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An Aerospace Component Cost Modelling Study for Value Driven Design

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Abstract
Demand is increasing in aero-engine products for better efficiency and environmental performance whilst keeping the cost low. Unlike performance, the physics behind cost is least understood. This paper presents a proposed unit cost modelling methodology applied to a Rolls-Royce aero-engine fan blade. An objective of the cost model is the allow engineers to understand the breakdown of cost. A value driven design concept is outlined and presents an opportunity to conduct design optimisation.

Keywords:
Cost Engineering, Cost Modelling, Unit Cost, Value.

1 INTRODUCTION

1.1 Motivation

Rolls-Royce plc has formed a new methods group called the Research and Technology Cost Engineering group to develop cost modelling tools and techniques that can be adopted during the engine design phases.

The competitive factors underlying the aerospace industry are performance, cost and reliability. A trade-off is required between these factors in order to produce the optimum solution to meet customer requirements. Figure 1 shows the dependency of the factors. For example, by enhancing the performance this can increase the cost for the technology required, but may decrease the reliability due the complexity of a design.

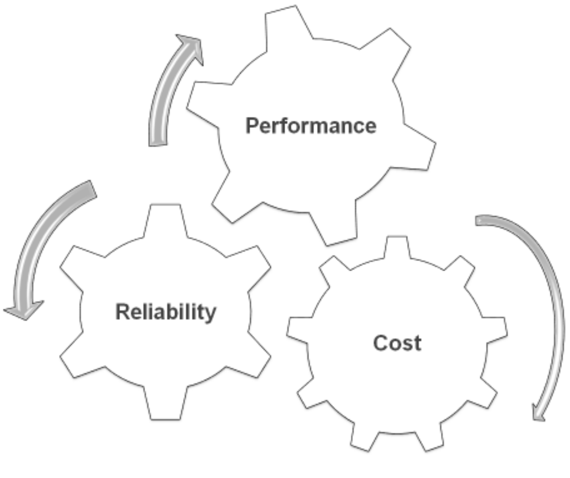

Figure 1: Dependency of business factors. [1]

Decisions on the design of a product influence its unit cost e.g. the method of manufacture of the design will affect manufacturing costs; the type of material selected and design determines the material cost and weight. Therefore, it is important to control cost throughout the design phase, in particular, at the early stages of design where there are greater opportunities for cost reduction [2].

Understanding cost drivers is one of the goals in the design cycle. There is now a shift to explore processes that incorporate other measures important to the stakeholder, which as a result generates an optimal design solution. Value Driven Design (VDD) presents an opportunity for this [3]. Further explanation of VDD is in section 2.2.

This paper introduces an aspect of a research project by discussing a unit cost modelling approach for novel components in Rolls-Royce plc, such as the composite fan blade, and how this could feature in value driven design.

1.2 Research Scope

The aim of the research project is to understand, develop and implement a strategy to allow future generations of gas turbines to be designed to meet not only performance and cost targets but to also take into account other stakeholder requirements in the form of a value objective function.

The aim is to develop a costing framework which includes:

- Cost modelling case studies – novel components and whole engine level.
- Investigation of alternative cost modelling techniques e.g. data mining and proximity engineering.
- Exploration of other measures important to the stakeholders and how value driven design can be applied.

Figure 2 illustrates the connection between topics that will be considered for researching a value driven design process.

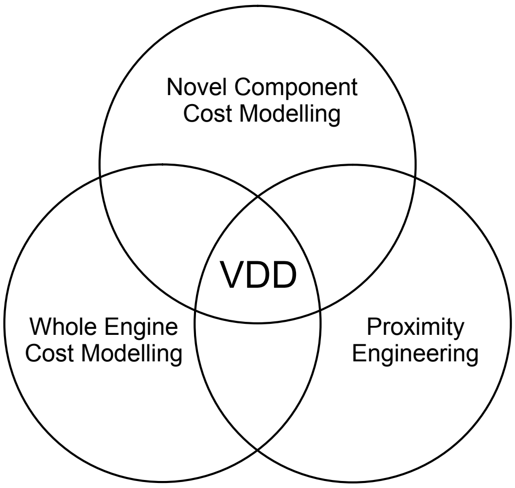

Figure 2: Case studies considered for VDD.

2 BACKGROUND

2.1 Cost Engineering

Today, there is a comprehensive selection of cost estimation literature for engineering. Curran et al explains that cost estimating provides a forecast of a product's cost generated from analysing historical data [4].

The European Aerospace Cost Engineering Working Group (EACE) created a list of definitions to describe the work involved in cost engineering [5]. The following is a few which outline some of the Rolls-Royce cost engineering activities:

- cost estimating methods and processes development;
- cost estimation;
- cost control;
- design to cost;
- development of cost models;
- participation in IPPT (Integrated Product/Process Team)
- value analysis.

The current aspiration is to work towards a more automated cost estimating process that can provide credible cost information [6]. To achieve this, an understanding of the design and manufacturing process is required, which highlight that cost depends on design decisions made about the product [7]. Furthermore, a set of good quality historical data and knowledge to support the cost estimation process will allow quicker responses to the designer (Figure 3).

Niazi et al describes the various techniques available for product cost estimation [8]. The granularity of the cost information depends on the type of data used in the cost estimating method or cost model. For instance, intuitive techniques are based on the past experience. This requires an extensive product range in order to generate a good correlation for cost estimation. Analytical techniques delve into more design and manufacturing detail, hence breaking down a product into activities and resources consumed in the development process.

Cost engineering takes into consideration design and engineering principles and uses this knowledge to evaluate trade-off studies. Therefore, it is important to treat cost as an independent design parameter [4], which can feature in life-cycle costing and optimisation processes.

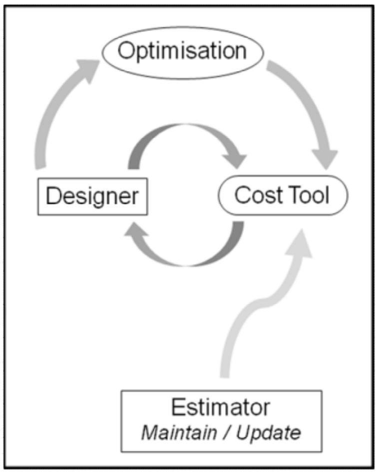

Figure 3: A cost estimation process [9]

2.2 Value Driven Design

"Value-driven design is an improved design process that uses requirements flexibility, formal optimization and a mathematical value model to balance performance, cost, schedule, and other measures important to the stakeholders to produce the best outcome possible" [3].

Value driven design is an emerging topic within the concurrent engineering community, as it provides a concept where designers can utilise value models to determine the value of their product designs as a single objective function.

Collopy has applied the value modelling approach to aerospace products, whereby profit is used as a metric for 'value' of the product to the business within the competitive market [10].

However, in engineering as opposed to ecomonics, a single objective function that represents the design attributes (Figure 4) is much more desirable [11]. The single measure or scoring function would theoretically indicate the 'goodness' of the product design, where a high 'score' yields a better optimal value-adding product [10] e.g. for a component in an engine, the output would be the value that the component provides to the engine system level. This technique can then support decision-making when assessing options in the early stages of design.

Investigation of the possibilities of value modelling and value analysis of aero-engine components will be within the scope of this research project.

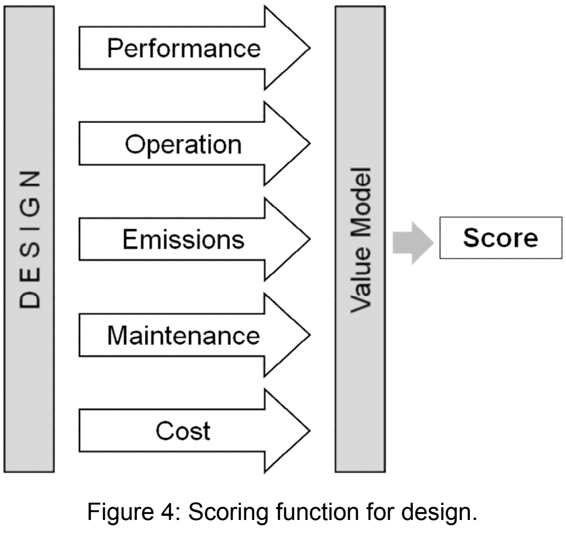

Figure 4: Scoring function for design.

3 COST MODELLING APPROACH

3.1 Novel Component Unit Cost Modelling

Novel components, in this case, mean a product that has not been produced before in Rolls-Royce plc. It is a completely new unique component with a new design and manufacturing process.

In this unit cost modelling case study, a composite fan blade is considered. It is not unique in the aero-engine industry as General Electric has developed the GEnx and GE90 engines, which uses composite fan blades [12]. Figure 5 shows an assembly of Rolls-Royce plc Trent 1000 titanium fan blades [13].

Figure 5: Traditional Rolls-Royce plc titanium fan blades.

An aim for Rolls-Royce plc to deliver light weight and **low cost** composite fan blades has recently been announced [14]. Today, alternative materials and manufacturing methods have been considered in the aero-engine market due the rising demands from airline businesses for better efficiency and environmental performance [15].

Therefore, an alternative technique to re-use historical data or experience is needed for novel component cost modelling.

3.2 Methodology

The methodology presented in this case study for novel component cost modelling adopts a similar approach to Shehab's [16] cost modelling framework whereby the design, manufacturing process and material attributes are modelled. In addition to this a discrete event simulation (DES) factory model is introduced to capture the dynamic operations in the factory.

Two software packages are used for modelling the manufacturing cost of the fan blade: Vanguard Studio [17] and ExtendSim [18]. The combination of a static and dynamic model benefits one another to help the user understand and highlight the cost drivers. Figure 5 shows a high level breakdown of the manufacturing cost.

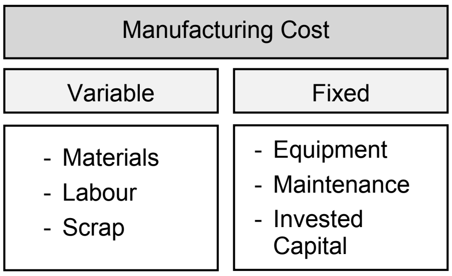

Figure 5: Manufacturing costs.

Figure 6 is a diagram of the framework by which to model the manufacturing costs. It is proposed that Vanguard Studio acts as the user interface with ExtendSim running in the background. Therefore, design attributes are entered in Vanguard Studio. The transfer of data between the two packages is further explained in the subsequent sections.

Marsh et al linked a factory model to Vanguard Studio to demonstrate the advantages and shortcomings of the system [19].

Vanguard Studio Cost Model

The DATUM project [20] introduced Vanguard Studio (formerly Decision Pro) to Rolls-Royce plc as a cost modelling tool. The fixed costs have been captured in the 'static' model e.g. machine and tooling costs, amortised costs, raw material cost. Figure 7 shows the type of data entered for the Vanguard cost model. Notice that the equipment and labour times are fed into the factory model.

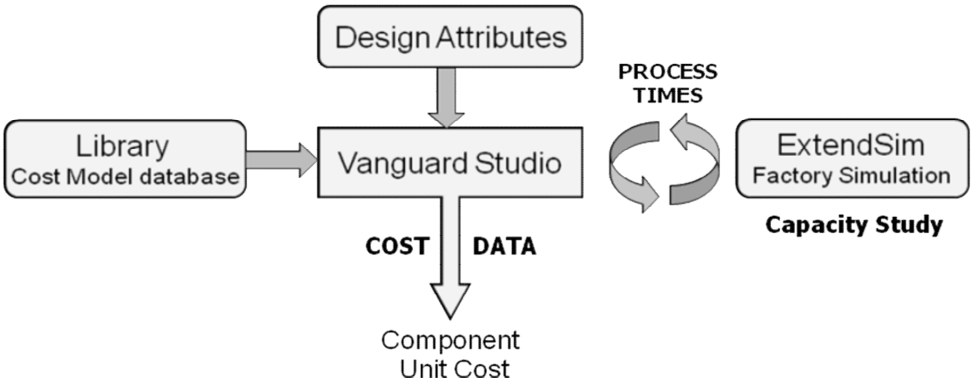

Figure 6: Cost modelling framework applied to novel components

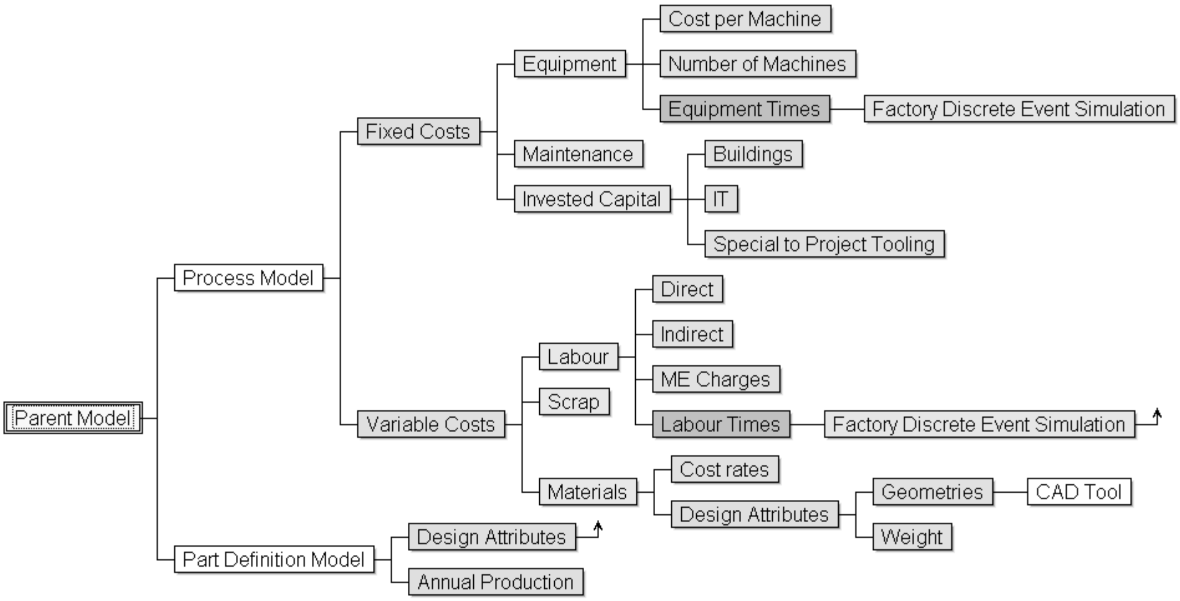

Figure 7: Abstract of the Vanguard Studio cost model data structure.

Factory Model

The factory model is broken down to manageable hierarchical blocks (Figure 8). In each cell are the operations required for that particular process e.g. buffers, operator tasks and operations.

The model acts as a capacity study, whereby the factory operation is modelled and tested to evaluate if the annual demand of fan blades is met. Equipment and labour times, with uncertainties (distributions) defined in Vanguard Studio, are applied to the factory model. The output of the simulation identifies queuing times of work-in-progress; bottlenecks and resource availability. When the outputs are analysed, this can help resolve factory logistic issues and improve efficiency to yield the target annual demand.

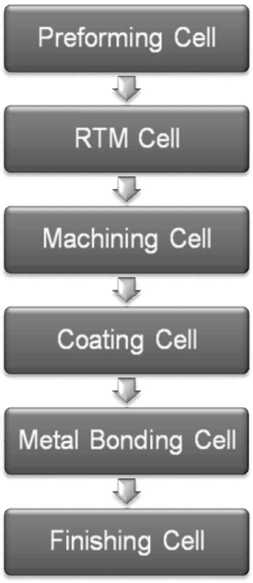

Figure 8: High level composite manufacturing process blocks for factory modelling.

An advantage of building a dynamic model is gaining credible manufacturing costs based on the manufacturing process [21]. Therefore, deriving the unit cost is traceable which helps with the verification process - when discussing the model with experienced manufacturing engineers (ME's). Hence, it is important for validation that the model reflects the ME's thoughts.

Currently, manual optimisation is required via 'what-if' experiments to generate the optimal factory layout to meet annual demand i.e. number of tooling or operators. Example scenarios for the factory model:

- Apply limited resource (operators and equipment) – experienced manufacturing engineers can apply their knowledge of factory operations in the model. The model can then be simulated to discover any bottlenecks and also highlight where the manufacturing process/logics could fail.
- Apply unlimited resource – this scenario assumes there is an unlimited financial budget for resource, which is unlikely in real life. Therefore, this scenario can determine how many equipment, tooling and operators are required to meet the annual demand.
- Compare automated and manual composite manufacturing processes to highlight the benefits of each process in terms of cost. This is a useful scenario to aid decision-making and the long term cost benefits.

4 FUTURE WORK

4.1 Cost Modelling Study

Further development and analysis is required for the composite fan blade cost modelling case study:

- The Vanguard Studio cost model will need fine-tuning to accurately represent cost information and Rolls-Royce's accounting system e.g. amortise cost either over number of years or number of parts produced.
- As both the cost and factory model reaches a maturity level; the goal is to develop a reusable robust model to accommodate design changes.
- The results of the factory model scenarios will be analysed. The effects of these scenarios on the Vanguard Studio cost model will be recorded and sensitivity analysis applied.
- All models will need to go through a rigorous verification and validation process in order to achieve a mature status.

Whole Engine Unit Cost Model

Figure 6 shows that a library of cost models can be utilised, which holds Rolls-Royce standard material cost information; standard labour cost rates; equipment and process cost rates. Additionally, a library of engine component cost models exist that can be used to build a whole engine cost model. Therefore, the cost model for the composite fan blade can be included in the library and implemented into the whole engine model to assess the cost impact of a design change.

4.2 Value Modelling

The fan blade cost study is a potential application for value modelling – the value it brings to the engine and the business. Collopy states the ideal engine design is one that maximises unit profit. This acts as a parameter in a value model and brought together with an engineering cost model, presents an opportunity for design optimisation [22].

Currently, a deeper understanding is required to define value and how a tool can translate engineering parameters, customer needs and cost into a single 'goodness' objective function or score. A methodology will be explored to verify that value driven design is capable of representing design attributes and beneficial to the design and manufacturing community.

5 SUMMARY

This paper has discussed the importance of understanding cost at the early stages of design to help design decision making. The cost modelling approach for a novel component was presented along with the scope for a value driven design process.

The implication of the cost modelling methodology for a novel component supports design trade-offs and emphasises the importance of unit cost as a parameter in the design optimisation process. For new products, it may not be necessary or possible to deliver detailed cost. Instead, the cost information generated from the cost models reflects the amount of design attribute details available at the particular design stage.

Further developments and analysis of the method will reveal the credibility of the cost results, which combined with a value model provides a mean for design optimisation. In future, this approach can be adopted for other aero-engine components.

6 ACKNOWLEDGMENTS

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