UNIVERSITY OF Southampton
School of Engineering Sciences

Design Complexity, a surrogate measure of unit cost

UTC for Computational Engineering
Stephan Langmaak and Jim Scanlan, CEDG, School of Engineering Sciences
Steve Wiseall, Rolls-Royce plc.

I. BACKGROUND:

In comparison to a conventional blade and disc assembly, a blisk (bladed disk) is up to 30% lighter but more expensive to manufacture and repair because the blades cannot be installed and removed easily, see figure 1. This project is focussed on the Linear Friction Welded (LFW) blisk because it is one of the most expensive, novel and complex components Rolls-Royce make. These factors make it difficult, but nevertheless important to be able to cost LFW blisks accurately during the early stages of design.

As LFW blisks can have up to 400 features and 10000 measured points, each design is highly unique. This leads to a cost variation between £30,000 and £220,000 per blisk, depending on the complexity of the design. Currently, only sparse and inaccurate data is available for five pre-production Joint Strike Fighter (JSF) blisks due to the relatively immature state of the technology involved and hence a constantly changing method of manufacture. In order to build a cost model around a stable method of manufacture the manufacturing engineers had to estimate mature operation times for 2015.

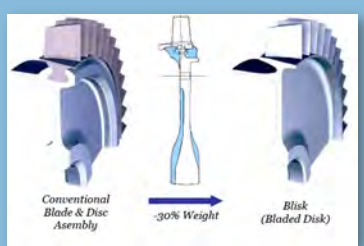

Figure 1 – Bladed disks

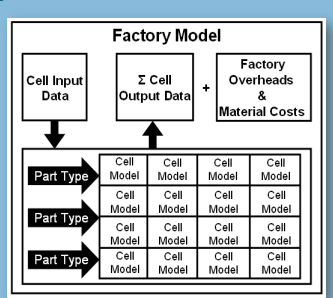

Figure 2 – Factory cost model.

II. PROJECT STAGES:

This project is divided up into a series of stages as follows.

Blisk Factory Cost Model

a) Develop a generic factory cost model in Vanguard Studio using the activity based costing methodology where cost rates are calculated for each manufacturing operation.
b) Populate this model with the cost data for the future LFW blisk production line in Crosspointe, Virginia, USA to be able to predict the factory cost rate and the unit costs of blisks.
c) Feed the cost model with the output data of a factory simulation for Crosspointe, including the number of machines, realistic operation, labour and inter-operation times to make the cost predictions more accurate.

Scalable Blisk Cost Model

a) Collect the operation times for all LFW blisk manufacturing operations.
b) Convert these times into scaling rules by either using a constant time or applying a linear fit if the times vary.
c) Create a blisk operation time calculator in Vanguard Studio based on these scaling rules.
d) Use this model to calculate all the operation times for any future LFW blisk design. Paste the operation times into the factory cost model to predict the unit cost for this particular design.

Design Complexity

a) Develop complexity metrics that could contribute to a surrogate measure of unit cost.
b) Calculate the values of the complexity metrics for simple non-aerospace components, blades, discs, shafts, casings and eventually blisks.
c) Analyse the correlation between the complexity metrics and unit cost by using regression analysis and neural networks.
d) Compare the accuracy of costs predicted by the scalable blisk cost model and the complexity metrics, taking into account the benefit of each methodology and the effort required to produce the cost estimates.

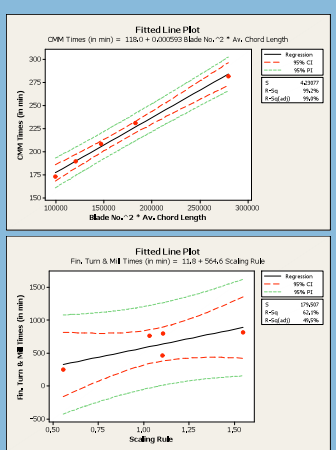

Figure 3 – data fits for two manufacturing operations

III. CURRENT WORK: BLISK COST MODELLING

Factory Cost Model (figure 2)

•The **Factory Cost Model** is made up of various Manufacturing **Cell Cost Models.**
•Machines are allocated to these **Cell Cost Models.**
•Part Types pass through the **Cell Cost Models** according to their method of manufacture.

Blisk Operation Time Calculator

- While 35 scaling rules account for standard manufacturing operations (turning, NDT inspections, etc.), special features (i.e. seals, holes) and optional operations (e.g. laser shock peening) are modelled by 15 additional scaling rules.
- Manufacturing operations that have a constant time will nevertheless be modelled as triangular 3-point estimates to take into account that processes are likely to change by 2015.
- The uncertainty associated with the linear fits will also be stored in the operation time calculator. This accounts for the lack of fit of the graphs as well as the lack of more data.
- Figure 3 shows the linear fits for two different manufacturing operations. Statistically there is a 95% chance that any additional point will lie in the region between the two green outer lines on each diagram, known as the prediction interval. The accuracy of the collected data and the scaling rules vary considerably as the width of the prediction intervals in the two examples show.
- The operation time range can be predicted once the user specifies the values of the variables in the equation of the fit.

Blisk Cost Modelling Methodology

•Figure 4 shows the flow chart that the user follows to enter the values of key blisk design variables (Inputs 1) and data from the blisk factory simulation (Inputs 2). The factory cost rate as well as the unit cost of the blisk can then be predicted.

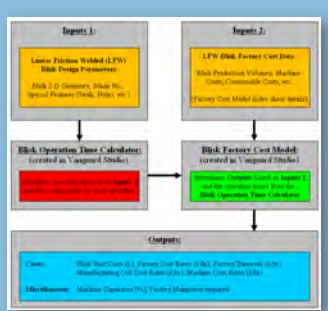

Figure 4 – Data entry flow chart.

IV. FUTURE WORK: DESIGN COMPLEXITY

- Complexity metrics have to be quantitative, non-dimensional, surrogate measures of unit cost that are based on design related parameters and are independent of production volume and monetary factors (exchange rate, inflation).
- Each of the 10 complexity parameters that contribute to the Design Complexity Index used here will be normalised against the highest value in the dataset. They will then be weighted and aggregated using regression analysis or neural networks to produce the desired index.
- The index will be calibrated against historical unit cost data or alternatively against historical development times.
- The Design Complexity Index should be useful throughout the design process even if, for example, the surface roughness and tolerances of individual features might not be known initially. These should then either be guessed using historical design information or added at a later design stage.
- Although the index is calculated at a part/component level, the values could be added up to calculate the complexity of an entire system.

www.soton.ac.uk/ses/research/ced/posters.html | email: j.p.scanlan@soton.ac.uk
Computational Engineering and Design Group, University of Southampton, SO17 1BJ, UK