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COMPONENT-SPECIFIC MODELING*

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Introduction

Modern jet engine design imposes extremely high loadings and temperatures on hot section components. Fuel costs dictate that minimum weight components be used wherever possible. In order to satisfy these two criteria, designers are turning toward improved materials and innovative designs. Along with these approaches, however, they must also have more accurate, more economical, and more comprehensive analytical methods.

Numerous analytical methods are available which can, in principle, handle any problem which might arise. However, the time and expense required to produce acceptable solutions is often excessive. This program addresses this problem by setting out a plan to create specialized software packages, which will provide the necessary answers in an efficient, user-oriented, streamlined fashion. Separate component-specific models will be created for burner liners, turbine blades, and turbine vanes using fundamental data from many technical areas. The methods developed will be simple to execute, but they will not be simple in concept. The problem is extremely complex and only by a thorough understanding of the details can the important technical approaches be extracted. The packaging of these interdisciplinary approaches into a total system must then conform to the modular requirements for useful computer programs.

Objective

The overall objective of this program is to develop and verify a series of interdisciplinary modeling and analysis techniques which have been specialized to address three specific hot section components. These techniques will incorporate data as well as theoretical methods from many diverse areas, including cycle and performance analysis, heat transfer analysis, linear and nonlinear stress analysis, and mission analysis. Building on the proven techniques already available in these fields, the new methods developed through this contract will be integrated to provide an accurate, efficient, and unified approach to analyzing combustor burner liners, hollow air-cooled turbine blades, and air-cooled turbine vanes. For these components, the methods developed will predict temperature, deformation, stress, and strain histories throughout a complete flight mission.

Background

This program, to a great extent, will draw on prior experience. This base of experience is invaluable for understanding the highly complex interactions among all the different technical disciplines as well as for estimating the importance of different engine parameters. In particular, there are four specific areas in which experience will be especially beneficial.

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First, with the recent increases in fuel costs, greater emphasis has been placed on more accurate solutions for stresses and strains in order to understand and improve the durability and life of hot section components. Conventional linear elastic analyses are no longer sufficient; instead, they now provide the boundary values for more refined creep and plasticity calculations. These nonlinear analyses are now performed routinely as part of the design process at General Electric. This extensive experience with these plasticity and creep methods will contribute directly to developing component specific models.

Second, advances in 3-D modeling capability are being achieved by the concepts developed under the NASA-supported ESMOSS program. ESMOSS concepts will provide the basis to develop an efficient modeling system for geometric and discretized models of engine components.

Third, the NASA-funded Burner Liner Thermal/Structural Load Modeling Program will contribute strong support to this program. The specific area addressed, transfer of data from a 3-D heat transfer analysis model to a 3-D stress analysis model, will provide the background and framework for the data interpolation required for all thermomechanical models in this contract.

Fourth, over the past 10 years, General Electric has developed internally a family of computer programs: LASTS, OPSEV, and HOTSAM. These programs all have the common thread of using selected points from cycle data, heat transfer, and stress analyses, and a decomposition/synthesis approach to produce accurate values of temperature, stress, and strain throughout a mission. These programs are totally consistent with the overall objectives of this program, and represent a proven technology base upon which the component specific models will be developed. Significant advances to be made are the inclusion of nonlinear effects and the introduction of improved modeling and data transfer techniques.

Approach

The program is organized into nine tasks which can logically be separated into two broadly parallel activities (Figure 1). On the right of Figure 1 we have the Component Specific Thermo-Mechanical Load Mission Modeling path. Along this path a Decomposition/Synthesis approach will be taken. In broad terms this means developing methods to generate approximate numerical models for the engine cycle and the aerodynamic and heat transfer analyses needed to provide the input conditions for hot parts stress and life analysis.

The left path, Component Specific Structural Modeling will provide the tools to develop and analyse finite element nonlinear stress analysis models of combustor liners and turbine blades and vanes. These two paths are shown in more detail in Figures 2 and 3.

Software Development, Task IV consists of planning and writing the computer programs for both paths, with the necessary interconnections, using a structured, top down approach.

In the Thermomechanical Load Mission Modeling portion of the program (Figure 2) we will develop, in Task III, a Thermodynamic Engine Model which will generate the engine internal flow variables for any point on the operating mission. The method for doing this is described below. Task V will develop techniques to decompose flight missions into characteristic mission segments. In Task VII a Thermomechanical Mission Model will be developed. This will use the flow variables from the Thermodynamic Model to determine metal temperature and pressure distributions for a representative combustor liner and turbine blade and vane.

Individual tasks for the Structural Modeling activity are shown in Figure 3. The requirements of Software Design, Task II, will be factored into Task VI, the evaluation of the structural analysis methods which were selected for evaluation in Task I. Task VIII will provide the capability for structurally modeling current state-of-the-art combustor liners and hollow turbine blades and vanes, given the defining dimensional parameters. These parameters will be chosen to facilitate parametric studies.

The component specific models will be developed in two steps. In the first a geometric model will be defined. In the application of the Component Specific Modeling Program this data will then be transferred to the Thermomechanical Load Mission Model to provide the geometry for determining component pressures and temperatures. Thus, a data transfer link will be developed to do this in Task IV, Software Development. The capability for generating from the geometric model a discretized, finite element model will also be part of Task VIII. At this point another link between the two paths will be needed to transfer the component temperatures and pressures from the Thermomechanical Load model to the finite element model, interpolating the data as needed to define nodal temperatures and pressures. This also will be completed in Task IV.

The final function in Task VIII will be the development of component-specific stress analysis models for the three components to perform cyclic elastic, plastic and creep analyses using loading conditions defined by the Thermomechanical Load Models Progress.

At this time considerable progress has been made on the Thermodynamic Engine Model. The model is being developed as a simple calculational tool which will take as inputs the three variables, altitude (h), Mach number (M) and power level (PL) for the allowed flight map of an engine, as shown in Figure 4. In addition, ambient temperature deviations from the standard atmosphere, airframe bleed air requirements and engine deterioration can also be included as part of the input to the Thermodynamic Model. For each input condition, specified by h, M and PL the Thermodynamic Engine Model will calculate gas weight flow ($\dot{w}$), temperature (t) and pressure (p) at selected aerodynamic engine stations, as needed to determine component thermal loadings. These stations are shown in Figure 5.

The technique for developing a Thermodynamic Engine Model is shown in Figures 6 and 7. The engine to be analyzed must be defined thermodynamically by an engine cycle deck (computer program) which can be run to generate the internal flow variables at the chosen aerodynamic stations (Figure 6). To encompass the complete engine operating map (Figure 4), 148 operating points are chosen and $\dot{w}$, t and p are calculated using the cycle deck for the selected stations, as well as N_1 and N_2, the fan and core speeds. From this station data an Engine Performance Cycle Map is constructed. This is essentially a set of three-dimensional data arrays which map the station data ($\dot{w}$, t, p, N_1 and N_2) on to the engine operating map (Figure 4). Given an arbitrary operating point defined by h, M and PL it is then, in principle, possible to interpolate on the Engine Performance Cycle Map to determine station data. In practice the station parameters are nonlinear functions of the input parameters and considerable effort was needed to develop these multi-dimensional interpolations. The computer program used to generate the Engine Performance Cycle Map from the engine cycle desk output has been developed as part of Task III. The functioning of the Thermodynamic Engine Model is shown in Figure 7. Given an engine mission, as shown schematically in Figure 8 it can be defined by values of the input variables h, M and PL at selected times through the mission. Using these input variables and the Engine Performance Cycle Map an Interpolation Program, now being developed in Task III of this program, will calculate engine station parameters throughout the mission (Figure 7). These are then used to define Station Mission Profiles of $\dot{w}$, t, p, N_1, and N_2, as functions of time at each aerodynamic station. These Station Mission Profiles are become the input to the Thermomechanical Engine Model.

The Thermomechanical Model is less well developed at this time than the Thermodynamic Model. Its form will be based on types of correlations previously developed within General Electric. Figure 9 shows a representative correlation for a turbine vane. Metal temperatures at various points on the vane T_{VA} are correlated in terms of a vane overall cooling effectiveness, η, and station gas temperatures T_3 at compressor discharge, and T_4 at combustor discharge. Using the Station Mission Profiles it will be possible to calculate the temperatures at selected locations on each component as functions of time, given the input parameters h, M and PL that define the engine mission. These then will provide the boundary conditions for the component stress analyses.

On the Component Specific Structural Modeling path, concepts have been defined and are being implemented. Additional evaluations are needed, however, before they can be presented for discussion.

Conclusion

When completed this program will provide a stress analysis system for hot section parts that will allow the component designers to evaluate quickly the effects of mission variations, be easy to use, cost effective, and make a significant contribution to assessing hot section durability.

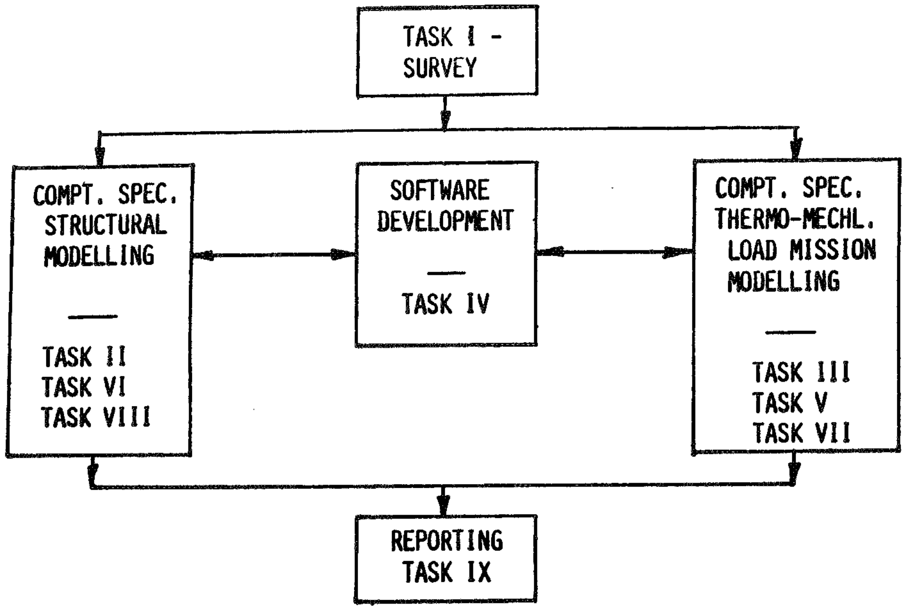


FIGURE 1. COMPONENT SPECIFIC MODELLING - BASE PROGRAM

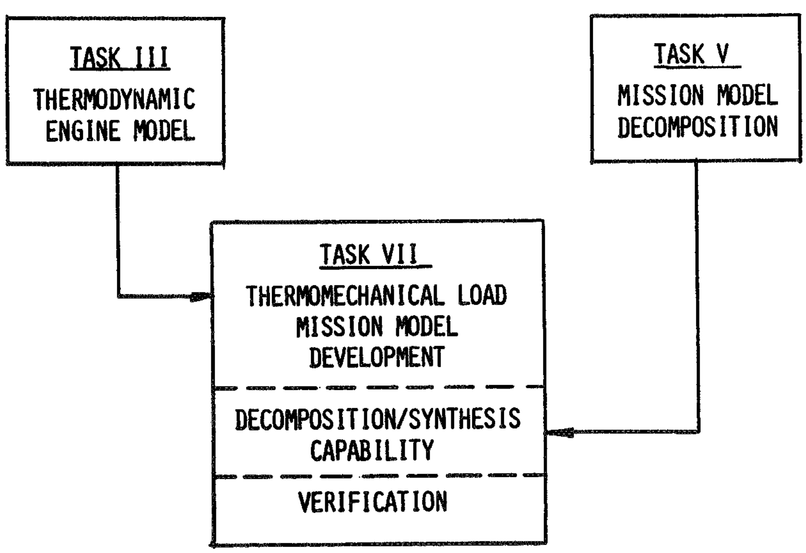


FIGURE 2. COMPONENT SPECIFIC THERMOMECHANICAL LOAD MISSION MODELLING

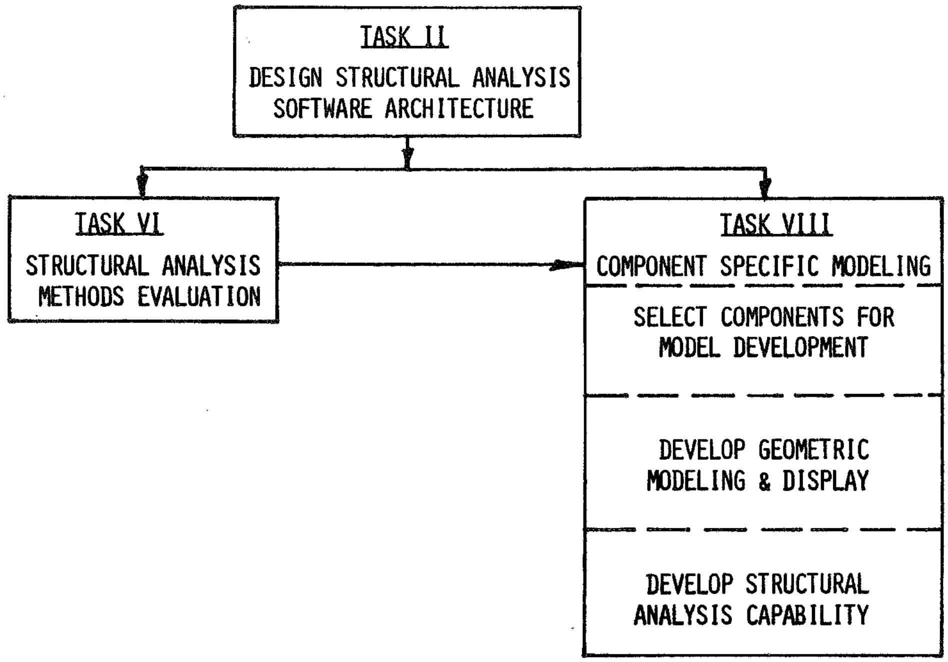


FIGURE 3. COMPONENT SPECIFIC STRUCTURAL MODELING

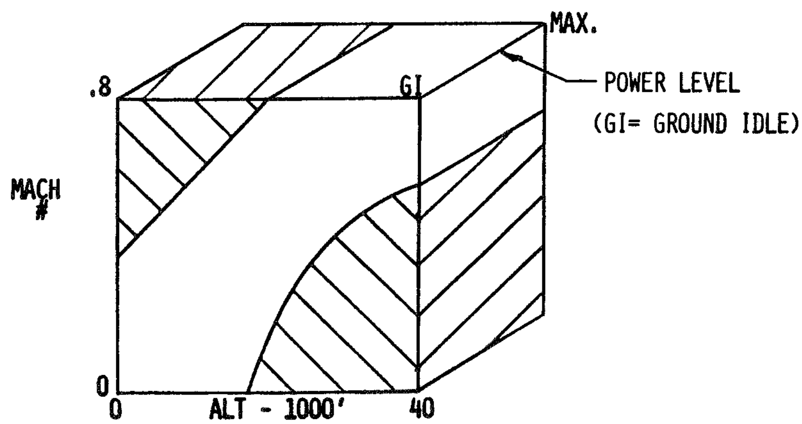
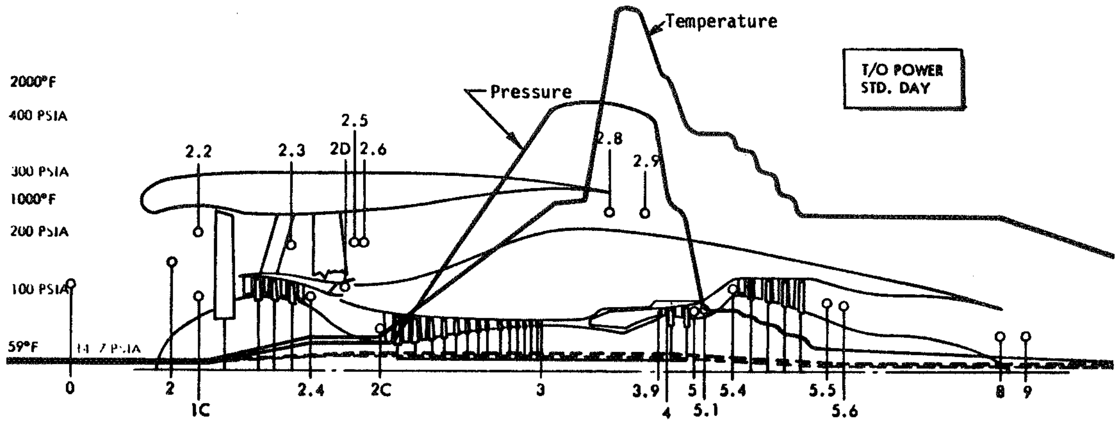


FIGURE 4. ENGINE OPERATING MAP



LEGEND:

0	AMBIENT	2C	HP COMPRESSOR INLET
2	ENGINE INLET	3	HP COMPRESSOR DISCHARGE
2.2	FAN TIP (BYPASS) STREAM INLET	3.9	HP TURBINE 1ST-STAGE NOZZLE INLET (W/O COOLING FLOW)
1C	FAN HUB (LP COMPRESSOR) STREAM INLET	4	HP TURBINE ROTOR INLET (W/ COOLING FLOW)
2.3	FAN DISCHARGE	5	HP TURBINE DISCHARGE (W/O COOLING FLOW)
2.4	LP COMPRESSOR DISCHARGE	5.1	HP TURBINE DISCHARGE (W/ COOLING FLOW)
2D	LP COMPRESSOR DISHCARGE BLEED PORT EXIT	5.4	LP TURBINE INLET (W/ COOLING FLOW)
2.5	BYPASS STREAM MIXING PLANE	5.5	LP TURBINE DISCHARGE (W/O COOLING FLOW)
2.6	BYPASS DUCT INLET (AFTER MIXING)	5.6	LP TURBINE DISCHARGE (W/ COOLING FLOW)
2.8	BYPASS DUCT JET NOZZLE THROAT	8	PRIMARY JET NOZZLE THROAT
2.9	BYPASS DUCT JET NOZZLE EXIT (COMPLETE EXPANSION)	9	PRIMARY JET NOZZLE EXIT (COMPLETE EXPANSION)

TEMPERATURE FAN — — — — —
CORE ————

PRESSURE FAN — — — — —
CORE ————

FIGURE 5. **CF6 AERODYNAMIC STATIONS**

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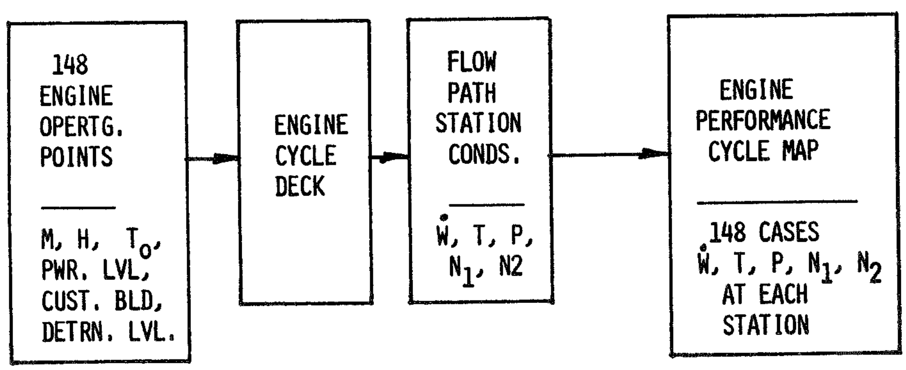

FIGURE 6. THERMODYNAMIC ENGINE MODEL
CYCLE MAP GENERATION

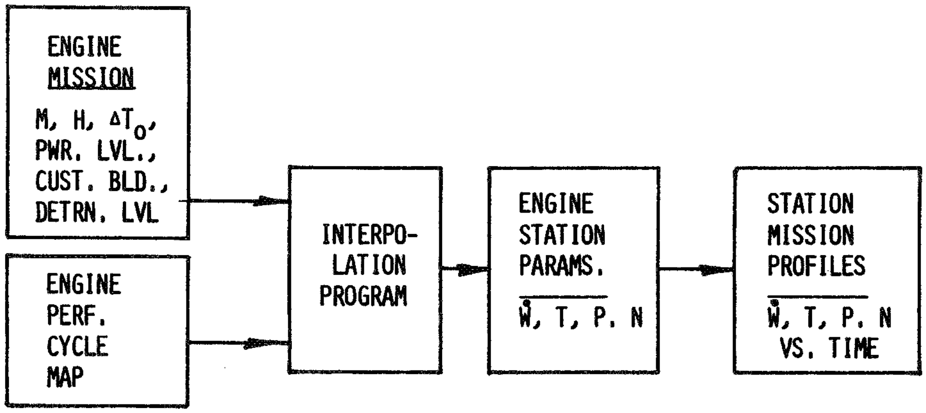

FIGURE 7. THERMODYNAMIC ENGINE MODEL

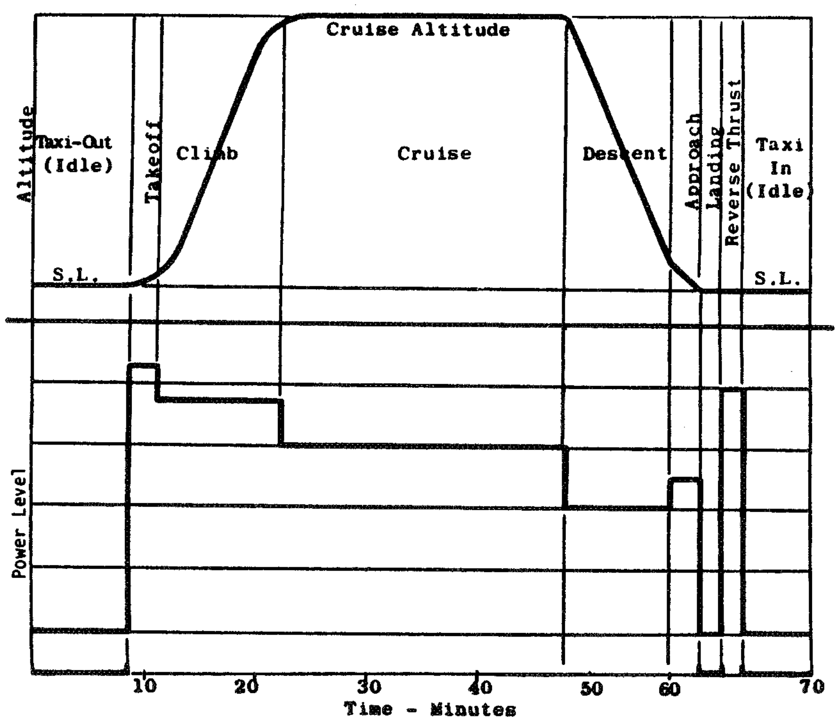

FIGURE 8. TYPICAL FLIGHT CYCLE

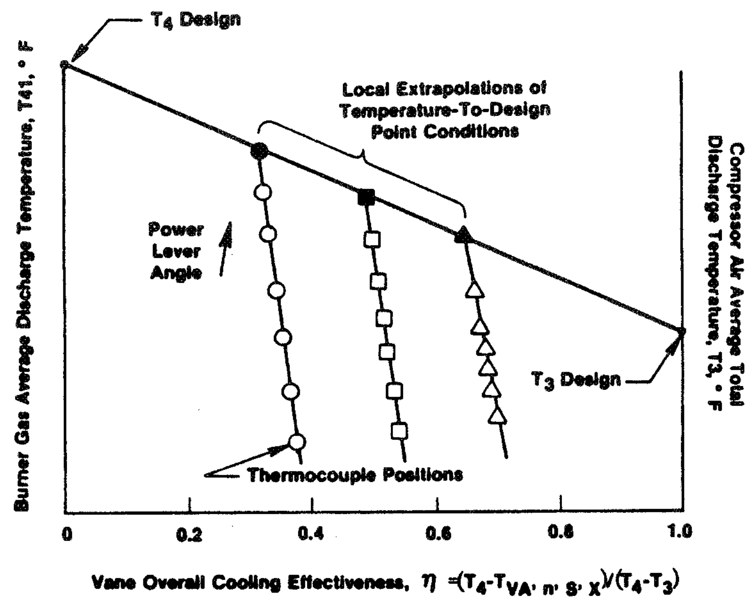

FIGURE 9. TURBINE VANE COOLING EFFECTIVENESS