NASA HOST PROJECT OVERVIEW

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INTRODUCTION

Since introduction of the gas turbine engine to aircraft propulsion, the quest for greater performance has resulted in a continuing upward trend in overall pressure ratio for the engine core. Associated with this trend are increasing temperatures of gases flowing from the compressor and combustor and through the turbine. For commercial aircraft engines in the foreseeable future, compressor discharge temperature will exceed 922 K (1200 °F), while turbine inlet temperature will be approximately 1755 K (2700 °F). Military aircraft engines will significantly exceed these values.

Increasing fuel prices, especially since 1973, have created the demand for energy conservation and more fuel efficient aircraft engines. In response to this demand, engine manufacturers continually increased the performance of the current generation of gas turbine engines. Soon afterward, the airline industry began to experience a notable decrease in durability or useful life of critical parts in the engine core hot section -- the combustor and turbine. This was due primarily to cracking in the combustor liners, turbine vanes, and turbine blades. In addition, spalling of thermal barrier coatings that protect some combustor liners was evident.

For the airlines reduced durability for in-service engines was measured by a dramatic increase in maintenance costs, primarily for high bypass ratio engines. Higher maintenance costs were especially evident in the hot section. As shown by Dennis and Cruse (1979), hot section maintenance costs account for almost 60 percent of the engine total. Widespread concern about such soaring maintenance costs led to a new demand -- to improve hot section durability.

Durability can be improved in hot section components by using any combination of the following four approaches. They are the use of (1) materials having higher use temperatures, (2) more effective cooling techniques to reduce material temperatures, (3) advanced structural design concepts to reduce stresses, and (4) more accurate analytical models and computer codes in the design analysis process to identify hot spots, high stresses, etc.

High temperature metallic materials currently include nickel- and cobalt-based superalloys. Certain elements of these alloys, such as cobalt, are in short supply and are expensive. Ways for reducing these alloying elements were presented by Stephans (1982). In addition, advanced high temperature superalloy components also include directionally solidified, single crystal, and oxide-dispersion-strengthened materials. Development time for new materials is lengthy, fabrication is sometimes difficult, and again costs are high. Thus, successful use of these materials requires a balance among design requirements, fabrication possibilities, and total costs.

Current cooling techniques tend to be sophisticated; fabrication is moderately difficult. In higher performance engines, cooling capability may be improved by increasing the amount of coolant. There is a penalty for doing this, however, in the reduction of thermodynamic cycle performance of the engine system. In addition, the coolant temperature of such advanced engines is higher than that for current in-service engines. Consequently, more effective cooling techniques are being investigated. They are generally more complex in design, demand new fabrication methods, and may require a multitude of small film-cooling holes, each of which introduces potential life-limiting high stress concentrations. Acceptable use of the advanced cooling techniques requires accurate models for design analysis.

The introduction of advanced structural design concepts usually begins with a preliminary concept that then must be proven, must be developed, and -- most critically -- must be far superior to entrenched standard designs. Acceptance certainly is time consuming, and benefits must be significant. For improved durability in high performance combustors, an excellent example of an advanced structural design concept is the segmented liner as discussed by Tanrikut et al. (1981). The life-limiting problems associated with high hoop stresses were eliminated by dividing the standard full-hoop liners into segments. At the same time, designers realized increased flexibility in the choice of advanced cooling techniques and materials, including ceramic composites.

Finally, the design analysis of hot section component parts, such as combustor liners or turbine vanes and blades, involves the use of analytical or empirical models. Such models often are put into the form of computer codes for predicting and analyzing the aerothermal environment, the thermomechanical loads, and material and structural responses to such loading. When the parts are exposed to cyclic high temperature operation as in a turbine engine, the repetitive straining of the materials leads to crack initiation and propagation until failure or break-away occurs. The useful life or durability of a part is usually defined as the number of mission cycles that can be accumulated before initiation and propagation of significant cracks. Thus, designers need to predict useful "life" so they can design a part to meet requirements.

Efforts to predict the life of a part generally follow the flow of analyses portrayed in Fig. 1. In practice, designing of a part such as a turbine blade to meet a specified life goal may require a number of iterations through the "Life Prediction System" of Fig. 1, varying the blade geometry, material, or cooling effectiveness in each pass, until a satisfactory life goal is predicted.

Analysis models and codes have frequently predicted physical behavior qualitatively but have exhibited unacceptable quantitative accuracy. To improve predictive capability, researchers generally need (1) to understand and model more accurately the basic physics of the phenomena related to durability, (2) to emphasize local as well as global conditions and responses, (3) to accommodate nonlinear and inelastic behavior, and (4) to expand some models from two to three dimensions.

Fortunately, at the time of demands for improved hot section durability dramatic increases were occurring in mathematical solution techniques, electronic computer memory, and computer computational speed. The time was ripe for significant improvements in analytical predictive capability.

OVERVIEW OF THE HOST PROJECT

To meet the needs for improved analytical design and life prediction tools, especially those used for analysis of cyclic high temperature operation in advanced combustors and turbines, the NASA Lewis Research Center sponsored the Turbine Engine Hot Section Technology (HOST) Project. The project was initiated in October 1980 and completed in late 1987.

Objective

The HOST Project developed improved analytical models for the aerothermal environment, the thermomechanical loads, material behavior, structural response, and life prediction, along with sophisticated computer codes, which can be used in design analyses of critical parts in advanced turbine engine combustors and turbines. More accurate analytical tools better ensure -- during the design process -- improved durability of future hot section engine components.

Approach

Addressing the complex durability problem in high temperature cyclically operated turbine engine components requires research efforts in numerous technical disciplines. In the HOST Project six disciplines were involved: instrumentation, combustion, turbine heat transfer, structural analysis, fatigue and fracture, and surface protection. This involvement was not only through focused research but was sometimes interdisciplinary and integrated.

Most disciplines in the HOST Project followed a common approach to research. First, phenomena related to durability were investigated, often using benchmark quality experiments. With known boundary conditions and proper instrumentation, these experiments resulted in a characterization and better understanding of such phenomena as the aerothermal environment, the material and structural behavior during thermomechanical loading, and crack initiation and propagation. Second, state-of-the-art analytical models were identified, evaluated, and then improved by more inclusive physical considerations and/or more advanced computer code development. When no state-of-the-art models existed, researchers developed new models. Finally, predictions using the improved analytical tools were validated by comparison to experimental results, especially the benchmark quality data.

Programs

Fulfillment of the HOST Project objective was accomplished through numerous research and technology programs. HOST management issued contracts for 40 separate activities with private industry, most of which were multiyear and multiphased. In several activities, more than one contractor was involved because of the nature of the research and each contractor's unique qualifications. Thirteen more separate activities were conducted through grants with universities. Finally, at the NASA Lewis Research Center, 17 major efforts were supported by the project. Table I lists all the technical activities conducted in the project.

TECHNOLOGY TRANSFER

The HOST Project research activities were usually organized, conducted, and reported along the above discipline lines. This report is organized accordingly and summarizes research results accomplished in the project.

Numerous publications provide further details about research results from the HOST Project. Six annual workshops were conducted with conference proceedings (Turbine Engine Hot Section Technology, 1982 through 1987) being provided for each one. Each of the proceedings generally covers research results for the preceding year. The last two proceedings also included a bibliography of definitive research reports. Progress in the development of advanced instrumentation and in the improvement of combustor aerothermal and turbine heat transfer models was reported by Sokolowski and Ensign (1986). Finally, a comprehensive bibliography of the HOST Project is being prepared and is scheduled for publication later this year (Sokolowski, 1988).

REFERENCES

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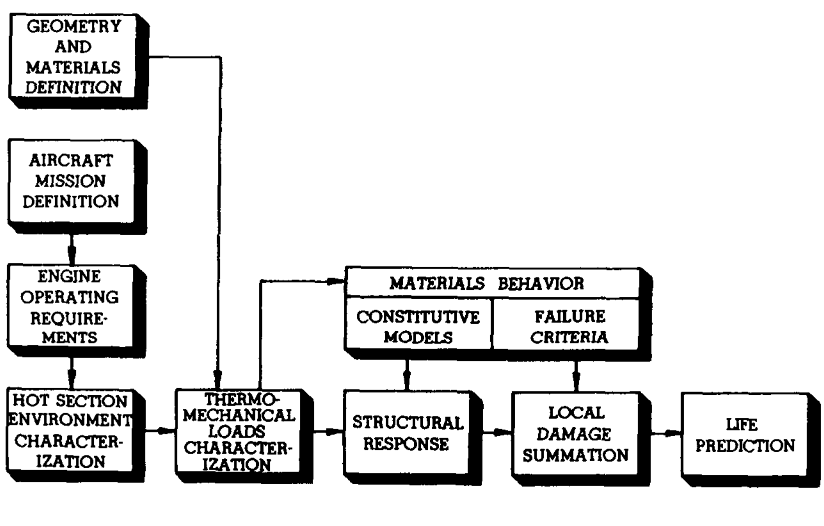

FIGURE 1. - INTEGRATION OF ANALYSES LEADS TO LIFE PREDICTION OF HOT SECTION PARTS.

TABLE I. - HOST Project Activities

	Contract (C), Grant (G), or NASA Organization (N)	Number
Instrumentation		
Hot Section Viewing System	C	NAS3-23156
Dynamic Gas Temperature Measurement System - A	C	NAS3-23154
Dynamic Gas Temperature Measurement System - B	C	NAS3-24228
Turbine Static Strain Gage - A	C	NAS3-23169
Turbine Static Strain Gage - B	C	NAS3-23722
Turbine Heat Flux Sensors	C	NAS3-23529
Laser Speckle Strain Measurement	C	NAS3-26615
High Temperature Strain Gage Materials	G	NAG3-501
Hot Section Sensors	N	2510
Laser Anemometry for Hot Section Applications	N	2520/2530
HOST Instrument Applications	N	2510
Combustion		
Assessment of Combustor Aerothermal Models - I	C	NAS3-23523
Assessment of Combustor Aerothermal Models - II	C	NAS3-23524
Assessment of Combustor Aerothermal Models - III	C	NAS3-23525
Improved Numerical Methods - I	C	NAS3-24351
Improved Numerical Methods - II	C	NAS3-24350
Improved Numerical Methods - III	G	NAG3-596
Flow Interaction Experiment	C	NAS3-24350
Fuel Swirl Characterization - I	C	NAS3-24350
Fuel Swirl Characterization - II	C	NAS3-24352
Mass and Momenta Transfer	C	NAS3-22771
Diffuser/Combustor Interaction	C	F33615-84-C-2427
Dilution Jet Mixing Studies	C	NAS3-22110
Lateral Jet Injection into Typical Combustor Flowfields	G	NAG3-549
Flame Radiation Studies	N	2650
Turbine Heat Transfer		
Mainstream Turbulence Influence on Flow in a Turning Duct - A	C	NAS3-23278
Mainstream Turbulence Influence on Flow in a Turning Duct - B	G	NAG3-617
2-D Heat Transfer without Film Cooling	C	NAS3-22761
2-D Heat Transfer with Leading Edge Film Cooling	C	NAS3-23695
2-D Heat Transfer with Downstream Film Cooling	C	NAS3-24619
Measurement of Blade and Vane Heat Transfer Coefficient in a Turbine Rotor	C	NAS3-23717
Assessment of 3-D Boundary Layer Code	C	NAS3-23716
Coolant Side Heat Transfer with Rotation	C	NAS3-23691
Analytic Flow and Heat Transfer	C	NAS3-24358
Effects of Turbulence on Heat Transfer	G	NAG3-522
Tip Region Heat Transfer	G	NAG3-623
Impingement Cooling	G	NSG3-075
Computation of Turbine Blade Heat Transfer	G	NAG3-579
Advanced Instrumentation Development	N	2640
Warm Turbine Flow Mapping with Laser Anemometry	N	2620
Real Engine-Type Turbine Aerothermal Testing	N	2640
Structural Analysis		
Thermal/Structural Load Transfer Code	C	NAS3-23272
3-D Inelastic Analysis Methods - I	C	NAS3-23697
3-D Inelastic Analysis Methods - II	C	NAS3-23698
Component Specific Modeling	C	NAS3-23687
Liner Cyclic Life Determination	N	5210
Structural Components Response Program	N	5210
High Temperature Structures Research Laboratory	N	5210
Constitutive Model Development	N	5210
Constitutive Modeling for Isotropic Materials - I	C	NAS3-23925
Constitutive Modeling for Isotropic Materials - II	C	NAS3-23927
Theoretical Constitutive Models for Single Crystal Alloys	G	NAG3-511
Biaxial Constitutive Equation Development for Single Crystals and Directionally Solidified Alloys	G	NAG3-512
Fatigue and Fracture		
Creep-Fatigue Life Prediction for Isotropic Materials	C	NAS3-23288
Elevated Temperature Crack Propagation	C	NAS3-23940
Life Prediction and Material Constitutive Behavior for Anisotropic Materials	C	NAS3-23939
Analysis of Fatigue Crack Growth Mechanism	G	NAG3-348
Vitalization of High Temperature Fatigue and Structures Laboratory	N	5220
Surface Protection		
Effects of Surface Chemistry on Hot Corrosion	C	NAS3-23926
Thermal Barrier Coating Life Prediction - I	C	NAS3-23943
Thermal Barrier Coating Life Prediction - II	C	NAS3-23944
Thermal Barrier Coating Life Prediction - III	C	NAS3-23945
Airfoil Deposition Model	G	NAG3-201
Mechanical Behavior of Thermal Barrier Coatings	G	NCC3-27
Coating Oxidation/Diffusion Prediction	N	5160
Deposition Model Verification	N	5160
Dual Cycle Attack	N	5160
Rig/Engine Correlation	N	5160
Burner Rig Modernization	N	5160

Notes: A, B — Activities in series
I, II, III — Activities in parallel