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Towards an Algorithm for the Design of Robust Composite Structures

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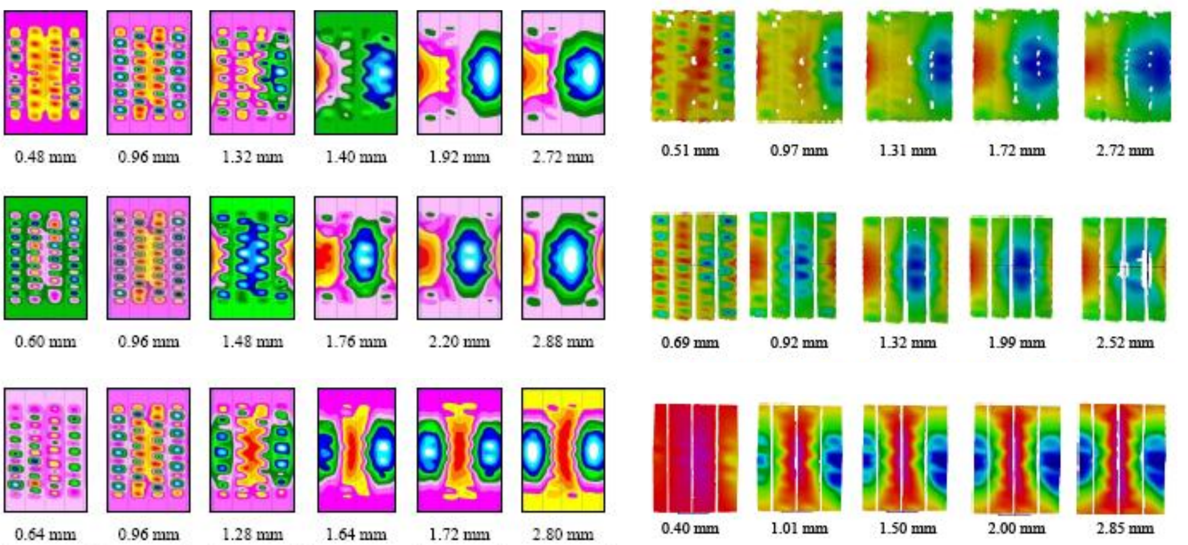
The compression response of curved stiffened composite structures presents several challenges in both the postbuckling and collapse stages of response. In the completed European Commission 6th Framework Project COCOMAT [1] (Improved **MAT**erial Exploitation at Safe Design of **CO**mposite Airframe Structures by Accurate Simulation of **CO**llapse), significant statistical variation in buckling behaviour and ultimate loading were encountered in the experimental work packages. The variations observed in the experimental results were not predicted in the finite element analyses that were done in the early stages of the project. It was recognised that there was a gap in knowledge about the effect of initial defects in the input variables of both the experimental and simulated panels. The initial defects observed included poor bond adhesion, quality of lamina layup, geometrical imperfections from the curing process, loading conditions, etc. A combination of these factors led to the varied postbuckling behaviour observed under experimental testing such as the collapse load and postbuckling mode shapes. Using stochastic analysis [2], where a variety of measured and assumed variations were introduced into the finite element models, the results observed in the experiments were captured (see figure 1).



(a) Finite element simulations (b) Experimental results

Figure 1: Out of plane displacement plots from finite elements and experiments

At the completion of the COCOMAT project, a stochastic methodology to identify the impact of variation in input parameters on the response of stiffened composite panels and the development of *Robust Indices* to support the design of new panels was developed. The stochastic analysis included the generation of metamodels that allow quantification of the impact that the inputs have on the response using two first order variables, *Influence* and *Sensitivity*. These variables are then used to derive the *Robust Indices* [3] which measure the effect that defects and variations have on the response of structures. In Ref. [3], two stiffened composite fuselage panel designs were tested and the results were evaluated together with numerical models using finite elements.

The feature which is currently lacking in the stochastic procedure is a methodology which assists in designing structures for robustness. Therefore this aspect of designing for robustness using the stochastic procedure will be addressed here. Particle Swarm Optimisation (PSO) [4] has proven to be a versatile technique to achieve the desired output, both single and multiple objectives, with a relatively short number of iterations. This algorithm has already been applied in the design of composite structures for strength and stiffness [5] and it provides a good starting point for the development of an algorithm for the design of robust composite structures. A heuristic algorithm, adapted from PSO, is being developed to design structures for robustness. The basic steps of the algorithm are:

(i) Initialise the sample space using the stochastic procedure (see Ref. [3]) to produce a metamodel to represent the output response against each input variable in the analysis.
(ii) Using the metamodel, compute the Robust Index, $[R.I.]_{X_i}$ for each input variable, X_i.
(iii) Set $\min[R.I.]_{Xi}$ as $R.I.^I$ for the structure.
(iv) Search for the individual where $I=max(X_i)$ in the metamodel from which $R.I.^I$ is obtained.
(v) Set the design value of the input variable found in step (iii), X_i, as the Individual, I, found in step(iv). An acceleration offset [1,2] can be included to reduce the number of iterative steps.
(vi) Repeat steps (i) to (v) until desired $R.I.^I$ values are reached. If structural robustness does not improve, repeat steps (ii) to (vi), using the individual where $I=min(X_i)$.

Note that the derivation of the Robust Indices can be found in Ref. [3]. This algorithm achieves a robust design by identifying the input variable that has the lowest robustness and this is followed by shifting the nominal mean in order to change the robustness of structure. The stiffness and strength of a structure will be affected by a modification to the input variable of a structure.

The algorithm can be applied for member sizing and laminate configurations as the robustness of structures is dependent on both geometry and material properties. Figure 2 illustrates the outcomes which can be achieved using the algorithm which aims to reduce the *Sensitivity or* gradient of the sample as well as *Influence*, the spread of the sample from the *Sensitivity* line. These derived variables are functions of robustness. Results from a redesign of the stiffened panels will also be presented at the conference.

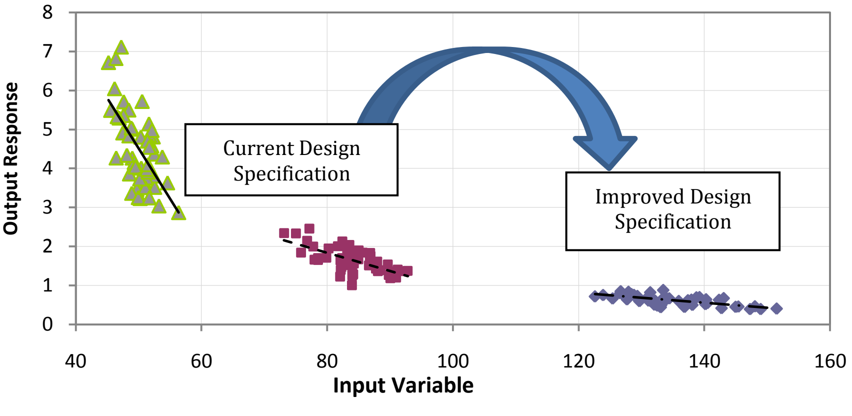


Figure 2: Illustration of outcomes from Robust Design algorithm

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