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STRUCTURES DIVISION

STRUCTURAL MECHANICS BRANCH

AEROSPACE TECHNOLOGY DIRECTORATE

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3-D INELASTIC ANALYSES FOR COMPUTATIONAL STRUCTURAL MECHANICS

D. A. HOPKINS/C. C. CHAMIS

NASA LEWIS RESEARCH CENTER

NASA WORKSHOP ON COMPUTATIONAL STRUCTURAL MECHANICS

NASA LANGLEY RESEARCH CENTER, HAMPTON, VIRGINIA

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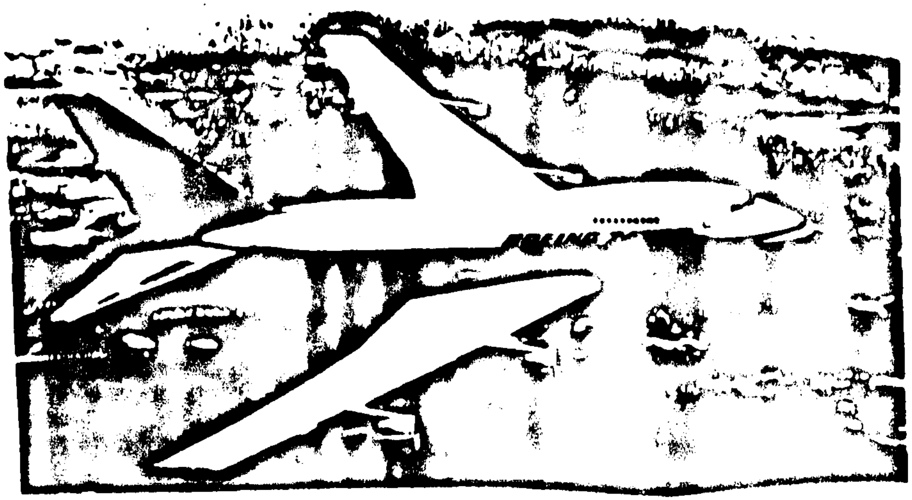
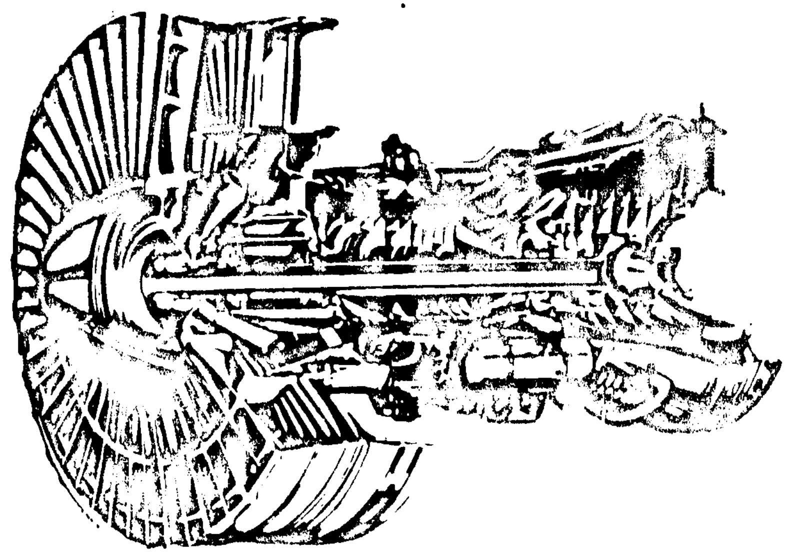
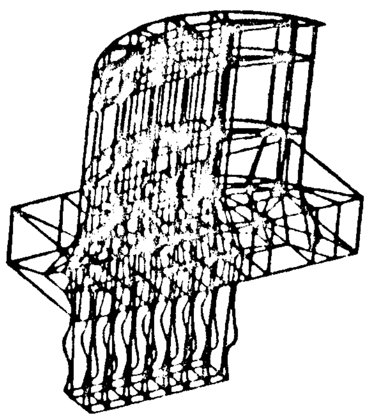
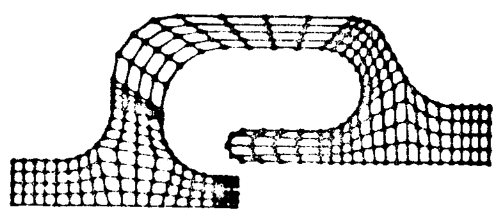
3-D NONLINEAR HIGH TEMPERATURE STRUCTURAL ANALYSIS









- MATERIAL NONLINEARITIES
- GEOMETRIC NONLINEARITIES
- TEMPERATURE DEPENDENCE
- TIME DEPENDENCE

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THE 3-D INELASTIC ANALYSIS METHOD IS A FOCUSSED PROGRAM WITH THE OBJECTIVE TO DEVELOP COMPUTATIONALLY EFFECTIVE ANALYSIS METHODS AND ATTENDANT COMPUTER CODES FOR THREE DIMENSIONAL, NONLINEAR TIME AND TEMPERATURE DEPENDENT PROBLEMS PRESENT IN THE HOT SECTION OF TURBOJET ENGINE STRUCTURES. DEVELOPMENT OF THESE METHODS WAS A MAJOR PART OF THE HOT SECTION TECHNOLOGY (HOST) PROGRAM OVER THE PAST FIVE YEARS AT LEWIS RESEARCH CENTER.

OBJECTIVE:

DESCRIBE ADVANCED METHODS DEVELOPED FOR 3-D INELASTIC ANALYSIS, COMPUTER CODES, AND REPRESENTATIVE RESULTS FOR ENGINE STRUCTURES CRITICAL HOT SECTION COMPONENTS

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PRESENTATION OUTLINE

- o DESCRIPTION OF METHODS
  - APPROXIMATE METHODS (MOMM)
  - SPECIALTY FINITE ELEMENTS (SFINES)
  - MIXED FINITE ELEMENTS (MHOST)
- o CONCLUSIONS

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THREE DIFFERENT FORMULATION APPROACHES WERE USED IN THE DEVELOPMENT OF THE 3-D INELASTIC ANALYSES METHODS. THESE INCLUDE: (1) APPROXIMATE METHODS BASED ON MECHANICS OF MATERIALS METHODS (MOMM), (2) SPECIALTY FINITE ELEMENTS (SFINES) AND (3) MIXED FINITE ELEMENTS INCORPORATED IN A MODIFIED AND SCALED DOWN MARC CODE (MHOST). EACH OF THESE WILL BE DESCRIBED IN SUMMARY FORM WITH RESPECT TO CAPABILITY, FEATURES AND REPRESENTIVE RESULTS.

MECHANICS OF MATERIALS METHODS

MOMM COMPUTER CODES

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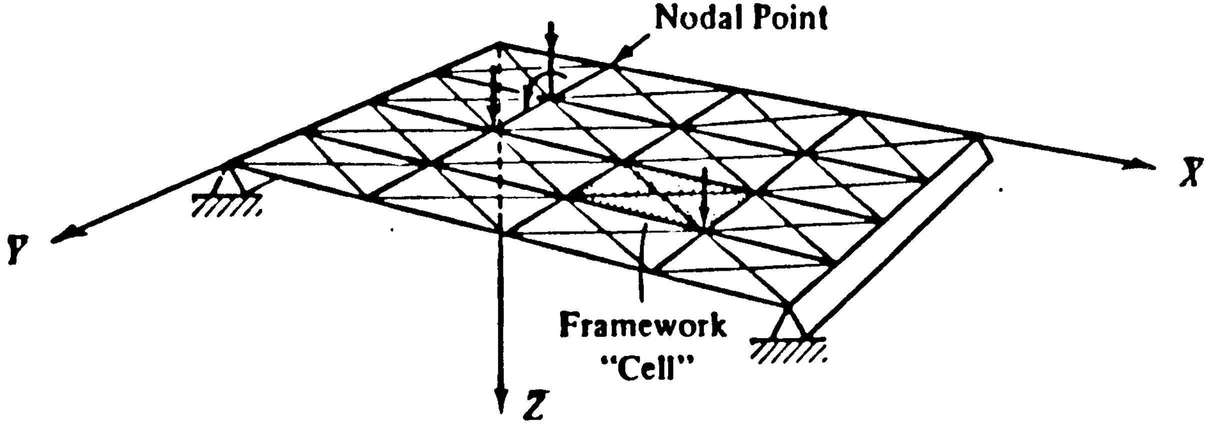
FRAMEWORK REPRESENTATION OF PLATE



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MOMM IS BASED ON A FRAMEWORK OF BEAM ELEMENTS WHERE EACH BEAM IS REPRESENTED BY A CUBIC ISOPARAMETRIC DISPLACEMENT INTERPOLATION FUNCTION. THE FRAMEWORK IS TRANSPARENT TO THE USER. THE USER SPECIFIES ONLY THE COMPONENT GEOMETRY AND THE DESIRED ANALYSIS-MODEL MESH.

CONSTITUTIVE MODELS

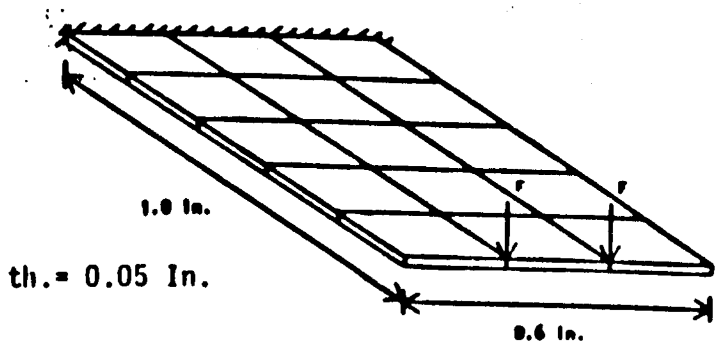
- SIMPLIFIED MODEL
  - USES BILINEAR STRESS–STRAIN CURVE BASED UPON ELASTIC MODULUS AND HARDENING SLOPE

- STATE OF THE ART MATERIAL MODEL
  - ELASTIC–PLASTIC–CREEP STRAIN DECOMPOSITION
  - STEADY STATE POWER LAW CREEP MODEL
  - PLASTICITY MODEL CONTAINS ISOTROPIC AND KINEMATIC HARDENING

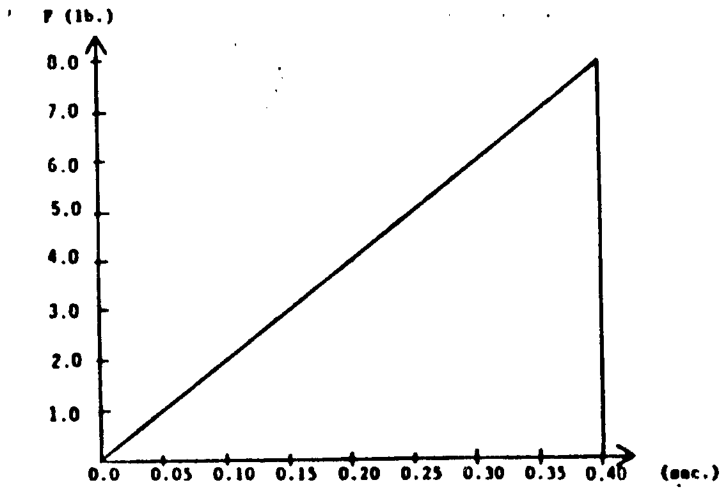
- MODIFIED WALKER'S MODEL
  - UNIFIED VISCOPLASTIC MODEL
  - ACCOUNTS FOR INTERACTION OF CREEP AND PLASTICITY UNDER CYCLIC LOADING

THREE DIFFERENT NONLINEAR CONSTITUTIVE RELATIONSHIPS, WITH PROGRESSIVE LEVEL OF SOPHISTICATION, ARE INCORPORATED IN MOMM. THE LAST ONE IS CONSIDERED TO BE THE MOST ADVANCED AVAILABLE AT THIS TIME. NONLINEAR 3-D INELASTIC PROBLEMS CAN BE ANALYZED USING EACH OF THESE CONSTITUTIVE RELATIONSHIPS IN ORDER TO OBTAIN RELATIVE ACCURACY WITH RESPECT TO LOCAL STRESS STATES AND RESPECTIVE MATERIAL NONLINEARITIES.

MOMM CPU TIME COMPARISONS



Cantilevered Plate with Edge Load



(8 Load Increments)

LOAD HISTORY

	CPU Time	Max. Displ.(In.)
MOMM – Simplified Material Model	29 sec.	0.0309
MOMM – Elastic–Plastic–Creep Model	35 sec.	0.0351
MOMM – Modified Walkers Model	73 sec.	0.0361
MARC – Modified Walkers Model (4 node plate element #50)	47 sec.	0.0376

C-3

REPRESENTATIVE RESULTS OBTAINED WITH EACH OF THESE NONLINEAR CONSTITUTIVE RELATIONSHIPS, USING THE MOMM CODE, ARE SUMMARIZED IN THE ACCOMPANYING CHART TOGETHER WITH COMPUTER CPU TIMES.

SPECIALTY FINITE ELEMENTS FOR

3-D INELASTIC ANALYSIS (SFINES)

(9 - DIFFERENT CODES)

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INPUT FEATURES

FEATURE		SIMPLE MODEL			CLASSICAL MODEL			UNIFIED MODEL		
		8-NODE	9-NODE	20-NODE	8-NODE	9-NODE	20-NODE	8-NODE	9-NODE	20-NODE
Free Format Data Input		X	X	X	X	X	X	X	X	X
Global Coordinate System:	Cartesian	X	X	X	X	X	X	X	X	X
	Cylindrical									
	Spherical									
Local Coordinate System:	Cartesian	X	X	X	X	X	X	X	X	X
	Cylindrical									
	Spherical									
Automatic Generation of Nodal Coordinates			N/A			N/A			N/A	
Automatic Generation of Element Connectivities		X	X	N/A	X	X	N/A	X	X	N/A
Skewed Coordinate System		X	X	X	X	X	X	X	X	X
Orthotropic Orientation Definition		X	X	X	X	X	X	X	X	X

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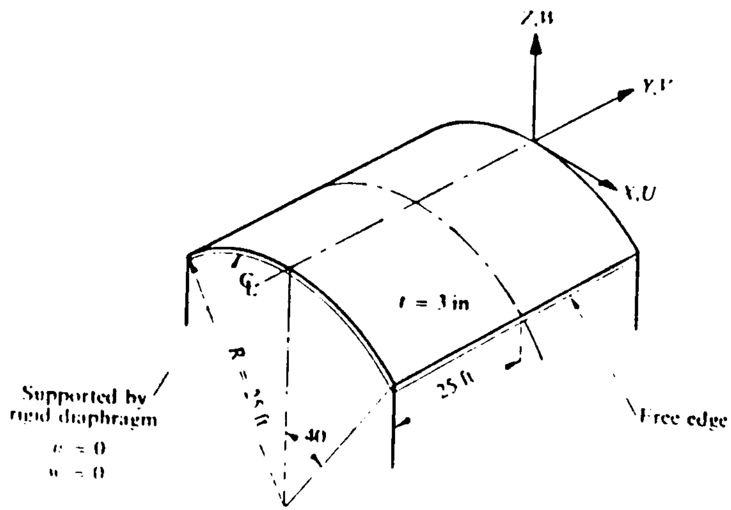
SIGNIFICANT FEATURES OF THE SPECIALTY FINITE ELEMENTS (SFINES) CODES INCLUDE THOSE ASSOCIATED WITH USER FRIENDLY ASPECTS.

ANALYSIS TECHNIQUES

FEATURE	SIMPLE MODEL			CLASSICAL MODEL			UNIFIED MODEL		
	8-NODE	9-NODE	20-NODE	8-NODE	9-NODE	20-NODE	8-NODE	9-NODE	20-NODE
Dynamic Allocation	X	X	X	X	X	X	X	X	X
Blocked Column Skyline Equation Solver	X	X	X	X	X	X	X	X	X
Initial Stress Iterative Scheme			X			X			X
Aitken's Acceleration Scheme			X			X			X
Dynamic Time Incrementing			X			X			X
Convergence Criteria: Effective Plastic Strain			X			X			X
Effective Stress			X			X			X
Dynamic Analysis: Eigenvalue	X	N/A	N/A	X	N/A	N/A	X	N/A	N/A
Eigenvector	X	N/A	N/A	X	N/A	N/A	X	N/A	N/A

CAPABILITIES IN THE SFINES CODES INCLUDE THREE DIFFERENT FINITE ELEMENTS, EACH WITH ONE DEDICATED NONLINEAR CONSTITUTIVE RELATIONSHIP. THIS PROVIDES NINE DIFFERENT AND STAND ALONE COMPUTER CODES. THE FINITE ELEMENT FORMULATIONS ARE BASED ON ISOPARAMETRIC DISPLACEMENT SHAPE FUNCTIONS. EACH CODE CONTAINS A LIBRARY OF NONLINEAR SOLUTION FEATURES.

CYLINDRICAL SHELL ROOF



Shell Thickness = 3 in.

E = $432(10)^6$ psf

Specific Weight = 360 pcf

Poisson's Ratio = 0.0

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REPRESENTATIVE RESULTS OBTAINED FOR THE CYLINDRICAL SHELL ROOF "CLASSICAL EXAMPLE" IN THE ACCOMPANYING CHART ARE PRESENTED GRAPHICALLY VERSUS ELEMENT ASPECT (EDGE/THICKNESS) RATIO IN THE NEXT CHART WHERE RESULTS FROM COMMERCIAL CODES AND INDEPENDENT ANALYSIS ARE ALSO SHOWN.

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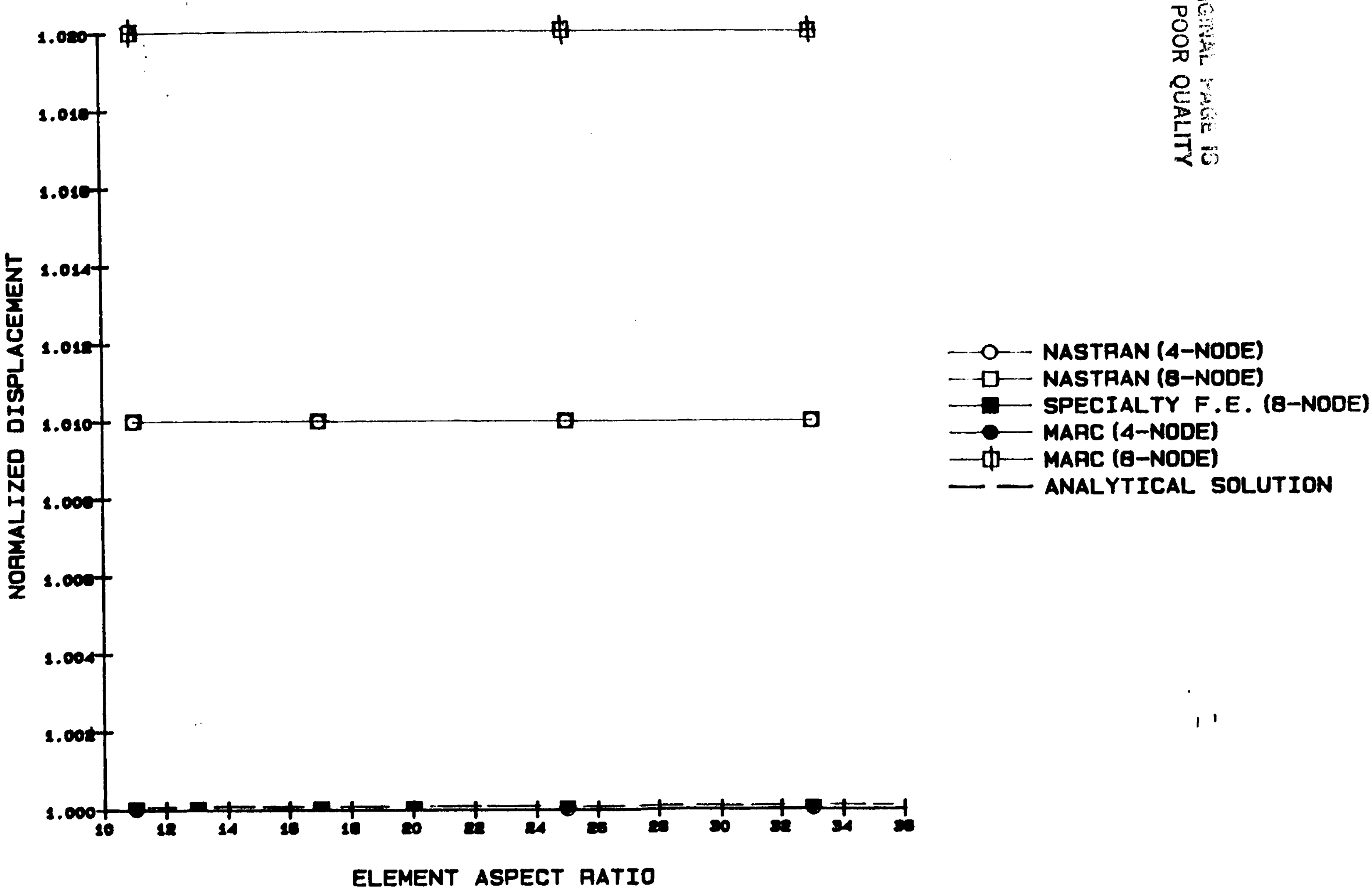
VERTICAL DISPLACEMENT AT POINT A OF
THE CYLINDRICAL SHELL ROOF



MIXED FINITE ELEMENTS FOR
3-D INELASTIC ANALYSIS

(MHOST CODE)

MHOST SOLUTION CAPABILITY

ELEMENT DEFINITION OPTIONS	BEAM	PLANE STRESS	PLANE STRAIN	AXI-SYMMETRIC SOLID	THREE-DIMENSIONAL SOLID	THREE-DIMENSIONAL SHELL
LINEAR ISOTROPIC ELASTICITY	X O	X	X	X	X O	X O
ANISOTROPIC[1] ELASTICITY		X	X	X	X O	
COMPOSITE[1] LAMINATE						X O
SIMPLIFIED PLASTICITY		X	X	X	X O	X O
ELASTO-PLASTICITY		X	X	X	X O	X O
UNIFIED CREEP-PLASTICITY		X O	X	X	X O	X O
STRESS STIFFENING	X	X	X	X	X O	X O
CENTRIFUGAL MASS	X	X	X	X	X O	X O
THERMAL[2] STRAIN	X	X	X	X	X O	X O
CREEP[2] STRAIN	X	X	X	X	X O	X O

NOTES: [1]APPLICABLE ONLY TO LINEAR ELASTICITY.
[2]NOT APPLICABLE TO THE UNIFIED CREEP-PLASTICITY IN WHICH THE QUANTITIES ARE INTEGRATED AS PART OF THE MODEL.

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THE MHOST COMPUTER CODE HAS SIX DIFFERENT FINITE ELEMENTS, EACH BASED ON MIXED-ELEMENT FORMULATION. THESE ELEMENTS CONTAIN THE ISOPARAMETRIC DISPLACEMENT FORMULATION AS A SPECIAL CASE. THE SOLUTION CAPABILITIES ARE SUMMARIZED IN THE ACCOMPANYING CHART. MHOST: (1) CONISISTS OF ABOUT 50,000 FORTRAN 77 STATEMENTS; (2) IS HIGHLY PORTABLE (PRIME, VAX, IBM, CRAY); (3) IS MODULAR WITH MULTIPLE-DRIVER PROGRAMMING FOR MAINTAINABILITY; (4) IS PROGRAMMED TO BE USED IN EITHER BATCH OR INTERACTIVE MODES; AND (5) IS SELF DOCUMENTED USING EXTENSIVE COMMENTS IN THE SOURCE CODE.

MHOST SOLUTION ALGORITHM LIBRARY

ANALYSIS MODULE OPTION	BEAM	PLANE STRESS	PLANE STRAIN	AXI-SYMMETRIC SOLID	THREE-DIMENSIONAL SOLID	THREE-DIMENSIONAL SHELL
QUASI-STATIC ANALYSIS	X	X	X	X	X O	X O
BUCKLING ANALYSIS	X	X	X	X	X O	X O
MODAL ANALYSIS	X	X	X	X	X O	X O
MODAL SUPERPOSITION	X	X	X	X	X O	X O
TRANSIENT DYNAMICS	X	X O	X	X	X O	X O

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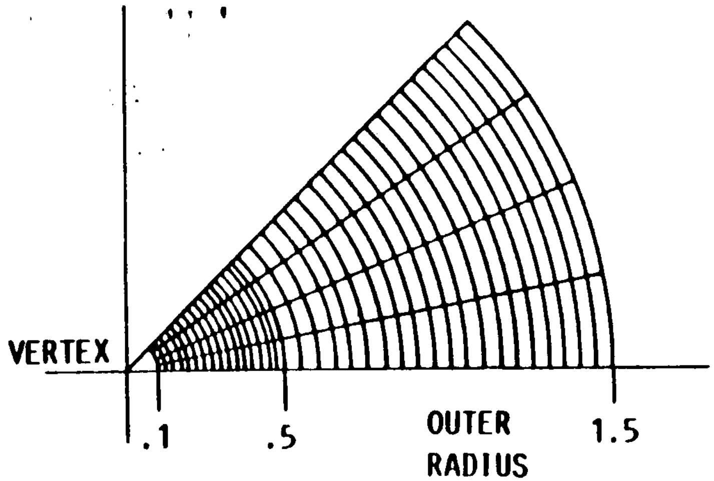
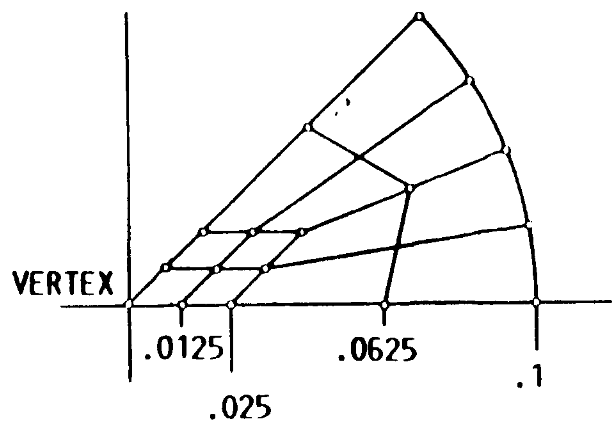
MHOST INCLUDES A LIBRARY OF SOLUTION ALGORITHMS. THESE ALGORITHMS ENHANCE ITS COMPUTATIONAL EFFECTIVENESS FOR 3-D INELASTIC PROBLEMS. A UNIQUE FEATURE OF MHOST IS THAT THE STRUCTURAL RESPONSE VARIABLES (DISPLACMENTS, FORCES, STRAINS, STRESSES) ARE DEFINED AT THE NODES. ANOTHER FEATURE IS THAT NONLINEAR/LARGE DISPLACEMENT SOLUTION IS BASE ON THE UP-DATED LAGRANGEAN WHICH SIMPLIFIES THE DESCRIPTION OF THE NONLINEAR CONSTITUTIVE RELATIONSHIPS (LOCAL DEFORMED GEOMETRY VERSUS INITIAL UNDEFORMED GEOMETRY).

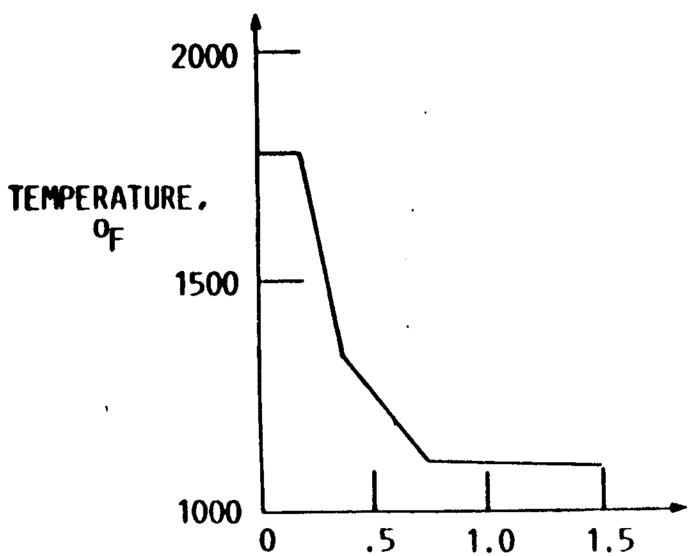
BURNER BLISTER MHOST ANALYSIS

FINITE ELEMENT MODEL

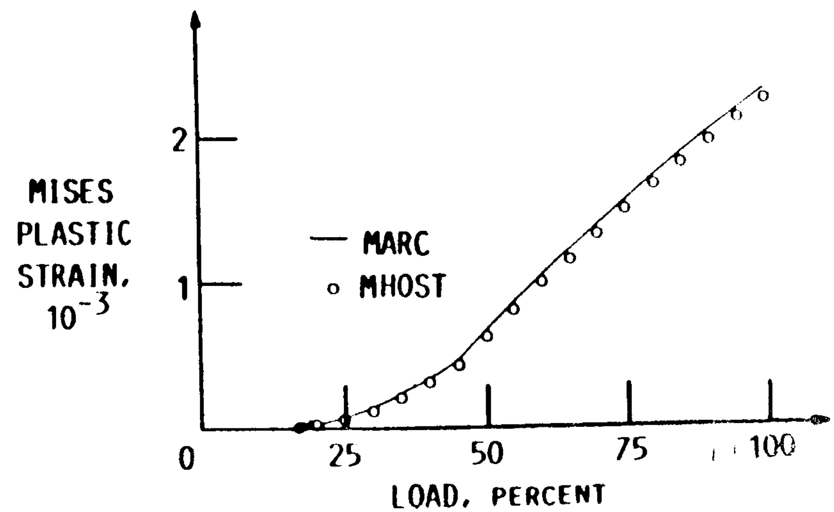


BLISTER REGION MODEL





HOT SPOT TEMPERATURE DIS-
TRIBUTION (MID-PLANE)



MISES PLASTIC STRAIN AT MID-PLANE
VERTEX MODE

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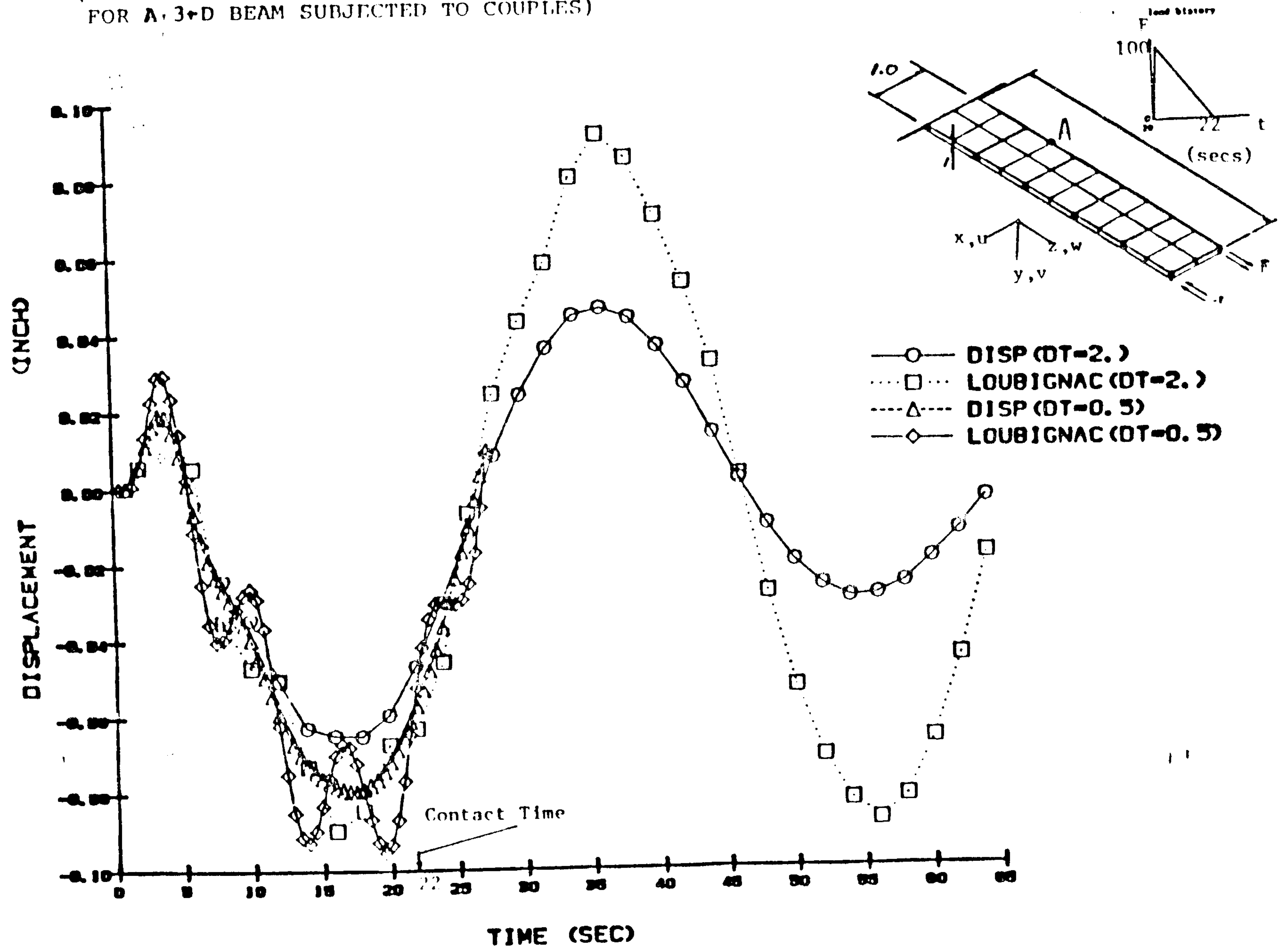
MHOST RESULTS FOR A HOT SPOT PROBLEM ARE PRESENTED IN THE ACCOMPANYING CHART AND COMPARED WITH THOSE OBTAINED BY USING THE THE MARC CODE.

TIME-STEP SENSITIVITY ON TRANSIENT RESPONSE

(TIME HISTORY OF DISPLACEMENT AT POINT A IN X DIRECTION FOR A 3-D BEAM SUBJECTED TO COUPLES)



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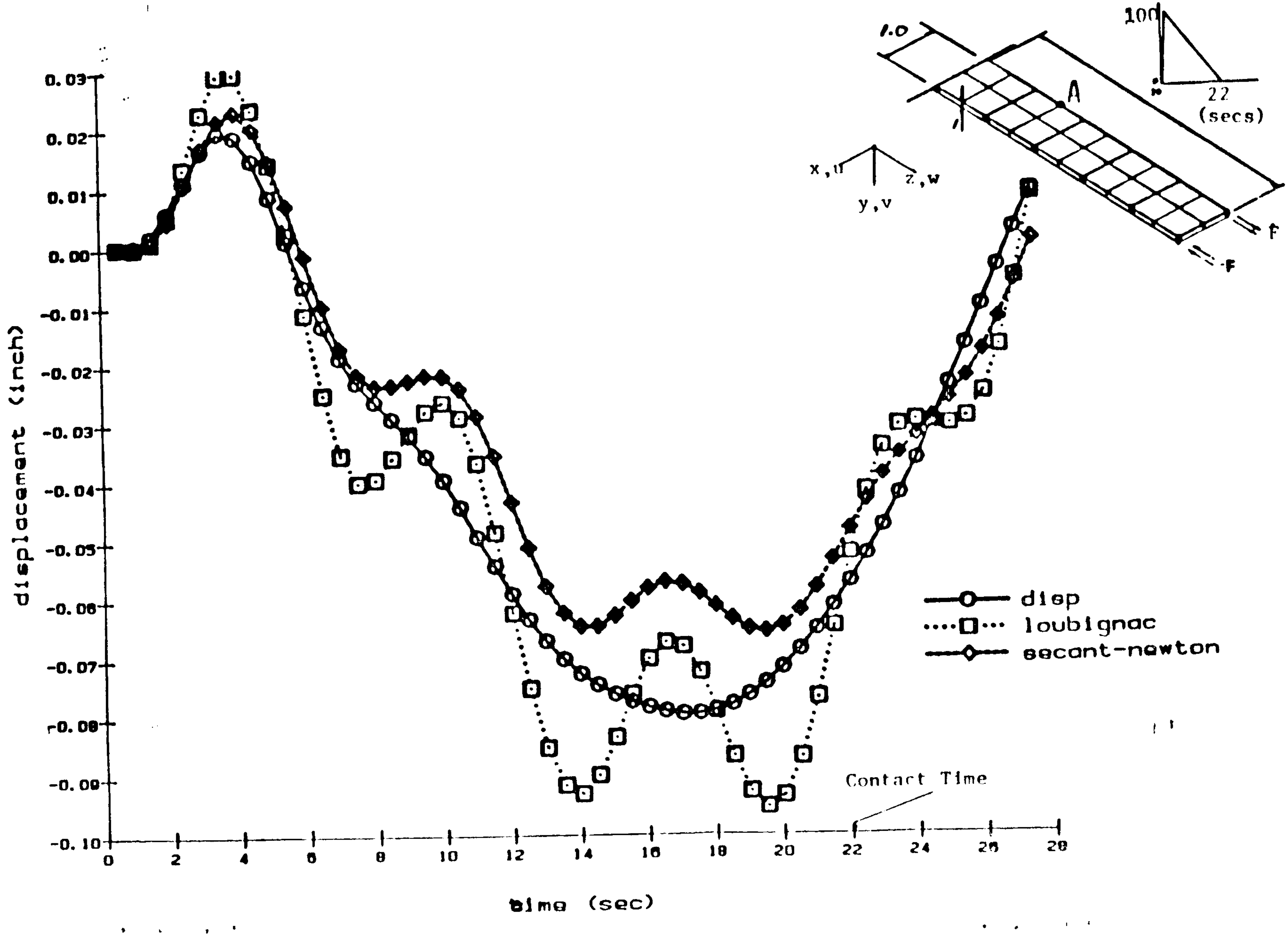
MHOST TRANSIENT RESULTS COMPARING THE TIME-STEP SENSITIVITY ARE SHOWING IN THE ACCOMPANYING CHART. AS IS WELL KNOWN, THE TIME-STEP CANNOT BE SELECTED ARBITRARILY. THE VARIOUS SOLUTIONS ALGORITHMS IN MHOST PROVIDE AN ADAPTIVE STRATEGY FOR SELECTING TIME-STEP/SOLUTION-ALGORITHM TO OBTAIN A CONVERGENT SOLUTION - ACCOMPANYING AND NEXT CHARTS.

SOLUTION ALGORITHM INFLUENCE ON TRANSIENT RESPONSE

(TIME HISTORY OF DISPLACEMENT AT POINT A IN X DIRECTION FOR A 3-D BEAM SUBJECTED TO COUPLES)



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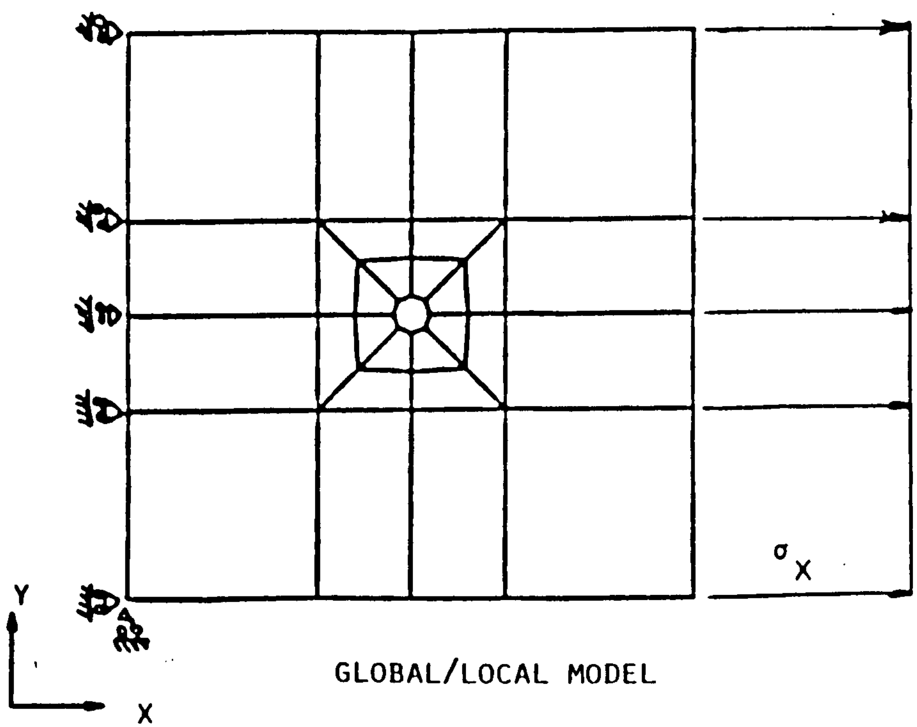
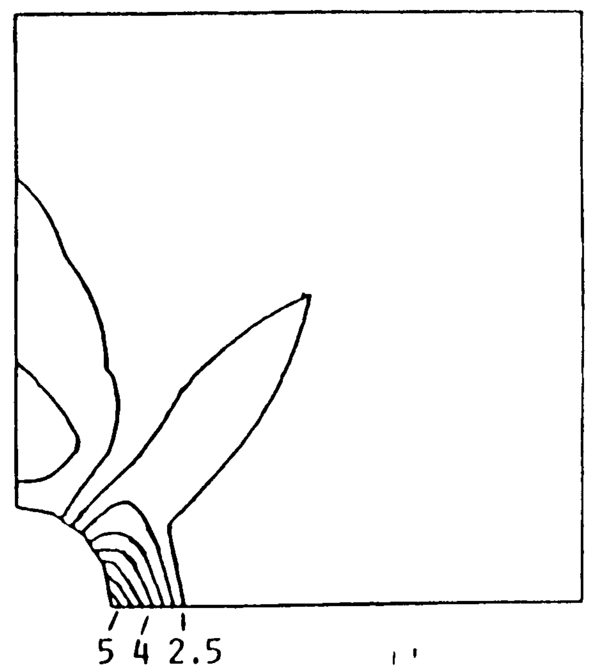
MHOST ILLUSTRATIVE EXAMPLE OF VERSATILE GLOBAL/LOCAL ANALYSIS CAPABILITIES FOR INELASTIC STRESS CONCENTRATION PROBLEMS



GLOBAL/LOCAL MODEL



LOCAL (ϵ)/GLOBAL (ϵ_X) STRAIN CONTOURS

NOTES:

- O GLOBAL MODEL - LINEAR ELEMENTS
- O LOCAL MODEL - QUADRATIC ELEMENTS

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MHOST IS THE ONLY CODE WITH EMBEDDED SUB-ELEMENT CAPABILITY FOR SIMULTANEOUS LOCAL/GLOBAL ANALYSIS NEAR DISCONTINUITIES. RESULTS OBTAINED BY USING THIS CAPABILITY ARE ILLUSTRATED IN THE LAST CHART.

THE LONG RANGE OBJECTIVE OF THESE 3-D INELASTIC ANALYSIS METHODS IS TO DEVELOP THE METHODOLOGY READINESS TO RELIABLY PREDICT THE INTEGRITY, DURABILITY AND LIFE OF HOT SECTION ENGINE STRUCTURES. THESE CODES CONSTITUTE ANALYSIS MODULES IN THE ENGINE STRUCTURES COMPUTATIONAL SIMULATOR, CURRENTLY UNDER DEVELOPMENT AS A PART OF THE LEWIS RESEARCH CENTER COMPUTATIONAL STRUCTURAL MECHANICS PROGRAM, DESCRIBED ELSEWHERE IN THESE PROCEEDINGS.