

Final Technical Report
for
**Development & Application of Viscoplastic
Models in Nonlinear Structural Analysis**

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Research Objectives

The overall objective of the research grant was to develop and apply advanced constitutive modeling and structural analysis capabilities for improved and rational designs of aerospace propulsion systems. The capabilities developed in the project were applied to perform deformation and life analyses on monolithic superalloys and advanced composite material systems

Accomplishments

A number of numerical solution technologies involving the finite element method were developed. These technologies were incorporated into several advanced viscoplastic models. The technologies were applied to a wide spectrum of structural engineering problems involving extremes of thermal/mechanical loadings. The problems ranged from simple geometric forms such as cylinders and disks to those involving complex geometries such as the Space Shuttle Main Engine, a combustor liner, actively cooled engine inlets (cowl lips) and structures made of continuous fiber reinforced metal matrix composite materials. In several cases, the life analyses of the structural components were made and their cyclic lives assessed. Whenever possible, the predicted cyclic lives were compared with the observed cyclic lives of the components. The solution technologies developed in the project are being utilized by aerospace companies in the design of aerospace components.

Results of the research performed under the grant were presented at a number of scientific meetings and conferences and have resulted in numerous publications. The a list of these publications is provided in the following.

Presentations

1. Presented a paper at the Structural Integrity and Durability of Reusable Space Propulsion Systems, Cleveland, USA, 1989.
2. **Chaired** a session and presented a paper at the International Symposium - PLASTICITY-89, Tsu, Japan, 1989.
3. Presented a paper at the International Conference on Computational Plasticity, Barcelona, Spain, 1989.
4. Presented a paper at the International Conference on Structural Testing, Analysis and Design, Bangalore, India, July, 1990.
5. Gave an invited paper and **Chaired** a session at the International Symposium PLASTICITY-91, Paris, France, 1991.
6. Presented an invited paper and **Chaired** a session at the 22nd Midwestern Mechanics Conference, Rolla, MO, USA, Oct. 1991.
7. Presented a paper at the Workshop on Computational Methods in Life Prediction. NASA-Langley Research Center, Hampton, VA, USA, 1992.
8. Presented a paper at the Third International Conference on Computational Plasticity, Barcelona, Spain, 1992.
9. **Organized an International Symposium, Chaired a session and Presented** a paper at ICES '92, Hong Kong, 1992.
10. Presented a paper, **Chaired a session and Member of Panel Discussion Team** at International Seminar on Inelastic analysis, Fracture and Life Prediction, Paris, France, August 1993.
11. Presented a paper at the 2nd EUROMECH conference, Genoa, ITALY, September, 1994.

LIST OF PUBLICATIONS

Journals

1. Analytical and Finite Element Solutions of Some Problems Using a Viscoplastic Model. **Journal of Computers and Structures**, **33**, **4**, 957-967, 1989.
2. Finite Element Implementation of Robinson's Unified Viscoplastic Model and Its Application to Some Uniaxial and Multiaxial Problems. **Journal of Engineering Computations**, **6**, **3**, 237-247, 1989.
3. An Elastic-Plastic-Creep and Life Analysis of a Cowl Lip. **International Journal of Fatigue & Fracture of Engineering Materials & Structures**, **9**, **4**, 201-208, 1991.
4. Application of Finite Element Based Solution Technologies for Viscoplastic Structural Analyses. **Communication in Applied Numerical Methods**, **7**, 435-444, 1991.
5. Finite Element Analysis of Structural Components Using Viscoplastic Models With Application to a Cowl Lip Problem. **Journal of Materials at High Temperatures**, **9**, **4**, 201-208, 1991.
6. Application of a Thermal Life Prediction Model to High-Temperature Alloys, B1900+Hf and Haynes 188. **American Society of Testing Materials, Special Technical Publication No. 1122**, 1992.
7. Nonlinear Structural Analysis of Cylindrical Thrust Chambers Using Viscoplastic Models. **AIAA Journal of Aerospace Propulsion and Power**, **8**, **3**, 598-604, 1992.
8. Viscoplastic Analysis of an Experimental Cylindrical Thrust Chamber Liner. **AIAA Journal**, **30**, **3**, 781-789, 1992.
9. Thermomechanical and Low Cycle Fatigue Life Prediction of Metal Matrix Composites - A Local Stress-Strain Approach. **Special Technical Publication No. 1122, American Society for Testing of Materials**, pp 107-119, 1992.

10. Reduction of Thermal Residual Stresses in Advanced Metallic Composites Based upon a Compensating/Compliant Layer Concept. **Journal of Composite Materials. 26, 9, 1287-1309, 1992.**

Reports/Proceedings

11. Structural Response of SSME Turbine Blade Airfoils. **Proceedings of the Earth-to-Orbit Conference, 1989.**
12. Analysis of Damage in MMC Components Using an Internal State Variable Model. **NASA CP-10030, 53-58, 1989.**
13. Finite Element Elastic-Plastic-Creep and Cyclic Life Analysis of a Cowl Lip. **NASA TM-102342, 1990.**
14. Application of Finite-Element-Based Solution Technologies for Viscoplastic Structural Analyses. **NASA CR-185196, 1990.**
15. Finite Element Analysis of Structural Components Using Viscoplastic Models. **Proceedings of Second International Conference on Computational Plasticity, Barcelona, 1989.**
16. Finite Element Analysis of Structural Components Using Viscoplastic Models With Application to a Cowl Lip Problem. **NASA CR-185189, 1990.**
17. Application of a Thermal Life Prediction Model to High-Temperature Alloys, B1900+Hf and Haynes 188. **NASA TM-4226, 1990.**
18. Nonlinear Structural Analysis of Cylindrical Thrust Chambers Using Viscoplastic Models. **NASA CR-185253, 1990.**
19. Elastic/Plastic Analyses of Advanced Composites Investigating the Use of a Compliant Layer Concept in Reducing Residual Stresses Resulting from Processing. **NASA Technical Memorandum, 103204, 1991.**
20. Viscoplastic Analysis of an Experimental Cylindrical Thrust Chamber Liner. **NASA Technical Memorandum, 1990.**

21. Reduction of Thermal Residual Stresses in Advanced Metallic Composites by Application of a Compensating/Compliant Layer Concept. **Proceedings of HITEMP Conference, Lewis Research Center, Cleveland, OHIO, USA, 1990.**
22. Application of Viscoplastic Models in the Finite Element Analyses of Structural Engineering Problems. **Computational Mechanics '92.** (Editors: Atluri et al.)
23. Life Assessment of Structural Components Using Inelastic Finite Element Analyses. **Proceedings of the Workshop on Computational Methods for Failure Analysis and Life Prediction.** NASA-Langley Research Center, Hampton, Virginia, 1992.
24. Structurally-Compliant Rocket Engine Combustion Chamber - *Experimental/Analytical Validation.* NASA TP-3431, 1993.
25. Finite Element Analysis of Structural Engineering Problems Using a Viscoplastic Model Incorporating Two Back Stresses. **Proceedings of Int. Seminar on Inelastic Analysis, Fracture and Life Prediction, Paris, France, 1993 and NASA TM-106046, 1993.**
26. Large Displacement Structural Durability Analyses of Simple Bend Specimen Emulating Rocket Nozzle Liners. NASA TM 106521, June 1994.
27. Efficient and Accurate Explicit Time-Integration Algorithms with Application to Viscoplastic Models. NASA CR 195342, August 1994.
28. Kinetics of Oxidation and Cracking and Finite Element Analyses of MA 956 and MA 956/Sapphire Composite System. Part I - Experimental. **NASA-HITEMP Proceedings, 1994.**
29. Kinetics of Oxidation and Cracking and Finite Element Analyses of MA 956 and MA 956/Sapphire Composite System. Part II - Analytical. **NASA-HITEMP Proceedings, 1994.**