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Reliability Analysis of Rocket Motor Case based on Response Surface Method and Importance Sampling

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In the aerospace and defence industry, solid rocket motors (SRM) are widely used for launch vehicles for satellite deployment and missiles due to several attractions such as simple structure, high thrust, and low development cost. In the design of SRM, assessing the reliability is important in order to ensure successful mission completion without failure. Although a simple practice is to carry out factor-of-safety design, and verify the reliability through a series of real testing, it is virtually impossible in the case of SRM due to the high cost and technical difficulties. In order to overcome this, reliability analysis techniques have been developed for the last decades, which is to model various uncertainties such as dimensional variance and material imperfection in terms of probability distributions, evaluate the distribution of the response variables by solving the relevant physical problems, and a failure probability (or reliability) is calculated from the resulting distributions.

In this study, reliability analysis is carried out for a rocket motor case, being one of the most important parts, that undergoes high pressure loading caused by the combustion of propellant during the operation. Potential failure modes are case rupture and fracture due to the excessive internal pressure and leakage and breakage of bolted joints at the forward and aft skirt extensions (see Figure 1). The procedure consists of the following steps: 1. design parameters affecting the failure of case are identified and their uncertainties are modelled by probability distribution, 2. combustion analysis in the interior of the case is carried out to obtain maximum pressure within the chamber as illustrated in figure 3, 3. stress and other structural performances are evaluated, and 4. failure probabilities are calculated for the above mentioned failure modes.

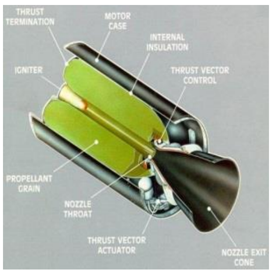

Figure 1 Solid rocket motor[1]

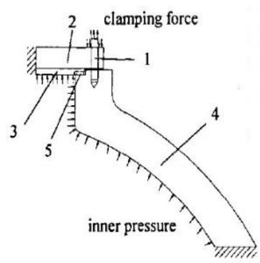

Figure 2 Bolted joint of rocket[2]

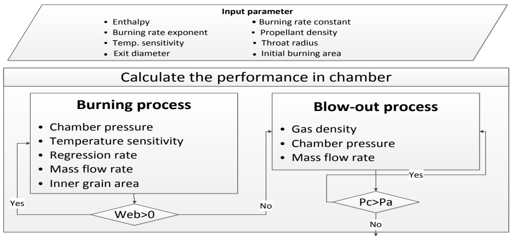

Figure 3 Combustion analysis(3)

During the procedure, large number of costly computations for combustion and structural analyses are required to incorporate the probability distribution into the variables. To remedy this while maintaining its accuracy, an efficient procedure is presented in this study as shown in Fig. 4,5,6: 1. find MPP (Most Probable Point) using FORM (First-Order Reliability Method) to locate failure region, 2. construct surrogate or response surface model around centered this to avoid costly computation, and 3. draw samples of response due to the distribution of input variables using importance sampling which is much more efficient than the crude Monte-Carlo simulation.

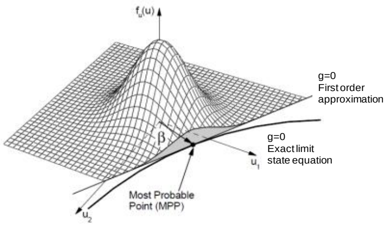

Figure 4 Finding most probable point

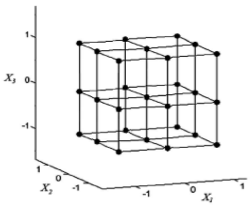

Figure 5 Constructing response surface

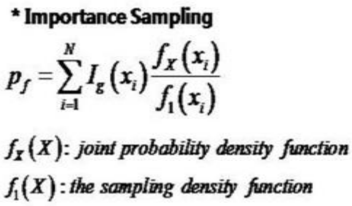

Figure 6 Importance sampling

The failure probabilities of each mode – hoop stress rupture, fracture due to crack, and leakage and breakage of bolted connection, are obtained by this method, and the results are validated by the Crude Monte-Carlo Simulation as well as the NESSUS which is the commercial reliability analysis software. As a part of the study, failure probability of the hoop stress rupture is obtained based on the procedure, and is listed in the table 1.

Table 1 Result of probability analysis

	Proposed Method	Crude Monte-Carlo	NESSUS
Probability	0.0558	0.057456	0.05474

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