Cost-Based Methodologies for Design Optimization

UTP for design

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Life cycle cost is one of the key issues in aerospace manufacturing as business models change from selling products to providing a service, for example; the concept of "Power by the hour" and "Total Care" contracts. Reliable and accurate cost predictions have to be made as early as possible within the design cycle and traded with other product attributes, as it becomes progressively more difficult and expensive to make modifications. This project aims to develop methods for integrating cost models within optimization processes to search for trade-offs between weight, stress and cost of an emerging design.

The research till date has focused on developing a system to perform manufacturing cost based optimization as shown in Fig.1. The four different elements essential to the process are: (1) a parameterized solid model of the component (2) a finite element analysis (FEA) tool (3) a cost model reflecting changes in cost as geometry is modified and (4) a robust optimizer.

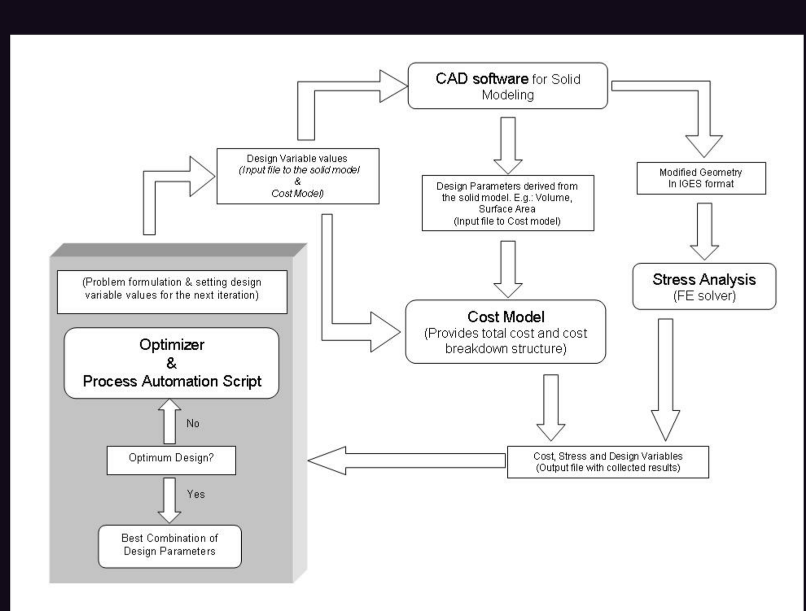

Figure 1. An overview of the proposed cost optimization methodology

The component used to demonstrate this concept is a three dimensional geometry of a Rear Mount link used in one of the Rolls-Royce civil aircraft engines. The link geometry is modeled parametrically in CATIA V5™. The input values to the parameterized solid model are controlled by the optimizer. Figure 2 shows a range of geometries developed by varying the inputs. Each of the candidate geometries is analyzed in ANSYS 6.1™ to extract the maximum *Von Mises* stress in the part for a predefined set of loading conditions. The inputs to the feature based cost model are the weight, volume, and surface area of the solid model. The outputs (stress and cost) are then passed back to the optimizer. The optimizer then uses a specified algorithm to calculate the input parameters for the subsequent iteration by comparing the outputs against the objective and constraint functions. This process is continued iteratively until the optimum design solution is found.

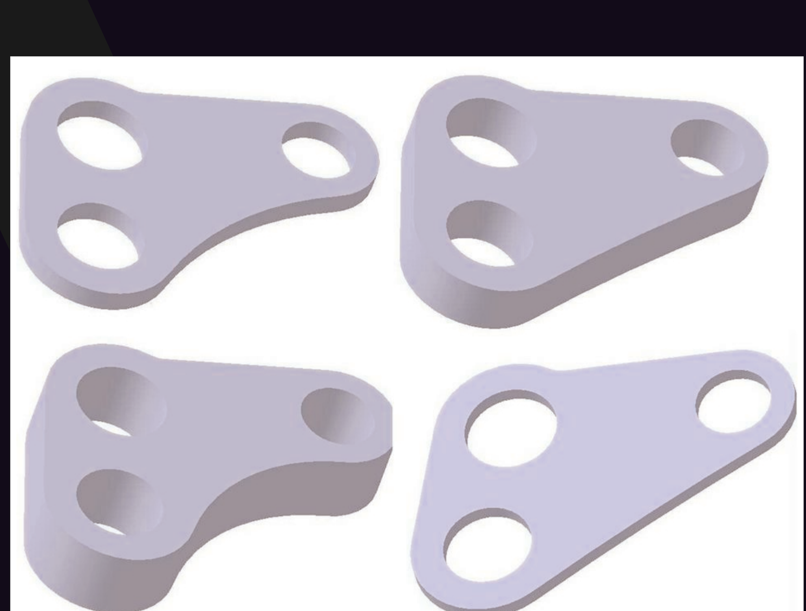

Figure 2. Different geometries developed parametrically

Feature based Costing

Cost estimation in this project is based on calculating the cost of a '*manufacturing feature*'. A manufacturing feature is defined as a change in the state of a component. This state change is often a change in geometry caused by a machining process. The final product geometry is achieved after a set of manufacturing features are applied to the raw material. The cost of a manufacturing feature is the cost of resources expended in making the transition from state *n-1* to *n* as shown in Fig. 3. The total cost is a summation of the constituent manufacturing feature costs. Since this method of costing relies on component geometry, it provides the incremental cost incurred by embedding a geometric feature within a design.

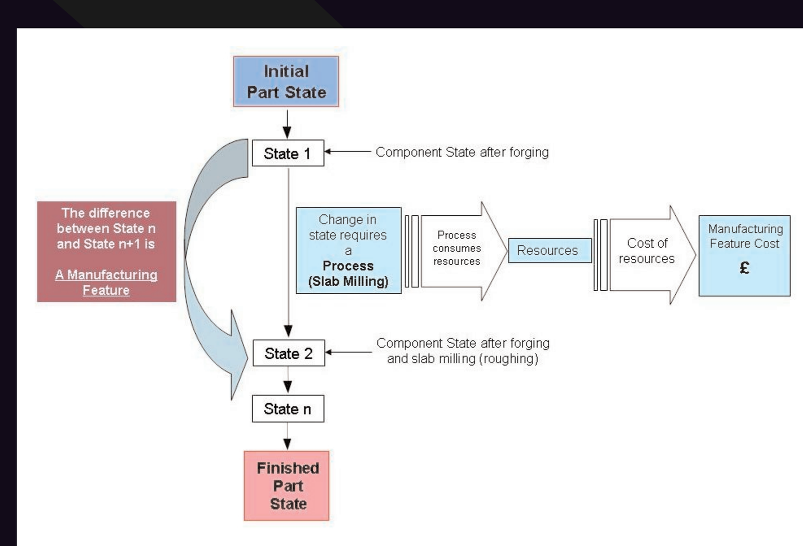

Figure 3. State Transition and Manufacturing Feature Costs

The costing method explained above has been encapsulated within DecisionPro™, a decision support software tool instrumental in building detailed cost models for complex products. DecisionPro provides a clear and logical format in the form of a hierarchical tree structure for capturing the various cost computations used in the model. This offers easy readability to developers and simplified audit procedures for end users (designers), unlike spreadsheets where the logic is often difficult to follow as the calculations assume greater complexity. It is also possible to include cost libraries of frequently used entities or objects. The cost models can also be uploaded to a server and queried remotely allowing better integration in an existing MDO environment. Figure 4 shows a snapshot from the cost model.

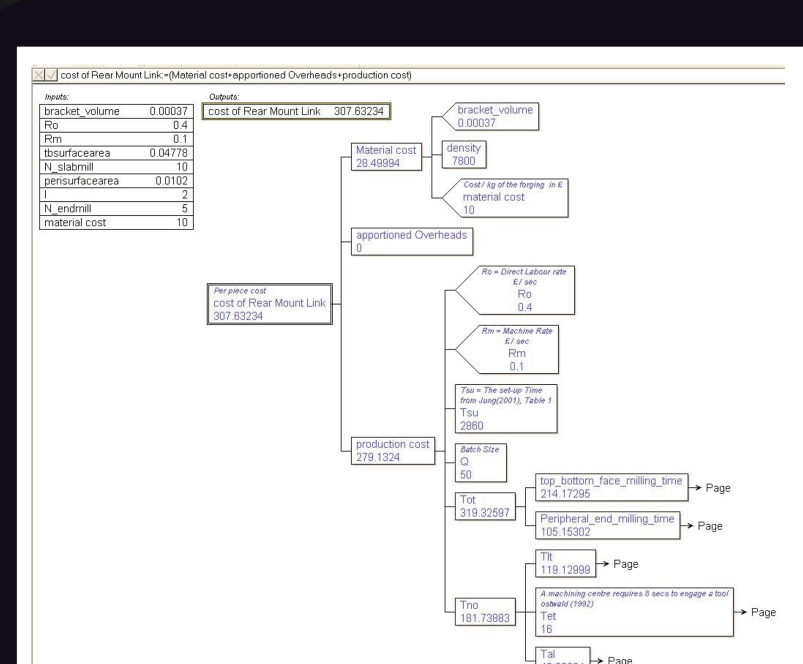

Figure 4. Detail from cost model

Two different optimization strategies have been tested so far on this system:
(1) meta-model based optimization, and
(2) multiobjective optimization and construction of a Pareto front for stress and cost.

Meta-model based optimization

The presence of multiple software and computationally intensive tools in this integrated system prohibit search using the full problem code over a very large design space. Meta-model based optimization is a technique designed to circumvent this problem. The objective is to construct an approximate model (the meta-model) that is computationally cheaper to evaluate and which approximates the output (objective function) from the input parameters (design variables) with reasonable accuracy. New data is periodically added to refine the meta-model gradually giving better approximations and a near optimal design at the end of the search.

In this specific case, the objective is to minimize manufacturing cost subject to *Von Mises* stress being less than 200 MPa. Two dimensions of the component (Arc Radius (*r*) and Thickness (*t*)) are selected as the design variables to be modified in the search. The meta-model is constructed by generating an initial set of candidate designs using the $LP\tau$ sampling technique. A radial basis function (RBF) is used to approximate the actual relationship between *r*, *t*, Cost and *Von Mises* stress using the data generated from the candidate designs. A simulated annealing algorithm is then employed to search the meta-model over 5,000 design points before every update. In total, the meta-model is updated at fifty points before the optimal design is predicted. Figure 5 shows the search space at which the full problem code was used to evaluate different candidate designs. The feasible designs are shown in blue circles and the designs that violate the imposed constraints are denoted by red asterisks.

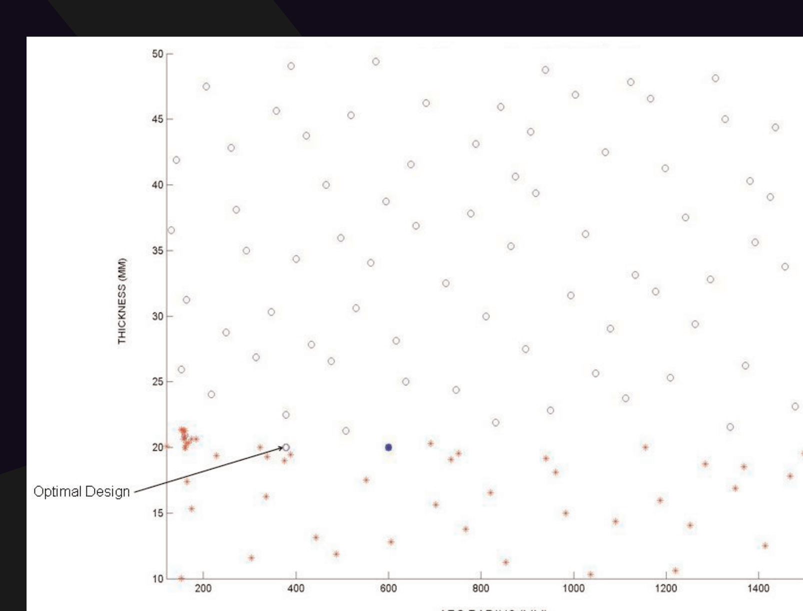

Figure 5. The design concepts evaluated by the optimizer.

A solid model representation of the geometry achieved after optimization is shown in Fig. 6. Figure 7 shows the variations of cost and *Von Mises* stress with respect to the design variables using the final meta-model generated after fifty updates.

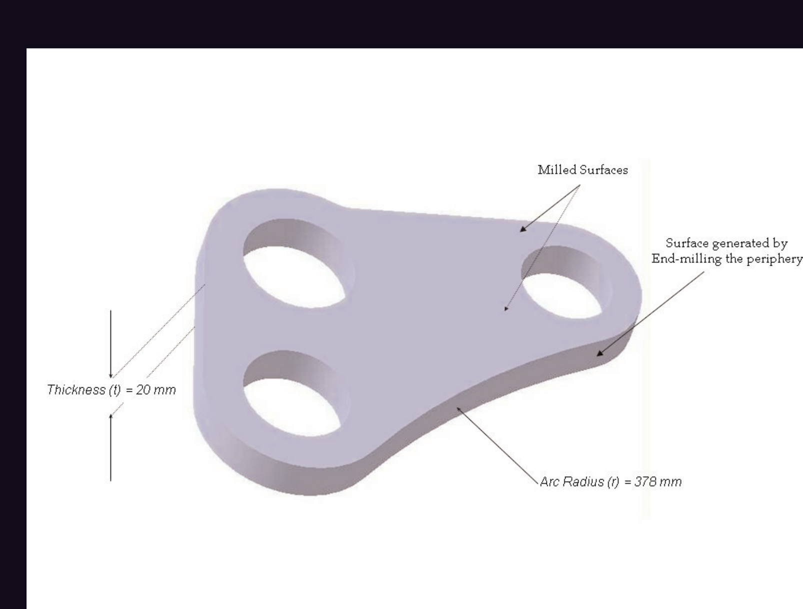

Figure 6. Minimum cost geometry

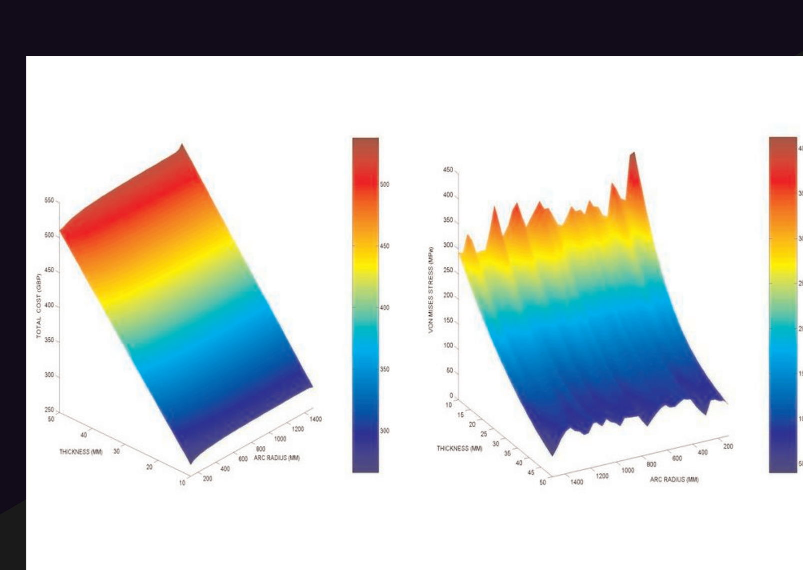

Figure 7. Response Surfaces of Cost and Von-Mises Stress against the Design Variables

Multiobjective Optimization of Stress and Cost

The present problem can also be formulated with two objectives by simultaneously trying to minimize both stress and cost. This leads to the construction of a Pareto front and the idea of Pareto Optimization. A Pareto front is formed from a set of design solutions to a single design problem where each member of the set is an optimal solution for an aggregate goal. This aggregate goal can be formulated by assigning weights to each objective and taking the weighted sum. Results from this analysis led to the construction of a Pareto curve as shown in Fig.8.

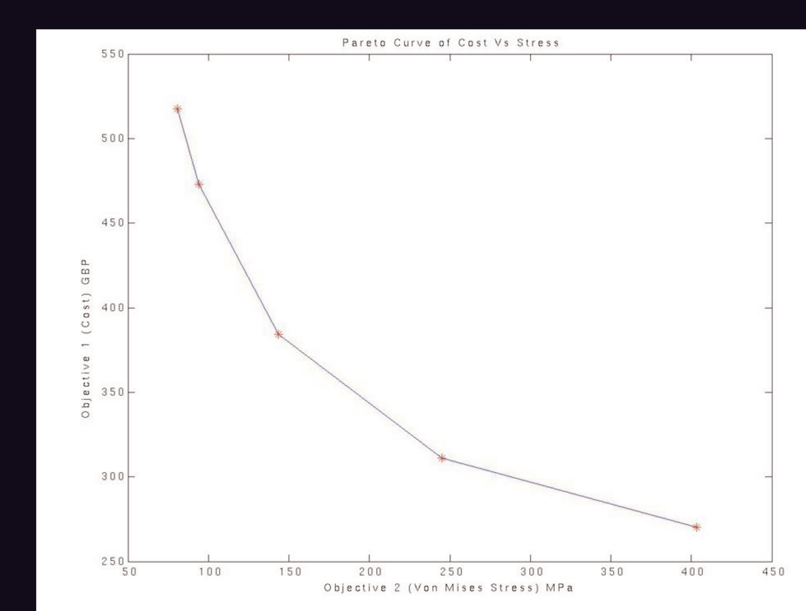

Figure 8. The Pareto curve plotted through five points of evaluation.

This Pareto curve has five points, all of them optimal combinations of the parameters *r* and *t* for different values of weighting between stress and cost. A designer can now easily move along this surface to choose the best trade-off that fits into the specific requirements of his product and company. In practice, many more combinations would have to be evaluated to form a dense Pareto curve which may make this strategy computationally expensive.

The entire process is automated as computational time may run into hours. In future, we plan to develop a manufacturability model to reflect the relative ease of manufacture of a design as a metric and use it in optimizing designs in a multiobjective framework. This method will also be applied in the design of more sophisticated parts than the present component and at different stages of the design process.

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