N93-31570

[redacted]

EXPERT SYSTEM DEVELOPMENT FOR PROBABILISTIC LOAD SIMULATION

H. Ho and J.F. Newell
Rockwell International Corp.
Rocketdyne Division
Canoga Park, California 91303

The Composite Load Spectra Load Expert System LDEXPT

A knowledge-based system LDEXPT using the intelligent database paradigm has been developed for the Composite Load Spectra (CLS) project to simulate the probabilistic loads of a space propulsion system. The knowledge-base approach provides a systematic framework of organizing the load information and facilitate the coupling of the numerical processing and symbolic (information) processing. It provides an incremental development environment for building generic probabilistic load models and book-keeping the associated load information.

Large volume of load data is stored in the database and can be retrieved and updated by a built-in database management system. The database system standardizes the data storage and retrieval procedures. It helps maintain data integrity and avoid data redundancy. The intelligent database paradigm provides ways to build expert system rules for shallow and deep reasoning and thus provides expert knowledge to help users to obtain the required probabilistic load spectra.

Expert System Development

Considerable investigation has been given to the load simulation and expert system implementation issues during the development of the expert system. The first important issue even before the construction of the program was the load simulation using a probabilistic method versus a deterministic method. In a deterministic analysis, several worst-case variable limits are often used together in a calculation to produce a worse-case load. The result is maybe too conservative and is typically inconsistent with the real situation. On the other hand, the load generated from a probabilistic method will not be an unrealistic maximum value. If the correlation between loads is accounted for there will be no inconsistency in the simulated loads.

A system model was required to simulate the operational condition of the system so correlated component loads could be synthesized for a space propulsion system. The issue was that of building a detail physical model versus a heuristic system model. Detail physical models are developed for steady state performance calculations and for transient solutions as system operation tools. These models require significant computer resources and solution time and are inappropriate for probabilistic solution schemes requiring hundreds or thousands of solutions to develop distributional responses of component loads. Whereas a heuristic model was doable, has sufficient accuracy and requires minimal computing time. The CLS system model of the expert system is such a heuristic model : a multi-level engine model that employs the influence model technique, scaling and perturbation method that are anchored with results from available deterministic models and test data.

A crucial implementation issue for CLS was the choice of a knowledge-base approach over that of a pure procedural approach. A pure procedural approach for a load simulation program was not impossible. However, a modular structural approach would be much more difficult to implement. There would be problems in data maintenance and data redundancy. It would be more difficult to automate the complete load simulation process in a consistent way and could end up with codes that require considerable manual work in between different tasks.

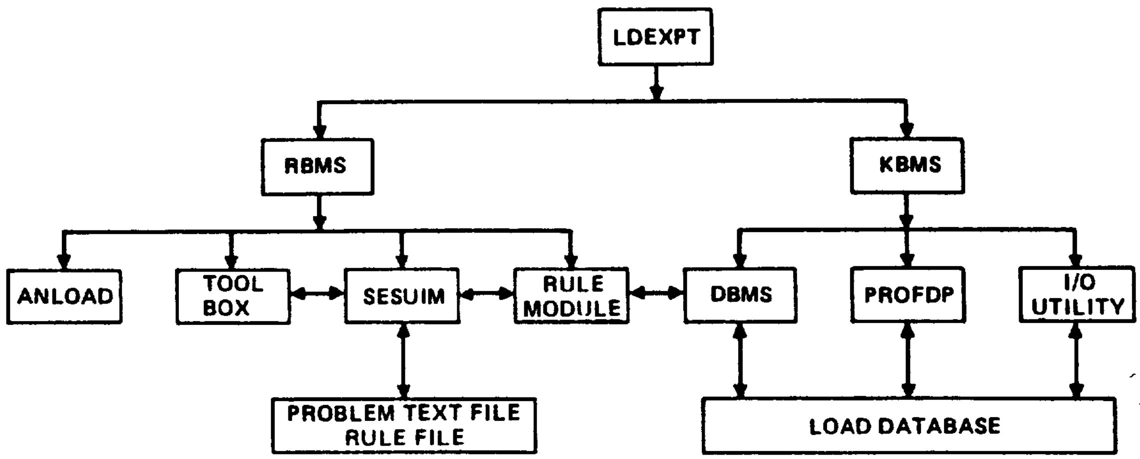
A knowledge-base approach with the intelligent database paradigm provided a natural knowledge representation to load simulation. The knowledge representation is object-oriented. The object can be a real object such as a component -- the LOX (liquid-oxygen) post or a conceptual object such as a dependent load -- the HPFTP (high pressure fuel turbopump) turbine inlet pressure. With this representation, modular incremental development was facilitated as new components and their associated loads were added to the program. If a generic load model already exists for the new component, then only the new load information and associated data are required to be added to the knowledge base and no new model is required.

The knowledge base approach employed in CLS does not dwell on a pure rule-based system. In this implementation, the symbolic processing is coupled with the numeric processing to achieve the objective of synthesizing the probabilistic loads. Intelligence is achieved by coupled rules with clever algorithms (for deep reasoning). Tremendous knowledge and expertise have been incorporated in the knowledge base of the composite load spectra program. Further development on the expert system is being pursued in the option phase of the contract to exploit the knowledge base to provide tutorial on rocket engine loads.

Future Development

A development task that can be benefitted from the existing vast amount of knowledge on the rocket engine loads is to develop a simple hypertext tool to provide tutorials on rocket engine loads. It is perceived that the expert system will be able to answer simple questions such as what are the important component local variables required to simulate the thermal load of the LOX post.

LDEXPT: LOAD EXPERT SYSTEM



Composite Load Spectra

CLS Load Expert System: LDEXPT v3.0

Features:

Knowledge-Based System

with intelligent database

Multi-Level Engine Model

Influence Model: 64 Independent Loads
99 Dependent Loads

Component Load Models: 4 components

Probabilistic Methods

Gaussian
RASCAL
Monte Carlo

Full Mission History Duty-Cycle Capability

Steady-State & Quasi-Steady-State
Transient Spike & Rare Event Models

Composite Load Spectra

Load Expert System Version 3.0
Load Model Knowledge Base

Independent Loads	System Level Dependent Loads	Component Level Composite Loads
• Commanded power level • Engine operating parameters Mixture ratio Fuel inlet pressure & temperature Oxidizer inlet pressure & temperature • Engine hardware parameters Pump efficiency Turbine efficiency Main oxidizer valve resistance Turbine flow coefficient • total of 64 independent loads	• Engine performance parameters Engine fuel flowrate Engine oxidizer flowrate Engine thrust • Engine operating parameters Pump speed Turbine inlet & discharge pressures Turbine torque HGM fuel inlet pressure • Total of 99 dependent loads	• Component loads HPFTP turbine blade pressure & temperature Transfer duct static pressure Transfer duct dynamic pressure LOX post temperature • Local independent loads Coolant seal leakage Hot gas seal leakage • Composite loads for Turbine blades Transfer ducts LOX posts HPOTP discharge duct

89c-4-339-30

Composite Load Spectra

Load Expert System Version 3.0
Load Model Knowledge Base

Engine System Model	Component Load Models
• Load distributions Means Coefficients of variation Distribution types Nominal value coefficients • Probabilistic influence model Influence coefficients 1 σ gain values	• Generic static pressure scaling model • Generic probabilistic thermal load model • Generic turbine blade pressure load model Tip, mean & hub cross section pressures Turbine blade pressure interpolation scheme • HPFTP 2nd stage turbine blade pressure & temperature loads 2519 nodes geometry model Reference nodal pressures & temperatures • Turbine blade dynamic pressure load model • Duct dynamic pressure load model Transfer ducts, LOX posts, HPOTP discharge duct • Transient LOX post thermal load model • Vibration model

89c-4-339-31

Composite Load Spectra

Load Expert System Version 3.0

Expert System Characteristics

- Intensive numerical computation
- Large volume of data
- Coupled symbolic & numeric computation
- Deep reasoning
- Modular

What Has CLS Done Right

- Stay with FORTRAN
- Have a data base system
- Decision tree inference
- Couple rules with computational routines
- Rules modules
- Working memory for communication btn rules

89c-4-339-32

Composite Load Spectra

Important Issues

Probabilistic Load Simulation Issues

- Probabilistic Method vs Deterministic Method
- Heuristic Engine Model vs Physical Engine Model
- Correlation Field vs Random Variation Loads

Expert System Implementation Issues

- Knowledge-Based System vs Procedure Approach
- Symbolic Processing vs Numeric Processing
- Intelligent Database System vs Pure Ruled-based System