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ROCKETDYNE PSAM - IN HOUSE ENHANCEMENT/APPLICATION

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Rocketdyne has embarked on the development of the Probabilistic Design Analysis (PDA) Process for Rocket engines. This will enable engineers a quantitive assessment of calculated reliability during the design process. The PDA will help choose better designs, make them more robust and help decide on critical tests to help demonstrate key reliability issues to aid in improving the confidence of the engine capabilities. Rocketdyne's involvement with the Composite Loads Spectra (CLS) and Probabilistic Structural Analysis Methodology (PSAM) contracts started this effort and are key elements in our on-going developments. Internal development efforts and hardware applications complement and extend the CLS and PSAM efforts. The completion of the CLS option work and the follow-on PSAM developments will also be integral parts of this methodology. A brief summary of these internal efforts to date follows.

METHODS/CODE DEVELOPMENTS

The CLS loads work has spawned method developments or extensions in thermal analysis and fluid dynamics. The CLS thermal loads approach addresses loading from a scaling of deterministic responses based on specific temperature variations of critical points or temperature profiles in the hardware for the key independent load variables. A more general methodology has been developed at Rocketdyne to allow a full scale probabilistic thermal analysis by essentially substituting the SINDA thermal code for the NESSUS FEM module along with its own modeling input techniques. This adds a general solution to the thermal problem for separate thermal assessments or as another tool for developing thermal models for CLS and NESSUS. (Figure 1).

The CLS acoustics loads work is limited to defining a generic systems modeling approach and developing specific modes for the components in the CLS study. The development of other source inputs and modeling elements like pumps, combustors and valves are needed to make such an overall systems model viable. In house work is addressing these needs as they arise for specific hardware problems as well as maturing the CLS developed acoustics source-propagations code.

Resistance models for Rocketdyne specific applications have been developed to allow reliability assessment for specific hardware and applications. These include models for strength, fatigue and fracture mechanics. Production oriented codes for preliminary design use have been developed to allow both sensitivity assessment and reliability calculations and also furnish a simple presentation of these results. (Figure 2)

PDA APPLICATIONS

The CLS, PSAM and in house developed methodologies are being used and tested against specific hardware and related tasks as they evolve. Examples of PDA applications include its use as: a evalution tool to develop a criteria for flaw acceptance by dye penertrant for specific hardware (Figure 3); analysis of the accumulated fatigue damage for a turbopump bearing carrier; a turbopump

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stator vane study to relate geometric tolerance variations to vane natural frequencies, engine duct analysis to determine acoustic transfer functions and fluctuation loads on elbows (Figure 4), and the development of a single flight reliability methodology basis using a reliability requirement.

Support to JPL's certification/reliability analysis of specific hardware components has also been accomplished on eight engine parts. This effort has also added to Rocketdyne's analysis capabilities for probabilistic damage assessment. A critical need to effectively use PDA is to calibrate this methodology against deterministic factor of safety approaches. Work in this area is an on-going effort at Rocketdyne (Figure 5).

RELIABILITY BASED DESIGN ANALYSIS

An overall approach on how to design for reliability is evolving at Rocketdyne. New engine programs such as ALS and NASP are planning on require quantitive reliability assessment of the engine during the design process. An initial design methodology has been developed and proposed for use on the ALS engine (Figure 6). An example of a combustion chamber liner was completed to demonstrate the use of this methodology. This effort included an FMEA, reliability allocation to specific hardware elements including the liner, the use of CLS to develop the loads and PSAM to evaluate the structural response and an in-house damage assessment code (Figure 7, 8, 9). The effort used the approximate modeling approach rather than a detail finite element assessment so that the work could focus on the overall methodology aspects.

CHALLENGES

The main challenges are to move this technology from a research tool to a production tool and to further developments in the overall methodology. Calibration of PDA against deterministic methodologies is required to gain confidence in how to properly use and understand its application to hardware. Training analysts in its use and getting acceptance of PDA from program management and customers are further key efforts in integrating the technology to production hardware. Joint efforts between engineering, reliability, quality and manufacturing organizations are required to implement these techniques in new or on-going programs.

REFERENCES

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2. Newell, J.F., Ho, H.O., Rocketdyne Division, Rockwell International Corporation, Canoga Park, California, "Probabilistic Load Modeling for Rocket Turbomachinery Components", 3rd ASME-JSME Thermal Engineering Joint Conference and ASME-JSME JSES Solar Energy Conference, Reno, California.

3. O'Hara, K.J., Rockwell International Corporation, Canoga Park, California, "Liquid Propulsion System Reliability 'Design for Reliability'", AIAA/ASME/SAE/ASEE 25th Joint Propulsion Conference, Monterey, Californai.

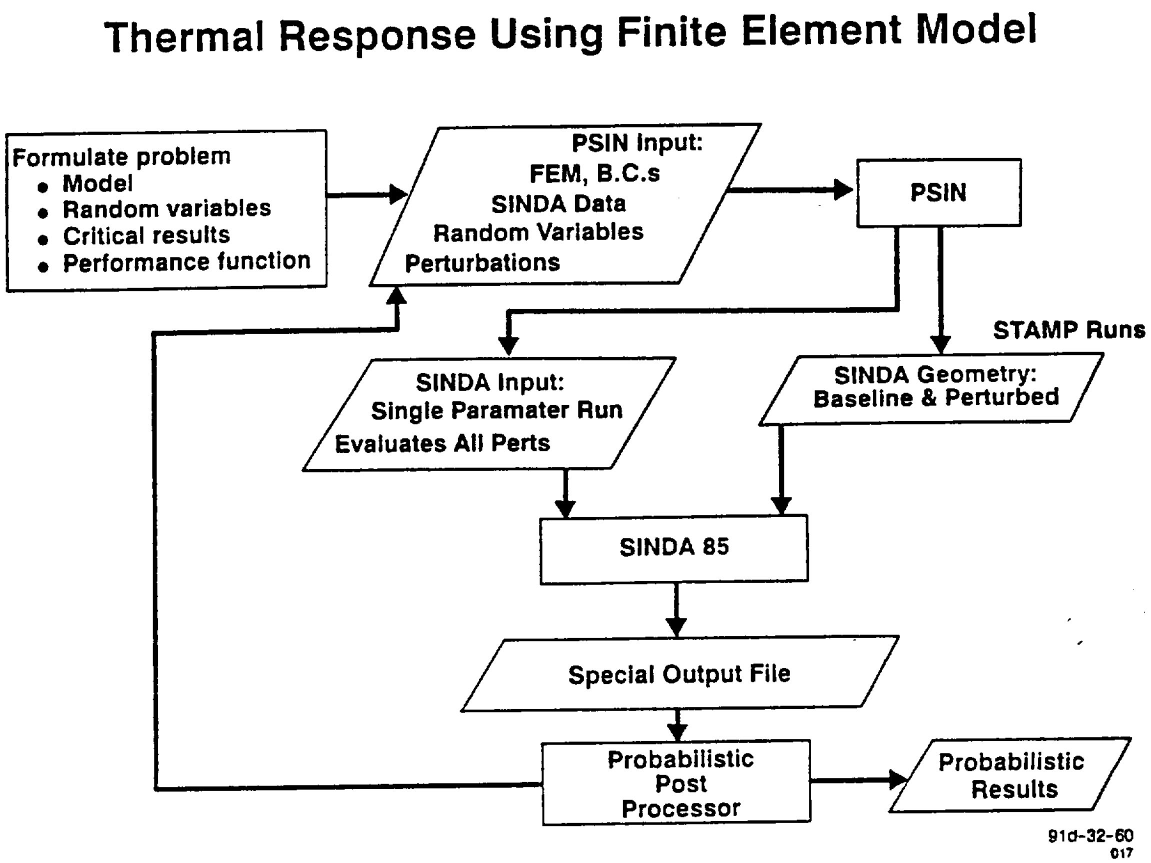
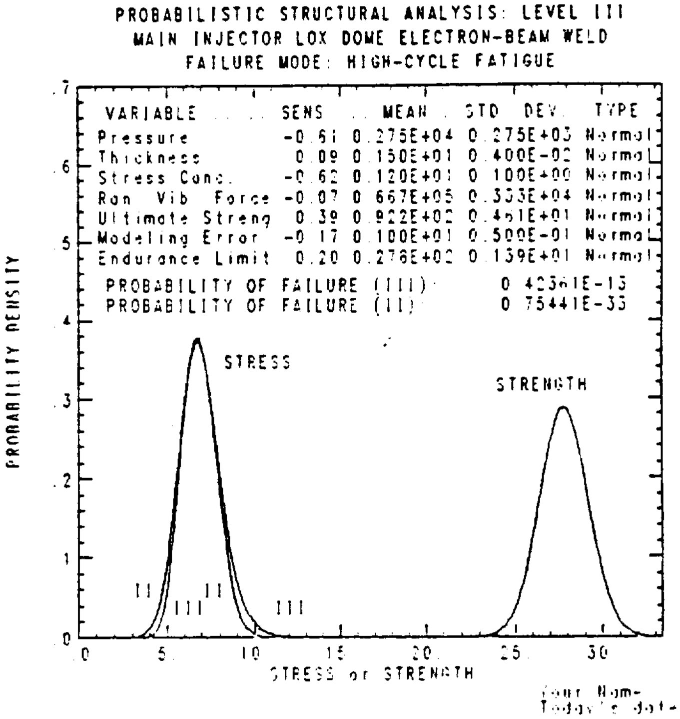


Figure 1. Sinda/Probabilistic Assessment Implementation.



VARIABLE	SENS	MEAN	STD DEV	TYPE
Pressure	-0.61	0.275E+04	0.275E+03	Normal
Thickness	0.09	0.150E+01	0.400E-02	Normal
Stress Conc.	-0.62	0.120E+01	0.100E+00	Normal
Ran Vib Force	-0.07	0.667E+05	0.333E+04	Normal
Ultimate Streng	0.39	0.922E+02	0.461E+01	Normal
Modeling Error	-0.17	0.100E+01	0.500E-01	Normal
Endurance Limit	0.20	0.276E+02	0.139E+01	Normal

PROBABILITY OF FAILURE (III) 0.42361E-13
PROBABILITY OF FAILURE (II) 0.75441E-33

Figure 2. Example Levels-II and -III Results for PROBABILISTIC.

SIMULATION DESIGN

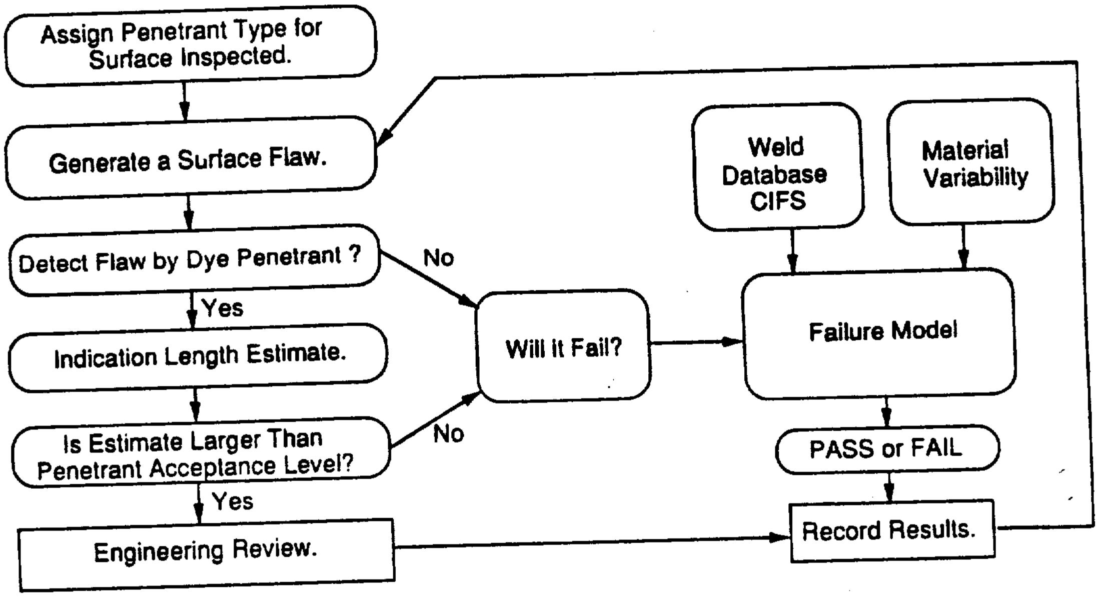
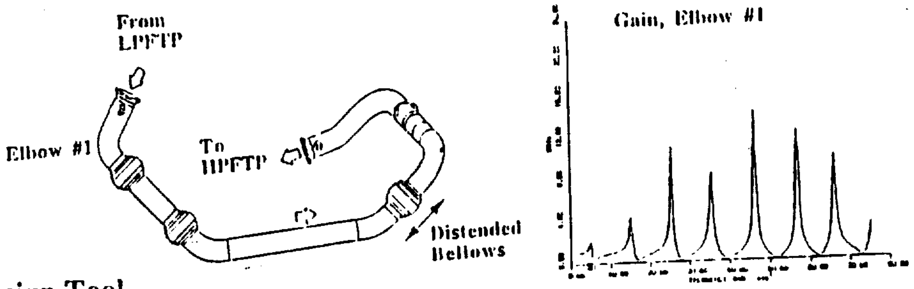


Figure 3. Flaw Acceptance by Dye - Penetrant Inspection.

NOISE PROPAGATION & ACOUSTIC MODES ANALYSIS

(C) Transfer Function Analysis: Gain & Phase

(i) Problem Diagnosis



(ii) Design Tool

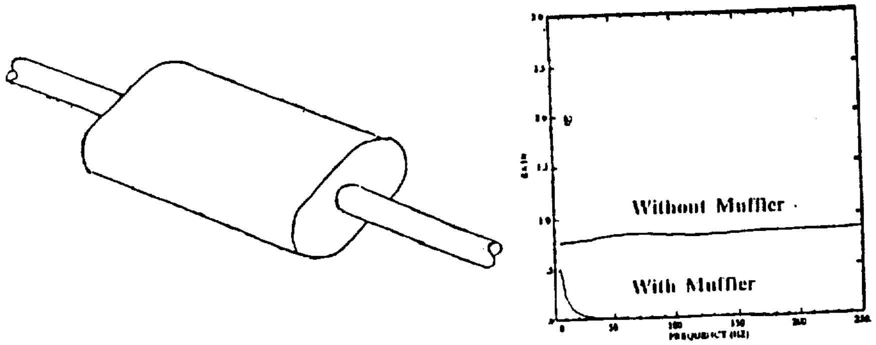


Figure 4. Duct Analysis Acoustic Transfer Function Analysis.

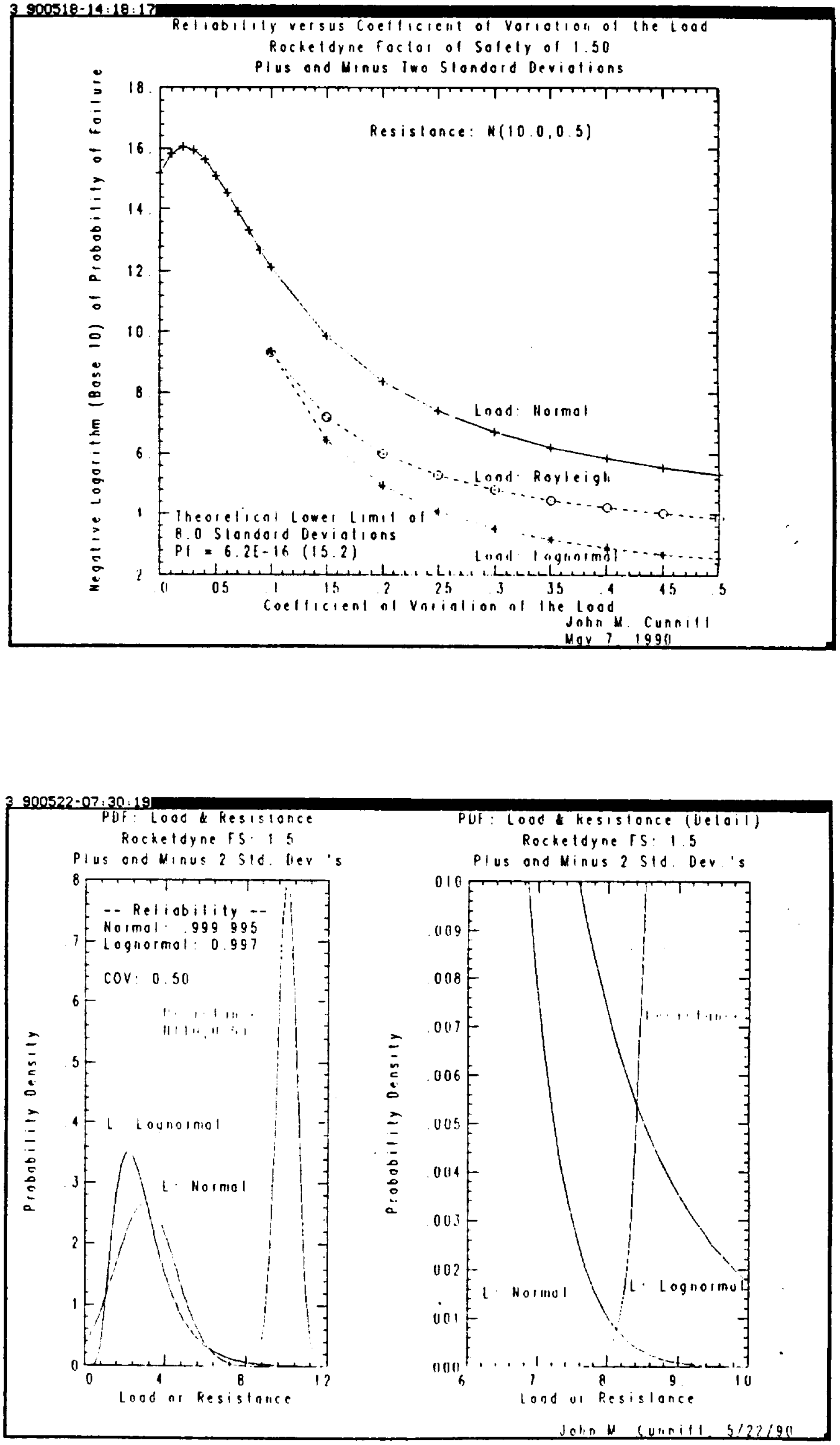


Figure 5. Reliability vs. Factor of Safety of 1.5.

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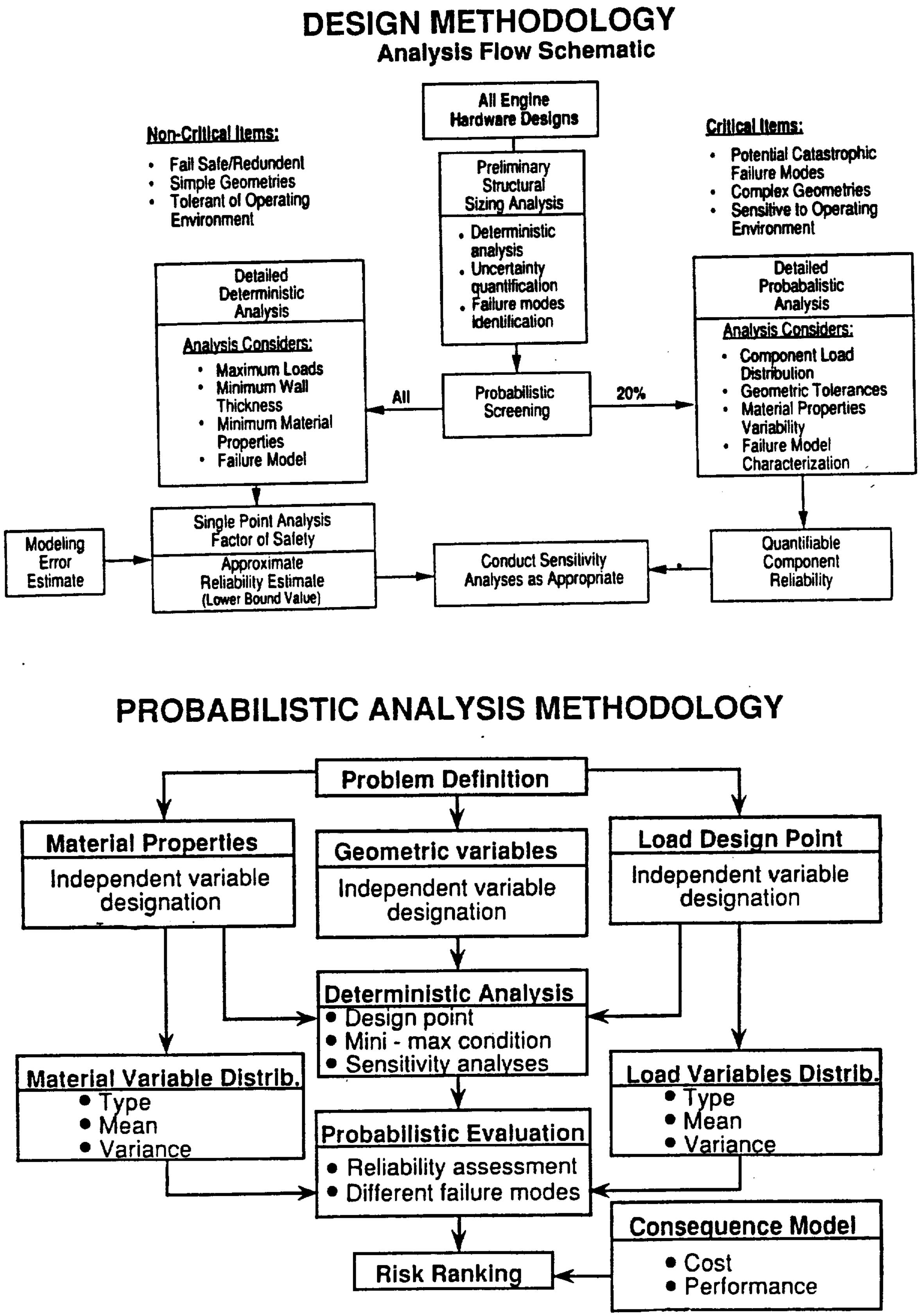

Figure 6. Probabilistic Design & Analysis Methodology Outline.

Application to Main Combustion Chamber Liner

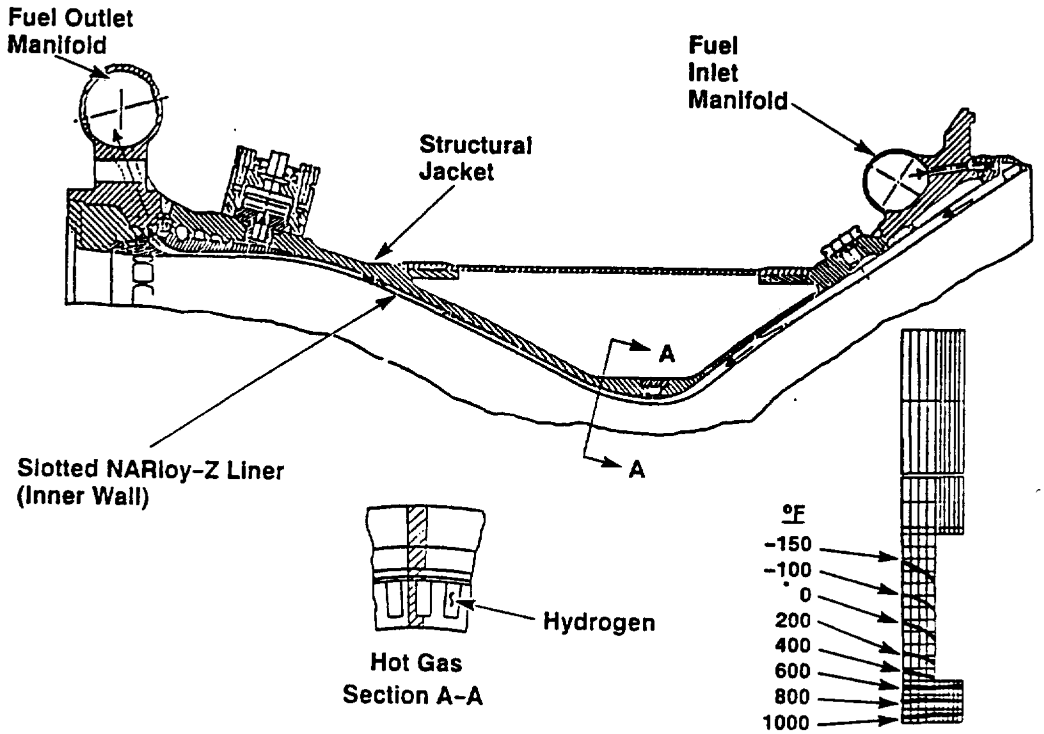

Figure 7. Typical Main Combustion Chamber Geometry.

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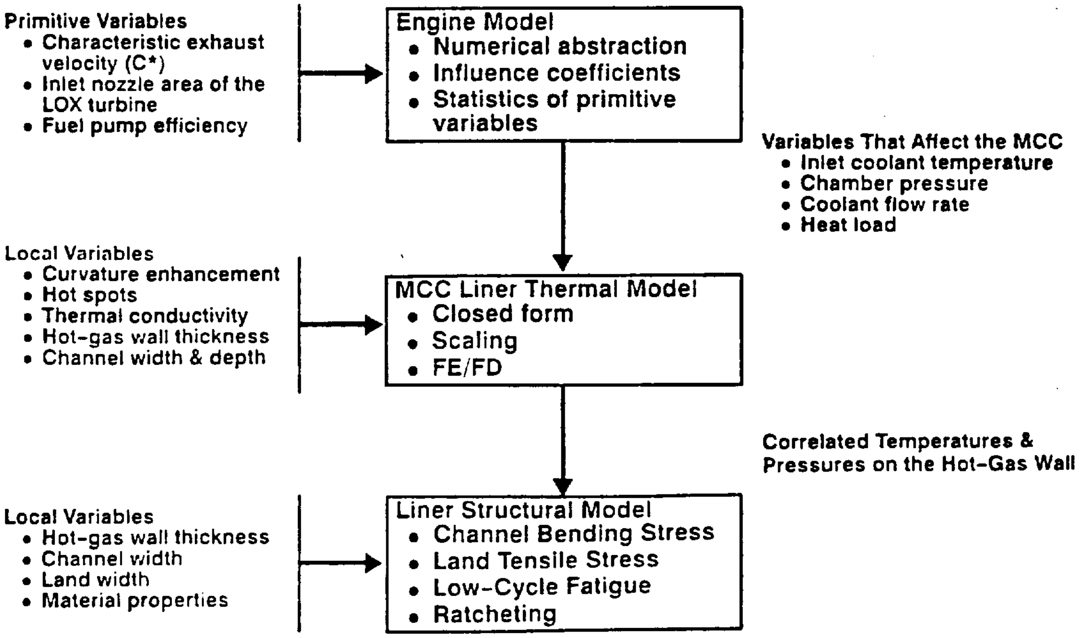
Probabilistic Analysis of the MCC Liner



Primitive Variables
- Characteristic exhaust velocity (C*)
- Inlet nozzle area of the LOX turbine
- Fuel pump efficiency

Engine Model
- Numerical abstraction
- Influence coefficients
- Statistics of primitive variables

Variables That Affect the MCC
- Inlet coolant temperature
- Chamber pressure
- Coolant flow rate
- Heat load

Local Variables
- Curvature enhancement
- Hot spots
- Thermal conductivity
- Hot-gas wall thickness
- Channel width & depth

MCC Liner Thermal Model
- Closed form
- Scaling
- FE/FD

Correlated Temperatures & Pressures on the Hot-Gas Wall

Local Variables
- Hot-gas wall thickness
- Channel width
- Land width
- Material properties

Liner Structural Model
- Channel Bending Stress
- Land Tensile Stress
- Low-Cycle Fatigue
- Ratcheting

Figure 8. Probabilistic Analysis of the MCC Liner.

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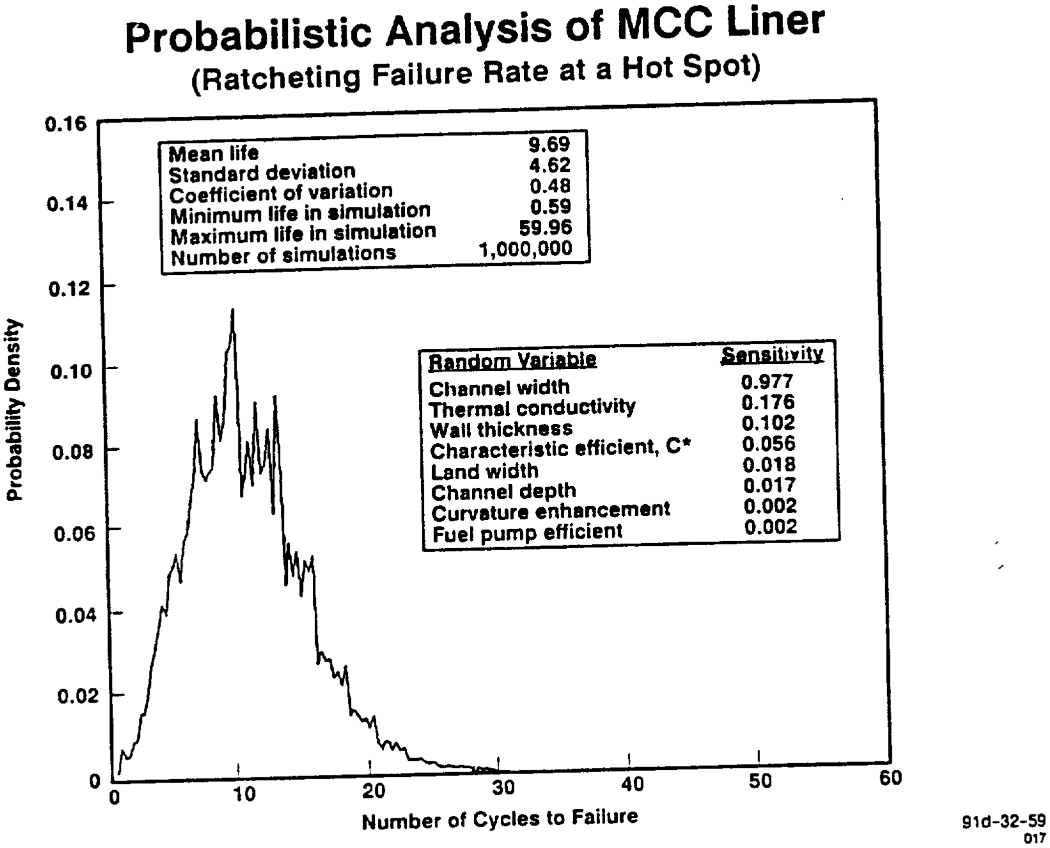

Figure 9. Ratcheting Failure Mode Response.