NONLINEAR STRUCTURAL AND LIFE ANALYSES

OF A COMBUSTOR LINER

Albert Kaufman
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

Abstract

In this study, three dimensional nonlinear structural analyses were performed for a simulated aircraft combustor liner specimen in order to assess the capability of nonlinear analyses using classical inelastic material models to represent the thermoplastic-creep response of the component. In addition, the computed stress-strain history at the critical location was input into state-of-the-art life prediction methods in order to evaluate the ability of these procedures to predict crack initiation life.

The overall operating cost of the modern gas turbine engine is significantly affected by the durability and efficiency of the major hot section components. These are the combustor and turbine structures in the engine. During each flight cycle, these components undergo large thermally induced stress and strain cycles which include significant amounts of creep and relaxation. Primary responsibilities of the combustor, in the engine cycle, are gas temperature level and pattern control, required for efficient turbine operation, and exhaust emission control at the various flight operating conditions. These goals are accomplished by the precise metering of air throughout the combustor structure. The high pressure and high combustion gas temperature characteristic of this environment require that the combustor liner be cooled for durability. These requirements for control of exit gas temperature, emissions, and metal temperature generate an intense competition for utilization of combustor airflow. The more aggressive performance, efficiency, and emission goals set for current and future engines emphasize the need for development of durable combustor structures which can operate with reduced levels of cooling air. This requires detailed knowledge of the operating environment and the ability to accurately predict structural response for these loadings.

Over the past decade, nonlinear finite-element programs have become available for the structural analysis of multiaxial components subject to cyclic thermomechanical loading. These programs involve sophisticated computational algorithms and advanced finite element formulations, yet rely on material models whose applicability to the hot section component environment is questionable. Of primary concern is the response of materials to cyclic loading involving simultaneous creep and plastic behavior. A major need is the development of appropriate hot section component structural response data, sufficient to evaluate the advanced structural analysis capabilities with emphasis on the effectiveness of the material models.

Creep-fatigue life prediction methods used for aircraft engine hot section components are currently calibrated to simplified models for predicting the local cyclic hysteresis response to thermal-mechanical loading. Further, these models generally lack calibration to well-controlled hot section component fatigue test data. Thus, a second major need is for the evaluation of life prediction models for creep-fatigue response of hot section components using the results of nonlinear stress-strain analysis and well-controlled component response data.

This program addresses a critical issue in the development of advanced life prediction technologies-the need to establish the limitations of current nonlinear structural modeling and creep/fatigue life prediction schemes for a major hot section component. In order to make a critical evaluation of these tools, a well controlled component simulation test served as the calibration data source for the program. The component test used a prototypical combustor liner specimen constructed in an identical configuration with current combustor liners in engine service.

A three dimensional non-linear finite element analysis of the liner was conducted with the MARC computer code. The analysis used existing time independent classical plasticity theory with a Von Mises yield surface and the combined (isotropic-kinematic) hardening rule. A constant rate creep model was used to account for instantaneous time dependent plasticity effects. Both the plasticity and creep models were calibrated to isothermal Hastelloy X material response data. The computed strain-temperature history at the critical location of the combustor liner was imposed on a uniaxial specimen in a strain-temperature controlled test. The uniaxial test results were compared to the analytical stress-strain results. The computed strain-temperture history was also input into two life predicton methods (Strain Range Partioning and the PWA Combustor Life Prediction Method) in order to compare predicted combustor crack initiation life against experimental observations.

The nonlinear structural analysis indicated that the time dependent plasticity model and the creep model did not accurately predict the cyclic thermomechanical response at the louver failure location. Tests of a uniaxial strain controlled specimen run with the same mechanical strain-temperature history as computed at the failure location showed that the stress-strain response stabilized within the first few cycles. Analytical simulation of the experiment with the Hastelloy X creep-plasticity models exhibited continued cyclic hardening (increasing peak tensile stress and reduced inelastic strain range) after many cycles. Potential modification to the plasticity model, including a multi-yield-surface concept, non-linear hardening or use of one of the rate dependent (unified) theories currently under development, may be required to improve the prediction for the varying temperature loading condition. Determination of correct thermomechanical response is critical for the life prediction of the component.

The two high temperature, creep-fatigue life prediction methods considered were the Strain Range Partitioning Pratt and Whitney Aircraft-Commercial Products Division Combustor Life Predicton, and Continuous Damage methods. Both assume that time independent plastic and time dependent creep damage mechanisms are present at elevated temperature. Isothermal fatigue and creep rupture tests are used to define the material life relationships.

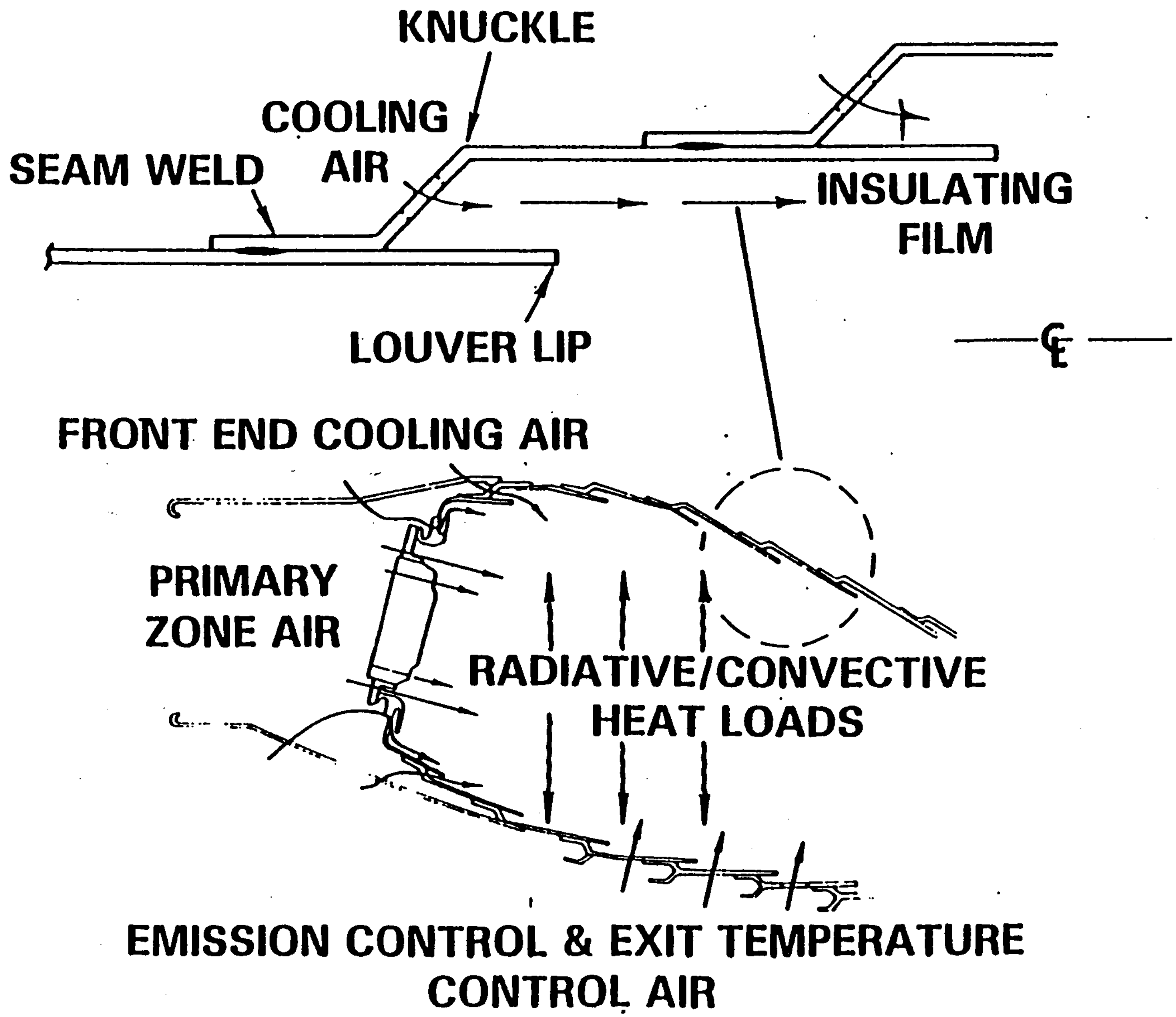
The Strain Range Partitioning and PWA-CPD methods are based on the existence of generic types of fully reversed damage cycles composed of combinations of the plastic and creep mechanisms. For this analysis, the combustor louver lip response contained only the pp(tensile plasticity reversed by compressive plasticity) and pc(tensile plasticity reversed by compressive creep) damage cycles.

The Strain Range Partitioning method overpredicted the louver cracking life (8500 cycles vs. 1000 cycles). Part of this discrepancy may be associated with uncertainity in the definition of the generic pp and pc fatigue life curves. Better definition of the curves may reduce the predicted life (and improve the correlation). However, it appears that the SRP method will overpredict the cracking life by at least a factor of 2.

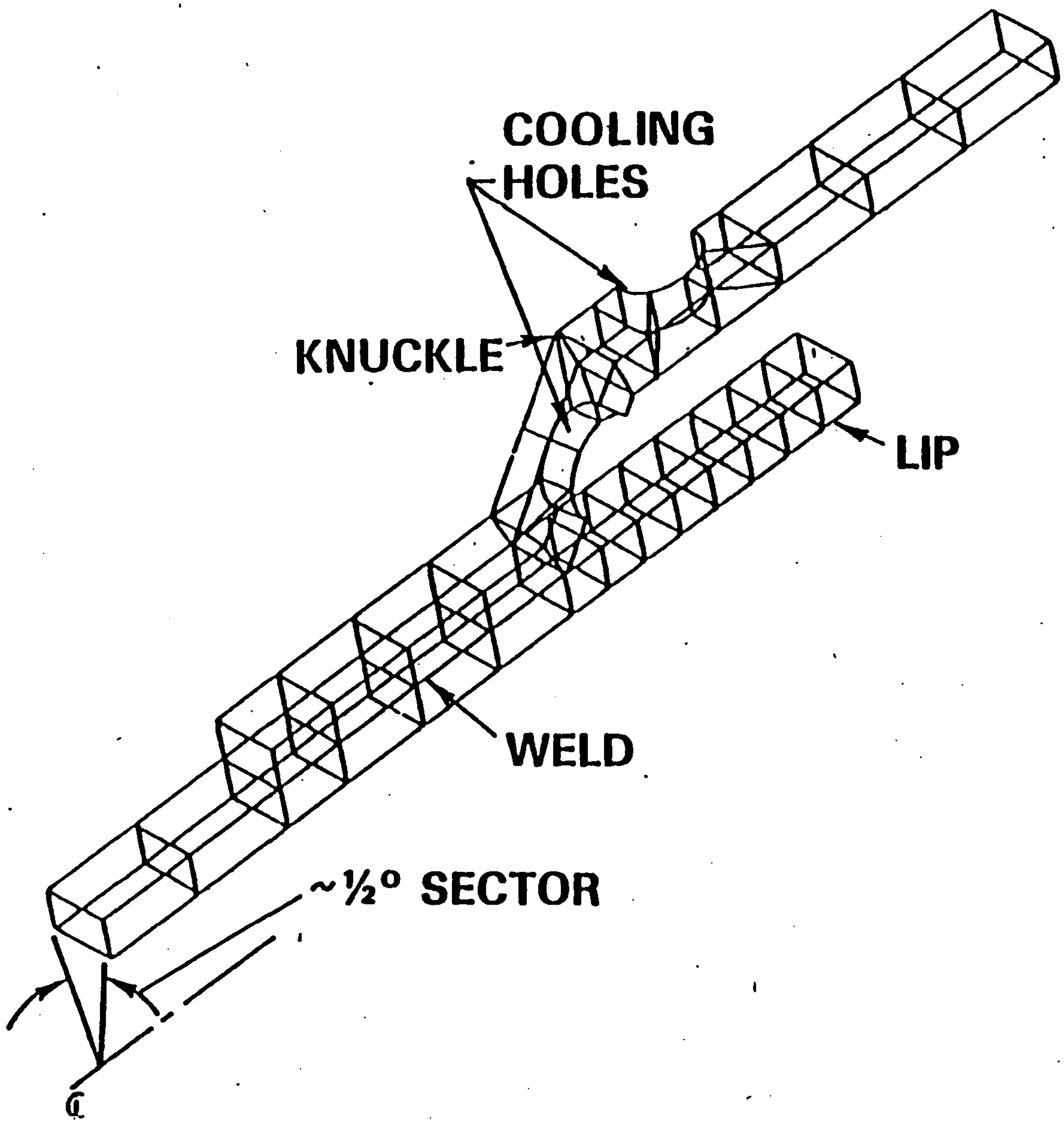
The Pratt and Whitney Aircraft-Commercial Products Division method also overpredicted the louver cracking life (1700 cycles vs. 1000 cycles). This improved correlation (relative to SRP) is due, in part, to the fact that the inelastic strain range predicted by this method is larger than the observed inelastic strain in the louver. Equating the inelastic strain value results in a predicted life of 8000 cycles, which is similar to the SRP calculation. In actual design practice, this method is used with experimental and field service data to assess the overall service life of the component.

The overpredictions in the combustor liner life based on the analyses in conjunction with isothermal, strain controlled fatigue test data suggest that a thermomechanical fatigue cycle may produce damage at a faster rate than a comparable isothermal cycle.

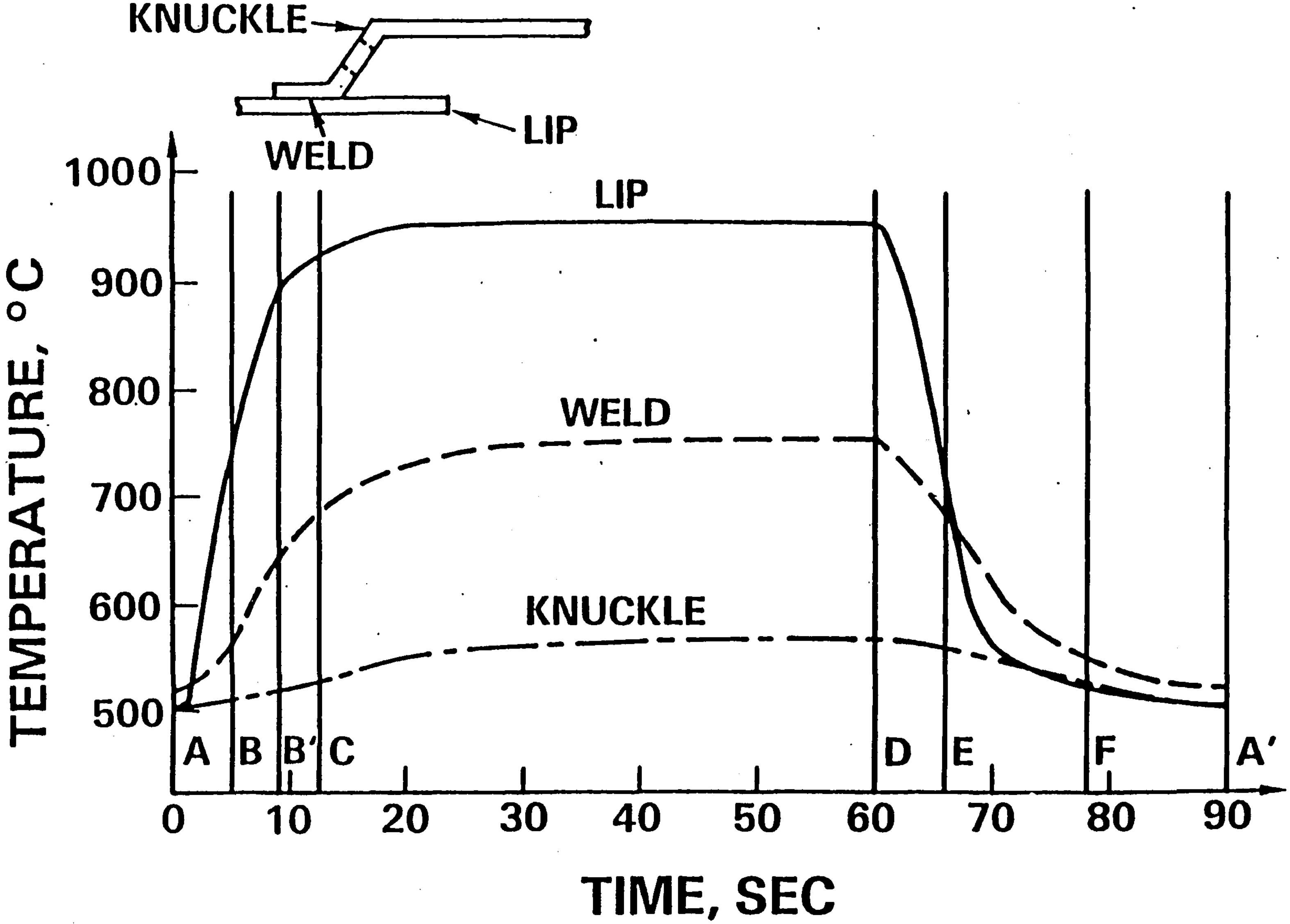
TYPICAL LOUVER COMBUSTOR LINER CONSTRUCTION AND AIRFLOW DISTRIBUTION



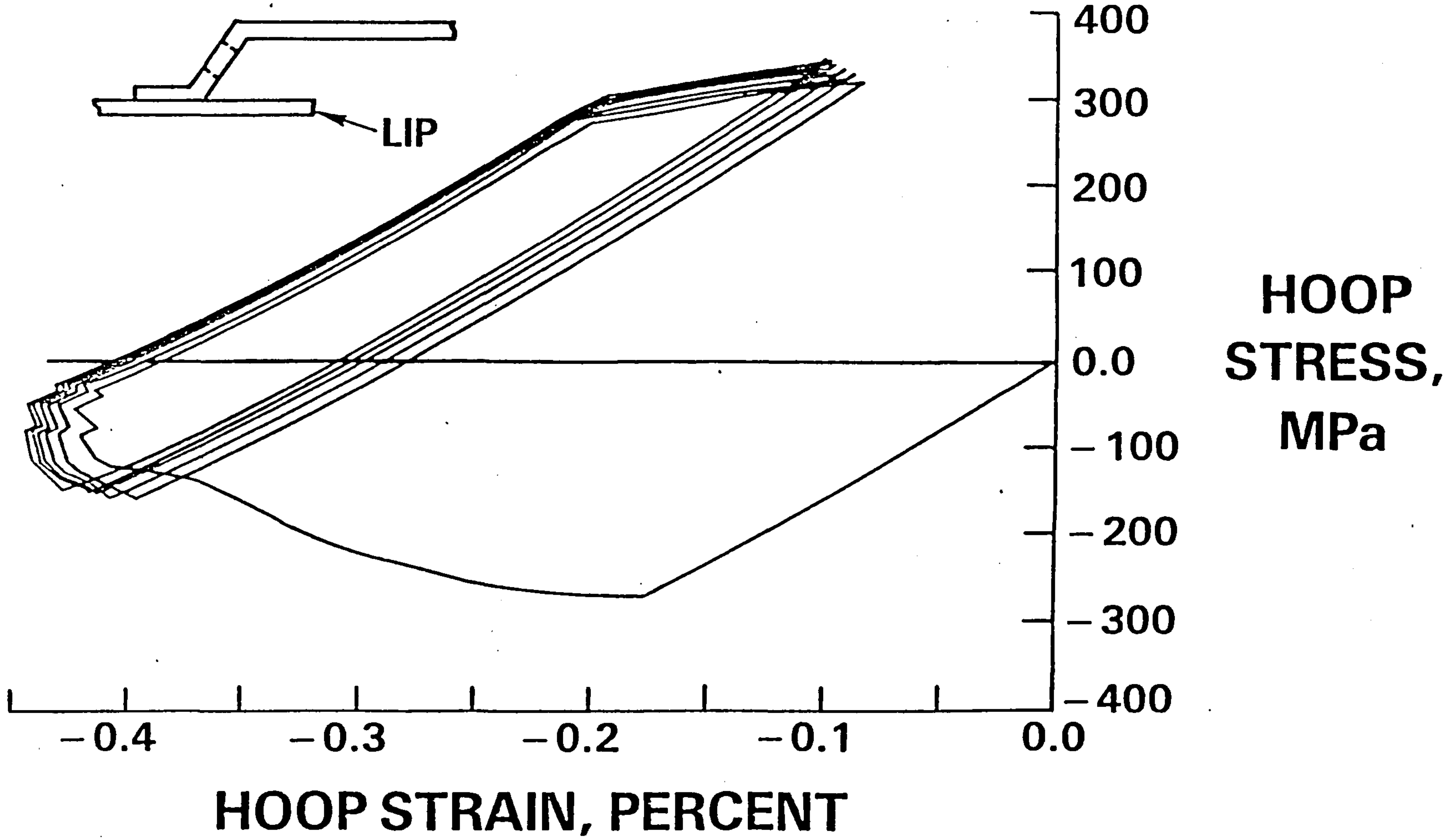
FINITE ELEMENT MODEL



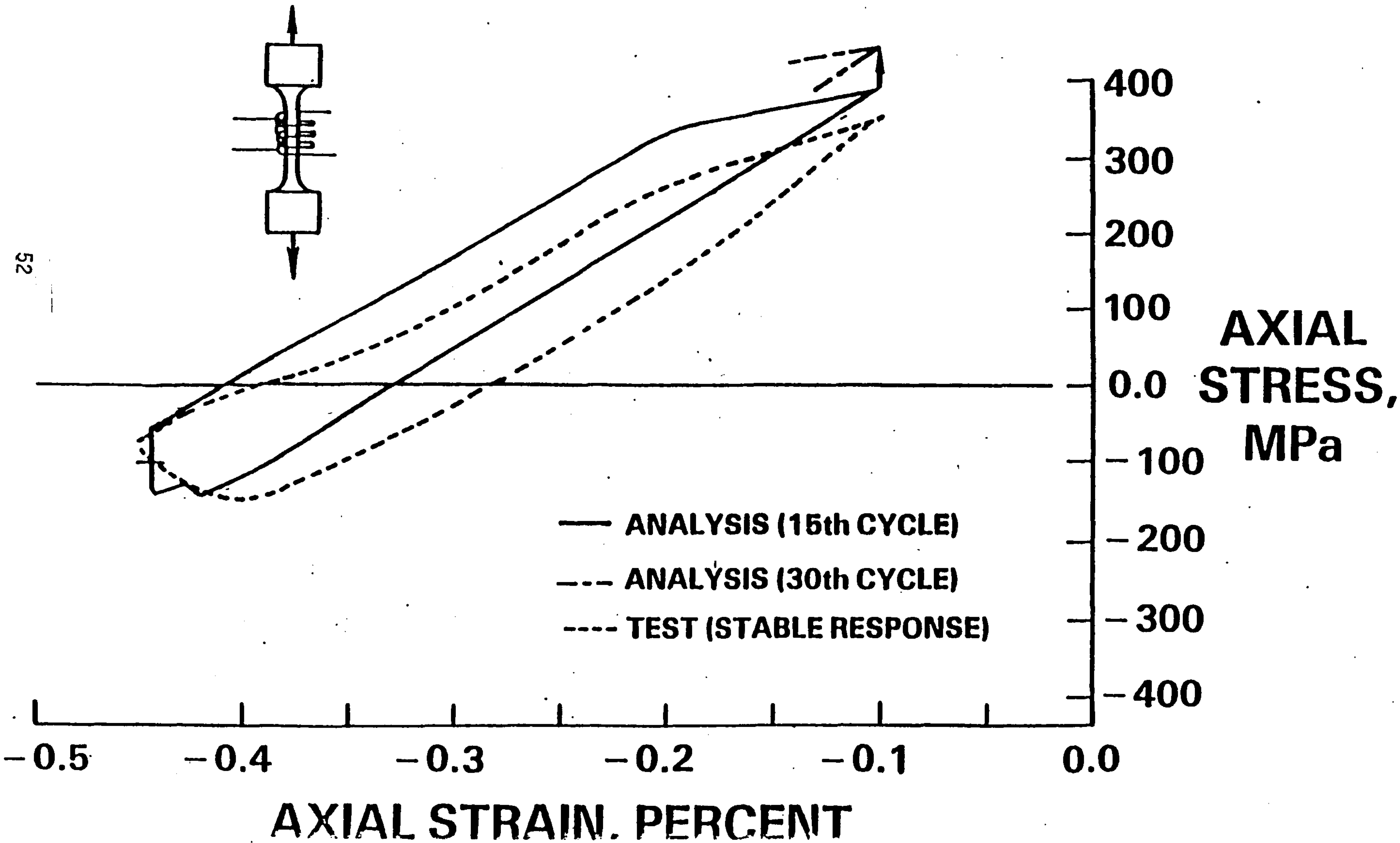
LOUVER TEMPERATURE RESPONSE



PREDICTED LOUVER LIP RESPONSE FOR SIX (6) LOADING CYCLES



COMPARISON OF UNIAXIAL THERMO MECHANICAL TEST AND ANALYTICAL RESULTS



CONCLUSIONS

- ELASTIC ANALYSIS ADEQUATE FOR OBTAINING STRAIN RANGE AND CRITICAL LOCATION
- INELASTIC ANALYSES DID NOT ACCURATELY REPRESENT CYCLIC BEHAVIOR OF MATERIAL
- NONE OF CRACK INITIATION LIFE PREDICTION METHODS WERE SATISFACTORY