PROGRAM TO DEVELOP A PERFORMANCE AND HEAT LOAD PREDICTION SYSTEM FOR MULTISTAGE TURBINES

FORTY-FOURTH TECHNICAL PROGRESS NARRATIVE AND FINANCIAL MANAGEMENT REPORT

For the Period
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Prepared For

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Flows in low-aspect ratio turbines, such as the SSME fuel turbine, are three-dimensional and highly unsteady due to the relative motion of adjacent airfoil rows and the circumferential and spanwise gradients in total pressure and temperature. The systems used to design these machines, however, are based on the assumption that the flow is steady. The codes utilized in these design systems are calibrated against turbine rig and engine data through the use of empirical correlations and experience factors. For high aspect ratio turbines, these codes yield reasonably accurate estimates of flow and temperature distributions. However, future design trends will see lower aspect ratio (reduced number of parts) and higher inlet temperature which will result in increased three-dimensionality and flow unsteadiness in turbines. Analysis of recently acquired data indicate that temperature streaks and secondary flows generated in combustors and upstream airfoils can have a large impact on the time-averaged temperature and angle distributions in downstream airfoil rows.

The objective of the program is to develop 'closure-models' that will permit predictions of time-averaged effects of unsteadiness in multistage turbines. The predictive capabilities of these closure models will be verified through design and testing of hardware in a large scale rotating rig. Generalized formulations of these closure models will enhance the state-of-the-art of turbine design procedures to allow designers to optimize the performance, life and structural integrity of turbines used in airbreathing and rocket propulsion systems in a cost-effective manner.

The technical program comprises the following effort. Closure models will be formulated by using existing unique experimental and numerical data. These closure models will provide numerical values needed for 'average-passage' solvers developed by scientists at NASA to predict effects of periodic unsteadiness on time-averaged flows in multistage machines. Computational Fluid Dynamics (CFD) codes with these closure models will be used to redesign a row of airfoils for the UTRC large scale rotating rig to reduce heat loads and to improve the performance of the second stator. The redesigned airfoil will be fabricated. An experimental program will be conducted to define the distribution of the heat load and aerodynamic performance of the second stator and to allow verification of the predictive capabilities of the closure models. The closure models will then be assessed for their predictive capabilities and contribution to the enhancement of the current design system.
SECTION II
TECHNICAL PROGRESS SUMMARY
February 1994

The period of performance for this program has been extended twelve months for a new completion date of March 9, 1994.

TASK 1 - FORMULATE CLOSURE MODELS

The objective of this task is formulate closure models for mathematical expressions which appear in time averaged equations of motion due to the effect of periodic unsteady flows in turbomachines. Numerical and experimental data base, together with the description of the turbine which provided the basis for these closure models, will be delivered to NASA.

Status:

Physical "closure models" are being formulated that will be consistent with the system of equations describing the 3-D time-averaged viscous flow through multistage turbinines as presented by Adamczyk (Refs. 1, 2). These closure models are expected to yield an improved and more physically based predictions of time-averaged effects of periodic unsteadiness on both heat load and performance than that being provided by the prediction system used in the current turbine design process. The closure models are being formulated in a three-step approach as follows:

   Step 1 (Task 1.1): Interrogation of Existing Data Base
   Step 2 (Task 1.2): Interrogation of Multirow Computations
   Step 3 (Task 1.3): Implementation of Closure Models in CFD Codes.

Work under Steps 1 and 2 have been completed. Progress made to date under Steps 1, 2 and 3 is discussed below.

Task 1.1 Interrogation of the Existing Data Base

This task has been completed.

Task 1.2 Interrogation of Multi-Row Computations

This task has been completed.

Task 1.3 Implementation of Closure Models in CFD Codes

Work directed towards completing the modification of a 2D-boundary layer code to account for the deterministic stress terms to quantify the impact of periodic unsteadiness heat loads has been delayed due to increased allocation of resources in Tasks 4 and 5.

Task 2. Design of an Airfoil Row

This task has been completed.

Task 3. Fabricate an Airfoil Row and Prepare Test Plan

This task has been completed.
Task 4. Conduct Experimental Program

Data acquisition under contract funding has been delayed due to rig and data processing modification and verification.

Task 5. Assessment of Closure Models

Effort in this area has been to ensure that the rig modifications are consistent with the remaining portion of the contract.

SECTION III
CURRENT PROBLEMS

Retesting of the baseline may delay the completion of the program.

SECTION IV
WORKED PLANNED

- Continue with rig modifications and verifications
- Continue to review and process data from the LSRR.
- Continue analysis of baseline configuration.
REFERENCES


| TASK 1 | FORMULATE CLOSURE MODELS (COMPLETED) |
| TASK 2 | DESIGN OF AN AIRFLOW ROW (COMPLETED) |
| TASK 3 | FABRICATE AIRFOIL ROW AND PREPARE TEST PLAN |
| 3.1 | Aerodynamic Hardware |
| TASK 4 | CONDUCT EXPERIMENTAL PROGRAM |
| 4.1 | Aerodynamic Performance Data |
| 4.2 | Heat Transfer Data Base |
| TASK 5 | ASSESSMENT OF CLOSURE MODELS |
| 5.1 | Aerodynamic Performance Prediction Capability |
| 5.2 | Heat Load Prediction Capability |
| 5.3 | Prediction Capability for Deterministic Stresses |
| TASK 6 | Reporting |
| Monthly Report |
| Final Report Draft |