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RESPONSE CHARACTERISTICS OF MHOST FOR 3-D INELASTIC ANALYSIS OF HOT-SECTION COMPONENTS

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Hot-section durability problems appear in a variety of forms ranging from corrosion, erosion, and distortion to the occurrence of fatigue cracking. A modest change in the shape of an airfoil due to erosion or distortion can lead to the deterioration of the airfoil's performance. Such changes in the airfoil's shape or other critical components must be known as accurately as possible in order to design a propulsion system with long-term efficiency. A discussion of a code that has been developed under a contract with NASA Lewis Research Center to perform structural analysis of these types of components is presented in this paper.

General purpose finite-element computer codes containing a variety of three-dimensional elements and with capabilities to model inelastic materials have been available for more than a decade. Incorporation of such codes into one hot-section design process has been severely limited by high costs associated with the extensive labor and computer and/or time resources required to obtain reasonably detailed results. With today's computers and solution algorithms, models described by a few hundred displacement degrees of freedom commonly consume 1 to 3 hr of mainframe central processing unit (CPU) time during simulation of a single thermomechanical loading cycle. Since more accurate modeling of components with only a few geometrical discontinuities can easily contain several thousand degrees of freedom, performing a three-dimensional inelastic analysis of hot-section hardware with existing codes falls outside the realm of practicality.

The inelastic methods program addresses the need to develop more efficient and accurate three-dimensional inelastic structural analysis procedures for gas turbine hot-section components. A series of new stand-alone computer codes is being created for the comprehensive numerical analysis of combustor liners, turbine blades and vanes, and other hot-section components. Under NASA contracts, Pratt & Whitney Aircraft in partnership with MARC Analysis Corporation are participating in programs for development of modeling methods and are writing a new computer code to perform three-dimensional inelastic analysis. The code discussed in this paper is referred to as MHOST (MARC - Hot Section Technology). The models in the code address the effects of high-temperature and thermal and mechanical loading on the local (stress and strain) and global (dynamics and buckling) structural behavior of hot-section components. Attention is being given to the development of solution algorithms, integration algorithms for stiffness, strain recovery and residual terms, and modeling methods that permit accurate representations of thermal effects on structural loading and material properties, and geometrical discontinuities as well.

The finite elements for modeling three-dimensional inelastic analysis of hot-section components in MHOST are based on mixed finite-element methods derived from the Hu-Washizu Principle (refs. 1 and 2). Three constitutive models are used in the code. These models are the secant elasticity model, von Mise's plasticity model, and Walker's creep plasticity model. Temperature dependency and anisotropy can be obtained through user subroutines. Nonlinear transient analysis and eigenvalue extraction for buckling and modal analyses are some of the important features in the program.

To test the validity of the MHOST finite-element code, considerable efforts have been made in applying the codes in different cases with results compared to theoretical predictions or numerical values generated by other codes. A cylindrical shell roof under dead weight loading was modeled using various types of elements from different codes in which the aspect ratio was varied by refining the element mesh size from 2 by 2 to 18 by 18.

Figure 1 shows the normalized vertical displacement of the center of the structure versus aspect ratio. Results in both solution schemes show convergence as the aspect ratio decreases. In order to study the effect of curvature on the solution, a test case of a clamped square plate subject to uniform pressure loading was investigated. The plate was divided into 4 by 4 meshes in the study, but the aspect ratio could be varied by changing the thickness of the plate.

The results given by the MHOST code in figure 2 show no effect due to the variation of the aspect ratio. A similar observation can also be found in the four- and eight-node element of the MSC/NASTRAN code. Transient analysis of a cantilever beam subject to two impulsive couples at the free end was then studied using the eight-node three-dimensional solid element to test the dynamic performance of the code.

Figure 3 shows the time history of displacement at a corner node located about two-thirds of the beam from the free end. Two solution algorithms, the mixed finite element and displacement methods, were adopted in the model with time step integrations of 2.0 and 0.5 sec, respectively. Since there is no damping involved in the vibration, no energy dissipation is expected in the response after the impulses.

The code was then applied to a real CF 6-50 engine blade and rotor model with data generated by a computational structural mechanics simulator system to predict the static and dynamic responses of the engine at any flight cycle condition. The simulator system provides data, such as pressure and temperature distribution, centrifugal force, and time duration, at various stages of flight. Figure 4 shows the variation of the radical displacement of the leading edge tip in the static condition during the entire flight without consideration of the centrifugal force effect.

The code was finally implemented in the sector model with different flight cycles, as mentioned in the static case, to perform the transient dynamic analysis of the blade-rotor system using the Newmark integration scheme with $\beta = 0.25$ and $\gamma = 0.5$. The curves with different time steps and/or material properties are designated by circles, squares, and triangles, respectively in figure 5. The curve with the triangles differs from the one with the squares since the thermal effects on material properties are taken into consideration.

Other results show similar trends but different magnitudes. The CPU time used in the shell roof test case, as an example, is given in table I. Results show that the MHOST code is more efficient than other codes if the standard displacement method is used. The efficiency of using the mixed finite-element solution algorithms depends greatly on the convergence criteria provided by the user.

In summary, the advantages of the newly developed code are demonstrated by comparisons of the analyses with existing theoretical data as well as with other available finite-element programs. The new code shows a promise to significantly reduce the computer time and also permits accurate and efficient structural analyses of engine hot-section components. The methods and computer code described in this paper constitute the focused recent developments in advanced three-dimensional inelastic analysis for engine hot-section components.

REFERENCES

1. Hu, H.C.: "On Some Variational Principles in The Theory of Elasticity and Plasticity," Scintia Sinica, 4, pp. 33-54, 1955.

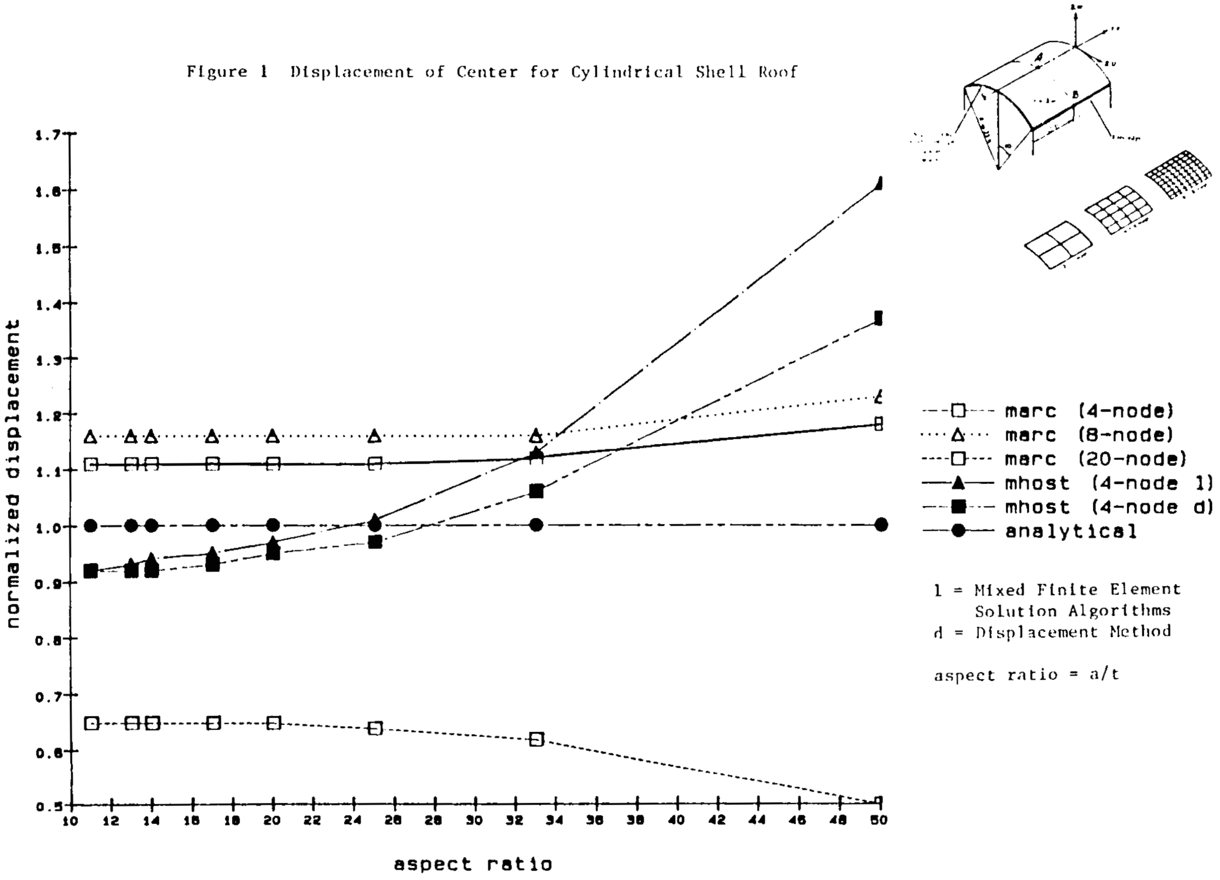
2. Washizu, K.: Variational Methods in Elasticity and Plasticity, Pergamon Press, Oxford, 1974.

TABLE I. - COMPARISON OF CPU TIME FOR CYLINDRICAL SHELL ROOF CASE

Mesh	MARC			MSC/NASTRAN			MHOST	
	4-node	8-node	20-node	4-node	8-node	20-node	4-node[a]	4-node[b]
	CPU time, sec							
2 by 2	9.61	9.73	8.12	1.42	1.91	2.61	2.48	0.90
4 by 4	10.06	-----	9.39	1.70	3.96	6.47	4.49	1.05
6 by 6	10.79	11.93	12.34	2.20	7.92	13.94	5.91	1.33
8 by 8	11.78	14.05	16.75	2.93	15.94	30.03	8.83	1.65
10 by 10	13.07	-----	25.94	4.0	29.36	65.8	12.67	2.11
12 by 12	14.66	22.13	35.26	5.03	56.58	144.15	17.37	2.66
14 by 14	16.59	27.65	48.96	6.47	106.45	328.89	22.90	3.33
16 by 16	19.20	36.73	69.95	8.33	202.45	745.73	30.59	4.43
18 by 18	21.90	43.90	103.48	10.17	471.36	1657.0	36.72	4.98

[a] Loubignac mixed finite element.
[b] Displacement method.

Figure 1 Displacement of Center for Cylindrical Shell Roof



1 = Mixed Finite Element Solution Algorithms
d = Displacement Method

aspect ratio = a/t

Figure 2 Displacement of Center for Clamped Flat Plate

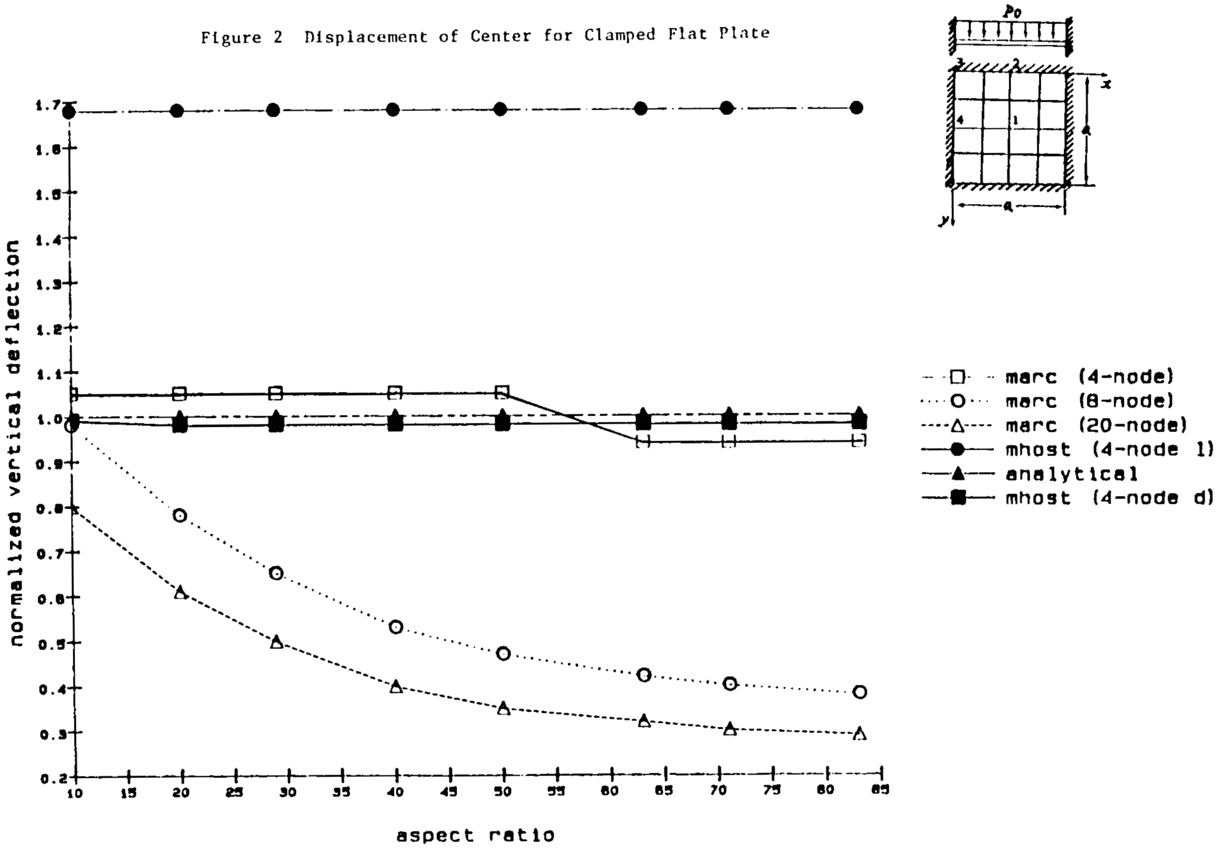


Figure 3 Transient Analysis of A 3-D Beam

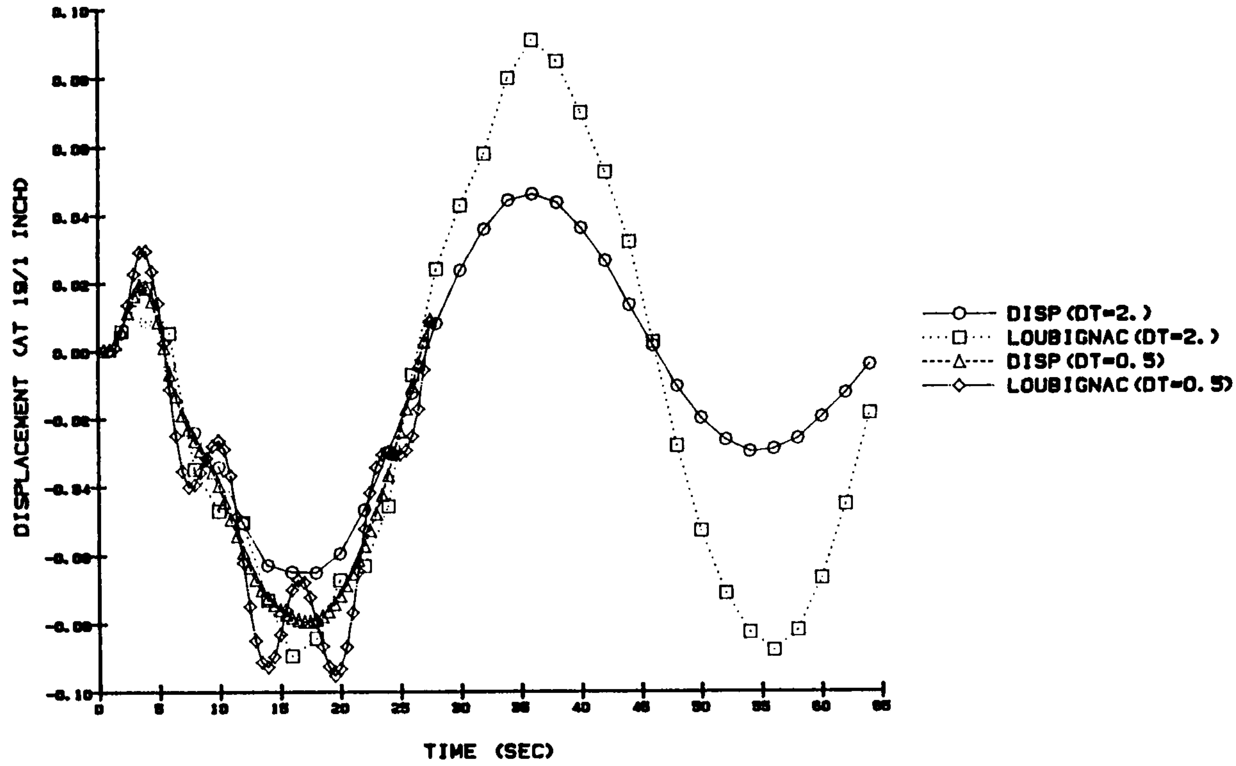


Figure 4 Radial Displacement of Leading Edge Tip (Static)

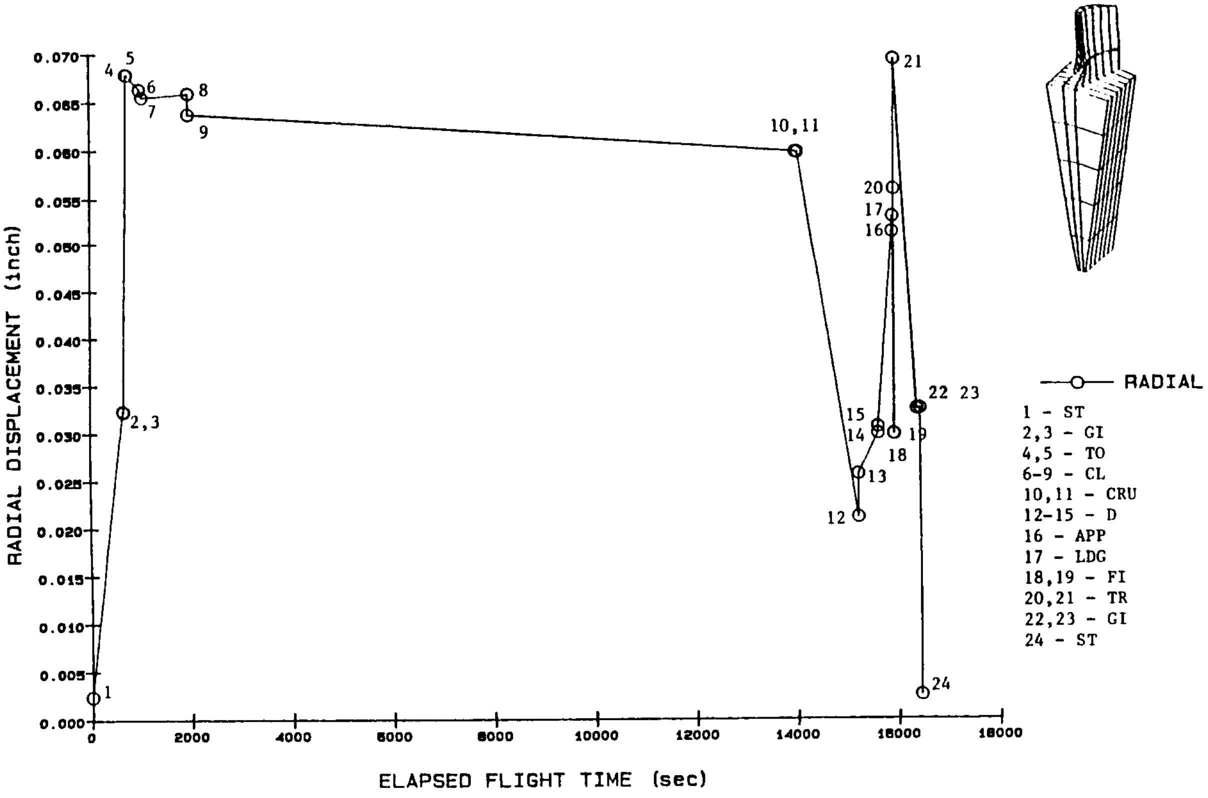


Figure 5 Radial Displacement of Leading Edge Tip (Tranient with Different Flight Conditions)