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THERMAL BARRIER COATING LIFE PREDICTION MODEL DEVELOPMENT

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The effort to increase engine efficiency has received added impetus in recent years because of the sharp increase in fuel cost. Several generations of superalloys have been developed over the years to permit increases in turbine inlet gas temperatures to increase engine efficiency, but the practical temperature limits make this increasingly difficult and expensive. The use of thermal barrier coatings has potential to increase engine efficiency by permitting increased gas inlet temperatures at present metal temperatures, or maintaining current gas inlet temperatures and reducing coolant requirements and the efficiency penalties associated with cooling air usage. Alternatively, TBCs can be utilized to reduce metal temperatures and extend life.

Thermal barrier coatings are now commonly used on combustors, afterburner flameholders, and other low-risk applications, and extend the useful lives of those components significantly. Also, TBCs have been successfully tested on several high pressure turbine (HPT) nozzles and blades. The occasional loss of some of the ceramic insulating layer of the TBC from combustors and flameholders is not unduly harmful to engine operation or life, and the ability to predict coating life in such applications is not essential. On the other hand, the reliability of coatings used on HPT components is critical. Loss of the coating from such components has the potential to shorten life to less than that of uncoated parts, particularly if cooling air has been reduced to obtain engine efficiency. Thus the long-term use of TBCs on HPT hardware under engine operating conditions where safe metal temperatures must be maintained requires absolutely predictable coating performance. At the present time, the ability to quantitatively predict TBC life does not exist.

In order to fully exploit thermal barrier coatings on turbine components and achieve the maximum performance benefit, the knowledge and understanding of TBC failure mechanisms must be increased and the means to predict coating life developed. The proposed program will determine the predominant modes of TBC system degradation and then develop and verify life prediction models accounting for those degradation modes. The successful completion of the program will have dual benefits: the ability to take advantage of the performance benefits offered by TBCs, and a sounder basis for making future improvements in coating behavior.

The program is composed of eight technical tasks as described briefly below.

Task I - Failure Mechanism Determination

The work in this task will consist of designing and performing experiments to determine the relative importance of various potential failure modes of a plasma sprayed TBC system and to conduct additional tests to confirm that the identified failure modes are correct. The TBC system will consist of a low pressure plasma sprayed (LPPS) Ni-22Cr-10Al-0.3Y (wt. %) bond coat and a plasma sprayed yttria partially stabilized zirconia (ZrO_2-8%Y_2O_3) top coat on conventionally cast Rene' 80 alloy substrate. Bond coat thickness will be 0.005 inch±0.001 inch, and the zirconia thickness will be 0.010±0.002 inch.

Task II - Major Mode Life Prediction Model

The objective of this task is to develop life prediction models for those predominant failure models determined in Task I. This will be accomplished by designing a suitable set of experiments and concommitant analyses, thus creating a life prediction model by means of a combined analytical experimental program.

Task III - Model Verification

The plan for this Task is to use instrumented burner rig testing of TBC coated Rene' 80 specimens to verify the life model under conditions which are generally simulative of turbine blade conditions. The variables to be covered are: 1) strain (TMF) cycle, 2) peak cycle temperature, and 3) cycle duration.

Task V - Thermomechanical Life Models

The stress analysis and life modeling to be conducted in this and following tasks will require the knowledge of several coating properties (thermal/physical properties, deformation properties, failure characteristics), some of which will be determined in the program.

The primary objective of this Task is to develop a "continuum" mechanics life prediction model by applying a structural analysis code based on publicly available heat transfer and stress analyses codes modified to deal with the thermal barrier coating problem.

Task VI - Thermochemical Failure Modes

In this task, oxidation and hot corrosion failure models will be developed. Assuming that oxide scale growth on the bond coat surface is found to be a predominant factor in TBC failure, and further that the relationship between scale thickness and stress is determined in earlier tasks, then the effort in this task will be to determine the rate of oxide scale growth at various anticipated use temperatures. Thus, it should be possible to develop a model for predicting TBC life at various operating temperatures or combinations of temperatures.

Task VII - Exceptional Failure Modes

A data base on erosion and foreign object damage will be developed in this Task for use in predicting anticipated erosion and foreign object damage to thermal barrier coated components.

Task VIII - Comprehensive Model Development

The objective of this task is to develop a comprehensive life prediction model. This model will include four activities:

- Structural Analysis - Determination of the mechanical and thermal fields in the structure for a given flight profile.
- Continuum Analysis - Evaluation of potential for crack initiation through appropriate mechanisms as well as gross structural instabilities; for example, creep or buckling.
- Exceptional Failure Modes Analysis - Evaluation of those events which require external agents to produce failure, e.g., FOD or erosion.
- Fracture Mechanics Analysis - Determination of the structural life once a dominant crack is formed.

Task IX - Life Prediction Model Verification

The test plan developed in Task VIII to test the dominant features of the model will be conducted. Details of conditions, data, analysis, etc., will depend on each particular test to be defined at that point in the program.

This contract began in April of this year and work to date has been exclusively in Task I. A literature search has been completed and preliminary experiments aimed at definition of predominant failure modes are underway.