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Knowledge-Based Engineering System to Estimate Manufacturing Cost for Composite Structures

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A costing application utilizing the knowledge-based-engineering environment in CATIAV5 has been developed in this research. The application can be used to estimate the cost of an assembly of composite components modeled in CATIA V5 during the initial conceptual design phase. The assembly cost is determined by extracting manufacturing process costings from a process cost analysis database. The tool uses design rules for aerospace structures to add detail to a conceptual design enabling an estimate of the cost to be determined. In addition, the tool can modify the structures to achieve the design goal of compliance with performance criteria with minimum weight. The tool is thus able to answer "what-if" questions as the design concept evolves.

Nomenclature

a = length of the short side of the rectangular panel
E = Young's modulus of the plate
q = uniform pressure
T = time
t = plate thickness
w = out-of-plane deflection of a panel
α = deflection coefficient
ν = first-order velocity
ν_0 = steady-state velocity or rate
τ = dynamic time constant with the unit of time
τ_1 = time to reach the steady-state velocity

I. Introduction

THIS paper describes a tool for estimating the cost of manufacture of composite structures implemented within a computer-aided design environment. It is essential that cost awareness be a factor in all decisions in the design of a structure so that efficient designs are created. Cost estimation is particularly important for composite structures because the modern composite product must win benefits against well-developed metal technologies.[1,2] Manufacturing composite components are known to consist of labor-intensive high-cost processes, and material costs are comparatively higher for high-performance carbon fiber. In spite of this, the use of composite structures has been gradually increasing in industries requiring light products because of their excellent performance in terms of high strength with low weight and potentially lower life-cycle costs. Such potential is indispensable to the aerospace industry.

It is also important that the cost awareness is promoted as early as possible in the design cycle because decisions can be made at the outset that have a significant affect on the final cost of the product. A knowledge-based-engineering (KBE) tool has therefore been developed in this research program to estimate the cost of an assembly manufactured from composite materials during the preliminary design stage. The tool is intended to be used interactively by a designer working in the visual environment of a CAD system. The aims of the project are 1) to develop a knowledge-based application for estimating the manufacturing cost for composite components based on manufacturing processes, 2) to develop a tool that can deliver rapid cost estimates during the conceptual phase of the design process by adding the detail necessary for accurate cost and weight estimates from a knowledge database, and 3) to deliver a tool that can help the decision process by answering "what-if" questions relating to changes to the design.

The costing tool has been created in the KBE environment in CATIA V5.[3] This environment allows cost-sensitive structural detail, such as joining methods for assembly, to be added to a simple conceptual model. The cost estimates can then be based on the process cost analysis database (PCAD) approach that breaks the manufacturing process into a sequence of steps and estimates the time to complete each step.[1] Geometry properties are extracted from the CATIA V5 model and used as costing parameters. A graphical user interface (GUI) has also been developed for the costing tool with results being summarized in an Excel spreadsheet. An important factor for the tool will be the time it takes for presentation of the cost estimate following the issue of a request by the designer.

The algorithm can also check compliance with stiffness and deflection constraints and modify a dominant structural parameter to ensure all design constraints are satisfied with minimum weight. This facility enables the tool to be used to determine the effect of changing the configuration by adding an extra stiffening member. The cost comparison does not simply reflect the cost of the additional structure and assembly tasks that would always indicate an increase in cost, but is able to include changes to other parameters to move the design back onto the constraints. As a result, the net effect of the change can be a reduction in cost. The resulting cost increment then compares the cost of optimized designs for the current and new configuration.

A simplified spoiler subjected to uniform pressure is used as a design problem to demonstrate how the costing tool works. The design goal for such a problem includes minimum cost and weight.[4–9] Performance requirements include stiffness and an aerodynamic constraint on the local slope of the thin skins (the upper and lower skins) that form the box structure. The dominant design variable for these constraints is the thickness of the skins. The internal configuration includes ribs and spars that must be fastened to the skins and so contribute significantly to the parts count. The new tool was used to perform a tradeoff study to determine the optimal number of internal members in the spoiler as well as an application to show how the tool can be used to assess a what-if question related to adding extra internal members to an existing compliant design.

The new algorithms are expected to provide a valuable tool for conceptual design ensuring the designer can check the cost, weight,

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and cost/weight fraction of both the current configuration and the finished product continuously as the design evolves. As just stated, accurate cost estimates are essential as early as possible in the design process. Decisions taken during the conceptual phase of the design process are known to determine up to 65% of the cost of the project.[10]

II. Knowledge-Based Engineering

KBE is, in brief, an engineering methodology in which knowledge that has been accumulated in a certain field is applied to a new design.[11] Knowledge exists in various formats, such as graphs, equations, data, fuzzy rules, human intuition, etc. The success of a KBE software tool depends heavily on whether it has accurate knowledge of a problem and how well the knowledge is presented and applied to each problem.

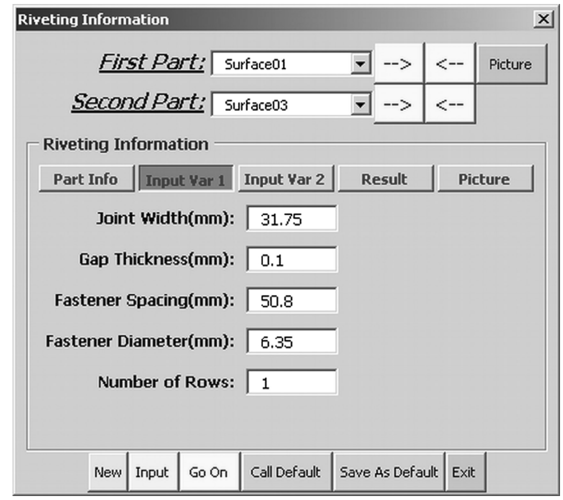
The KBE tool developed here is a Visual Basic application (VBA) in CATIAV5 R12. This application interface allows the user to extract geometry data from a solid or surface model and to generate new features in the model using a separate executable program. The tool also includes a process-based approach for defining the cost of composite components. This approach requires information about the surface area, perimeter, and volume of parts. This information is drawn from the CATIAV5 model. If the required information is not included in the model, it is added from the knowledge database. For example, the model can be an assembly of simple surfaces to evaluate load paths and the stiffness of different configurations for the internal stiffening members. The evaluation of these structural responses might not require the definition of detail in the design. However, the cost for this type of structure is significantly affected by the cost of assembly, including the fastening or bonding of the skin to the internal members. If bonding is used, the cost of inspection is higher than for a mechanically fastened joint, and both the weight of the structure and the cost of inspection depend on the width of the flange on the internal member. These details can be defined from a knowledge base to improve the accuracy of cost and weight estimates. Finally a redesign algorithm is included to modify the design to achieve compliance with constraints so that the net effect of a design change can be assessed.

The process-based costing tool, PCAD, was developed in the aerospace industry for determining the cost of manufacture of composite components. Similarly, CATIA V5 is the state-of-the-art CAD system implemented throughout the aerospace industry for structural design. It provides a knowledge-based engineering environment as a standard workbench using Visual Basic as a programming interface.

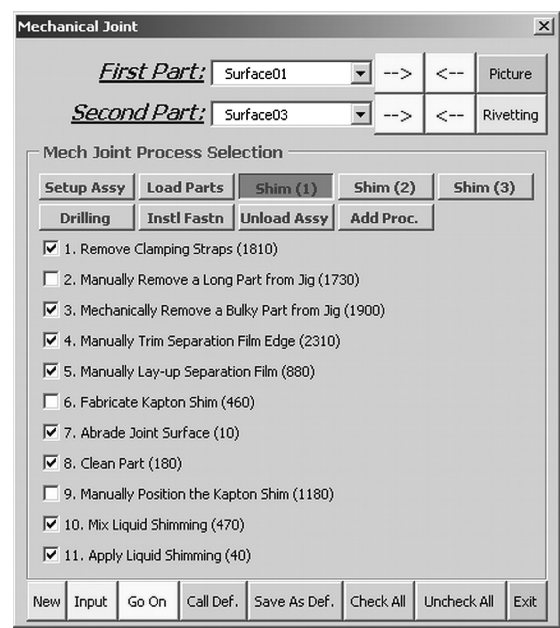
A. User Interface

The cost estimation program in this research provides a GUI for user interaction with the computer and better understanding of the knowledge used. Figure 1 shows the form of the user interface for the application. The primary goal of the GUI is to hold the user's attention to enable the user to work efficiently.[12] There are techniques that can be introduced to guide attention at the interface.[13] Spatial and temporal cues, color, and alerting techniques such as flashing and visual and audible warnings are methods used to focus attention on the relevant information in the interface.

When a numerical computation is performed by the program, the user waits for completion and then goes to the next step. If the computation takes too long, the user tends to be distracted involuntarily. Consequently, the system needs to respond quickly to hold the user's attention. It is natural that a shorter system response time results in higher productivity because a user starts thinking after a result is presented by the system. There are no specific criteria about system response time. Before becoming distracted, a user's patience depends on the task being done. For example, a user might expect a word processor to respond within 0.1 s and to wait for 30 s for a red traffic light to turn green, for two days to receive a letter. However, it was suggested that response times longer than 15 s in computer systems yield slower work, more emotional irritation, and more errors.[14] The costing tool in this research needs to have a minimum response time with different (optional) levels of refinement in the analysis and in the accuracy of the cost estimate.



a) Form of riveting information



b) Form of mechanical joint process selection

Fig. 1 User interface for the cost-estimation program.

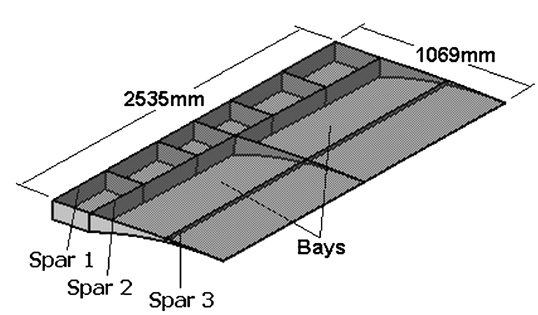


Fig. 2 Simplified spoiler used to demonstrate application of the costing tool.

B. Structural Analysis

The model used in this research to illustrate use of the tool is the simplified spoiler in Fig. 2. Spoilers are located at the wing trailing edge generally above the flaps. On modern aircraft, the spoilers can be used throughout all phases of flight for lift moderation. Because of their location on the wing, they must provide a clean aerodynamic

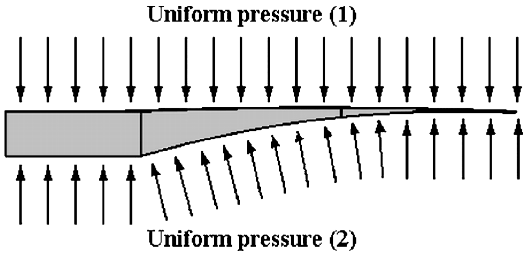


Fig. 3 Side view of spoiler under uniform pressures.

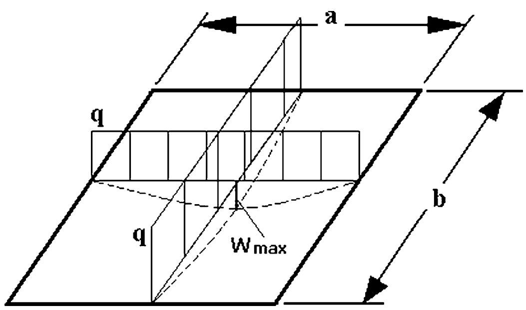


Fig. 4 Uniformly loaded rectangular plate.

flow over the flaps when the flaps are deployed. The dominant design criteria are therefore usually the stiffness of the structure and the slope of individual panels under the pressure loads.

The spoilers are therefore exposed to various load cases in flight including zero, partial, and full deployment with flaps retracted or deployed. In this research, two uniform pressures were applied as shown in Fig. 3. The upper skin thickness was determined with uniform pressure (1), and the lower skin thickness was determined with uniform pressure (2).

The costing algorithm includes a basic structural analysis capability in order to check compliance with stiffness and deflection constraints and to modify the skin thickness to ensure all design constraints are satisfied with minimum weight. This facility enables the tool to be used to determine the effect of design changes while searching for optimized design configurations.

Some assumptions are necessary for the purpose of this research:

1) The design variables include the number of ribs and the number of spars and the thickness of the upper skin and the thickness of the lower skin. The upper and lower skins have uniform thickness.

2) New spars and ribs can be added only to the two bays in Fig. 2.

3) The material for skins is quasi-isotropic.

Structural analysis for these skins is usually executed using finite element analysis. However, to reduce the response time for the analysis and hence the delay time to execute a cost estimate, the analysis is based on classical analytical techniques. This requires three further assumptions as follows:

4) Each panel of the skin is assumed to be simply supported by the ribs and the spars.

5) The deflection of the panels of the skins is the only constraint for structural analysis.

6) The panels aft of spar 3 in Fig. 2 are supported by honeycomb.

According to the preceding assumptions, the following equation can be used for evaluation of the deflection w[15]:

$$w_{\max} = \alpha(qa^4/Et^3) \tag{1}$$

where α depends on the aspect ratio of the panel (b/a) in Fig. 4. The analysis is applied to the panels forward of spar 3 in Fig. 2.

C. Structure of the Costing Program

The costing application uses the VBA of CATIA V5. A model is created in CATIA, and the VBA extracts geometry properties such as an area, a perimeter, etc. from the model and uses them as parameters for the PCAD cost estimation. Figure 5 shows the structure of the costing application.

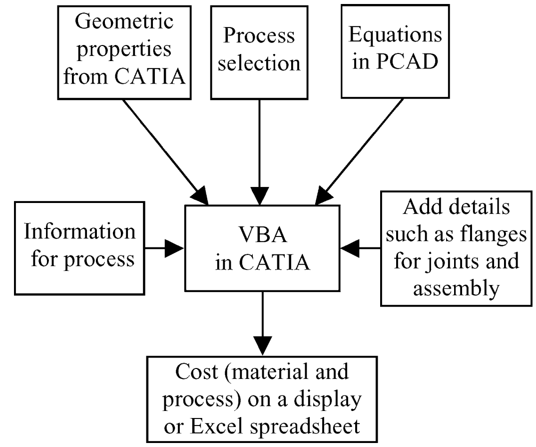


Fig. 5 Structure of the costing application.

It is important to recognize key assumptions inherent in the costing method in terms of both benefits and limitations. The cost estimates are of a preliminary nature in keeping with the preliminary nature of the design concept. The estimated costs are based on simplified assumptions about average process times, labor rates, etc. The costs are representative of part count, process times, and material volume.

Cost estimation for an assembly is more complicated than that for a single part. Cost estimation for an assembly includes cost of fabricating parts and cost of assembling parts such as mechanical joining and adhesive bonding. Assembly cost can also be a large portion of the whole cost of manufacturing an assembly with such processes as drilling, shimming, and riveting for mechanical joining. The flanges required to overlap joints also contribute significantly to the weight. For this reason, a well-known strategy to reduce the cost of manufacturing an assembly is to lessen the part count.[16] However, the reduction of part count is likely to increase the part complexity or part thickness in order to meet structural strength requirements. The design change in complexity and thickness can invoke higher cost for part fabrication.

D. Process Cost Analysis Database

Two methodologies have been defined in the literature for cost estimation for aerospace composite parts. The Advanced Composite Costing Estimating Manual has been developed by Northrop Corporation, and the Process Cost Analysis Database (PCAD) has been developed by a Massachusetts Institute of Technology (MIT) laboratory.[1,2]

In this research, PCAD is used as the costing database. The theoretical model in PCAD is based on the first-order velocity model.[1,2] According to this model, the total process of fabrication is divided into suboperations. Each operation is represented by a first-order velocity expression

$$v = v_0(1 - e^{-T/\tau}) \tag{2}$$

The dimension of v_0 is (y/T), where y is the appropriate extensive variable such as length, area, or weight for the task. Integration of the equation leads to

$$v = v_0[T - \tau(1 - e^{-T/\tau})] \tag{3}$$

The advantage of the relationship between the extensive variable y and time T is that it uses two physically based parameters (v_0 and τ) to define operations. Also, the two parameters are determined by experiments.

Based on the first-order velocity, the MIT laboratory made a database consisting of over 400 processes that represent composite manufacturing operations. Equations are used to estimate the time consumed for each process, where all processes can be represented in terms of v_0 and τ (time to reach the velocity). An example is as follows:

$$\text{Process Time} = \left\{ \frac{\text{Setup}}{\text{Run}} + \left[\frac{\text{Delay}}{\text{Operation}} + \sqrt{\left(\frac{\nu_1}{\nu_0}\right)^2 + \frac{2\tau_1\nu_1}{\nu_0}} \right] \times \frac{\text{Operations}}{\text{Run}} \right\} \frac{(\text{Parts/Shipset})}{(\text{Lots/Run})(\text{Parts/Lot})} \quad (4)$$

where Setup and Delay are the times for setup for production and time delays not directly accounted for in the velocity model. Both are normalized over the number of items produced (Run) or the number of operations grouped with the delay. Setup, Delay, ν_0, and τ_1 are obtained from experimental data, and ν_1 is a parameter of geometric features (e.g., part area, ply perimeter). The other coefficients (Parts, Shipset, and Lot) are related to manufacturing information and have been set to be one in the application in this paper.

Application of the costing tool requires the definition of a set of operations that are executed in the production process. For example, the hand lay up of a laminate involves 40 steps starting with positioning and cleaning of the tool and ending with trimming and storing of the final product. Each operation is identified and an equation generated for determining the process time using the relevant geometry measures such as surface area or perimeter. Here, the operation list was stored in an Excel spreadsheet, the tool is executed by a Visual Basic program, and coefficients for the equations are drawn from the MIT website http://web.mit.edu/lmp/www/. These coefficients have been tuned to reflect the manufacturing experience of the Cooperative Research Centre for Advanced Composite Structures.

III. Application of the KBE Tool

In the conceptual phase of the design process, the design can be represented as an assembly of simple surfaces. The focus is on defining the configuration such as the arrangement of the internal members and the number of rib and spars. Alternate concepts include rib- and spar-dominated designs with thin skins or semimonocoque construction with stiff skins. Various arrangements of the internal members include members arranged in a star pattern spreading from the point of application of the actuator and various orthogonal arrangements. At this stage, little attention is paid to detailed aspects of the design such as the width of flanges forming the joints between the internal members and the skin and the number and type of fasteners to be used. These details are, however, important for weight estimates as the flanges contribute significantly to the weight. They are also important for cost estimates because quality control and inspection procedures following manufacture can dominate the cost if bonded joints replace the mechanical fastening of the skins to these members. The present tool adds these features to the model based on data stored in the knowledge base. The knowledge in the application therefore includes the formulas used in the costing tool, parameters such as flange size and details of joining of the components and information about modification of the design that can influence the net cost of a change to the design. Table 1 shows some examples of the knowledge that was extracted and used for the costing application. The knowledge generally belongs to a company or an expert.

Two cost estimates are coded. The user can request the direct cost of the configuration defined in the database. This requires only the evaluation of the cost of manufacture of each component, the cost of materials, and the cost of assembly. Factors can be included to write off the cost of capital, equipment, and other fixed costs.[17] As the design evolves, this tool can be used to determine the additional cost of a modification to the design if all other design parameters remain fixed.

Table 1 Knowledge used for application of the costing tool to the spoiler

Procedure	Item	Detail
Mechanical joining	Rivet size	D (Diameter) = 6.35 mm (default)
	Rivet spacing	Spacing = $8D$
	Flange width	Width = $5D$
Adhesive bonding	Flange width	Width = 40 mm
	Interface gap	Thickness = 0.254 mm
Analysis	Out-of-plane panel bending	Eq. (1)
Costing	PCAD	Coefficients from website http://web.mit.edu/lmp/www/

To discover the net cost of a change, a functionality to modify the design is also required. The addition of an extra internal member will add to the direct cost of the structure if the rest of the design is unchanged. However, the inclusion of an internal member reduces the dimension of a in Eq. (1) and hence the skin thickness required to satisfy the slope constraint. The net effect, once the flow-on design changes have been made, can therefore be a reduction in cost. This functionality depends on the number of design parameters that can be affected by the design change. The knowledge base can be used to assess the dominant variables that affect the design constraints and the design objectives.

In this research, q is 59.7 KPa for uniform pressure (1) for the upper skin of the simplified spoiler and is 29.65 KPa for uniform pressure (2) for the lower skin. The material is carbon fabric with thickness per ply of 0.25 mm. The ribs and spars have uniform thickness of 14 plies. The laminate for the skins is defined in groups of plies, each group consisting of three plies. E is taken to be 70,000 MPa. The constraint on the out-of-plane deformation of the panel is for $w_{\max}/a$ to be less than 0.1 giving an average slope of 10%. The dimension a is evaluated from the location of spars and ribs. The number of groups is selected to be the minimum number to give the thickness greater than or equal to that defined by Eq. (1). The maximum thickness for any panel on the upper skin is applied to all panels in the upper skin, and the maximum thickness for a panel on the lower skin is applied to all panels in the lower skin.

A. Comparison of the Computation Time

Time for the costing application was measured with default values for the costing parameters. Table 2 shows the result for the elapsed time using a desktop computer of 2.8 GHz CPU and 2 GB RAM. Zero spar and zero rib represent the initial configuration in Fig. 2. The tool was first applied to determine the cost of this model. Ribs and spars were then added to modify the spoiler, and the tool was applied again to determine the change to the cost. It can be seen that the addition of new members results in an increase in time. The most time is taken in determining the length of an intersection. Compared with a conventional manual method, the costing tool is more efficient. However, as a user gets accustomed to this costing tool, attention is likely to be lost because response times exceed 15 s. To prevent a user from becoming distracted and to arrange for user-think time, the costing tool includes a visual prompt (status bar in percentage) to inform how much of the task has been completed.

The algorithms in this research have been developed using the VB interface. Speed increase would be achieved by working in the component application architecture or rapid application development environment. These are alternate generic environments for CATIA V5 application development.[3]

B. Tradeoff Study Based on Cost and Weight

A tradeoff study was conducted using the new tool on the simplified spoiler model in order to demonstrate cost and weight changes for different configurations of the internal structures.

The original spoiler configuration is shown in Fig. 2. Spars and ribs were added to the two bays as shown in Fig. 6, and the thickness of the upper and lower skins were recalculated under the load and

Table 2 Time consumption for an execution of the application

Number of new		
Spars	Ribs	Time, s
0	0	5
1	1	7
2	1	11
2	2	16

Table 3 Number of plies for the upper skin

Number of new ribs	Number of new spars 0	1	2
0	36	15	9
1	30	15	9
2	24	15	9

Table 4 Number of plies for the lower skin

Number of new ribs	Number of new spars 0	1	2
0	27	12	9
1	24	12	9
2	21	12	9

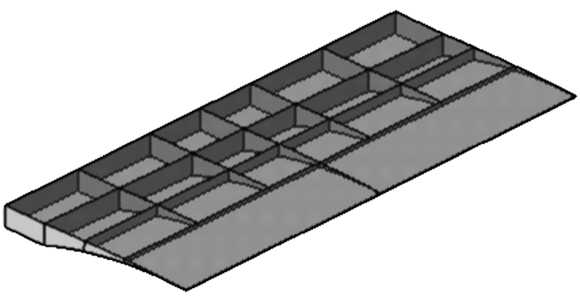


Fig. 6 Modified spoiler with one new spar and two new ribs in each bay.

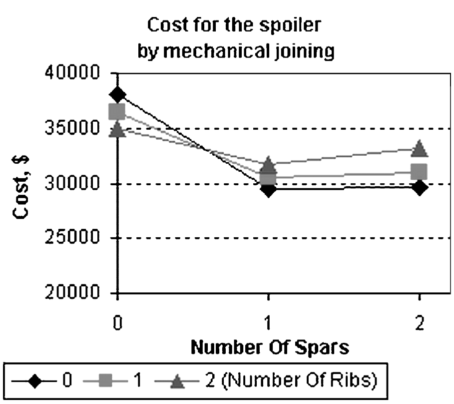


Fig. 7 Graph for cost for the spoiler assembled by mechanical joining.

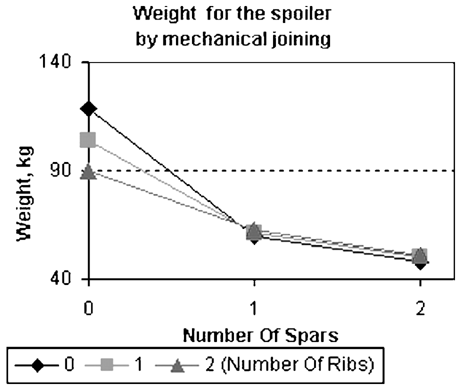


Fig. 8 Graph for weight for the spoiler assembled by mechanical joining.

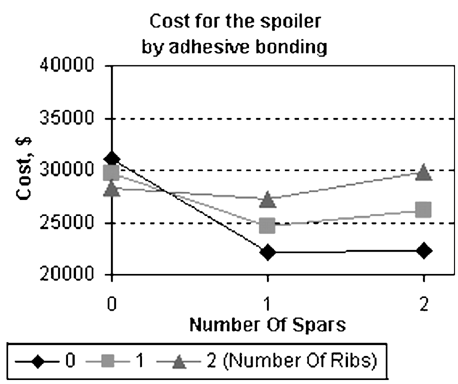


Fig. 9 Graph for weight for the spoiler assembled by adhesive bonding.

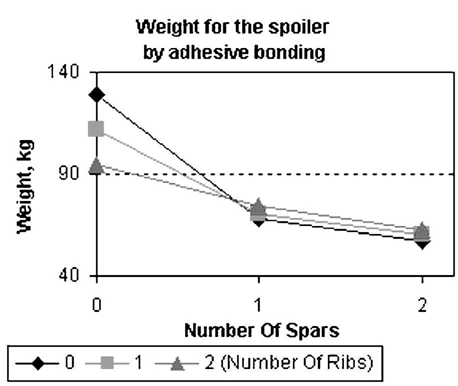


Fig. 10 Graph for weight for the spoiler assembled by adhesive bonding.

boundary condition using Eq. (1). This spoiler is close to a symmetric model in configuration. Therefore, new spars and ribs were introduced symmetrically and with uniform thickness. The design goal includes minimum cost and weight.

The resulting change in thickness for each skin is shown in Tables 3 and 4. It is seen from the two tables that the increase in the number of new ribs does not significantly affect the thickness of the panels except for the case of no new spar because new ribs do not contribute to the length of the short side in Eq. (1). To the contrary, the increase of new spars has a significant effect on the number of plies. One spar addition to the bay reduces the thickness of both the upper and lower skin dramatically because it lessens the length of the short side by a half and increases α slightly.

Cost and weight estimation for the modified spoiler assembly was performed for each configuration change. Figure 7 shows the cost for each model manufactured by hand lay-up operation for part fabrication and by mechanical joining for part assembly, and Fig. 8 shows the weight.

It can be seen from Figs. 7 and 8 that the lowest cost occurs for the spoiler with one new spar and no rib, whereas the lowest weight occurs with two new spars and no rib. When the second new spar is added, the location of the maximum deflection according to Eq. (1) moves to a panel forward of spar 2 in Fig. 2, and the skin thickness is determined from that panel. This leads to a reduction in weight, but the cost increases. The plots have not been extended to the addition of three new spars because the skin thickness is now defined by a panel forward of spar 2, and both the weight and cost increase.

The addition of ribs increases the cost and weight except for the case of no new spar. The change in cost is dominated by the changes in skin thickness as critical panel dimensions change. This result can be seen more clearly by referring to Tables 3 and 4. The changes in weight for each configuration shown in Fig. 8 show a similar trend, which is dominated by skin thickness caused by the much larger volume of material in the skins compared with the ribs and spars.

Figure 9 shows the cost for each model manufactured by hand lay-up operation for part fabrication and by adhesive bonding for assembling, and Fig. 10 shows the corresponding change in weight.

It can be seen from Figs. 9 and 10 that for the spoiler assembled by adhesive bonding the lowest cost again occurs with one spar and no rib, and the lowest weight occurs with two new spars and no rib. The cost trend is similar to the one for mechanical fastening, but the cost is lower. Similarly, it is seen from Fig. 10 that the weight of the spoiler assembled by adhesive bonding is higher in this case.

The study shows that the most significant reduction in cost and weight occurs when one spar is added. New ribs reduce the cost and weight only for the case of no additional spars. The optimal spoiler based on cost is shown in Fig. 11. The configuration, of the optimal spoiler is close to the final configuration, which was chosen for a spoiler in a real design.[18] The spoiler with two new spars is the optimal design based on weight.

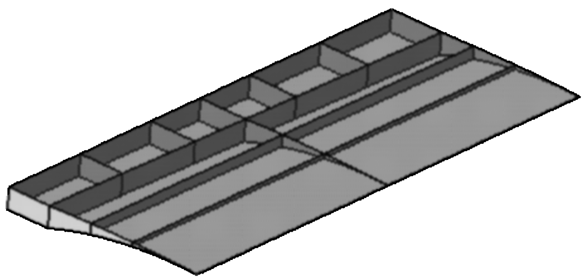


Fig. 11 Optimal spoiler based on cost with one new spar.

A novice designer working with this tool can determine the effect on both cost and weight when conducting tradeoff studies of compliant designs and hence identify near-optimal design concepts.

C. Interactive Application of Costing Tool to Answer What-if Questions in Design Process

The preceding application considered tradeoff studies. The tool can be implemented in an interactive mode providing continuous tracking of cost as a design is developed in the CATIA V5 environment. The tool can also be used in a what-if mode evaluating the effect on compliance, cost, and weight for each proposed modification to a design. This aspect is particularly useful in evaluating changes suggested in the interests of produce-ability concerns. It is recognized that the design must be modified so as to achieve compliance with design criteria to correctly assess the effect of design changes. For example, starting with the original configuration in Fig. 2, a designer could ask: "what is the effect of adding one spar and two ribs to the assembly as shown in Fig. 12.[17]" These changes reduce the panel size to create a model dominated by internal members. The display window in Fig. 12 indicates the cost and weight for the new and old configuration, together with comparison for mechanical joining and adhesive bonding of the entire assembly. Table 5 describes the abbreviated names used in Fig. 12.

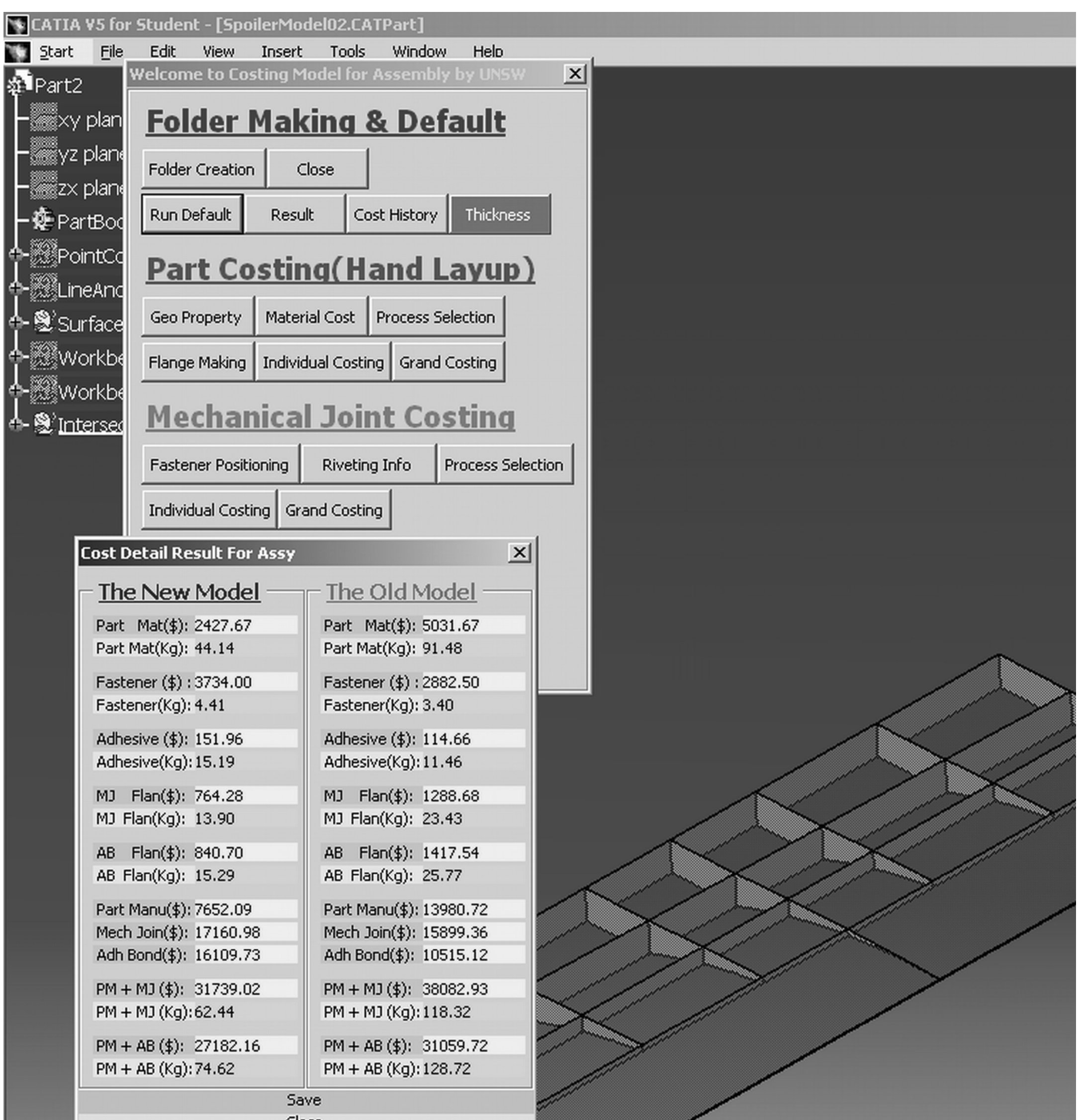


Fig. 12 Cost comparison for the initial and modified spoilers in Figs. 2 and 6.

Table 5 Abbreviated names used in Fig. 12

Abbreviated names	Descriptions
Part Mat ($)	Cost of total part material
Part Mat (Kg)	Mass of total part material
Fastener ($)	Cost of total fasteners
Fastener (Kg)	Mass of total fasteners
Adhesive ($)	Cost of total adhesive
Adhesive (Kg)	Mass of total adhesive
MJ Flan ($)	Cost of total flanges for mechanical joining
MJ Flan (Kg)	Mass of total flanges for mechanical joining
AB Flan ($)	Cost of total flanges for adhesive bonding
AB Flan (Kg)	Mass of total flanges for adhesive bonding
Part Manu ($)	Cost of part manufacturing
Mech Join ($)	Cost of mechanical joining
Adh Bond ($)	Cost of adhesive bonding
PM + MJ ($)	Cost of part manufacturing and mechanical joining
PM + MJ (Kg)	Mass of part manufacturing and mechanical joining
PM + AB ($)	Cost of part manufacturing and adhesive bonding
PM + AB (Kg)	Mass of part manufacturing and adhesive bonding

IV. Conclusions

In this research, an application of knowledge-based-engineering (KBE) for cost estimation has been developed in the CATIA V5 knowledge-based engineering environment. The tool can be used to continuously monitor cost in the early stages of the conceptual design process. The design detail required for accurate cost and weight estimates is generated from the knowledge base. Manufacturing cost was estimated in less than 20 s for an assembly composed of 25 components manufactured from composite materials.

The use of the tool in the decision-making process has also been demonstrated. A tradeoff study was completed to determine the best internal configuration of stiffening members in a spoiler model. The following conclusions were drawn:

1) The appropriate number of new spars reduced the cost and weight for the model not only for assembly by mechanical joining but also by adhesive bonding.

2) The tool delivers rapid evaluation of cost for designs that comply with performance constraints.

3) The tool allows a user to identify near-optimal design concepts.

Because the success of a design constructed from composite materials is very sensitive to cost, it is envisaged that the new tool will be useful in all stages of the design process. Preliminary weight estimates can be determined from the CAD model. However, cost is at least equally important, and the cost implication of each change to the design must be evident to the designer during the evolution of the design.

The procedures for estimating cost that have been reported in the literature for conceptual design are usually based on reduction of part count or on data collected from previous designs using parameters based on dollars/kilogram or size of the component. In the absence of design detail, these approaches allow working estimates of the cost to be derived. The new feature of the approach that is proposed here is the use of KBE to associate detail to a simplified conceptual design. A future development will be to improve the cost estimates by including a measure of complexity for part manufacture. This measure can be derived from the CATIA model and from procedures defined in the knowledgware.

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