CATIA V5 Intelligent Aerospace Design Advisor for Manufacturing Costing

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Abstract

The function of Concurrent Engineering (CE) is to reduce both Time to Market and Life Cycle Design cost by minimizing the level of sequential design activity, where one activity must be completed before the next can begin. CE provides the ability to pursue narrow market windows of opportunity or maximally exploit a competitive advantage.

A number of knowledge based engineering tools exist within the aerospace industry, designed to enhance the concurrent engineering approach to product design. Many, like Knowledge Technologies International's (KTI) ICAD, are based around a programming language that requires considerable expertise and training, over that required to use one of the current series of 3D Computer Aided Design software like CATIA V5, making CATIA a more cost effective solution if it is able to fulfil the same function as more expensive packages.

As a precursor to an Intelligent Design Advisor, this paper examines the concept of linking existing cost databases with a CATIA V5 computer solid product model. There is a large body of knowledge concerning manufacturing and design cost in the corporate domain, and a knowledge based engineering tool to automate data extraction from a computer model should support assimilation of costing with existing methodologies of CE practice.

A tool that utilizes CATIA V5 Knowledgeware is proposed. The potential of a tool to monitor cost continuously, making the designer aware of expense implications of design decisions is readily acceptable. This tool will require the merging of simple estimates based on cost per unit weight of a manufactured product, and detailed estimates based on manufacturing processes. The tool will allow cost to become a design driver at a much earlier stage of the design process through linking existing spreadsheet based cost data with a CATIA V5 solid model. The automation of data extraction from a model will accelerate the costing aspect of a design project, and allow greater scope for inspecting a larger number of design alternatives, at moderate cost to a company.

1. Introduction

Concurrent Design is a process where cost is calculated at each step of the design process and is evaluated against a selling price determined before detailed designs are developed. It "helps to improve the quality of early design decisions and thereby reduces the length and cost of the design process" [1]. An organisation has the ability to evaluate the product at each stage against a stable cost target, in contrast to the classic procedure where a completed design is revisited to reduce costs if necessary.

Much of the design process requires decisions to be made, often repetitively as a result of iterative activities. A tool capable of evaluating inputs and suggesting a solution, or information leading to a solution, could therefore by described as 'intelligent'; a tool with the capability to rapidly assemble information, reducing the time impact of the decision making process.

Historically, costing of product manufacture occurs after detail design, where design is carried out for function, quality and manufacture/assembly, and the solution to high unit prices of product was to manufacture in high volume [1]. In compressing the Life Cycle Design Time, the designer requires feedback on manufacturing options and associated costs earlier in the detailed design process, to reduce the time length of the feedback loops described in Figure 1.

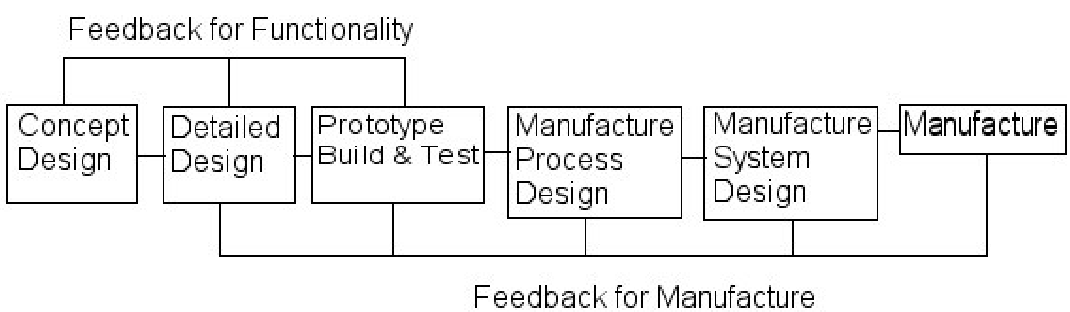

Figure 1: Traditional (Sequential) Product Development [2]

Additionally, is it accepted that the largest proportion of final product cost is determined during design [3] and feedback at this stage is the most effective in terms of speed and expense. Figure 2 shows that design has the largest affect on manufactured product cost, and occurs earliest in the design cycle so is the simplest to change.

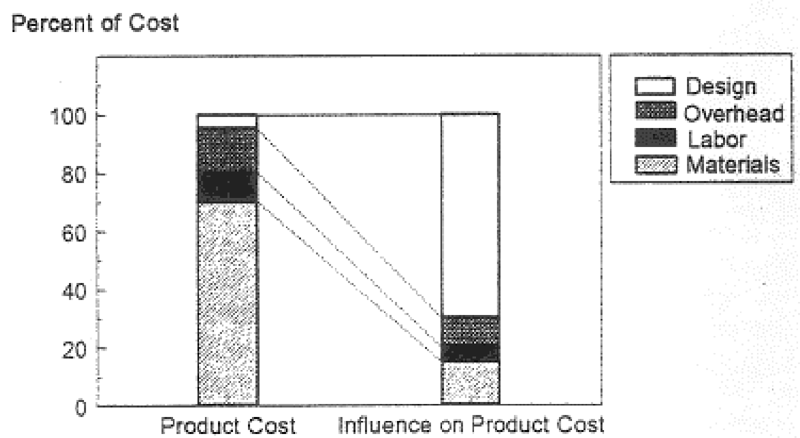

Figure 2: Influence of Design on Product Cost [2]

A number of Knowledge Based Engineering (KBE) tools exist within the industry, however many, like the ICAD package from KTI, are based around a programming language, requiring considerably more expertise and training, than that required to use one of the current series of CAD software, like CATIA V5 or Pro/ENGINEER.
In view of the substantial investment associated with software and training, a tool to assist a designer with manufacturing options and costing, utilizing existing software is believed to offer significant value as a solution.

Given the dominance of Dassault Systemes' CATIA in the global aerospace marketplace as a 3D solid model design and Product Life Management tool [4], a reasonable approach to examine the concept of an integrated costing tool is to choose the current revision of the suite, CATIA V5. Additionally, spreadsheets are commonly used to store product data and costing information, and this conceptual tool should act as a mediator between the product model and existing spreadsheet capabilities, in order to make use of significant volumes of existing company knowledge.

2. Determining Manufacturing Process Cost

As a company's ability to produce a competitive product is critical to its profitability, the availability of real-world costing data is quite limited. The manner in which companies approach the costing task is also likely to be highly variable, and so a common database was used for a simple analysis.

One commonly available database is the Process Cost Analysis Database (PCAD), developed by Boeing, MIT and NASA as a simple method for estimating manufacturing process costs for composite materials.

> *"PCAD specifically managed cost model data, providing cost input files… performed stand-alone cost estimates for a given design, and allowed for its part feature values to be update…, after design optimization"[5]*

It takes the form of a stepwise breakdown of processes into components, and each component has an associated time, together with one or more cost drivers. The cost drivers include volumes or masses for material estimates and machining operations, tool areas for cleaning operations and so on. The extraction of such cost drivers from the product model is an important process as it is both time consuming and repetitive. Using a simple aerospace component as an example, the following product model data for a composite wing spoiler is required for the PCAD:

1. Panel Area;
2. Panel Material Mass or Volume;
3. Panel Perimeter Length and
4. Material Properties – type, resin, number of plies, fibre weave

For assembly evaluation, a number of additional assessments are required, including:

5. Type of Beam section, ‘C’ or ‘I’ for example;
6. Joint Lengths, for assembly;
7. Joint Type – fasteners, bonded;
8. Manufactured Condition of composite parts – are individual parts co-cured, or do they require further assembly and
9. Type of Manufacturing Labour or Machinery – Hand Lay-up, Resin Film Infusion, Automatic Tape Laying

Further considerations may include factors relating to manufacture of the composites and the tooling required, including:

- Use of simple jigs and fixtures;
- Use of collapsible jigs and complex fixtures; and
- Availability of company equipment or outsourcing potential.

The information described in the first six points above can be recovered from a simple product model using feature recognition processes. The remainder require information from a user about manufacturing aspects of a product and the complexity of the cost evaluation.

The classical approach of dollar per kilogram ($/kg) is intrinsically useful in that as more material is used, the more bulk cost and working/processing cost is required, for designs of equivalent performance (equal peak stress, fatigue life, etc). There are certain heuristic factors in the $/kg approach that tend to compensate for many design variables. For example,

- Steel is much heavier metal than aluminium, but also much cheaper to purchase.
- A welded structure is lighter than an equivalent riveted structure (through material overlap and fasteners), but also cheaper to produce (faster and less process work).

Historically this approach may have been used as a consequence of easy measurement during design, and it is very easy to parametrically relate to experience of complete products. It does not make sense however to apply the same technique to detailed design of sub-components as the relationship between weight and cost reverses; effort expended to reduce weight increases as weight decreases and part complexity thus increases.

The basis for estimating cost will therefore depend on the complexity of the analysis. If looking at a complete product, or a substantial subcomponent for example, an approximation of cost based on the amount of material present may yield an accurate result. Hinrichson [6] suggests that, for composite materials, costs may be assigned a $/kg value accounting for the material type, material overhead costs, including storage and scrap, and the method of material lay-up.

It is interesting that the $/kg type of analysis has persisted for many years, and still appears to give reasonable results for products as a whole, where reduction of mass means less material expense and thus lower cost. Counter to this however, is detailed design, where typically design cost increases as effort is expended to reduce a part weight, meaning that potential cost drivers should include a measure of the complexity of an item. Whilst factors of complexity have many attributes, they may include:

1. Single or double curvature of panels;
2. Type of machining – 3 axis prismatic against multiple axis curved surface;
3. Number of fasteners required for assembly;
4. Manufacturing tolerances and
5. Production rates required, in number of items per period, or kilograms per hour.

Under investigation is the ability of CATIA V5 product models to store feature based data related to costing and manufacture, and, through the use of suitable computer code, to extract detailed data from the product model in a form that is usable by a costing system like PCAD. Detailed design is the hardest to cost, and also the most rewarding in terms of long term cost reduction in the context of CE. It is of greatest use in the Design for Cost field, where the design target cost is the difference between a selling price and a profit margin.

In all but the niche markets, the selling price is dictated by the market and not by the designer, requiring design to a specific sale price. Design to cost involves an iterative process in order to meet a budget, in contrast to design for cost, which aims to design a product only once, for minimum cost [7]. A design advisor used in either of these cost driven design processes should be able to use such inputs as are required by PCAD, and, using a CAD solid model, suggest means of minimising cost through a suitable manufacturing process, or reduce design cost by accelerating the iterative costing procedure.

3. The Product Model

Preliminary design typically begins with a configuration or layout, and automated optimizing tools like Finite Element Analysis may be used to accelerate the speed or quality of this task. When creating a design for tender, the quality of the initial design analysis is critical to the profitable future of the product, and large amounts of time and resources are devoted to its functional aspects. Whilst equally critical, the costing process tends to be time consuming and complex, and does not readily lend itself to automation. For this reason, companies complete a limited number of complete costs on conceptual designs – perhaps only one .

For a costing tool to have transparent integration with existing design processes it should fit within the existing design framework, and have sufficient speed to encourage cost appraisal of all conceptual products. CATIA V5 is regarded as a rational tool for this purpose as it has an wide existing user base in the aerospace industry, is already used for creating product models and drawings, and it contains a number of other useful design tools for industry, including digital mock-up analysis and stressing tools. To choose CATIA V5 means enhancing the functionality of an existing tool at minimum outlay for industry and existing users.

CATIA V5 offers an open standard architecture called Component Application Architecture (CAA), allowing external programming access to the design and manufacturing tools of CATIA V5. Whilst CATIA V5 does contain a number of internal KBE tools they are aimed at product synthesis and capture/reuse type operations, and are thus not directly suitable for the task of feature recognition, requiring the use of CAA.

A Three Dimensional solid model was created in CATIA V5 and, through Visual Basic and CAA, information was extracted from the model and passed to a spreadsheet. The spreadsheet provides array storage, mathematical calculation and visual output capability and is the basis for presenting information to the user through graphs and data tables.
The program that has been created can be run either as source code from within a Visual Basic 6 compiler, called the Integrated Design Environment (IDE), or compiled to an executable file and run locally on the machine running the CATIA V5 session. The Windows platform of CATIA V5 is bundled with a simple, integrated Visual Basic Editor, allowing any user access to the same capability displayed in this project and, like its full-featured commercial brethren, allows access to all database, spreadsheet and word processor applications using the same architecture.

As illustrated in Figure 3, the compiled program runs as a graphical window on the Windows desktop, giving the user access to:

1. The costing routines;
2. File system operations – load/save spreadsheet and CATIA model; and
3. Feature creation menu – the user can run external code to achieve a modelling or analysis task.

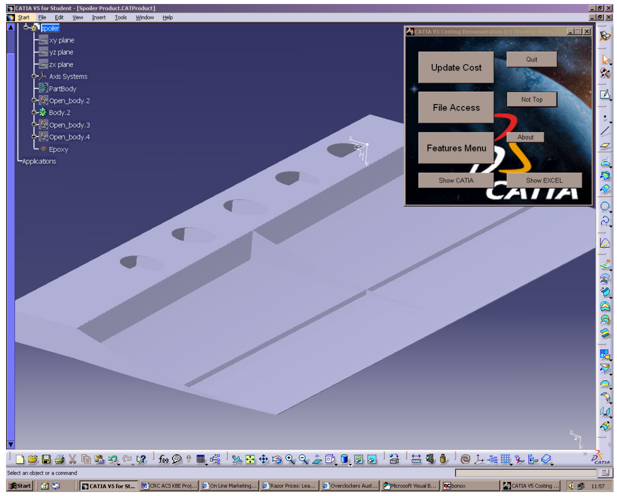

Figure 3: Compiled Program Running with CATIA V5

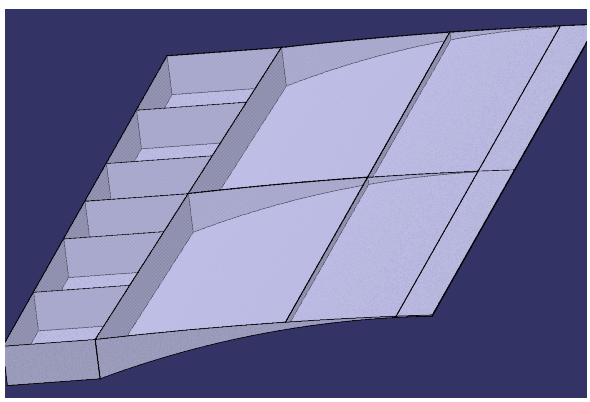

Figure 4: Aircraft Spoiler Geometric Model

Work was based around the model of a commercial aircraft spoiler (Figure 4) intended for manufacture using composite materials. Data extractable from the CATIA V5 model of the spoiler includes:

1. Mass of Product
2. Density of Parts within a Product
3. Lengths of Intersections between surfaces – i.e. for bonded joints analysis
4. Number of holes, for joints analysis
5. Projected areas of panels
6. Perimeter lengths of surfaces
7. Material Properties if they are specified in the model.
8. Descriptive data recorded about a feature.

The results of this data extraction may be stored in many ways, and is the subject of continuing work. Two methods appear to be the most useful:

1. Store data in a spreadsheet; and
2. Store data in file based records.

The first solution gives direct access to other spreadsheet based solutions like PCAD, however it does not give much storage space for a large project, and has the disadvantage of unnecessarily exposing the end user to a large volume of data that is only used by the computer.

The database storage file, utilizing either Visual Basic or a dedicated database, has virtually unlimited storage potential and, through judicious coding methods, does not expose the user to data other than that required to verify or modify the process. This method does require a higher user skill with the programming tools, but yields much greater versatility should it be required in the future.

Having developed a simple tool to extract cost driver information from a CATIA V5 product model, it has been discovered that, in comparison with other KBE packages like ICAD, CATIA V5 knowledge based functions are very shallow. It is accepted that many downstream applications exist for costing designs from CAD models, however similar feature recognition processes could be used in a more complex tool. It is the subjectivity of design, together with the complexity of most problems that leads towards the concept of an Intelligent Design Aid. The natural aim of any design is to satisfy product requirements at minimum cost, and processes like those described here with CATIA V5 are an initial step towards establishing a precedence of manufacturing criteria.

4. Intelligent Design Advisor

As the CE philosophy becomes more prevalent in industry, it is important that new tools support integration with existing ones. At present a large number of commercial and proprietary tools exist for assisting aircraft design. These range from material performance databases like the Engineering Sciences Data Unit and materials testing results, to statutory guidelines like the Federal Aviation Regulations and processes for evaluating fatigue life and design stress. Like any human designer, an intelligent design advisor should make use of existing data and processes to support a decision, like a suitable manufacturing process.

The proposed costing technique presented here relies on one primary foundation; that the manufacturing process is known in advance. The PCAD makes allowances for changes in labour rate, although it is tied to a set of cost values based exclusively on a specific process set. Future development of a costing tool suggests an ordered list of manufacturing processes ranked by cost. Substantial pieces of information are missing from a simple CAD model like that presented here, that would be required to accurately and completely cost a product. This information is primarily involves the manner in which the product may be manufactured, and a certain level of ‘intuition’ would be required to extract information from a simple model concerning:

- Production quantity
- Tolerance and surface finish

- Availability of machinery.

A software tool capable of assembling this information, and combining it with the feature types of a product to suggest a most appropriate manufacturing process, most effective method of jointing, or some other aspect of a design is an Intelligent Design Advisor (IDA).

An IDA is an agent, expected to be viewed as a member of a design team, used for consulting concerning technical issues, or for reducing the load of iterative work. It should not replace design engineers nor be required to output a design solution. It becomes a tool designed to offer manufacturing input to a design upstream of design solidification, in opposition to most applications offering downstream comment on the most suitable process for a completed design. As an example, an IDA may suggest areas for improvement, or factors for consideration, including:

- Cost reduction;
- Design for X approaches; or
- Comment on end of life disposal effects of aspects of the design.

in contrast to attempting to voice an optimum solution in any particular field.

Additionally, the use of an IDA suggests an opportunity to track design intent for recording as design rationale. Design rationale becomes useful for tracing the reasoning behind modifications to a product, particularly when the change originator leaves the company: Kletz (1993) states that “Organizations have no memory; only people have memories and they move on.” [8], giving rise to a number of points:

- Once designs are certified, paperwork is created for any change/modify justification. During initial design however, many decision evaluations may be consigned to non recordable means like scrap paper or discussion only
- Future advances in technology can render contemporary decisions less effective – products may be more readily modified if design rationale is available on which to base the change. “A deeper understanding of the design will reduce the chances of dangerous modifications.” [8]

The most important step in a manufacturing process Intelligent Design Advisor (IDA) is matching the product model to a manufacturing process. This step requires a method of feature recognition, in addition to decision-making processes capable of handling ill-defined situations. The solution of a set of mutually exclusive rules is a single response; engineering design, however, is filled with ambiguous tradeoffs. Decisions based on such tradeoffs require processes capable of selected reasoning, and such should be sought if an intelligent agent is to be created.

In the same manner as the feature recognition used for this costing work, an IDA will need to recover information from the product model concerning features to be manufactured. This process has the benefit that an appropriate feature recognition set should feed not only the manufacturing process decision, but also in costing each of the possible manufacturable outcomes in order to suggest the most effective to the user.

Much theoretical work appears to have been done in the technical area of feature recognition, however most tend only to focus on a single domain; STEPA224 machining features [9], casting or moulding features [10] and so on. The subject of future research will be to offer a general suite of recognition potential from a large number of manufacturing disciplines. The purpose, together with integration of general product manufacturing information, is to provide a system capable of suggesting an optimal manufacturing process to a user.

As with all KBE tools, its value will rise with number of products to be designed, as the cost of producing the tool as a function of useful output falls with number of repetitions or iterations of the same product.
For this reason, a KBE manufacturing process tool is likely to be more useful for high volume parts than for low volume or unique designs, particularly where there is a clearly defined process in place for design and analysis.

Large, unique parts generally have a distinct material and are consequently designed in view of a deliberate manufacturing process. Smaller, more common parts are less likely to be designed with a process in mind, although the material is probably specified as part of the conceptual model. In the aerospace industry, an IDA is more likely to be directed towards parts like cleats and brackets. Parts of this type have a large number of useful manufacturing processes, including:

- Machine from solid;
- Fold from sheet and machine;
- Extrude and machine;
- Cast and machine; and
- Fold and rivet, or butt weld.

Most products are probably more suited to one of these, when considering detailed aspects of web/flange interactions, hole number and placement, required number of parts, strength, inspect-ability and so on. A decision is therefore required to ascertain the most appropriate process, supported by an IDA.

A secondary consequence of feature recognition processes may be to suggest design modifications or at least bring regions of interest to the attention of the user. Fatigue issues in machined parts for instance, may be mitigated by use of crack stopping features or by moving to a separated jointed design. The process may also find use in achieving design consistency in a team or company, or indeed in assisting engineers reduce the time involved in isolating the most appropriate manufacturing processes, particularly in the time oriented domain of Concurrent Engineering.

5. Limitations of CATIA V5

Whilst CATIA V5 is a much easier package to learn than its predecessor, it is still the subject of a number of teething problems when compared to more established KBE tools. This should not necessarily be seen as a long-term limitation of the software; but merely that requirement breeds innovation, and innovation lacks familiarity.

The CATIA V5 programming language appears to be relatively immature when compared to more advanced products, like Knowledge Technologies International's ICAD and Genworks' GDL, that use a more general LISP based language. In its favour however, CATIA V5's capability for feature recognition in both part and assembly models is quite advanced in terms of how the feature is defined by the CAD system. There are very few primitive object types, replaced by more flexible approaches to feature modelling. It will take further work to extrapolate feature types to manufacturing processes, together with associated costs.

At present, a CATIA V5 product model does not appear to allow capture of data related to it, but not connected to its modelling. Generative CAD software like ICAD and Genworks are effectively programming languages that allow a user to store any information about a product in the code required to generate the model, and may be more suited to handling multiple variable, non-exclusive inputs. The programming language behind these two software packages is LISP, and its use in the creation of similar expert systems is well documented [11]. In a similar vein, creating a CATIA V5 product model using CAA and Visual Basic should yield the same capability.

CATIA V5 is a developing software package that is subject to around six service packs per year, and at least one major revision every year. Today, CATIA V5 sits at revision 11, since its release in March 1999, showing that this tool is, if not unstable, then highly dynamic, particularly in operation and requisite syntax. Functions and procedures are subject to modification or deletion, forward and backward compatibility of program scripts is not guaranteed by Dassault Systemes, making coding for CATIA V5 something of an enlightening challenge.
As a platform for costing and feature based research, CATIA V5 is not ideal, as much effort is likely to be expended in working with unknown limitations of software, in preference to dealing merely with the problem at hand.

Whilst Dassault Systemes states that, given certain limitations, the Visual Basic and Unix True Basic languages are interchangeable, no UNIX platform was available for testing. In addition to Visual Basic, CAA is purported to support the C++ and Java languages, both of which are available across many computer platforms. The differences in nature of each platform will mean that, while references to CATIA V5 objects are universal, application or operating system references are bound to a specific platform, limiting some application areas of CATIA V5 generative models. Packages like ICAD share a common language across all platforms, and should not have to be modified, meaning that a developer and customer need not necessarily be using identical platforms in order to utilize the application.

The development of flexible manufacturing cells and shorter setup times for batch type processes means that the machinery capability is conceivably running away from a company's ability to exploit it. If a designer is unable to reduce design cycle time sufficiently, manufacturing processes may lie idle unnecessarily. Deployment of an intelligent design advisor to reduce this cycle time should result in higher machine usage rates and greater returns on investment.

This costing tool, at present, is not a generic feature-based analysis tool, as it refers to CATIA V5 specific feature types. It is therefore applicable only to CATIA V5 users, however, with appropriate program coding, the principles may be adapted for use with other solid modelling CAD packages. Together with further work, it is hoped that these principles will be adopted into a broad spectrum intelligent design advisor to help engineering designers reduce product cost, select a most appropriate manufacturing process and reduce design cycle time.

6. Future Research

CATIA V5 programming tools have been used to extract cost drivers from an aircraft spoiler solid model using feature recognition techniques. Given the industry dominance of CATIA, choosing CATIA V5 means that aerospace companies utilise existing software rollout and training costs to accomplish complete integration of new tools with existing product models and add functionality to an otherwise independent system.

Because of its open, architecture independent programming tools, CATIA V5 Knowledgeware may be expanded at will by customers, with little fear of obsolescence, in fields like the development of costing and manufacturing process suggestion tools. Such tools require the implementation of feature recognition processes to match criteria against the attributes of a product 3D solid model.

CATIA V5 does have a number of limitations for creating an intelligent design advisor, but is comparatively easy to learn, has an engineering history and existing user base with training. Extraction of feature-based data with the purpose of providing cost drivers to a database has been demonstrated, however solid product models will need to be created with more than geometric only data in future if the concept of an IDA is to be adequately realised.

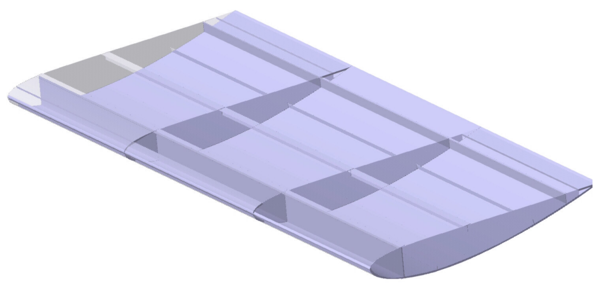

Figure 5: Aircraft Wing Structure

ICAD, as a generative (programming) software package has the capability to store any information related to a product in the solid model. The advantage of this approach over a geometry only model is in capturing information relating to manufacturing, costing, design intent and rationale and so on. Forthcoming work is likely to be assembling an expert system to offer manufacturing advice on a simple conceptual aircraft structure like the wing in Figure 5, with the assistance of GKN Aerospace.

This paper has discussed aspects of a precursor to an Intelligent Design Advisor, or technical agent that may assist a design team, however much additional work is yet to be done. CATIA V5 shows potential in the domain of feature recognition and product modelling, however it is not as stable as existing products like ICAD. Accurate methods of estimating manufacturing costs should be investigated, together with feature recognition concepts to link information like product number and type of manufacturing process to the product model. This data will be an input to an IDA; a tool that may suggest outputs or propose concepts or ideas for consideration based on partial conclusions drawn from limited facts.

Work on expert systems is still progressing and, while work on algorithms to generate outputs from non-exclusive inputs exist, this work needs to be incorporated with the remaining parts of an IDA. Future research involves the integration of costing, design and analysis tools to realise the goal of a complete and intelligent design aid to assist engineers and designers achieve high product quality at lowest manufacturing cost.

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