Gas Turbine Reheat Using In-Situ Combustion

FACT SHEET

I. PROJECT PARTICIPANTS

A. Prime Participant: Siemens Westinghouse Power Corp.

B. Sub-Award Participant: Texas A&M University

II. PROJECT DESCRIPTION

A. Objectives:

The overall objective of this project is to develop a novel gas reheat concept for gas turbine engines, in which fuel is injected directly into the turbine through one or more stages of vanes and/or blades. The key research goals involved in concept selection are to understand the combustion kinetics (burnout, emissions), blade performance and effects on turbine power output and efficiency. The concept is being evaluated for maximum energy efficiency (full reheat) and as a means to achieve power boost (minimum reheat)

B. Background/Relevancy:

Background. Gas turbine efficiency and power output have historically been increased by increasing gas turbine firing temperature. This approach is limited by the generation of thermal NOx and by the need for advanced materials at higher temperatures.

A well known alternative approach is to add reheat combustion between turbine stages to achieve higher mean temperatures at which heat is extracted, without increasing maximum temperature. More fuel is burned, to give higher power output. If this is accompanied by increased pressure ratio, or used in combined cycle with higher steam cycle inlet temperature, then cycle efficiency is also increased.

Prior suggested reheat schemes have used discrete reheat combustors, either within a larger shell or external, between two separate turbines. In the concept of this work, reheat fuel is injected directly into the turbine flow via injection holes in the turbine vanes or blades. The advantages are: 1) simplicity in turbine design with no increase in casing size and no external reheat combustor and transition. 2) Lower reheat peak combustion temperature; 3) near zero reheat NOx formation, with normalized NOx (to 15% oxygen) actually reduced; 4) reduced parasitic pressure loss; 5) substitution of fuel for some airfoil coolant flow.

Relevancy. The in-situ reheat concept represents a new approach that can allow gas turbine engines to move toward DOE goals of higher efficiency, higher power output, low emissions engines. This work will develop the scientific basis for the concept of in-situ reheat. In particular the work will identify the combustion kinetic basis for injection, will identify practical designs (simple or flame-held) for achieving injection, and will quantify effects on airfoil aerodynamics and turbine performance.

C. Period of Performance: October 1, 2000 through January 31, 2004.

D. Project Summary:

The project is divided into four technical tasks:

Task 1, Blade Path Aerodynamics. A CFD model, CoRSI (Combustion and Rotor-Stator Interaction) is being modified at Texas A&M to incorporate simplified combustion kineitcs, with blade path flow. The model is being used to investigate the effect of injection parameters (stage, fuel flow, fuel temperature, injection angle) on turbine performance (burnout location, forces on blades, power output, efficiency).

Task 2, Combustion and Emissions. Detailed (Chemkin and GRI data base) calculation are being performed to characterize reheat fuel burnout (as check on simplified Task 1 kinetics) and emissions kinetics. Operating maps and flame-held injection designs result.

Task 3, Sub-Scale Testing. The theoretical analyses of Tasks 1 and 2 are being checked by testing under blade path conditions in existing rigs with 0.5 and 1.5 lb/s air flow. The progress of direct injection combustion is being measured as a function of residence time.

Task 4, Conceptual Design and Development Plan. A preferred design approach will be identified and prepared for pre-commercial development based on the results of prior tasks.

III. PROJECT COSTS

A. DOE Costs: $603,629.
B. Prime Contractor Cost Sharing: $201,210.
C. Partner Cost Sharing, If Applicable: NA

IV. MAJOR ACCOMPLISHMENTS SINCE THE BEGINNING OF THE PROJECT

- Parametric detailed chemical studies showed theoretical efficacy of injection at first and second stages without flameholding (12/00). Provided basis for further studies.
- A flameholding model was developed (4/02). Will provide basis for late-stage design.

- CFD modeling showed performance improvements and limitations for direct injection (12/02). Confirmed benefits of early stage injection.
- Two test rigs were prepared for operation, and testing was initiated (12/02). These enable proof-of-concept testing and combustion kinetics measurement.

V. MAJOR ACCOMPLISHMENTS PLANNED DURING THE NEXT 6 MONTHS

- Parametric CFD studies will be extended to 3D (5/03). This extensive is needed to account for anomalous 2D results at some conditions of interest due to flow path area estimation by the two means.
- Blade path aerodynamics topical report (6/03). This report will summarize evaluation of the impact of reheat on blade aerodynamics and turbine performance.
- Parametric analyses of flameholder designs will be completed (4/03). Show how injection can be accomplished in stages where spontaneous mixture combustion does not occur.
- Testing at 0.5 lb/s air flow will be completed (2/03). These tests will serve as a test run for larger scale tests, verifying methods, and providing some insight into practicability.
- Test plan for 1.5 lb/s tests (3/03). Testing at 1.5 lb/s air flow initiated (4/03). These parametiric tests will demonstrate concept and measure combustion rates, assisting in concept design.

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

- Combustion and Emissions Topical report (7/03). Chemical reactor design scoping for flameless and flame-held design approaches.
- Completion of testing (8/03).
- Conceptual Design and Development Plan Topical Report (11/03). A design concept and plan for scale-up through engine demonstration will be developed.
- Final report (1/04). Summarize project results.

VII. MAJOR MILESTONES FOR ENTIRE PROJECT

- The theoretical basis for in-situ reheat will be developed.
- A conceptual design for a preferred in-situ reheat approach will be developed, along with a going-forward plan for concept development.

VIII. ISSUES

The major issue for the commercialization of in-situ reheat will be assessment of the market drivers and justification of engine modification engineering expenditures. The minimum reheat approach (power boost) would have less direct impact on engine design.