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3D INELASTIC ANALYSIS METHODS FOR HOT SECTION COMPONENTS

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INTRODUCTION

The objective of this research is to develop analytical tools capable of economically evaluating the cyclic time-dependent plasticity which occurs in hot section engine components in areas of strain concentration resulting from the combination of both mechanical and thermal stresses. The techniques developed must be capable of accommodating large excursions in temperatures with the associated variations in material properties including plasticity and creep.

The overall objective of this research program is to develop advanced 3-D inelastic structural/stress analysis methods and solution strategies for more accurate and yet more cost-effective analysis of combustors, turbine blades, and vanes. The approach will be to develop four different theories, one linear and three higher order with increasing complexities including embedded singularities.

The objective will be achieved through a four-phase program consistent with the NASA Statement of Work.

In Task I, a linear formulation theory is being developed. These consist of three linear formulation models in which stress, strain, and temperature are linear functions of the spatial coordinates; and the increments in loading, temperature, and time are linear. Three constitutive relations are being developed for these linear formulation models each capable of predicting elastic, plastic, thermal, and creep strains and cyclic effects. One constitutive relation will be approximate, one will be of the current genre, and one will be a unified theory.

In Task II, the polynomial formulation theory is being developed. These consist of three polynomial formulation models in which stress, strain, and temperature are polynomial functions of the spatial coordinates, and the increments in loading temperature and time are quadratic. They will also accommodate two-intersecting embedded discontinuities. Three constitutive relations are associated with these polynomial formulation models.

In Task IV, the special functions theory will be developed. These will consist of three special function formulation models in which stress, strain, and temperature are special functions of the spatial coordinates and the increments in loading, temperature, and time are special functions. These models will accommodate eight intersecting embedded similar discontinuities and have three associated constitutive relations.

In Task V, the general functions theory will be developed. These will consist of three general function formulation models in which stress, strain, and temperature are general functions of the spatial coordinates and the increments in loading, temperature, and time are general functions.

These models will accommodate eight intersecting embedded different discontinuities and have three constitutive relations associated with them. One of the constitutive relations will be more complex than those used for the special functions theory.

Task III and VI are reporting requirements.

The above approach will provide the hot section designer/analyst with a wide variety of tools in his nonlinear toolbox. Each of these tasks will produce a matrix of constitutive models and formulation models of varying complexity. There will be three constitutive models (simple, classical, unified) coupled with a mechanics of materials model, a special finite element, and an advance formulation model. This will allow the selection of that tool which best fits the problem to be solved with the appropriate combination of accuracy and cost.

Three constitutive models have been developed in conjunction with the Task I linear theory. These consist of a simple model, a classical model, and a unified model. The simple model will perform time-independent inelasticity analyses using a bilinear stress-strain curve and time-dependent inelasticity analyses using a power-law creep equation. The second model will be the classical model of Professors Walter Haisler and David Allen (Reference 1) of Texas A&M University. The third model will be the unified model of Bodner, Partom, et. al. (Reference 2). All of these models have been customized for a linear variation of loads and temperatures.

The three formulation models for Task I are a nine-noded shell element, a twenty-noded brick element both with and without time embedment, and a boundary integral model. The nine-noded shell element is obtained by "degenerating" a 3D isoparametric solid element and then imposing the necessary kinematic assumptions in connection with the small dimension of the shell thickness (References 3 and 4). This nine-noded Lagrangian formulation overcomes the shear-locking problem experienced by the lower order elements as the element size versus thickness aspect ratio becomes very large. Lobatto quadrature is being used with this element to effectively provide the equivalent of upper and lower surface nodes and for recovery of stresses/strains at the node points.

In the conventional format, the 20 noded brick element will use Gaussian quadrature to develop the stiffness and mass matrices and the right hand side load vectors; however stresses/strains will be recovered at the nodal points. This element will also be implemented in a time-embedded format. This will add an extra degree-of-freedom at each node-time.

The boundary element method linear formulation consists of an eight noded, curved surface compatible with the 20 noded brick element. In this element, inelastic behavior is treated as a body force and its effect is determined by integrating over the volume. Stresses and strains can then be found at any point by performing a differentiation of the integral equations.

REFERENCES

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