas turbines as they are cheaper and produce considerably less carbon monoxide than conventional methods of power generation. While there has been some progress in the design of gas turbines with a view towards increasing their efficiency over the past four decades, the main stumbling block is the inability to manufacture turbine blades that can withstand significantly higher inlet temperatures, and the development of cooling systems that can allow the temperature of the gas entering the turbine to be significantly higher than at the present moment.

Conventional polycrystalline materials that are used in gas turbines have poor creep response. Creep at high temperature results from two different mechanisms, the first due to dislocation motion such as gliding and climbing (power-law creep) and the second associated with diffusion of boundaries, point defects, and interstitials(diffusional creep). Newer forms of polycrystalline materials based on Ni and Ti super alloys exhibit improved creep strength with respect to power-law creep, but not with regard to diffusional creep. Newer alloys such as NiAl single crystal alloys incorporating Ti and Hf seem to offer better diffusional creep response; however, the modeling of single crystal alloy materials has not kept pace with the material development. The proposed research is aimed at developing a systematic framework for describing the behavior of these newer alloys, where material symmetry and orientation are critical to the performance.

C. Period of Performance

October 1, 2001 – September 30, 2004

D. Project Summary

This project will develop a common framework to study creep and plastic flow in state-of-the-art single crystal alloys with particular emphasis paid to incorporating the crystallographic symmetry of the material and the microstructural deformation mechanisms. The framework will be based on the notion that materials possess multiple natural configurations with their own distinct symmetries. The model will predict the steady-state and time-dependent response of single crystals within a fully thermodynamic framework. Specific emphasis will be placed on the study of specific boundary value problems for single crystals that corresponds to the geometry of the single crystal turbine blades.

III. PROJECT COSTS

A. DOE Costs: $353,667

B. Prime Cost Sharing: $89,119

IV. MAJOR ACCOMPLISHMENTS SINCE THE BEGINNING OF THE PROJECT

● Developed the framework for a constitutive model that incorporates the micro-structural scale effects into a macroscopic model that can then predict the macroscopic response of the single crystal blade (12/02).

● Derived specific constitutive equations from the basic constitutive framework (3/03).

● Implemented material subroutines incorporating the constitutive model and interfaced with the finite element code as part of a computational module (6/03).

● Derived the tangent stiffness matrix for specific single crystal constitutive equations (9/03).

V. MAJOR ACTIVITIES PLANNED DURING THE NEXT 6 MONTHS

● Calibrate the constitutive model by testing its robustness for specific idealized geometries for which there is experimental data. Obtain values for the material parameters by correlating with available experimental results (12/03).

● Develop finite element analysis (FEA) code subroutines incorporating the constitutive model (3/04).

VI. MAJOR ACTIVITIES PLANNED IN OUTYEARS (6-18 MONTHS)

● Perform FEA analyses of turbine blades incorporating realistic geometries, boundary conditions and thermal history, gaining insights into the creep behavior of superalloys under actual turbine operating conditions (FY04).

● Finalize the computational code and draw conclusions with respect to the factors influencing the viscoplastic response of single crystal turbine blades, including the orientation of the crystallographic axis and operating temperature (FY04).

VII. ISSUES

None.