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PROBABILISTIC LOAD SIMULATION - CODE DEVELOPMENT STATUS

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Objective and Approach

The objective of the Composite Load Spectra (CLS) project is to develop generic load models to simulate the composite load spectra that are induced in space propulsion system components. The probabilistic loads thus generated are part of the probabilistic design analysis (PDA) of a space propulsion system that also includes probabilistic structural analyses, reliability and risk evaluations (Figure 1). The development and applications of the project to selected space propulsion system structural components have been carried out under the sponsorship of NASA Lewis Research Center.

Probabilistic load simulation for space propulsion systems demands sophisticated probabilistic methodology and requires large amount of load information and engineering data. The CLS approach is to implement a knowledge-based system coupled with a probabilistic load simulation module. The knowledge-base manages and furnishes load information and expertise and sets up the simulation runs. The load simulation module performs the numerical computation to generate the probabilistic loads with load information supplied from the CLS knowledge base.

CLS Engine Model and Component Load Models Development

A multi-level engine model (Figure 2) was developed for the probabilistic load simulation. It consists of the engine system model at the base of the model, the subsystem (load environment) models and the component load models at higher levels (Figure 3). The engine system model can evaluate 99 system dependent loads, which consist of system performance variables and subsystem interface operating loads, based on a certain engine configuration defined by 64 engine hardware and operational parameters (or primitive variables). The subsystem load environment models generate the boundary information that is used by the local component model. It uses a set of correlated system dependent loads to define the boundary information. The complexity of these subsystem models vary depending on the complexity of the physical model used to define the boundary conditions. The component load models, one for each component load, then use the boundary loads to generate the probabilistic component loads for the corresponding engine operating condition (Figure 4).

The load simulation module provides three probabilistic methods for generating probabilistic loads. They are the Gaussian moment method, the RASCAL (Random Sampling Condensation Algorithm) method and the Monte Carlo method. During the last two years, a correlation field formalism was developed to systematically simulate the correlated component loads. This formalism provides a robust proce-

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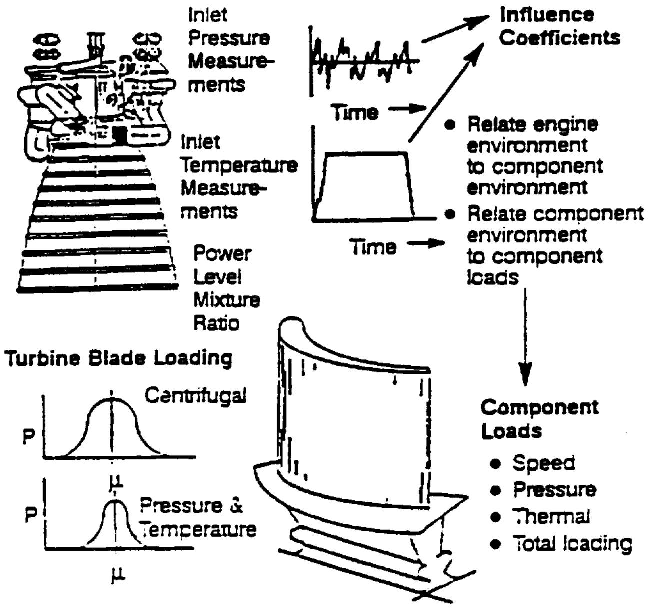
dure to supply simulated probabilistic loads as input to a structural analysis. With the correlated input loads, a probabilistic structural analysis code such as the Probabilistic Structural Analysis Method (PSAM) project's NESSUS can calculate sensitivity information and response distributions of stresses, strains, etc. as functions of engine hardware and operating parameters. Knowledge of this information is better help the design of rocket engine and guide test data requirements and analysis.

Component load models such as static pressure loads and temperature loads were developed as part of the basic CLS contract work. Recent work on the CLS project has emphasized development of generic physical models for loads where no physical models were available, such as acoustic (perturbated flow) related loads. The reason for this emphasis is that during the development phase of the SSME engine the lack of models for the high-energy flow conditions in both propellant and hot-gas systems allowed designs that caused significant problems. An acoustic flow system model (Figure 5) is under development to better define the engine dynamic fluid loads. It has an overall framework for a full system model, but is currently limited to the components applicable to the CLS project. The model is divided into elements; the acoustic waves undergo continuous reflections and transmissions at the element boundaries. The system can have noise sources from elbows (Figure 6), pumps, combustors, valves, etc. The individual sources propagate through system elements acoustically. By superimposing the contributions from all waves passing through a given point in the system, the pressure and velocity at that point can be obtained as a function of time. The pipe bend elbow or flow turning noise model is a good example of a generic flow load model. Acoustic loads are key loads on all four components evaluated by CLS - turbine blade, LOX post, transfer duct and engine system duct.

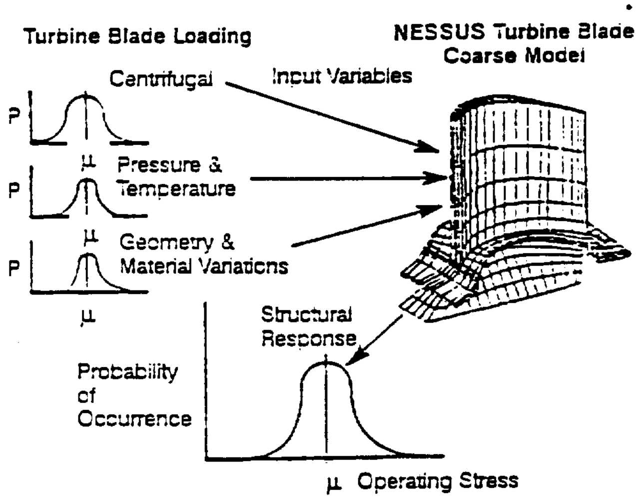
Another significant effort is the development of a fluid-structural based scaling model to address mechanical vibration as a forced response to fluid loading (Figure 7) rather than a simplistic scaling from overall engine power - the Barrett's approach. This new approach is much more generic and shows real promise in allowing significant better definition of the mechanical vibration environments (Figure 8). When validated, it should be a major improvement to either deterministic or probabilistic load definition. Application of the pressure fluctuation model and the vibration model to rocket engine components is currently underway under production contract work and is being reported in another presentation in this conference.

CLS Applications

Applications of the CLS load simulation to component probabilistic structural analysis have been carried out over the years in conjunction with the PSAM project. The most recent ones are the LOX post full cycle thermal strain analysis and the Advanced Launch System (ALS) main combustion chamber (MCC) liner analysis. Details of these efforts are discussed in other talks in this session.



Component Loads Analysis



Component Response Analysis 5818-1

Figure 1. Integrated Loads and Response Analysis.

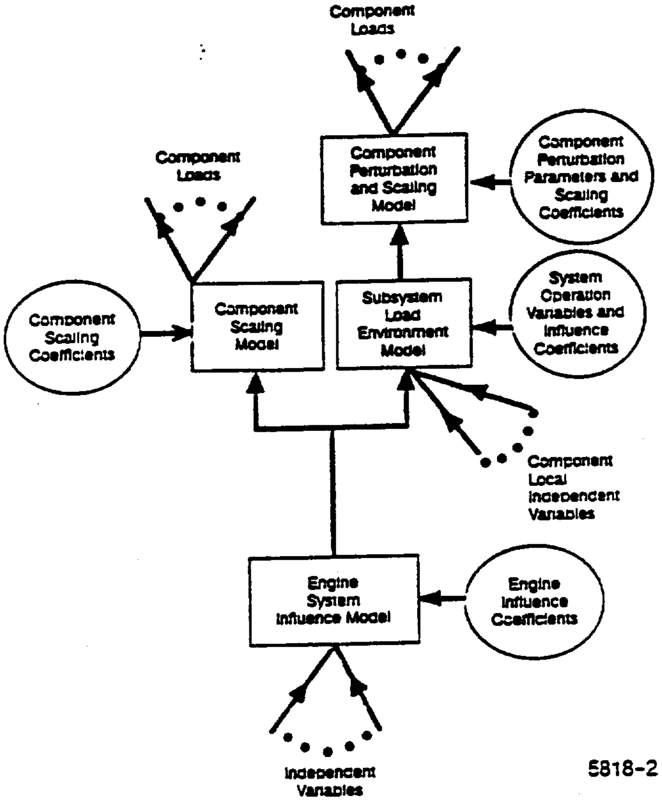


Figure 2. Multi-level Engine Model.

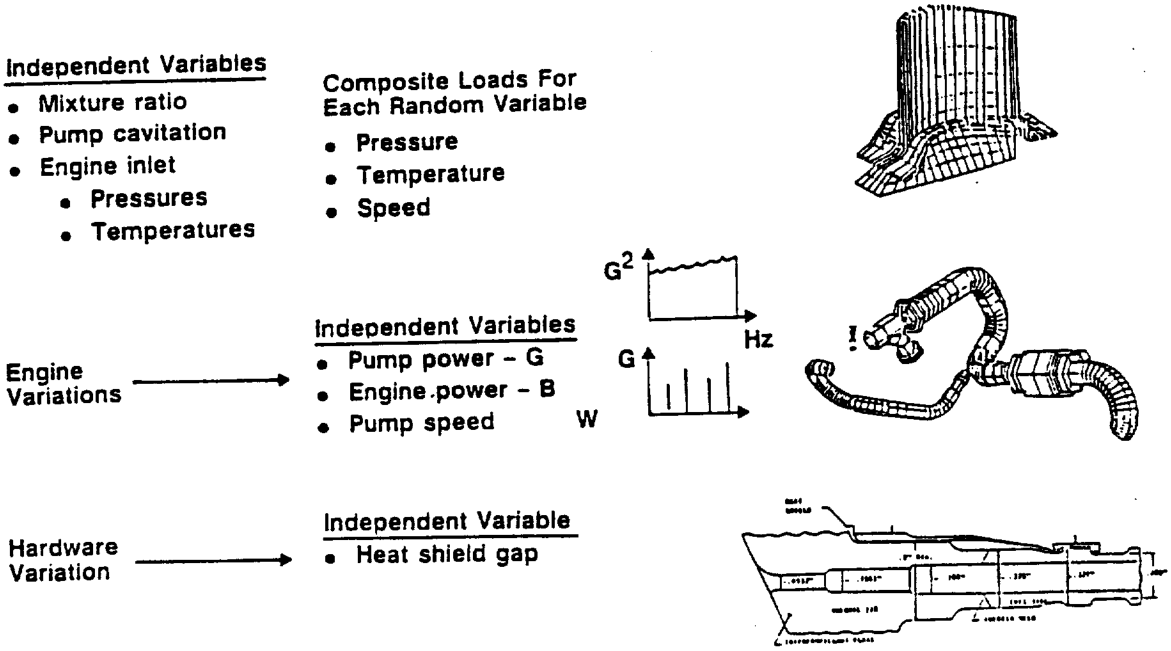


Figure 3. Examples of System, Subsystem and Component Loads.

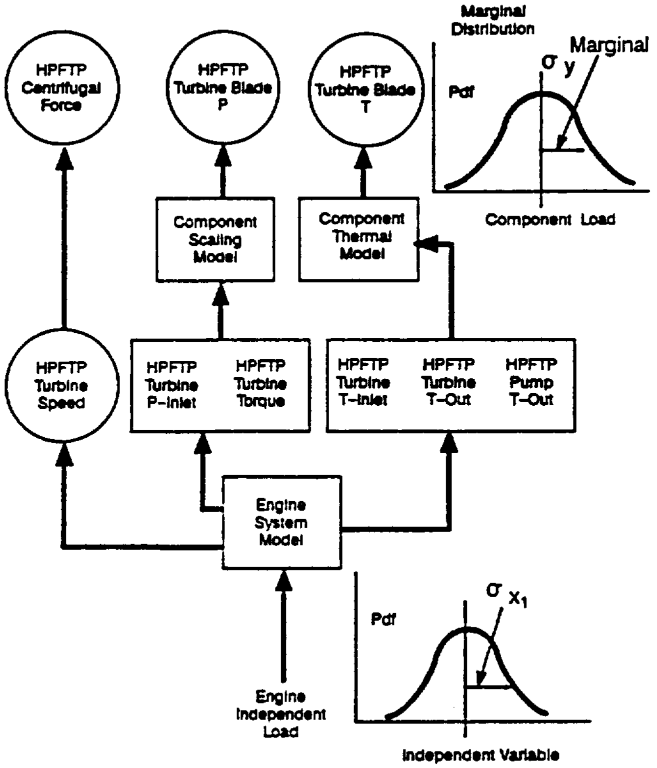


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Figure 4. Turbine-Blade Load Component Diagram, showing how a system load spreads theoughout all component loads.

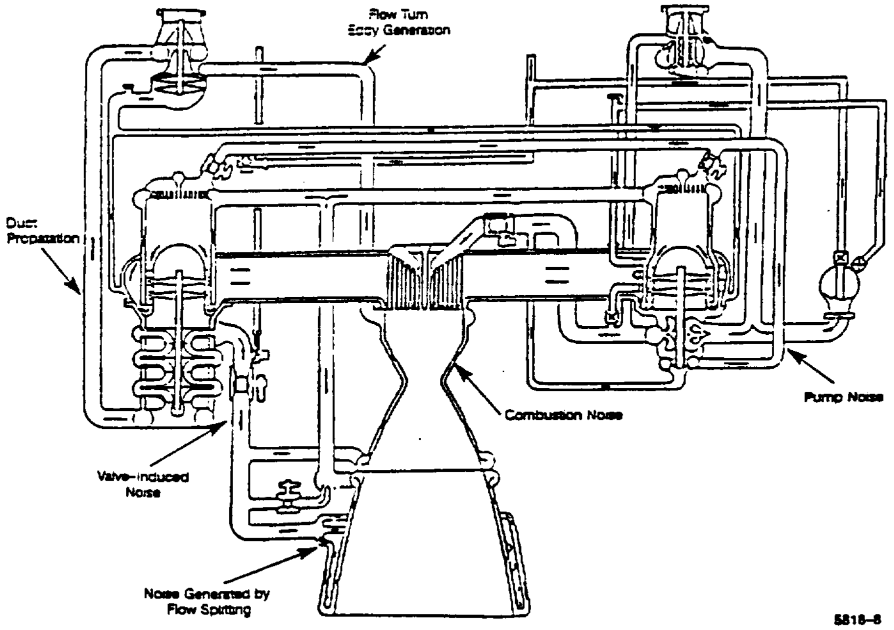


Figure 5. Flow System Model.

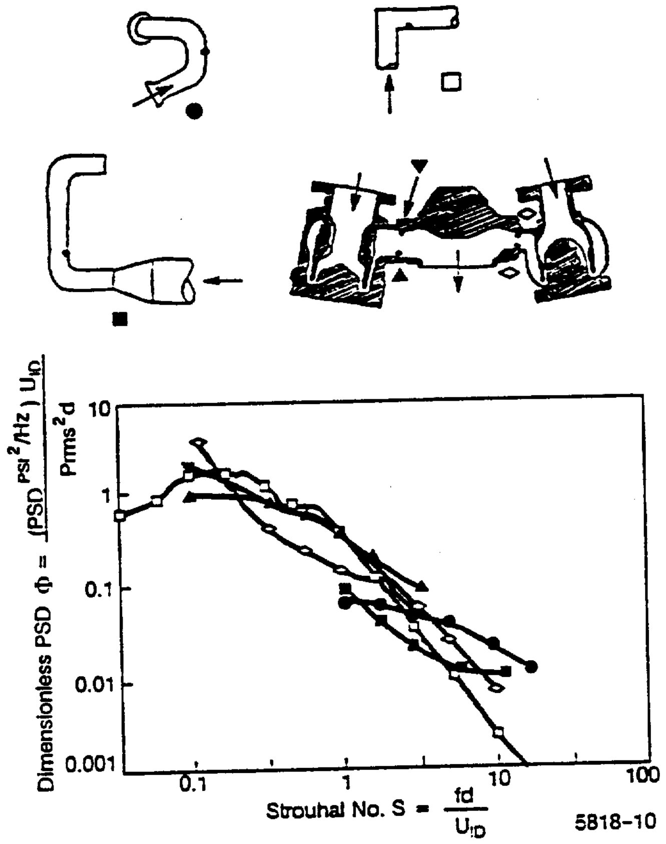


Figure 6. Dimensionless Power Spectral Density for Different Turned Flows.

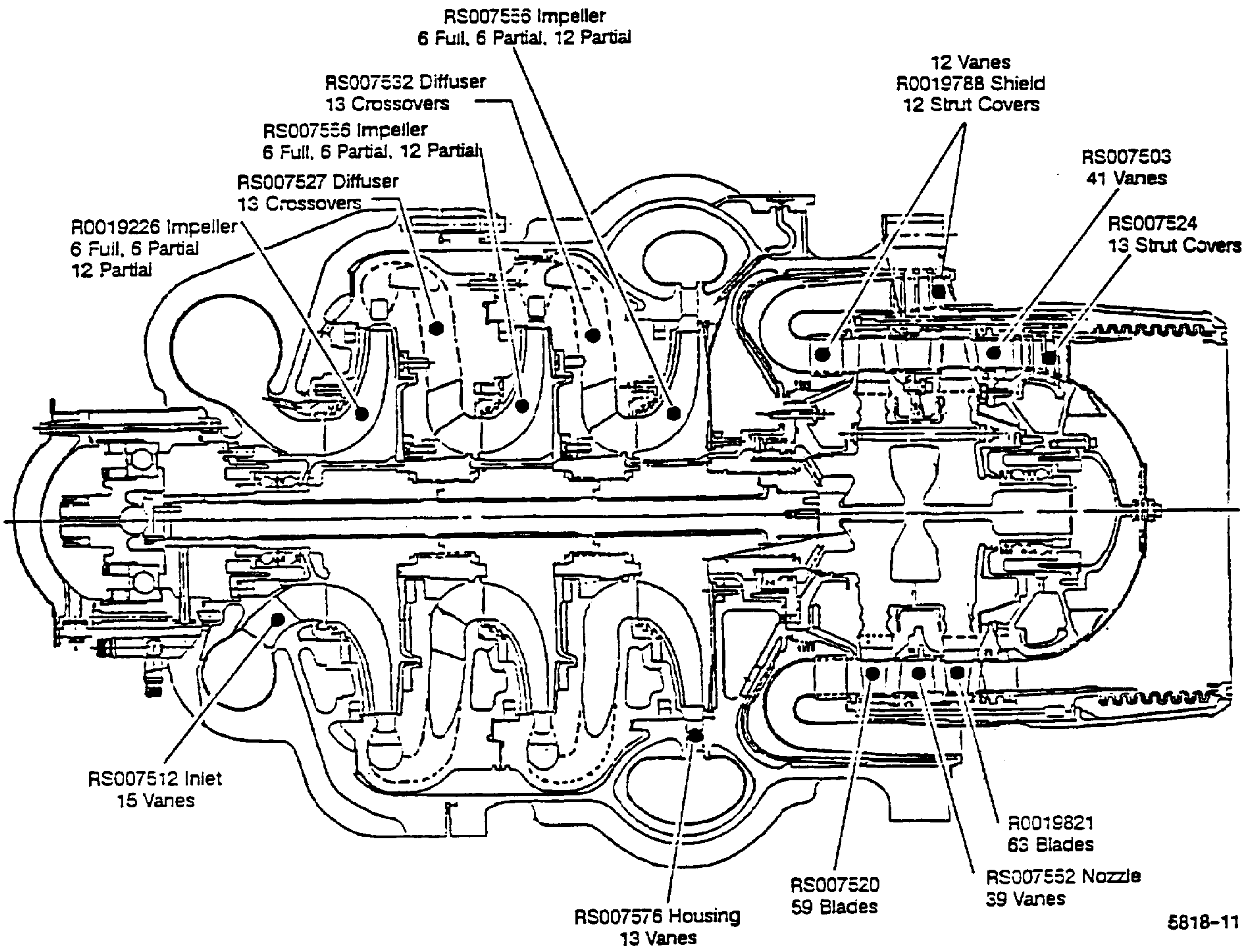
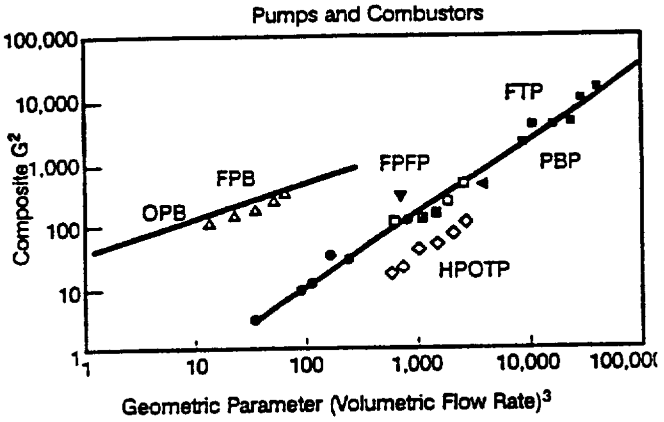
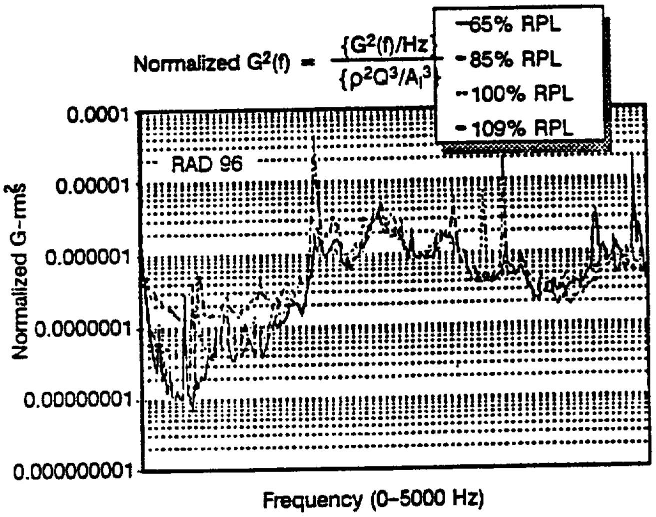


Figure 7. Example Turbopump, showing flow Interruption Drivers and Flow Paths used to calculate fluid power parameters.



a. Fluid Mechanisms Scaling Composite Levels



b. Fluid Mechanisms Scaling Pump Spectra

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Figure 8. Engine Vibration Scaling Based on Fluid Power Variables.