Applying Bayesian calibration and validation for performance evaluation of pyrotechnically actuated device.

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A pyrotechnically actuated device (PAD) is a component that delivers high power in remote environments by combustion of a self-contained energy source. Examples are pin puller, pyro-valve and so on and they are usually used for aerospace industry. Historically, the design of PAD has been largely empirical, which has often resulted in loss of functions. Therefore the analytical evaluation of PAD performance has emerged as a necessary step in its design. As many iterative calculations are needed for this, it is not feasible to conduct direct 3-D analysis. So, recent efforts are directed to the development of simple analytical model, which can efficiently evaluate the performance. In the PAD analysis, the model is integrated by two disciplines that are coupled with each other. First is the analysis of explosive combustion within an actuator and resulting gas flow in an expansion chamber. Second is the elasto-plastic analysis that simulates insertion of tapered piston into a housing by the pressure generated in the chamber. While the former is relatively well established over the times, the latter is recently paid attention. So the main object of the current study is to develop a simple mathematical model that quickly evaluates the resistive force, instead of using complex nonlinear FEA. The main idea is that during the piston insertion, each cross sectional segment of the piston and outer housing is assumed as shrink fit of two cylindrical members with given interference. Depending on the degree of interference, the inner and outer part may undergo elastic, elasto-plastic or full plastic deformation. Tresca criterion is employed to identify plastic part, in which linear strain hardening rule is used for plasticity. The interface pressure is computed by closed form solution for each of these cases. The resistive force is obtained by applying friction coefficient to these and integrating the axial components over the whole interface. Finally the model is integrated into the simultaneous ODE's which describes mass and thermal energy evolution and piston motion.

In the procedure, it is apparent that the analysis model includes several uncertainties due to the simplification and some unknown parameters like friction and plastic coefficients. So it is important to validate the model and quantify the uncertainties based on the experimental data. In this study, Bayesian approach is employed to calibrate the unknown parameters and to validate the resulting model in a statistical manner. The method includes computer model with some unknown parameters and bias model that comes from the model deficiency due to the simplification of the problem. Usually the bias model is expressed by Gaussian stochastic process. Applying the Bayes' rule, the posterior distribution of all the unknown quantities is established conditional on the experimental data. Sampling algorithm such as Markov Chain Monte Carlo (MCMC) are used to determine the distribution of each parameters. Consequently, the unknown parameters are calibrated in the form of probability distribution, and the model output is given by the confidence bounds, which have adequately accounted for the uncertainties conditional on the given experimental data.