COMPONENT-SPECIFIC MODELING

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As a result of the recent drastic increases in fuel costs, the aircraft gas turbine engine industry has placed much higher technical priorities on reducing engine weight and increasing engine efficiency. As part of this effort, engine temperatures, internal gas pressures, and rotational speeds are being increased, while the size and weight of the engine components are generally being reduced. The result is that components, in many cases, are operating closer to their structural limits. This places much greater importance on the ability to accurately structurally analyze engine components to assure that they can survive for their designed lifetime in an increasingly harsh environment.

The burner liner, turbine blades and vanes are among the most structurally burdened and analytically complex components in the engine. High mean temperatures with severe transients, local hot spots, and steep gradients characterize the thermal environment of all three components. Additionally, the vanes and turbine blades are subjected to the highest gas pressures in the engine, and the turbine blades are loaded even further by strong centrifugal forces. The geometry of these parts is equally complex. The burner liner can be designed as overlapping stepped louvers with many cooling holes. The turbine blades and vanes may also have regions densely packed with tiny slanted cooling holes as well as complex internal gas paths along the span. In addition, there are small radius fillets near the base of the blades and vanes. As a result of the geometry and thermo-mechanical loading, these components have locally steep stress and strain gradients, regions which undergo varying degrees of cyclic plasticity and creep deformation, and material properties which can vary significantly in time and space.

In order to increase the durability and life of hot section components, new high-temperature materials and fabrication techniques are being applied to these components. These new materials have significantly anisotropic material behavior, such as with single crystal blades and directional solidification. This makes accurate and efficient structural analysis of hot section components even more difficult.

Currently, there are basically two general approaches to structurally analyze complex engine parts. One is to use general purpose analysis codes, such as NASTRAN and MARC. These are extremely powerful tools which can be applied to a wide variety of problems. However, they are not tailored to the needs of any one problem and depend very heavily on the user to adapt them to specific problems. Furthermore, these programs are designed as "one-shot" problem solvers based on the finite element method of analysis. That is, a problem is first modeled by whatever method the program is based on, and then the whole problem is solved at one time. It is up to the user to decide how the problem is modeled and whether the solution obtained is accurate to the desired degree. If the problem is to be re-solved, say with a finer finite element mesh, or if a non-linear approach is required, it is up to the user to remodel and to develop his analysis strategy. All sub-problems, approximate solutions, or sensitivity studies must be controlled by the user. To some extent this effort can be reduced by writing geometric and discretization pre-processors, and in the case of NASTRAN, new Rigid Formats can be added. Essentially, with general purpose codes, the analyst tends to overpower very complex problems, but at great expense in computational effort and man-hours.

The second approach is similar to the first, except that the analysis codes are streamlined to meet the needs of more focused problems. These codes have built-in pre- and post-processors to reduce the modeling effort, facilitate sequencing of programs, and to make the display of data easier. However, they still rely on a single analysis method and are still designed to model and solve the structural analysis problem in a single pass through the program. These programs may have features to deal with component specific problems such as special axisymmetric shell elements or crack elements. Often the analysis method is greatly simplified in order to reduce the cost of repeated analyses during a design process. In both cases analysis decisions such as local model refinement, or how and when to use linear and non-linear analyses are left to the analyst.

Either of these approaches, or a combination of them, may be adequate when a single, conservative, feasible design is acceptable. With the increasingly harsh thermo-mechanical environments expected for hot section components as engines are made lighter and more efficient, the structural limits of these components will be more severely challenged. Better, more efficient analysis methods must be developed in order to be able to assure in advance that hot section components will survive for their design lifetimes.

Under the HOST (HOt Section Technology) program, advanced component-specific modeling methods, with built-in analysis capability, will be developed separately for burner liners, turbine blades and vanes. These modeling methods will make maximum use of, but will not rely solely on, existing analysis methods and techniques, to analyze the three identified components. Nor will the complete structural analysis of a component necessarily be performed as a single analysis. The approach to be taken will develop complete software analysis packages with internal, component-specific, self-adaptive solution strategies. Each package will contain a set of modeling and analysis tools. The selection and order of specific methods and techniques within the set to be applied will depend on the specific-component, the current thermo-mechanical loading, and the current state of the component. All modeling and analysis decisions will be made internally based on developed decision criteria within the solution strategies; minimal user intervention will be required. In this way, the structural analyses of burner liners, turbine blades and vanes may actually be comprised of a series of global approximate analyses and local detailed analyses which lead to computationally-efficient, total structural analyses with assured accuracy, and without extensive, time-consuming user intervention.

The software packages will be modular and open-ended to allow the addition or substitution of new modeling and analysis methods and to allow modification to or change of the solution strategies. The primary structural analysis method will be the finite element method. However, additional methods such as approximate closed form analyses, semi-analytical solutions, and boundary integral methods will be considered to develop the complete solution strategies. Linear and non-linear solution capability for static and dynamic responses will be included in each component-specific model. Automatic options within the solution strategies will include remeshing with optimization, substructuring of the mass and stiffness matrices, and automatic load step and time step control. During development the accuracy and computational efficiency of the component-specific models will be verified by comparison with established solutions and data sets.

To support the advanced structural analysis capability developed herein, advanced thermo-mechanical load mission models will be developed to predict detailed time-related pressure and temperature distributions in the burner liner, turbine blade and vane. These distributions will accurately represent conditions experienced during an arbitrary commercial aircraft mission cycle. Also, as part of this load modeling effort, an advanced thermodynamic engine cycle model will be developed to predict the gross temperatures and pressures throughout the hot section of the engine as a function of the power lever setting. The advanced thermo-mechanical load modeling capability will be designed to interact with the component-specific structural models developed herein, as well as to supply detailed loading data for independent analysis programs. Acting together the structural and loads models will provide highly advanced capability to accurately predict the loading and structural response of the burner liner, turbine blade, and vane over an entire arbitrary mission cycle.

This capability will be further enhanced by developing methodology to synthesize the loading and structural response histories of the hot section components over an arbitrary mission cycle. The synthesis process will involve developing methods which can use sparse, pre-computed, component-specific structural and mission cycle data to construct these histories with minimal interaction with detailed analysis codes. This technology will significantly reduce the cost of predicting the loading and structural response histories of the burner liner, turbine blade and vane over complete cycles.

The thermo-mechanical load models and mission model synthesis methodology will be developed essentially independent of the component-specific structural models. As such, the progress of either part of the total program will not depend on the other. In this way, both parts can be designed more effectively to interact with independent loading or structural analysis programs.

COMPONENT-SPECIFIC MODELLING

PURPOSE

DEVELOP ADVANCED HIGH-LEVEL STRUCTURAL ANALYSIS CAPABILITY FOR HOT SECTION COMPONENTS

1) BURNER LINER

2) TURBINE BLADE

3) VANE

TWO MAIN THRUSTS

1) COMPONENT-SPECIFIC STRUCTURAL MODELLING

   A) GEOMETRIC MODELLING AND DISPLAY

   B) SELF-ADAPTIVE SOLUTION STRATEGIES

2) THERMO-MECHANICAL LOAD/MISSION MODELLING

   A) ADVANCED THERMODYNAMIC ENGINE MODEL

   B) DETAILED TEMPERATURE AND PRESSURE LOADING MODELS

   C) MISSION MODEL "DECOMPOSITION/SYSTHESIS" METHODOLOGY

TASK STRUCTURE

BASE PROGRAM

SURVEY
DESIGN OF STRUCTURAL ANALYSIS ARCHITECTURE
THERMODYNAMIC ENGINE MODEL
SOFTWARE DEVELOPMENT
MISSION MODEL DECOMPOSITION
STRUCTURAL ANALYSIS METHODS EVALUATION
THERMO-MECHANICAL LOAD/MISSION MODEL DEVELOPMENT
COMPONENT-SPECIFIC MODEL DEVELOPMENT

OPTIONAL PROGRAM

SURVEY
STRUCTURAL ANALYSIS METHODS EVALUATION
COMPONENT-SPECIFIC MODEL DEVELOPMENT
MISSION MODEL DEVELOPMENT
VERIFICATION TESTING