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THERMAL BARRIER COATING LIFE PREDICTION

MODEL DEVELOPMENT

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Thermal barrier coatings (TBC's) for turbine airfoils in high-performance engines represent an advanced materials technology with both performance and durability benefits. The foremost TBC benefit is the reduction of heat transferred into air-cooled components, which yields performance and durability benefits (fig. 1). To achieve these benefits, however, the TBC system must be reliable. Mechanistic thermomechanical and thermochemical life models are therefore required for the reliable exploitation of TBC benefits on gas turbine airfoils. Garrett's NASA HOST Program (NAS3-23945) goal is to fulfill these requirements.

This program focuses on predicting the lives of two types of strain-tolerant and oxidation-resistant TBC systems that are produced by commercial coating suppliers to the gas turbine industry (fig. 2). The plasma-sprayed TBC system, composed of a low pressure plasma sprayed (LPPS) applied oxidation resistant NiCrAlY bond coating and an air plasma sprayed yttria (8 percent) partially stabilized zirconia insulative layer, is applied by both Chromalloy (Orangeburg, New York) and Klock (Manchester, Connecticut). The second type of TBC is applied by the electron beam-physical vapor deposition (EB-PVD) process by Temescal (Berkeley, California).

A viable model must predict TBC life on a turbine airfoil as a function of engine, mission, and materials system parameters. These parameters are incorporated into mechanical, oxidation, and salt deposition functions of TBC degradation as indicated in figure 3. The approach adopted in this program for developing a TBC life model is similar to that in use at Garrett for prediction of oxidation/hot corrosion lives of metallic coatings as a function of engine, mission, and materials system parameters (fig. 4). Similarities and differences in these models are illustrated in figure 5.

A rapid computational capability is required for preliminary design and mission analyses of TBC lives. Substructure models are being developed to facilitate the rapid computation of TBC life as indicated in figure 6. TBC life analysis will be performed for each of the critical damage modes.

Burner rig and mechanical property data are being obtained to quantify the capabilities of each of the TBC systems for each critical mode of degradation. Burner rig test data and zirconia fracture toughness data are illustrated on figures 7 and 8.

Lives of these TBC systems will be predicted for TFE731 high pressure turbine blades for factory engine test, business aircraft and maritime surveillance missions. Complementary engine validation tests are planned.

This program is now at the midpoint of Phase I. The program schedule is provided in figure 9.

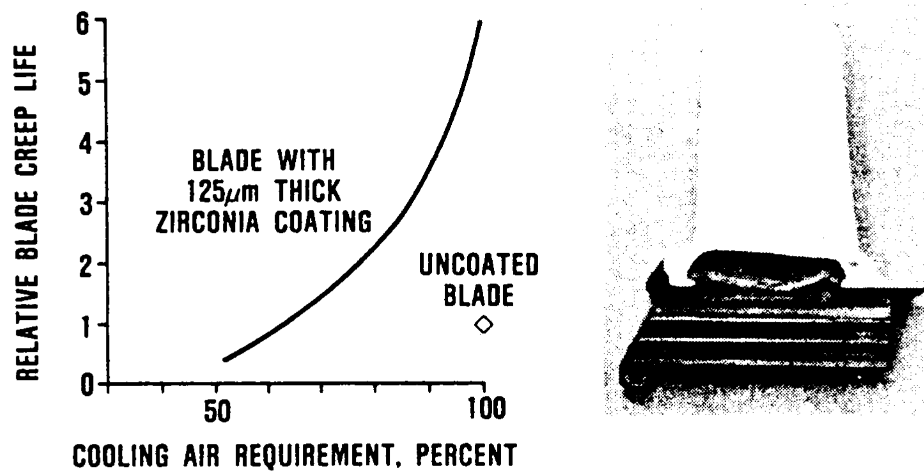

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Figure 1. TBCs Improve Creep Life and Reduce Cooling Air Requirements for the Garrett High-Pressure Turbine Blade.

PLASMA SPRAY	ELECTRON BEAM — PHYSICAL VAPOR DEPOSITION	
APS Y_2O_3 (8%) STABILIZED ZrO_2	EB-PVD Y_2O_3 (20%) STABILIZED ZrO_2	TBC
LPPS Ni-31Cr-11Al-0.5Y	EB-PVD Ni-23Co-18Cr-11Al-0.3Y	BASE COAT
MAR-M 247 SUPERALLOY	MAR-M 247 SUPERALLOY	SUBSTRATE
• CHROMALLOY • KLOCK	• TEMESCAL	

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Figure 2. Life Prediction Models are Being Developed for Plasma-Sprayed and EB-PVD TBC Systems.

TBC DEGRADATION RATE = **F_1 (MECHANICAL)** + **F_2 (OXIDATION)** + **F_3 (SALT DEPOSITION)**

F_1 (MECHANICAL)

- COATING STRESSES
- TEMPERATURE
- MATERIAL SYSTEM
  - K_{IC}
  - FLAW SIZE
  - ELASTIC MODULUS
  - SPALLING STRAIN

F_2 (OXIDATION)

- TEMPERATURE
- CYCLE SEGMENT LENGTH
- MATERIALS SYSTEM

F_3 (SALT DEPOSITION)

- ALTITUDE (SALT INGESTION)
- TURBINE PRESSURE
- SALT EVAPORATION
- SALT SOLIDIFICATION
- TEMPERATURE
- GAS VELOCITY
- AIRCRAFT LOCATION
- MATERIALS SYSTEM

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Figure 3. TBC Life is a Function of Engine, Mission and Materials System Parameters.

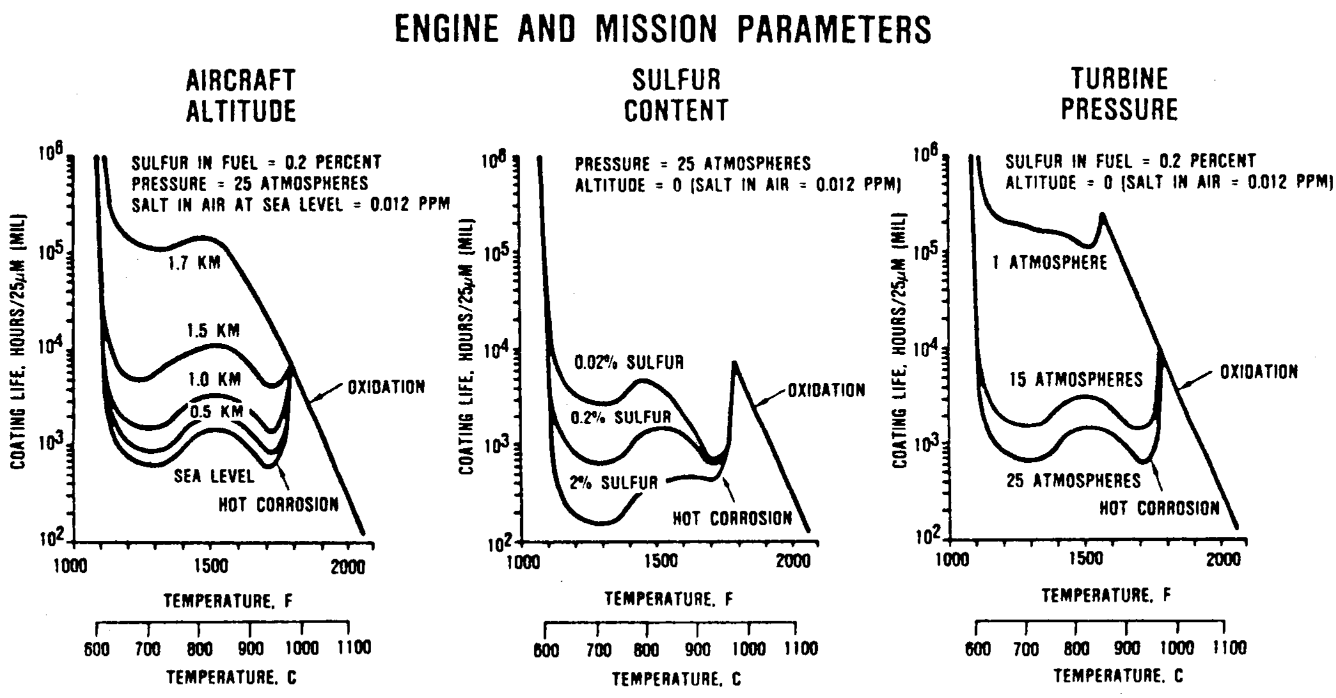

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Figure 4. Turbine Airfoil Coating Life Predicted by Computer Model.

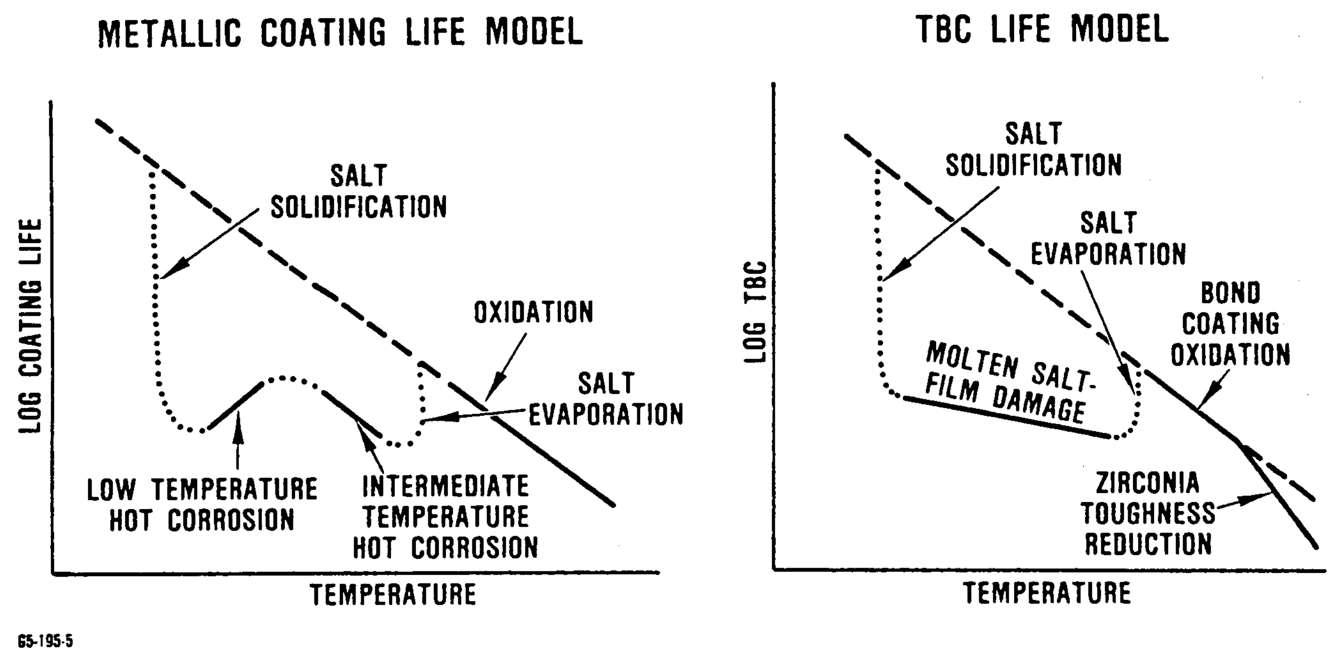

Figure 5. Approach to TBC Life Model Development is Facilitated by GTEC Metallic Coating Life Model.

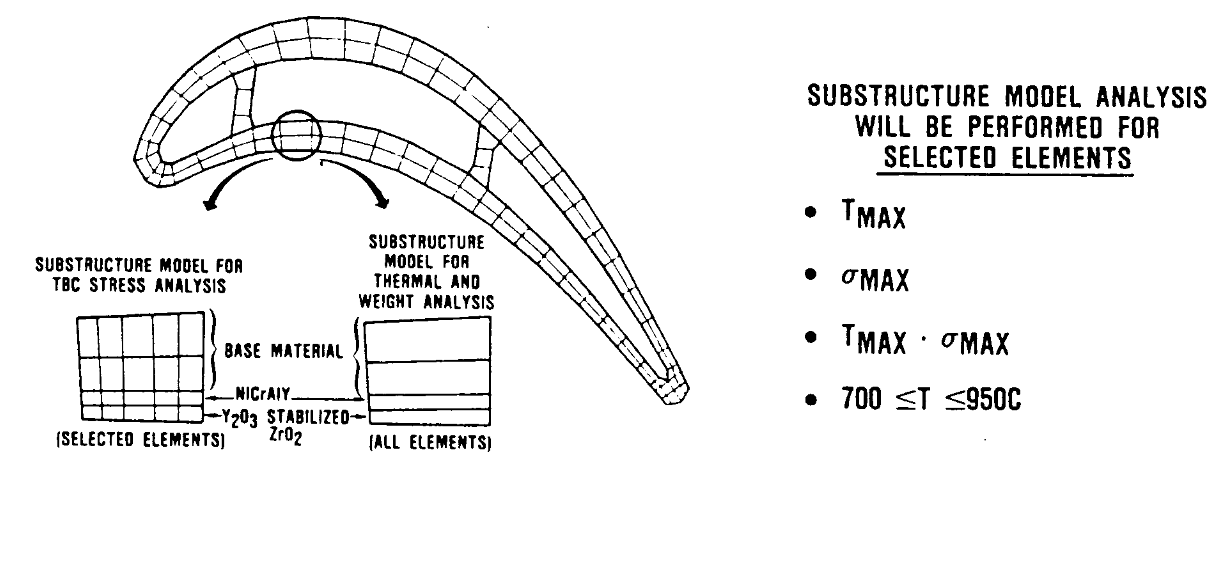

Figure 6. Substructure Models Facilitate the Rapid Computation of TBC Life Required for Preliminary Design and Mission Analysis.

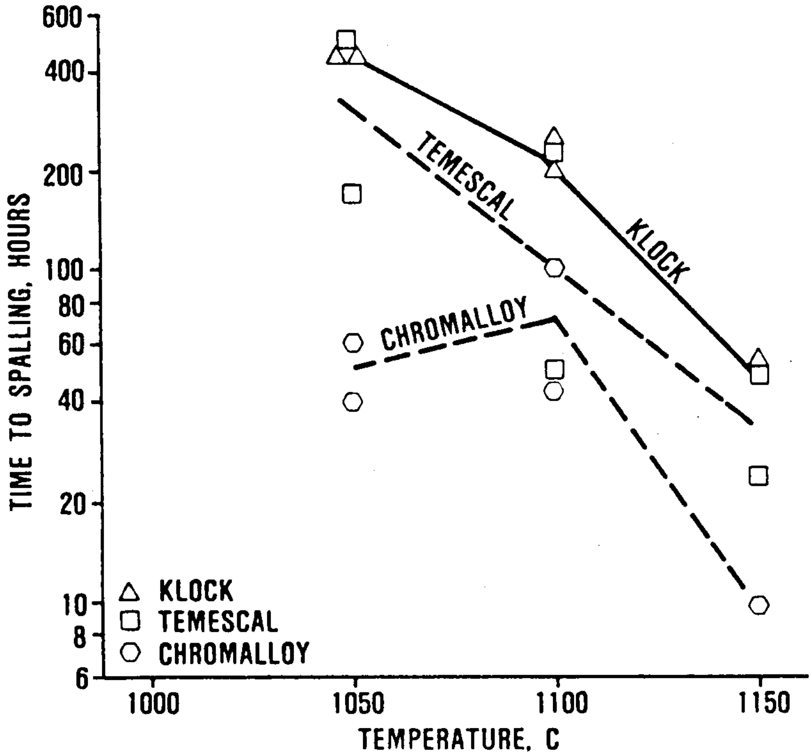

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Figure 7. TBC Spalling in Burner Rig Test is a Function of Temperature.

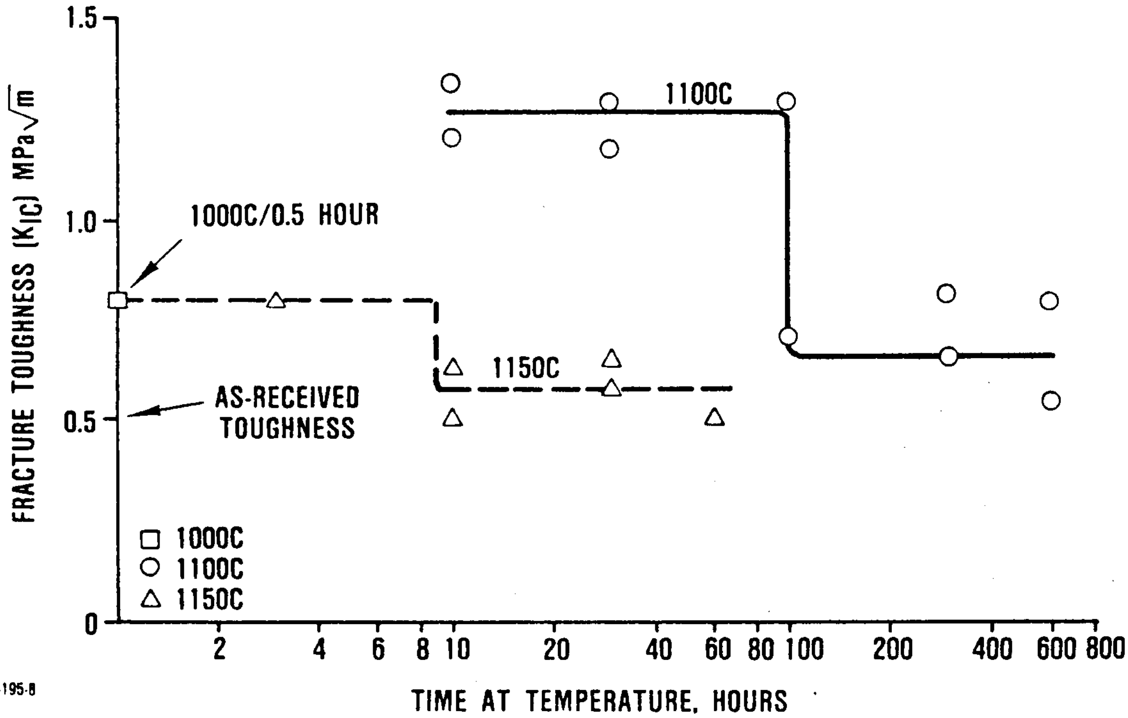

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Figure 8. Zirconia Fracture Toughness of Chromalloy Plasma-Sprayed TBC System is a Step Function of Exposure Time and Temperature.

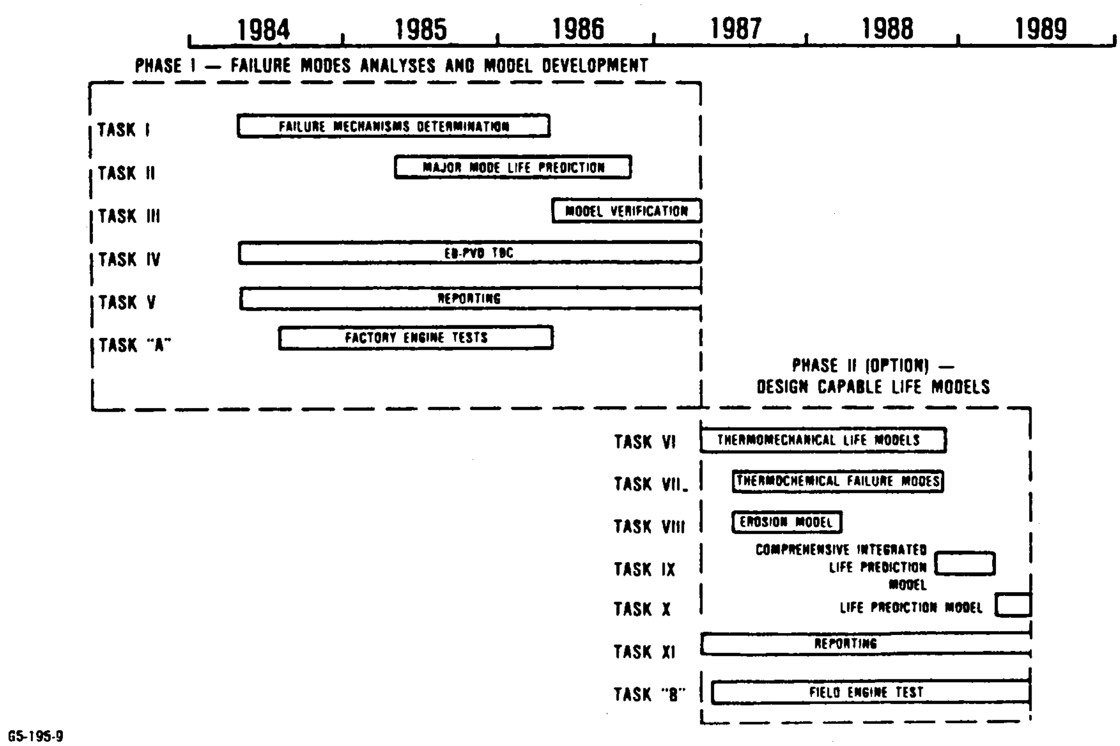

Figure 9. TBC Life Prediction Schedule.