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TURBINE ENGINE HOT SECTION TECHNOLOGY (HOST) PROJECT

Daniel E. Sokolowski and C. Robert Ensign
NASA Lewis Research Center
Cleveland, Ohio

The Hot Section Technology (HOST) Project is a NASA-sponsored endeavor to improve the durability of advanced gas-turbine engines for commercial and military aircraft. Through improvements in analytical models and life-prediction systems, designs for future turbine-engine hot section components - the combustor and turbine - will be analyzed more accurately and, thus, will incorporate features required for longer life in the more hostile operating environment of high performance engines.

Started in fiscal year 1981, the HOST Project has activities currently planned through 1989 with an estimated total cost of over $44 million. While the Project's focused research activities are necessarily analytical in nature, significant experimental testing is required for better understanding of problems as well as model verifications. The efforts are being conducted in-house at the NASA Lewis Research Center, under contracts with major domestic turbine-engine manufacturers and under grants to qualified universities. The contract and grant total funding is approximately one-half of the total budget for fiscal year 1987.

At NASA Lewis the HOST Project serves as the focal point for advocacy, funding, technical coordination, and information exchange. This workshop serves as the primary vehicle for this last function; that is, to disseminate information and elicit the exchange of ideas among participants.

Activities of the HOST Project are categorized under six disciplines: (1) instrumentation, (2) combustion, (3) turbine heat transfer, (4) structural analysis, (5) fatigue and fracture, and (6) surface protection. Management of the project uses the matrix approach, as shown in figure 1. A subproject manager is responsible for each discipline and reports to the manager of the HOST Project

All technical activities initiated and supported by the HOST Project are listed in table I. To summarize these activities and their objectives, instrumentation is being developed to obtain high-temperature, benchmark-quality data to develop and verify analysis methods. These include flow sensors (LDV), heat flux sensors (thin film), strain sensors (1800 °F static thin film), a high-frequency-response gas temperature sensor (frequency compensated), and a hot-section optical viewing system. Combustion work includes aerothermal model assessment and development as well as dilution jet modeling. In turbine heat transfer two- and three-dimensional flow and heat transfer are being studied on airfoil external boundaries, emphasizing boundary-layer transition and viscous modeling. Also being investigated is coolant-passage heat transfer, including midchord jet impingement cooling and rotational passage effects. Structural analysis includes research into thermal mechanical load models, component geometry-specific models, three-dimensional inelastic analysis methods development, development of a thermal structural cyclic test facility, and constitutive model development for both isotropic and anisotropic materials in single-crystal and directionally solidified forms. Fatigue and fracture includes research in life-prediction methods for creep-fatigue interactions and elastoplastic crack propagation. Surface protection research includes studies of corrosion phenomena, and thermal barrier coating analysis method developments.

To further understand the organization of the project and, more importantly, the reasons for its activities, it is useful to consider the critical steps leading to life prediction. The flow diagram in figure 2 shows such critical steps and may be used for any hot section subcomponent; for example, combustor liners, turbine blades, or turbine vanes. The first series of steps in figure 2 defines the engine subcomponent geometry, material, and operating requirements. The remaining steps are those being addressed by the HOST Project: (1) characterizing the hot section environment, (2) characterizing thermomechanical loads, (3) determining material behavior and structural response due to imposed loads, and (4) predicting life for subcomponents exposed to cyclic operation. For these steps the technology needs and notable technical progress to date are shown in figures 3 to 6.

Workshop publications and many contractor final reports carry the label "For Early Domestic Dissemination" (FEDD) to protect national interests and, thus, are available only to qualified U.S. citizens. Although contractor final reports have been published, they often represent initial phases of multiphased work. Thus, this annual workshop report is the primary document for reporting technical results for the entire project.

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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.

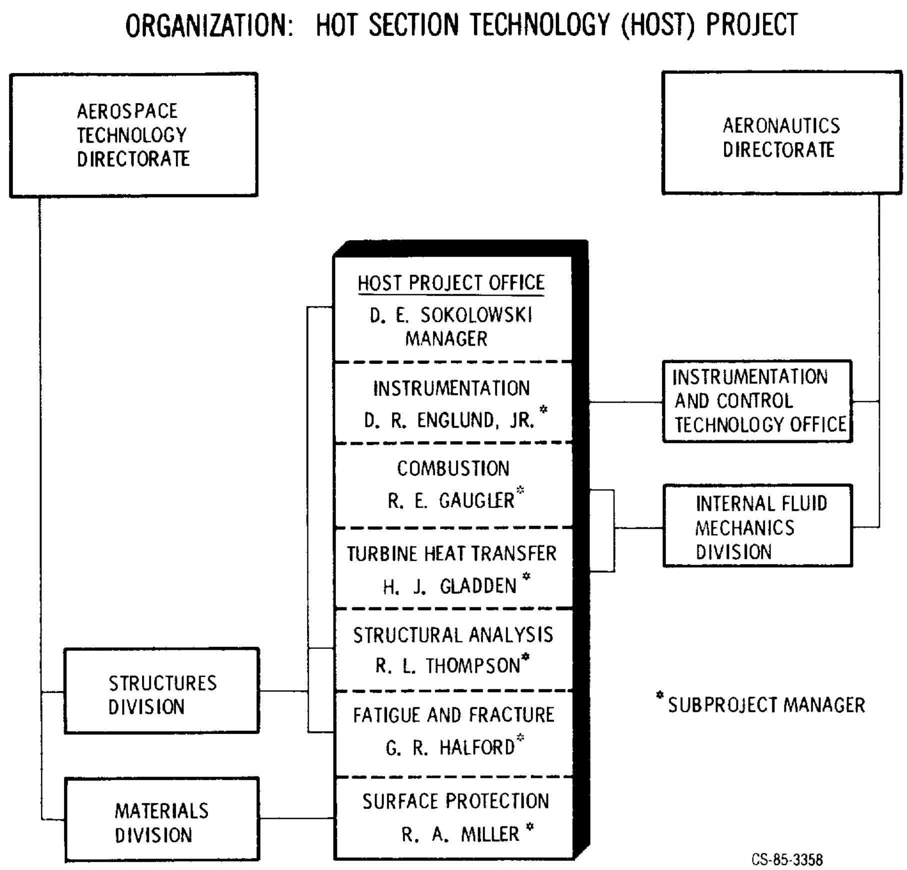

Figure 1

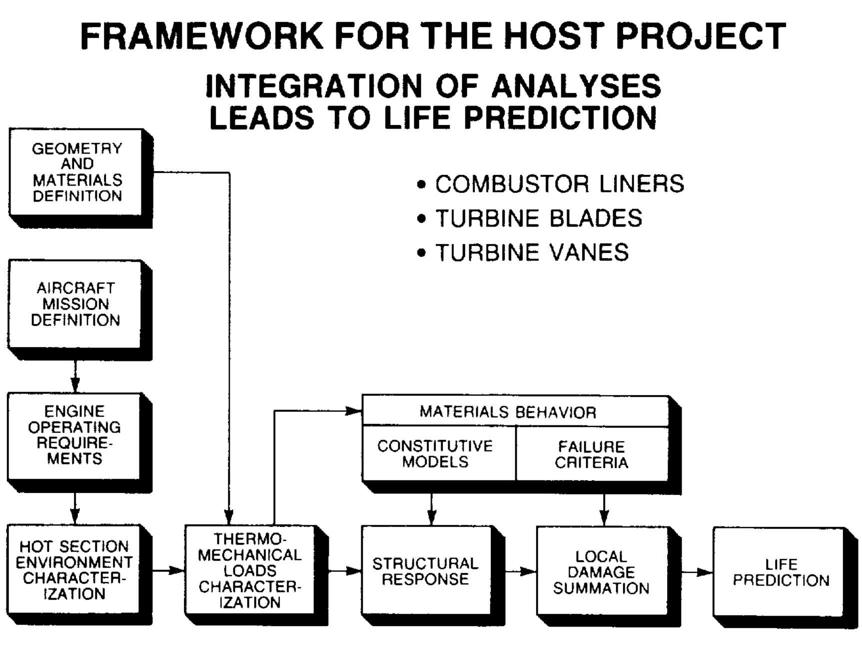

Figure 2

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HOT SECTION ENVIRONMENT

NEED

- TO BETTER UNDERSTAND AND PREDICT THE AEROTHERMAL ENVIRONMENT AROUND HOT SECTION PARTS.

HOST PROGRESS

- DEVELOPED VIEWING SYSTEM AND TESTED IN PW 2037 AND HPF; FUEL INJECTOR OPERATION, LINER HOT SPOTS, AND LINER/VANE CRACKING CAN BE OBSERVED.
- DEVELOPED DYNAMIC GAS TEMPERATURE MEASUREMENT SYSTEM AND TESTED IN F-100 AND HPF; GAS TEMPERATURE FLUCTUATIONS CAN BE ACCURATELY DETERMINED UP TO 1-KHz AND 3000 °F PEAKS.
- EVOLVED LASER ANEMOMETRY FOR MEASUREMENTS IN COMBUSTOR EXHAUST STREAM; EFFORTS UNDERWAY FOR MEASUREMENTS WITHIN TURBINE.
- IMPROVING RESOLUTION OF SPATIAL PROPERTY VARIATIONS AND QUANTITATIVE ACCURACY OF AEROTHERMAL CODES, THROUGH 3-D NUMERICAL SCHEMES, IMPROVED TURBULENCE AND CHEMISTRY MODELS, AND RELEVENT BENCHMARK DATA.
- OBTAINED BROAD DATA BASE AND DEVELOPED EMPIRICAL MODEL FOR MIXING DILUTION AIR JETS WITH COMBUSTION GASES; COMBUSTOR EXIT TEMPERATURES PREDICTED ACCURATELY WITHIN RANGE OF DATA BASE; 3-D NUMERICAL CODES BEING IMPROVED IN SPEED AND GEOMETRIC CAPABILITIES.

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Figure 3

THERMOMECHANICAL LOADS

NEED

- TO BETTER UNDERSTAND AND PREDICT THE THERMAL AND MECHANICAL LOADS ON CRITICAL PARTS LIKE LINERS, BLADES, AND VANES.

HOST PROGRESS

- EVOLVED TOTAL HEAT FLUX SENSORS FROM LINERS TO AIRFOILS; SENSITIVITY TO HEAT FLUX GRADIENTS ALONG AIRFOIL MUST BE MINIMIZED.
- DETERMINED THE EFFECTS OF ROTATION ON COOLANT HEAT TRANSFER IN SMOOTH-WALL PASSAGES AND MODIFIED "TEACH" CODE; SIMILAR EFFORTS UNDERWAY FOR TURBULATED PASSAGES.
- DETERMINATION OF ROTATION ON AIRFOIL HEAT TRANSFER STARTING TO PRODUCE RESULTS.
- ASSESSED 3-D BOUNDARY LAYER CODE; AGREEMENT WITH DATA IS GENERALLY GOOD.
- OBTAINED BROAD DATA BASES AND MODIFIED STAN5 CODE TO ACCURATELY PREDICT HEAT TRANSFER COEFFICIENTS, ESPECIALLY AT THE TRANSITION POINT, FOR FILM AND NON-FILM COOLED AIRFOILS.

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Figure 4

STRUCTURAL RESPONSE

NEED

- TO IMPROVE PREDICTION ACCURACY AND EFFICIENCY OF STRESSES AND STRAINS ON HOT SECTION METALLIC PARTS DUE TO THERMOMECHANICAL LOADS.

HOST PROGRESS

- DEVELOPED STRAIN MEASUREMENT APPROACH HAVING 1300 °F CAPABILITY; EFFORTS UNDERWAY TOWARD 1800 °F CAPABILITY.
- DEVELOPED INTERFACING CODE WHICH AUTOMATICALLY TRANSFERS 3-D THERMAL INFORMATION FROM A HEAT TRANSFER CODE (COARSE GRID) TO A STRUCTURAL ANALYSIS CODE (FINER GRID).
- DEVELOPED 3-D INELASTIC STRUCTURAL ANALYSIS CODES FOR NONLINEAR BEHAVIOR AT HIGH THERMOMECHANICAL LOADS; THREE CODES COVER DIFFERENT APPROACHES--MOMM, MHOST, BEST3D; PROVIDED TENFOLD INCREASE IN COMPUTATIONAL EFFICIENCY WITH IMPROVED ACCURACY.
- DEVELOPED SEVERAL VISCOPLASTIC CONSTITUTIVE MODELS FOR BOTH ISOTROPIC AND ANISOTROPIC MATERIALS; BROADENED DATA BASE; VERIFIED MODELS FOR RANGE OF TEST CONDITIONS; HIGH TEMPERATURE STRESS/ STRAIN PREDICTION CAPABILITY IMPROVED BY 30-PERCENT; LEWIS IS INTERNATIONALLY RECOGNIZED LEADER IN CONSTITUTIVE MODEL DEVELOPMENT.
- DEVELOPED MODULAR CODE FOR NONLINEAR STRUCTURAL ANALYSES OF LINERS, BLADES, AND VANES OVER MISSION CYCLE; AUTOMATIC SOLUTION STRATEGY FOR LINERS--SIMILAR STRATEGY UNDERWAY FOR BLADES AND VANES.

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Figure 5

LIFE PREDICTION

NEED

- TO ACCURATELY PREDICT THE NUMBER OF CYCLES TO FATIGUE CRACK INITIATION (LIFE) AND CRACK GROWTH FOR COMPONENTS MADE OF ISOTROPIC AND ANISOTROPIC MATERIALS THAT ARE SUBJECTED TO COMPLEX CYCLIC MECHANICAL AND THERMAL LOADS AT HIGH TEMPERATURES.
- TO ACCURATELY PREDICT THE LIFE OF THERMAL BARRIER COATINGS ON LINERS AND AIRFOILS.

HOST PROGRESS

- DEVELOP NEW CONSTITUTIVE EQUATIONS AND LIFE MODELS THAT CAN BE USED TO PREDICT LIFE FOR ADVANCED CONFIGURATIONS AND MATERIALS UNDER COMPLEX LOADING CONDITIONS.
- EXTENDED MODELING CAPABILITIES TO INCLUDE MULTIAXIAL (2-D AND 3-D) STRESS STATES AND THERMOMECHANICAL LOADING CONDITIONS.
- EXTENDED LABORATORY TESTING CAPABILITIES TO PERMIT COMPLEX THERMOMECHANICAL TESTS NEVER BEFORE POSSIBLE.
- SOME PREDICTIONS HAVE SHOWN IMPROVEMENTS IN ACCURACY BY A FACTOR OF TWO.
- SIGNIFICANT PROGRESS TOWARD DEVELOPING LIFE PREDICTION MODELS FOR BLADES MADE WITH ANISOTHOPIC MATERIALS.
- FORMULATED OXIDATION/THERMAL STRAIN MODEL FOR TBC LIFE PREDICTION (LeRC) THAT IS BASIS FOR TWO PRELIMINARY LIFE PREDICTION MODELS DEVELOPED BY P&W AND GTEC.

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Figure 6