A Multi-Agent System Approach to Reliability Based Design Optimization Including a Future Test

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1 Introduction

When designing complex systems, such as airplanes, components are often subjected to various tests after the initial design stage. The purpose of the test is to catch dangerous designs, as well as check for any unexpected behaviors. Therefore, it is expected that a design will actually be safer after a test ; that is, by catching dangerous designs and unexpected behaviors there will be a reduction in the uncertainty of the reliability of the design. However, these tests are rarely, if ever, taken into account during the calculation of the reliability during this initial stage.

A methodology to include the effect of a future test and redesign in a reliability calculation of an integrated thermal protection system was developed by Villanueva et al. [1]. This work only considered the effect of a future test (and any subsequent redesign based on the test) on the probability of failure and the uncertainty of this probability of failure. The design was previously probabilistically optimized for minimum mass with constraints on the reliability without including the effect of a future test. In the proposed paper, we will optimize the design considering reliability constraints that consider a future test. In addition, we include constraints on the information gained from this optimized design when calibrating the computational model. This will be done by examining goodness-of-fit statistics, such as cross-validation error and prediction variance.

Due to the nature of the simulation of a future test, this optimization problem can become quite computationally complex. To address this problem, we seek to distribute this problem amongst many agents, which forms multi-agent systems (MAS). We will examine "formulation agents" where each agent is attached to solving a simplification of the above global reliability based design with future tests. These agents exchange design points and characteristics of the optimization criteria (e.g., safety factors) in an attempt to achieve both agent autonomy and collective increased efficiency.

An application to an integrated thermal protection system (ITPS) is provided. An ITPS is part of the structure of a space vehicle, which provides both thermal and structural load carrying capabilities. The conceptual design we consider, a corrugated core sandwich panel, has been the subject of many studies, such as that found in [2]. In this study, we will examine the temperature, T, of the bottom face sheet of the structure, which is important due to its proximity to the underlying vehicle structure.

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2 Methodology

2.1 Calculating Reliability with a Future Test

The details of the reliability calculation are outside of the scope of this abstract, and the reader is referred to [1] for a complete description of this methodology. In short, we have an existing computational model, from which the calculated temperature T_{calc} for a given design d is found. Due to computational error, there is uncertainty in this temperature, and we can form a probability distribution (pdf) of the calculated temperature. The probability of the failure, P_f, which is the probability of the bottom face sheet exceeding the allowable bottom face sheet temperature T_{allow}, can be calculated.

To simulate a future test, we sample a possible T_{meas}, and update the pdf of T_{calc} through Bayesian inference. This changes the probability of failure after the test. Since we simulate many possible T_{meas} values, we have a distribution of the probability of failure. If the test result is unacceptable, the design is re-designed, so that the mass is changed. Therefore, there is also a distribution of the mass.

2.2 Optimization Problem

In the proposed paper, we seek a design that meets reliability constraints that include a future test at a minimum mass. Since we consider multiple outcomes of a single future test, we must examine the expectation in the optimization criteria (e.g., the expectation on P_f rather than a single probability of failure). A constraint on the probability that the test results in redesign (with set redesign criteria) $P_{redesign}$ is included. The prediction variance s^2 and the prediction error sum of squares, $PRESS_{RMS}$, are also constrained :

$$\begin{array}{llcr} \underset{d}{\text{minimize}} & m(d) & & \\ \text{subject to} & E[P_f] & \leq & P_f^{allow} \\ & E[P_{redesign}] & \leq & P_{redesign}^{allow} \\ & E[s^2(d)] & \leq & s^{2allow} \\ & \underset{\text{with addt'l pt}}{E[PRESS_{RMS}]} & \leq & \underset{\text{orig DOE}}{PRESS_{RMS}} \end{array} \qquad (1)$$

2.3 Agent Formulation

The optimization problem described in Eq.(1), is the complete optimization problem. It is reformulated and distributed amongst several agents. Various agents autonomously solve subproblems that are spawned from the complete formulation and communicate with each other [3]. The agents vary in the number of degrees of uncertainties they consider. For example, a "deterministic" agent is a subproblem formed from the complete formulation where probabilities of failure and redesign are replaced by safety factors. Such a low-fidelity formulation is solved extremely quickly in comparison to the complete formulation but it requires optimal safety factors. It will provide to other higher fidelity agents possible solutions d and retrieve from them updated safety factors.

Références

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